Routledge Research in Aesthetics

ABSTRACTION IN SCIENCE AND ART

PHILOSOPHICAL PERSPECTIVES

Edited by
Chiara Ambrosio and Julia Sánchez-Dorado

ROUTLEDGE

Abstraction in Science and Art

This volume explores the roles and uses of abstraction in scientific and artistic practice. Conceived as an interdisciplinary dialogue between experts across histories and philosophies of art and science, this collection of essays draws on the shared premise that abstraction is a rich and generative process, not reducible to the mere omission of details in a representation.

When scientists attempt to make sense of complex natural phenomena, they often produce highly abstract models of them. In the history and philosophy of art, there is a long tradition of debate on the function of abstraction, and – more recently – its relation with theories of depiction. Adopting a process-oriented perspective, the chapters in this volume explore the epistemic potential of a diversity of practices of abstracting. The systematic analysis of a wide range of historical cases, from early twentieth-century abstractionist painting to contemporary abstract photography, and from nineteenth-century physics to recent research in biology and neurosciences, invites the reader to reflect on the material lives of abstraction through concrete artefacts, experimental practices, and theoretical and aesthetic achievements.

Abstraction in Science and Art: Philosophical Perspectives will be of interest to scholars and advanced students working in aesthetics, philosophy of science, and epistemology, as well as to historians of science and art, and to practicing artists and scientists interested in exploring foundational questions at the heart of the creative practice of abstracting.

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Introduction

Abstraction in Science and Art

Chiara Ambrosio and Julia Sánchez-Dorado

I.1 From "Abstraction" to "Abstracting" in Science and Art

The fields of philosophy of science and aesthetics have increasingly joined forces in recent years. The last decade witnessed a number of publications at the intersection of these two fields, with the welcome result of a range of novel and exciting pathways of inquiry emerging from this strengthened interdisciplinary dialogue. These new approaches probed and stretched the boundaries of philosophical inquiry into science and art (Bueno et al. 2017), contributed to re-orient debates on scientific representation and depiction (Frigg ad Hunter 2010) and gave new visibility to the role of fictions in science (Suárez 2009), brought creativity and imagination right at the centre of philosophical analysis (Gaut and Kieran 2018; Godfrey-Smith and Levy 2020) and reignited debates on the role of aesthetic judgements in theory evaluation, theory choice and mathematical practices (Ivanova and French 2020; Breitenbach and Rizza 2018; see also McAllister 1999). This growing body of research has significantly contributed to establish a productive academic dialogue between philosophers of science and aestheticians in a way that had only taken place sporadically and anecdotally before, with noteworthy exceptions in the work of Nelson Goodman and Catherine Elgin (Goodman 1968; Goodman and Elgin 1988; Elgin 1996). The nature of these collections is broadly exploratory: and rightly so, as their aim was to carve up a space for those interdisciplinary debates to take place in the first instance. The time has now come to take a step forward in this interdisciplinary endeavour and investigate in greater detail some of the avenues of inquiry opened up by these earlier studies. The recently published volume *The Aesthetics of Scientific Experiments*, edited by Milena Ivanova and Alice Murphy (2023), is an exciting contribution precisely in this direction, as it discusses the specificities of the aesthetic judgements involved in practices of experimenting in the natural sciences. In the spirit of this novel scholarship, our collection proposes a sustained,

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interdisciplinary inquiry into the roles and uses of abstraction across scientific and artistic practice.

When scientists attempt to make sense of complex natural phenomena, they often produce highly abstract models of them. Theories, laws, graphs and explanations in science are frequently considered to include abstractions too. But while ubiquitous across a very diverse range of scientific practices, abstraction has remained only partially explored in philosophy of science. Often confined to debates about scientific models and representations, abstraction has been considered primarily as a foil to idealisation. In an influential article that systematised and detangled these two concepts, Martin Thomson-Jones suggested "that we should take idealisation to require the assertion of a falsehood, and abstraction the omission of a truth" (Jones 2005, 175). Thus, idealisation is a form of misrepresentation, while abstraction involves omission without misrepresenting: "omission, in this restricted sense", Thomson-Jones points out, "is a matter of complete silence" (ibid) about the properties of a model's target that are left out of the representation. Thomson-Jones was clear in stating that this proposed framework was not aimed at capturing the "essence" (ibid., 179) of these two categories and their philosophical usage, nor did it aim to exhaust the ways in which they feature in scientific practice. And yet, the clarity and applicability of the framework soon became a standard way (or the "orthodox" way, following Carrillo and Martínez [2023]) of characterising abstraction, narrowing it down to its relation with, and explicitly contrasting it to, idealisation. Accounts that draw on this distinction are found in the works of Anjan Chakravarty (2001), Peter Godfrey-Smith (2009), Arnon Levy (2021), Roman Frigg (2023) and Demetris Portides (2021).

The chapters included in this collection show that, far from being "a matter of complete silence", the process and practice of abstracting has actually a great deal to say. Indeed, one of the aims of our volume is to shift attention away from the project of advancing an all-encompassing definition of abstraction – either in contrast or complementary to the orthodox definition of abstraction as omission – and explore the epistemic contributions of various processes of abstracting in practice. There are indeed precedents in the philosophy of science to the approaches we collectively take in this volume. Hans Radder (2006, 110), for instance, has highlighted the fundamental role of the *process* of abstracting – as both leaving out idiosyncrasies and setting apart what is relevant and common – in the extension of concepts. Sabina Leonelli (2008) substantively shifted the debate on abstraction in scientific modelling from a focus on its finished product (exemplified by the conventional use of "abstract" as an attribute of the model itself) to *abstracting* as an epistemic activity, achieved in different ways and drawing on different kinds of skills depending on the context and purposes of the modelling practices involved. Sergio Gallegos Ordorica (2016) has argued that, in addition to omission, abstraction can also be understood as involving a whole range of processes of aggregation of features or information, which he sees as central in endowing models with explanatory value. Nancy Nersessian (2008) has drawn attention to the different and varied forms abstractive processes take in model-based reasoning, demonstrating how suppressing some details while selectively highlighting others provides ways of representing problems in a cognitively tractable manner. More importantly, she has shown how different kinds of abstractive practices are crucial to conceptual change, carving a space for genuine novelty to emerge from the integration of information from different sources and domains (Nersessian 2008, 191–5). Carrillo and Martinez (2023) described the cognitive function of metaphors in science and how these often become part of *abstraction paths*, resulting in criteria of relevance that guide scientists in assessing a model's potential to advance understanding. Our collection, with the new vistas on abstraction it proposes, firmly belongs to this process and practice-oriented family of accounts. But it also aspires to stretch it further, in an open dialogue with colleagues in aesthetics, history of art and art practice, who have been thinking systematically about abstraction for far longer than philosophers of science.

Indeed, in the history and philosophy of art and in art criticism, there is a long tradition of debate on the aesthetic and epistemic nature and function of abstraction, especially with regards to the pictorial arts but also to literary and musical art forms. Our collection explicitly aims at building bridges with how artists have theorised and practically approached abstraction. Importantly, in the visual arts, the notion of abstraction is not only used to describe certain processes involved in depiction, necessary to convey three-dimensional and moving objects onto a two-dimensional surface, but it also refers to a specific Western avant-garde style initiated in the early twentieth century. Key figures like Hilma af Klint, Wassily Kandinsky, Paul Klee, Piet Mondrian and Kazimir Malevich contributed to elucidate how abstract composition could serve the artist in achieving their expressive and epistemic aims. Kandinsky, for instance, claimed that in each human manifestation, there is "the seed of a striving towards the abstract, the non-material", and that in this striving lay "one of the storehouses of artistic possibilities" (Kandinsky 1911, 53, 74). These pioneering approaches to abstraction never reduced it exclusively to mere omission, nor did they frame it solely as a linear progression towards the elimination of figurative elements. The parallel trajectories of Hilma af Klint and Piet Mondrian, recently brought together in the exhibition *Hilma af Klint & Piet Mondrian: Forms of Life* (London, Tate Modern), are a case in point. Both artists began their career as landscape painters;

both engaged in methodical practices of observation and worked *with* nature in the development of an abstract language that served as a dynamical exploration of form in its multiple manifestations; both mobilised and combined scientific and spiritualist ideas, which allowed them to probe the boundaries between observable and unobservable aspects of the world. As the exhibition curators state, for af Klint and Mondrian, "it was clear that looking inwards…was also a means of looking outwards to a wider world, and vice versa" (Nabi, Fer, Morris and Stamps 2023, 8).

It is precisely at the crossovers between scientific and artistic experimentation with concepts of form, matter and space at the turn of the twentieth century that we believe the generative potential of abstraction comes into sharper focus. As Linda Dalrymple Henderson's rich body of works demonstrates (see, for example, Henderson [1983] 2013, 2004, 2014, 2023a, 2023b; Henderson and Clarke 2002), early twentieth-century artists actively engaged with and responded to the scientific ideas of their time and their public presentation in the print and material cultures surrounding them. The revival of the "recalcitrant" (Navarro 2018) concept of the ether at the beginning of the twentieth century, and its profound influence on research at the interface of physics and psychics (Noakes 2019), alongside the "meta-realities" opened by the spatial concept of the fourth dimension (Henderson [1983] 2013), for instance, were important "leitmotifs of international modernism" (Henderson 2014, 242) and had a crucial impact on the birth of abstract painting. Far from arguing that these early artistic experiments provided the *same* kind of knowledge we would attribute to (or expect) from science, what we want to highlight here is that abstraction offered a complementary creative and transformative conduit for experiencing and making sense of concepts that eluded direct perception, giving them a new kind of concreteness. By attending to the voices and writings of artists involved in this quest, our volume is an explicit invitation to philosophers of science and philosophers of art to consider, and embrace, the creative possibilities arising from an interdisciplinary study of the practice of abstracting.

Surprisingly, despite this long tradition of artistic discussions about abstraction, not much space has been dedicated to abstract pictures in recent analytic aesthetics either. The exclusion of abstract form from the domain of representation may be an unwanted effect of the centrality that the debate on depiction, and its emphasis on figurative representation, has come to acquire over the past decade: "depiction", Catherine Abell and Katerina Bantinaki state, "is a distinctive form of representation, characteristic of figurative paintings, drawings, and photographs" (Abell and Bantinaki 2010, 1). A common misconception is that "figurative" and "representational" are overlapping categories, and that abstraction is in tension with both. But this misconception has been challenged by philosophers of art, some of whom have been in fact themselves key players in the debate about depiction. Criticising the “crude identification of the representational with the figurative”, Richard Wollheim (1974, 28), for instance, placed the distinction between abstract and figurative firmly within the realm of representational art, pointing out that the representational content of a painting derives from what can be seen in it, whereas a painting’s figurative content derives from what can be seen in it *and* is further constrained by what can be brought under non-abstract concepts, such as “table”, “chair” or “woman” (Wollheim 2001). Kendall Walton (1990) also considered abstract images as representational, insofar as they prescribe imaginings about actual features of their surfaces. With reference to Kasimir Malevich’s *Suprematist Painting*, for instance, Walton states:

> the painting is a prop; it makes it fictional in games of make-believe played by viewers that there is a yellow rectangle in front of a green one. Surely, also, it is the painting’s function to serve as such a prop. So, *Suprematist Painting is* representational.
>
> (Walton 1990, 55–6)

Michael Newall (2011) has reconciled abstraction and depiction arguing that abstract images are indeed depictive insofar as they occasion non-veridical seeing of a wide range of properties (relations of depth, seemingly overlapping forms), while frustrating the recognition of volumes and objects as we would see them in everyday life.

Engaging with the perspectives developed in this volume by Elisa Caldarola and Diarmuid Costello, who have themselves offered important contributions to these debates (Caldarola 2012; Costello 2018), helped us refine and give greater focus to the significance of the distinction between “figurative” and “representational” as well as specify with greater clarity the ways in which an abstract picture can represent despite being non-figurative. Philosophers of science have a great deal to learn from engaging with these distinctions, which show once again how the narrow focus on abstraction as mere omission hardly captures the complexities of the processes of perception and recognition at play in our encounters with abstract works. But it is our hope that philosophers of science, with their emphasis on the potential epistemic value of practices of abstracting, can also provide insights that will advance the debate on depiction in aesthetics – perhaps too focused on the formal aspects of pictures – in new interdisciplinary directions.

I.2 Abstraction in Science and Art: Key Themes and New Perspectives

The range of proposals on abstraction included in this volume is ample. But the reader will soon detect suggestive common threads emerging throughout it, as well as common questions and motivations guiding the diversity of arguments and selection of cases presented. Read together, the chapters share a concern with the limitations of the philosophical debate on abstraction in the contemporary literature and programmatically propose new ways in which the cognitive value of practices of abstracting should be examined in future research. Here, we would like to highlight some of the common threads of the book and point out to the reader ways in which our different approaches intersect. Rather than providing a linear summary of the chapters as they appear in the volume, we offer five possible thematic pathways, which will bring to the fore the main contributions of our interdisciplinary exploration of abstraction. Of course, this thematic summary is itself an exercise in creative abstraction, which further illustrates how selecting, aggregating and recombining perspectives can produce novel pathways of understanding.

I.2.1 Questioning the "Orthodox View" of Abstraction as Omission

That abstraction cannot be reduced exclusively to the "mere" omission of properties or features is a common motif across our collection. Michael T. Stuart and Anatolii Kozlov's contribution to our volume (Chapter 6) is a useful departure point here, as they present a systematic overview of how the received view of abstraction, which they recast as "the subtractive view", has played out in the recent literature on models in philosophy of science. There are two particularly useful insights emerging from this critical review of the literature, which recur in various ways through other chapters. First, they point out that abstraction is often cast as a "necessary epistemic evil" when it comes to scientific modelling: an abstract representation is taken to deliberately simplify a complex phenomenon or situation by subtracting irrelevant features of the target for the purpose of understanding a specific portion of it. As we pointed out earlier on in this introduction, this implies that – contrary to idealisation – abstraction does not introduce falsehoods: it merely consists in the omission of a truth. The task of philosophy of science, with respect to this subtractive view of abstraction, becomes then to explain how a model can provide knowledge or understanding about complex phenomena despite, or in virtue of, this process of simplification. Secondly, Stuart and Kozlov note that abstraction, in this view, is also presented as reversible: omitted features can in principle be added back into the representation to produce more detailed or accurate models. All this points to a certain sense of dispensability often attached to abstraction, or at least to a view of abstraction as subservient to the more important goal of surrogative reasoning about the target of a representation, which is assumed to be fixed and stable throughout a modelling practice. Having delineated this subtractive view of abstraction as the foil to their argument, Stuart and Kozlov develop their own positive account of "generative" abstraction, which they build up through an insightful analogy with abstract art. Early twentieth-century abstract artists, they point out, did not stop at subtractive abstraction (though it was part of their practice): they also created entirely new, more "universal" targets for their representations, leaving behind the concrete objects that formed the departure points of their practice. Stuart and Kozlov show that an analogous process is at work in the case study of a series of connected models of how the brain learns in a neuroengineering laboratory, where in response to epistemological and practical problems both the models and their targets changed together. The result is that the original target (human learning) was left behind, but the important gain is the generation of novel questions and affordances not offered by earlier models.

The transformative and creative role of the practice of abstracting is also at the centre of Julia Sánchez-Dorado's contribution (Chapter 7). Focusing on pictorial representation, Sánchez-Dorado argues that a creative, reconfiguring process is often involved in acts of abstracting. Even if omitting certain features or constructing a representation that is "poor in detail" can still be the first step towards abstract composition, a further step needs to intervene in genuine acts of abstracting: relevant relations among the components of the abstract space created on the pictorial surface (abstract pictorial world) are recognised by the viewers, in such a way that the "imagined seeing" of such relations is transferred to the target in the world represented, allowing to bring to light important but previously unrecognised features. Sánchez-Dorado illustrates this creative view of abstraction with a suggestive and sustained comparison between artistic and scientific practices in Germany during the interwar period, drawing parallels between how abstracting was theorised and taught in the educational programme of the Bauhaus at Weimar and Dessau, and how it was actively pursued in visual experiments in fluid dynamics produced roughly at the same time.

Tarja Knuuttila, Hanna Johansson and Natalia Carrillo (Chapter 9) bring this novel philosophical line of inquiry into abstraction directly in dialogue with Science Studies, particularly with Bruno Latour and Michael Lynch's writings on scientific representation. Building on the premise that abstracting is an *enriching* process that cannot be reduced to simple omission, Knuuttila, Johansson and Carrillo present the apparently counterintuitive claim that it instead involves concreteness: concrete actions, methods and practices intervene in the material translations and transformations that participate in the creation of an abstract representation. To illustrate how this process of material translation takes place, they examine the production of the artwork *Homage to Werner Holmberg* (1985–86), by the Finnish constructivist and environmentalist artist Lauri Anttila. In seeking to render with scientific methods the landscapes in the paintings of nineteenth-century Finnish landscape artist Werner Holmberg, Anttila's compositional practice exposed precisely the kind of material work that scientific abstractions, in their narrowly construed sense, tend to hide.

I.2.2 An Alternative, Richer View of Abstraction as Omission

An important insight emerging from this volume is that (a suitably reformulated version of) the subtractive view of abstraction does not necessarily need to be abandoned. Attending to abstracting as a practice and a process across science and art allowed some of our contributors to show that omissions are less of a "necessary evil" or a mere removal of details that can eventually be added back to a model, and more a matter of actively and selectively carving pathways to access epistemically significant features through models. Catherine Elgin (Chapter 1), for example, reconceptualises abstraction as "selective disregard": through abstraction, both art and science convert an initially undifferentiated portion of reality into a manageable entity, bringing out significant properties that would remain otherwise occluded. Elgin demonstrates that selective disregard crucially involves exemplification, a mode of reference by which an item refers to some of its own properties by instantiating them. Drawing on cases like the Lotka-Volterra model of predator and prey interaction and Yves Klein's IKB79, a work realised entirely in International Klein Blue paint, Elgin shows that exemplification can often be the only avenue to features that may be at the outset semantically unmarked, and the significance of which could not be demonstrated otherwise.

Mauricio Suárez (Chapter 8) proposes a processual view of abstraction which recasts omission as a creative and generative process in its own right. Through a suggestive analogy between abstract physical theory and abstract painting, Suárez dynamically reinterprets abstracting as a process that strips away layers of materiality in a concrete reality to reveal its abstract form. This process, Suárez argues, can be seen at work through the example of two champions of abstraction in fin-de-siècle science and art: James Clerk Maxwell and Piet Mondrian. Maxwell's unified theory of electromagnetism was guided by a process of abstraction upon the concrete mechanical models of the ether he had previously constructed. Analogously, Mondrian's paintings of trees show the progressive elimination of concrete and material details to arrive at the formal representation of the absolute or universal form of their nature. In both cases, the abstract was brought out of the concrete, with the result of the generation of a new abstract object.

Chiara Ambrosio and Grant Fisher (Chapter 5) probe and expand the subtractive view through a historical and philosophical investigation of the ribbon drawings of proteins produced by Jane Richardson in the 1980s. Drawing on Dominic Lopes' (1996) account of "aspectual structure", Ambrosio and Fisher show that abstracting is a practice that entails the complex articulation of commitments to what to include, what to occlude and what to omit from a representation. This distinction casts light on how abstracting as manipulating aspectual structure involves choices and selectivity in the design of a representation, which have epistemological consequences on how representational content is structured. Thus, even though omissions do feature in Richardson's drawings, they are not merely "a matter of complete silence" (Jones 2005, 175): they are the products of complex decisions that, according to Richardson, can and *should* be operationalised and made communicable and usable by the scientific community.

I.2.3 Abstracting and Moving Targets

The views on abstraction we presented thus far have an interesting and important feature in common: they all highlight in various ways that, as representations progressively change through the process of abstracting and the translations and transformations it involves, so do their targets. Some of our contributors show this explicitly: Stuart and Kozlov, for instance, systematically show through their neuroengineering case study how scientists left behind the initial target of inquiry – how the brain "learns" – and through their iterative abstracting practice they progressively shifted to the new targets of mice brains, arrangements of mouse neurons on a dish and a computational simulation of the previous dish model. In each of its stages, the process generated new questions that could not be posed through previous models. But our contributions show that shifting representational targets are not just distinctive of inquiries into the biological sciences, where processes and change appear to be the order of the day. Suárez's chapter makes the compelling case that even the most theoretical achievements of physical theory, and their interpretations, result from a process of generating an abstract target and conferring it reference as a self-standing reality. In this sense, Suárez importantly points out, Maxwell's equations are representational – but in a minimalist sense that echoes the analogous ways in which Mondrian's paintings are: as the creative process of abstracting progressively shifts away from concrete material details, so the target of the representation shifts from a concrete description of phenomena towards their abstract forms.

In other chapters, the dynamic nature of the target is perhaps addressed less explicitly, but it still surfaces as an implication of the emphasis of the material practices concretely involved in the process of abstracting. Anttila's artistic practice, discussed by Knuuttila, Johansson and Carrillo, deliberately exposes the translations and interventions that transform an initial tentative object of inquiry into a very different kind of abstract, and yet material, realisation. Sánchez-Dorado shows how the creative practice of abstracting, systematically theorised by Kandinsky and Klee, aimed to produce a "new naturalness" in the work, which could serve as an entry point into extra aesthetic worlds (the semantically unmarked territories highlighted in Elgin's chapter) beyond the painted surface itself. And even when targets appear to be far more defined, as in the case of Richardson's drawings of proteins, Ambrosio and Fisher show that manipulations of design do have epistemological consequences on how pictorial content is dynamically and selectively constituted and made visible through the very process of drawing.

Our discussion of shifting targets suggests that retaining a representational function for abstraction is not just a crude form of old-fashioned representationalism. Fleshing out the dynamics of abstracting as a representational process and practice shows instead how objects and relations are made and remade through material, experimental and pictorial practices, how new features and properties are brought out and investigated through exemplification and imagined seeing, and how the products of abstracting have the generative power to pose new questions in their own right.

I.2.4 Aesthetic and Epistemic Trading Zones

Another way of challenging the "orthodox view" of abstraction as omission in philosophy of science is through the explicit dialogue that our collection builds with accounts of abstraction in aesthetics and philosophy of art. Elisa Caldarola (Chapter 2) goes beyond concerns about reasoning about the target (even when dynamically construed, as we suggest in the section above) and offers a more comprehensive account of how abstract images in art and science have "aboutness". Addressing directly the place of abstraction in debates on depiction, Caldarola distinguishes between *depictive* images, which abstract from some visual properties of the objects they depict, and *genuinely abstract* images, which abstain from depicting altogether but still convey something (represent, express, convey meaning) by virtue of the configurations on their surfaces. She then proposes four ways in which genuinely abstract images convey content: conventionality, indexicality, exemplification and expressivity. Alongside a wide array of artistic images, Caldarola presents a fascinating analysis of how images produced by the ALICE detector at CERN qualify, according to her proposed taxonomy, as expressive genuinely abstract images, showing how their expressive character also helps explain their rhetorical force in a science communication context. In this, her account provides an illuminating analytical toolkit that usefully complements approaches to the persuasive power of scientific images produced by STS scholars (see, for example, Lynch and Woolgar 1990; Coopmans et al. 2014; Carusi et al. 2015).

Diarmuid Costello's contribution (Chapter 3) takes our interdisciplinary dialogue into a domain where abstraction is rarely addressed: photography. Costello revisits his (2018) article "What Is Abstraction in Photography?", which has been one of the original inspirations for the interdisciplinary approach to abstraction we adopt in this volume. There, he proposes a (non-exhaustive) taxonomy of abstraction in photography that comprises the categories of "proto", "faux" and "constructed faux" abstraction, "weak" and "strong" abstraction, "constructed" abstraction and "concrete" abstraction. When we originally envisioned the proposal for this volume, we fully saw the potential of these categories to move the debate in philosophy of science beyond its narrow construction of abstraction: "one of the goals of my typology" Costello states, "is to show that what is often generically typed as 'abstract photography' is a complex, multi-faceted phenomenon that comes in many forms" (Costello 2018, 399). These "many forms", we thought, would easily carry over to the sciences. Alas, in his chapter for our volume, Costello revisits his taxonomy, questioning its completeness and showing that the crossover to scientific uses of photography is not as straightforward as we originally envisioned. Drawing on a comparison between several spectacular artworks by the artist Wolfgang Tillmans and a set of bubble chamber photographs produced in the 1970s, Costello takes us back again to depiction. He shows how the (remarkably few) formalist accounts of abstraction put forward by proponents of depiction theories fall short of explaining, only on the bases of their formal properties, the epistemic uses and functions of non-artistic photographs such as the bubble chamber examples that form his scientific case study. Costello's chapter is a lesson in evaluating critically the scope, limits and applicability of comparisons between art and science, and a warning about how far we can stretch the sharing of tools and method in the "trading zone" between aesthetics and philosophy of science. But it is also an invitation to continue the conversation and refine the grounds over which our common concerns might, in fact, continue to overlap.

I.2.5 Abstraction in Its Historical and Material Contexts

This volume was designed from the outset as an integrated historical and philosophical investigation of abstraction in its concrete and material contexts. Thus far, we have highlighted the philosophical contributions of our interdisciplinary examination of a range of practices of abstracting. In this last section, we want to highlight how most of our analyses have emerged from the sustained investigation of concrete historical case studies, the specificity and locality of which have been absolutely crucial to the argument that there is no single "essence" to abstraction as such. Our engagement with advocates and practitioners of abstraction has been developed deliberately with a grounding in the specific historical, philosophical, scientific and aesthetic contexts in which they operated – Victorian Britain and fin-de-siècle Europe (Suárez), Germany in the interwar period (Sánchez-Dorado), post-war crystallography research and its relationship with protein research (Ambrosio and Fisher), the 1980s philosophical, sociological and artistic challenges to the authority of science (Knuuttila, Johansson and Carrillo). This deep historical grounding gave concreteness to the claim that abstraction is best examined as a wide and varied range of practices and processes, inextricably tied to aesthetic values and epistemic virtues that change with time and that are negotiated and renegotiated in concrete and material contexts.

Rasmus Winther and Marie Raffn's contribution (Chapter 10) fully captures the integrated spirit of our collection and takes its generative potential in exciting new directions. Drawing on a remarkably rich range of historical and contemporary case studies, Winther and Raffn explore abstraction as *what if?*-thinking, fully bringing to the fore the exploratory and creative functions that abstracting can take in both artistic and scientific contexts. Conceived and construed as an experimental collaboration between a philosopher of science (Winther) and an artist (Raffn), the chapter *practices* precisely the kind of *what if?*-thinking it advocates, folding episodes from the parallel histories of abstracting in science and art into its argument. We thus discover the fascinating (and still far too often overlooked) trajectory of cartographer, oceanographer and geologist Marie Tharp, whose experimentation with abstraction as *what if?*-thinking culminated in a series of spectacular maps that led to the discovery of the Atlantic median rift, and to inferring a global mid-oceanic ridge system. Placing Tharp's remarkable cartographic accomplishments in dialogue with a range of artistic experiments in abstraction, Winther and Raffn show, prompts a process of *what if?*-thinking in its own right. It also shows the multiplicity and variety of abstractive processes this experimental practice involves: imaginative pathways to abstraction can be found in the sublime landscapes of Caspar David Friedrich as well as in the spiritual worlds opened by the diagrammatic forms of Hilma af Klint. But they also emerge out of the concrete practices and articulate semiotics guiding Marie Raffn's sculptures and installations, which invite the spectator to commune simultaneously with the mystical and with the formal and quasi-mathematical. "The abstract is generous", Winther and Raffn point out – and it is this generosity that underpins, and indeed multiplies, the possibilities opened by re-envisioning it as *what if?*-thinking.

There is another important sense in which historical investigation has enriched the multi-layered view of abstraction we pursue in this volume, and it comes – perhaps unsurprisingly – from the history of art. But in a rather surprising move (and through the remarkable ability to "make visible" that is so distinctive of art historical methodologies) Oliver O'Donnell's contribution (Chapter 4) has forced us to search for abstraction in an unusual place, prompting a meta-reflection on the place of abstraction in the genealogies of analytic philosophy itself. O'Donnell takes us back to 1941, in the main gallery of the Barnes Foundation in Philadelphia, established by chemist, businessman and art collector Albert C. Barnes. It was here, in this visually saturated and material context, that Bertrand Russell delivered the first of a planned five-year series of lectures that would eventually converge in his *History of Western Philosophy*. O'Donnell's chapter brings out precisely the tension between the lectures' location – a world-renowned collection of French modern art that predated the establishment of the Museum of Modern Art in New York – and Russell's obliviousness to the topic of aesthetics within the lectures themselves. Russell's lectures were imbued with aesthetic commitments: ideals of austerity, eternity and indeed, the very place of abstraction in scientific knowledge. However, O'Donnell insightfully shows, Russell's stubborn refusal to recognise these commitments, and particularly his absent aesthetics of abstraction, ended up alienating his audience – which paradoxically had been primed to sympathise precisely with his celebration of the place of abstraction in scientific knowledge.

There is a particularly instructive historical detail in O'Donnell's chapter that can serve as a prompt for a further and final connection between several of the contributions in our volume. Early on in his lectures, O'Donnell observes, Russell complained about the many modernist nude paintings displayed in the main gallery, which he considered a distraction and "somewhat incongruous" with the philosophical content of his lectures, and requested moving his lectures to a different room. But it is precisely the ironic irritation of Russell's reaction to his surroundings that brings to the fore the *insistence* of their materiality, paradoxically drawing attention to his inability to abstract from them. Where Russell's austere and ascetic view of abstraction (which O'Donnell shows was an aesthetic choice in its own right) is an escape from materiality and concreteness – beautifully epitomised by the physical act of moving to another room! – the perspectives we offer in this volume deliberately co-opt and mobilise them, exploring the creative, material and concrete strategies that artists, scientists and indeed philosophers adopt in tackling distractions, handling complexity and generating new questions and new abstract objects out of the concrete. In a sense, our volume contributors stayed in the very art-saturated room that Russell left behind. From the material translations of Anttila's artworks to the drawing practice of Jane Richardson, from the cartographic discoveries of Marie Tharp to the sketching exercises at the Bauhaus workshops, from the abstract accomplishment of Maxwell's equations to bubble chamber photographs and all the way to the expressive potential of the images produced by the ALICE detector at CERN, our engagement with abstracting as a material practice has been both the prompt and the fuel for the discoveries we made through this volume.

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Editing a volume involves a great deal of work. And yet, academics persevere in publishing edited collections because they are the places where wonderful encounters happen, and where ideas circulate within our disciplines and – with some luck and effort – across disciplines too. This is precisely what happened in the making of this volume. We want to express our most heartfelt gratitude to all the contributors to this volume, who shared their time and insights with us in the most generous and collegial scholarly way. It has been a pleasure and a genuine honour (and also a lot of fun!) to work with all of you.

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Due to copyright restrictions, two images (8.4 and 10.8) cannot be viewed in the Open Access version of this volume. They are available online: we have added links in their captions, so that readers may still be able to view them while reading the text.

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London/Washington D.C.
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1 Selective Disregard

Catherine Elgin

Introduction

> A pleasure boat, *The Blue Dolphin*, captained by 35 year old, red haired Maria Bogdan, a native of Brooklyn now living in Dortmund, travels 30 km up the Wibbley River in the same time it takes to travel 50 km down the Wibbley. If the river's current flows at 5km/h, and the water temperature is 12°C, what is the speed of the boat in still water?

We remember such problems from elementary algebra. They are not hard to solve. The first step is to eliminate inessentials. Omit them, disregard them, set them aside. It makes no difference who the captain was, what sort of boat it was, where it was sailing, or what the water temperature was. In fact, it makes no difference that the problem concerns a boat. All that matters is the mathematical relationship that connects the boat's upstream rate, its downstream rate, and the rate of the current.

Abstraction is the first step toward a solution. As the problem is originally posed, relevant and irrelevant facts intermingle. The more details a vignette includes, the harder it is to isolate the relevant elements. When irrelevancies are swept aside, what remains is a representation that highlights the features that bear on the solution. The new, austere representation exemplifies those features, making them epistemically accessible. Mastering algebra involves learning how to set a problem up: that is, how to identify the features of the situation that are relevant, and how to represent them in such a way that their bearing on one another leads to a solution. Abstracting fosters selective disregard.

One mode of abstraction consists in omission (Godfrey-Smith 2009). An abstract representation simply leaves out the features we seek to ignore. A black and white photograph of a tulip garden abstracts from color by restricting itself to a gray scale. It does not register color. A verbal

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description abstracts by describing the tulips as colorful, while remaining silent about what colors they instantiate.

Pretty clearly, some abstractions are products of omission. Locke's discussion may suggest that they all are. An abstract general idea, he says, is one that does not contain the information that its more concrete counterparts include. Because, like the black and white photograph, the abstract general idea of a tulip omits color, there is no danger of being misled into thinking that instantiating a particular color is distinctive of being a tulip. As far as I know, Locke doesn't talk about tulips, but he does talk about triangles. He says that the abstract general idea of a triangle is a representation of a triangle that is 'neither oblique nor rectangle, neither equilateral, equicrural, nor scalene, but all and none of these at once' (Locke 1984: IV, vii, §9). The abstract idea is a mental image of a triangle, but of no specific sort of a triangle. That is why it can represent triangles in general. Berkeley balks. He has, he insists, no mental image of a triangle that has no specific triangular shape. Nor does he think that anyone else does. Rather, he insists, in reasoning about triangles in general we take any particular triangle we like and appeal only to features it shares with all other triangles (Berkeley 1957: §10–16). That is, we selectively disregard the features that distinguish one triangle from another.

The dispute between Locke and Berkeley focuses on ideas – private, mental, quasi-pictorial representations. I am concerned with intersubjectively available representations – words, drawings, diagrams, etc. in the public domain. Nevertheless, the same issues arise. If one can form a mental picture of a triangle that has no particular triangular shape, it should be possible to draw a physical picture of a triangle that has no particular triangular shape. Unsurprisingly, I side with Berkeley. If Felix uses an isosceles triangle in his reasoning but does not invoke anything about the equal sides or equal angles, he could just as well reason with a scalene triangle. The proof would be the same. His proof abstracts from the particularities of the triangle he uses, and because it does, demonstrates something about triangles in general. Nor is this just a point about geometry. When a biologist uses a fruit fly as a model organism, she ignores everything that is specific to that individual insect and typically ignores everything that is specific to that particular species. The individual, concrete fruit fly functions abstractly because it represents only features that are common to all members of the target class. In cases like these, abstraction is a matter of ignoring the particularities of a particular.

As Berkeley's discussion shows, abstraction is not always a matter of omission. Some constellations of features so tightly intertwine that they cannot be prized apart. Even in these cases, however, selective disregard is possible and often epistemically valuable. It is facilitated by representational choices. Something that looks messy, convoluted, intractable, or irrelevant under one mode of representation may turn out to be orderly, streamlined, manageable, and relevant under another. This is so even when both representations are accurate. The difference lies not in their fidelity to the facts, but in their suitability to the task.

We often deliberately deemphasize, set aside, overshadow, or occlude information. This raises an epistemological question. The motivation for selectively disregarding information via abstraction is not that the information is suspect. We are instructed to disregard the obvious, undisputed shape of the triangle or the obvious, undisputed color of the tulip in order to focus on something more general. But if our goal is to advance understanding, throwing out manifestly reliable information seems unwise.

The Need for Abstraction

Perhaps surprisingly, it is not. William James characterizes the world, as a baby first experiences it, as 'a blooming buzzing confusion' (1890: I, p. 488). The raw inputs into the neonatal cognitive system – the stimuli that impinge on the baby's nervous system – are multitudinous, diverse, and disorganized. She has to determine what to ignore, discount, or overlook; what to focus on, attend to, emphasize. The baby needs to learn to discriminate and amalgamate, organizing her experiences into repeatable, identifiable, useful kinds. Once she has done so, she automatically overlooks, disregards, or downplays similarities and dissimilarities that do not align with her systems of classification. The process is partly ontogenic. The baby's developing brain naturally coalesces some of its inputs. Environmental factors also play a role; her brain reinforces the synaptic connections among the phonemes that her language contains, pruning the connections among phonemes that her language does not deploy.

This is a start, but it is far from enough to keep confusion at bay. We cannot count on our central nervous system to automatically highlight features that we need to highlight or to block from awareness factors we ought to ignore. We may need or want to override what we are automatically inclined to do. So we devise and revise modes of representation that serve our purposes. Since our purposes are multiple, divergent, and sometimes in tension with one another, our representational resources need to be versatile.

According to James, abstraction is an act of singling out (1890: I, p. 505). The process highlights an item, enabling it to stand out from its surroundings. Abstraction demarcates, converting the initially undifferentiated bit of reality into an entity capable of exemplifying relevant features that might, in their natural setting, have been hard to discern.

Exemplification

Exemplification is a mode of reference by which an item refers to some of its own properties via its instantiation of those properties (Goodman 1968; Vermeulen et al. 2009). Examples and samples exemplify. They highlight and emphasize, making features of their objects salient. A fabric swatch exemplifies its pattern, color, texture, and weave. It marginalizes other properties of the cloth – its shape, location, age, and so on. A sample problem worked out in a text book exemplifies a particular reasoning strategy – one that enables students to calculate the area of a parallelogram or divide by a two-digit number, perhaps. The sample problem ignores the precise size of the parallelogram, focusing only on the factors that generalize to parallelograms as such. We regularly encounter and properly interpret examples and samples, having learned what to attend to and what to disregard.

Any item, no matter how mundane, can function as a sample or example, simply by being treated as such. A tufted titmouse is just a bird – a bit of nature – until an ornithologist points it out. By treating it as an example of its kind, or its color, or its propensity to sing at dawn, or its being smaller than the average house cat, she converts it into a symbol – a telling instance of the feature it exemplifies. Moreover, an item can function as an exemplar of any of its properties, no matter how obvious or obscure that property is. The titmouse can exemplify the range, cadence, frequency, pitch, or timing of its song. It can exemplify its diet, or the way its diet varies with the seasons. It can exemplify the way changes in its diet correlate with its metabolism, and so forth.

An exemplar may be part of a regimented system. The tailor's swatch is part of a commercial system devised to make available fabrics accessible to potential customers. It is cut in such a way that the pattern it displays is representative of the pattern of the fabric. Once we learn how such samples function, we can easily interpret them. We know what features to focus on and what ones to ignore. Other examples are ad hoc, contrived on the spot for a specific purpose. A driving instructor might point to a passing car as an example of careless driving. With no regimented system in place, greater responsibility falls on the listener's shoulders. Is the lane shift an example of carelessness merely because it is a lane shift, or because it was done without signaling, or because the driver seemed oblivious to oncoming traffic, or what? A priori the question is hard. But in context it may be perfectly obvious what qualifies the maneuver as an example of careless driving.

Not all exemplification is a matter of repurposing ordinary items, elevating them to the status of symbols. Much exemplification in art and science, as well as in commerce, consists in creating items to exemplify particular properties, patterns, or configurations that are not found, or not easily found in the wild. Rather than taking a sample of water from the lake and ignoring impurities, scientists work with distilled water from which the impurities have been eliminated. It is pure H_2O. It is not a representative sample of natural water. But if we construe natural water as a complex of H_2O and impurities, we can treat H_2O as a component of natural water. The distilled water used in the lab then exemplifies properties it shares with natural water. In some scientific contexts, these are the properties that matter. Rather than seeking out a particular tone by listening assiduously to birdcalls, car horns, braying donkeys, and fire alarms, a musician might create a chord in which separate tones interact to exemplify a distinct, audibly complex sound. Like the water used in the lab, the sound in the concert hall is an artifact that exemplifies specific features. Throughout art and science, items are created to exemplify features of interest.

In principle, an exemplar can exemplify any of its properties. A fourth-grade teacher might display a student paper, using it as an example of what she wants (or does not want) her students to emulate. She shows, rather than tells, them what she is looking for. She might use it as an example of appropriate (or inappropriate) length, structure, argument, or topic. She might use it as an example of neat (or sloppy) handwriting, straight (or crooked) margins, proper (or improper) punctuation. She would not treat it as an example of all of these at once. That would swamp the poor students, nearly replicating the baby's blooming buzzing confusion. Instead, she would bring it about that the students ignored some features of the example so as to focus on others.

Exemplification requires instantiation. That might make its scope seem narrow. A blue tile can exemplify 'blue', being an instance of that color. It cannot exemplify 'red' since it is not red. But although the instantiation requirement is a real restriction, exemplification's scope is far from narrow. Every item belongs to indefinitely many extensions and bears a likeness to the other members of each extension it belongs to. Some of these extensions are semantically marked. The bird at the feeder is a titmouse, a tufted titmouse, a songbird, a harbinger of spring, an animal that is not a giraffe, a material object that is noisy, a descendant of dinosaurs, etc.

It also belongs to a vast number of semantically unmarked extensions. Whether or not an extension is semantically marked, a given member can in principle exemplify the feature that all members of that extension share. Usually membership in an unmarked extension is of no interest. If we have no reason to care about the feature shared by the members of the extension consisting of the titmouse, the Milky Way, and a map of the Boston subway system, the opportunity to exemplify that feature is not, and should not be, exercised. But sometimes membership in a semantically unmarked extension is significant. An exemplar can highlight that significance by affording epistemic access to the unmarked property.

International Klein Blue (IKB) is a distinctive, vibrant shade of deep blue. The color was created by artist Yves Klein in collaboration with paint supplier Edouard Adams. It is exemplified in a series of Klein's monochrome paintings. Klein's exemplars afford epistemic access to a shade that had never before been seen. Initially that shade could only be ostended – '*that* very shade'. It is a shade that, until he baptized it, was semantically unmarked. Still, it could be pointed out and recognized as a color one had never before seen.

Here the newly identified feature is a product of increased refinement of the color palette. In other cases, it is a matter of drawing new boundaries – of recognizing membership in extensions that bridge traditional divides, or that group together things that are typically considered different. This occurs, for example, when we find stylistic affinities that cut across art forms. The category *impressionism* began as a characterization of a style that exemplifies fleeting visual properties. Like IKB, it was introduced via exemplification. Paintings like *this* qualify as impressionist. The category is broadened when the restriction to the visual is lifted. Works like Debussy's *La Mer* come to qualify as impressionist when the criterion for membership is fleeting sensory properties rather than merely fleeting visual ones. Works like Virginia Woolf's *Mrs. Dalloway* come to qualify when the criterion extends to fleeting emotional properties as well as sensory ones. At each step, the incentive to broaden the category is grounded in the recognition that despite differences in medium, certain works exemplify an aesthetically interesting commonality. They are all instances – telling instances – of fleeting, felt properties.

Cases in which exemplification precedes denotation are common in the sciences as well. A curious phenomenon – something eliciting a 'That's weird!' response – exemplifies something scientists (currently) do not understand. Initially they are confronted with an exemplar of a seemingly unmarked feature. Research is conducted to identify the feature and demarcate its extension. Having discerned that mold on a Petri dish apparently inhibited bacterial growth, Fleming took it to exemplify something odd and worth investigating. He had no name for the specific sort of mold and no criterion for what other items were relevantly similar. Eventually he identified the mold as penicillin and recognized that what was exemplified on the Petri dish was the property of being antibiotic. The process that eventuates in a label is not a matter of mere dubbing. It is an empirical inquiry that seeks to find out what sort of thing a phenomenon is, and what other things are relevantly like it. Even if all of the candidate extensions are initially semantically unmarked, the investigation is an effort to discriminate among them and find out which is worth marking out. The investigation is apt to be iterative. A variety of unmarked extensions may be tried out, before the inquirer arrives at the one that groups together all and only the items of interest.

As my examples show, once we have identified and demonstrated the utility of recognizing the similarity among the members of a currently unmarked extension, we can give it a label which becomes part of the lexicon. But the exemplification of a feature often is temporally prior to labeling and may provide reason to think that the label will be useful.

Exemplification makes certain features salient by marginalizing, overshadowing, or occluding others. Often this is easily accomplished. We can readily direct attention to the features we want to focus on. In a suitable context, an ornithologist can simply point and thereby get the bird she ostends to exemplify its species. She can say 'listen!' and highlight the bird's song. But in other cases the problem is harder. It is not always easy to ignore at will. If a situation is sufficiently complex or chaotic, it may be difficult to identify or focus on a particular feature. It is not easy to distinguish the subtle flavor of coriander by tasting a mulligatawny soup. Merely being instructed to pay attention to that specific ingredient is not likely to succeed. In cases like this, abstraction is a boon. Taste the spice apart from the soup. Abstract its flavor from the flavors of the other ingredients. When distractions are diminished, factors of interest stand out.

Exemplification is selective. To focus on some features of an object, to highlight them or bring them to the fore, the exemplar marginalizes or overshadows others. This suggests that exemplification in itself is a mode of abstraction. Because Felix's isosceles right triangle exemplifies triangularity, but not being isosceles or having a right angle or, for that matter, being drawn with a pencil, it serves as an abstract representation of a triangle as such.

Case Studies

Scientific models are abstract representations that highlight certain features of their targets by downplaying or omitting confounding factors. This typically involves idealization as well as abstraction.

> Suppose we have an ecological system composed of foxes and rabbits. There are periodic fluctuations in the population levels of the two species and the explanation turns out to be that the foxes eat the rabbits to such a point that there are too few rabbits left to sustain the fox population, so the foxes begin dying off. After a while this takes the pressure off the rabbits who then begin to multiply again until there is plenty of food for the foxes, who begin to multiply, killing more rabbits, and so forth.
> (Garfinkel 1981, p. 53)

There's nothing special about foxes and rabbits. The dynamic holds for predator/prey population pairs generally. The Lotka-Volterra model represents the dynamic via a pair of differential equations.

$$dx/dt = \alpha x - \beta xy$$

$$dy/dt = \gamma xy - \delta y$$

where

x	represents the number of prey;
y	represents the number of predators;
t	represents time;
αx	represents the growth rate of the prey populations;
βxy	represents the rate of predation;
γxy	represents the growth rate of the predator population;
δy	represents the death or emigration rate of predators.

The model involves a number of simplifying assumptions. It assumes that the prey have ample food and that the prey are the predators' only food source. This may or may not be realistic depending on the species pairs and environments in question. It assumes that predators are insatiable and that prey are immortal unless eaten. Neither, of course, is true. But the rationale for incorporating them is that something of significance is revealed if we treat the deviations from the assumptions as negligible. The model also assumes that during the time frame in question, there are no significant environmental changes; nor is there significant genetic drift. The model simply sets these contingencies aside and implicitly acknowledges that it is inapplicable when they obtain. Insofar as many of these assumptions are strictly false, one might wonder why we should think the model has any scientific value. Why isn't it a bit of science fiction? The answer is that the assumptions are felicitously false. They are falsehoods that reveal something worth noting. When a divergence from truth is negligible, it is permissible to substitute a felicitous falsehood instead; when the divergence is fruitful, it is desirable to do so[1] (see Elgin 2017). In an environment where foxes overwhelmingly feed on rabbits, and the vast majority of rabbits die by being killed by foxes, it is at least presumptively reasonable to ignore the exceptions, particularly if the exceptions seem to be scattered and do not lend themselves to a systematic account. The exceptions can be dismissed as noise. The Lotka-Volterra equations exemplify the resulting pattern.

The model is silent about mechanisms. It indicates nothing about how the populations modulate their sizes. This may seem surprising. If a population modulates its size in response to certain pressures, one might think, we should want to know how it does so. No doubt we do. But it does not follow that because the model prescinds from mechanisms, it is defective or that the understanding it yields is regrettably incomplete. For the omission enables it to be quite general. The model reveals a pattern that holds across species with radically different reproductive systems: fish in the Adriatic, starfish and mollusks, foxes and rabbits, even loan sharks and needy borrowers. However it is that starfish modulate their reproduction in the face of mollusk scarcity, it is not the same way that foxes do when the rabbit population diminishes. Indifference to mechanism then enables the Lotka-Volterra model to exemplify a broad pattern, and thus to exemplify the surprising fact that for certain purposes, at a given level of abstraction, the mechanisms don't matter.

Because it is remarkable that wildly divergent population pairs display the same pattern, the model itself becomes an object of scientific study. Representing at this particular level of abstraction, sidelining specific confounding factors, connecting the data points into particular curves reveals something interesting. The pattern is projectible. It is not just a summary of previously examined cases. It affords reason to expect that other predator/prey population pairs will display the same dynamic. It is thus more informative than the individual instances taken separately or even conjointly (see Ambrosio Forthcoming). So the question arises: why does abstracting from the blooming buzzing confusion in just this way yield an understanding of the phenomena? Why are these particular simplifications and idealizations fruitful (see Cristalli and Pietarinen 2021)?

Let us turn now to a case drawn from art. IKB79 is a monochromatic painting by Yves Klein. The canvas is covered in IKB paint, the distinctive, vibrant shade of blue that Klein and Adams created. It is then entirely a patch of blue. This might suggest that it is no different from the samples that commercial paint companies distribute to advertise their wares. Like commercial paint samples, it exemplifies a particular shade of blue, thereby affording epistemic access to that shade. Even under this description, the painting would be of interest, since it exemplifies a color its audience has not previously encountered. But to stop there would fail to do the work justice. The experience of IKB is uncanny. The color seems to float above the canvas, not to inhere in it. The experience is rather like that of staring up at a cloudless sky. There too we have a perception as of a color that does not inhere in a material object. Through the analogy with the sky, we can appreciate that the painting exemplifies the boundless, the intangible, the immaterial, maybe the sublime. The painting exemplifies absence – the void. But the void is not exemplified as ominous. What it portends is an open question. This leads us to consider what sort of absence is exemplified. Is it an absence of obstacles or of opportunities? Is the void only lacking in particular, bounded material objects, properties and relations? Or is it also lacking in hopes, dreams, feelings, and aspirations?

Abstract art is often characterized as non-figurative. Abstract works do not even purport to denote. This makes the characterization of a particular work parasitic on a metaphysics which determines what is there to be denoted. One might wonder then whether IKB79 is a work of abstract art. Might it be a figurative painting denoting a cloudless sky? Might it be a figurative painting realistically depicting something – perhaps absence – that is itself abstract? For our purposes, it does not matter whether the painting qualifies as *abstract art*. What is important is that it abstracts. It sidelines irrelevancies (e.g., about material objects) to highlight immaterial factors. It affords resources for distinguishing the experience of color from the experience of something colored. It exemplifies boundlessness, absence, and the perils and promises that absences provide. It effects a reorientation toward the world and our place in it.

A Worry

My discussion may make it plausible that abstraction in art and science is a matter of singling items out for attention, as James said. But I suggested that exemplification is the vehicle for abstraction. This seems problematic, since exemplification requires instantiation. Is it the case that the abstract exemplars instantiate the features of their targets that they purport to afford epistemic access to?

In one respect, success is guaranteed, at least if we restrict the target enough. There is no danger of failure of reference, because the exemplar itself instantiates whatever it exemplifies. The Lotka-Volterra model exemplifies a pair of differential equations. IKB79 exemplifies its own shade of blue. But I have claimed something more, and perhaps more doubtful. I said that the Lotka-Volterra model exemplifies the pattern of interdependence of predator and prey populations and that IKB79 exemplifies boundlessness.

One worry about the model can be set aside. Some might object that since mathematical relations are abstract and regularities pertaining to predation are concrete, the two cannot share properties. I do not see why. A pattern can have both material and immaterial instances. When Joe says, 'each person has only one birthday' and 'only one even number is prime', the word 'one' is univocal.

The real concern is that the pattern displayed by the foxes and rabbits is not quite the one captured in the model's equations. I allowed for the exceptions by construing them as noise. The model, by affording epistemic access to a pattern that is displayed when the noise is ignored, highlights an important aspect of what occurs in the noisy environment. Still, calling the exceptions noise might seem like sweeping the problem under the rug. But taken jointly, many of the foxes and rabbits instantiate the pattern, even though the pattern is overlaid by a few readily ignorable confounds. The model affords access to an unmarked or not easily marked extension. The preponderance of cases instantiates the pattern even though we lack a term to mark out just those cases.

There is a plethora of semantically unmarked properties. They are capable of being exemplified, even if we have no word to denote the extensions they constitute. It seems straightforward to interpret IKB as exemplifying a previously unmarked shade of blue and perhaps a previously unmarked experience of boundlessness. Klein's first example of IKB appeared before the color had a name. That being so, there seems to be no principled objection to interpreting IKB79 as exemplifying additional unmarked properties – one, a distinctive sort of absence; another, a hitherto unnoticed similarity to the boundlessness of the sky.

Some unmarked properties are higher order properties. Maxwell's model of the ether instantiates and exemplifies a previously unrecognized higher order structure shared by the electromagnetic and the mechanical realms. A Rothko painting consists of swaths of color instantiating and exemplifying a higher order property, neither visual nor emotional, that it shares with a distinctive feeling of melancholy. The painting connects the visual and the emotional realms by visually displaying how that emotion feels.

The abundance of extensions provides opportunities to reorder things – to mark out new individuals, kinds, patterns, and relations as worthy of attention. Through abstraction we distance ourselves from mundane ways of thinking, representing, and acting that blind us to alternatives. Abstraction enables us to entertain new modes of organization, to test them out to see if they contribute to an advancement of understanding. We can exemplify at a finer grain or a coarser grain than is typical and see what results. We can forge connections across conceptual divides using the shared instantiation of higher order predicates to demarcate commonalities that bridge standard categorial divides.

Are All Symbols Abstract?

Inasmuch as omission is a type of abstraction, it seems to follow that all representations are abstract. Not only does the Lotka-Volterra model present an abstraction of predator/prey relations, so does a picture of a lion stalking a gazelle. Not only does a Rothko present an abstraction of melancholy, so does Munch's depiction of a sad young man. This is true. Every representation omits something. To capture the difference between ordinary omissions and the more extreme ones we are apt to call abstractions, it pays to look again at exemplification. I suggest that the representations we call abstract omit or occlude standardly salient features in order to exemplify features that are not ordinarily salient. Which features are standardly salient is a function of our representational practices. Melancholy is a mental state. We therefore expect a picture that expresses melancholy to be a picture of someone who is manifestly sad, despondent, downhearted. That's what Munch's *Melancholy* is. We might even think that it would be impossible to pictorially convey melancholy without representing a melancholic figure. Rothko disagrees. He abstracts further: he leaves the sufferer of melancholy out. His subject is melancholy, not a melancholic person. He presents a colored surface that expresses the mood. It exemplifies the feeling without depicting a person who has that feeling. Predation is a relation between animals. We expect a representation of predation that depicts predators and prey. The Lotka-Volterra model abstracts. It leaves out the animals and just presents a dynamic mathematical relation that is characteristic of certain population pairs. In both cases, the abstractions pay dividends. By failing to provide the resources for a mundane way of looking at things, they enable us to see what we would otherwise miss.

Conclusion

Abstraction is ubiquitous. Every representation, no matter how detailed, standardized, or regimented, omits some features of its target. Every representation emphasizes some features, while obscuring, occluding, or downplaying others. In so-called realistic representations, the mode of representation is self-effacing. Realistic representations deliver their content straightforwardly. Audiences ordinarily know how to interpret them and what they convey. The information itself may, of course, be surprising. But it is typically no surprise that this particular sort of symbol conveys this particular sort of information. The picture of a cat on a can of cat food looks the way we expect a depicted cat to look.

So-called abstract symbols are different. Non-figurative works in the visual arts, and mathematical representations in the sciences, exemplify features without representing the material objects in which these features normally inhere. They dissociate the feature from its material instantiations thereby affording epistemic access to the feature itself. One might think that such distancing always moves from the more specific to the more general. We saw in Berkeley's discussion of the triangle how abstraction can promote generalization. But this is not always the case. The emotion a Rothko expresses, the shade of blue a Klein exemplifies, the magnitude an equation conveys may be extraordinarily fine-grained. Indeed, it may be so fine-grained that it cannot be put into words. Abstraction is an avenue to epistemic access because it pulls us away from the familiar, prompting us to look more deeply, and pointing in a direction in which it might be fruitful to look.

Note

1 Something is negligible if it can permissibly be neglected. That depends on its function in the context in which it is used. A slight divergence may be non-negligible if it makes a big difference; a large divergence may be negligible if its distance from the truth does not matter. This is why it is possible to treat a gas giant like Jupiter as a point mass.

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2 How Abstract Images Have Aboutness

An overview

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In this chapter, I argue that genuinely abstract images do not depict but have aboutness, nevertheless.[1] All images have aboutness in virtue of the visual configurations on their surfaces: it is through those configurations that they can convey something – they can mean something, represent something, express something, and so on. On the one hand, in depictive images, the visual configurations on the images' surfaces depict visible objects while abstracting completely from some of their visual properties. In Giovanni Bellini's *Portrait of Doge Leonardo Loredan* (1501), for instance, the visual configurations on the pictorial surface depict Doge Loredan's head and torso, as seen frontally.[2] The image, however, completely abstracts from, e.g., Doge Loredan's legs, nape, and back. On the other hand, as I shall argue, when the visual configurations on a two-dimensional surface do not depict anything at all but have aboutness in ways other than the depictive, that two-dimensional surface is a *genuinely* abstract image. As I shall show, all genuinely abstract images entirely abstain from depicting but can nevertheless abstract in different measures from the visual properties of objects.

The first step for an account of genuinely abstract images is to distinguish accurately between depictive images and genuinely abstract ones. For this, one needs an account of depiction – this is provided in the first section of this chapter. In the second section, different kinds of depictive images are singled out: this facilitates focusing on images that qualify as genuinely abstract. In the third section, four ways in which genuinely abstract images have aboutness are discussed: conventionality, indexicality, exemplification, and expressivity. The fourth section concludes with some general observations on the peculiarities of genuinely abstract images.

2.1 Projective Accounts of Depiction

In this section, I briefly introduce projective accounts of depiction, explaining why I think they are superior to alternative accounts. In the

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next section, I then rely on projective accounts of depiction to distinguish between depictive and genuinely abstract images.

There are different types of theories of depiction. The most successful accounts are those that explain depiction in terms of resemblances between pictorial content and depicted content,[3] those that explain depiction in terms of a peculiar perceptual experience aroused by some pictures,[4] and those that explain depiction in terms of "a relation of geometrical projection between a picture and the space it expresses as content" (Greenberg 2021: 847).[5] Here, I shall follow Gabriel Greenberg's two versions (2013 and 2021) of the geometrical projection theory, for reasons that I shall clarify below.

Depictive content, Greenberg argues, corresponds to the situation a depictive image represents (Greenberg 2021: 849–60). In particular, "a picture's content includes exactly those (quite abstract) spatial and chromatic properties had in common by the myriad possible scenes which could project to the same picture" (860). Spatial scenes, situations, are thus the source of the projection that generates a picture. The idea at the core of projection theories of depiction is that projection is not only a traditional method to produce pictures (as in, e.g., the Albertian model of perspective) but is also a mechanism that can be regarded as the norm for interpreting pictures and thus used to define pictorial content: "for a picture to express a content, the picture must be a projection of that content" (857). Any pictorial projection is indexed to a viewpoint. More specifically, a viewpoint is "a pair of indices, the first of which gives the spatio-temporal location of the projection source, and the second the spatio-temporal location of the picture plane" (858). Importantly, "pictorial space fills a three-dimensional region with objects and properties, whose locations are given by a direction and depth from a general viewpoint" (855): every part of a pictorial surface stands in a specific directional relation with the viewpoint the pictorial projection is indexed to (for instance, part X of a certain pictorial surface can be above the viewpoint, or to the right of the viewpoint, etc.).

Why argue that pictorial content is grounded in pictorial projection? I concur with Greenberg in claiming that there are two reasons to favor the projective theory of depiction. First, to explain depiction it makes sense to focus on geometrical projection because of how the human visual system works:

> According to the computationalist understanding of vision, a central function of the visual system is to generate an estimate of the kind of scene that must have produced the retinal image [...] the visual system hypothesizes an environmental space on the basis of a retinal image. [... analogously] a viewer hypothesizes a pictorial space on the basis of a

> pictorial image. In the first instance, the hypothesis is an (unconscious) inference to the best explanation about the actual environment. In the second, the hypothesis is an interpretation, a guess about the type of scene the image purports to be projected from. The Projection Principle [the principle at the core of Greenberg's geometrical projection view of depiction] thrives in human transaction because the computations it requires can be carried out on much of the same computational machinery already supplied by the visual system.
>
> (Greenberg 2021: 870–1)

According to computationalists, to guess what kind of three-dimensional space has generated a certain retinal image, the visual system has developed certain computational abilities; according to Greenberg, it makes sense to hypothesize that we exploit those abilities also when guessing what kind of three-dimensional space has generated a certain image, via a certain projection system.

Second, projection theories are better at accounting for the organization of pictorial space than resemblance and experiential theories (Greenberg 2021: §6). On the one hand, according to resemblance theories, for a picture to be accurate with respect to a certain scene, there must be similarities between the picture and the scene. However, Greenberg (2013: 271–84) shows that if a picture is produced via a transformative method of projection such as curvilinear perspective, for instance, a picture that is accurate with respect to a certain scene looks different from that scene, rather than similar to it. Resemblance theories thus attribute wrong directional structures to pictures produced via certain methods of projection: structures that do not map onto the spatial situation represented by the picture.[6] On the other hand, according to perceptual theories, the basic tenet of an account of depiction is that there is a connection between perceptual content and pictorial content. However, there are gaps between how we see spatial scenes and how we depict them through certain methods of projection. As Greenberg explains,

> early vision normally treats certain kinds of converging lines in the retinal image as indicative of parallel edges in the environment. But in parallel projection, converging lines on the page can only indicate converging edges in the scene. Applying normal visual perception to such cases yields incorrect interpretations. Projection semantics captures the fact that depiction conforms with the general structure of vision, but unlike perceptual theories, allows that depiction also departs from vision in myriad ways.
>
> (Greenberg 2021: 879)

Greenberg's account is not dissimilar to Hyman (2006) and Kulvicki's (2006) views on depiction. Both of Greenberg's versions of the theory (2013, 2021), however, differ from Hyman and Kulvicki's views in that the latter account for the depictive character of a narrower range of images than the former does (see Greenberg 2021: notes 32 and 33, p. 869). I favor Greenberg's account because of its broader explanatory power.

Notwithstanding these differences, we can trace the following distinction: while, on the one hand, according to Hyman, Kulvicki, and Greenberg (2013) the projection theory provides necessary and sufficient conditions for depiction, according to Greenberg (2021: 860), on the other hand, it only provides necessary conditions for depiction. This, he argues, is because there are many "deviant scenes" (860) that the projection theory cannot by itself rule out as the spaces expressed by certain pictures. For instance, it cannot rule out that a picture which apparently expresses a scene inhabited by a cube is, actually, a picture projected from a scene inhabited by an object that is only partially cube-like. And, for the same reasons, the projection theory cannot explain why we are prompted to attribute, e.g., certain depth, shape, and texture features to projected scenes. Greenberg concludes that the projection theory provides necessary, but not sufficient conditions to produce pictorial content. This is important for the present discussion, because, as I shall explain below (Section 2.2), to the divide between Hyman, Kulvicki, and Greenberg (2013), on the one hand, and Greenberg (2021), on the other hand, there corresponds a distinction concerning abstract images: while Hyman, Kulvicki, and Greenberg (2013) allow for the kind of images I shall call "abstract depictions", Greenberg (2021) does not. Thus, the realm of genuinely abstract images is broader for the latter than it is for the former.

In what follows, I shall not be interested in adjudicating whether the projection theory provides necessary and sufficient, or only necessary conditions for depiction: my focus is on abstract images. Thus, I shall distinguish between three varieties of depictive images, from a projection theory perspective, clarifying whether they fit Greenberg's (2021) framework or not and what consequences ensue for our understanding of abstract images.

2.2 Varieties of Depictive Images

In the three following sub-sections, I delve deeper into projective theories of depiction, showing that they allow for distinguishing between different kinds of depictive images. This, as we shall see, is relevant for understanding in what genuinely abstract images differ from depictive images.

2.2.1 Full-Blown Depictions

This is the kind of images that are depictive according to all versions of the projection theory. Velazquez' *Las Hilanderas* (1657), for instance, is a full-blown depiction: we can describe it not merely in terms of the generic objects whose shapes and colors it presents us with, but in much more detail, relying on our acquaintance with three-dimensional objects such as female bodies, tents, ladders, spindles and so on.[7] Famously, we can describe the depicted fuse as spinning, thanks to the brushstrokes Velasquez skillfully applied to suggest motion in a static image.

Note that one might fail to produce a full-blown depiction of a certain object and still produce a full-blown depiction, albeit of another object, as it might happen to one who sets to produce a picture of a larch and, inadvertently, produces a picture of a spruce. Thus, the criterion of correctness for full-blown depiction can be stated as follows: *X* is a full-blown depiction of *Y* iff it presents *Y*'s spatial properties as well as (some) of *Y*'s fleshed out visual properties, as seen from a certain viewpoint, and projected onto a pictorial surface via a specific method of projection.

2.2.2 Bare-Bones Projections

This is the kind of images that merely result from the production of a pictorial space that can be traced back to a specific method of projection applied to a certain kind of spatial scene.[8] As we have seen, on the one hand, according to Greenberg (2021), this kind of images abstain from properly depicting and are, rather, quasi-depictive: all depictions necessarily are pictorial spaces that can be traced back to a specific method of projection applied to a certain kind of spatial scene. However, this condition is necessary, but not sufficient, for depiction. It thus seems appropriate to infer that, according to Greenberg's (2021) framework, images of this kind must be some kind of *genuinely abstract*, *albeit quasi-depictive* images (see Section 2.3). On the other hand, according to Hyman (2006, 2012), Kulvicki (2006, 2020), and Greenberg (2013), bare-bones projective images are instead depictive: they are *bare-bones depictions*.

> Consider a drawing of a man's head. The head may be bulbous or narrow, the nose may be Roman or snub, and the chin may be a rounded curve or a jutting wedge. […] But even if we cannot find the right words to describe them, the shapes of the head, the nose, and the chin are the shapes they are represented as having.
>
> (Hyman 2006: 79–80)

A bare-bones projection is an image that can be fully described in terms of the particular pictorial space that results from applying to a certain kind of spatial scene a specific method of projection. In Hyman's example, it is a space occupied by a head, a nose, and a chin that present certain shapes when seen from a certain viewpoint and projected onto a pictorial plane via a specific method of projection.

Note that one might fail to produce a bare-bones projection of an object of a certain kind, as seen from a certain viewpoint, via a specific method of projection, and still produce a bare-bones projection of an object of a different kind, as seen from a certain viewpoint, via that same system of projection. For instance, one might seek to produce a bare-bones projection of a cube, as seen frontally, within the linear perspective system, and end up producing a bare-bones projection of a trapezoid, as seen frontally, within the linear perspective system. The criterion of correctness for bare-bones projections can be stated as follows: *X* is a bare-bones projection of a kind of object *Y* iff it presents the shape of *Y*-objects as seen from a certain viewpoint and projected via a specific method of projection.

2.2.3 Recognitional Bare-Bones Depictions and Abstract Bare-Bones Depictions

I argue that for those theorists who admit for bare-bones depictions, there ensues the need for distinguishing between two such kinds of depictions: recognitional ones and abstract ones.

Recognitional bare-bones depictions are such that, when we look at them, we can recognize three-dimensional objects we are acquainted with and can describe in non-abstract terms (as is the case with the picture of a head, a nose, and a chin described in Section 2.2.2). Often, however, bare-bones depictions do not allow for recognition, as they are very generic: to describe those depictions, we can only describe in abstract terms the configurations and colors we see on the pictorial surface and the pictorial space that is presented to us, while we cannot rely much on our previous acquaintance with three-dimensional objects. Consider, for instance, a picture we can only describe "as grayish-pink and yellow and shaped like a piece of molten wax" (Hyman 2006: 64), as well a picture thus described by Kulvicki:

> A bare bones content might specify a trapezoid-shaped region, from a certain vantage point, but not specify that there's a square thing there, at an oblique angle, or a trapezoid, seen head-on. It might specify a region of streaked light and dark, but not specify whether it is a uniformly colored thing illuminated streakily, or a streaky thing illuminated uniformly.
>
> (Kulvicki 2020: 27)

According to theorists who admit for bare-bones depictions, those pictures are depictive, although they disregard visual properties that would allow us to describe their depictive contents less abstractly, in terms of three-dimensional objects we are acquainted with. I suggest calling this sub-kind of bare-bones depictions "abstract bare-bones depictions" or, more shortly, "abstract depictions". Abstract depictions do not abstain from depicting but abstract from those visual properties of the objects they depict that would allow for recognizing them and describing them in precise ways.

Against the view that there exist abstract depictions, one might however raise the following criticism: we cannot claim that there are abstract depictive pictures, because we have no way to ascertain whether abstract "depictions" truly are depictive. The reason is that, when it comes to that kind of images, we have no means to make sure whether we are supposed to look at the configurations on their surfaces as at mere marks or as at projected shapes of three-dimensional objects in certain spatial scenes. In full-blown depictions, as well as in recognitional bare-bones depictions, we recognize depicted objects and, in virtue of this, we get a grasp of what method of projection those depictions are products of. With abstract "depictions", however, we cannot rely on recognition of depicted objects as a clue for identifying the perspectival system the picture is a product of. Thus, we cannot understand whether the picture truly is depictive, i.e., whether it expresses a depictive content by means of being a projection of that content.[9]

I think the force of this criticism is limited, however, as recognition of depicted objects is not the only available guide to grasp whether a certain visual content is appropriately interpreted as the result of the use of a certain method of projection. Another way consists in considering whether there is evidence that the image maker sanctioned that a certain image is to depict via a certain method of projection, and ascertaining whether their sanction was successful.[10] How, then, can we get a grasp of an image maker's sanctions? In what follows, I shall consider some available strategies.

In the first place, titles might offer us reliable clues to identify the author's sanctions concerning the depictive character of the image, or lack thereof (see Levinson 1985). Consider, for instance, Piet Mondrian's *Oval Composition (Trees)* (1913).[11] The picture presents a variety of superposed plans, which do not immediately recall the shapes of trees. On learning about the picture's title, however, we can understand that the picture was successfully sanctioned to be an abstract depiction painted in linear perspective, which significantly abstracts from many visual features of trees.

In the second place, contextualizing a candidate for the status of abstract depiction within the wider context of its author's oeuvre, interests, and projects might be instrumental to understanding whether a given abstract image is depictive (this remark is inspired by Walton 1970: 360–3). Suppose we know that at a certain time a painter was interested in producing images by employing a very unusual method of projection, and we find out that at that time she produced an abstract painting that can easily be interpreted as an abstract depiction presenting some very generic spatial features of an everyday scene, once it is recognized as a product of that peculiar method of projection. It seems to me that, in such case, we would have good reasons to claim that the image qualifies as an abstract depiction. Moreover, we would have good reasons to claim that a certain image is an abstract depiction also in case we could ground the claim not on our knowledge of the maker's intentions, but on our knowledge of the pictorial practices prevailing in the picture maker's cultural and artistic context. Finally, we would have good reasons to claim that a certain image is an abstract depiction produced via a certain method of projection also in case, in the absence of reasons to deem the image non-depictive, regarding it as depictive would confer to the image higher artistic value.

To sum up, I have shown that both Hyman and Kulvicki's versions of the projection theory of depiction, and Greenberg's (2013) version, allow for claiming that there are abstract depictions. Abstract depictions are usually the kinds of images that also some scholars who subscribe to perception theories of depiction are happy to consider representational in the distinctively pictorial way. For instance, Richard Wollheim claims:

> we must not confuse the *representational* content of a painting with its *figurative* content. The idea of representational content is much broader than that of figurative content. The representational content of a painting derives from what can be seen in it. The figurative content derives from what can be seen in it *and* can be brought under non-abstract concepts, such as table, map, window, woman.
>
> (Wollheim 2001: 131)

In a similar vein, but backing his proposal with research in vision science, Michael Newall argues that representational abstract pictures prompt experiences of "non-veridical seeing without recognition of volumetric form" (Newall 2011: 173), i.e., experiences where one sees, e.g., non-existent relations of depth, although one does not see everyday objects. More recently, Paul Crowther (2021) has distinguished among different sub-kinds of representational abstract pictures, while arguing from a perceptual approach to depiction. Crowther claims:

> both figurative and abstract works share a common ground in *optical illusion*. The very placing of a mark on a plane surface creates optical

> relations, whereby the mark appears to push from the surface or, by suggesting a puncture, pulls the gaze beneath it. In this way, the basics of pictorial space are created as the outcome of optical push/pull effects. An important cognitive factor is also involved. The retinal image is two-dimensional, but our cognitive processes resolve it into three-dimensional structure. Given, accordingly, a plane surface, it is only to be expected that vision will seek to interpret any configurations upon it in three-dimensional terms, even if we are dealing with no more than lines and/or dots, and the like.
>
> (Crowther 2021: 104–5)

The projection theorists' (minus Greenberg 2021) approach and the perceptual theorists' approaches to abstract depiction, however, produce different results in the categorization of some images. Namely, since projection theorists do not tie depictive character to the perception of depth, they (minus Greenberg 2021) allow for, e.g., the silhouette picture of a cube to count as abstract depiction, while perceptual theorists, who tie depictive character to the perception of depth, do not (see Hyman 2006: chapter 7). Moreover, Crowther's view that "Given, […] a plane surface, it is only to be expected that vision will seek to interpret any configurations upon it in three-dimensional terms" clashes against all versions of the projection theory. Crowther here seems to suggest that we have reason to interpret as a bare-bones (abstract) depiction any pictorial surface presenting some kind of configuration. However, by the standards of projection theories of depictions, this is too vague. According to those theories, namely, an image qualifies as an abstract depiction if we are prompted to describe it, in quite abstract terms, as a scene produced via some identifiable method of projection – and this is not true of any image configuration whatsoever. We have, for instance, no title-based, contextual, or artistic reasons to claim that Pollock's *Autumn Rhythm* (1950), one of his drip-paintings, is better regarded as a depictive abstract image: the painting's title is suggestive of a sound, rather than a visual scene, we know that Pollock produced the painting while engaged in the project of making work that did not encourage interpretation in depictive terms, and the artistic value of the work lies in part in its being capable of sustaining prolonged visual interest *in spite* of its lack of depictive content, rather than thanks to the presence of some depictive content.[12] Similar remarks apply to many images that merely present abstract configurations on a plane surface.

2.3 Genuinely Abstract Images

In this section, I argue that there are genuinely abstract images: images that entirely abstain from depicting – i.e., from representing in the distinctively pictorial way – but that nevertheless convey something in virtue of the configurations on their surfaces.

On the one hand, if we follow Greenberg (2021), the question arises whether the realm of genuinely abstract images admits for *bare-bones projections*: configurations that we have reason to see as resulting from the projection on a two-dimensional surface of visible aspects of three-dimensional objects as seen from a certain viewpoint, according to a certain method of projection, and that however do not convey full-blown depictions. As we have seen, Greenberg (2021) argues that those configurations only allow for descriptions of their content in quite abstract terms and are therefore not truly depictive. It follows, then, that those objects are candidates for the status of genuinely abstract images. Can we explain how they have aboutness and thus claim that they indeed qualify as genuinely abstract images, within Greenberg's (2021) theoretical framework? I submit that, staying faithful to Greenberg's (2021) account, we can claim that those configurations convey content in *quasi-depictive* fashion. Although they do not allow for recognizing three-dimensional objects while looking at them, they invite description in terms of scenes presenting generic shapes, organized relative to a viewpoint. In other words, they are suggestive of spatial scenes that, however, they do not fully depict: they are parasitic on depictive images, since they are images where we are expected to notice the absence of depicted content (see Walton 1988: 352). Mondrian's *Oval Composition (Trees)*, for instance, would qualify as an abstract projection. The picture is suggestive of a scene inhabited by trees, as hinted by the title, but trees do not properly constitute its depictive content, as we cannot really recognize trees in the picture: rather, while looking at the picture, we are expected to notice that it fails to depict trees, although it alludes to them. In this explanatory framework, then, *quasi-depictive genuine abstract images* are those images that abstain from depicting by abstracting from those visual properties of objects that would allow for recognizing them in an image and describing them in precise ways.

On the other hand, if we follow Hyman (2006), Kulvicki (2006) and Greenberg (2013), we must conclude that the realm of genuinely abstract images does not encompass bare-bones projections, as they qualify instead either as abstract bare-bones depictions or as recognitional bare-bones depictions. Be that as it may, all versions of the projection theory of depiction allow for identifying some configurations on two-dimensional surfaces that we have no reason to consider depictive, or parasitic on depictive images, and that, however, we have reason to consider images, nevertheless. All those configurations are genuinely abstract images. In the following sub-sections, I shall describe four ways in which those images can convey content, while not relying on depictive or quasi-depictive means: conventionality, indexicality, exemplification, and expressivity. These forms of aboutness are mutually compatible but, for the sake of explanatory clarity, I shall discuss each of them separately. Other forms of aboutness in genuinely abstract images might be possible: I do not aim to give a complete taxonomy.

Before delving deeper into this, let me spell out the criterion of correctness for genuinely abstract images: *X* is a genuinely abstract image if and only if (i) *X* has aboutness in virtue of the visual configurations on its two-dimensional surface and (ii) *X* is not depictive. On the one hand, if we embrace Greenberg's (2021) view, we can observe that one might seek to produce a genuinely abstract image with a certain configuration and end up producing a full-blown depiction by mistake. On the other hand, if we follow Hyman (2006), Kulvicki (2006) and Greenberg (2013), we can observe that one might seek to produce a genuinely abstract image with a certain configuration and end up producing an abstract depiction, or a recognitional depiction, or even a full-blown depiction.

2.3.1 Conventional Genuine Abstract Images

Conventional genuine abstract images convey meaning in virtue of established conventions. For instance, the yield sign means that drivers must slow down and yield their right to other vehicles and pedestrians approaching from different directions. Analogously, in the column charts often used in scientific communication, rectangles of different colors (and, if need be, heights) stand for different categories of objects – depending on the conventions holding for each image. Note that, without knowledge of the relevant convention, there is no understanding of the meaning of a conventional genuine abstract image, and the convention does not shine through the image itself: we need to learn it through other means.

Conventional genuine abstract images abstain from depicting but they may present some visual properties of the objects they conventionally represent, thus not abstracting entirely from the visible. For instance, a red monochrome image might conventionally stand for fire, thus presenting a visible aspect of the object it stands for. On the other hand, the same image might conventionally indicate a school building, thus not presenting a visible aspect of the object it stands for.

2.3.2 Indexical Genuine Abstract Images

Indexical genuine abstract images are about the object or event which produced them through a causal process – they are traces of that object or event. Consider Lucio Fontana's *Spatial Concept* series of images: the sharp cuts on the canvases are to be understood, among other things, qua traces of the precise slashing gestures that have produced them.[13] Indexical genuine abstract images are used in scientific practice too: for instance, while we do not yet have the instruments that allow us to observe directly the first stars that ever shone in the universe, we can get indexical genuine abstract images of those stars. This was done by astronomers who looked at the UV light emitted by the BD+44 493 star through a non-depictive image produced via the Cosmic Origins Spectrograph, attached to the Hubble Space telescope: the image is a product of the UV light emitted by the BD+44 493 star, which presented traces of phosphorus, sulfur, and zinc – particles that belonged to the first stars, which exploded quickly and disseminated their elements around the universe (see Roederer et al. 2016). Thus, the Hubble abstract image, having been produced, in part, by elements belonging to the first stars, is an indexical genuine abstract image of the first stars. The indexical character of genuine abstract images does not shine through the images themselves either: in order to be capable of understanding what those images are about, we need to be aware – through means other than looking at the images – of the causal history that links the images to the objects/events they are traces of.

Indexical genuine abstract images abstain from depicting but may present some visual properties of the objects they are indexes of, thus not abstracting entirely from the visible. For instance, an indexical genuine abstract image of a squid might show the black trace left by the squid's ink on a two-dimensional surface – a visual aspect of the squid. On the other hand, the indexical genuine abstract image produced by my thumb sliding on the sand does not show a visual aspect of my thumb.

2.3.3 Genuine Abstract Images With Exemplificatory Character

Genuine abstract images that have exemplificatory character exemplify one or more of the properties of the configurations on their surfaces, by means of possessing them and referring to them at the same time (see, e.g., Goodman 1976, 1978; Elgin 2018).[14] For instance, a column chart (see Section 2.3.1), consisting of three columns of different heights, each standing for a sub-set of set X in virtue of a convention, can be used to exemplify the particular height of each column in a context where the distribution of a specific property p is discussed, and the distribution of properties q, r, and s among the same three sub-sets of X turns out to be the same as the distribution of p. In the artistic context, Robert Ryman's white monochromes are a case in point. Ryman was interested in exploring the quality of paint in his works and, among other things, he produced a vast array of canvases where he applied white brushstrokes in various fashions. Those canvases are images: they have aboutness in virtue of the visual configurations on their two-dimensional surfaces. What they are about, I submit, are some properties of their two-dimensional surfaces that they exemplify, and which are perceived as salient by viewers encountering the works. In Ryman's white monochromes, those are properties of the white paint and of the pictorial support, which he manipulated in a variety of ways: *Twin* (1966), for instance, exemplifies the many parallel, horizontally oriented, white linear brushstrokes on its surface, while *Arrow* (1976) exemplifies its property of presenting a pictorial support with white paint applied on it in such a way that the support can be glimpsed by looking at the edges of the image and appears to be overwhelmed by the white paint.[15]

It seems to me that artistic, exemplificatory, genuine abstract images are analogous to music that "may present a very general concept by being, not representing, an instance of it" (Walton 1988: 357). For instance, as Walton explains, a musical recapitulation may exemplify "the general notion of returning […] Music might serve to show us what certain instances of returning from a trip, returning to health, returning to previous convictions, etc., have in common" (357–8). Applying Walton's reasoning to Ryman's white monochromes, I submit that those genuine abstract images show us what certain instances of, e.g., being a group of individuals with the same political orientation, being a set of independent elements physically oriented in the same way, and being a series of independent, concomitant events of the same length have in common, or what certain instances of, e.g., an individual overpowering another, a concrete slab poured over a plot of land, and a historical narration of certain events replacing another have in common.

Note that the exemplificatory character of genuine images can shine through the images themselves – although it does not need to: exemplified properties are usually perceptually salient and thus capture our attention. For instance, it is quite evident that, if Ryman's monochromes are about something, they are about the white regions of color on their surfaces. Note, also, that exemplificatory genuine abstract images abstain from depicting, but never abstract from visual content entirely. Namely, they always exemplify visible properties.[16] For instance, as we have seen, Ryman's *Twin*, exemplifies the parallel, horizontally oriented, white linear brushstrokes on its surface, while the column chart described above exemplifies the heights of the columns.

2.3.4 Genuine Abstract Images With Expressive Character

The issue of how to explain the perception of expressive character is much debated in philosophy, but mostly for what concerns works of music. A general theory of expressivity, that is suited to apply to a variety of objects and events (especially artistic ones), and that is backed by some research in cognitive science (as it is desirable), has however been put forward by Paul Noordhof (2008). Here, I shall briefly show how the theory can help us gain some insights into the expressive character of genuine abstract images. This is how Noordhof sums up his view:

> My proposal is that when we perceive expressive properties in a work of art, we imagine a particular kind of creative process which, when the expressive properties are those of emotions, is guided by emotions. […] we imagine how an emotion would be manifested through that creative process in non-expressively specified features of the artwork which realise the expressive property.
>
> (Noordhof 2008: 338)

Experiencing, e.g., a piece of music as joyful, according to Noordhof (330, 343), consists in sensuously imagining how joy feels and how one's feeling joyful would guide one's proceeding in composing that piece of music. Importantly, the imagining involved in the perception of expressive properties need not be conscious. At the core of this proposal lies the idea that emotions have "causal profiles": each emotion tends to cause certain behaviors, certain patterns of thought, certain patterns of feeling, and among the behaviors a certain emotion might cause there are not only simple behaviors like making certain gestures (e.g., smiling when we are happy), but also much more complex behaviors such as producing artworks with specific features (339).

Noordhof makes two remarks concerning the expressive character of images. In the first place, he argues, images can have properties that are expressive of emotions – for instance, properties of the brushstrokes – and thus work just like pieces of music that are expressive of emotions do, i.e., by prompting viewers to imagine how one's feeling the relevant emotion would guide one's proceeding in composing the image. Let me illustrate Noordhof's point with both a depictive and a genuinely abstract example. Consider Van Gogh's *Wheatfield with Crows* (1890): many brushstrokes in this painting prompt viewers to imagine how a feeling of angst would have guided the production of such an image.[17] Consider, also, Gerard Richter's multiple gray monochrome paintings, whose flat grayness prompts viewers to imagine how a feeling of despair would have guided the production of those images.[18]

In the second place, Noordhof observes,

> Expressive perception *can rest on our knowledge of mental life more generally*. Suppose that an artist wishes to paint a picture of a summer's day that reveals how, amidst all that sunshine, one' s mood can remain a contrasting one of sadness and despondency. It would not do to paint

> the day as sad and despondent because then we would lose the contrast. Rather the day must be painted bright and joyous. The mood will be conveyed by features upon which a sad and despondent person would focus, knowledge of which would enable us to see the emotion expressed in the picture.
>
> (Noordhof 2008: 336–7, my italics)

In a nutshell, images can have properties that are expressive not of emotions, but of sensuous ideas, such as an idea related to the experience of sadness on a beautiful summer day, or an idea related to the musical experience of jazz, which is key to grasping, e.g., the expressive character of Piet Mondrian's *Broadway Boogie-Woogie* (1942/1943), as Noordhof (336) stresses quoting Gombrich (1960: 311–3).[19] In the former example, grasping the expressive character of the image consists in imagining one's being guided by the sensuous idea of experiencing sadness during a beautiful summer day in one's painting that image. In the latter example, it consists in imagining one's being guided by the sensuous idea of jazz in one's painting the image. In such cases, Noordhof points out, understanding the relevant sensuous idea requires knowledge of "the features of the world the artist has chosen to focus on [...] and the artist's stylistic repertoire" (Noordhof 2008: 348–9). Pieces of knowledge such as an awareness of Mondrian's interest in jazz and/or, as Gombrich stresses, acquaintance with other, much more severe, works of his such as *Composition with Red, Black, Blue, Yellow and Grey* (1920) and *Painting I* (1926) are key to grasping the sensuous idea expressed by *Broadway Boogie-Woogie*.

Thus, the expressive character of genuinely abstract images that are expressive of sensuous ideas does not shine through the images themselves but requires appropriate contextual knowledge to be grasped. The same, however, might not be true of genuinely abstract images that are expressive of emotions, I believe. Psychological studies on the emotional perception of color abound, and they show significant regularity and similarity in the way subjects emotionally react to colors (see, e.g., Jonauskaite et al. 2020; Valdez and Mehrabian 1994). It seems, then, that to grasp the expressive character of, e.g., Richter's gray monochromes, one might just need to rely on their cognitive abilities, with no need of additional contextual knowledge.

Expressivity, I submit, is often key to grasping the aboutness of genuinely abstract images in the art realm. Let us briefly consider a few more examples. The configurations Pollock put together by quickly dripping paint on a very large canvas make *Autumn Rhythm* expressive of a feeling of angst and restlessness, in line with the changes the environment undergoes in autumn in the Northern Hemisphere (leaves fall, wind blows, and rain pours). Clyfford Still's *1953*, which presents a canvas painted mostly in deep blue, with a yellow edge at the top right, is expressive of a humanist, anti-authoritarian attitude, as the artist himself suggested.[20] Similar remarks apply to James Welling's *Fluid Dynamics* works.[21] Those are photograms that are reminiscent of watercolors and that result from exposing wet photographic paper to light from a color enlarger. Neither the photograms encourage the viewer to see them as depictions, or parasitic on depictions (importantly, as Costello 2018 explains, they are not causally linked to a three-dimensional scene captured by a photographic event), nor are they presented as conventional images, nor do they function as indexes – although they are the result of a causal process, there is no evidence that the artist presents them to be understood as signposts for the objects that produced them, or that they would acquire more artistic value if thus interpreted. The watercolor-like configurations in the *Fluid Dynamics* series of photograms are, however, expressive of a sense of malleability and changeability. This is (in part, at least) what they are about.

Let us now consider a case of expressive genuinely abstract image from the realm of scientific practice: the images produced via the ALICE detector at the CERN's Large Hadron Collider, Geneva, which *conventionally* represent different kinds of particles and collisions among them, aiming at understanding the state of the matter shortly after the Big Bang.[22] To each kind of particle there corresponds a different, fluorescent color, so that the various particle trajectories and collisions are shown as a pleasant bundle of effervescent lines. This is expressive of liveliness, and with Noordhof we can claim that our grasping the expressive character of the image consists in imagining the act of producing the image as guided by a feeling of liveliness. More specifically, it seems to me that, since we tend to mistakenly see the image as some kind of abstract photographic image *causally* produced by the particles, we grasp its expressive character by imagining anthropomorphized particles feeling lively as they have just, so to speak, sprung into the universe after the Big Bang. To my knowledge, the expressive character of these images does not convey relevant scientific information but is rhetorically effective: not only the fluorescent colors make the images more appealing, but they also evoke a "beginning of new opportunities" narrative that makes more approachable the topic of the state of the matter shortly after the Big Bang.

Importantly, the same genuinely abstract image can exhibit more than one non-depictive mode of aboutness. The ALICE images are both conventional and expressive, as I have just shown. Ryman's *Twin* exemplifies the brushstrokes on its surface, as we have seen, but is also an index of the painstaking gestures performed by Ryman while painting it. Yves Klein's International Klein Blue (IKB) monochromes, such as *Blue Monochrome* (1961), exemplify that particular shade of pure ultramarine but are also expressive of a feeling of boundlessness, thanks to the fact that his trademark shade of blue is made of pure color powder in an almost invisible resin solution: this allows individual grains of the powder to look autonomous, rather than bound together, when the paint is applied on surfaces.[23] When we look at the Klein monochromes, I submit, we are prompted to imagine the act of producing them as being guided by a feeling of boundlessness, because of the particular way the grains of IKB powder look on those pictorial surfaces.

Finally, note that expressive genuinely abstract images abstain from depicting and, being about emotions, feelings, and sensuous ideas, also abstract entirely from what is visible: although they are images, they are never *about* visible objects.

2.4 Conclusion

To conclude this overview, I shall briefly mention three general lessons about genuinely abstract images that, it seems to me, emerge from the analysis I have put forward. I hope they can be a starting point for further research.

In the first place, I have shown that, while all genuinely abstract images abstain from depicting, they do not always abstain from being about visible aspects of the world. To begin with, if developing on Greenberg's (2021) view we include quasi-depictive images within the realm of genuinely abstract images, it follows that there are genuinely abstract images which are always about visual scenes. Furthermore, genuinely abstract images that have exemplificatory character are always about the visible aspects they exemplify.[24] Conventional and indexical genuine abstract images, on the other hand, may or may not present visual aspects of visible objects. And expressive genuine abstract images, on the contrary, are always about non-visible objects – the emotions, feelings, and sensuous ideas they are expressive of.

In the second place, "abstract" in "genuine abstract images" tends to be synonymous with "general". Firstly, if we admit for quasi-depictive genuine abstract images, then we have genuine abstract images that are about the generic scenes they suggest. Secondly, expressive genuine abstract images are about kinds of states of mind that can, in principle, be experienced by many individuals. Thirdly, exemplificatory genuine abstract images are samples which refer to visual properties usually possessed by a variety of objects, thus achieving a high degree of generality. Conventional genuine abstract images, on the other hand, may or may not be about both generic and specific objects and events (a conventional genuine abstract image may stand for a particular building or for a generic one, for instance). On the opposite side of the spectrum, indexical genuine abstract images are indexes of specific objects or events, and thus they are always about something specific.

Finally, the degree to which we can understand what a genuinely abstract image is about merely based on the information we can gather while looking at the image is variable. Conventional and indexical genuine abstract images, as we have seen, require external information to be interpreted correctly. Quasi-depictive genuine abstract images, on the other hand, do not necessarily require external information to be interpreted correctly: it might be sufficient to look at them to see that they allude to generic visual scenes. Similarly, exemplificatory and expressive genuine abstract images, as we have seen, can sometimes be interpreted correctly without relying on external information.

Notes

1 My warmest thanks to Chiara Ambrosio and Julia Sánchez-Dorado for their helpful comments and suggestions on a draft of this paper, and to Leopoldo Benacchio and Piero Antonio Posocco for their insights on spectrographic images and on conventional didactic images in contemporary particle physics.
2 For an image of the painting, see www.nationalgallery.org.uk/paintings/giovanni-bellini-doge-leonardo-loredan
3 See Neander (1987), Peacocke (1987), Budd (1996), Hopkins (1998), Abell (2009), and Blumson (2014).
4 See, e.g., Schier (1986), Wollheim (1987), Lopes (1996), and Newall (2011).
5 See Hyman (2006, 2012), Kulvicki (2006, 2020), and Greenberg (2013, 2021).
6 Greenberg (2021: 877–8) also criticizes the *perceived* resemblance theory of depiction put forward by Hopkins (1998).
7 For an image of the painting, see www.museodelprado.es/coleccion/obra-de-arte/las-hilanderas-o-la-fabula-de-aracne/3d8e510d-2acf-4efb-af0c-8ffd665acd8d.
8 For the first lengthy discussion of the bare-bones content of depictive images, see Kulvicki (2006): chapter 6.
9 Thanks to an anonymous referee for suggesting this objection to me.
10 For a discussion of the notion of authorial sanction, see Irvin (2005).
11 For an image of the painting, see www.piet-mondrian.org/oval-composition-trees.jsp.
12 For images of Pollock's *Autumn Rhythm*, see www.metmuseum.org/art/collection/search/488978. For an influential account of Pollock's work, see Ellen G. Landau (1989).
13 For an image of one of the paintings in the series, see www.tate.org.uk/art/artworks/fontana-spatial-concept-waiting-t00694.
14 As Catherine Z. Elgin explains:

> Exemplification is the referential relation by means of which a sample, example, or other exemplar refers to some of its properties [...] An exemplar highlights, displays or makes manifest some of its properties by both instantiating and referring to those properties. Indeed, it refers via its instantiation of those properties. A swatch of herringbone tweed can be used as a

> sample of herringbone tweed. It is an instance of the pattern that refers to that pattern. A swatch of seersucker, not being herringbone tweed, cannot serve as a sample of herringbone tweed. A sample does not exemplify all of its properties. It can highlight some of its properties only by marginalizing or downplaying others. In its standard use, a fabric sample does not exemplify its shape, age, or origin. Exemplification is selective. In different contexts, the same object can exemplify different properties. Although they are not exemplified in a tailor's shop, the size and shape of the tweed sample might be exemplified in a marketing seminar, where the focus is on what features make a commercial sample effective.
>
> (Elgin 2018: 29)

Goodman remarked that abstract pictures exemplify some of their properties (Goodman 1978: 65). On exemplification and abstraction see also Elgin's chapter in this volume.

15 For an image of *Twin*, see www.moma.org/collection/works/80266. For an image of *Arrow*, see www.gregcolson.org/single-post/2016/02/28/robert-ryman-arrow-1976. For a critical reading of Ryman's work, see Hudson (2009).

16 Here, I am leaving aside metaphorical exemplification which, according to Goodman (1976), allows for exemplifying non-visible properties – such as being sad or happy, for instance – via visual objects, by means of the metaphorical meanings attached to their visible properties.

17 For an image, see www.vangoghmuseum.nl/en/collection/s0149V1962

18 For images, see https://gerhard-richter.com/en/art/paintings/abstracts/grey-paintings-13. For Richter's statements about his gray paintings, see https://gerhard-richter.com/en/quotes/subjects-2/grey-paintings-9

19 For an image, see www.moma.org/collection/works/78682

20 For an image of the work, see www.tate.org.uk/art/artworks/still-1953-t01498

21 For an image of one of the photograms in the series, see https://artmuseum.princeton.edu/collections/objects/85715

22 For images and more information, see https://home.cern/news/series/lhc-physics-ten/recreating-big-bang-matter-earth

23 For an image of Klein's work, see www.moma.org/collection/works/80103

24 As remarked above (note 16), I have set aside the issue of metaphorical exemplification in this chapter.

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3 Abstraction in Photography, Revisited

Diarmuid Costello

3.1 Abstraction in Photography: The Problem

In a previous paper, 'What Is Abstraction in Photography?,' I set out a non-exhaustive typology of kinds of abstraction in photography (Costello, 2018b). My goal was to show that a sufficiently generous conception of photography (call this the "New Theory") coupled with a sufficiently determinate conception of abstraction—shared by authors as diverse as Clement Greenberg, Richard Wollheim, Kendall Walton and Michael Newall—presents no prima facie difficulty for understanding abstraction in photography. This is not true on prior theories of photography (call these "Orthodox theories"). To my mind, the latter arises from formalizing a folk theory that understands photography as essentially a non-agential recording medium (Costello 2018a). This folk theory is benign so long as it is recognized as local, but it becomes tendentious as soon as it is mistaken for global. This happens whenever a putatively general definition of photography is derived from inducting over a limited range of vernacular and documentary uses of the medium (or their later, social media equivalents) as though these exhausted the domain. These are the kinds of photograph and uses of photography with which most of us become familiar early in life (via records of family events, holiday snaps, selfies, social media feeds and so on), hence the kinds that come to mind most readily when philosophers reflect on their own, more or less limited, experience of photographs and photography. Absent such a narrow inductive base, however, abstraction does not present any particular problem for theories of photography. It is by now a well-established artworld genre, subject to regular international survey shows and critical anthologies (Rexer 2013; Souben 2020). Indeed, the perception that abstraction *does* present some kind of special problem for theories of photography really only attests to philosophical laziness when it comes to getting up to speed empirically with one's object of enquiry.

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Once one does take the idea of abstraction in photography seriously, it becomes apparent that what is called "abstract photography" comes in a wide variety of guises that cannot be easily subsumed under any simple or univocal definition: different kinds of photograph have been typed as abstract for different kinds of reasons, and no one kind can be non-normatively privileged as "abstraction proper," contrary to what purists like Gottfried Jäger (champion of "concrete photography") have tried to argue (Jäger 2005). On examination, restrictive definitions of this kind almost always turn out to be concerned less with adequately capturing the domain in question than making normative recommendations as to what should be taken seriously as the genuine article within it. In an attempt to remain descriptive, I distinguished seven kinds of abstraction that may be extracted from recent artworld surveys of abstract photography.

Although this taxonomy was presented as non-exhaustive, I nonetheless meant it to be broadly representative of the field. I have since come to believe it remains fundamentally incomplete for reasons I was not then in a position to recognize. That being so, in the present chapter I revisit my earlier conclusions: it now seems to me that they depend on mistaking a part of the logical space for the whole. The irony does not escape me: after all, this was the standard charge levied by new theorists against orthodoxy. But, like others, I assumed that when we talk about "abstraction" in photography, we are talking primarily, if not exclusively, about *artistic* uses of photography. Though perhaps unsurprising—it is an impression easily formed by consulting surveys in art museums and galleries—it is nonetheless a self-evidently question-begging way of forming one's idea of the field. Most obviously, it fails to recognize the existence of scientific and other *non*-artistic uses of photography and photographically derived imagery that would clearly count as abstract on the characterization of abstraction I was then defending.

Abstract scientific photographs are interesting for a number of reasons, not least that, until recently, consensus in philosophy of photography tended to conceive photography's epistemic and aesthetic capacities as a zero-sum game. Photographic images are taken to be epistemically privileged relative to hand-made images because photography is not vulnerable to various limitations (such as selective attention, lack of rendering skill, unconscious bias or false beliefs) that routinely afflict human beings as recording agents. This makes it difficult to be confident that the fact something does (or does not) appear in a hand-made image means it was (or was not) in the scene depicted; perhaps the person making the image was allowing their imagination free reign or failing to pay full attention. Imagine a melancholy landscape of barren fields with several oaks silhouetted against a low winter sky: were the fields really quite so barren, the trees really disposed just so, or did it rather suit the painter's purposes or sense of composition to so arrange them? Hand-made images, that is to say, are *non*-systematically selective; they do not select in or out for certain kinds of content on grounds that generalize. One cannot derive any kind of rule from one painter's sense of composition that will hold for another's, and that we cannot is one of the things that makes the work of individual artists interesting. Now imagine a photograph of the same, and (to rule out the most obvious forms of manipulation) suppose one is looking at the original negative or glass plate. In so far as photography is selective, it is *systematically* selective; it selects in or out along a number of axes and dimensions that can be understood, isolated and controlled for: it does not move, or remove, individual trees or empty out particular fields.

To take the most obvious case: one can make judgements about relative illumination but not colour variables from black and white photographs. This is not because black and white photography is *unreliable* with respect to colour, but because black and white film stock is *insensitive* to colour; it systematically "selects out" or brackets colour variables. Similarly, one can make judgements about the number of non-occluded objects, persons or animals (both static and moving) in photographs taken with sufficient depth of field and a fast enough shutter, but not in photographs taken with either a very shallow focus, a very slow shutter speed, or both.[1] Again, this is not because such images are *unreliable* as to the number of non-occluded objects in shot, but because slow shutter speeds systematically select out fast moving objects, and shallow depths of field systematically select out objects falling outside a narrow focal range.[2] Entities falling beyond the temporal or spatial parameters of what such images are able to resolve will tend to show up as an indeterminate blur, if they appear at all: one often cannot tell whether there is anything in the relevant portion of the image and, if there is, whether it is one thing or several.

Because photography is systematically selective in these (and other) respects and hand-made images are not, it is generally thought that we have greater warrant for beliefs formed on the basis of what *is* resolvable within a particular photographic image, given the camera variables employed, than we do for those formed by looking at hand-made images. Call this photography's relative, if not absolute, "epistemic advantage."[3] Set against this, it is also true that we value the work of particular photographers and schools for their distinctive stylistic properties, which reflect non-generalizable decisions about what to foreground and what to suppress. Such photography seems to be *non*-systematically selective in ways that cannot be so straightforwardly accounted for; indeed, this is arguably why we value the work of one photographer or school over another. For this to be true, however, it is widely believed that photographers need to be able to intervene in the photographic process in a way that makes their concerns salient in the resulting work. Doing so may make their work artistically valuable, but only to the extent that it also renders it impure photographically. This suggests that whatever it is that renders photography aesthetically interesting in such cases, it cannot be what makes it photography; were this is not so pure photography, sans intervention, should suffice.

Intuitions of this kind generate the perception of an irreducible conflict or trade-off between photography's epistemic and aesthetic capacities. Artistic uses of photography seem to require intervening in the process in ways that undermine the epistemic privilege that knowledge-oriented uses of photography depend upon, while knowledge-oriented uses of photography are epistemically privileged precisely in so far as they preclude the kinds of interventions that artistic uses of the medium require. In so far, that is, as the process and apparatus are *not* interfered with, and subjective preferences about what to thematize and what to suppress that give artistic uses of photography their interest and value are set aside in favour of allowing apparatus and process to deliver standard results (Costello 2018a).

Viewed in the light of this perceived zero-sum game, abstract photography is generally seen as an exclusively *aesthetic* use of the medium. Being non-depictive, it is taken to afford (at best) knowledge of the photographer's activities and intentions, rather than knowledge of how some slice of the world appeared at a particular time. Apparently abstract photographs produced in the course of doing fundamental scientific research put pressure on this intuitive division of the field, suggesting that whether or not it holds true may depend on features of the broader institutional context, use or kind of photography at stake. For example: are the images in question taken "out in the field," where the channel conditions (such as shutter speed, aperture, film speed, and so on) determining what may be resolved in a given image cannot be closely monitored or controlled, or in the lab, where such conditions are routinely monitored and recorded by highly trained technicians? Which is true has implications for the kind of inferences that can be reliably drawn on the basis of the resulting images. In fact, not only do scientific photographs put pressure on the view that abstraction is a *solely* aesthetic phenomenon, they also put pressure on the view that photography's epistemic capacities are best conceived in terms of what they enable us to learn about the world *through depiction*—where pictorial depiction is understood as the representation of a three-dimensional scene on a two-dimensional surface, such that its viewers can recognize that scene in that surface (Maynard 1997). Scientific uses of photography are knowledge-oriented uses of photography if anything is; despite this, they rarely do anything so simple or straightforward as capture how the world *appeared* at a particular moment of time. Not only are they increasingly generated through complex processes of data capture and processing that involve the accretion and aggregation of statistical data patterns over time, but most do not even record phenomena perceptible to human beings, either because they rely on parts of the electromagnetic spectrum unavailable to human perception, or because the images are not produced by harnessing light's ability to mark surfaces in any straightforward sense (Galison 1997). Typically, scientific research does not generate images that show us something that we could, even in principle, have seen for ourselves had we been there to do so.

Not only are such images a test case for recent views of abstraction in photography and standard ideas about the relation between photography's aesthetic and epistemic capacities, including its artistic and more instrumental uses; they may also present a challenge to New Theory itself, given its dependence on Patrick Maynard's characterization of photography as "a branching family of technologies […] whose common stem is simply the physical marking of surfaces through the agency of light and similar radiations" (Maynard 1997, p. 3). Appealing to Maynard offered new theorists a way of thinking about photography that did not build in any ground-level commitments to realism, resemblance or even reference that the resulting theory then had to make sense of. Rather than starting from questions about what is distinctive about the relation between a photograph and what it depicts, which is to assume without argument that all photographs must depict something, sending reflection on photography down a particular path, photographs were to be distinguished from non-photographic images by virtue of implicating a "photographic event" of recording information from a passing state of a light image in their causal history (Phillips 2009). The benefits for understanding abstract photography of not building in any unargued assumptions about depiction will be obvious. Dawn Wilson [née Phillips], Paloma Atencia-Linares, Dominic McIver Lopes, Catharine Abell and myself, among others, have all endorsed some version of this view (Abell, Atencia-Linares, Costello and McIver Lopes 2018). Whether the resulting view withstands consideration of scientific photography is one question I want to consider here.

I address that question here by focusing on two sets of images, one artistic, the other scientific. My artistic examples are several works by the photographer Wolfgang Tillmans bearing the collective title *Freischwimmer* (begun 2003), a set of enormous, arrestingly lush, photographic abstractions on a scale to rival mid-century gestural abstraction in painting. My scientific example is a series of black and white photographs taken from different angles of a single event: a large electromagnetic shower produced by a neutrino-induced collision in the 15-foot bubble chamber at Fermilab (Batavia, Illinois), at the time of its commission in 1973 the largest liquid hydrogen bubble chamber in the world. Not only is each set of images aesthetically captivating in its own right, they share some remarkable formal affinities. Yet it is hard to imagine two more different kinds of photography, not only in terms of what they depict, index or otherwise serve as evidence of, but in terms of their uses and epistemic affordances more generally. And since this is true *despite* their formal similarities, we will be unable to correctly mark the differences between these images until such time as we cease to ground our conception of abstract photography primarily on features of how images look. This suggests that any broadly *formalist* conception of abstraction, of the kind pursued by most of philosophers of depiction other than Lambert Wiesing to date, will be unable to capture either the intension or extension of abstract photography (Wiesing 2010).

On the view I have previously defended, a photograph is an image that implicates a "photographic event" in its causal history: that is, an event of recording information from a passing state of a light image formed in real time on a light-sensitive surface. This is the core of so-called new theories of photography, drawing on Patrick Maynard's recommendations for renewing philosophical research on photography. The centre of gravity for these theories is the role of light in the creation of the image, and not anything about the relation between photographs and what they are of that is supposed to distinguish photographs from other kinds of images. Importantly, for new theorists, the effect of light on light-sensitive surfaces is necessary but not sufficient for the creation of a photograph. The latter additionally requires not only the recording of information encoded by that light, but its subsequent output in a form that can be visually appreciated. The important point is that one cannot have an image that can be visually appreciated without some form of further chemical or electronic processing. And if such processing is necessary, it must also be *internal to* "photography proper," not something that can be relegated to the domain of "post-production" and thereby dismissed as eliminable because, strictly speaking, inessential.

Given that implicating a photographic event in its causal history is what distinguishes those images that are photographs from those that are not on this theory, the processes used for image-rendering need no longer do this. Images output in ways not traditionally deemed photographic, such as being projected onto canvas and painted in by hand would count, in virtue of implicating a photographic event in their causal history; while images that look for all the world like a photograph, and may even comprise the same digital code as an image that *is* a photograph, may not so count, in virtue of having the wrong causal history. Imagine two indiscernible digital images, one of which derives from a photographic event, while the other has been coded up from scratch by a software engineer: however, much the latter may resemble the former, even down to the code of which it is comprised, it cannot be one on this theory.

Abstract photographs, like any other kind of photograph, still count as *photographs in* virtue of fulfilling this set of requirements, but what makes them *abstract*? There has been remarkably little work on abstraction by philosophers of depiction, despite its centrality to the art of the last century. What little there has been seems to agree on the following broad claims. Abstract pictures may trigger a limited form of depth perception, such as when one colour, shape or form is perceived as floating in front of or receding behind another, despite being located on the same flat surface, but may not trigger recognition of three-dimensional objects occupying volumetric space, on pain of collapsing back into figuration. For Wollheim, the distinction between abstract and figurative is a distinction *within* representational art, not a distinction *between* the representational and the non-representational; in both, we are aware of a marked surface and what may be seen in that surface, regardless of whether what can be seen in it is abstract or figurative (Wollheim 1980, 1987). Similarly, for Walton, abstract images still count as representational in virtue of prescribing imaginings about what one sees in their surfaces; in the case of abstract paintings, these imaginings simply pertain to features of these paintings themselves, such as the spatial relations between their component parts (as when one colour appears to come forward and while another recedes in a Hans Hoffman painting) rather than what those paintings depict, as would be the case in figurative art (Walton 1990).

Drawing on research in vision science, Michael Newall has characterized this experience of seeming to see relations of depth, transparency or overlap that are not literally present, but not everyday objects, as "non-veridical seeing without recognition of volumetric form" (Newall 2011). Despite frustrating the recognition of volumetric form for which vision has evolved, abstract images continue to engage our recognitional abilities, by affording recognition of features such as edges, colours and textures that typically *subtend* recognition of volumetric form. Terminological differences aside, a shared view of abstraction thus emerges: abstract images permit perception of spatial relations between forms, planes and lines in shallow space but rule out perception of three-dimensional objects on pain of collapsing back into figuration. A picture is abstract, then, if and only if it is what Wollheim would call "two-fold" in a restricted sense: (i) it affords "non-veridical" perception (or what Walton would call "imagined seeing") of depth and spatial relations between lines, forms and plains in a shallow space, but (ii) it rules out perception of three-dimensional objects in space (or what Newall calls "volumetric form") on pain of collapsing back into figurative depiction. Whether depictive theories of abstraction of this kind can make any sense of scientific uses of photography is the question I now want to consider.

3.2 Uses of Abstraction in Photography: Two Case Studies

3.2.1 Artistic Uses of Abstraction

The images I take as my artistic case study are several of Tillmans' *Freischwimmer* abstractions. A word on the title first: "Freischwimmer" is the term used for the level of proficiency in swimming typically taught in German primary schools. Once pupils are able to swim uninterrupted for 15 minutes without holding onto the side of the pool (and dive from the lowest board), they are free to swim unsupervised in the deep ends of public pools. They have earnt, so to speak, "the freedom of the pool." There may be a faint suggestion of this theme in the impression of aqueous depths in some of the images, but a deeper resonance pertains to what the images index. The notion of "indexicality," drawing upon a highly selective reading of C. S. Peirce's distinction between iconic, symbolic and indexical signs, is one of the sacred cows of photo-theory (Peirce 1932, 1955).[4] Unlike images that have either a conventional or mimetic relation to their referents (symbolic and iconic images, respectively), photographs, the story goes, have a causal relation to their referents. Like the relation of smoke to fire, a footprint in the sand to the foot that left it, or the movement of a weathervane to the wind that turns it, they are a causal trace of their referents. Unless produced by a mechanism (such as a photographic lens) that ensures iconic resemblance, however, indexes need not resemble their causes: footprints do indeed resemble feet, but the turning of a weathervane does not resemble the wind, and smoke does not resemble fire. So only the former constitutes, like a photograph, an "iconic index."

It is tempting to assume that abstraction suspends photography's indexicality, but this would be too quick. It depends on the kind of abstract photography one has in mind: what I have previously called "proto," "faux," "constructed faux," "weak" and "strong" abstraction are *all* still indices of the world: each is still a causal product of the emitted or reflected light of what can be seen in them impacting a light-sensitive surface, irrespective of whether what can be seen in them can be immediately recognized. Only "constructed abstraction," images generated from scratch typically in a darkroom by utilizing various means of directly marking light-sensitives with light, and "concrete photography," images that take aspects or artefacts of photographic processes, materials and mechanisms as both their means and end, suspend indexicality in the term's standard sense (Costello 2018b, 398–400). This is because, unlike abstraction more generally, both are *additive* rather than *eliminative*; rather than arriving at an abstract image through a process of simplification, such as abstracting from, or reducing out, recognizable objects and space, both employ photographic processes and technologies to construct images from the ground up. But even if they evacuate indexicality in the sense of recording an image of the world, they not only retain an indexical dimension but might even be thought to insist upon it, in the absence of recognizable pictorial content; they index the actions that created them.

Consider the Tillmans in this light. I suggested there might be a faint echo of the title theme in the vague suggestion of watery depths in some of the images. The sheer scale of the images also contributes to this (the largest exhibition prints range in size from framed 171 × 230 cm C-type prints to 400 × 604 cm unframed inject prints). But I believe it is more plausible to see the *Freischwimmer* thematic played out in their distinctive mode of creation. In these images, one can see Tillmans enjoying, so to speak, the "freedom of the darkroom." Tillmans often remarks in interviews that he enjoys making these images, and I believe one can detect a sense of expansive freedom and creative spontaneity in many of the resulting images. About their distinctive mode of creation, Tillmans has said:

> Ever since I was in the position to make my own colour prints, I began to incorporate the errors that appeared during the many stages of this process into my practice. Soon enough, the mistakes became intentional, or rather they became a game of letting it go and reigning it in. From 1998, I have been actively manipulating the process in the darkroom, making devices with which I can influence light in particular ways [...]
>
> This manipulative and playful process is how, for example, the *Freischwimmer* pictures were produced. [...] they're made purely through the manipulation of light on paper. In this respect, their own reality, their creation and their time are absolutely central to their meaning: the time that I spend with the material in which I explore and intensify different effects. This intuitive recording and application of light, while a physical process, is at the same time liberated from a linguistic or painterly gesture of complete control. [...] it is often strikingly simple. And I take pleasure in this simplicity because a strength lies within it.
>
> (Tillmans 2014, p. 154)

Unlike other photographers (such as Marco Breuer, Walead Beshty or James Welling) who sometimes directly manipulate light and photographic materials in the darkroom in related ways, Tillmans is less forthcoming about the specifics of how his images are constructed. We are only informed that, the appearance of liquid flows notwithstanding, they are created through an entirely dry process: "*Freischwimmer* are made by manually moving light-sources and light-emitting tools and toys that I manipulate over light-sensitive paper in the darkroom. So their process is a completely dry one until I feed them into the normal developer bath." Further: "All associations with liquidity that the image and the name might suggest are made with light and without any liquids or other chemicals” (Tillmans 2011/15). As such, the works are a kind of “luminogram”: photographs created through the direct action of light on a light-sensitive surface without the mediation of a camera or (as still remains true of photograms) the presence of object(s) to occlude, refract or otherwise filter the passage of light. What one learns from the Tillmans, I suggest, is something about the kind of actions that made them. It is these actions that explain, if anything does, their title. We are prompted to imagine seeing in or through these images (Figures 3.1–3.3) a hint of the gestures that made them, and perhaps also something of the moods that inform them. The images are a residue of those actions and moods and thematize the photographic labour that subtends them. This already serves to weaken any hard and fast trade-off between their aesthetic and epistemic affordances: what one learns, one learns largely as a result of their distinctive aesthetic features.

What one learns does, however, remain rather vague. Since photographic papers react on exposure to light, darkening with the intensity of light to which they are exposed, one can assume that the black lines that appear throughout these works are generated by the movement of points of light impacting photographic media. Where there are dense clusters of lines that appear to move in unison in sweeping gestural flows, the images suggest that some kind of light-emitting tool has been swung in an arc by the artist. One imagines some kind of object punctuated by numerous tiny holes, illuminated from within by a light source and using lenses to focus the light. Clustered or speckled black pin pricks suggest a fine light source triggered in rapid bursts, sometimes held still, sometimes slightly jogged. The washes of colour could be the result of exposure to diffuse coloured lights, or passing light through coloured filters (such as gauzes or acetates). Much of this remains necessarily speculative, given not only Tillmans’ reticence about his methods but also the fact that, as photographers increasingly approach their media like painters, photography ceases to be systematically selective in ways that can be easily isolated or controlled for.[5]

The general point nonetheless survives: what one is responding to in viewing such images is not only their sumptuous aesthetic appeal, but the artistic performance of which they are both record and residue. One is encouraged to imagine seeing that performance—what the photographer has done—*through* its visual residue. There are passages in which one can clearly see, for example, a gesture that has folded back on itself, or a hoop-shaped light-emitting structure of some kind that has been rotated (Figure 3.2). In this respect, the scale of the largest exhibition prints can be misleading: these are enlarged from scans of originals created, on a much more modest scale, in Tillmans’ darkroom.[6] Gestures that, magnified many times over, suggest almost boom-like swings of an artificially extended arm may in fact result from nothing more dramatic than rotating a wrist.

So much for what these images *record*: what—if anything—do they *depict*? Recall that for most theorists of abstraction, abstraction remains one (non-figurative) kind of depiction, and not its contrast class. Tillmans' images often seem to suggest cosmic rather than aquatic spaces: even the high key colour has echoes of the kind of images created by astrophysicists for public relations and outreach purposes. Tillmans' palette in *Freischwimmer* (crimsons, vermilions and cadmium reds, veridian, emerald and cobalt greens, ultramarine, violets and deep cobalt blues, the occasional magenta, yellow ochre or cerulean) frequently recalls the high impact colours scientists assign to various gases detected in the early stages of cooling or coalescing into galaxies in astrophotography, even if Tillmans generally restricts himself to either a warm or a cold palette—sometimes bordering on near monochrome—for individual images in these works. The images often suggest a kind of open, indeterminate space, such as water, sky or perhaps deep space, untethered by any fixed points of reference, within which the events picked out by the black marks take place. The black marks themselves suggest a variety of possibilities: beyond indexing the movement of the body—presumably Tillmans'—manipulating a light source, some suggest a pulsing or surging that might be the ebb and flow of the tide, strange stop-start animal movements, birds or bees swarming in complex patterns (Figures 3.1 and 3.3), nodes of intensity as reminiscent of musical crescendos as of colliding weather systems, cloud banks gathering or filigrees of fine hair streaming in the wind. Occasionally, there may be a suggestion of burning residue falling back to earth, as after a firework explosion. Other passages seem to pulse or pump, recalling the kinds of movements that alternately expand and contract, like peristaltic motion, the circulation of blood or those undulating pulsations through which jellyfish propel themselves (Figure 3.2). Despite being abstract, then, most of the images at least appear to depict movement. Per the definition given above: we are prompted to (non-veridically) "see in," or "imagine seeing," some kind of force that pulses with inner life or, like waves, folds back upon itself when encountering some obstacle or form of interference, only to surge forward again once no longer impeded. Sometimes more than one force reacting to the presence of another is implied. Subtending this variety of events picked out within and against it, the surrounding colour itself has passages of intensity and moments of passion that might suggest visceral bodily responses such as arousal, attraction or repulsion or the interaction between more abstract forces. Many of the images seem, moreover, to open onto deep reservoirs of space, contrary to any view of abstraction—such as those canvassed above—that would insist on a strictly limited experience of depth. But it would seem indefensibly stipulative to

Figure 3.1 Wolfgang Tillmans, *Freischwimmer 79*, 2004. C-type print mounted on Forex in artist's frame. 180 × 240 × 6 cm, edition of 1 + AP. © Wolfgang Tillmans, courtesy Maureen Paley, London. Reuse not permitted.

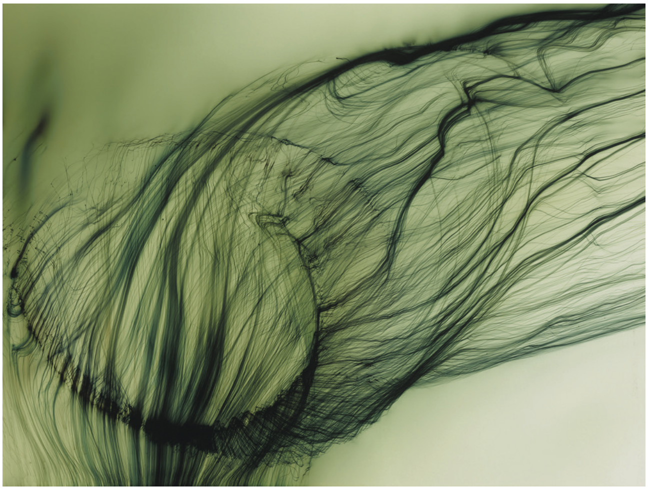

Figure 3.2 Wolfgang Tillmans, *Freischwimmer 16*, 2003. C-type print mounted on Forex in artist's frame. 190 × 253 × 6 cm, edition of 1 + AP. © Wolfgang Tillmans, courtesy Maureen Paley, London. Reuse not permitted.

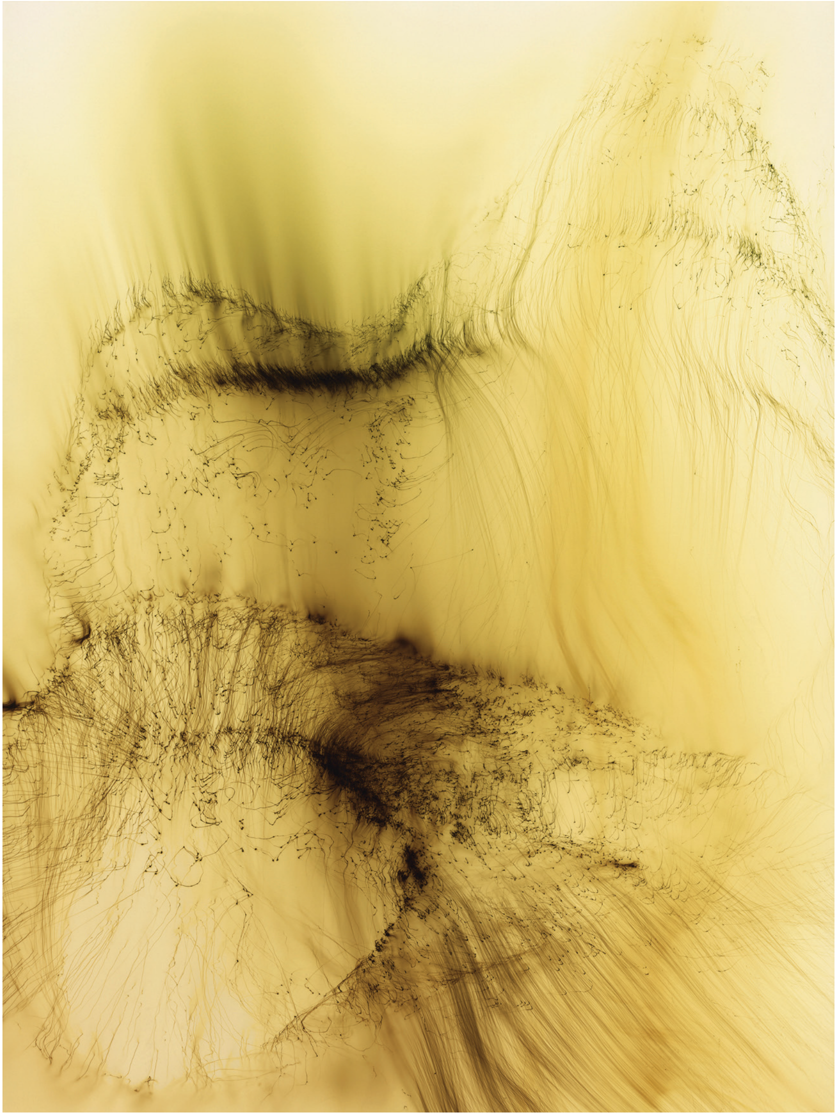

Figure 3.3 Wolfgang Tillmans, *Freischwimmer 78*, 2004. C-type print mounted on Forex in artist's frame. 251 × 190 × 6 cm, edition of 1 + AP. © Wolfgang Tillmans, courtesy Maureen Paley, London. Reuse not permitted.

refuse these images the status of abstraction for this reason: the counter-exemplification is more plausibly read to suggest that the definition itself is too narrow. Indeed, it is hard to imagine a more compelling case of what Michael T. Stuart and Anatolii Kozlov (this volume) call "generative" (as opposed to "subtractive") abstraction: that is, a kind of abstraction that proceeds less through processes of subtraction, selective omission or simplification keyed to an external target but is rather its own target and arises (whether in art or science) by *generating* a representation, often from the ground up.[7]

3.2.2 Scientific Uses of Abstraction

My second case study is of a very different kind: a series of images of particle trails in the large 15-foot bubble chamber at Fermilab, Illinois created in the course of doing fundamental research in particle physics. In fact they are all images of the same event, presented either in full or partial frame and from multiple points of view (Figures 3.4–3.6). All bubble chamber experiments are captured from multiple points of view simultaneously using high-speed flash photography. When aligned, using fiducial registration marks in the chamber, these different viewpoints allow an accurate three-dimensional reconstruction of what took place in the chamber. For the experiment in question, the chamber was filled with a mixture of liquid hydrogen and neon, and subjected to a beam of neutrinos. To fully grasp what such images show and, in particular, to understand the grounds for the conclusions that particle physicists draw from them, would require an understanding of sub-atomic physics, including quantum mechanics and relativistic kinematics. That is not required for my purposes here, and, since I am not a physicist, my own account will remain entirely non-technical.

In simple terms, bubble chambers enable scientists to measure the interactions and decays of charged particles by means of their traces, much as Tillmans' images enable their viewers to make inferences about his actions, albeit with the greater certainty afforded by scientific methodology. Bubble chamber photographs cannot depict sub-atomic particles directly; as the smallest known building blocks of the universe, they would be presupposed by any possible depiction, so they cannot be the object of one.[8] Rather, they allow physicists to make well-grounded inferences about the nature of such particles, and their interaction with other particles, by means of the traces they leave in a superheated medium.[9] A superheated liquid is unstable and boils as soon as a beam of particles is accelerated through it, generating bubbles, and it is the particle tracks these bubbles reveal that the resulting images capture.

A piston lowers the pressure of the chamber to the required atmosphere immediately prior to the beam of particles being introduced, causing

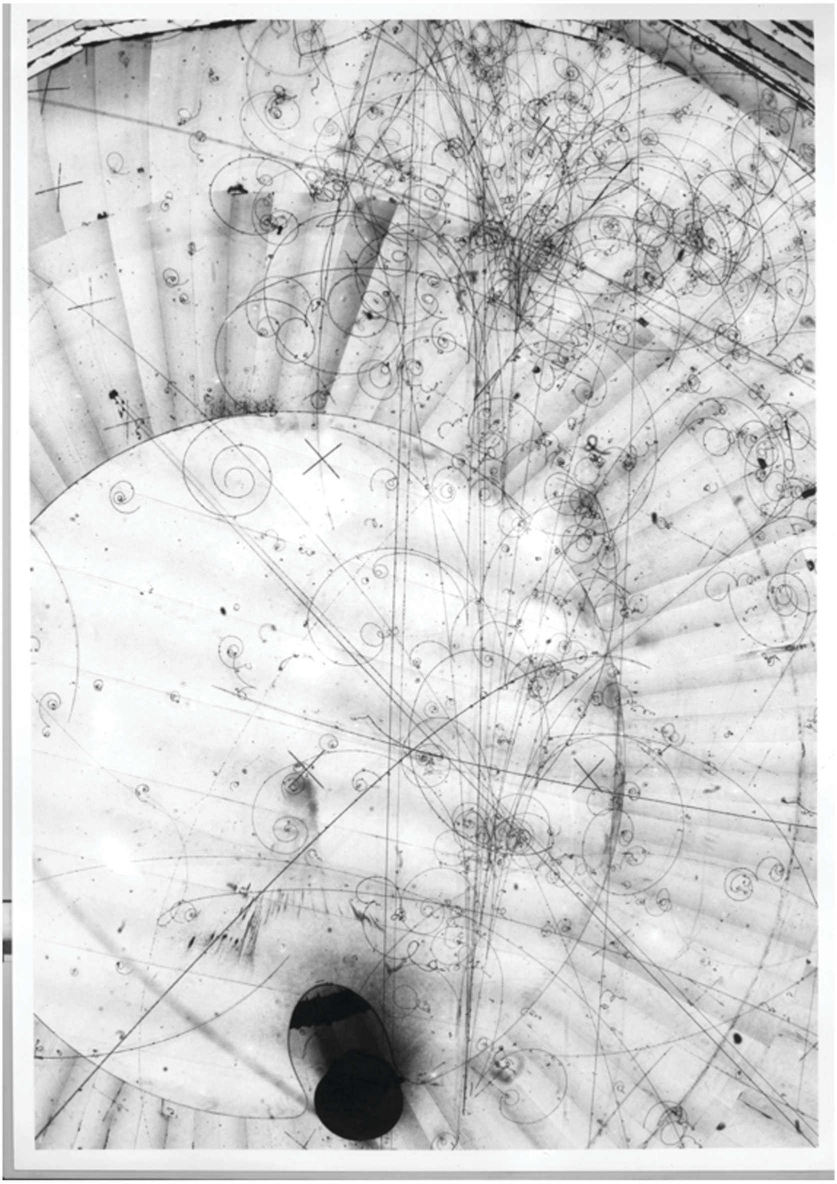

Figure 3.4 Full view of a neutrino-induced event producing a large electromagnetic shower in Fermilab's 15-foot bubble chamber. Image courtesy of Goronwy Tudor Jones, School of Physics and Astronomy at the University of Birmingham.

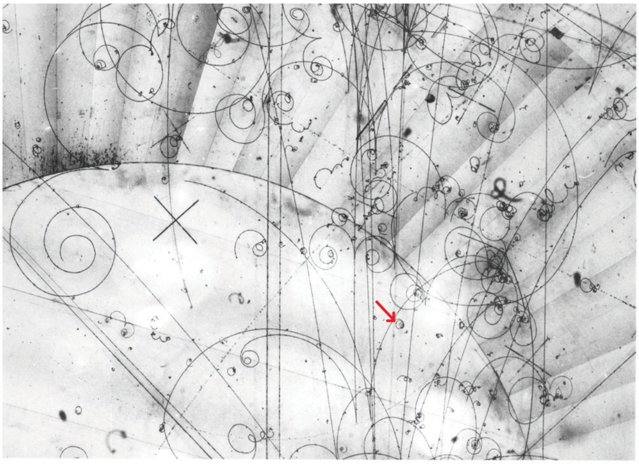

Figure 3.5 The red arrow picks out a tell-tale "knock-on" electron enabling us to determine that negative particles curve to the right. Image courtesy of Goronwy Tudor Jones, School of Physics and Astronomy at the University of Birmingham.

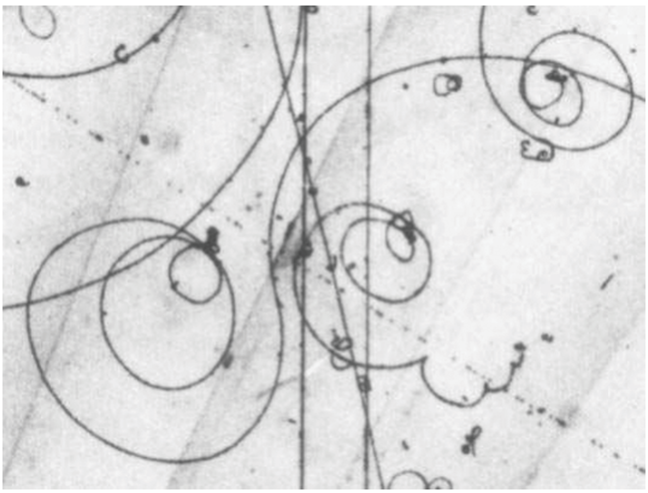

Figure 3.6 An apparent change in curvature of the incoming e^+ is followed by an e^- track – it spirals. A positron appears to have changed into an electron mid-flight. But this is impossible; it would violate charge conservation. What has happened? Image courtesy of Goronwy Tudor Jones, School of Physics and Astronomy at the University of Birmingham.

bubbles to form along the ionization trails left by charged particles traversing the liquid. As charged particles traverse the chamber, they expend some of their energy ionizing the atoms of the liquid within the chamber—that is, removing one or more electrons from its atoms through exerting an electrical force—and the resulting heat causes local boiling along the particles' path. Along the path of fast moving particles, one thus finds free electrons and positive ions.[10] Boiling starts around these ions, and vapour bubbles are formed. Should particles collide with nuclei in the chamber liquid, new particles are created, which, if charged, can also be tracked through their trails, since these too will also cause ionization of the liquid's atoms. The presence of neutral particles which, being uncharged, leave no trails of their own can nonetheless be inferred from the otherwise inexplicable production of particles apparently out of nowhere. Allowing these bubbles to expand to a size of at least half a millimetre is sufficient to afford something that can be captured photographically.

Bubble chamber experiments thus involve a particle accelerator, target and detector. The chamber itself is subject to a strong magnetic field, and this causes the paths taken by charged particles to curve. A key piece of information sought by physicists is the radius of curvature of the resulting particle tracks, which, in a magnetic field of known strength, allows a particle's momentum to be calculated. In principle, this should be simple, but in practice, it is complicated, given the margin for error, and the fact that particles lose energy as they force their way through the chamber, curving more as they lose momentum. A particle's charge is easy to determine: negatively charged particles curve in one direction and positively charged particles curve in the opposite direction. Once one locates the telltale spiral of a negatively charged "knock-on" electron (that is, an electron that has been knocked out of its atom by one of the larger particles accelerated into the chamber), one can determine the charge of all other particles from the curvature of their tracks (see Figure 3.5). Those that curve in the same direction as electrons are negative; those that curve in the opposite direction are positive.

James Elkins (2008) discusses several bubble chamber images, and I am indebted to his analysis. Elkins himself goes into some detail about the sub-atomic events captured in the images, drawing on correspondence and calculations by relevant physicists, most of which is unnecessary for my purposes here. What is required here is a more general sense of the kind of events such images document, as these would be interpreted by a particle physicist, rather than a layman.[11] Most of the tracks to be seen in these particular images document a large electromagnetic shower produced by the neutrino-induced collision (Figure 3.4). Here is a non-technical description, by the particle physicist Goronwy Tudor Jones, of how to interpret the exceptional event taking place in the middle of the picture. About two thirds of the way up, a track curving to the left changes its curvature (see detail in Figure 3.6):

> First, one needs to find a tell-tale knock-on electron to see which way negative particles curve. There aren't many, but there is a small one about 1/3 of the way up from the bottom, showing that negative particles curve to the right.
>
> (See arrow, Figure 3.5)

> Next, find where the positive track entering the blow-up picture comes from by looking at the main picture: it can be seen to be a positron, e^+, from a slightly obscured e^+e^- pair.
>
> In the blow-up, the apparent change in curvature of the incoming e^+ is followed by an e^- track—it spirals. So, a positron appears to have changed into an electron mid-flight: impossible—this would violate charge conservation.
>
> What has happened is that the e^+ has run directly into an e^-, transferring all its momentum to the e^-. This tells us that—within our experimental errors of measuring the curvature before and after the change in curvature—the mass of the positron equals that of the electron. Just by looking at a picture of something that happened in about a nanosecond, you have weighed a piece of antimatter. Wow!
>
> At this point, people ask, "Why did the positron and the electron not annihilate each other in the collision? Everybody knows that you get annihilation when matter and antimatter meet."
>
> The answer lies in the fact that the phenomena we are observing obey the rules of quantum mechanics. Within that realm, anything that doesn't violate conservation laws can happen. So sometimes an e^+ and an e^- can just bounce off each other as we've just seen; and sometimes they annihilate as, by a remarkable chance, happens in the same picture nearby: on the left hand side of the picture, just above a dark fiducial cross, an e^+ from an e^+e^- pair appears to stop mid-flight. If you look in the direction in which the e^+ was going you will see an e^+e^- pair pointing back.
>
> What has happened is the following: the original e^+ annihilated in flight with an electron in its path. Then, one of the photons produced in the annihilation went in the direction of the original e^+ and, after travelling 11cm in the bubble chamber, pair-produced a new e^+e^- pair.
>
> (Jones 2015, pp. 15–16)

The relative probability of the momentum transfer and annihilation described here depends on the energy of the original positron and requires complex quantum mechanics to resolve. The relativistic kinematics involved in demonstrating this is forbidding to the non-specialist (Jones 1993b, 1999). Given this, I have cited a non-technical gloss on what can be seen in these images, stripped of all mathematical justification for the interpretation advanced. But it is enough to bring out that what is most significant about such images *for the particle physicist* are the calculations they facilitate. It is not—or at least not primarily—a matter of "non-veridical seeing without recognition of volumetric form," "imagined seeing" or "seeing in." While this may explain, at the most basic level, how we are so much as capable of seeing such an arrangement of marks across a flat surface as a picture of something taking place in three-dimensional space, it does not capture what is most significant about such images for the physicist. This does not pivot on aesthetic savouring of what is seen, however captivating the images may be—which I am not denying (Elkins 2008, pp. 175–180). What is important about such images to the physicist are the interpretations they facilitate, and it is often the cumulative weight provided by a run of experiments rather than an individual image that underwrites a given interpretation. Granted: such analysis is based upon what can be seen in the images, which make the first order data available for analysis. But this is not what aestheticians would understand as their "focus of appreciation," but a basis for physicists' ongoing investigations into the most basic building blocks of nature and the forces they exert on one another. Indeed, it is because the calculations this requires can be achieved much more efficiently electronically, with the greater computational power of machines, that bubble chambers have now been obsolete for over a quarter of a century.

All this notwithstanding, these images clearly meet the general definition of abstraction that emerges from the limited reflection on abstraction by philosophers of depiction to date, and which I have previously appealed to myself in distinguishing various forms of abstraction in photography. In this view, abstract images permit perception of spatial relations between forms, planes and lines in shallow space but rule out the perception of three-dimensional objects on pain of collapsing back into figuration. But claiming that bubble chamber images are abstract *for reasons of this kind* is to disregard entirely what is going on in these images. It is to ignore their epistemic affordances—what they allow relevantly trained individuals to detect—by approaching them as though they were art, "with all the characteristics," as Elkins (2008, p. 175) notes, "of a painting or fine-art photograph." I have paired the bubble chamber images with the Tillmans precisely so as to bring out these commonalities. But commonalities of this kind are ultimately unilluminating. Philosophers of art may speculate about the actions performed to produce the Tillmans, while physicists may investigate what has happened sub-atomically to generate bubble chamber images. But since we can enquire about the causal conditions of *any* image, this ultimately falls away as trivial. Indeed, this might be thought particularly true of the photographic case, given how often photography has been understood, reductively, in causal terms.

3.3 Abstraction in Photography: The Problem, Revisited

This suggests that what has passed as a *general* characterization of abstraction in the philosophy of depiction to date cannot in fact be one. If that is right, we will either need to reconsider what visual abstraction is or accept a piecemeal account: what abstraction is, even in the limited sphere of photography, may turn out to be quite different, depending on whether the photography in question is art or science. And this will be the case irrespective of how similar or different the images in question may look; indeed, *how such images look* may not have the same relevance, or be the decisive consideration, across all domains. Given this, any account grounded solely on the visual properties of such images, such as the broadly formalist accounts that have exhausted the field to date, cannot suffice.

At this point, someone might object: why assume these images are abstract at all? Granted: they fulfil the pictorial conception of abstraction canvassed above. But given that the point of such images is to enable physicists to detect sub-atomic particle interactions lasting no longer than a few nanoseconds by means of the traces they leave in a superheated medium, the fact that they *do* still fulfil it might be seen as a reductio of that very conception. For if we abstract from the epistemic affordances of such images, by treating them as formal arrays in which picturesque clusters of arabesques intersect and overlay in various complex ways—as one might reasonably treat the Tillmans—we seem to lose sight of these images altogether. But refusing to accept that they are abstract for this kind of reason is no more straightforward. If we understand the images as *non-abstract* depictions and remain with accounts that understand depiction more generally in terms of "imagining seeing," "seeing in" and so on, we still need to be able to make sense of what we are doing when looking at such images in these terms: but can it make sense to understand the activity of looking at such images in terms of imaging seeing or seeing in, when what is thereby seen lies beyond the bounds of what *could*, possibly, be seen?

Are we constrained, then, to settle for a piecemeal account, according to which what counts as abstract in science (those processes of reduction, omission, selective disregard or idealization discussed at length elsewhere in this volume) is simply different to what counts as abstraction in art? But this does not seem right either: abstracting from three-dimensional space, volumetric form and figurative content are clearly an *instance* of reduction or selective omission, and as such of a piece with how abstraction is understood in science. Moreover, what Stuart and Kozlov call "generative" abstraction clearly spans this divide.

Rather than simply giving up on a unified account, what happens if we try to extend existing accounts to include bubble chamber images? Take the seven kinds of abstraction I distinguished in "What is Abstraction in Photography?": can bubble chamber images be accommodated within any of these categories, or are new categories required? Consider the alternatives. Bubble chamber images are not *proto*-, *faux*- or *weakly* abstract: they are not a way-stage on the road to abstraction proper; they do not isolate or estrange objects from their everyday environments; and nor do they record the world in such a way as to give rise to a perceptual experience that hovers indeterminately between abstraction and figuration. Nor are they *concrete* abstraction: they do not take artefacts of the photographic process as both means and ends. That leaves *constructed*, *constructed faux* and *strongly* abstract as possibilities. Each has something to be said for it, but also something that counts against it. Like constructed faux, the scene before the camera is constructed solely for the sake of being photographed; unlike constructed faux, there is no attempt to estrange by frustrating or delaying recognition. Like strong abstraction, bubble chamber photographs still record the world (here what happens inside the chamber) "in such a way as to no longer give rise to an experience, even an ambiguous or liminal one, of seeing everyday objects" (Costello 2018b, p. 397); unlike strong abstraction, it seems a stretch to call this "straight recording of the world," given how artificial and circumscribed that world is. Are they constructed? The comparison with Tillmans might be taken to imply this: but that comparison turns on formal similarities between images, and what qualifies a photographic image as constructed abstraction has nothing to do with how it appears, but whether it was created from scratch, typically without the use of a camera, by manipulating light-sensitive materials in a photographic darkroom. Given that this is not true of these images, and constructed abstraction was the only remaining possibility, we seem to have reached an impasse. Either these images are not abstract, abstraction in art and science needs to be understood in different terms, or the account of abstraction from which I began, based entirely on artistic examples, needs to be revised or augmented in the light of scientific practice to preserve the possibility of a unified definition. But if so, how?

Set what counts as abstract in art theory to one side, and briefly recall what counts as abstraction in science. Interpreting scientific data standardly involves various forms of modelling, and modelling itself is typically understood to involve abstracting or idealizing or both. Each strictly speaking misrepresents—raising questions as to how they are able to afford reliable insight into the relevant domains—but in different ways: the former omits certain aspects of the phenomenon under investigation in order to bring other aspects into view, thereby rendering them more salient; the latter introduces something not present in the target, in a bid to better understand it by way of its idealized reconstruction. As Roman Frigg puts it:

> An abstraction is the wholesale omission of a property […] an idealisation is the distortion of a property […] For this reason, abstractions offer a literally true (albeit incomplete) representation of the target, while idealisations assert, if understood literally, falsehoods.
>
> (Frigg 2023)

This perception of scientific modelling has come under increasing pressure, as several papers in this volume attest, for downplaying the more "generative" aspects of scientific abstraction itself. Representations that abstract do not only omit or "selectively disregard"; in doing so, they thereby reconfigure their target phenomenon in various, epistemically significant, ways (Stuart and Kozlov, this volume).

How does recalling this help? Note something that it implies, but that has yet to be thematized. What is the end user of artistic and scientific images looking for, as understood from within the perspectives of their relevant domains? Both could be understood to treat images as a kind of evidence, but evidence of what? In the case of scientific images, evidence of how some aspect of the world is or has been, or support for a particular model, theory or interpretation of how some aspect of the world is or has been. In the case of artistic images of the kind considered here, at least in part evidence of what the artist has done. In the latter case, however, this cannot be a purely descriptive question. In so far as making art is a kind of action, and humans act for reasons, there will always be a question of motivation: what was the artist getting at or trying to communicate? And if works of art are products of actions, to adapt the well-known formula of G.E.M. Anscombe, they must be responsive to a "reason-giving" sense of the question "Why?" (Anscombe 2000, §§ 5–7). Why *this*, rather than something else—or nothing at all? Indeed, this question was implicit throughout my own interpretation of Tillmans. But this is one question too many in the case of science: nature is not an actor in the relevant sense. There are of course grounds to be sought for why what happens does happen, and science asks after these grounds. But these are not grounds of the relevant sort. Since nature is not an agent, one cannot ask for its reasons. This reminds us of something that, one might think, should have been obvious all along: no adequate theory of abstraction can turn solely on how images look for the simple reason that, for any way an image might look, there could be a variety of perceptual arrays that look just like it but were generated in entirely different ways and belong to entirely different kinds as a result. Contrast a white monochrome with a pre-prepared primed white canvas in the artist's supply store, a white wall or, even, an uninterrupted expanse of snow. As a corollary, an adequate theory of abstraction will need to have more to say about the respective places of reasons and causes in the aetiology of images than has so far been the case.

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Notes

1 "Depth of field" refers to the distance between the nearest and further objects in focus relative to the lens and is inversely related to aperture (the fraction of the total lens surface that the aperture leaves open at a given "f-stop"). The smaller the fraction left open (the higher the f-stop number), the greater the depth of field: "f22," for example, means 1/22 of the lens is open, whereas f4 means ¼ of the lens is left open. For an explanation of why reducing aperture increases depth of field, see: https://physicssoup.wordpress.com/2012/05/18/why-does-a-small-aperture-increase-depth-of-field
2 The classic example is Louis Daguerre's *Boulevard de Temple* (1938), in which this busy Parisian thoroughfare appears deserted but for the shoeshine and his client in the foreground, because they were the only people who remained static for long enough to register given the prolonged exposure times required by early photographic optics and media, but the point generalizes. Whatever may have been true of the street when information from the scene was recorded, no other pedestrians, horses or carriages can be clearly distinguished.
3 Relative but not absolute because there are various drawing practices (such as botanical and ornithological illustration, or archaeological and other forms of technical drawing) that, through highly codified conventions for rendering various kinds of surface texture, plumage and so on, are better able to ground warranted beliefs about how the world depicted was than photographic images, which may not make the same differences clear.
4 Calling photographs "indices" plays broadly the same conceptual role in photo-theory as calling photographs *naturally* as opposed to *intentionally* counterfactually dependent on their sources does in the philosophy of photography. It is a staple of orthodox approaches to the medium. For a critique of

art historians' appeals to Peirce on indexicality, see Elkins (2003). For a critique of philosophers' appeals to natural counterfactual dependency, see Lopes (2016), Costello (2012, 2017) and Costello and Lopes (2019).

5 Despite this, it remains important to Tillmans that the viewer recognizes the photographic nature of these images: there is no intention to present images that might be mistaken for paintings.

6 The works Tillmans makes without a camera all have, as their standard smallest size, the size of the paper they are made on, in addition to the larger exhibition scans; in the case of *Freischwimmer*, this is typically 40.6 × 30.5 cm or 61 × 50.8 cm. These smaller works are sometimes also exhibited.

7 Tillmans' work would be an instance of the second form of generative abstraction they identify, one that *begins* in generation and is its own focus of enquiry, rather than arising out of a process of reduction or omission keyed to external object of enquiry that becomes increasingly distant from its original target. Tillmans even remarks: "the abstract picture is representational because it exists as a concrete object that represents itself" (Tillmans 2014, p. 154).

8 Electrons, for example, are conceived as point-like sources; in field theory they are given no radius (though in some low-energy calculations they may be assigned a "classical radius" of 10^{-15}). Entities with such magnitudes cannot be depicted in any conventional sense; they are essentially objects of pure calculation. See Elkins (2008).

9 That is, the unstable state a liquid enters into for those few thousands of a second immediately prior to boiling at a given atmospheric pressure. Think of water at a 110°C at one atmosphere (though water is not a suitable medium for bubble chambers).

10 "Fast-moving" in this context being of an entirely different order of magnitude to the "fast-moving" objects captured (or not) by conventional photography, depending on shutter speed. A particle might traverse the chamber in a few billionths of a second.

11 For the technical details of these images, including the associated calculations, see Jones (1993a).

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4 Bertrand Russell, Albert Barnes, and the Place of Aesthetics in the *History of Western Philosophy*

C. Oliver O'Donnell

On January 2, 1941, in the main gallery of the Barnes Foundation just outside of Philadelphia, the British philosopher Bertrand Russell (1872–1970) delivered the first lecture in what was then planned as a five-year series of lectures to an assembled group of some 50 students (Figure 4.1). The topic of the series was, as described by Russell that very day, "nothing less than… the history of ideas from the beginning of what you can call really civilized thinking to the present" (Russell, 1941, p. 1). To Russell that arrogantly meant the history of western philosophy from ancient Greece to himself. Such bias was typical of the period, of course, and Russell was undoubtedly established at the time as a leading intellectual voice; his reputation fundamentally rested on his early work in logic and the philosophy of mathematics and he had leveraged his renown to become a successful journalist and public lecturer on social and political issues. By the 1940s, these two strands of Russell's career were well established. At the time, however, he was in the United States as part of an effort to reestablish his traditional academic career, which had been derailed more than two decades earlier by his outspoken campaigning against the First World War and only unevenly resumed. Financially successful though he was as a popular commentator, Russell's friends convinced him that his true talents were misplaced outside of academia, a realization that was complicated by Russell's erstwhile student Ludwig Wittgenstein (1889–1951), whose meteoric rise and trenchant criticisms made Russell fundamentally question his previous contributions (Monk, 2000).

Such vagaries aside, the location of Russell's lectures in the Philadelphia suburbs was unexpected. Due to a successful lawsuit that had been brought against the City University of New York because of Russell's published – though no longer held – attitudes on marriage and sexual freedom, in 1940 Russell found himself in a foreign country during a time of war and suddenly unemployed (Dewey and Kallen, 1972). Coming to Russell's rescue was the confrontational and vituperative business man

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Figure 4.1 Albert C. Barnes and Bertrand Russell at The Barnes Foundation, Philadelphia Evening Bulletin, January, 2 1941. Photo: George D. McDowell Philadelphia Evening Bulletin Collection, Temple University Libraries, Special Collections Research Center.

Albert Barnes (1872–1951), whose foundation had only opened its doors in 1925 and which was the result of Barnes' quickly amassed fortune. Predating the establishment of the Museum of Modern Art in New York by several years and widely celebrated as one of the time's great collections of modern painting – itself a title that betrays the period's prejudice toward French modernism, not to mention American grandiloquence – the collection was integrated into an admirably progressive educational endeavor, at least for the time. Barnes initially hung many of his paintings in his company's factory, which produced Argyrol, a pioneering antiseptic that Barnes had successfully synthesized, manufactured, and distributed. And in its factory setting, the collection was accompanied by free seminars for Barnes' employees, who were disproportionately African American and with whom Barnes sympathized because he grew up attending Black churches in one of South Philadelphia's poorest neighborhoods. During his life, Barnes not only set up a trust fund for his employees, which would pay them each a modest stipend for life (McCardle, 1942), but would also leave control of his collection upon his death in 1951 to Lincoln University, a historically Black college outside of Philadelphia. Estimated to be worth some 25 billion US dollars today, the institutional gift would, nevertheless, be suspected by some to be an instrumentalization of the Black community for the purpose of Barnes' own vindictive agenda. Since his very decision to become an art collector was partially motivated by his having been snubbed by Philadelphia society, Barnes' generous bequest to Lincoln was, for his many critics at least, simultaneously an assurance that none of Philadelphia's more celebrated organizations would benefit from his largesse (Schack, 1963).

Into this fraught but still developing triangulation arrived Bertrand Russell, himself a true English aristocrat, grandson of a former prime minister, and political animal most comfortable somewhere in the murky ground between the liberal tradition and its socialist reform. A one-time Labour Party candidate for Parliament, Russell's self-image was heavily entangled with his extended family's distinguished lineage, a fact inevitably encouraged by his paternal grandparents, who raised him, and strengthened by John Stuart Mill, who was his godfather. Much like his grandfather, for instance, Russell significantly grounded his identity in the literal martyrdom of the Fourth Duke of Bedford, William Russell, who died for the cause of the Glorious Revolution (Monk, 1996). This led Russell to think about his own time through wide-ranging historical comparisons – likening Lenin, for instance, whom he met in 1920, to Cromwell – and claiming that the failures of the Russian Revolution "reinforce the conviction upon which English life has been based ever since 1688" (Russell, 1921b, p. 29). A deep-seated commitment to liberal tolerance, in other words, was an overdetermined aspect of Russell's thought, assuring that the more radical versions of socialism that captivated Russell's generation were largely too radical for him. Importantly, Russell and Barnes were in agreement on this point. Despite their divergent backgrounds, the two men were both critics of communism while sporadically claiming to be defenders of the working class. Barnes once even called himself a "true Communist" while also stating that "anyone who is a [actual] Communist is per se an idiot" (McCardle, 1942, p. 64). Fully redistributing the means of production, it turned out, was largely unpalatable for the comfortably patrician Englishman as well as for the self-made American millionaire.

Deeply intermingled with these political beliefs was Russell's and Barnes' overlapping commitment to that ill-defined practice known as mid-20th-century science. As a trained chemist, Barnes habitually claimed that virtually everything he did – including the educational program of his foundation – was guided by "science", which is not to say that he ever came to a satisfactory definition of that term. Barnes assigned his students and workers books like William James' *Principles of Psychology* and explicitly explained to Russell that "for more than twenty years we [have] been conducting a plan of adult education, putting into practice, by means of scientific method, the conceptions propounded in Dewey's classic volume, *Democracy and Education*" (Barnes, 1944, pp. 2–3). Having sought out John Dewey's graduate seminars in philosophy at Columbia University starting in 1917 – which was well into his middle age and after he had made his millions – Barnes became something of Dewey's student, a fact that baffled many of Dewey's academic disciples at the time and one that continues to puzzle some scholars today (Hook, 1952; Westbrook, 1991). Since Russell, of course, also defined his own form of philosophy as fundamentally shaped by science, Barnes assumed he would be a natural ally. Much to his chagrin, however, the Englishman mostly saw Barnes as a regrettable means toward a necessary income rather than an intellectual associate. On the one hand, Russell expressed little interest in visual art, and on the other, his conception of science was askew from Barnes' own quasi-pragmatist commitments. Whereas Dewey and Barnes' Pragmatism was premised on a holistic approach that often took the organism and its environment as fundamental units of analysis (Dewey, 1933, 1935), Russell's philosophy was premised on what he termed a logical-atomism, a mode of inquiry that attempted to break down experience and language into its most basic elements (Russell, 1917, 1931). This difference would, unsurprisingly, play itself out in the lectures Russell would give in Philadelphia and would ultimately contribute to – though perhaps not cause – their early and ignoble termination.

Be that as it may, all the more remarkable was what Russell almost entirely omitted from his Barnes' lectures: aesthetics, the philosophical topic to which his institutional host and its students were the most dedicated. In the almost 1000 pages of the book that would result from Russell's teaching at the Barnes – his *History of Western Philosophy* of 1945, a volume that has long been criticized for its errors and exaggerations but which would nevertheless shape introductory understanding of philosophy for generations to come – the word aesthetics occurs only eight times. The words paint and painting, moreover, the very media that dominated the walls of the rooms where Russell spoke every week for two full academic years, only six times between them. Such a conspicuous absence, however, does not mean that Russell's lectures were devoid of aesthetic commitments. Quite to the contrary, aesthetics is a fundamental and necessary part of all human experience, saturating our lives, our histories, and our closest convictions, meaning that we are left to reconstruct Russell's aesthetics as it tacitly emerges in his words and actions. Said another way – and this time through the ancient paradox of Parmenides, whose work Russell summarized at the Barnes – since the absence of anything also denotes its presence, otherwise we would not be able to speak about that absence, attending to the apparent absence of aesthetics in Bertrand Russell's lectures at the Barnes Foundation is only appropriate (Rockmore, 2021).

Luckily, previous scholars of Russell have done significant work in this regard, revealing the lie to Russell's habitual claim that he had no view on aesthetics and no opinion on art. As Carl Spadoni has pointed out, Russell himself even partially explained this contradiction, once writing that

> It is true that I have not written a separate book on the problems of aesthetics. I have never considered this was significantly different in its philosophical importance from problems in ethics and the general question of value statements. As for sense of "beauty", may I refer you to my books *Religion and Science*, *In Praise of Idleness* and my essay "A Free Man's Worship".
>
> (Spadoni, 1984, p. 50)

With these references in hand, a key to Russell's aesthetics, at least as I will pursue it here, is the concept of abstraction, a concept that lies at the center of Russell's thinking about science and one that was no less fundamental to the grand collection of paintings – meticulously arranged by Barnes himself – in which he was engulfed. Indeed, if we focus on what Russell meant by abstraction and why it was so central to how he thought about the history of philosophy, it becomes clear that the very paintings that surrounded Russell during his lectures at the Barnes Foundation expressed in "aesthetic form" – at least according to Barnes – some of the very commitments concerning "abstraction" that Russell held most dear. In what follows, I first develop and attempt to substantiate this claim before concluding by suggesting that Russell's lectures and the book that resulted very much suffered from a failure to recognize this fact. Russell's disadvantage, in short, was his absent aesthetics of abstraction.

Russell and Barnes on Abstraction

The self-evident place to begin any exploration of Russell's concept of abstraction as it relates to his work at the Barnes is found where his lectures at that Foundation began: with an account of ancient Greek culture. Russell praises the Greeks' "imaginative inventiveness in abstract matters" and their creation of "something … which proved of more permanent value to abstract thought": mathematics. "Geometry, in particular", Russell continued, "is a Greek invention, without which modern science would have been impossible" (Russell, 1945, pp. 38–9). Famously articulated, of course, in the treatises of figures like Euclid and finding classic expression in Plato's theory of forms, it comes as no surprise that Russell would laud such thinkers, especially considering his own investment in formal logic and deductive reasoning, practices which he also positioned as Greek inventions. What is slightly more surprising is that Russell would ground these fundamental origins of his own understanding of science in ancient Greek religion, claiming that the Greek attention to fate and destiny, "to which all were subject, even the gods, including Zeus", … "may have been the beginning of interest and belief in natural law" (Russell, 1945, p. 11). However true such speculative connections may be, as historical explanations they court *ad hoc* justifications of Russell's own authority, recursively positioning Russell as *fated* for his leading philosophical role. This function becomes notably evident by way of Russell's repeated comparisons of the height of ancient Greek culture to the 19th-century English culture from which he emerged. "The age of Pericles", Russell asserted, "is analogous, in Athenian history, to the Victorian age in the history of England. Athens was rich and powerful, not much troubled by wars, and possessed of a democratic constitution administered by aristocrats" (Russell, 1945, p. 81). Born in 1872 at the height of Victoria's reign, Russell himself was one of those aristocrats, meaning that abstraction and science were not only defined by Russell through concepts like mathematics and natural law but also by cultural formations that were originally Greek but proleptically British.

The tendentiousness of such comparisons is evident enough. But Russell's motivation for making them is more complex than furtive justifications for his own power, speaking as they do to some of his own most closely held beliefs. Few texts better clarify those beliefs than Russell's most reproduced essay, "A Free Man's Worship" of 1903, recognized by Russell himself – as noted above – as about as close as he came to articulating an aesthetics. There, in what is surely the essay's culminating passage, he wrote in a moment of quasi-religious ecstasy:

> To abandon the struggle for private happiness, to expel all eagerness of temporary desire, to burn with passion for eternal things – this is emancipation, and this is the free man's worship. And this liberation is effected by a contemplation of Fate; for Fate itself is subdued by the mind which leaves nothing to be purged by the purifying fire of Time.
> (Russell, 1917, pp. 55–6)

The appeal here to "a contemplation of Fate" as a kind of liberation from the pursuit of private, temporal – indeed earthly – matters self-evidently anticipates Russell's later claim in his *History of Western Philosophy* about the origins of science resting on Greek religion. The contemplation of fate, it turns out, was central to Russell's conception of eternity and to the value he found in abstraction. Having been largely raised by his pious grandmother, Russell's "Free Man's Worship" parallels his own description of his grandmother as "unworldly", as looking down on those who sought "worldly honours" (Russell, 1967, p. 22). Just as important, however, is how Russell marshals aestheticizing rhetoric to make his appeal, thereby also rebelling against the strict Victorian norms that shaped him. It is surely no coincidence that the above-quoted passage echoes the most quoted lines from the conclusion of Walter Pater's *The Renaissance* of 1873, which was widely read, admired, and imitated among Russell's Bloomsbury peers. Much like Russell above, there Pater asserted in a line so famous it hardly needs to be cited that "to burn always with this hard, gemlike flame, to maintain this ecstasy, is success in life" (Pater, 1901, p. 236). Notice how Russell, much like Pater before him, elucidated his ultimate life goal through a sentence that begins with a string of dependent clauses that themselves start with infinitive verbs and even ends his culmination by using the Paterian verb "to burn". So much, we might therefore conclude, for Russell's aversion to aesthetics; at the very center of Russell's history and philosophy of science is an aesthetic commitment, a commitment to eternity that – through his reliance on Pater's style – is revealed to be as much an aesthetic as an analytic concept.

Russell, of course, would have likely resisted the full implications of such a comparison. In his *History of Western Philosophy*, the few examples of aesthetic thinking that he cites are positioned as impediments to scientific progress. For instance, Russell prominently notes on several occasions that a dogmatic attachment to circular planetary orbits was a long-standing aesthetic bias of western thought that followed from the belief that the heavenly bodies should be perfect (Russell, 1945, pp. 131–2, 213, 526–30). Ironically, however, just as Russell criticized aesthetics, he also used aesthetic terminology to describe his most beloved mode of thinking.

> Mathematics, rightly viewed, possesses not only truth, but supreme beauty – a beauty cold and austere, like that of sculpture, without appeal to any part of our weaker nature, without the gorgeous trappings of paintings or music, yet sublimely pure, and capable of stern perfection such as only the greatest art can show.
>
> (Russell, 1917, p. 60)

The few works of art that Russell did admire unsurprisingly contain similarly stern and austere qualities: Giorgione's *Castelfranco Madonna*, wherein the tessellated floor in the foreground and the throne at the center directly employ rigid mathematic organization, and Piero della Francesca's *Baptism of Christ*,[1] a painting notably organized around the intersection of geometric shapes and a copy of which Russell supposedly hung above his bed (Spadoni, 1984). Needless to say, regardless of their geometric forms, the religious subject matter of such works also echoes – albeit in a different key – Russell's celebration of eternity.

The extent to which Albert Barnes understood or recognized this aspect of Russell's thought is unclear. At the center of Barnes' own thinking, however, was a concept that was also directed at eternity – or perhaps more accurately, at generality – and was non-coincidentally indebted to Pater, albeit at one degree of remove: form. Barnes himself was well aware of this indirect relation; in a book that Barnes co-authored, his long-time employee and tutor Laurence Buermeyer wrote that the idea of form was "clearly foreshadowed in Pater's assertion that art at all times strives towards the condition of music, in which the appeal to emotion is made without any recourse to images of real things" (Buermeyer, 1929, p. 92). Much like Russell, Buermeyer here celebrates the transcendence of individual, particular experience and does so through Pater's example. In Barnes' case, Roger Fry, also a mainstay of the Bloomsbury set, was his most explicitly acknowledged intellectual source for this approach. And given such overlap, it seems only appropriate to note that scholars such as Ann Banfield have gone so far as to argue that fundamental categories of Russell's philosophy – for instance, his distinction between knowledge by acquaintance versus knowledge by description – can be mapped onto Fry's art criticism, which is not to suggest that one caused the other but only to lay bare the connections between texts from a single cultural milieu (Banfield, 2000, pp. 245–93; Reynolds, 1905, p. 435). Said another way, despite their seemingly divergent foci on histories of science and art, respectively, and despite the ocean, culture, and class differences that separated them, the writings of Albert Barnes and Bertrand Russell were fundamentally related.

Perhaps unsurprisingly then, much like Russell, Barnes also constructed long-term teleological histories that were heavily weighted toward the concepts he valued the most. To wit, the French modern painters disproportionately represented in the Barnes collection were, its president assured his students, the legitimate successors of the old masters. And without abstract form as a hard-won perceptual practice – a practice that students at the Barnes were expected to master – the very ability to recognize the art in his collection as art would be an impossibility. As he put it,

> It is true that relevant judgment or criticism of a picture involves the ability to abstract from the appeal of the subject-matter, and consider only the plastic means in their adequacy and quality as constituents of plastic form. In that sense, a picture of a massacre and one of a wedding may be of exactly the same type as works of art. We abstract from each the form which is made up of the plastic elements – line, color, space, composition – and determine the quality of that plastic form

> as an organic, unified fusion of those elements. Until one has formed by study and long experience the habit of seeking the plastic form, the intrinsic appeal or repulsion of subject-matter itself will constitute the chief pleasure or displeasure afforded by pictures.
>
> (Barnes, 1928, p. 99)

Fatefully enough, Russell himself seemed to lack the very "habit of seeking the plastic form" by means of abstraction that Barnes here highlights. Early on in his lectures, Russell complained about being distracted by the many nudes on the main gallery's walls, describing them as "somewhat incongruous for academic philosophy", and even requested moving his class to another room in the building (Russell, 1967, II, p. 221). Earnest though such a comment and request undoubtedly were, they also contradict Russell's professed belief that he was insensitive to visual art. Had Russell been truly insensitive to paintings, it would have been easy enough for him to ignore the collection completely. Russell's documented reading of William James partially explains this situation. James' *Principles of Psychology* upheld a natural opposition between mathematics and the visual imagination by way of experimental research that confirmed the auditory and the visual mind to be divergent (James, 1890, II, p. 53). In the margins to his own copy of James' *magnum opus*, Russell wrote: "Mine is the auditory. I never think except in words which I imagine spoken" (quoted in Spadoni, 1984, p. 57). Unfortunately for Russell, the Barnes Foundation (Figure 4.2) was packed full of almost 900 paintings, meaning it would have been impossible for Russell to find a purely auditory setting there. Indeed, it is hard to escape from cloyingly voluptuous naked women when you have 181 Renoirs and only 23 rooms, which is the number of galleries in the Foundation's original premises in the Philadelphia suburbs. Moreover, since the Barnes Foundation itself was – as already mentioned – significantly informed by James' work and since that work was never meant to create an absolute or categorical chasm between the auditory and visual imagination, Russell's beliefs and request in this regard are perhaps best positioned as ideological overreactions, further betrayals of his quasi-religious aesthetics of eternity.

These contradictions notwithstanding, we can be sure that those who attended Russell's lectures would have been interested in how Russell's arguments resonated with the collection that surrounded them. After all, the students at the Barnes Foundation were there principally as students of the theory, history, and practice of painting and Barnes described Russell's course as "a supplement", "a systematic course in the historical and cultural conditions under which the traditions of art developed" (Barnes, 1944, p. 2). As Barnes himself wrote about art at length, this should come as no surprise, nor Barnes' description of Russell's lectures in aesthetic terms, writing to the philosopher that "not once was there a deviation [in

Figure 4.2 The Barnes Foundation's main gallery with Cezanne's *The Card Players* and Seurat's *Posers* in the background. On the right, paintings by Matisse hang between the windows and underneath a purpose-built mural also by Matisse, which was commissioned by Barnes in 1932. Photo: W. Robert Swartz Collection. Lower Merion Historical Society.

your most recent lecture] from that perfect fusion of emotion and idea that characterizes great art" (quoted in Meyers, 2004, p. 226). Aesthetics, in other words, even if largely absent from the explicit content of Russell's claims, was never far from his audience's mind.

And how could it have been? Even though Russell rarely mentioned aesthetic topics and only ever did so in passing, his students had been taught by Barnes to think about the art in the collection "scientifically", that is, through one of the central concepts that guided Russell's history. For instance, in the Preface to the book that would prove to be Barnes' most systematic attempt to elaborate his approach to painting – simply titled *The Art in Painting* and used as a textbook at the Foundation – Barnes described his own method of interpretation as

> a type of analysis which should lead to the elimination of the prevailing habit of judging paintings by either academic rules or emotional irrelevancy. In other words, this book is an experiment in the adaptation to plastic art of the principles of scientific method. So far as I know, the

> plan as a whole is new. The technique, in its general psychological and logical aspect, is derived from Dewey's monumental work in the development of scientific method. For the underlying principles of the psychology of aesthetics I owe much to Santayana.
>
> (Barnes, 1928, p. 11)

Despite his proclaimed originality, the true newness of Barnes' approach is dubious and already questioned by Barnes' citations of Dewey and Santayana as inspirations. Never much of a philosopher, the strength of Barnes' writing lay not with his elaboration of general principles but rather with his analysis of individual objects, as is often the case with collectors and connoisseurs. As already intimated, a particularly telling comparison for Barnes' thought is the writing of Roger Fry, or even Fry's popularizer, Clive Bell. Though not in his book, Barnes confessed to this debt elsewhere, frequently referring to a revelatory conversation he once had with Fry himself outside Paul Guillaume's gallery in Paris in 1920 (Barnes, 1924, p. 139). Barnes, in short, was a stereotypical kind of formalist with a penchant for late 19th-century psychological aesthetics, hardly an unusual combination and hardly a truly "scientific" basis for the analysis of visual art.

Nevertheless, the language of "science" unsurprisingly remained prominent at the Barnes Foundation and it would have literally haunted Russell's lectures there. For instance, one of the principal paintings in front of which Russell stood while lecturing was Cézanne's *The Card Players* (Figure 4.3) – proudly centered on the east wall of the main gallery and not coincidentally used as the frontispiece to Barnes' *magnum opus*. Barnes himself not only applied his own triumphantly scientific approach to Cézanne's work but also explicitly positioned Cézanne as something of a scientist manqué, making *The Card Players* a doubly fitting backdrop to Russell's history of philosophy. As Barnes himself put it,

> Cézanne, indeed, stands out as a unique figure among the painters of his time, if not of all time, because of the success of his passionate impulse to penetrate into the forms and structures of things. His constant pursuit of reality, in order to grasp it and portray it in its essence, was akin to the zeal and thoroughness of the investigator in science. Where Renoir found poetry and charm in everything, Cézanne found weight, mass, volume, texture, tactile qualities. He was critical and analytical, with a high intensity of mind and spirit in his search for facts by which to attain to the secret springs of form and structure. … Only a power to merge thought and feeling, to engraft relevant emotion upon substantial fact, to lend to an object his own life, kept such a personality out of the realm of science and within that of art.
>
> (Barnes, 1928, pp. 97–8)

Figure 4.3 Paul Cézanne, The Card Players, 1890–1892. Oil on canvas, 135 × 182 cm, Barnes Foundation. Photo: Courtesy of the Barnes Foundation, Merion and Philadelphia, Pennsylvania.

Barnes' description here of Cézanne's intense and profound relation to science is a conventional and long-standing trope of the interpretation of the artist's work (Schapiro, 1999). Yet it was an especially appropriate, albeit unwitting, foil to Russell's definition of philosophy. Just as Cézanne's art, for Barnes, was deeply saturated with a kind of scientific attitude but nevertheless safely within the realm of art, so too was philosophy for Russell, deeply shaped by science but nevertheless not reducible to it. Brought together, this would make Russell's lectures, at least in the mind of Barnes and his students, a kind of Cézannesque inquiry into the history of ideas.

Pushing the analogy further, it is interesting to note that some of Russell's and Barnes' more specific epistemological claims converge in unexpected ways. For instance, Russell had long associated himself with the doctrine of neutral monism, which he considered "the supreme maxim of scientific philosophising" (Russell, 1917, p. 155). Functioning much like Occam's Razor, Russell described neutral monism as following from the rule to "substitute [wherever possible] constructions out of known entities for inferences to unknown entities" (Russell, 1924, p. 363). Cézanne's *The Card Players* can add some clarity here, being a painting that fittingly contains a prominent representation of the very object that was Russell's most common example: an everyday table. Under Russell's neutral monism, Cézanne's table in *The Card Players* should not be simply understood as the cause of table-like sensations but rather as "the set of all those particulars which would naturally be called 'aspects' of the table from different points of view" (Russell, 1921a, p. 98). Such an approach, in other words, tried to frame our individual percepts – the patches of color on our retinas, for instance, caused by Cézanne's table – as events that are either mental occurrences or physical complexes depending on how we consider them. And it followed from Russell's own commitment to logical analysis as a form of scientific philosophizing because it made the construction of propositions about our raw experience a kind of testing ground, a place where our beliefs about the world and actual facts about the world could be brought together and analyzed.

Interestingly, Albert Barnes' very definition of form has some basic similarities with Russell's neutral monism; perhaps this is because both men drew on the work of William James, whose doctrine of "radical empiricism" Russell explicitly positioned as foreshadowing his own work (Russell, 1945, pp. 811–4). For Barnes,

> A man may be French, a Jew, an engineer, a thief, a celibate; New York is a city, a finance center, a harbor; in each case the man's or the city's form varies according to the grouping of relations which determine each category, and no single form represents either the man or the city in concrete fullness. Which of the various aspects we select to designate the man or the city depends upon the most representative or characteristic experience we have had with them.
>
> (Barnes, 1928, p. 38)

Note how for Barnes, just like for Russell, groupings of relation are key in determining form, an approach that they both define by emphasizing the importance of the multitudinous possible "aspects" of objects. Here we see again how their respective practices of "abstraction" overlap, being a cognitive process for both men that attempted to identify the shared structures of experience. If Russell was certainly more extreme in his analytic belief that the translations of such experiences into logical propositions would enable inquiry, Barnes was no less romantically optimistic in his definition of Art with a capital A by way of a vaguely structural conception of "form".

*****

The overlaps between the two men's beliefs, however, were not enough to reconcile their differences. Their opposed personalities – not to mention their wildly divergent backgrounds – soon intervened. Though Russell's lectures started well and were, as we have seen, initially celebrated by Barnes as high forms of art, the relationship between the philosopher and the collector slowly deteriorated. As was often the case with Barnes, this change for the worse was caused by a fittingly petty reaction to a minor occurrence that snowballed into a mound of resentment. In this instance, the ostensible issue began with Russell's wife, who was his third. Lady Russell's very attempt to access the foundation's galleries, then her comments to various staff members, and finally her knitting during her husband's lectures – all ostensibly innocent enough activities – proved too much for the overly sensitive and controlling Mr. Barnes. Seemingly unaware of his own domineering tendencies, Barnes positioned each act as an autocratic subversion of the foundation's strictly democratic rules (Meyers, 2004). Add to this the fact that Russell clearly believed that Barnes' pragmatist commitments were part and parcel of his commercialism – an insinuation that the two men tried to overcome by way of a dinner with Dewey mediating – the gulf between Russell and his employer seemed to widen by the day (Monk, 2000; Schack, 1963).

The eventual result of this uncomfortable situation was Russell's dismissal, which occurred at the end of December 1942, almost two years to the day after he had begun. Because Russell had continued to lecture at other institutions in the area during his employment by Barnes, Barnes had believed that he could fire Russell for breach of contract. He was, however, mistaken. Hiring a lawyer, Russell, in turn, sued Barnes on the same grounds and the presiding judge sided with the Englishman, forcing Barnes to pay the remaining three years of Russell's contract. Having only delivered his lectures through the medieval period, Russell used the remaining three-year's salary to finish the book he had planned from the beginning, a book that remains in print to this day, the sales of which provided Russell with significant income and financial stability for the rest of his life, and that was even cited by the committee that granted him the Nobel Prize in Literature in 1950 (Monk, 2000). Of course, considering the circumstances that led to that book's publication, there should be little wonder that references to "pragmatist" thinking are scattered throughout, though hardly in positive terms. Nevertheless, there were several points of contact and moments of convergence between Russell and that tradition of thought, some of which Russell was willing to concede. Beyond confessing his already noted admiration for William James' psychology and doctrine of radical empiricism, Russell also upheld John Dewey's theory of education, which was a doubly fitting connection to recognize. Not only were Dewey's educational ideals the guiding principles of the Barnes Foundation but Russell himself, along with his second wife Dora, once founded a school that had taken those ideas to heart (Gorham, 2005).

What such points of convergence begin to reveal, it seems appropriate to note in conclusion, is the self-defeating abstraction of Russell's lectures, at least when considered in context. By categorically avoiding the topic of aesthetics that was physically embodied in his lectures' surroundings and with which his arguments were unavoidably entangled, Russell exacerbated his own tendency toward "vicious abstractionism" (Winther, 2014). Defined by John Dewey as the danger of separating abstract thought from its context of emergence – concluding, for instance, that because a "thirsty man gets satisfaction in drinking water, bliss consists in being drowned" (Dewey, 1922, p. 123) – by avoiding the topic of aesthetics while simultaneously shoehorning history to fit his own aesthetic ideals, Russell effectively ensured that the attendance of his lectures would perpetually diminish. The book that resulted from those lectures, moreover, became an easy target for criticism. One reviewer wrote that

> the book embodies what seem to me the worst features of Lord Russell's previous more journalistic works, but it is of poorer quality than any of these. … [it] will teach successfully a popular substitute for thinking and for knowledge.
>
> (Smythies, 1947, p. 72)

Russell had, in fact, been warned of this danger by none other than William James. "My dying words to you", James wrote him in 1908, "are 'Say good-by to mathematical logic if you wish to preserve your relations with concrete realities!' " (Russell, 1967, II, p. 198). And Barnes criticized him for the same deficiency; "the history of ideas about which he lectured", Barnes wrote after their separation, "was a history of abstractions torn from their human context, with not the slightest recognition of the concretefulness of experience through all its history" (Barnes, 1944, p. 12). Had Russell been more connected to his senses and to concrete realities, of course, he arguably would not have been able to produce the pioneering works of philosophy that he did, would never, therefore, have established such a prominent reputation, and would simply not have been hired by Albert Barnes in the first place. Nevertheless, had Russell better acknowledged his commitments to an austere, mathematic, unworldly eternity *as aesthetic* and actually addressed his audience and context, perhaps his lectures at the Barnes Foundation would have been more balanced, more grounded, and thereby ironically become an even more enduring means for understanding the place of abstraction and science in the history of western philosophy.

Note

1 For an image of the painting, located at the National Gallery in London, see www.nationalgallery.org.uk/paintings/piero-della-francesca-the-baptism-of-christ

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5 Abstracting as Manipulating Aspectual Structure

Jane Richardson's Ribbon Drawings of Proteins

Chiara Ambrosio and Grant Fisher

Introduction

First published in 1981 in a landmark paper titled "The Anatomy and Taxonomy of Protein Structure", Jane Richardson's famous ribbon drawings of proteins remain only marginally discussed in historical and philosophical accounts of protein research (Strasser 2019; Fisher 2017; Ambrosio 2023). Originally based on molecular patterns produced through X-ray crystallography, Richardson's drawings departed from the complexity of earlier atomic models and followed instead her insight that pattern similarities among protein structures can be due to folding preferences. At a time of taxonomical confusion in the field, they answered the important question of whether proteins exhibit any regularities in their structures, and whether their structures could be compared for the purpose of classification.

In this chapter, we propose a sustained and systematic historical and philosophical study of Richardson's drawing practice and explore how her design choices crucially hinged on abstracting as a means of manipulating "aspectual structure" (Lopes 1996; Fisher 2017) for the purpose of representing and classifying proteins. In the first part of the chapter, we contextualize Richardson's work within a longer tradition of protein structure determination through X-ray crystallography. We show how her drawings emerged as an attempt at tackling issues arising from the complexity of earlier (atomic) models of proteins, offering a simple and effective method for comparing and classifying proteins according to their evolutionary relationships. In the second part of the chapter, we examine Richardson's drawings in detail, demonstrating how her system allowed her to approach protein structure dynamically and selectively, in line with her insight that the process of drawing can result in a change of understanding. It is in this second section that we present abstraction as the manipulation of aspectual structure, making the case that what the drawings refrain from showing through omissions and occlusions is equally

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constitutive of how they represent. For Richardson, we argue, the practice of abstracting involved making and operationalizing commitments and non-commitments that allowed her to present pictorial content in ways that would make protein structures visible and enable comparisons between them. Abstracting as manipulating aspectual structure in Richardson's system is thus a constrained process, which affects protein representation as a whole and is not reducible to mere omissions of individual properties of the representation's target system. In the third and final section, we show that abstraction as the manipulation of aspectual structure—and the operationalization of commitments and non-commitments it entailed—enabled *communicability* as well as comparability, and that this feature is at the core of the lasting legacy that Richardson's system of ribbon drawings continues to have in current methods of protein representations.

Richardson's Ribbon Drawings and the History of Protein Research

"Making a drawing can change one's scientific understanding of a protein, sometimes revealing a preferable classification" (Richardson 2000, 624), Jane Richardson commented in a feature article in *Nature*, which explained how her ribbon drawings of proteins came to be. Praised for their elegance and their taxonomic effectiveness, the drawings (which she also referred to as "ribbon schematics") introduced a still lasting system to represent proteins based on their secondary structure—the type of folding adopted by a protein's polypeptide chain: spiral ribbons stand in for alpha helices, smoothed arrows (with added thickness to emphasize their orientation) for beta strands, and rounded ropes for molecular loops (Figure 5.1).

Richardson's drawings mark one of the many turning points in the complex history of protein research. This history has been explored from a variety of angles by historians of science in recent years. Soraya de Chadarevian (2002), for example, has inscribed protein research, and particularly the key role of Max Perutz and John Kendrew's X-ray analysis of protein structure, within her broader history of molecular biology in post-World War II Britain. While not directly engaging with Richardson (who has always been based in the US), de Chadarevian's work offers an illuminating reconstruction of the techniques and methods of the tradition of protein crystallography in which Richardson herself worked, and of the dissemination and use of Kendrew's atomic models of proteins which—as we will show below—would form one of the foils to her own drawings. More recently, Bruno Strasser (2012, 2019) has shown how protein research, including Richardson's own taxonomical approach, contributes to challenge established narratives of molecular biology as paradigmatic of the assumed "victory" of experimentalism in biology over natural history and its culture of collecting. Strasser's argument that, far

Figure 5.1 Ribbon schematic (hand drawn and coloured) of the 3D structure of the protein triose phosphate isomerase.

Source: Richardson (1981); https://en.wikipedia.org/wiki/File:TriosePhosphateIsomerase_Ribbon_pastel_photo_mat.png ©Jane Richardson (Dcrjsr) CC BY 3.0 https://creativecommons.org/licenses/by/3.0/legalcode

from being at odds with each other, experimentalism and natural history come together in protein research (and, in his account, in the life sciences more broadly) is a valuable starting point for our analysis. It makes a compelling case for the lasting epistemological significance of the comparative way of knowing which informs Richardson's own "new natural history" of protein classification (Richardson 1981, 170). In this chapter we want to probe this epistemological line of investigation even further and show that abstraction—construed as the manipulation of aspectual structure—was crucial in advancing the taxonomical approach made possible by Richardson's drawings.

Richardson's work tackled a question that had been right at the heart of protein research for a long time: how to compare and classify the different protein structures that were progressively derived through X-ray crystallography. But this classificatory aim emerged later: in its early applications to protein research in the mid-1940s and 1950s, X-ray crystallography was seen primarily as supporting the idea that knowing the structure of proteins was a way of understanding their function. The hope, at least at the beginning, was that the solution to the structure of one protein would provide researchers with clues that would lead to the solution of the structure of all proteins. This hope was based on the expectation that proteins conformed to some overall plan or structure—an expectation that was soon proved wrong, but that for some time guided researchers through an otherwise too complex problem to tackle (de Chadarevian 2002, 102–103; 2018, 1137). Richardson herself (1981, 169) acknowledges the pioneering work of Max Perutz and John Kendrew, who applied X-ray crystallography to determine the structure of haemoglobin and myoglobin, respectively. Indeed, it was Kendrew in 1958 who first obtained a three-dimensional model of the structure of myoglobin from X-ray crystallography data (Kendrew et al. 1958). But even in this first, groundbreaking publication, Kendrew expressed his disappointment at the unexpectedly complex and irregular structure of his newly designed "sausage model"[1] of myoglobin: "Perhaps the most remarkable features of the molecule", he wrote,

> are its complexity and its lack of symmetry. The arrangement seems to be *almost totally lacking in the kind of regularities which one instinctively anticipates*, and it is more complicated than has been predicated by any theory of protein structure.
>
> (Kendrew et al. 1958, 665, emphasis added)

Kendrew's "instinctive anticipation" was that general principles for protein structure and folding would compare in simplicity and elegance to the double-helical model of DNA, built five years earlier by James Watson and Francis Crick at the very same laboratory in Cambridge where he was based (de Chadarevian 2018, 1140). But precisely in contrast with Watson and Crick's model, Kendrew's sausage model of myoglobin remained open to interpretation. It showed the molecule's polypeptide chain as a twisting cylindrical shape, and the oxygen binding structure as a disk, but no obvious rules for protein structure or protein folding could be derived from it. As de Chadarevian points out, the model "brought home the realization that there was no regularity in the structure of proteins and that the structure of every protein would need to be established from scratch" (de Chadarevian 2017, 1141).

Following the puzzling results of the sausage model, in 1959 Kendrew produced an atomic model of myoglobin. The model consisted in a "forest" of steel rods connected by Meccano clips to indicate electron density and skeletal model parts to give the exact position of each atom.[2] The model was also beautifully rendered in two dimensions in the *Scientific American* (Kendrew 1961) by the artist Irving Geis, whose career as a "molecular artist" took off precisely as a result of his collaboration with Kendrew (de Chadarevian 2002, 143–151; Gaber and Goodsell 1997). 3D atomic models of the kind Kendrew produced for myoglobin would later be produced for other proteins and came to be called "Kendrew models". They were incorporated in a routine for protein structure determination that was still in use when Richardson embarked on her drawings.[3] The process started from obtaining crystals of the protein under investigation, and projecting X-rays at the crystal at different angles to obtain X-ray diffraction patterns of spots that could be recorded on photographic film. The resulting picture gave a "slice" of the three-dimensional structure of the crystal, each spot corresponding to an index of the atoms present in the crystal.[4] The intensities of the spots and their phases, determined through the technique of "isomorphous replacement" (the measurement of two or more molecules, in which some atoms had been replaced by heavier ones),[5] were then combined by Fourier transform. This would produce contour maps of the molecules, whose peaks represented the highest electron densities indicating the presence of an atom. Electron density maps were then hand drawn on transparent plexiglass sheets which, when stacked, would give a rough three-dimensional image of the molecule. But even with this three-dimensional map, the structure of proteins remained elusive. Built consistently with electron density maps, Kendrew models remained at least until the 1970s a standard way of interpreting electron density maps and obtaining the precise positions of atoms in the protein structure.[6] As Soraya de Chadarevian points out, it was only by building the models that the structure of a protein could be viewed, the amino acids making the structure identified, and the coordinates of individual atoms determined (de Chadarevian 2002, 140). The structure, thus determined, could be analysed, interpreted, and represented in a number of ways. The ribbon schematics were one of them, and they tackled specifically the problem of comparing and classifying structures after having determined them.

"Protein crystallographers…have always insisted that the results of their work, embodied in three-dimensional models, were hard to convey in words or pictures", de Chadarevian (2002, 136–137) points out. Her argument was a direct critique of the widespread emphasis on text and images at the expenses of models which still characterized the history of science and science studies when she published her study in 2002. At the time, it was especially important to make a case that model construction in protein crystallography "was indispensable as to the experimental process of structure determination as to the appreciation of the proposed structures themselves" (ibid. 137). Indeed, it is precisely this historical work (see also de Chadarevian and Hopwood 2004), combined with the "turn to practice" and the revival of models in philosophy of science (starting from Morgan and Morrison 1999),[7] which paved the way for the establishment of a large body of literature on models and scientific representations more broadly. Far from arguing against the importance of models in protein research in the senses advocated by de Chadarevian, we want to suggest that Richardson's ribbon schematics embraced precisely the challenge of *conveying* and *operationalizing* commitments and non-commitments to structural properties that would allow protein chemists to arrive at a taxonomy of proteins. In that, they facilitated the development and shared use of classificatory knowledge about proteins—one of the very areas of research that crystallographers, following de Chadarevian's description, considered "hard to convey" (as we will see below, even through models). Crystallographers' early models escaped the limitations of the flat pages of journals through which research was disseminated; Richardson brought proteins back onto the flat page for the purpose of classification—and she did so via abstraction.

Abstracting as Manipulating Aspectual Structure: Richardson's Ribbon Drawings

"Proteins are so complex", Richardson wrote in a 1992 article, "that showing every atom is almost immediately rejected as hopelessly confusing". Directly referencing a Kendrew model included in the article, she continued: "an all-atom brass model of a small protein… is only a little more illuminating than a list of all the x, y, z's" (Richardson et al. 1992, 1186). From the outset, crystallographers experienced first-hand the difficulty of conveying in print the structural information that their models were supposed to convey. de Chadarevian's archival work reveals the very pioneer of crystallography, Lawrence Bragg, commenting on this well-known difficulty in 1968 and resolving that "the 'paper' sent to a colleague should be a model. There seems to be no simpler way of conveying the information" (cited in de Chadarevian 2002, 146). But while models served as essential research tools for molecular structure determination, by the late 1970s they still left unsolved the problem of comparing molecular structures. For this, protein chemists needed to return to drawings.

Early drawings of proteins were available at least since Geis' collaboration with Kendrew, but as Richardson (2000, 624) notes they were mostly schematics of individual proteins. When Richardson set out to produce her own ribbon schematics, the structures of 75 widely different known proteins had been determined. The number was in fact higher, but the very prompt for Richardson's work was the realization that evolutionarily related proteins with similar folds (such as haemoglobin and myoglobin) could be counted as in the same group. Tasked by the editor of the journal *Advances in Protein Chemistry* to produce a review of all known structures up to that time, Richardson realized that her review could be turned into a taxonomy of folds accompanied by the anatomy of the local motifs in protein structures. This would result in her now classic 1981 paper "The Anatomy and Taxonomy of Protein Structure".

In an oral history interview, Richardson recalls that even when drawings would be produced specifically for comparative purposes,[8] the question remained of devising a consistent system to make protein structures comparable:

> There were several versions of similar drawings that people had done one or two of to illustrate a particular protein. But they were all slightly different, and they were all done from different viewpoints and with slightly different conventions. And so even for proteins that were very, very similar, if you looked at two of these drawings, you wouldn't know that. And so what I was trying to do was make a uniform set of conventions and to draw all seventy-five of the structures that were known. And so for related ones, I would draw them from the same viewpoint, so that you could see what was the same and what was different. And of course the big challenge is to take something where the three-dimensionality of it and even the handedness of the structures and how they relate in 3D is really the important part. And to put that on a 2D page is not easy.
>
> (Richardson 2007, 37:34–38:27)

Richardson here is describing how producing taxonomical order required the choice of an "aspect" from which the three-dimensional structures of proteins could be easily grasped and compared. What we want to show in the rest of this section is how this entailed specific commitments and non-commitments in selecting structural aspects that would facilitate comparison and classification, enabling protein chemists to "see what was the same and what was different". In a 1985 paper titled "Schematic Drawings of Protein Structures", she helpfully operationalizes what these selective choices involved. Embedded in a volume of the *Methods in Enzymology* series titled "Diffraction Methods for Biological Macromolecules (part B)", her article gives precise instructions for producing her drawings.[9] In what follows, we will focus on the contents and methods detailed in this illuminating paper to argue that Richardson's design choices were a means of selectively manipulating "aspectual structure", a formulation we borrow from Dominic McIver Lopes' (1996) *Understanding Pictures*.

Lopes argues that pictorial content is "aspectually structured" (Lopes 1996, 121). We make commitments and non-commitments in representing a given target. A picture, as a member of a system, is "committal" about a property if its target is represented as either possessing or not possessing that property, "inexplicitly non-committal" if it abstains from representing the target as possessing or not possessing that property, and "explicitly non-committal" if in representing the target as possessing a property, this precludes the representation of some other property (Lopes 1996, 118–119). Aspectual structure is intended to explain how pictorial content is not constrained by visual experience. Some pictorial systems might comprise types of properties that can be observed from a single viewpoint, like atmospheric colour or having straight edges. But other systems include pictures that do not make commitments and non-commitments shared with an observer's visual experience, such as reversed perspective, paradoxical pictures, and X-ray photographs (Lopes 1996, 121). Aspectual structure challenges naïve resemblance accounts of representation without deflating representational content or the use of perceptual skills in recognizing this content. Lopes calls this "aspect recognition": "…identifying what a picture represents exploits perceptual recognition skills. In particular, viewers interpret pictures by recognizing their subjects in the aspects that they present…" (Lopes 1996, 144).

There are two ways in which aspect recognition is relevant to our discussion of Richardson's drawings. At one level, explicit non-commitments individuate particular systems as *pictorial*, in contrast to non-pictorial systems. Lopes states that "every picture is *explicitly non-committal* in some respect. That is, every picture represents its subject as having a property that precludes it from making commitments about some other property" (Lopes 1996, 125). Aspect recognition contributes to distinguish depiction from other forms of representational contents: there are, for example, no explicitly non-committal descriptions. But on a different level, aspect recognition and the particular combination of commitments and non-commitments that distinguishes it also provide criteria to specify *how* pictorial systems differ from each other. While Lopes does not explicitly deal with abstraction, his account helps us make sense of a fine distinction that is key, as we will show below, to understand how Richardson's drawings work: where inexplicit non-commitments work as omissions, explicit non-commitments work as occlusions. This distinction casts light on how abstracting as manipulating aspectual structure involves choices and selectivity in the design of a representation (Fisher 2017), which have epistemological consequences on how the target is structured. Thus, we look at aspect recognition from the viewpoint of the *generation* of Richardson's system of drawings, and how, in producing the drawings, abstracting one property might mean that other properties cannot be represented or can only be represented in certain ways.

There are few accounts that apply the idea of aspectual structure and aspect recognition to the sciences (Fisher 2017; van Fraassen 2008, 36–39).

However, here we make the case that Richardson's idea of protein chemistry as natural history aimed at classifying proteins hinged on abstracting as the manipulation of aspectual structure, and hence that aspect recognition lies at the heart of her representational practice. The wider applicability of aspect recognition to the sciences, and to models in chemistry in particular, can be easily demonstrated. Chemists have choices regarding how to represent molecular structure. Sometimes chemists are committal with regard to static molecular structure and explicitly non-committal about dynamical representation, i.e., the fact that molecules "vibrate". Representing static structure precludes the possibility of representing the aspect of dynamic structure. A simple two-dimensional structural formula is inexplicitly non-committal about representation in three-dimensions. It does not preclude the possibility of employing the appropriate conventions associated with representing structure in three-dimensions on a two-dimensional surface; it merely abstains from representing three-dimensional bond orientations. A stick representation is inexplicitly non-committal with regard to having or not having the property of possessing atomic nuclei. The model does not preclude the possibility of representing the nuclei; chemists merely suppress them. But explicit non-commitments distinguish a stick representation and a ball-and-stick representation from a space-filling representation. The latter is explicitly non-committal concerning the relative positions of the atomic nuclei and their bonds because the representation of atomic volumes precludes the representation of nuclei and bonds.

Many modelling techniques in chemistry, including ball-and-stick and space-filling representations, are unsuitable for portraying complex molecules such as carbohydrates and proteins. The standard ways of representing molecules are explicitly committal about molecular connectivity or shape but explicitly non-committal about overall molecular structure because the atomic details "swamp" the ability to grasp the overall structure of larger molecules (Kuttel et al. 2006). Richardson's drawings of protein structure aimed at overcoming not simply the limitations of standard molecular modelling, but especially the limitations of existing techniques of modelling proteins encountered by Kendrew and others, while bringing order to the often inconsistent conventions already deployed by biochemists and molecular biologists to represent protein structure.

Richardson's main aim was to portray the overall structure of proteins as a "unified object" that could be compared to other structures while allowing for the perception of symmetry relationships. Her drawings were designed to convey accurate three-dimensional information by mimicking binocular vision, which may involve exaggeration of monocular depth cues to facilitate "a realistic perception of the three-dimensional relationships" in an essentially unfamiliar object (Richardson 1985, 359). Producing schematic drawings of proteins meant that commitments had to be made regarding both the direction in which one views the "object" and "local cues to depth and orientation. The overriding criterion for evaluating a schematic drawing is its final overall appearance, judged as a representation of the major patterns and relationships you see in the three-dimensional structure" (Richardson 1985, 361).

Choosing an optimal viewing direction is a commitment to represent proteins in a way that includes looking through as near to the minimum depth of the structure as possible and placing features of special interest near the "front" of the image. This commitment introduces an explicit non-commitment because it occludes parts of the structure that might have been viewed, had one chosen another viewpoint. Here we are in agreement with van Fraassen that, in drawing a picture, the kinds of occlusions introduced by a choice of perspective not only rule out other perspectives, they also invite us to "[attend] to its alternatives: thinking of it as set in a 'horizon' of other perspectives on the same objects" (van Fraassen 2008, 39). This is nicely illustrated by Richardson's emphasis on portraying proteins as unified structures. Richardson aspectually structured ribbon diagrams according to the "visual continuity" of protein structures, avoiding placing features behind one another when that continuity was disrupted. Therefore, as a pictorial system, the commitments made using Richardson's ribbon drawings entail explicit non-commitments: some commitments should be avoided in order *not* to occlude parts of the structure and to maintain the visual continuity of the representation. In a sense, one has to attend to the "horizon" of perspectives in making these crucial commitments.

Visual continuity contributes to the aim of constructing ribbon diagrams capable of reproducing the perception of a three-dimensional object from the two-dimensional drawing. For example, the correlation of "twists and bends" of the ß-strands that comprise the ß-sheet is a "powerful signal to perceive them as part of a unified structure" (Richardson 1985, 368). The representation of the prealbumin dimer (Figure 5.2) is a case in point. It has ß-strand arrows with a variety of orientations and twists and consists of a double sheet, with one sheet passing diagonally under the other at a shallow angle. The drawer attempts to adjust the image in a way that reproduces the viewing of a "macroscopic" object by facilitating the perception of depth. At the same time, the lines associated with the ß-sheet passing behind need to be offset in a way that mimics perceptual experience and tackles optical illusions such as the Poggendorff illusion, associated with the misperception of diagonal lines (Richardson 1985, 372; Figure 5.3). In these ways, the drawing is aspectually structured to preserve the perception of the protein as a unified object.

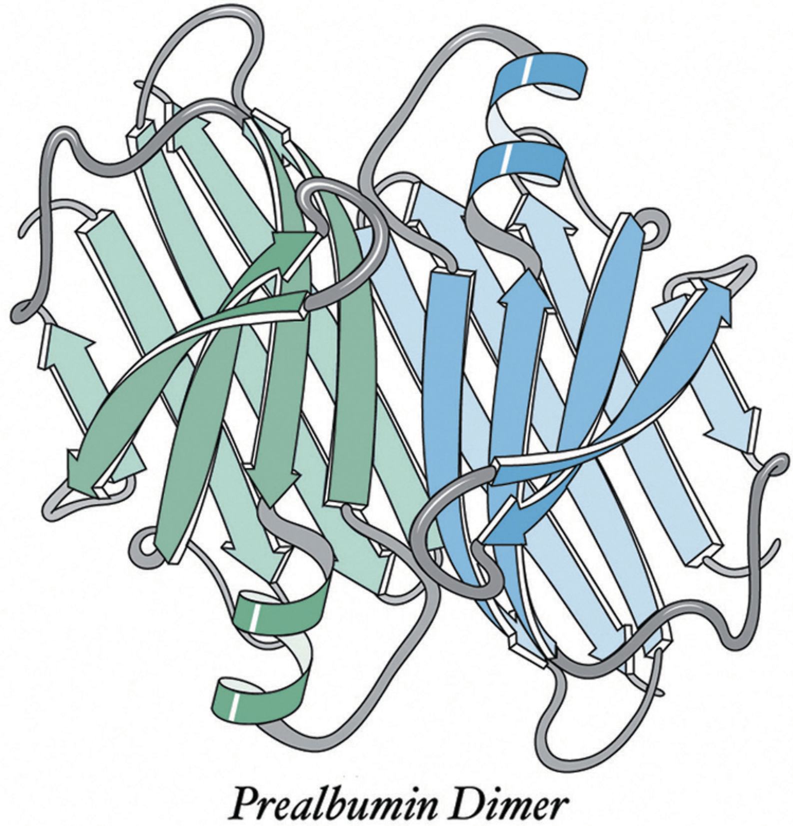

Figure 5.2 Ribbon diagram of the protein dimer molecule of prealbumin, or transthyretin (PDB file 2PAB).

Source: Richardson (1981); https://commons.wikimedia.org/wiki/File:PrealbuminDimer_ribbon.jpg ©Jane Richardson (Dcrjsr) CC BY 3.0 https://creativecommons.org/licenses/by/3.0/legalcode

On the other hand, the act of drawing itself can impose inexplicit non-commitments, which were in a sense "worked out" as Richardson developed a procedure for drawing protein structure. These inexplicit non-commitments included things to avoid when attempting to reproduce the overall structure of a protein, although the ribbon schematic system itself does not necessarily preclude alternative but less favourable ways of representing the overall structure. This presents the drawer with

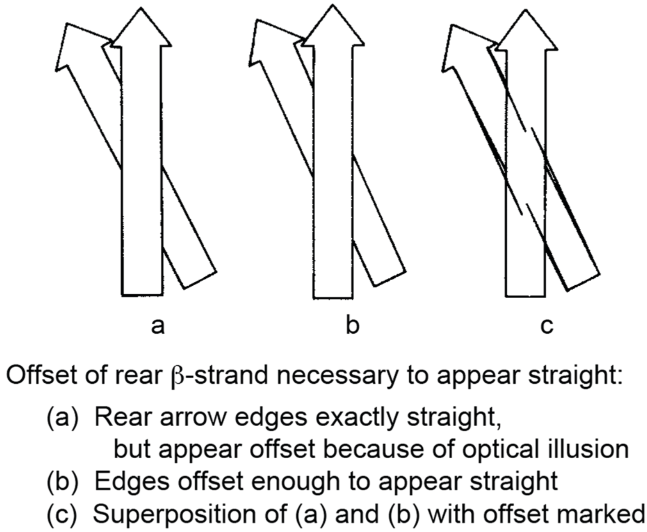

Figure 5.3 Photograph of a 1984 pen-and-ink hand drawing, using the offset-line illusion to draw convincing overlapping beta-strand arrows, for ribbon diagrams of protein 3D structures.

Source: Richardson (2011); https://commons.wikimedia.org/wiki/File:Offset_lines_illusion_for_beta_ribbons.jpg ©Jane Richardson (Dcrjsr) CC BY 3.0 https://creativecommons.org/licenses/by/3.0/legalcode

a wide range of contextual choices regarding how to aspectually structure the drawing by introducing inexplicit non-commitments as well as explicit non-commitments associated with preserving the unified structure described above. For example, drawings should avoid end-on viewing of α-helices and ß-strands, and it is particularly important to aspectually structure ribbon diagrams in a way that will promote local cues to depth and orientation, thereby facilitating the perception of a three-dimensional object. Thus, the drawer should favour slight overlaps "which provide valuable hidden-line depth cues", depict ß-sheets with at least one corner turning over, "which looks best" because it helps the viewer to perceive the shape of the ß-sheet, choose identical viewpoints if structures are to be compared, and prefer drawing from more than one view for enhanced clarity (Richardson 1985, 363). α-helices are drawn as ribbons without any thickness because they already contain information about orientation and thickness, since (for example) α-helices are spiral ribbons with a cylindrical diameter slightly larger than the α-carbon positions. Helices are therefore inexplicitly non-committal with respect to additional details

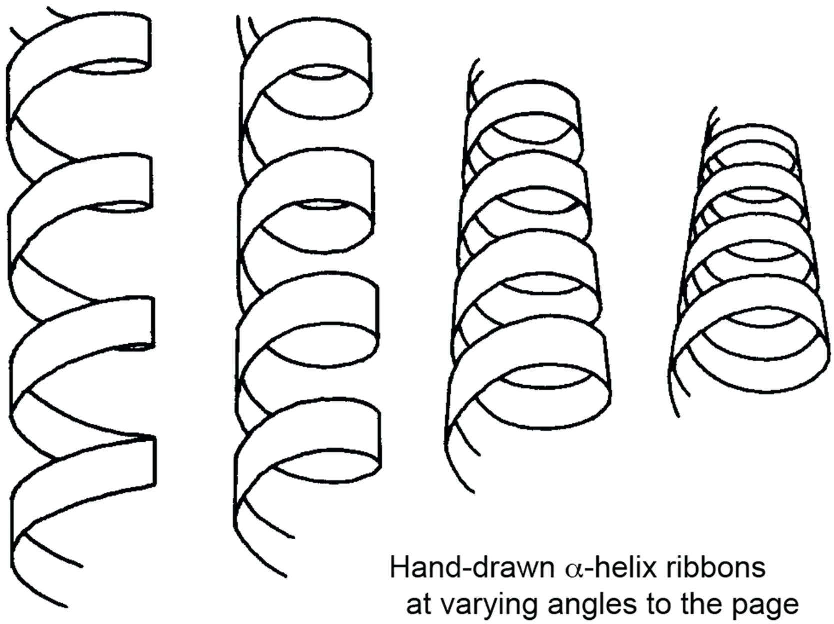

Figure 5.4 Photograph of a 1984 pen-and-ink hand drawing of alpha-helix ribbons at various angles to the page, for ribbon diagrams of protein 3D structures. Both the curl and the foreshortening need to be somewhat exaggerated.

Source: Richardson (2011); https://commons.wikimedia.org/wiki/File:Hand-drawn_helix_ribbons_at_various_angles.jpg ©Jane Richardson (Dcrjsr) CC BY 3.0 https://creativecommons.org/licenses/by/3.0/legalcode

that would add complexity to the image. Furthermore, helices are drawn "curlier" at the desired angle than would be the case, with more open curves at the back than front due to the steepness of the angle of view (Richardson 1985, 366). Better perception of the length and relationships of the helices is achieved when angles are low with respect to the plane of the paper (see Figure 5.4). ß-sheets emphasize hydrogen bonding and are drawn as arrows with thickness conveying perceptual cues about the orientation of bonds linking the strands into ß-sheets. They are drawn only as wide as to allow seeing behind the strands, and not so small that they interfere with visual continuity. The arrow plane is perpendicular to the sheet and determined by the direction of hydrogen bonds. These kinds of commitments can profoundly affect the success with which one conveys key properties of proteins individually or in comparison to other structures.

As we have illustrated above, the manipulation of aspectual structure is constrained in an attempt to preserve the continuity of the structural motifs as they pass behind other parts so as to allow one to grasp the overall structure of an unfamiliar object in a way comparable to the perception of three-dimensional objects. The commitments one makes must not entail explicit non-commitments that occlude properties of the proteins in a way that disrupts the perception of a unified structure. Richardson's work also demonstrates how the distinction between inexplicit and explicit non-commitments need not always be clear cut, and it emerges as part of the process of drawing. While some explicit non-commitments are clearly delineated in the ways we describe above, in other cases the difference between inexplicit non-commitments (where one abstains from representing the target as possessing a given property without ruling out the possibility of representing it as possessing another property) and explicit non-commitments (where the decision to represent the target as possessing a given property precludes the representation of another property) is not so much a difference of kind but more one of degree. Some representational choices do not simply suppress others but rather practically preclude them given the aim of generating a unified, continuous structure that can function as a means to communicate and compare protein structures. In representing a protein as possessing ß-strands, sidechain molecules as well as the "pleats" of the ß-strands are left out. This is an important part of a process of abstraction which is aimed at representing overall structure. Similarly, loops used to represent non-repetitive structure are "smoothed" rather than depicted more accurately with a zigzag orientation of bonds because "smoothing is critical for unambiguous perception of the continuity of the loop as it passes behind another piece of the chain" (Richardson 1985, 372; see Figure 5.5). It is not so much that one simply abstains from representing or precludes the possibility of representing a target as possessing a given property. The design choices Richardson makes permit flexibility in drawing ribbon diagrams, but given the overall aim of generating a unified, communicable image that can function in a system of classification, *some* choices are practically precluded, while others are precluded as a matter of necessity in order to preserve the visual unity of the drawings. In other words, while some commitments are inexplicit and are thus omissions one makes practically, other commitments entail occlusions of parts of the structure that should not interfere with the perception of unity of structure and are thus crucial explicit non-commitments that characterize ribbon drawings as a pictorial system.

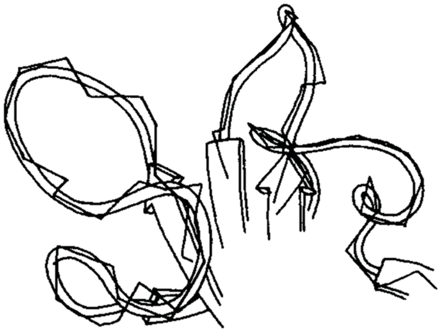

Figure 5.5 Photograph of a 1984 pen-and-ink hand drawing showing the technique for drawing smoothed "ropelike" ribbons for the protein loops in a ribbon diagram, following the C-alpha backbone closely but providing continuity for the eye.

Source: Richardson (2011); https://commons.wikimedia.org/w/index.php?curid=16237034

Emphasizing the manipulation of aspectual structure in Richardson's ribbon schematics allows us to account for selectivity in her system for protein representation without necessarily defaulting into standard accounts of abstraction as merely "subtraction" or "omission" of details.[10] True, Richardson herself at times seems to swing towards this view, particularly when she places emphasis on the judgements and decisions that need to be made on the structures to be included in the drawings. For example, in discussing the principles and methods of her taxonomical system in her 1981 article, she writes:

> To someone studying haemoglobin function, the relevant level of description includes all the structural detail that can be made comprehensible, or perhaps generalized to include what is common to all protein structures. On the other hand, if one is concerned, as we are, with obtaining a memorably simple description of the whole structure and relating it to other protein structures, then the issue is deciding which features are the most important to include in the simplification and with which, if any, other proteins can be meaningfully compared.
> (Richardson 1981, 287)

We want to argue, however, that an analysis of abstraction as the manipulation of aspectual structure allows us to recast what the standard view qualifies as a mere removal of detail from a model or representation in positively productive terms. To do this, we need to momentarily go back to a key feature of Lopes' account of the aspectual structure. Lopes defines pictorial aspect as a pattern of visual salience, "a pattern as much of what a picture leaves out as of what it includes" (Lopes 1996, 119). Recall also how Lopes stresses the key role of explicit non-commitments in distinguishing pictures from verbal descriptions, as we highlighted in our discussion of the aspectually structured character of chemical representations: "every picture", he argues, "is *explicitly non-committal* in some respect. Every picture represents its subject as having a property that precludes it from making commitments about some other property" (Lopes, 1996, 125; emphasis in the original). So, at a very basic level, while inexplicit commitments are "omissions", this barely does justice to the complexity of the decisions and practices of representation in this case. Most importantly, explicit non-commitments in the ribbon drawings are also not merely "omissions": they are occlusions imposed upon practice by the pictorial system used. Furthermore, the process of drawing can itself sometimes be the determinant of whether non-commitments are explicit or inexplicit, demonstrating that both are *constitutive*, together with pictorial commitments, of the aspectually structured character of pictorial content.

Another important point in Lopes is that pictorial systems differ from each other in how they selectively represent their content: "pictures may be *individuated* according to the aspects they present" (Lopes 1996, 125, emphasis added). Thus, in the passage above (and in far greater detail in the 1985 article we discussed earlier on in this section), Richardson is "individuating" her newly developed system by operationalizing the commitments and non-commitments that are distinctive of her ribbon schematics. She is doing so in relation to the key aims of her proposed system: obtaining "a memorably simple description of the whole structure"—which in the passage is contrasted to other possible aims, such as representing function—and making whole structures obtained through drawing *comparable*. Richardson's natural history of proteins entailed comparability for the purpose of classification: abstraction as the manipulation of aspectual structure in that sense aimed at generating unified and memorable patterns that would facilitate establishing similarities between the folds of evolutionarily related proteins. This captures another key insight from Lopes: "…that if we do not understand pictures by noticing resemblances, then *we notice resemblances as a result of understanding pictures*" (Lopes 1996, 36, emphasis added). While Lopes' original statement is a critique of standard mimetic accounts of representation, here it seems to apply well to Richardson's classificatory goals. Rather than "carving protein structures at their joints", the ribbon drawings show that establishing resemblances is an achievement of the process of abstracting as manipulating aspectual structure through drawing.

Aspectual Structure and Communicability

Richardson's system of ribbon drawings was not an inevitable development in protein research. On the contrary, its contingency is even more striking when one considers the drive towards automation that characterized the field starting from the 1950s, when Kendrew began using systematically one of the early experimental electronic computers, the EDSAC (Electronic Delay Storage Automatic Calculator), to calculate electron density maps of myoglobin. For Kendrew, the EDSAC was as much a system for the storage, retrieval, and display of data as it was a calculating device that efficiently reduced work carried out over weeks to a matter of hours (Bennett and Kendrew 1952; de Chadarevian 2002, ch. 4, and de Chadarevian 2017, 1138–1140). As Strasser (2019) notes, the rise of automated methods fulfilled different goals in protein research. After Kendrew's initial experimentation with the EDSAC, improvements in computer hardware in the 1960s and 1970s resulted in the development of "virtual" models that allowed protein researchers to display and manipulate molecular structures (Strasser 2019, 159–163). These virtual models had the advantage of giving automatically the coordinates of each atom in a protein structure—a problem that Kendrew himself had struggled with, when working on myoglobin. At the same time as providing new ways of interacting with models, computers also allowed protein scientists to store, retrieve, and crucially share crystallographic data and the models that could be generated from them. By the early 1970s, the establishment of the Protein Data Bank (PDB)—which was the very source of data for Richardson's (1981) classification—brought all these aims together and provided scientists with a system that could be used to determine new structures as well as analyse and compare existing ones (Strasser 2019, 171).[11]

This changing landscape had an impact on protein taxonomists too, who by the late 1970s became heavily invested in developing automated methods to analyse the structure and coordinates of proteins and identify distinct functional and structural units in them, which they came to call "protein domains". Adopting a rhetoric of "mechanical objectivity" (Daston and Galison 2007), they extolled the virtues of automated methods against the subjective nature of models and other "visual" methods, which they dismissed as introducing confusing and conflicting criteria to identify secondary structure (Levitt and Greer 1977, 182; Strasser 2019, 179). Thus, for example, in 1977 the biochemists Michael

Levitt and Jonathan Greer introduced a computational method "to analyse automatically and objectively the atomic co-ordinates of a large number of globular proteins" (Levitt and Greer 1977, 181), which they explicitly pitted against existing methods in X-ray crystallography. "At present", they wrote,

> there is no precise rule for characterizing secondary structure in proteins. In this paper we make such precise rules, use *automatic objective* methods to derive secondary structure assignments for many proteins, and then test the results against the reported assignments made by X-ray crystallographers.
>
> (Levitt and Greer 1977, 182, emphasis added)

Within this context, Richardson's choice of using drawing to represent secondary structure and facilitate protein classification might seem counterintuitive, but it is important to stress that—in contrast to early advocates of automated methods—she did not see her system as incompatible with computational methods. On the contrary, much of the subsequent work carried out jointly with her husband David Richardson extensively incorporated computational techniques and indeed crucially contributed to develop a range of novel computational methods for protein structure visualization and classification (Richardson, Richardson and Goodsell 2021).

That automated methods were an important foil for the ribbon drawings is clear since at least as early as Richardson's (1985) article, which we used extensively in the previous section to discuss her systematic operationalization of the aspectually structured nature of her visual system. There, in direct response to advocates of automated methods, she argues that any representation aimed at producing new understanding—including automated ones—will inevitably involve interpretation and choice:

> A schematic drawing can summarise the overall features of a structure in a quickly graspable and relatively memorable form, and can provide a framework within which to place further details. Such a drawing has inherent dangers, of course: by definition any simplification must omit information, and any representation which aids conceptual understanding must involve interpretation and choice (which is equally true of an automated computer drawing). But even if one is led to miss alternative interpretations, something worthwhile is gained, because understanding one conceptualization of a structure is much better than not understanding it at all.
>
> (Richardson 1985, 359)

Richardson here argues that, automated methods notwithstanding, there is still a great deal to gain from the ways in which her own system aspectually structures content. Omissions and occlusions may come at the price of missing alternative interpretations, but they are also constitutive of the distinctive kind of classificatory and comparative understanding afforded by the choice of presenting proteins as aspectually structured according to the commitments and non-commitments that individuate her system. While not being the be-all and end-all of protein classification, understanding the particular conceptualization of secondary structure provided by her drawings offered a framework within which researchers could place further details and carry out further comparative work.

As an important pay-off of the sustained justification of the distinctive features of her system, what Richardson's drawings brought to the fore in subsequent publications were the methodological flaws of a conception of automated methods as inherently more "objective" than visual ones. This was a lesson that emerged precisely from her practice of manipulating aspectual structure and from the operationalization of the commitments and non-commitments that individuated her drawings in relation to other methods. In a 1992 article titled "Looking at Proteins", she made this stance very clear:

> Much of what we have discussed about types of representations is directed toward the researcher trying to find new, significant relationships in a protein structure. But a second, especially crucial role of models, drawings, and computer graphics is *to make explicit a relationship that you have found, enabling other people to see it as well*. This often can be done just by making the relevant part a heavier line or a brighter color, or by deleting most of everything else, but it always requires explicit effort. *The total process of looking scientifically at proteins involves communication as well as perception*.
>
> (Richardson et al. 1992, 1189, emphasis added)

And less than a decade later, in her 2000 *Nature* article, she addressed the question of objectivity even more explicitly and directly:

> Ribbon drawings are an excellent tool for first comprehending the overall organization of a protein structure, on which one can later hang the important details. Decisions about representation, secondary structure, and viewpoint, *whether done by hand or by a computer algorithm, are inherently arbitrary and subjective but also serve to communicate ideas about which structural aspects are important*.
>
> (Richardson 2000, 625, emphasis added)

Two important insights emerge from these two passages. First of all, in line with the stance Richardson developed as early as the 1980s, computational methods do not eliminate subjective judgements: the rhetoric of objectivity that surrounded their applications simply black-boxed them. What she proposes here is precisely the opposite: that decisions about representation, secondary structure, and viewpoint can and *should* be made explicit, and this is precisely what she achieved with her system of drawings and through the operationalization of the commitments and non-commitments that characterized it. Secondly, Richardson seems to be aware that the solution to the question of objectivity in representing protein structures is ensuring *communicability*: "to make explicit a relationship that you have found, enabling other people to see it as well" (Richardson et al. 1992, 1189).[12] The whole point of *individuating* her pictorial system by operationalizing its commitments and non-commitments was precisely to enable the community of protein researchers to step into the viewpoint she adopted to aspectually structure pictorial content and manipulate that content according to shareable principles. It is in this sense that communication and perception go hand in hand in the "total process of looking at proteins" (Richardson et al. 1992, 1189). This brings to the fore again an insight from Lopes that we highlighted at the beginning of the previous section: that "viewers interpret pictures by recognizing their subjects in the aspects they present" (Lopes 1996, 144). Aspectual structure incorporates the use of perceptual skills in constructing and interpreting pictures without reducing perception to a mere "direct copying" of visual experiences, while affording an account of how pictorial content can be selectively presented, interpreted, and made shareable within a community of practitioners. By operationalizing the workings of the system—by presenting α-helices, for example, as inexplicitly non-committal with respect to thickness, or the configuration of the ß-sheet as explicitly non-committal to sidechain molecules—Richardson captures precisely how the drawings coordinate and orchestrate the perceptual and interpretative skills that need to be deployed by a community of researchers to make protein structures comparable for the purpose of classification.

Conclusions

"A whole generation of scientists see proteins through my eyes" (Bahar 2004, 7), Richardson stated with surprise in one of the many feature articles celebrating her drawings and their lasting legacy. But that it is indeed possible to see proteins through her eyes should not be surprising at all, given the systematic work she carried out in developing and operationalizing her system. In this chapter, we explored how that system came to be, how it tackled specifically the problem of making protein structures comparable for the purpose of classification, and the role that the practice of abstracting played within it.

Drawing on Lopes' (1996) account of the aspectually structured character of pictorial content, we examined in detail the commitments, inexplicit non-commitments, and explicit non-commitments at work in Richardson's ribbon schematics. We showed that what the drawings refrain to show are not mere "omissions": in Richardson's system inexplicit and explicit non-commitments are equally constitutive of protein structure representation. Combined with Richardson's publications, the drawings show that commitments and non-commitments can be operationalized, and thus made communicable, in the construction of a visual system of protein classification. Different modes and degrees of abstraction in protein structure representation depend upon different ways of manipulating aspectual structure; the relationship between commitments and non-commitments that individuates Richardson's ribbon system tells us *how* her system selects and aspectually structures its content to enable comparisons and establish relationships between evolutionarily related proteins.

We can indeed "see" proteins through Richardson's eyes. By providing clear instructions about how to selectively manipulate content, she made the very process of abstracting in protein classification visible, communicable, and ultimately usable for the scientific community: to use her own words, she made explicit the relationships that she found, enabling us to see them as well.

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Notes

1 Kendrew's original "sausage model" of myoglobin is on display at the Science Museum in London and can be viewed on the Science Museum's website at: https://collection.sciencemuseumgroup.org.uk/objects/co13543/kendrews-original-model-of-the-myoglobin-molecule-molecular-models-proteins (last accessed 18 July 2023).

2 Kendrew's "forest of rods" model is also on display at the Science Museum in London and can be viewed on the Science Museum's website at: https://collection.sciencemuseumgroup.org.uk/objects/co8059866/forest-of-rods-model-of-myoglobin-myoglobin-models-molecular-models (last accessed 18 July 2023).

3 See the online exhibition "Seeing the Invisible: 50 Years of Macromolecular Visualization", hosted by Duke University Libraries and available at https://exhibits.library.duke.edu/exhibits/show/invisible/intro (last accessed 11 April 2023). The exhibition revolves specifically around Richardson's drawings, her joint work with her husband David Richardson and their laboratory at Duke University, and traces the techniques, instruments, and processes that contributed to the development of her ribbon drawings.

4 An example of how the crystal molecule of superoxide dismutase (Cu, Zn) was obtained by Jane and David Richardson is in Richardson et al. (1972).

5 Isomorphous replacement was a solution to the "phase problem": while intensities could be directly measured from X-ray diffraction pictures, their phases could only be determined by trial and error (de Chadarevian 2002, 101 and 125–126). Even with the introduction of this technique, the calculations would remain remarkably complex and time-consuming, until the introduction of computers. See de Chadarevian (chapter 4) for a reconstruction of how computers entered early research in protein crystallography; Strasser (2019, especially chapters 3 and 4) gives an account of how this later led to the construction of databases, including the Protein Data Bank used by Richardson herself for her classification, to share their results.

6 The Richardson Lab's Kendrew model of Cu, Zn can be viewed at: https://exhibits.library.duke.edu/exhibits/show/invisible/case03 (last visited 11 April 2013). Incidentally, the brass model pieces of this model were designed by Kendrew himself and first built in the Cavendish Laboratory in Cambridge and subsequently manufactured by Cambridge Repetition Engineers LTD, from whom the Richardson Lab purchased them. On the role of Cambridge Repetition Engineering in commercializing Kendrew models, see de Chadarevian (2002, 143–144).

7 For a compelling historiographical account of how Morgan and Morrison's revival of models carries forward the legacy of a much older "modelling attitude" in the sciences, see Suárez (2024). Morgan and Morrison (1999), and the literature that followed the approach they introduced, was in turn a response to the semantic view, which challenged the then "received (syntactic) view" of scientific theories reframing them as collections of (mathematical) models. For an overview of this tradition in philosophy of science, see Winther (2021).

8 In 1976, protein chemists Michael Levitt and Cyrus Chothia attempted a first set of ribbon schematics (Levitt and Chothia 1976), but they soon abandoned the drawings for a different kind of abstract diagrams.

9 Here we only focus on Richardson's systematic drawing instructions. But this particular article is a goldmine for material culture researchers in how it presents detailed information of her choices of drawing equipment, including the kind of paper, pens, colour overlay films and masking films she used, and even suggestion of suppliers in the US where they could be purchased at the time!

10 Carrillo and Martínez (2023, 237–239) describe this view as "the orthodox view of abstraction in philosophy of science". This approach, dating back to McMullin (1985) and developed by Jones (2005) and Godfrey-Smith (2009), framed abstraction in contrast to idealization in modelling practice: broadly

speaking, idealization involves misrepresentation by asserting a falsehood about the target, while abstraction involves the omission of truth without misrepresenting the target (for a recent refinement of this distinction, see Levy [2021]). For critiques and alternatives to this view, see Stuart and Kozlov and Knuuttila, Johansson and Carrillo in this volume.

11 For a recent overview of Jane and David Richardson's subsequent work with and contributions to the Protein Data Bank, see Richardson, Richardson and Goodsell (2021), written specifically for the celebrations for its 50th anniversary.

12 This nicely resonates with the notion of exemplification and its role in abstraction presented by Catherine Elgin in this volume.

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6 Moving Targets and Models of Nothing

A New Sense of Abstraction for Philosophy of Science

Michael T. Stuart and Anatolii Kozlov

6.1 Introduction

Abstraction is a process that is required for building scientific models. Typically, it is thought to involve subtracting irrelevant details. In this sense, it is sometimes portrayed as a necessary but acceptable epistemic evil, since it doesn't introduce anything false, and it is reversible.

However, "that there are different kinds of abstractive processes is not often addressed in philosophy of science or cognitive science" (Nersessian 2008, 191). We want to focus on another, very different sense of abstraction, one that is found in discussions of abstract art in aesthetics. This sense is non-representational in some ways, but not in others (Goodman 2003). We think this concept of abstraction better describes certain processes of model-building in science.

In this chapter, we follow the approach of Nancy Nersessian (2008, section 6.2.2.) and Sabina Leonelli (2008) in foregrounding the cognitive-epistemic *process* of abstraction. We begin by looking at the history of work on abstraction in the philosophy of science, to get clear on the "standard" notion of abstraction, which we label "subtractive" abstraction. Then we canvas the history and philosophy of abstract art to present a different notion of abstraction, which we label "generative" abstraction. Then, we employ case studies to show that some scientific processes of abstraction are correctly labelled as generative, not subtractive. Finally, we consider some philosophical implications.

6.2 "Subtractive" Abstraction in Philosophy of Science

In philosophy of science, abstraction is usually discussed with reference to scientific representation, especially scientific models. Demetris Portides sums things up: "models are primary devices of scientific representation" and "idealizations and abstractions are manifest in most (if not all) kinds of scientific representation". Thus, "it has become commonplace that

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scientific models, scientific representation and idealization/abstraction are entangled concepts" (Portides 2021). While the terms "abstraction" and "idealization" are sometimes applied to objects other than models, for example, explanations, objects, or "paths" to representations, these discussions are usually closely related to models (Carrillo and Martínez 2023; Jansson and Saatsi 2019; Verreault-Julien 2022).

Why are these notions so closely entangled? Representation is important (at least) because of its central role in epistemological questions about surrogative reasoning in science. Ideally, it is thought, a representation would capture all the aspects of a target system, and so whatever we learn about the representation will also be true of the target system that was represented. In practice, however, scientists cannot represent all the aspects of any target system. So, they employ abstraction and idealization. This complicates the idea that models give us straightforward epistemic access to the world. The main epistemological question, then, asks how a model can provide new epistemic desiderata (knowledge, truth, approximate truth, epistemic access, understanding, pursuit-worthy hypotheses, etc.) about a target system despite (or in virtue of) being abstract or idealized.

Ernan McMullin differentiated between several concepts that would later form the basis of the distinction between abstraction and idealization (McMullin 1985). These two concepts were more recently redefined by Martin Thomson-Jones such that "idealization" should refer to misrepresentation and "abstraction" should refer to mere omission (Thomson-Jones 2005). Idealization "requires the assertion of a falsehood", and abstraction "involves the omission of a truth" without misrepresentation (175). Thomson-Jones doesn't claim to capture all the useful ways of talking about model-building, but proposes this distinction as a useful framework for analysing the epistemology of scientific representations. Peter Godfrey-Smith presents a view that differs "only in points of emphasis" (Godfrey-Smith 2009, 48). Specifically, an abstract description "leaves out a lot", while an idealized description "fictionalizes" in the sense that it does not present a literally true description of the target, and at the same time, it describes an imaginary system that would be concrete if real. This way of thinking about abstraction and idealization still dominates the literature in philosophy of science. Here is a recent statement: "An abstraction is the wholesale omission of a property…An idealisation is the distortion of a property…For this reason, abstractions offer a literally true (albeit incomplete) representation of the target, while idealisations assert, if understood literally, falsehoods" (Frigg 2023, 317).

The literature on abstraction and idealization has since exploded, and many detailed epistemological accounts of both now exist. On abstraction, Michael Strevens argues that one model is more abstract than another if the causal influences described in the latter are also described by the former, and every proposition in the latter model is entailed by the former (2008, 97). Leonelli distinguishes between abstract models understood as (a) non-concrete models, (b) models requiring more information to make empirical statements about the real world, and (c) models applying to more phenomena (2008, 520). Arnon Levy argues that one representation is more abstract than another if it is relatively less informative about the same target (2021). Thus, "mammal" is more abstract than "Red-tailed Chipmunk". Idealization has tended to take up more of the spotlight because idealizations are (or include) misrepresentations, which present a greater challenge to those trying to account for epistemic uses of scientific representations. Many strategies now exist to deal with this challenge. For example, we can claim that only the true parts of idealized models refer, or that idealizations are merely practical shortcuts, or that idealizations do some epistemic heavy lifting without figuring into the content of the scientific understanding they produce, or that idealizations are not misrepresentations (see, e.g., Strevens 2008, 2017; Khalifa 2017; Lawler 2019; Yablo 2020; Levy 2021; Nguyen 2020).

There is an important assumption shared by almost everyone who participates in the above debates, and it can be traced back to McMullin. Idealization and abstraction (and their subtypes) have *one general aim*: "a deliberate simplifying of something complicated (a situation, a concept, etc.) with a view to achieving at least a partial understanding of *that* thing" (1985, 248; emphasis added). It is important to point out that this aim focuses on simplifying a single, unchanging target system. The goal "is not simply to escape from the intractable irregularity of the real world" but "to grasp the real world from which the idealization takes its origin" (1985, 248). In other words, the target system for abstraction and idealization is deliberately set from the start, and learning about *that* target is the aim. This is a natural assumption to make given the prevalence and importance of surrogative reasoning in science. And indeed, a great deal of scientific modelling does take place in this way.

This idea, that abstraction is a process directed at a single (concrete) target that doesn't change, also plays a role for philosophers who focus on abstraction as a process rather than as a product. For example, Leonelli characterizes abstraction as "the activity of selecting some features of a phenomenon P, as performed by an individual scientist within a specific context, in order to produce a model of (an aspect of) P" (2008, 521). For Leonelli, abstraction is a process that transforms features of the target system into parameters used to model *that very target system*. In Leonelli's case study, the target might be a concrete organism, such as *Arabidopsis thaliana*, or something less-concrete, such as a signalling pathway. But it remains constant from the beginning to the end of the process.

Due to this assumption, scientific model-building is imagined as beginning with the choice of a particular target system (e.g., the pendulum, the atom, an economy, a population of rabbits, a signalling pathway, etc.). Idealizations and abstractions are introduced which shape the model, that is then manipulated, and conclusions are finally drawn about *that* target system. This raises the epistemological question of how those conclusions are justified. In the case of abstract models, the answer might go something like this: the scientist had originally removed some details without misrepresenting the system, so the model will deliver (at least approximately) correct information about the aspects of that target that were not removed. Better still, the scientist can add back in the details that they had earlier removed, to produce conclusions that are even more justified.

In this chapter, we focus on a different way of thinking about abstraction, one that does not hold the target fixed. That is, rather than considering abstraction as a process that is always epistemically tied to a single target system which is given from the start, we consider processes of abstraction that create new systems, new targets, and leave the old targets behind. This is inspired by a notion of abstraction that we find in discussions of abstract art.

6.3 "Generative" Abstraction in Abstract Art

Abstract art is said to originate somewhere between 1910 and 1920. Often regarded as "the most important development of early 20th-century [Western] art", it is connected with artists like Hilma af Klint, Wassily Kandinsky, Kazimir Malevich, Piet Mondrian, Paul Klee, Mark Rothko, and Jackson Pollock, who were reacting to movements like impressionism and cubism, especially the work of Paul Cézanne, Henri Matisse, and Pablo Picasso (Chilvers and Glaves-Smith 2009). The impressionists, cubists, and abstract artists were united in demanding a new aesthetic that would break away from the kind of mimesis characteristic of artistic realism. However, while cubists and impressionists departed from realism in important ways, it was characteristic of their work that they never gave up on representationalism.

> When Braque and Picasso found their work approaching the non-representational or non-figurative or non-objective (all these terms are used), both artists 'recoiled.' They chose, like Cézanne and Matisse and the great majority of post-impressionist and modernist painters, not to lose sight of the object. For this reason among others it is often said that the aim of Cubism was essentially to represent reality more accurately and completely.
>
> (Vargish and Mook 1999, 129)

A cubist might present a person, a landscape, or a piece of fruit in a very different way, but they were still presenting a person, a landscape, or a piece of fruit.

What made abstract art different from other kinds of modern art? Calling it "non-representational" is misleading: all its key figures insisted that their work did, in fact, represent something. The difference is that what they chose to represent wasn't a typical visual object, like a person, landscape, or piece of fruit. Abstract artists might start with an object like that, but through a series of changes, they would remove all traces of the object, in order to present a series of lines, shapes, and colours.[1] So far, this looks like subtractive abstraction. But the key is that the result would come to represent something else, something non-visual (Sánchez-Dorado, this volume). This is the sense in which abstract art is non-representational: "modernist abstraction is best understood not in terms of a loss of realistic detail but in terms of shifting the frame of reference away from the object" (Vargish and Mook 1999, 131).

Let's illustrate with some examples. To repeat, omitting details in a painting was something the cubists and other modern artists were already doing. For example, each of Matisse's four nude female backs comprising his *The Back* series (1908–1931) progressively "lose realist detail without losing representational force" (Vargish and Mook 1999, 132).[2] Around the same time that Matisse was working on *The Back I* (1908–1909), Kandinsky was beginning to use the same subtractive abstraction for a different purpose. His early work employs strong blotches of colour and retains a clear link to representational impressionist art, for example, his *Treppe Zum Schloss* (1909).[3] The work that comes even one year later, however, has already moved away from any concrete objects as its focus.[4] For another example, consider Mondrian's increasingly abstract paintings of trees.[5] The point we want to emphasize is that while subtractive abstraction is often involved, even centrally, in creating abstract art, that is not what makes abstract art abstract.

Of course, this wasn't the first time non-representational art was produced (Gertsman 2021), and there were (and still are) disagreements among scholars and practitioners about what abstract art is. Alfred Barr identified two broad approaches, corresponding to the work and motivations of Kandinsky on the one hand, which was intuitional and emotional, and Malevich on the other, which was intellectual and geometrical (Barr 1936). Barr's distinction has been as controversial as influential. More recently, Diarmuid Costello has identified seven kinds of abstraction (2018). But there is always a core idea: abstract art leaves behind figurative visual representations in order to draw attention to a new object that represents a non-figurative target.

By moving away from initial concrete objects, artists were able to break free of the constraints of mimetic representationalism, the "prison" of limited form (Mondrian 2007). If an abstract artist wanted to investigate something like ambition, for example, they would not need to paint Napoleon on a horse, or anyone, on any horse. Thanks to the cubists, space on a canvas was no longer modelled on a single viewpoint or constrained by the rules of perspective. Further, if you want to express something "divine" or "universal", as Kandinsky, Malevich, and Mondrian all did, then you will likely need to adopt some kind of common language that will enable you to get the point across to audiences despite the difficult subject matter. In response, artists employed colour, line, shape, contrast, and so on, to present visual melodies and compositions that (they hoped) would convey the right message to different audiences. As Kandinsky wrote,

> Colour is a means of exercising direct influence upon the soul. Colour is the keyboard. The eye is the hammer, while the soul is a piano of many strings. The artist is the hand through which the medium of different keys causes the human soul to vibrate.
>
> (Kandinsky 1977, 43)

Only by moving to more "universal" forms of expression like harmony, line, and colour, which these artists (controversially!) took to be less culturally specific than other means of expression, did these artists believe they could convey more universal messages, or messages about more universal things, like inner harmony, psychic effect (Kandinsky), feeling (Malevich), and pure aesthetic relationships (Mondrian).

One might be tempted to conclude that abstract art is abstract just in the sense that it focuses on abstract targets instead of concrete ones. While this might be, we will remain focused on the *process* of abstraction itself without assuming that the artwork, artefact, model, or target system that is the output of such a process is abstract in some metaphysically heavy sense. Whether feelings are more or less abstract than fairies, functions, or fruit flies, we do not say. Targets of abstract art might always be abstract in the sense that they are significantly (if not entirely) non-figurative. But this does not require such targets always be abstract in the sense of being non-concrete, non-specific, or existing in Plato's heaven. (For examples of concrete abstractions, see Knuuttila, Johansson, and Carrillo, this volume.)

What we are calling "generative abstraction" is a process of creating a representation. It may begin by representing some particular concrete target. It may involve subtracting features from that target in creating the representation. But then it moves on to become a representation of something other than the target that initially inspired it. It is generative in the sense that in the process of creating it, a new target is generated, which is different from the initial target. We will complicate this idea in a moment. But first, consider Costello's helpful discussion of types of abstract photography. One is called "weak" abstraction, in which a photograph contains no easily recognizable objects, though it is clear that one is looking at everyday things (like a detail of a wall). "Strong" abstraction works like weak abstraction, only it is no longer possible to tell what one is looking at, beyond lines, shapes, and colours. Next is "constructed" abstraction, which interferes with the photographic process directly (e.g., in a darkroom, using light, shadow, and chemicals) to produce images that are not "of" anything, but which still might resemble or call to mind certain material textures or natural phenomena we recognize. Finally, we have "concrete" abstraction, which produces something entirely new, "from scratch" (2018, 399), and which refers to nothing outside the processes of photography and the image itself. An artist might go through each of these "stages" of abstraction, either in their career or in the course of creating a single artwork. Obviously, an artist might directly begin by producing "concrete" abstractions that were inspired by no target system outside the artwork, without going through the other "stages". Still, thinking of it as a process that moves away from a concrete target system will be helpful in what follows.

We have distinguished two abstractive processes, and now we want to suggest that each requires its own epistemological account. We called the process of intentionally leaving certain details out of a representation "subtractive" abstraction. This we find in both scientific model-building and abstract art (as well as non-abstract art). The epistemology of such a process has been accounted for by philosophers primarily using what we might call a "preservative" epistemology. A representation is created and used in an argument for a particular conclusion about a particular target system. For example, a particular pendulum is presented, a model is built of that pendulum, which subtractively abstracts certain features but retains important truths. We find something holds in that model (for example, that the pendulum's period is proportional to the square root of the length of the string of the pendulum), and we extend this finding to the real pendulum. And this extension is thought to be justified because the model already contains accurate information about that very target. Thus, the model is epistemically preservative. The justificatory force behind the conclusion was just the empirical observations and justified theoretical background knowledge that we already had. What justifies extending our knowledge to *all* pendulums is a separate inductive argument, which says that what we've learned about *this* particular concrete pendulum should hold (roughly) for *all* pendulums, because pendulums are similar in a way that is relevant for induction (for discussion, see Norton 2021). While we want to draw attention to another notion of abstraction, we recognize that there is much more to be said about the practice and epistemology of subtractive abstraction (see, e.g., Suárez, this volume).

We called the second kind of abstractive process "generative abstraction", and this process is more complex, at least insofar as it can contain processes of subtractive abstraction. Abstraction in this sense is a process of creating representations that mostly or completely leave the initial target system behind, to produce artefacts that become a more central focus than the initial target system. These created artefacts may still represent something, and what they represent tends to be expressed in a more "universal" language that can be interpreted from a range of different perspectives. "As David Bohm has observed, the abstract images of Kandinsky's maturity rely for their visual effect only on what is immediately presented: they are considered complete creations in and of themselves by virtue of their inherent structure and qualities" (Berry 2005, 101).

There are at least two ways in which the process of generative abstraction might go: first, in a stepwise manner, moving further and further away from an initial, concrete, inspiring target. In this case, generative abstraction might begin as subtractive abstraction, but it goes beyond this when it severs its ties to the initial system and draws attention to itself and the new target. Second, a generatively abstract representation can be built directly, without any initial, concrete, inspiring target system. What qualifies instances of the second type as instances of abstraction is that the finished product has the same set of epistemological features as the first, resulting from their lack of reference to any initial concrete target system. For example, consider Mondrian's *Composition B (No. II) with Red*.[6] This painting aimed to represent "the dynamic equilibrium of true life" (Mondrian 1987, 283). We may fairly assume that it was not inspired by a concrete initial target and was created to represent the dynamic equilibrium of life directly. Both processes of generative abstraction are processes of *abstraction* because they take us to "a more abstract place". And neither can be understood wholly as subtractive abstractions, because in the first case, we eventually cease subtracting and start building, while in the second case, we were never subtracting at all.

The epistemology of abstractive representations cannot be exhausted by a preservative account: it must be supplemented by a *generative* account (for a related distinction between preservative and generative accounts, see Miyazono and Tooming 2022). The question is not about justifying conclusions concerning a single target, but about producing new and epistemically valuable targets, about which our representation can teach us. The goal of the rest of this chapter is to discuss the epistemology of generative abstraction as it appears in science. To do this, we first identify some cases.

6.4 Scientific Models Can Be Generatively Abstract

Nancy Nersessian's book *Interdisciplinarity in the Making: Models and Methods in Frontier Science* (2022) presents the results of more than 15 years of ethnographic research into how scientists make models. The case we want to focus on concerns a series of connected models built in a neuroengineering lab. Very roughly, we might describe their work as follows. The scientists wanted to understand how the brain "learns", which they operationalized in terms of the construction and stabilization of networks of neurons in response to external stimuli and feedback. To investigate this sense of "learning", they turned to studies on the brains of rats. Rather than performing *ex vivo* studies on rats brains, they "harvested" cortical neurons from rat embryos, separated them to break any existing neural connections, and placed them on top of an 8 × 8 grid outfitted with 60 electrodes. These electrodes were able to provide electrical inputs, receive outputs, and make possible the tracking of neural activity as the neurons established synaptic connections. This model, which could be metaphorically understood as a "brain" on a dish, provided data that the scientists were not able to characterize using known concepts and theory. In response, they built computational models of the dish models. This is characteristic of much scientific work: in response to epistemological and practical problems, the targets and models change together. With each iteration, the target of inquiry shifts, and overall, we claim, the scientists participated in a process of generative abstraction (see Fig. 6.1).

In more detail, the neurons in the dish would fire in response to electrical stimuli. To understand how the dish "learned", some kind of meaningful patterns had to be discerned.

> The in silico model, which might be considered a second-order model, was constructed initially by one researcher in an attempt to understand the spontaneous, dish-wide firing of the neurons ("*burst*" phenomena) that was occurring in the in vitro model and that they assumed was an impediment to progress in the lab's research project of getting the dish to learn.
>
> (Nersessian 2022, 107)

Nersessian claims that "this kind of second-order modeling of built prototypes (which we consider the in vitro dish to be) is a common engineering investigative practice" (106). To overcome the difficulties of using the dish model, a participant in Nersessian's study decided that a new representation was necessary; in his words,

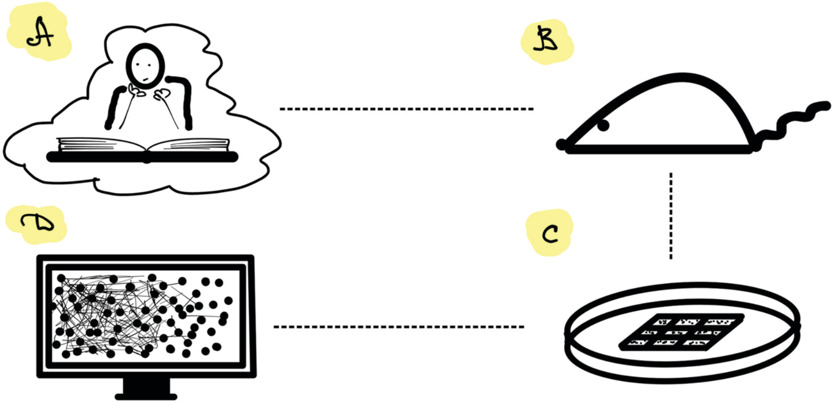

Figure 6.1 A process of generative abstraction. Each transition (from A to B, C, and D) involves abstraction in the subtractive sense but also introduces some idealizations and additional constraints to create the next vehicle of modelling. Taking up "learning" as our first target, we move to the rat brain; then we move away from the complexity and intricacies of the rat brain by dissociating rat neurons onto a dish – the resulting arrangement of cells is easier to control and less complex; finally, the dish is simulated in the computer to yield even more control of the input parameters while providing access to the internal processes that possibly underpin the neural interactions relevant for cognition. Each model shifts its target away from the original target of human learning (to learning in rats to behaviours of the dish, to the interaction of computational variables based on mathematical premises) and in so doing generates a new landscape of affordances, allowing scientists to pose new questions that were not possible for previous models.

> the advantage of modeling [computational] is that you can measure everything, every detail of the network......I felt that [computational] modeling could give us some information about the problem [bursting and control] we could not solve at the time [using the in vitro dish model-system].
>
> (quoted on 115)

Nersessian points out that this scientist

> felt that to understand the phenomena of bursting he needed to be able to "*see*" the dish activity at the level of individual neurons, to make precise measurements of variables such as synaptic strength, and to

run more controlled experiments than could be conducted with the physical dish.

(115)

This participant's long-term goal was to understand the behaviour of the neurons on the dish. But that behaviour, when translated into the computer model, took on a life of its own. This is at least partially because the computer model had different constraints than the dish model. Some constraints were built into the computer model from the dish: e.g., an 8 × 8 grid with 60 electrodes. Some came from the neuroscience literature, e.g., given 1000 neurons, theory predicted there should be about 50,000 synaptic connections. Values for other parameters came directly from the literature, including values for conduction velocity, delay, noise level, and action potential effects, as well as information about which types of synapses there should be, how they should be connected, what percentage of the neurons should be excitatory and what percentage should be inhibitory, and so on. Some constraints came from the modelling software, and finally, some became part of the model via the iterative process of model-building as the algorithm was tweaked and run over and over again until it produced behaviour similar to the behaviour observed in the dish.

Before going further, it is instructive to ask how we would characterize what the scientist was doing in terms of the traditional definitions of abstraction and idealization. Clearly, the scientist was not merely abstracting in the subtractive sense. Of course, at various stages, details are removed. For example, empirical values are converted into ranges, and a three-dimensional brain structure is collapsed into a two-dimensional dish. But other details (e.g., from the neuroscience literature) are added. So the model is both more and less abstract in the subtractive sense, insofar as it contains more and less information about the target system. Are the scientists also idealizing? Presumably some idealizations had to be made, though Nersessian only mentions a few potential cases. For example, when building the computational model, a participant assumed that the neurons would be randomly distributed over the dish, and he admits not being sure if this is the case in the actual dish, though it looks "pretty random" through the microscope (117). Assumptions like this, made for computational tractability, are at least one potential source of idealizations. It therefore seems likely that we'll be able to use the traditional concepts of abstraction and idealization to help understand what is going on here. But if we stopped there, we would be leaving out the importantly generative aspect of the story.

One way to characterize the generativity of this process is to focus on the different affordances of each model in the chain. The dish model, unlike *ex vivo* brain slices, was dynamic: it changed over time depending on the inputs it received. The computational model was also dynamic, but in a different way: it could be run in infinitely many different configurations, paused, replayed, and restarted, at will. For example, synaptic connection strength, which is a measure of "learning" as they operationalized it, could be measured in the computer model at any time, though it could not be measured in the dish. Additionally, running experiments on the computer model came without any great cost of time or danger of killing the neurons living on the dish, which had to be painstakingly cared for.

Another way to appreciate the generativity here is to focus on how data from each model was visualized (see also Bolinska 2013, 2016; Vorms 2010, 2011; Kulvicki 2010). For example, to understand the outputs of the computer model, a visualization was built. As Nersessian points out, this could have been done in "any number of ways" including some that were very familiar to the research group. However, the participant built a new visualization that was not yet used in the lab: he visualized the model as a network.

The behaviour of the *in silico* dish could now be shown to the entire research group, who quickly recognized that its behaviour was "novel and distinct from anything they had thus far understood about in vitro dishes" (121). This mode of visualization made new phenomena visible because the computer model tracked the activity of individual "neurons", which made the propagation of neural activity more clearly visible. A number of "burst types" were then identified: "you get some feeling about what happens in the network – and what I feel is that... the spontaneous activity or spontaneous bursts are very stable" (quoted on 121). This transformed the target of their research: before, bursts were noise; now, they are patterns to be investigated and employed. Around ten kinds of bursts were identified, and a new concept, the burst vector, was introduced. This became the new target: directional "waves" of "neural" "activation". Importantly, the scientists "had the information always... the information was always there" (quoted on 126–7), but it was hidden in the raw data. The computer model made it visible. This might be thought of analogously to an abstract artist who sees something worth investigating in the lines or shapes of a scene, and who produces a painting that brings that aspect out, aided (not frustrated) by the fact that the inspiring scene is no longer visible in the painting. The dynamic, functional qualities of the *in vitro* neural behaviour were brought out by the computer model in a way that allowed the researchers to "look inside the dish" (127).

At this point, someone might object that abstract art is supposed to be non-representational, and this computer model (like the dish model) is clearly representational. However, to repeat, abstract art is abstract in that it leaves behind the *original* inspiring visual target (if there was one). It can and often does make reference to new targets or systems of interest, which it might do by inventing targets of its own. So the question is not whether this chain of models represents *something* but whether they represent *the same thing* all the way through.

Someone could claim that they all represent the same thing: "learning". Despite this being the way scientists might frame their work in grant proposals or paper abstracts, "learning" is clearly not the main, or only target represented in all the models. We might think of the first target system as stable patterns of neural signalling including feedback loops in real brains. The second might be the same, in rat brains. The dish they used drew on single-neuron work as well as work on rat brain slices. They produced a physical dish model that was only one layer of neurons thick and fed by a bath of chemicals and kept to a uniform temperature. It only used cortical neurons, since these are the most adaptable. In the dish model, electrodes were attached to the neurons, and after about two weeks, neural circuits grew around these electrodes. The input the dish neurons received might simulate perception and haptic feedback, as the lab would connect the input and output to computer models of virtual environments or physical robots. For example, one dish was modelled after moths, as they tried to teach it to focus on a central "light" source (Nersessian 2022, 75, 128). Another was modelled after a human arm, which they gave a pen and a camera and tried to teach it to colour in between the lines. The target of the computer model was the behaviour of the dish model. This is clearly a different target than the behaviour of real brains. The computer model was further used to model the behaviour of the moth-dish, or the arm-dish, and was used successfully to "program" both. Clearly, this is an episode of scientific progress, despite it not being exhaustively characterizable as growing understanding about a single, original, target. The target moves, and this explains the difficulty that the scientists had in describing what the computational model was a model of. Their answers ranged from a model of learning, to a model of cortical neurons, to a model of itself (Nersessian 2012).

Further, the universalizing ambitions of early abstract artists can also be seen here, as the computer model helped to

> form a global perspective on the phenomena – a perspective that cannot be obtained from the more limited in vitro and real-world experimental possibilities of the target system. This global perspective is what informs the "*feeling for the model*," that [the participant] expressed, and that is ubiquitous among modelers.
>
> (Nersessian 2022, 134)

Nersessian calls the perspective "global" because the computational model offers something that can be applied much more broadly than to a particular brain-on-a-dish. It aims to reveal features of neural burst behaviour and neuronal networks more generally, just as abstract art aims to reveal features about emotion, experience, or aesthetic relationships more generally.

We mentioned above that there are at least two ways to practice generative abstraction. The first is by gradually leaving the initial concrete target system behind, ending with a new artefact and a new target that is typically more general (or more conceptual, or more universal). The second way is to develop such a representation directly, without any initial concrete system to serve as the starting point from which information would be subtracted. Above we presented an example of the first sort. Examples of the second sort include some of those with no original concrete target system, like those in synthetic biology in which computational or material systems are built to have certain functions that are found in no living system (see, e.g., Knuuttila 2021; Knuuttila and Koskinen 2021; Knuuttila and Loettgers 2021). One interesting case is the repressilator, which is a circuit of genes that turn each other on and off using proteins in a way that mimics the game of rock-paper-scissors. As in the case above, in attempting to understand this model scientists built a computational model, as well as an electrical analogue that uses voltages to represent protein concentrations (Knuuttiila 2021). Other examples include minimal cells and alternative genetic systems. These systems likewise represent general ways things could be, without having been inspired by any particular concrete system (Knuuttila and Koskinen 2021). Perhaps we could also include exploratory models that target possible or hypothetical systems, like Maxwell's ether model and supersymmetric particle models (Gelfert 2016; Massimi 2019). We think that all of these cases are well described as instantiating processes of generative abstraction. They are clearly abstract in some way, but not because they omit information about a particular system.[7]

One final point of clarification. We have defined generative abstractions in terms of new artifacts and new targets, but we want to be clear that each can be "new" in different ways. Thus, the new artifact is typically new in the sense of "previously not existing". The target of representation (what the model "points at") might be new in that sense, as in the minimal cell, but it could instead be new merely in the sense of being different from the original target. For example, abstract artists might produce a generative abstraction that refers to a feeling or state of being, while the neuroengineers above produced a generative abstraction that refers to neural behaviours, each of which already existed.[8]

6.5 Discussion

6.5.1 General Epistemological Considerations

In considering the epistemology of abstraction, philosophers have focused on a subtractive notion of abstraction. As a result, philosophers have pursued a preservative epistemology of abstraction. There are several ways this could go. Here is one: abstraction is done properly when the only features not abstracted away are the true "difference makers". Thus, models should be as abstract as possible (as long as they capture all the relevant difference makers), so that they are maximally cognitively tractable for humans (e.g., Strevens 2008). On such an account, the best abstractions are those that don't interfere with the truth, and which can easily be un-done.

We agree with Nersessian (2008), Leonelli (2008), Carrillo and Martínez (2023), and many of the contributors to this volume that subtractive abstraction is not the only kind of abstraction relevant to scientific model-building. One other important kind of abstraction is generative abstraction. This kind of abstraction is easy to spot when there are chains of connected models, especially in interdisciplinary contexts. Given the fact that generative abstraction is very different from subtractive abstraction, we should expect generative abstraction to require a different epistemology.

For one thing, generative abstractions, unlike subtractive abstractions, cannot be un-done. Adding information from the initial target system "back" into a model is not a sensible thing to do once the target has changed. This is even clearer in the case of generative abstract models that were not inspired by a particular concrete target system. For example, when scientists are trying to build cells that reveal how minimal a genome can be while maintaining core cellular functions, it would not be helpful to introduce information from a particular cell, like a human liver cell, into that minimal cell. Such information would not make the minimal cell a better representation of its target, which is the *minimal* cell. It would make it a *worse* representation of a minimal cell, because the extra information would make it less minimal.

Rather than staying true to some inspiring target system, generatively abstract models should be interesting as artefacts in themselves. They may still (come to) refer to things, and these things should be of scientific interest. In the neuroscience case discussed above, the target shifted from the human brain to the rat brain to the dish model to the computational model. Unlike subtractive abstraction, which ideally increases understanding about the initial target system, generative abstraction explores new features, like bursts and burst vectors, which may or may not be found in the original target.

Generative abstraction is successful to the extent that it improves our epistemic standing with respect to the new target. Just as abstract artists manage to explore musical harmony (Kandinsky), feelings (Mondrian, Rothko), or religious themes (af Klint) via lines, shapes, and colours, scientists invent new systems with interesting properties, just as the computer model discussed above enabled scientists to "see significant system behaviors" (Nersessian 2022, 137). But how is the process of generative abstraction done *well*? What could we say to a scientist embarking on such a process? This is a difficult question. Often the abstractor might desire to leave the initial target behind without knowing what the final artefact should be or what the final target system should be. Or they might know what they want the final target to be, but they don't know what to build in order to explore it.

Generative abstractions are useful because they enable scientists to break away from what may be a limiting focus on a particular target system. Because of this, the practitioner has a lot of flexibility in creating them. This might be frustrating for someone who wants to follow a set of rules to build a generative abstraction, but there cannot be such a set of rules. For Kandinsky, the process should be intuitive, as well as slow, careful, and rational: "Reason, consciousness, purpose, and adequate law play an overwhelming part. Yet, it is not to be thought of as a mere calculation, since feeling is the decisive factor" (Kandinsky 1977, 108, 109, 117, 123). For Malevich, it should be a completely rational process, carefully planned out from the beginning: "In constructing painterly forms it is essential to have a system for their construction, a law for the constructional interrelationships of forms" (Malevich 1969, 100). However, Malevich never gave rules for such a system.

Unlike subtractive abstraction, where scientists can (in simple cases) chip away irrelevant information bit-by-bit until an explanatory kernel of dependency relations is revealed, scientists abstracting generatively must be permitted to move playfully, adding detail here, removing detail there, building up and breaking down, as they try to create something new that is interesting and useful. Nersessian argues that the choices they make are not necessitated: there are always many equally rational moves to make. All that is required is that each step of the model-building process must be justifiable from the present perspective. This way, the process may be rational, as Kandinsky, Mondrian, and Malevich demand, even without a foolproof method that could be specified in advance.

Perhaps this coheres best with a consequentialist epistemology. Such an account would judge a process of generative abstraction based on the epistemic quality of the output (Stuart 2022a, 2022b). What makes one output better than another? Generative abstraction is a way to build models, and models have many epistemic uses. So a process of generative abstraction will be better to the extent that it contributes to some epistemic aim, for example, providing a good starting point, providing a proof-of-principle demonstration, generating a potential explanation, leading to an assessment of the suitability of a target, delivering knowledge of causal possibilities, or delivering knowledge of objective possibilities for hypothetical entities (see Gelfert 2016 and Massimi 2019). An internist version of this idea would claim that a process of generative abstraction has more epistemic value to the extent that, as far as the abstractors can foresee, it would best promote some of the above epistemic aims. An externalist version would claim that a process of generative abstraction has more epistemic value to the extent that it really turns out to best promote such epistemic aims. It might also be possible to formulate a deontic epistemology of generative abstraction, such that a process of generative abstraction is epistemically correct when each act that makes it up respects duties of maintaining representational accuracy or staying consistent with background knowledge. But given the artistic, experimental, and imaginative nature of generative abstraction, perhaps developing and obeying strict rules would not be the main way that scientists (should) perform and justify this kind of work (Stuart 2020).

Another way to explore the epistemic powers of generative abstraction is to make reference to existing epistemologies of scientific representation, which explain how representations produce new knowledge or understanding of their targets. While it would be interesting to see how this might go in detail for each account, doing so would not give any definite answer about how we should understand the epistemological contributions of generative abstraction until it was clear which of these accounts was the correct one. Thus, structuralists (e.g., da Costa and French 2003; Bueno, French, and Ladyman 2002) can explain successful generative abstractions by reference to homomorphisms, monomorphisms, isomorphisms, or partial isomorphisms that obtain between the model and the new target. Inferentialists (e.g., Suárez 2004) can argue that generatively abstract models succeed when they enable correct inferences to be drawn about the new target. Each of these accounts produces explanations concerning how generative abstractions work, but which explanation is to be preferred depends on which account is correct, and that is still very much an open question.

However, it might be interesting to turn the question around and use the existence of generative abstraction as a test for accounts of representation. If generative abstraction is a genuine and important part of science, then accounts that have difficulty accommodating it face a challenge. Consider the two main kinds of fictionalist accounts of scientific representation. Fictionalists claim that a model is a fiction in the sense that it constrains "games of make believe" that we can play. To play such a game, we follow certain implicit and explicit rules, as well as "props" around which the game is focused. The model, or the model description, serves as a prop in the game, and our goal is to determine what else is true in the fiction. *Indirect* fictionalists claim that model descriptions inspire the creation of imaginary systems which can be explored and compared to a target system. These accounts are indirect in the sense that they claim we learn about the real target system by means of a third thing, the imaginary system. We think that indirect fictionalist accounts like Frigg and Nguyen's (2016, 2020) can handle generative abstract models since the last stage of model-based reasoning in their view freely "keys up" properties instantiated in the imaginary system with properties that are to be attributed to the target, and as far as we can tell, nothing in their account prevents that target from being different than the initial target system on which the model was originally based. However, there are also *direct* fictionalists, who claim that the model is always about some real world target system. There is no "third thing", no fictional system, through which our investigation detours. For example, a mathematical model of a pendulum is always and only about a specific desk pendulum, or the set of all actual pendulums (Toon 2012; Levy 2012, 2015). This seems to require that models created via abstraction must only tell us about some particular real-world target system. Generatively abstract models still count as representations on this account, as they prescribe imaginings in the context of a game of make believe. However, as scientists go through a process of generative abstraction in their model-building, they change target or produce new targets. When this happens, the resulting model becomes either a *bad* representation of the initial target, or we must ignore the process of model-building and simply say of the finished model that it represents the new target. The first option is unattractive because the process of generative abstraction can create *better* models, not just worse ones. And this improvement is substantial: generative abstraction helps scientists to achieve particular epistemic aims, like explanation, prediction, and opening up new theoretical possibilities. To ignore this and claim that any changes in the target inevitably make the model worse would be to ignore all the good reasons that scientists have for making generative abstractions. The second option is unattractive because attention to scientific practice makes it clear that very few models are really "complete" such that we can say once and for all what the "real" target is or should be. We want an account of scientific representation that can accommodate the flexibility and open-endedness of models and model-building practices. Genuinely moving targets therefore present a challenge to direct fictionalism as a descriptive and normative account of scientific practice.

6.5.2 Considerations for the Scientist

What consequences, if any, does the existence of generative abstraction have for the practicing scientist? One main consequence is that generative abstraction should be kept distinct from subtractive abstraction, even in the mind of the scientist. This is because the different kinds of abstraction are justified in different ways, and scientists should keep track of which past scientific actions were justified and how.

Recall that subtractive abstraction can be used for generative purposes. This is because subtraction has a capacity to *reconfigure* a model, its workings, internal commitments, constraints, and representational relations to the target. Scientists should be aware that with enough subtractive abstraction, they might find themselves *generating*. Once they have embarked down this path, a generative rather than preservative justification will be required, and employing only a preservative epistemology will yield incorrect evaluations of past practice.

To see how an abstraction can reconfigure the model landscape, let us look back at the dish model. From a theoretical perspective, moving from an intact rat brain to a dissociated rat brain seems like a mere abstraction of constraints or features that define the functioning of a brain, such as the quantity of connected neurons and their spatial organization. On the dish, we are dealing with a smaller number of neurons arranged in two rather than in three dimensions, so it is easier to study. Here, the problem is that subtraction in the theoretical sense may be not the same as in the material sense: what theoretically looks like removal of some constraints or features in fact results in a substitution of one set of constraints for another, which may reshape the behaviour of the model in an unanticipated way. On the positive side, new or unnoticed effects or phenomena may surface, such as the phenomenon of bursting; however, on the negative side, it may produce contingencies and artefacts that may not have anything to do with the original target. (They may still be interesting effects to study by themselves, and this is one source of generativity.)

One may reply that such a danger is only pertinent to abstractions in the case of material models. We disagree: subtractions can turn into reconfigurations also in the case of conceptual, mathematical, or computational models, because even if abstraction in the model may be theoretically tractable, its effect on what the target is, generally speaking, isn't always foreseeable. There probably are no cases where we could *guarantee* that further subtractive abstraction would not lead to generative abstraction. Perhaps, instead, there are some contexts in which this is not a very serious epistemic risk. For example, as long as we have a firm intention to fix the target, and the model is relatively simple, the effects of greater and greater subtractive abstraction can be tracked. Common pedagogical uses of the mathematical model of the pendulum are one example. But such a situation seems to be an exception, not the norm, in the scientific practice of model-building and model-using. And this is why supposedly small subtractions in mathematical models or simulations might not work as innocently as one expects them to. Consequently, their effect cannot be just "un-done": one may not know in advance if they abstract contingent features of some real difference makers. Thus, subtraction should always come with evaluations of the effect of this subtraction, as cutting off the "wrong wire" may lead to (good or bad) unpredicted epistemic consequences, which require a new kind of epistemological justification. We are not suggesting that all generative abstractions must be planned in advance or done with conscious foresight. We are merely pointing out that generative abstraction and subtractive abstraction have different epistemic features and yet one can easily lead to the other, so it would be epistemically irresponsible to pretend that subtractive abstraction alone exists, especially when the stakes are high. Scientists should keep track of their targets, even, or especially, when those targets are being brought into and out of existence.

6.6 Conclusion

Our main goal in this chapter has been to add to the existing repertoire of concepts for describing scientific practice. Generative abstraction is something that scientists do, and it is worth looking at more closely. Focusing on this sense of abstraction is helpful in celebrating the complexity of the practice of crafting scientific models. A secondary contribution is to consider the epistemology of this way of model-building. One upshot is that "abstraction" is not always reversible, since only subtractive abstraction is (arguably) reversible. We could recover the traditional way of speaking by disqualifying generative abstraction as a kind of abstraction. But given the intuitively abstract nature of its outputs and its connection to abstract art, this would require argument.

Generative abstraction raises new questions. One is how generative abstraction relates to idealization. Do generative abstractions introduce intentional misrepresentations of their targets? In some cases, the model system will no longer function as a representation of a particular inspiring target system. Instead, it will *become* a target system. In that case, like the concrete abstractions discussed above, the model cannot misrepresent, since it only represents itself. For example, consider genetic variants of a model organism. Each new genotype has a specific (and different) part of the wildtype phenotype as its original target, yet it is studied for its own features and is not clearly a misrepresentation of anything. In other cases, a generative abstraction will require building a representational analogy base that starts from a particular concrete system, and as we noted above, this can include the use of idealizations. However, as the target of the model changes, what were once idealizations (in the sense of misrepresentations) can become accurate representations. What this suggests is that generative abstraction is not identical to idealization; however, much more can and should be said about this connection.

A second question concerns the differences between generative abstraction in art and science. One interesting historical difference is that abstract art was sharply criticized for its idea that shapes and colours could really serve as a "universal language". In science, the idea that generative abstractions are more universal might be appealing, since such models are typically more formal, more mathematical, and more likely to "travel" across disciplinary boundaries. There are surely other informative (dis)analogies between the two contexts that would be worth exploring.

A final question concerns whether generative abstraction arose first in art and then travelled into science, or vice versa, or whether it arose independently in both.[9] A natural thought is that generative abstraction arose first in art. However, there are scientists who made generative abstract visualizations already in the 1890s, like W.E.B. DuBois, whose visualizations were said to "anticipate Kandinsky's famous Bauhaus color and shape tests administered to his students decades later" (Battle-Baptiste and Rusert 2018, 97; Phull forthcoming).[10] If the arrow of historical connection runs from science to art, this would help to explain why generative abstractions are found so readily in science. If it arose independently in both, this would suggest that similar problem-solution pairs arise in both science and art, which could support continuum theorists about science and art. In any case, exploring and comparing the history of generative abstraction in both science and art will be imperative for learning more about the kinds of problems that generative abstraction has been used to solve, and where it has been, and can be, more or less successful.

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Notes

1 As Julia Sánchez-Dorado helpfully reminded us, Kandinsky himself rarely removed *all* traces of material objects, as such traces often served his goals as an abstract artist.

2 Each of the four backs can be viewed via the Museum of Modern Art (New York). The first: www.moma.org/collection/works/80762?artist_id=3832&page=1&sov_referrer=artist, the second: www.moma.org/collection/works/81190, the third: www.moma.org/collection/works/80772, the fourth: www.moma.org/collection/works/80778

3 This image can be viewed through its current holder, Sotheby's here: www.sothebys.com/en/auctions/ecatalogue/2018/impressionist-modern-art-evening-sale-n09930/lot.18.html

4 See, for example, his *Improvisation Auf Mahagoni* (*Improvisation on Mahogany*), 1910, which can be viewed through its current holder, Sotheby's, here: www.sothebys.com/en/auctions/ecatalogue/2018/impressionist-modern-art-evening-sale-n09930/lot.6.html

5 For example, *Avond: De rode boom* (*Evening: The* red *tree*) (1908-10), *De grijze boom* (*Grey tree*) (1911), *Bloeiende appelboom* (*Blossoming Apple Tree*) (1912). All three paintings can be viewed on the Hague Art Museum website: *De rode boom* (www.kunstmuseum.nl/en/collection/avond-evening-red-tree?origin=gm); *De grijze boom* (www.kunstmuseum.nl/nl/collectie/de-grijze-boom?origin=gm); *Bloeiende appelboom* (www.kunstmuseum.nl/nl/collectie/bloeiende-appelboom-0)

6 View this artwork here: www.tate.org.uk/art/artworks/mondrian-composition-b-no-ii-with-red-t07560

7 Other examples of this second kind of generative abstraction might include the Kac ring model from statistical physics, and Norton's Dome (Norton 2008). Both models could be understood as being created specifically to explore certain important theoretical possibilities, rather than particular concrete systems. For more interesting examples, see Costello, this volume.

8 Thanks to Michela Massimi for prompting us to think more about this.

9 For excellent work on this connection generally, see the entries in this volume by Sánchez-Dorado, and Tarja Knuuttila, Hanna Johansson and Natalia Carrillo.

10 To view these visualizations, see the Library of Congress's collection, here: www.loc.gov/pictures/item/2005679642/

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7 The Novel Naturalness of Abstract Space

Julia Sánchez-Dorado

I.

The idea of producing a replica of the world to gain knowledge about it is supported by an old, ingrained metaphor of representation as the mirror of nature. Following Nelson Goodman in *Languages of Art* (1968), if we aim to understand what actual human efforts to learn about the world consist of, we should first discard copy theories of representation that embrace the mirror metaphor. In representing an object, Goodman claims, we do not copy, we *achieve* "a construal or interpretation" (9).

But what does it take to achieve fruitful "construals or interpretations" in actual epistemic practices? Offering a compelling response to this question, while avoiding the appeal to imitation, copying, or searching for similarities with the aspects of the world that we aim to represent, is not an easy task. In science, two of the strategies that philosophers have identified as being used to produce fruitful construals – most frequently in the form of models – are *abstractions* and *idealizations*. Stressing the epistemic role of abstractions and idealizations certainly moves the attention away from copy theories of representation, since recognizing the cognitive potential of these two strategies exposes the selective, approximate, sometimes distorted, and certainly partial nature of modelling practices in science.[1]

In the recent modelling literature in philosophy of science, the most common distinction made between these two strategies is that abstraction is the act of omitting some aspects of the natural or social world that are deemed irrelevant during the process of constructing a model, while idealization is the purposeful introduction of falsehoods in a model (Cartwright 1999; Chakravartty 2001; Jones 2005; Radder 2006; Godfrey-Smith 2009; Levy 2018).[2] Thus, an idealized model offers a false image of a certain target while an abstract model presents an incomplete, poor-in-detail image of that target.

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One of the motivations for this chapter, in line with the collective drive of the volume it is part of, is that abstraction remains the least studied and seemingly considered less interesting among these two strategies, at least based on the extensive literature on idealization found in recent philosophy of science.[3] It seems that, if abstraction is the act of omitting or leaving out unnecessary details of a target investigated, there isn't much of epistemological interest to be said about it, beyond the acknowledgement that modellers need to discriminate between features that are central in the study of a phenomenon and the myriad other features that they also encounter in their enquiry. There is a related second motivation for this chapter. The definition of abstraction as the mere omission of unnecessary features is too limiting to account for the epistemic potential of this strategy. To capture what is cognitively at play in acts of abstracting, something in addition to omission ought to be considered. Otherwise, it would remain obscure how "being poor in detail" helps construct fruitful representations of phenomena that are highly complex.

This chapter proposes that a creative, reconfiguring process is often involved in acts of abstracting. This claim aligns with other recent proposals, such as Gallegos Ordorica (2016), who suggests that there are aggregative forms of abstraction; Carrillo and Martínez (2023), who discuss how metaphors often turn into scientifically important abstractions (not via omission); and Stuart and Kozlov (this volume), who describe a generative – as opposed to a subtractive – kind of abstraction (see also Introduction by Ambrosio and Sánchez-Dorado, this volume). The specific approach adopted in this chapter consists in drawing the attention to how practices of abstracting have been conceptualized in the modern history of art, since there one can find explicit and rich characterizations of abstraction as a creative activity, not reducible to omission.

When abstractionism appeared in the panorama of the artistic Western avant-gardes at the beginning of the twentieth century, art theorists, critics, as well as artists themselves had to address the challenges it brought into traditional conceptions of depiction in art. Abstract art was characterized, beyond its different branches – expressionist, geometric, suprematist – by the adoption of a conscious aesthetic of distancing from figurative form. Influential figures like Wassily Kandinsky, Paul Klee, Piet Mondrian, and Kazimir Malevich, and other figures whose work was only acclaimed decades later, like Hilma af Klint and Anni Albers, contributed to elucidating the distinct nature of abstract composition through their writing, developed in close connection to their own artistic practice. This chapter looks specifically at the reflections on abstraction traceable in the educational program of the Bauhaus at Weimar and Dessau (1919–1933), where precisely some of these abstractionist artists, like Kandinsky and Klee, taught. Recollections of their classes by students and their own teaching materials can bring insight into a key function of abstraction beyond omission: abstractions can prompt the spatial imagination of the viewer, leading to the exploration of possible insightful relationships (between shapes, lines, edges, colours) occurring on the surface of the abstract space created. This exploration would, in its most successful cases, allow the viewer to uncover relevant relationships also occurring in the natural, social, and even intimate worlds, which had remained occluded until the viewer's encounter with the abstract artwork.

To illustrate how abstraction can contribute to science in an analogous way, this chapter presents an example in the field of fluid dynamics from approximately the same period and location as the Bauhaus writing on abstraction discussed (Germany in the interwar years). There, one can observe how researchers gained novel epistemic access to the complex behaviour of turbulent flow thanks to the imaginative exercise prompted by the abstract spaces created through diagrams of flows. Philosophers of science would benefit from a more open dialogue with the history of art, especially with early abstractionist thought, insofar as they could gain access to rich creative views on abstraction that are not yet familiar in the contemporary modelling and scientific imaging literature.

II.

The Bauhaus School opened in Weimar in 1919 under the directorship of Walter Gropius. Some years later, it would be transferred to Dessau, where it flourished as an educational institution until its forced closing by the Nazis in 1932. Fine arts, crafts, and architecture were taught in close relation to one another at the Bauhaus. In the proclamation of the school in 1919, Gropius said: "Together let us conceive and create the new building of the future which will embrace architecture and sculpture and painting in one unity" (*Manifest und Programm des Staatlichen Bauhauses*, April 1919). One of the principles that guided the program at the Bauhaus was that craftsmanship had to be given the status it deserves, next to the arts, instead of below them. Thus, the school was considered to be "the servant of the workshop", and instead of having teachers and pupils, there were "masters", "journeymen", and "apprentices" (ibid.).

The first semester at the Bauhaus consisted of a series of preparatory courses (*Vorlehre*), where students would learn elementary principles of design. Afterwards, they had to select a specialization in one of the workshops, among which they could find architecture, carpentry, printing, mural painting, scenography, metal work, pottery, glass work, and weaving[4] (ibid.). They also received painting and photography classes and attended a series of lectures where invited speakers would discuss matters of topicality in various scientific fields, ranging from physics to psychology (ibid., 8–9).

From 1922 to 1932, Kandinsky taught some of the preparatory courses at the Bauhaus, focused on the learning of basic forms, colours, and composition principles, and where thinking about abstraction was a fundamental part (his course was titled "Abstrakte Formelmente und analytisches Zeichnen") (Catalog Bauhaus Dessau 1988, 8). Klee also taught preliminary courses on composition between 1920 and 1930 (named "Elementare Gestantungslehre der Fläche"), as well as Laszlo Moholy-Nagy, Josef Albers, and Johannes Itten did. Given the abstractionist inclinations of its teachers, the Bauhaus soon became a central international meeting point for the investigation of the theoretical as well as applied principles of abstract composition (Moszynska 2020, 86). One student, Ursula Schuh, recalls how at the Bauhaus "we loved abstraction, we experienced 'the abstract'" (Schuh, in Neumann 1971, 134; my translation).

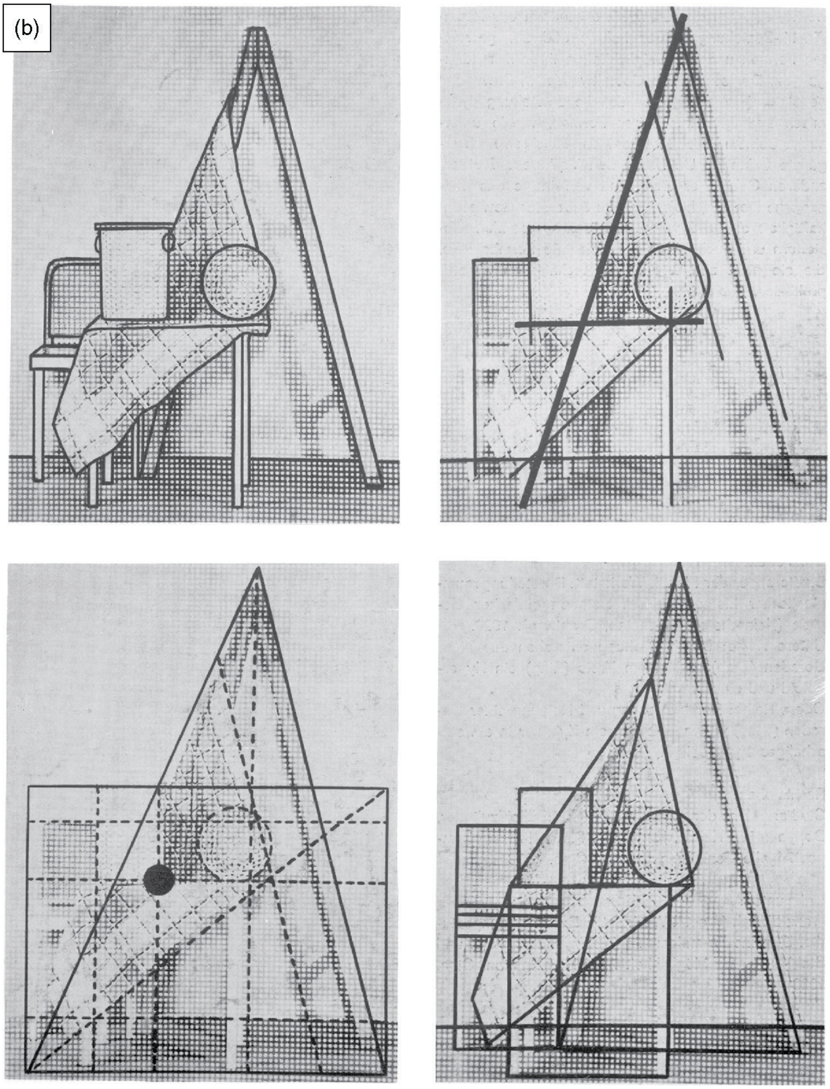
To get a sense of the class exercises students did at the preliminary courses, and the role of abstract composition in them, it is telling to read the recollections of a student in Dessau from 1927 to 1930, Werner Feist:

> Kandinsky, like Klee, divided his teaching period into two segments. The second period began with real objects. He had us set up a simple "still life" of objects within easy reach, such as a chair, a waste basket lying on its side, perhaps, a blanket or tablecloth if one could be found, casually draped. These objects now formed a three-dimensional configuration, no longer chair, blanket and waste basket, but a configuration of volumes, directions, positive and negative spatial shapes, plastic tensions and other relationships which we were to project selectively on our pieces of paper. The task was to analyze what we saw and to express it in simple graphic terms. But since most visual phenomena seem to be ambiguous there always emerged a variety of possible geometric interpretations, none intended to represent recognizably the objects before us. We acquired an additional vocabulary in the new language of vision. I have never ceased since that time to see everything I look at consciously as a diagram of forces and plastic relationships, as if hypnotized by Kandinsky's analytical perspective.
>
> (Feist 2012, 58)

Sketches by another student, Hannes Beckmann, who also took part in Kandinsky's course, closely match Feist's description of this abstracting class exercise (see Figure 7.1).[5] Students started from the observation of a set of objects arranged on a scene, and then, in a subtracting exercise,

Figure 7.1 Photograph and sketches of a still life, produced by Hannes Beckmann as exercises for Wassily Kandinsky's course at the Bauhaus school in 1929. Reproduction rights granted by the Bauhaus-Archiv Berlin. Copyright belongs to Cathy Beckmann. Permission to reproduce the sketches of Hannes Beckmann are granted by the David Hall Gallery. Reuse not permitted.

7.1a: "Stillleben mit Tisch, Stuhl, Leiter, Decke, Papier- und Brotkorb" (Still life with table, chair, ladder, tablecloth, waste-paper and bread baskets). Photograph of a still life arranged in class.



7.1b: "Analytisches Zeichnen nach einem im Unterricht aufgebauten Stillleben in vier Abstraktionen" (Analytical drawings of a still life arranged in class, in four abstractions). Four consecutive sketches drawn by Hannes Beckmann, where figuration is progressively lost, and different relations between the objects in the scene are emphasized.

eliminated the aspects that were obstructing the geometric analysis of the scene, until everyday objects could not be recognized anymore. Until that point, the process of abstracting that Feist describes and Beckmann sketches coincides with the idea of abstraction as the omission of irrelevant features discussed above. It also coincides with what Kandinsky himself described as "one of the first steps in the turning away from material objects into the realm of the abstract" in *Concerning the Spiritual in the art,* his seminal theoretical work on abstraction (Kandinsky 1911, 94). That first step consisted in the "rejection of the third dimension", the central component of figurative art, which permitted the identification of everyday objects on the canvas (ibid.). Beckmann's successive sketches show the gradual elimination of the third dimension from the surface of the painting, to the point when no volumetric form corresponding to a basket, chair, or ladder could be recognized by the viewer.

The process of abstracting did not conclude here though. After omission, Kandinsky describes a later stage of "striving after a new form of composition", where the material plane is transformed to "create an ideal plane" (1911, 95). That is, by the continued work towards abstract composition, the artist constructs a space on the canvas that contains its own internal organization, independent – largely, if not completely – from the original scene. Viewers might not be able to identify volumetric form on that newly created space, as illustrated in the last three sketches of Beckmann's sequence (in contrast to the first sketch, at the upper left side, where this is still possible). But the combination of lines, edges, and shapes, intersecting with one another on the abstract spaces created, exhibits a self-contained configuration that allows the viewer to explore relevant relationships among its components. Each of the last three sketches, in fact, is uncovering a different key relationship between the parts of the composition: a relationship of tensions and main forces organizing the scene (in the upper right sketch), a relationship of balance and proportions (in the lower left sketch), and a relationship of contour and continuity between various shapes (in the lower right sketch). In exercising their imaginative as well as perceptual abilities during the construction of these sketches – and later on when observing them – artists and viewers can go back to the initial scene and gain new insight about it, in ways that the realistic photograph (see Figure 7.1a) and the figurative drawing (see upper left sketch in Figure 7.1b) wouldn't allow. Namely, they can expand their understanding of the scene in terms of the relevant forces, proportions, and visual continuities operating in it.

As it has been advanced, for Kandinsky the specific plastic means used to transform the material plane into an independent, self-organized abstract space are the variations in lines ("the thinness or thickness of a line") and shapes ("the placing of the form on the surface, the overlaying of one form on another") (Kandinsky 1911, 95). In the more didactic book on abstraction that he published in 1926, *Point and Line to Plane,* part of the Bauhaus book series, Kandinsky describes how lines can even be employed to add a temporal dimension to the abstract space created by the artist:

> the time required to follow a straight line is different from that required for a curved one, even though the lengths are the same; the more animated the curved line becomes, the longer is the span of time it represents. Thus, the possibilities of using line as a time element are manifold.
>
> (1926, 98)

The combination of colours also contributes to shaping the internal dynamic of an abstract space. When colours are "rightly used", Kandinsky said, they "can advance or retreat, and can make of the picture a living thing, and so achieve an artistic expansion of space" (Kandinsky 1911, 95). The idea that colours can "expand space", despite the strict physical limits of the two-dimensional canvas, paper, or photographic material use for the composition, and turn a picture into a "living thing", is telling of the highly creative conception – in the most literal sense of *creating,* giving rise to something – of abstraction that Kandinsky held.

A series of prints, entitled *Kleine Welten* (Small Worlds), published by Kandinsky as a portfolio short after he started to teach at the Bauhaus in 1922, is an intriguing example of the new, independent realms that abstraction helps create.[6] The twelve small, self-contained worlds exhibit fascinating spatial relationships between the coloured and black and white shapes existing within their limits. The epistemic power of these abstract spaces lies in the fact that they urge the viewer to explore their internal dynamic, and to imagine what organizing principle brings each of them together, forming a coherent (even when chaotic) whole. This act of exploration and imagination does not demand to describe these autonomous little worlds in terms of recognizable volumetric forms (people, animals, scenery), but only in terms of the relationships between properties perceived on the marked surface. For instance, in Kandinsky's work, there was a well-established relationship between redness, squareness, and immobility, as well as a relationship between acute angles and warmth (Newall 2011, 174; Kandinsky 1926, 73–75). In other cases, relationships between properties are much more indeterminate, and thus the exploration process is more open to surprises. Ultimately, and this is the key to the epistemic potential of abstraction, learning to identify relevant relationships in abstract space can lead the viewer to cultivate an aptitude to detect also important, previously unexplored, relationships in the world outside of the pictorial space. Feist, Kandinsky's student, seems to acknowledge precisely this epistemic potential of abstract creation in the quote above. Upon reflection on the exercises they did in class, he recognizes that the practice of abstracting indeed changed his perception of relationships in the world throughout his life: "I never ceased since that time to see everything I look at consciously as a diagram of forces and plastic relationships" (Feist 2012, 58).

The recollections from classes taught by Moholy-Nagy and Klee at the Bauhaus also reflect the creative conception of abstraction they endorsed. Similarly to Kandinsky, the starting point of their teaching at the preliminary courses was the open rejection of the mere imitation of the appearances of nature. Moholy-Nagy said that "nature was only a point of departure" (Moholy-Nagy 1947, 68–71). In practice, the way he helped students to unlearn the imitative forms of representation was to encourage them to experiment with materials in class, to develop their haptic and sensorial abilities, and to counterbalance the learnt mimetic ways of observation and depiction (Moholy-Nagy 1947, 23–24; see also MoMA 1951, 160; Catalog Bauhaus Dessau 1988, 8).

Meanwhile, for Klee the experience of natural objects, and the growth in the contemplation of those objects, was an important part of the education of students (1923, 17). But such contemplation, by itself, does not allow one to penetrate beyond the mere appearances. Klee reflected on how pictures of the past had usually been obtained by a "painfully precise investigation of appearance", with the aim of representing the "object's surface filtered by the air" (Klee 1923, 15). That is, the external volumetric form of objects had been the central preoccupation of traditional figurative art. But now, thanks to the recourse to abstraction, "a more spatial conception of the object as such is born" (Ibid.).

This last claim by Klee might seem contradictory. How could Klee reject traditional figurative art for its obsession with objects in three-dimensional space and then vindicate the idea that abstract art produces a "more spatial conception" of objects? The key is that abstraction is not opposed to the experience of seeing spatial relationships on a plane. It just reacts against the goal of causing the perception of volumetric form associated with everyday objects in the viewer. Abstractions create a kind of "shallow space" on the canvas, where the perception of depth and occlusions is still possible (Newall 2011; Costello, this volume; see also Caldarola, this volume). In this shallow space of abstract pictures, the viewer exercises an "imagined seeing" (Wollheim 1980) or "non-veridical seeing" (Newall 2011) of relations between the elements found in it. Furthermore, in the case of Klee, he kept recognizable figurative elements in many of his abstract works. But they merely functioned as beacons, as indicators of the inner actuality of the abstract shallow space he had created, inviting the viewer to imaginatively examine possible relationships in that space (see Sybil Moholy-Nagy, introducing Klee's *Pedagogical Sketchbook* from 1925; in Klee 1953, 7).

The intersection and combination of lines were for Klee also a fundamental instrument that the contemporary artist counted on to construct abstract spaces on the two-dimensional pictorial surface. In his *Pedagogical Sketchbook* (1925), Klee claimed that "a tendency towards the abstract is inherent in linear expression" (1920, 7). Students remember how in his classes they had to carry out an investigation of the basic properties and dynamics of line configurations and explore their creative potential (Feist 2012, 50). Moreover, they recall, "we were made to use them like words of a language […], making us understand the multiplicity of meanings a line could magically be endowed with" (Ibid.). The idea that lines can form an autonomous visual language within the limits of the abstract composition is also present in Moholy-Nagy's writing, who, reflecting on the work of other abstract artists like Munch, Schiele, and Kokoschka, affirmed that he "now understood why they used unusual combinations of curved, straight and zigzagging lines. This was part of their language, based upon visual fundamentals" (Moholy-Nagy 1947, 68–71). The superposition of lines helped configure a new, largely independent realm, with its own internal dynamic or visual language. With "ecstasy I made a drawing", Moholy-Nagy said, where "there were no objects, only lines, straight and curved", and "I observed that lines could have a power beyond me" (ibid., 71). The fact that no objects could be identified on the abstract composition was no reason to belittle its representational power; to the contrary, lines could grow beyond the initial intentions of the artist and help uncover relevant relationships – forming patterns, new groupings, significant arrays – that could not be foregrounded by the mere reproduction of the appearances of nature.

Anni Albers, student of both Klee and Moholy-Nagy, describes how, influenced by their teaching, she produced weaving patterns by "trying to build something out of dots, out of lines, out of a structure built of those elemental elements", using the material resources available to her, such as thread and loom operations (Oral history interview with Anni Albers 1968). Throughout her weaving practice, novel abstract spaces were created on the two-dimensional textile surface. Albers would defend that textile work should be treated as art, not by bringing it closer to painting, but by acknowledging the genuine abstract character of weaving – its structure and process – and its creative nature: "weaving in any form is a constructive process" (Albers, in Fer 2018, 21).

The strongest consequence of asserting the creative nature of abstraction, already advanced above, is that abstract compositions can tell us something genuinely new about the extra-aesthetic world, that is, the world outside of the limits of the surface painted, weaved, or photographed (see Elgin 2017; Elgin, this volume). Michael Newall gives us some keys to explain how this is possible: the space of abstraction is a "space other to that of our everyday experience", where the "planes, lines and strokes of paint that do inhabit it appear to be ruled by different laws to those of gravity and mechanics" (2011, 194). As in a liberated territory, relationships between features can occur more freely there, "according to some alternative, pictorial mechanics" (ibid.). So the viewer can freely explore possibilities, counterfactual visual hypotheses, that would not be accessible to the same extent through figurative representations that reproduce the impression of a space ruled by the same laws (i.e. physical laws, social conventions) that we encounter in our everyday experience.[7]

Moholy-Nagy argued, precisely endorsing this view, that "abstract art creates new types of spatial relationships, new inventions of forms, new visual laws – basic and simple – as the visual counterpart to a more purposeful, cooperative human society" (1947, 76). That is, a purposeful human society can be more clearly envisioned after the "imagined seeing" (Wollheim 1980) of certain relationships (of cooperation, harmony, assimilation between lines, shapes, colours) in the liberated space of an abstract artwork. Klee hoped that his students would eventually be able to construct "free abstract structures which surpass schematic intention and achieve *a new naturalness, the naturalness of the work*" (1925, 17, my emphasis). To accept that an abstract artwork has its own *naturalness* is to accept that in our encounter with it we are called to embed ourselves temporarily in its autonomous functioning, to explore its internal possibilities, and, hopefully, to learn something that helps reconfigure our conception of certain problems or phenomena that exist outside of the artwork. When that is achieved, Klee was right in saying that "art does not reproduce the visible; rather, it makes visible" (1920, 7). If omitting irrelevant features of a target was, at best, the first step in the practice of abstracting, "making visible" would be the last step, the one that reveals its most creative nature.

III.

Ideas on abstraction were disseminated across central Europe during the interwar years, thanks, among others, to the educational program of the Bauhaus school. The fact that distinguished artists were developing their theoretical work on abstraction at the same time as being engaged in their own abstract practices, and while they carried out their teaching commitments and produced educational materials, provided exceptional circumstances for the spreading of their ideas. A Bauhaus student recalls, with reference to how a design he produced at the school was exhibited in his hometown, that "this small school in Dessau gained influence by showing its face in many minor demonstrations of its ideas in various scattered spots all over Europe, wherever students returned home or began to work and, more importantly, to teach" (Feist 2012, 80).

Some of the same principles of composition endorsed at the Bauhaus school, including the systematic combination of lines and shapes in the creation of abstract spaces, can be found outside of the domain of the plastic arts around the same period, especially in scientific practice. More than claiming that ideas on abstraction conceived in the arts were unidirectionally transferred to science – influences in the opposite direction often occurred as well – it is worth pointing out how some of the same assumptions on the creative nature of abstraction discussed above, held by Kandinsky, Klee, and Moholy-Nagy among others, were manifest in broader circles of academic and public life in the interwar years.

Indeed, at the Bauhaus, ideas on abstraction were conceived both as having a scientific character and as applicable to scientific and technological design. When they joined the school, Kandinsky and Klee had a more intuitive and expressivist approach to abstraction. But they progressively moved towards the more technologically oriented, mathematically precise, and objective trend of abstraction, represented at the Bauhaus by Hannes Meyer – the new director after Gropius – and Moholy-Nagy, in line with central European constructivism (Moszynska 2020, 92–93). More generally, students remember how "without actually being scientists or engineers, Bauhaus people venerated scientific thought and technology and aimed to apply scientific principles to their life and work" (Feist 2012, 84).[8]

It was clear that the Bauhaus educational program wanted to break with traditional distinctions between crafts, fine arts, sciences, industrial production, and other domains of public life. In his essay "The New Vision" (1928), Moholy-Nagy describes how in the teaching at the Bauhaus they were "uniting artistic, scientific and workshop training – with tools and basic machines" (in 1947, 21). Theorization about the new art was closely linked to scientific and technological developments, since together they could produce designs that assisted in the "reshaping of daily life" (Ibid.). At a more conceptual level, scientific conceptions of space were highly influential in the new pictorial art forms appearing during the avant-garde period. For Linda Henderson, the popularization of Einstein and Relativity theory after 1919, and before that of theories of the ether and ideas on the fourth dimension from the second half of the nineteenth century, had a direct impact on the development of cubism and abstract painting (Henderson 1988; Henderson 2008; see also Ambrosio 2016).

An analysis of how the same modernist impulses were shared by avant-garde artists, philosophers and to an important extent also scientists during the interwar years is found in Peter Galison's (1990) article "Aufbau/Bauhaus". Galison discusses the connections between members of the Vienna Circle and the Bauhaus school as a case in point. The commonalities between the projects of these artists and philosophers were real – political, scientific, programmatic – not only metaphorical (insofar as they also shared some of the same "construction" and "building" metaphors in their thinking) (ibid., 711). The two groups even legitimatized one another: the "Vienna Circle bestowed an aura of scientificity on the Bauhaus and the Bauhaus conferred an image of progressivism and postwar reform on the Vienna Circle" (ibid., 749). Carnap, for instance, was one of the invited speakers at the Bauhaus lecture series in 1929. There he stated before the audience that "I work in science, and you in visible forms; the two are only different sides of a single life" (in ibid., 710).[9]

On the close connection between ideas on abstraction in art and science, Kandinsky affirms in *Point and Line to Plane* that, on the one hand, the methods of art need "a more exact and objective way to make collective work in the science of art possible", in comparison to the far too haphazard art methods of past years (1926, 76). Advancing rules of abstract composition, where specific colours, types of lines, and shapes had concrete meanings within a coherent visual language, was the strategy Kandinsky proposed to advance a more objective and exact "science of art". On the other hand, the plastic resources employed by abstract artists were applicable to scientific composition: "in a neighbouring field of art –engineering art and the technics closely related to it – the line grows ever more in importance" than in artistic composition (ibid., 102). This was observable in the design sketches and blueprints of engineers, and in the systematic use of lines in scientific diagrams, where numbers were expressed graphically – for instance, in meteorological charts – with great cognitive potential. Graphic representation in science "makes possible the reduction of the use of number to a minimum – the line partially replaces the number. The resulting diagrams are clear and also comprehensible to the layman" (1926, 102). Abstraction in the sciences involved, for Kandinsky, the clear and meaningful use of straight, curved, thin, and thick lines, thoroughly combined forming a consistent visual language within the limits of a graph, a diagram, or a sketch.

In the essay "Exact Experiments in the Realm of Art", written in 1928 before he left the Bauhaus, Klee also compares the practice of experimenting in art and science. He had no doubt that "in art, too, there is room enough for exact research, and the gates have been open now for quite some time" (Klee 1928, 18). This more scientific approach to experimentation in art is closely linked to the idea that, like the scientist, the artist shouldn't be "merely focused on the appearances of objects or their 'finished form', but needs to look inside, to the function and basic components that organize those objects" (Klee 1928, 18). The analysis of plastic form could teach us to see "what flows beneath" appearances, what the basic components that give rise to a phenomenon are, and how to move "towards the essential, towards the functional as opposed to the impressional" (ibid.). Abstracting is, as much in science as in art practice, a strategy to avoid the impressional and make visible crucial parameters and patterns that would remain otherwise concealed.

IV.

The recourse to abstraction, sometimes sustained on omission, but comprising a strong creative component, has a comparable epistemic potential in scientific practice. An example of research carried out in the field of fluid dynamics can help illustrate the parallel between artistic abstract composition and the use of scientific visual abstraction. In fact, the example presented below, also set in Germany in the early twentieth century, is more than illustrative, as it is meant to reinforce the observation sketched above that comparable ideas on abstraction were in circulation beyond the domain of the visual arts in the years when the Bauhaus school was operative. Even if no concrete personal or institutional relations are identified between Bauhaus artists and the investigations in fluid dynamics presented here, it is telling to observe comparable motivations, as well as similar visual and compositional resources in the construction of abstract images.[10]

In the history of the study of fluids, physicists and hydraulic engineers had frequently needed to use devices for visualization, given the complex behaviour of flows evolving in space and time, and the associated challenge of analysing them through direct observation (Fermigier 2017, 595). In the nineteenth century, developments in photography and film (chronophotography and cinema) were introduced as new tools in fluid dynamics, to be used together with earlier drawing techniques to represent such complex behaviours (ibid., 597–598). Étienne Jules Marey was a pioneer in designing devices that allowed to take effective photographs of flows, such as smoke boxes. They consisted of a series of smoke lines injected upstream and facing some obstacle, which facilitated the capture of images where flows traced clearly visible parallel and curved lines surrounding such obstacles (ibid.). Henry Hele-Shaw also produced outstanding photographs of flows, taken from his experiments in water tanks. Clear, contrasted lines, created through long photographic exposures and the coloration of thin sheets of water, allowed to visually grasp the differences between the regular (laminar) motion of a liquid at some points, and the sinuous, unstable motion of the liquid at other points (Hele-Shaw 1898; in ibid., 600).

In the German context, Ludwig Prandtl presented his boundary layer theory in 1904, which has been read in recent years as an instrumental contribution to establish a bridge between the theoretical and the empirical strands of research in fluid dynamics (Hinterwaldner 2015; Eckert 2018).

On the cognitive strategies used in his research, Prandtl recognized that singling out crucial features of the problem that determined the motion of fluids was a fundamental part of his investigation. In addition, he attempted to gain a "thorough visual impression" of the phenomenon at hand (Prandtl 1948). That is, the visual treatment of his research question, requiring the introduction of photography and other graphical techniques, was indispensable to advance the understanding of the question of interest. At the intersection of these two research strategies, namely, the singling out of key features of a phenomenon and the visual grasping of a problem, is precisely where the recourse to abstraction stood out.

One can identify a step-by-step modelling practice in Prandtl's work. First, experiments in water tanks were designed to afford a direct, observational, even tactile contact with the behaviour of fluid investigated, although in controlled conditions. Then, visualizing procedures were introduced to help isolate the central features of interest in the behaviour observed. For instance, Prandtl collected and compared photographs of numerous experiments in water tanks, where different obstacles triggered different behaviours in the fluids in motion. He also produced a series of films of the formation of eddies in isolated conditions, which could be repeatedly watched and carefully examined.[11]

The omission of irrelevant features was indeed an important cognitive resource at these stages, achieved through experimental control and the elimination of variables in the water tank setup, as well as through the filtering process afforded by the photographic medium. Yet, a properly creative abstracting activity intervened after omission: Prandtl created abstract, black, and white graphs, combining lines of different thicknesses and styles (dashed, solid, arrowed), which were associated to specific photographs or film recordings of flows in motion, but which aimed to represent a broader range of events (see Figure 7.2a and 7.2b). This abstracting process permitted a graphical exploration of the flow and helped uncover important relationships between different sections and features of the dynamic flow filmed that had remained occluded until then. In the direct observation of the phenomenon in the water tank, the complex structure of eddies and the fact that both laminar and turbulent flow were present in the tank made the dynamics of the formation of vortices hardly discernible. The photographs and films did facilitate the visualization of key features of interest. But the relationships between those features were not brought to the fore until the diagrammatic, highly abstract composition permitted qualitative access to them.

Prandtl recognized years later, reflecting on his research methodology, that only after this central cognitive and material step had taken place – that is, the creative abstracting activity of producing the graphs – he could venture to study the phenomenon of turbulence in a quantitative manner.

(a)

(b)

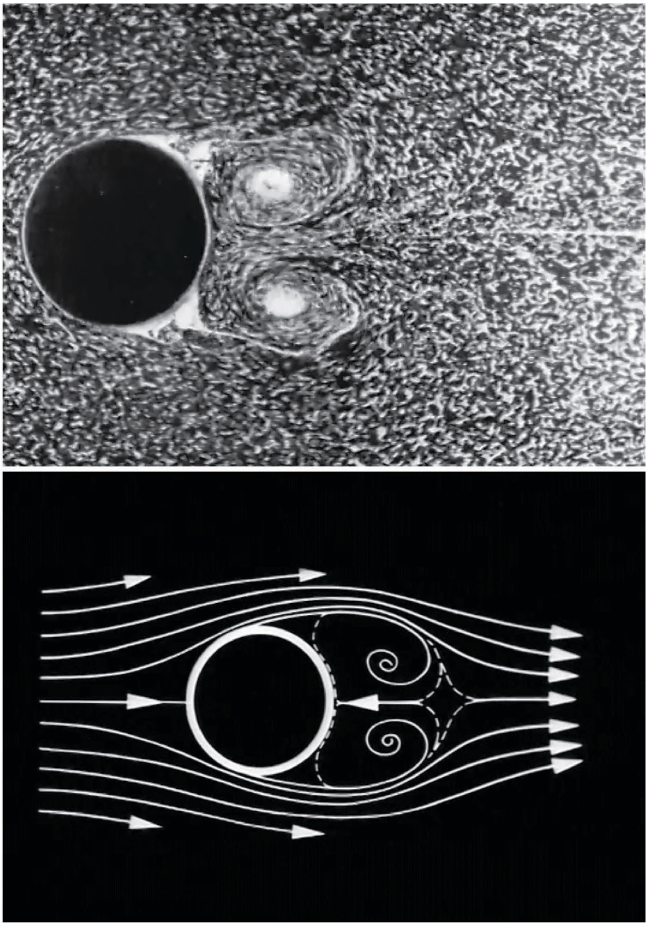


Figure 7.2 Film stills from Ludwig Prandtl's experiments in a water tank, carried out at the Kaiser-Wilhelm-Institut für Strömungsforschung in 1933. "Entstehung von Wirbeln bei Wasserströmungen – 1. Entstehung von Wirbeln und künstliche Beeinflussung der Wirbelbildung" (Formation of Vortices in Water Currents – 1. Formation of Vortices and its Artificial Influencing). Film publisher: IWF Knowledge and Media gGmbH. Permission for reproduction provided by Technische Informationsbibliothek (TIB) DOI: https://doi.org/10.3203/IWF/C-1.

7.2a: Film still of water tank experiment.
7.2b: Abstract representation of flow, where relations between different parts of the flow and an obstacle are uncovered through the creative use of lines (thin, thick, arrowed, dashed).

Prandtl strived for a thorough visual understanding before he approached a problem mathematically (Eckert 2018, 400): "The equations come only later when I believe that I have grasped the matter" (Prandtl 1948, 89; in ibid., 399–400). Abstraction was the crucial strategy introduced to assure the grasping of such matter.

Contemporary to Prandtl, Friedrich Ahlborn also performed visual experiments that provided a novel qualitative access to the behaviour of fluids (Fermigier 2017). Ahlborn was aware that "true understanding of the mechanical relationships is not possible without a certain knowledge of processes that unfortunately elude immediate, subjective observation" (Ahlborn 1905, 69; in Hinterwaldner 2015, 2). To counteract the limitations of the immediate, subjective observation of flows, Ahlborn designed sophisticated photographic setups to capture the changes in the turbulent movement of water in experimental tanks. Like in Prandtl's work, photographs played a filtering role, insofar as they omitted irrelevant or secondary behaviours occurring in the water tank, which were not essential to characterize the object of investigation. However, if we only attend to the direct products of those photographic setups – that is, the concrete photographs taken of the flows – we wouldn't be able to fully appreciate the productive epistemic function of abstraction in Ahlborn's practice. The more fruitful, creative exploitation of abstraction came after omission, with the continuous transformation of those photographs into two- and three-dimensional spaces for exploration.

Inge Hinterwaldner's (2015) article helps us understand the consecutive steps involved in Ahlborn's representational practice. She describes the operations carried out by Ahlborn as those of "splitting", "superimposing", and "intersecting". To start with, Ahlborn produced three types of photographs of the surface behaviour of flows occurring in the water tanks, namely, photographs respectively capturing force lines, path lines, and flow lines in the fluid. Each of these types of photographs offered a different view of the same motion: if the camera located above the water tank remained static and took a shot of the flow using a short exposure time, then force lines would be visible on the photograph; if the camera remained static but used a long exposure time, then path lines would be visible on the photograph; and if the camera travelled along the tank, together with the plate that functioned as obstacle to the flow, then flow lines were visible on the photograph. In Figure 7.3, one can appreciate the difference between two of those three types of photograph: above, a photograph of flow lines (*Stromlinien*) (taken with the camera in movement); below, a photograph of force lines (*Kraftlinien*) (taken with the static camera), corresponding to the surface behaviour of Ahlborn's experimental water tank (in Ahlborn 1909, 380, Plate II, fig. 1 and 2; for a comprehensive analysis of the setup used to take these images, see Hinterwaldner 2015,

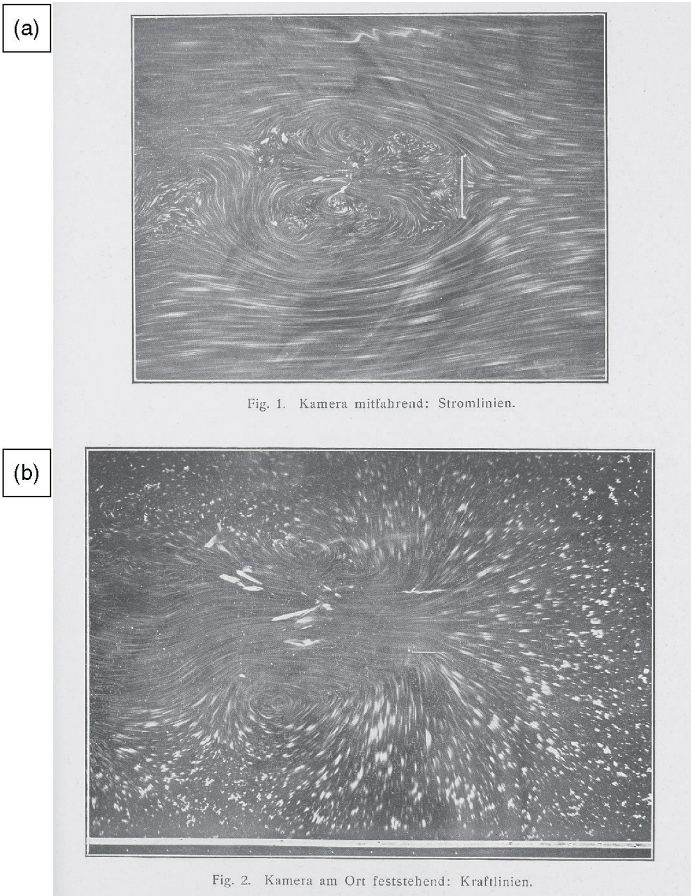


Figure 7.3 Photographs of the surface of Ahlborn's experimental water tank. Taken from Ahlborn (1909, 380, Plate II, fig. 1 and 2). For further analysis of the setup used to take these photographs, see Hinterwaldner (2015, 3–4). Images courtesy of the Smithsonian Institution.

7.3a: Photograph taken by a camera that travelled along the experimental water tank, together with the plate that functioned as obstacle to the flow. Here flow lines (*Stromlinien*) are visible.
7.3b: Photograph taken by a static camera located above the water tank, using a short exposure time. Here force lines (*Kraftlinien*) are visible.

3–4). The three types of photographs were usually exposed next to one another in publications, to motivate a comparative, back-and-forth analysis of them. It required an exercise of synthesis from the viewers, who "had to assume the position of the camera mentally and combine the type of movement with the mode of recording" to make sense of what could be seen in each image (Hinterwaldner 2015, 7).

Now, Ahlborn developed a procedure to transcribe the three types of lines visible on the different photographs into drawings, in a way that they could be integrated into a single representation with the help of different line conventions (see Figure 7.4). Ahlborn asked:

> What do the photographs teach us about resistance? To answer this question, let us extract the essentials from the photographs in the form of a schematic illustration, which we obtain if we draw a system of parallel lines at equal distances through the ordered part of the current not yet influenced by the plate [i.e. obstacle], and let these lines follow exactly the directions of the photographic current lines in the resistance area. The space between two neighbouring lines then represents an elementary current or current thread, and we can imagine that the water flows in the thread like in a tube, if we disregard friction.
>
> (Ahlborn 1904, 423)

The schematic illustrations designed by Ahlborn created an abstract space with which scientists could explore the relationships between different parameters intervening in the phenomenon of resistance. The abstract space prompted the "imagined seeing" of water running between lines as if they were confined inside tubes. In imagining so, the viewer, typically aware of how water moves in pipes, could explore different possibilities of the behaviour of current threads by looking at the internal dynamic of parallel lines in the drawing. For instance, the viewer could imagine that water would move faster when running between parallel lines that are closer to one another in the illustration (similarly to when water runs in narrower sections of a tube) (Ahlborn 1904, 423). In short, the exercise of imagination prompted by Ahlborn's abstract compositions was possible because "in his schematizations, he created space for possibility" (Hinterwaldner 2015, 15).

Moreover, the superimposing character of Ahlborn's schematic illustrations, shown in Figure 7.4, allowed scientists to simultaneously perceive flow lines, present across the whole abstract space (represented as solid lines in the illustration); force lines, radiating in opposite direction from the flow lines (represented as arrowed lines in the illustration); vortices, recognizable in the oval shapes underneath the obstacle (at the centre of the illustration); and the height or depth difference of the fluid (represented

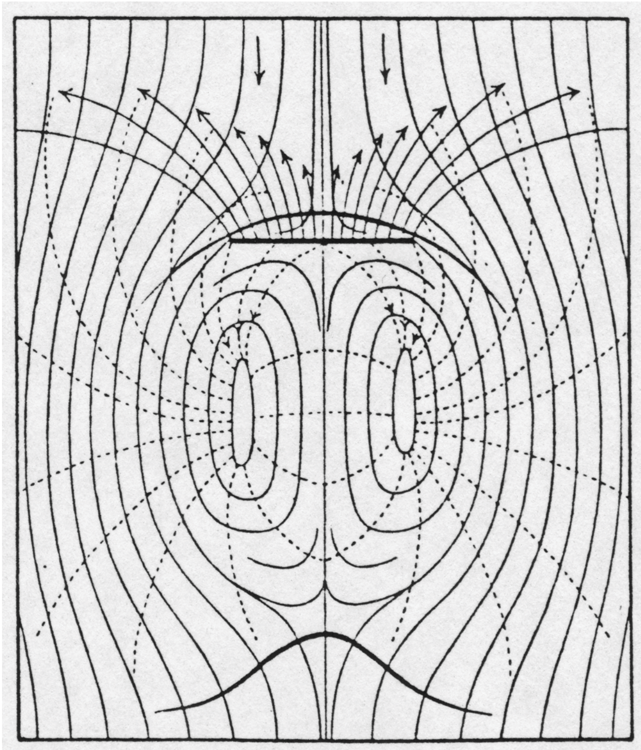


Figure 7.4 Abstract graph of the water flow drawn by Ahlborn to explore the phenomenon of resistance. It combines in a single abstract image different types of lines, only visible separately in the three types of photographs. Flow lines are here represented as solid lines, force lines are represented as arrowed lines, vortices are identified as oval shapes in the middle, and the height or depth difference in the flow is represented as dashed lines. Image reproduced from Ahlborn (1904, 424, fig. 6); for further analysis, see Hinterwaldner (2015, 15). Courtesy of the Deutsches Museum, Munich (Archive, CD69891).

as dashed lines in the illustration) (Hinterwaldner 2015, 15). Through the relatively free, imaginative, explorative observation of how the different lines are organized within the abstract composition, the researcher starts comprehending key relationships held between the constituents of the phenomenon of resistance. Later, those relationships might be more systematically interpreted, in a way that the researcher would be able to make specific inferences from the different lines in the illustration to a unified phenomenon of resistance operating in nature. This process exemplifies the idea, advanced by philosopher of science Mary Morgan, that scientists create artificial, self-contained "worlds in a model", which serve both as objects to enquire into and to enquire with (2012, 280–282).

There was an additional creative abstracting practice in Ahlborn's research. Well aware that his photographic and diagrammatic techniques for the visualization of flows had only examined the motion of fluids at the surface of the water tank, Ahlborn developed new devices to study flow movement (in air and water) occurring in three-dimensional space. Namely, he built a new experimental device to be able to take photographs under water, consisting of a water container furnished with glass walls (Hinterwaldner 2015, 8). This time Ahlborn produced stereoscopic images. But, unsatisfied with the result, he decided to explore ways to assemble the information afforded by the new, cross-sectional images, into a three-dimensional, physical construct in the form of a concrete model (see Figure 7.5). For Hinterwaldner, these abstract, yet very material models were the logical continuation of his schematic drawings (ibid.). The copper wires with which the models were built facilitated the perception of vortices in three-dimensions, caused by a glass plate located at a certain angle of inclination, which served as an obstacle to the imagined flow running from one extreme of the model to the other. At the front of the model, Ahlborn assembled some vertical barns, so that viewers could appreciate from that side how flow lines were at the beginning[12] geometrically aligned

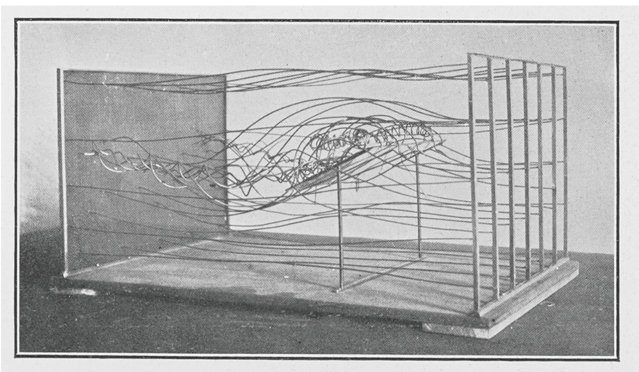


Figure 7.5 Copper wire model constructed by Ahlborn to explore the phenomenon of resistance in fluids. It represents in an abstract manner the three-dimensional configuration of eddies evolving in time, after flows encounter an obstacle, here represented by a glass plate. Image reproduced from Ahlborn (1909, 378, plate 1, fig. 3); for further analysis, see Hinterwaldner (2015, 11). Courtesy of the Smithsonian Institution.

to one another, and after the encounter with the obstacle, they started to curve (ibid., 10).

The "imagined seeing" of important relationships between physical parameters was, in this creative practice of abstracting, sustained on the visual, as well as haptic, exploration of the abstract space created. The different components of these three-dimensional abstract models, brought together in a coherent concrete structure, allowed Ahlborn to gain a richer epistemic access to significant regularities in the phenomenon of resistance in flows.

V.

The crossdisciplinary nature of the argument presented in this chapter, at the intersection of scientific and artistic practices, was motivated by the observation that some of the same epistemic strategies, in particular the recourse to abstraction, were exploited in the two domains. However, I started arguing that the epistemic value of abstraction in modelling practices has not received enough attention in contemporary philosophy of science. This, I tried to show, is partly due to a limiting understanding of abstraction as the omission of irrelevant features of a target investigated. A dialogue with early abstractionist thought in the history of art, where a richer, more creative conception of the possibilities that abstraction can bring into representation, should encourage philosophers of science to expand their current views.

I suggested that the central feature of acts of abstracting is that they prompt the spatial imagination of the viewers, inviting them to explore possible insightful relationships between the component parts existing within the limits of the abstract space created. Scientists as much as artists aim to "achieve construals or interpretations" (Goodman 1968, 9) that help them make sense of complex aspects of the natural, social, or inner personal worlds. The autonomous spaces created by abstraction can function precisely as cognitive entries to aspects of those worlds that are particularly difficult to grasp or conceptualize. If artists can create artworks that have their own "naturalness" or internal dynamic (Klee 1925, 17), and scientists can create "a world in a model" (Morgan 2012), leading to novel ways of understanding aspects of reality, the creative recourse to abstraction is one of the keys to explain how this is possible.

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Notes

1 One might still wonder if it is possible to fully dispose of the ideal of imitation when characterizing these two strategies (from what does a model abstract or idealize if there isn't an apparent similarity between that model and its target in the world?).

2 In ethics and political philosophy, the same type of distinction between abstraction and idealization, with regard to the formation of theories and moral norms, is often established. See O'Neill (1987), Mills (2005), and Schwartzman (2006).

3 There is, at any rate, a history of debates on the role of abstraction in knowledge production traceable back to the origins of philosophy of science in the nineteenth century. See for instance Whewell (1847), McLellan and Dewey (1895), Peirce (1998), and James (1890/2007); for recent reviews of this literature, with a focus on abstraction, see Laurence and Margolis (2012), Winther (2014), Cristalli and Pietarinen (2021).

4 Gropius had founded the Bauhaus on apparently egalitarian principles, also regarding gender. However, it was clear very soon that women were encouraged to choose the weaving workshop, which was popularly known as "the women's class" (in Coxon and Müller-Schareck 2018, 14).

5 Galison (1990, 739) incorrectly attributes the authorship of Hannes Beckmann's sketches to Kandinsky, who was the teacher of the Bauhaus preliminary course where this exercise was done.

6 The twelve prints of the portfolio *Small Worlds* (*Kleine Welten)* by Kandinsky from 1922 can be seen as part of MoMA's digitalized collection: www.moma.org/collection/works/portfolios/143911. Retrieved in July 2023. I thank Ross Shields for the lead to these artworks.

7 I thank Anatolii Kozlov and Chiara Ambrosio for helping me rephrase and strengthen this point.

8 Other references to the close relationship between artists at the Bauhaus and scientists and engineers are found in an essay by Gropius in 1925 (in Scheiffele 2003, 241–2), as well as in Annie Albers' (1968) and Josef Albers' (1968) oral histories.

9 Mutual influences between the artistic avant-gardes and science in the late nineteenth- and early twentieth century have been widely studied. Colour and perception theories, such as Chevreul's *On the Law of the Simultaneous Contrast of Colours* (1839), were an important source of inspiration for the impressionists, neo-impressionists, and some artists who ventured into colour abstraction like Frantisek Kupka (Moszynska 2020, 16–17). For others like Kandinsky, French optical theories were not as significant as Goethe's *Theory of Colour* (1810), from which he developed a grammar that stressed "colours' moral effects" (Moszynska 2020, 24–25).

10 A more direct link between the scientific advancements in fluid dynamics and avant-garde art in the interwar period can be found in Max Ernst's paintings The *Blind Swimmer* from 1934. Ernst's inspiration for these paintings were images of experiments published in the French journal *La Nature,* where air and water flows were photographed to test the resistance of objects (such as boats) moving through water (Stokes 1980, 462). Ernst's paintings, like the images of hydraulic experiments, were "concerned with making felt – but invisible – force visible" (ibid., 464). One of those paintings can be seen at MoMA's digitalized collection: www.moma.org/collection/works/79200

11 Access to some of those films, produced at the Kaiser-Wilhelm-Institut für Strömungsforschung, can be found here: https://av.tib.eu/media/12263 and https://av.tib.eu/media/10981

12 We assume that the model included a temporal dimension, and the "beginning" was the imagined edge of the model where the flow was injected.

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8 Maxwell/Mondrian

Abstraction as a Process in Science and Art

Mauricio Suárez

8.1 Modes of Abstraction in Art and Science

In this chapter I set out to explore suggestive analogues between abstract physical theory and abstract painting. The word "abstract" is routinely used in both fields to refer to certain kinds of creations and is in fact often employed by their creators themselves. I argue that this is not coincidental. Instead, I suggest that "abstract" refers to some common elements in the creative processes followed to generate both abstract theories and abstract art. It also consequently denotes how certain elements in the products of such processes (i.e., in the actual theories, and paintings created) are then routinely interpreted. The abstract elements in both processes and interpreted products then inform what are the apt representational uses of both abstract theory and abstract art. It is indeed a consequence of this, my most considerate view, that both abstract art and abstract physical theory are representational – but only in a very specific minimal sense to be explained in due course, and which may at least in part be explicated by appeal to the concepts of communication theory.

Note upfront an evident disparity, which may make us suspicious of the analogy. Abstract physical theory is always assumed to be representational, but not so abstract art. That is, while abstract physical theory is assumed to aim, one way or another, to capturing some "elements of reality", it has often been thought that abstract art is in no way representational. Towering figures in the philosophy of art in the 20th century, such as Nelson Goodman and Richard Wollheim – on so many other things opposed – came to defend that at its most extreme end abstract art neither aims nor achieves a representation.[1] The view is tempting and somewhat suggested by some pronouncements of the artists themselves, and I have fallen for it myself in the past. I now think that it ought to be resisted. The appropriate contrast is not a functional one between abstract and representational uses of a representational source or object, but a distinction in both the processes arrived at its construction, and the ontology of

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what is thereafter represented by that object. The contrast that matters, in art and science alike, is one between the abstract and the concrete. And the process that matters is the sort of abstracting, or abstracting away, that brings the abstract out of the concrete. Other terms have been used for these contrasts before. They include Mondrian's dichotomy between figurative and nonfigurative art, and Malevich's between objectivist and non-objectivist painting. I argue that both are best construed as creative processes towards "the abstract", where the term is best placed along the abstract-concrete axis, rather than the abstract-representational axis.

I will work my way towards this conclusion by looking closely at two prominent historical examples of abstract physical theory and abstract art, respectively by two of the main protagonists of the fin-de-siècle move towards abstraction in mathematical physics and painting, namely James Clerk Maxwell (1831–1879) and Piet Mondrian (1872–1944). Maxwell's electromagnetic theory, adumbrated explicitly for the public for the first time in his seminal *Treatise on Electricity and Magnetism* (Maxwell, 1873), was an astonishing breakthrough in physical science, and an outstanding exercise in what I shall refer to as "abstract physical modelling" or "physical abstraction". This is an attitude to scientific knowledge, and a way of doing science, enthusiastically taken up by "the Maxwellians" in Britain, and in continental Europe, which perdures to this day. At the other end, Mondrian led the way, in the wake of and alongside Russian abstractionist painters like Vassily Kandinsky (1866–1944), Natalia Goncharova (1881–1962), and Kazimir Malevich (1879–1935), in the development of abstract art in the mid-1910s. They started an artistic movement with consequences that are felt today. I pick on Mondrian in particular for the elegant and serene quality of his artworks, but particularly because he best epitomises the move away from concrete representational targets, and towards abstract forms. Besides, Mondrian was also articulate, in multiple essays in French, Dutch, and English, where he was vocal in defending the emancipation of abstract art from the constraints of figurative painting. Mondrian's "neo-plasticism" has art aim at universal abstract forms. These motifs illustrate and ground the analogy between abstract art and abstract theory.

Two preliminary caveats are in order to firstly frame this paper within the larger debate regarding scientific representation, and secondly prevent any misunderstanding regarding the normative implications of what is claimed. The first caveat is that the ideas in this paper are the result of conversations and exchanges over the years with a number of people working on scientific representation (including the editors of the volume!). One of those conversant was the late Margaret Morrison, with whom I had exchanges over the nature of Maxwell's theory. They began with the publication of a paper of mine (Suárez, 1999), where I employed a provocative analogy with abstract art to advance a controversial claim about the nature of scientific theory. I suggested that scientific models are inherently intended for a given target system, or class of target systems (real or fictional). By way of contrast, I suggested that scientific theories are not intended for any target at all – they are, to put it in the words of Piet Mondrian (1971 [1932]), just "pure form".

The claim has some virtues, not least to back up the form of instrumentalism about theories that I was developing at the time. Nevertheless, on reflection, and in response mainly to Morrison's exquisite – and exquisitely polite – critical rejoinders (Morrison, 2009; in person at a conference Madrid in 2006, and in other friendly occasions and exchanges), I came to withdraw this claim. Morrison was right to object that the apt slogan "Maxwell's theory is Maxwell's equations" is not – as I claimed in 1999 – a vindication of the targetless nature of theory. For, however abstract they may be, Maxwell's equations must surely be physically interpreted, in terms of the electric and magnetic fields that they describe. In other words, the equations only make sense as representations of some of the furniture of the physical world ("physical stuff"). We misunderstand those equations if we interpret them as a piece of pure mathematics with no physical target. This paper, many years on, is in part an attempt to do better in response. I shall continue to defend the analogy with abstract art, but on different grounds. The key does not lie in whether the uses of the products of artistic and scientific activities are non-representational, but in the process followed to arrive at them, a process of progressive abstraction from concrete material details. This process eventually confers a certain type of reference to an abstract self-standing reality. I would like to think that Margie would concur, but sadly we shall never know.

The second caveat can be expressed more briefly and is really a disclaimer. I am not claiming particular methodological virtues, nor deficiencies, on behalf of abstract as opposed to more concrete modes of representation. I claim neither that abstract theorising is superior to concrete material modelling in the sciences, nor that abstract art is more insightful, fertile, or superior to figurative or "objectivist" art. This may not be a dichotomy, nor is it needed to take sides. One can enjoy all kinds of art and all kinds of science: theoretical and experimental; abstract and concrete; figurative and plastic. In this, I do not necessarily follow the protagonists of my story, since it seems that both Maxwell and Mondrian came to see their abstract modes of representation as the naturally evolved, or more superior versions of their concrete predecessors. (Yet, they were clearly skilled at both: Mondrian was an accomplished figurative painter before he turned to abstract form, and Maxwell was a sensationally good experimenter and instrument-builder as well as a superb theoretician.) I am wary, however, of Feyerabend's cautionary tales against abstraction and his call to keep our feet firmly anchored in concrete reality (Feyerabend, 1999). The way I tell the story, however, "the abstract" is firmly rooted in a creative process that necessarily begins with the concrete.

Much of the debate in aesthetics regarding the value of abstract art is of course directed at this evaluative project, which I shall not enter. For a dispassionate observer obvious examples of excellence in all styles abound and would make any such judgement, beyond one of personal taste, rather perilous. Similar debates rage in the history and philosophy of science over the value of abstract mathematical theorising as opposed to concrete mechanical modelling. One can instead think that all approaches to artistic and scientific representation can have their merits, when suited to their purposes, and there are good reasons to appreciate and employ all of them. Since I argue that a key to their epistemic virtues and qualities as abstract products lies in their process of creation, I focus on the singular creative impulses and acts that give way to abstraction in both art and science.

The structure of the paper is as follows. Section 8.2 explains how Maxwell was led towards his unified theory of electromagnetism (Maxwell, 1873) by a process of abstraction upon the concrete models of the ether that he had previously constructed. The ensuing theoretical representation omits details regarding the mechanical action of the ether, but in doing so it achieves a much more precise representation of the abstract features of the electromagnetic field. In Section 8.3, I explore some tools from information theory in order to shed light upon this contrast between abstract and concrete in representational sources. Following previous joint work with Agnes Bolinska, I argue that abstraction in a communication channel introduces equivocation in a signal, thus decreasing its efficiency, but conveniently streamlining the description and making certain elements in the targets much more salient. This suggests that, in informational terms, the value of abstraction resides not in the *quantity* of information that it transmits, but in its *quality*. Section 8.4 addresses head on the issue of how abstractive processes can generate, or reveal, abstract entities, or abstractions. Section 8.5 explores the consequences of this *abstract minimalism* and argues that there are common features of the creative processes that lead to streamlined abstract representations in both art and science. These features answer the need to suppress detailed information regarding the concrete entities in order to then communicate salient information regarding their abstract features. The brief final sixth section throws out a couple of open questions regarding *abstract minimalism*, and the prospects for an informational analogy between art and science.

8.2 Maxwell: Analogies, Conductors, and Abstract Physical Theory

The emergence of the electromagnetic theory of light provides, I argue, an outstanding example of physical abstraction. James Clerk Maxwell (1831–1879) was a Scot, born in Edinburgh, and educated at Edinburgh's Academy and University between 1843 and 1850. At Edinburgh Maxwell was instructed in natural philosophy, including its experimental aspects (particularly regarding colours and colour vision), its mathematical practice (with an emphasis on the geometry of curves), and the more metaphysical underpinnings (concerning mainly the use of analogy and analogical thinking).[2] Maxwell's inquiries into the elasticity of solids began at around this time, and some of his earliest papers besides those on colours and curves are devoted to this topic. However, he only seems to have fully confronted Michael Faraday's experimental research on electricity and magnetism, and their mutual interactions, once he moved down to Cambridge, where he continued his studies at Trinity College from the end of 1850. Maxwell's first major paper on what we would nowadays recognise as electromagnetic phenomena "On Faraday's Lines of Force" was published in 1856. In this paper, the first in a celebrated series, Maxwell proposed to conceive of the luminiferous ether as an imaginary fluid in rotational motion. This model was openly an idealisation far from the truth, and its representation of the ether as a fluid endowed with some extraordinary properties was never countenanced seriously as a description of reality. It was purposefully a useful fiction and Maxwell at no point pretends otherwise:

> The substance here treated of must not be assumed to possess any of the properties of ordinary fluids except those of freedom of motion and resistance to compression. It is not even a hypothetical fluid which is introduced to explain actual phenomena. It is merely a collection of imaginary properties … The use of the word 'Fluid' will not lead us into error, if we remember that it denotes a purely imaginary substance.
> (Maxwell, 1856 [1890], p. 160)

The 1856 paper is the start of a process of progressive refinement in Maxwell's treatment of the ether that culminates in Maxwell's full field theoretical treatment of electric and magnetic phenomena in the *Treatise on Electricity and Magnetism* (Maxwell, 1873). However, Maxwell's theory as we know it is even a later development in the hands of "the Maxwellians", a group of physicists devoted to the development and application of the Maxwellian field theoretic conception in the 1880s and 1890s (Hunt, 1991). It was mainly Oliver Heaviside's work that paved the way to our contemporary understanding of Maxwell's theory as the set of four fundamental equations for the electromagnetic field (Hunt, 1991, p. 48), and that is the form of the theory that was eventually internationally acknowledged. This abstract mathematical theory then gained widespread worldwide acceptance with the discovery of electromagnetic waves by Heinrich Hertz in 1888, at his laboratory in Bonn. Maxwell's theory predicts the existence of electromagnetic waves and entails that light is one such wave, i.e., a mode of vibration in the "visible" spectrum of the electromagnetic field putatively conducted by the ether. (Maxwell's theory also entails that the inverse of the square root of the electrical permittivity and magnetic permeability constants in free space is identical to the speed of light *c* in vacuum.)

How did Maxwell and the Maxwellians reach such a streamlined abstract mathematical formulation of electromagnetic theory? A genealogical answer offers itself. To understand the function of an abstract representation, one needs to consider the context and the intellectual process that generates it in the first instance. At least some of the keys to an apt understanding of the abstract nature of electromagnetic theory, I claim, are to be found in a close historical study of the process that takes from Maxwell's first mechanical model of the ether as a concrete imaginary incompressible fluid with free motion to the elegant formal simplicity of Maxwell's four equations that came to encapsulate the theory. Maxwell's path to abstraction is also informed by the resources (technical and philosophical) that he had acquired at Edinburgh and elsewhere in dealing with "analogy" (an early term in Maxwell's time for what we would nowadays describe as "modelling"). The history, moreover, has been chronicled extensively (Cat, 2001; Harman, 1998; Hon and Goldstein, 2020 amongst other sources). And Maxwell's carefully collected papers and letters, edited by Niven (1890) and Harman (1990), provide a good guide to the various stages in the development of electromagnetic theory. I can only offer a very brief summary here, but the critical stages in the long march towards abstraction include Maxwell's epoch-making paper "On Lines of Force" (Maxwell, 1860 [1890]) and the paper where the electromagnetic nature of light is first announced "A Dynamical Theory of the Electromagnetic Field" (Maxwell, 1865 [1890]), besides obviously the *Treatise* itself (Maxwell, 1873).

The widespread use of analogy during the Scottish enlightenment is well documented (Davie, 1961; Harman, 1998; Olson, 1975; Suárez, 2024). Its roots are not only in Scottish common-sense philosophy but also in the abstractive practice characteristic of the "metaphysical" school of Scottish mathematics (Davie, 1961). For similar reasons, both Scottish common-sense philosophy and the Scottish school of mathematics emphasised geometry, and they showed a marked preference for geometrical over algebraic methods and reasoning. The principal textbook in the Scottish "metaphysical" school of mathematics was Robert Simson's (1756) commentary on Euclid's Elements, which went through multiple editions through the entire 19th century. In a notorious passage (Davie, 1961, pp. 132ff.; Harman, 1998, p. 21), Simson develops the concept of a surface, or a plane, by abstraction. Consider a solid geometrical object in three-dimensional space, such as a perfect rectangular-shaped block. Now perform an operation entirely in thought on this block: Divide it in two perfect halves. Compare the experience of the surface that both halves share in the initial situation with that which we would have in the imaginary situation after the division. Had the surface thickness, it would belong to either half. Yet, it cannot belong to either half, because if, in the imaginary situation, we remove that half, the surface shared would still exist in the remaining half. Therefore, by reductio, the surface has no thickness, but only length and width. It is not part of any of the halves. A surface is an *abstraction* that we only apprehend when comparing a real situation with an imaginary analogue. This key insight from the Scottish school of mathematics is carried forward by Maxwell and the British modellers in the Victorian era into their modelling practices in the empirical sciences.

Maxwell, in particular, uses abstractive methods throughout the different stages in the process of deriving electromagnetic theory. First, in "On Lines of Force" (1860), he introduces another imaginary analogue for the ether, the celebrated "vortex-and-idle-wheels" model (see Figure 8.1). The model postulates a mechanical ether, where vortices at every point in space communicate electric impulses. Yet, for the contraption to be dynamically stable, counterrotating idle wheels in between the vortices must be introduced to prevent the system of vortices to collapse out of friction. In an astonishing piece of analogical reasoning, Maxwell derives the existence of a displacement current from the motion of the idle wheels – this current appears in Maxwell's later work, even once the postulated "idle wheels" are dropped and any mechanical contraption is abandoned for the electromagnetic field. The displacement current eventually feeds into the second term in the final fourth equation in Maxwell's theory and appears as such in Maxwell's later work. When combined with physical analogies, the application of abstractive mathematical methods yields extraordinary fruits also in empirical science.

The process followed by Maxwell in his 1865 paper and 1873 book in effect abstracts from the detailed mechanical contraptions (there is not even a mention of the mechanical vortices-and-wheels model in the *Treatise*), and towards a much more general mathematical formulation in terms of formal equations for a putative electro-magnetic field. In this process, Maxwell progressively ignores or comes to overcome, rather than refuting or in any explicit way abandoning, any mechanical physical details. His conception of the ether becomes correspondingly thinner, and

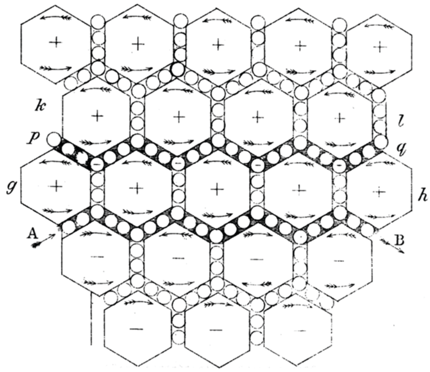

Figure 8.1 Maxwell's illustration of his 1860 vortices-and-idle-wheels mechanical model of the ether (figure 2 in Maxwell, 1860 [1890], p. 488).

by the time of the Treatise, he ceases to locate any of the physical properties of the electromagnetic field in a mechanical ether. This in fact led to some spirited critique from some of his contemporaries, most prominently Kelvin, who never countenanced Maxwell's stripping away the mechanical robes of electromagnetic phenomena (Hunt, 1991, Chapter 7; Wise and Smith, 1987). Yet, of course, the emancipation of electromagnetism from its putative mechanical foundations marched on, reaching its climax in the Einsteinian relativistic revolution. Einstein's 1905 theory of special relativity can in fact be seen as the final stage in the process of progressive abstraction away from the concrete material mechanical details that began with Maxwell in 1856.

8.3 Enter Information: Abstraction and Equivocation in a Communication Channel

Philosophers of science have tended to follow Martin Jones' leading (2005) in precisely distinguishing abstraction and idealisation in virtue of their relational properties as representations. In a representation, a source A represents some real or fictitious target B. ("A" can be a sentence, a diagram, a picture, a model, a theory, an equation, while the target "B" is the phenomenon of interest.) Then we may say that the representation *abstracts*, or is an *abstraction*, if the source omits features of the target; and it *idealises*, or is an *idealisation*, if it imputes features to the target that B does not have. Most representations can and often do both. In short, Jones' valuable lesson is that abstraction trades in omission (of truth), while idealisation trades in commission (of falsehood).

This shall prove apt for most of our purposes, and I shall adopt the definition in this section, even though there are some ways in which the definition falls short of full generality. For a start it is a definition that relies on the sharing of features or properties possessed by the source and target. It is not clear that all representations trade in property sharing, unless rather generous notions of "possess", "property", and "share" are adopted. For example, a sentence expressing a proposition represents a state of affairs, but it is hard to see what properties they share; ditto for an equation, or for a theory formulated as a set of equations, like Maxwell's theory, in the contemporary formulation. This limitation can be overcome at least in part by appealing to information theory. But it is not the only limitation. It is in addition unclear that all abstractions are representations (even in an account of representation as minimal as my own), or that abstraction is always a reference to the qualities of the source of the representation, rather than a reference to the object of the representation. As we shall see, Mondrian made a case for abstract art as the representation of abstract universal form. What matters to his sense of "abstract" is not so much the medium as the ontology of its object – and this shall be relevant to an assessment of abstraction in painting as well as science in the next section.

Let us stick fully to the conventional definition for now. A representation functions as a communication channel if and when the source serves to communicate to an agent relevant information about the target. Scientific models are often used this way: When they are properly used, there is often an informational function they serve. It is more of an open question whether art ever works in any way like this. But it is a question worth exploring, because the informational function of representations affords a good handle on how abstraction works in models. Consider the notion of a communication channel in greater detail. In Shannon's theory, a communication channel is a complex five-part entity, diagrammatically described in Figure 8.2.

Noise is introduced extraneously into the signal whenever there is a conflating source of information that mixes its signal into the original signal, or any other way adds extraneous information. Noise can be organised or random depending on the quality of the generator. It is noise regardless because it does not originate in the actual communication channel source. Since the extraneous information is not present in the source, it can mislead if the signal is taken to convey faithfully information only originating in the source. By way of contrast, a signal suffers from *equivocation* if it fails to entirely reach the destination because it is eroded, silenced, or otherwise gets lost along the way. In this case the signal that arrives is faithful but incomplete and can be grossly incomplete. (A simple example that helps to understand the concepts is an old-fashioned telephone line, where noise is contributed by the constant rumination in the background produced by

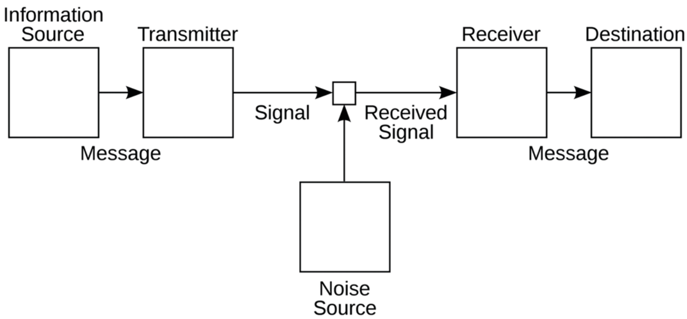

Figure 8.2 Shannon's communication channel.

Source: Adapted from Shannon (1948, p. 2).

adjacent electromagnetic sources, while equivocation is constituted by the bits of the voice that fail to be heard in anyway, thus generating silent gaps in the voice stream.) Both noise and equivocation measure the inefficiencies in a communication channel. There are ways to filter out noise and reduce equivocation, but it is ultimately a losing battle, and no communication channel is 100% efficient.

When a representation functions as a communication channel – and many scientific models do play this role at least some of the time – the information source is what we have called the target of the representation (the object concerning which we aim to gain knowledge and information), the communication channel is the representation, or model, transmitting the relevant information with certain efficiency, and the information receiver is the agent expecting to find out about the phenomenon in question by means of the representation or model. The analogy holds for scientific models when they are used as tools for surrogate inference and invites the following association. The measure of noise in the communication channel corresponds to the degree idealisation of the model, while the equivocation of the channel is equivalent to the degree of abstraction.

Recall that an idealised model incorporates false assumptions – misleading "noise" from this point of view – while an abstract model omits relevant information – hence it equivocates as a communication channel. Obviously, most models are both idealised and abstract, just as most channels contain a measure of noise and equivocation. Yet, while a model can be very inaccurate, it only fails to function as a, however rudimentary, model if it completely fails to convey any reliable knowledge about the source, either because all the information conveyed is false ("misinformation"), or because it is entirely unrelated to the target ("irrelevant").

Similarly, a communication channel is 100% noisy if the entirety of its signal is extraneous, and 100% equivocated if the signal entirely dissipates before it reaches destination – nothing is heard at the other end. In either case, there is not a bit of information that reaches the receiver that is of any relevance regarding the source.[3] From an informational point of view, then, the maximal degree of abstraction can be achieved by shutting down the communication channel, or – in the more prosaic terms that best convey the sense of artistic awe that attracts mystics and occultists (and which certainly attracted the first abstract artists) – by remaining resolutely silent.

8.4 The Abstract Products of Abstractive Processes

The first sense of abstraction as a communicative feature of representation is applicable to some aspects of both the origin of abstract art, and to Maxwell's process in his quest for a general theory of electromagnetism. Yet, the limitations are also felt in both cases, and there is another sense of "abstract" that seems apt too. If the object of an abstract representation is itself abstract, or even "the abstract", there seems to be no need to equivocate in order to communicate it. The aim would rather be a faithful representation, or perhaps simply expression, of the abstract form in itself. In the artistic case, at least, this can be a phenomenal achievement in itself, as it is guided by aesthetic values, or even a sense of the transcendental. In the scientific case, it often boils down to an expression of logical, formal, or intuitive physical coherence, sometimes referred to by "elegance", "beauty", or similar epithets.

The most intriguing questions then surround the links between both senses of abstraction. While they are clearly conceptually distinct, I would argue that in practice they often go together. The ontological sense of abstraction as the minimal, yet faithful, representation of "the abstract" is often the end result of a creative abstractive process that progressively streamlines and strips off a representation of concrete material reality. From an informational point of view, this process is driven by the goal to minimise noise in the representation of what is essential for our purposes in the description of phenomena. So as the creative process climbs up the ladder of abstraction in devising increasingly abstract representations, so does the specified target shift from the concrete material description of a phenomenon towards its abstract form. The argument is perhaps clearest in the scientific case. Maxwell develops an account of electromagnetism progressively deprived of any material details. Even if the mechanical ether is supposed to physically support and carry through the electromagnetic waves – this is an assumption to which Maxwell is always explicitly wedded, as is any 19th-century physicist – the details of how it materially incorporates the electromagnetic field are progressively cast aside. Not in a spirit of refutation or rejection, but as posits that are progressively revealed to be otiose to our understanding of the phenomena. This is the genial part in Maxwell (and later Einstein): No matter how the ether is mechanically instantiated, no matter what its actual workings are, abstraction shows that it generates the sort of electromagnetic phenomena that can be succinctly expressed by means of a few mathematical equations.

Thus, Maxwell's progression is ever towards a streamlined abstract formal representation of the functional relations between electric and magnetic fields and fluxes, which makes those material details redundant. What Maxwell searches for is an expression of the form of those relations, in terms of differential functions, a set of abstract mathematical equations that makes the material grounds and the mechanics that support the relations irrelevant. There is a mechanical ether, undoubtedly, and it materially conducts electromagnetic waves, but we can only truly apprehend the functional relations between the fields that propagate those waves. The underlying mechanical action of the ether is not for us to know or represent in any faithful detail.

For this progression towards the most abstract rendition of the phenomena, the idealisations and fictions, which are, of course, often involved in scientific models, are insufficient. Maxwell uses his concrete mechanical models of the ether (the imaginary fluid, the vortices-and-wheels contraption) as ladders towards the abstract conception of the electromagnetic field, which is his ultimate goal. The key here is not that Maxwell's theory is merely a bunch of formal mathematical equations without referent, a sort of non-representational artefact. That would be too easy, and it would not do justice to the colossal achievement. It is a physical theory, and the symbols that appear in the equations have full physical referents (***E*** truly stands for the electric field, ***B*** truly stands for the magnetic field, as ***i*** stands for the displacement current). It is rather that these physical referents are no longer concrete properties of the ether and its particular action upon moving objects – they are rather themselves abstract quantities, the physical properties of a far from concrete but most general expression of those entities that are revealed to fundamentally constitute electromagnetic phenomena. In theoretically unifying electricity and magnetism, Maxwell reveals the abstract electromagnetic field to be a self-sustaining entity, capable of its own action and dynamics, and moreover ultimately responsible for electromagnetic waves in media, and for the peculiar form of vibration in the electromagnetic field in free space that we call light.[4]

Margie Morrison saw this clearly. She opposed the thought that the slogan "Maxwell's theory is Maxwell's equations" expresses of a non-representational "flat surface", an uninterpreted formal theory. She was right. Maxwell's equations are representational, even though they are not concrete representations of the ether. They are rather representations of the abstract entities that constitute electromagnetic phenomena. The process that takes us to this height of abstraction is no ordinary model-building; it is no simple arraying of idealised or fictive models of concrete target systems. It is rather a continuous process of stripping off the material details in our representations of electromagnetic phenomena, so that the substantively explanatory relations that underlie them may be revealed. The explanatory role of an array or succession of fictive models of concrete target systems is rather limited. Both because a fictive or idealised model trades intentionally in falsehood, but also because the patchwork that is thus composed may lack coherence. The abstract models of Maxwellian electromagnetism run "deeper". Their coherence is guaranteed because they are expressed in terms of mathematical formulas. And because they are so minimal, they have wider scope, which allows them to unify disparate phenomena (Kitcher, 1981). Thus, Maxwell's theory is considerably more explanatory than a mere motley collection or patchwork of concrete models. As Morrison put it:

> Introducing a mathematical abstraction that is necessary for obtaining certain results involves a different type of activity from constructing a model you know to be false in order to see whether certain analogies or similarities with real systems can be established. To simply classify all forms of nonrealistic description as fictional runs the risk of ignoring the importantly different ways that scientific representation is linked with explanation and understanding.
>
> (Morrison, 2015, p. 90)

8.5 *Abstract Minimalism*: Maxwell Meets Mondrian

Now, to the claim that this precise move towards abstraction is also beautifully exemplified in modern abstract art, from the 1910s onwards, around the time of the epoch-making climax of Maxwellian abstraction in Einstein's theory of relativity. There is first the claim about the process, then about its product. The process of abstraction is, I have suggested, a stripping away of material detail, so as to reveal the most general relations. It is not driven by the sort of realistic concerns that would lead us to discard false assumptions in fictional or idealised models (McMullin, 1985). In abstracting, you don't strip away – or omit – what you know to be false. You rather strip away what you know to be redundant, a distraction. What remains does not have a higher probability to be true of the concrete phenomena you start with. It has rather the promise to faithfully represent the abstract form that underlies that phenomena. In other words, the product of this process is the representation of a new type of abstract entity, a pure form if you like. An entity (e.g., the electromagnetic field) unbeknownst to us beforehand, perhaps except in the vague intuition of a prospective goal of inquiry. Yet, an entity at last readily shown to be the key explanatory posits underlying the diversity of the concrete objects and phenomena that routinely present themselves to us.

The move from figurative to abstract art follows the same sequence. Thus, Mondrian repeatedly argues that "nonfigurative" or "pure plastic" art (both terms that he used at different points in his writings) results as the end point of a process of abstraction from figurative art (Mondrian, 1971 [1932], p. 153): "Figurative art of today is the outcome of figurative art of the past, and nonfigurative art is the outcome of the figurative art of today". His artistic development brings it out nicely. Consider the succession of Mondrian's increasingly abstract depictions of trees (some also discussed by Stuart and Kozlov, this volume), fully sequenced in time below.

There is no lack of rich texture throughout the sequence, but the earliest painting is clearly fuller in detail and palette (Figure 8.3). The canvas is

Figure 8.3 Piet Mondrian. *Pollarded Willows* (Silhouette d'arbres, 1902–1904), oil on canvas (URL location at Kunstmuseum: www.kunstmuseum.nl/en/collection/pollarded-willows).

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Figure 8.4 Piet Mondrian. *The Tree* (Silhouette d'arbres aux coleurs vives, ca. 1908), oil on linen (URL location at the McNay Art Museum: https://collection.mcnayart.org/objects/1905/the-tree).

fully covered in paint, and the trees are recognisable in all detail from the trunk to the branches to the leaves. By 1908 the colours stay, and the trunk and branches are about recognisable, but the leaves are a blur, and their shape has been rendered invisible (Figure 8.4). Little in the way of the landscape or the sky remains. If the sequence was regarded as faithful depiction of detail in the visual field, and both canvasses as a means to communicate such detail, it would follow that some sources of information have been diminished or switched off. There is less of a possibility of error in those details because the degree of "equivocation" has increased in the "signal" that the 1908 canvas delivers.

This progression continues as we follow the sequence of paintings. By the time we reach the rightly famous Blooming Apple Tree in 1912 (Figure 8.5), all detail concerning the three-dimensional object that is depicted has been minimised if not eradicated, and the signal's equivocation is maximal. For most of us, at first glance, at least, if not instructed by the title or knowledgeable of the sequence, any semblance of a tree is gone.

Figure 8.5 Piet Mondrian. *Flowering Apple Tree* (Pommier en fleurs, 1912), oil on canvas (URL location at the Kunstmuseum Den Haag: www.kunstmuseum.nl/en/collection/flowering-apple-tree).

We have lost all manner of detail that would permit an identification of the object. Malevich's term seems justified – the painting is properly not that of a recognisable object. It is "non-objective" in this precise sense.

Eventually, Mondrian would even dispense with some of these forms, those that are not lines, perfectly at angles, diagonally inclined initially, but eventually only straight up rectangles as in the celebrated New York series from the 1940s. The curvilinear forms, those curves that originate in the tree trunk, the twisting branches, the contours of leaves, closing upon themselves, encircling the space, will also be dismissed. Not out of any hankering after symmetry, not even that of a perfect geometry (even though "geometrical forms being so profound an abstraction of form may be regarded as neutral, and on account of their tension and the purity of their outlines they may even be preferred to other neutral forms", Mondrian, 1971 [1932], p. 153). It is rather "because the line has the function of destroying the plane as such that it will have to be straight" (Bois, 1990, p. 247–8). It is the ultimate dismissal, the final silent act in the concept of a canvas as a communication channel, that even the intimation of space in the representation must be suppressed.

However, at this point, what is lost in terms of quantity of detailed information regarding concrete reality is arguably gained in terms of the quality of the information regarding its abstract or formal nature in the visual field. Mondrian's ideal of "pure plastic art" induces a process to progressively trade off concrete informativeness for the sake of greater abstractive power. Mondrian certainly travelled further towards this goal and up the road of abstraction, entirely away from trees, starting in 1913. Three of his paintings exemplify this transition.[5] The first (*Arbre I (Tree A)*, 1913) is one of Mondrian's last explicit depictions of trees, now uprooted and displaced from the horizontal line that is natural to a terrain – thus, even gravity becomes immaterial. The second (*Compositie I (Arbre)*, 1913) is one of his first "compositions", yet still also, simultaneously, we are told, the depiction of a tree. The third one ("*Compositie IV (Composition IV)*", 1914), painted just a few months later, is the first pure "composition", clearly still within the same sequence of abstraction, but about which Mondrian no longer cares to refer to as a tree in any way or form. It is therefore simply entitled "Composition II". At that point the object or type of object that originated the sequence is finally entirely done with. We are left only with the abstract pure form, and the question "is *Compositie II* a representation of a tree?" becomes irrelevant (Janssen and Joosten, 2002, pp. 195–7). Why deny it that it is? But what is the point of stating it?

Just as Maxwell dispenses with the need to represent the mechanical trappings of the ether, or the electromagnetic field, so does Mondrian become unconcerned with the material stratum of trees – pursuant now only to the formal representation of the absolute form of their nature, or "the universal", as he called it (Mondrian, 1987, p. 42). *Compositie II* remains a representation, in a minimal sense, but its target object has been transformed. It is no longer a representation of any concrete material object, but only of the pure forms of matter, which have emancipated themselves from their material recipients. Mondrian would carry the project of progressive abstraction to its ultimate consequences during the 1920s, perhaps his greatest decade, when he produced his best known paintings (Golding, 2000, p. 40): "By now he had evolved a formal vocabulary of total clarity. Each of the compositional types that had been created within the rigours of his Neo-plastic principles had been honed down and refined to its simplest expression".

A process of abstraction that begins as the progressive omission of material details (the informational equivalent of an increasingly streamlined but minimally informative signal) eventually gives way to the clearest and most faithful rendition of an abstract reality behind the appearances. This is reminiscent of mystical enlightenment, and indeed Kandinsky, Malevich, and Mondrian were all deeply wedded to occultism and theosophy. Mondrian, in particular, joined the Theosophical Society of Holland in 1909 and attended some of Rudolf Steiner's lectures there in the years 1909–1913, coinciding with his decisive shift towards abstraction.[6] What Mondrian found useful in theosophy is disputed – not least because theosophy itself, while very popular at the turn of the century, eventually became discredited. In his celebrated essay "The Iconoclast", Bois argues that theosophy for Mondrian is "a kind of Darwinism (crossed with a hint of Buddhism on the question of reincarnation); Mondrian views his pictorial work as oriented toward a final revelation, as a constant progress toward the pure unveiling of the 'universal'" (Bois et al., 1994, p. 329.). In other words, I would argue, a creative process whereby the abstract progressively emerges out of the concrete.

There are interesting similarities in how Maxwell viewed his science in light of his own lifelong religious commitment (Harman, 1998; Hon and Goldstein, 2020), but let us leave them aside for a more pressing historical connection. From 1913 onwards Mondrian no longer aims to represent material reality as it presents itself to us but hankers instead after the universal forms that lie "behind" matter: "We must see *through* nature. We must see deeper, see *abstractly* and above all *universally*" (Mondrian, 1987, p. 88). At this point precisely, Mondrian's palette moves from grey to white, while the dark contours become straight black lines and an object of the representation itself. In achieving the "flatness" that characterises the *De Stijl* movement that Mondrian embraced and joined towards the end of World War I (Henderson, 2013, pp. 453–90; Seuphor, 1956, pp. 137–50), Mondrian – just like Kandinsky had done beforehand – also reached towards the ether that permeates space. The invisible and ubiquitous ether in popular science as well as theosophy at the time (Henderson, 2002, 2020) is pure white, since translucent, and it is universally understood to be the carrier of Maxwellian electromagnetic radiation. The reality of Maxwellian waves had become indisputable after Hertz's 1888 experimental detection, and Roentgen's discovery of X-rays in 1895.[7] Our two protagonists finally meet here, at the invisible but all permeating ether:

> Between the physical and the ethereal spheres, there is a boundary, clearly delimited for our senses; yet the ether penetrates the physical sphere and acts upon it [...] In order to approach the spiritual in art, one employs reality as little as possible because reality is the polar opposite of the spiritual.
>
> (Mondrian, quoted in Henderson, 2020)

8.6 Concluding Prospects

Abstraction is not merely a mode of representation but a creative process (Sánchez Dorado, this volume). What process is it? I have suggested that it often is one that starts as the progressive omission of material detail in a representation of the appearances, in order to arrive at a more faithful representation of an abstract reality behind the appearances. This is the process of Maxwell's progressive "unveiling" of the true nature of the electromagnetic field, and Mondrian's "ascension" towards abstract universal form. Two questions then present themselves and would call for further study. The first concerns explanatory power and is particularly salient in the scientific cases. How does abstraction inform us about the material reality that it leaves behind? How exactly does the postulation of an electromagnetic field explain our experiences of magnetic and electrical phenomena, such as induction? Clearly it does, and we know precisely how Maxwell's equations can be put to use in the description of any sort of electromagnetic phenomena, by identifying the relevant variables in the equations with quantities we are in a position to measure experimentally. But how must the abstract relate to the concrete so as to make such uses possible? This is a philosophical question regarding the ontological relation of the abstract to the concrete, regardless of the methodological applications. Cartwright and Mendell (1984) precisely suggest linking the abstract/concrete distinction to the nesting of explanatory factors, which is intriguing but may seem circular as an account of how the abstract can explain.

The second question concerns the limits of the application of communication theory to abstract representation. This one becomes most poignant in the artistic cases. Kandinsky and Mondrian, but particularly Malevich, and later on Rothko, all expressed a sense of awe at pure form – a sort of mystical exaltation of the ineffable. This insight for sure does not seem amenable to a description in terms of Shannon's communication theory. So, what communication can there be, after all communication channels break down? What sort of information, non-quantifiable yet relevant to our actual existence in the actual world lies beyond the reach of a communicable signal? However ineffable, even if pure plastic form is ultimately an unreachable goal, an end that we can merely gesture at, even in art, it would be good to have some sense of what that end is and why it remains of such great value to us.

Acknowledgements

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Notes

1 This requires qualification in the case of Richard Wollheim, whose account of representation as "seeing-in" makes room for non-denotative paintings to represent, and for whom much contemporary abstract art is undoubtedly representational (see Suárez, 2004, p. 777, which also refers to Rothko's

paintings, about which Wollheim himself gave extraordinary renditions of his own phenomenological experience). Nevertheless, when seeing-in into a canvas is impossible (and Mondrian's paintings approach that extreme end), representation is also as a result not available. See Caldarola (this volume), and Suárez (2024, chapter 8), for further discussion of Wollheim's phenomenological approach.

2 See Olson (1975) and Harman (1998) for Maxwell's background in the Scottish liberal educational system and common-sense philosophy.

3 See Suárez and Bolinska (2021) for the details. Incidentally, Kandinsky was openly of the view that his art was genuinely a communication channel, where he played the role of "sender" and the audience was the "receiver" (Henderson, 2020).

4 Maxwell was no social constructivist though. Instead, he often expressed the thought that the electromagnetic field was always there, behind the veil of the concrete material detail of the mechanics of the ether, awaiting to be revealed.

5 They can be viewed at hyperlinks as follows. "Arbre I (Tree A, 1913)": www.tate.org.uk/art/artworks/mondrian-the-tree-a-t02211. "Compositie I (Arbre, 1913)". www.fondationbeyeler.ch/en/beyeler-collection/work?tx_wmdbbasefbey_pi5%5Bartwork%5D=102&cHash=4cbd97ff48cffa837b0330cb04c1d4b7. "Compositie IV (Composition IV, 1914)": www.kunstmuseum.nl/en/collection/composition-no-iv-composition-no-iv-composition-6

6 Henderson (2013, 2020) is excellent on the role of theosophy in the development of abstract art, specifically in connection with Kandinsky, Malevich, and Mondrian. For Mondrian's membership of the Theosophical Society of Holland – and his reverence for Madam Blavatsky and her writings –, see Seuphor (1956). This provides evidence that Mondrian remained attached to theosophy throughout his life, even though very discreetly, since it "was absorbed (after 1916) by Neo-Plasticism, which for him was to be capable or expressing everything *without words*" (Seuphor, 1956, p. 56, my italics). For the profound catalytic role that mysticism played in Mondrian's "ascension" to abstraction, particularly in the 1908–1913 years, see Milner (1992, pp. 45–87).

7 The invisible ether was moreover understood widely at the time – in popular scientific culture as well as theosophy – to reside in a higher four-dimensional space of which our three-dimensional Euclidean space was only a projection. (For the extraordinary currency and impact of the fourth [spatial] dimension in the emergence of abstract art, see Henderson, 2002, 2013, 2020.)

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9 Abstraction as Material Translation

An Artistic Reflection of (Re)Presentation

Tarja Knuuttila, Hanna Johansson, and Natalia Carrillo

9.1 Scientific Representation Analysed by Artistic Means?

Abstraction is a central concept in many fields. In art, abstraction can mean different things, from non-figurativeness of works of art to "processes of image-making in which only some of the visual elements usually ascribed to 'the natural world' are extracted" (Goodman 2003). In current philosophy of science discussions, abstraction in science is frequently approached as omission[1]—i.e., "abstracting away" from concrete details of the object or the system of interest. We are interested in the counterintuitive claim that abstraction in science involves concreteness, being not only *subtractive*, as the notion of abstraction as omission suggests, but also *enriching*. Instead of thinking about abstraction as a reductive operation doing away with concreteness, we study the translations, transformations, and displacements across different *material* realisations that facilitate abstraction.[2] Through the use of different representational and experimental artefacts, material translations enable scientists to arrive at abstractions. As such abstractions usually do not display the underlying material and semiotic work, they are prone to "epistemological horrors", as Steve Woolgar has provocatively put it. Lacking access to the concealed scientific work, it becomes challenging to understand how abstract representations relate to the concrete realities they supposedly represent or derive from.

To examine and illustrate the displacements and translation that takes place in scientific abstraction, we juxtapose the artwork of Finnish artist Lauri Anttila, *Homage to Werner Holmberg* (1985–1986), to Bruno Latour and Michael Lynch's work on scientific representation. *Homage to Werner Holmberg* provides a provocative reflection of scientific representation, in that the work appears to parody the scientific method in seeking to render the landscapes in the paintings of Werner Holmberg, a renowned Finnish landscape artist from the 19th century, with scientific instruments. Through its artistic use of scientific methods, this work addresses scientific representation in the very same spirit as constructivist science studies—even partly preceding the publication of these texts (e.g., Lynch & Woolgar 1990). Indeed, Anttila has said about his work:

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> I have intentionally wanted to submit the concept of scientific certainty to ironic scrutiny. To set the notions of exactness, of the purity of science, in the framework where coincidence, as part of the whole, imparts the spirit and exposes the method only as a method, not as the truth.
>
> (Anttila 1989, 103)

Likewise, constructivist sociologists of science have explicitly challenged the idea of science as searching for *the* truth, whose products would correspond to real objects as accurately as possible. The parallels and affinities of Anttila's artistic analysis of scientific representation and Bruno Latour's (1995) philosophical report on his fieldwork in the Amazon are striking. Crucial for the processes of abstraction that both Anttila and Latour study are the technologies and media used to translate a local object through a series of displacements into an abstract object of knowledge. These translations render a tentative object into quite another kind of material realisation, which, through its more generic nature, is conducive to further conceptual and theoretical development.

9.2 Werner Holmberg and Lauri Anttila

Lauri Anttila (1938–2022) was interested in the differences and similarities between scientific and artistic perception, being also a lifelong member of The Finnish Astronomical Society. Many of Lauri Anttila's works point to scientific activities and make use of scientific instruments in diverse ways. An excellent example of such border crossings is *Homage to Werner Holmberg* (Kunnianosoitus Holmbergille), which is regarded as one of his main works. *Homage to Werner Holmberg* is a showcase that embarks on a dialogue with the natural sciences. It combines themes, methods, and media familiar to Anttila. As the title of the work indicates, it is simultaneously a tribute to the Finnish painter, Werner Holmberg (1830–1860). Anttila has said that Holmberg led him to "look at painting with totally different eyes" (Anttila 2002, 30). Travelling in Holmbergian landscapes in Finland led him to an understanding that Holmberg's paintings are not "products of pure imagination and tradition", but that there was something concrete behind them (ibid).

Werner Holmberg has been regarded as a romantic landscape painter, but, in his production, idealistic landscapes started to give way to more realistic features that become more and more recognisable therein. It has been claimed that Holmberg, in his last paintings and sketches, anticipated the aims of painting outdoors like Constable in England and Corot in France (see, e.g., Reitala 1986, 83–84, 95; Thomas 2002). Holmberg

Figure 9.1 Lauri Anttila, *Homage to Werner Holmberg (Kunnianosoitus Werner Holmbergille)*, 1985–86, installation, black-and-white photograph, colour photograph, drawing, text, books, dried plants, diary, 114.0 × 441.0 cm, Finnish National Gallery/Ateneum Art Museum. Photo: Finnish National Gallery/Jukka Romu. Reuse not permitted.

never totally gave up composing a painting from various landscape elements; his oil paintings were made indoors using sketches, and they have features from German, Norwegian, and Finnish landscapes. In the works he painted in his last years, however, one can note a clear attempt to communicate an "authentic" experience in nature. In addition to conveying the sense of "place", works such as *Mail Road in Häme* (*Postitie Hämeessä*, 1860, Figure 9.2) or *Cottage in Kuru* (*Talonpoikaistalo Kurussa*, 1860, Figure 9.3) impart feelings about nature, such as air full of dust or humidity from the rain. Such sensory perceptions are prominent in Holmberg's sketches and especially in the watercolours he painted while out in nature. They give more direct glimpses into the paths and places where Holmberg hiked as well as into their weather and vegetation than do his oil paintings. In his sketches, we can see Holmberg's attempt to depict nature based on observation and experience.[3]

The showcase, *Homage to Werner Holmberg* (1985–1986), is based on the material Anttila collected on his treks in Finland from 1985 to 1986. The main impetus for these treks was to use Holmberg's diaries and follow along the routes he took in the central parts of Finland during his last

Figure 9.1 (continued)

summer. In a piece of writing that is part of the work and sheds light on its background, Anttila writes,

> Werner Holmberg was the first real Finnish landscape artist [...]. I have tried to find out about the factors, the so-called structure of the land, where those works were born. I have explored the places where the sketches were made by walking there and attempted to follow the dates of the sketches. This I have done so as to find out what concrete things the works entail—how one could experience those landscapes today, what sets Holmberg's "pictures" apart from what I experience.

Anttila's reference to how one would experience Holmbergian landscapes today targets the connections between arts and science. Writing about this work over 15 years later, Anttila mentions, "To me, that scientific point of view was important. When I understood the time Holmberg had lived in, I wanted to show how the Holmbergian experience in nature could be expressed using the means at our disposal today" (Anttila 2002, 30). For Anttila, scientific instruments and the scientific method provided a contemporary way of reviving Holmberg's landscapes. In addition to (often serialised) photos, he makes use of other recording and reproduction technologies ranging from a tape recorder to keeping a diary to collecting plants and rocks. Additionally, the work makes use of different

Figure 9.2 Werner Holmberg, *Mail Road in Häme* (*Postitie Hämeessä*), 1860, oil on canvas, 40.0 × 58.0 cm, Victoria Laurell Bequest, Finnish National Gallery/Ateneum Art Museum. Photo: Finnish National Gallery/Jenni Nurminen.

kinds of technological devices to measure and convey the phenomena in the surroundings: a thermometer, a watch, and a compass.[4]

The work refers at multiple levels to Werner Holmberg's works. Fragmentation is one of those features. Just as is the case with Holmberg's seemingly vivid and integrated landscapes, Anttila's work, too, is composed of parts found at sundry places, referring to the Holmbergian landscapes. In the middle of the showcase, we can see the actual *Homage to Werner Holmberg* section (see Figure 9.4). The fragments in that section were collected on the excursions where Anttila walked following Holmberg's footsteps in Kuru, Ruovesi, and Leppälahti 126 years after Holmberg had been there. These sections of the work include a three-part "watercolour" that was completed by Anttila on 18 July 1985, and which was based on Holmberg's work *18 July 59*.

Below Anttila's watercolour are two pictures showing its origin, namely the watercolour Holmberg painted in Leppälahti. On the left we see the entire work, whereas the picture on the right is a detail depicting the

Figure 9.3 Werner Holmberg, *Cottage in Kuru* (*Talonpoikaistalo Kurussa*), 1859, oil on canvas, 71.7 × 116.0 cm, Finnish National Gallery/Ateneum Art Museum. Photo: Finnish National Gallery/Antti Kuivalainen.

vegetation on the shore. The close-up draws our attention to the plants around Anttila's "watercolour"; this parallel shows that the same species of vegetation are still there. Below these is a photo of the inventory slip from Holmberg's sketchbook for the 19–24 July 1859 expedition, and, next to it, we see Anttila's journal from his *Homage to Werner Holmberg* expeditions. Included in the work is also a cassette tape, which has a recording of the expedition to the Leppälahti croft on 18 of July, and "silence" in Kovero on 19 July 1985, as well as a description of the work written by Anttila. In the middle of the showcase, as if in the place where Jesus would be in Christian iconography, Anttila has placed a colour photo, which was taken in Kuru just as the birch was dropping its leaves on the 125th anniversary of Holmberg's untimely death on 24 September 1985.

The *Grove (Lehto)* section on the right-hand side (and the lower middle part) of the work was made from materials and photos of a grove in Hangonkylä in December 1985 (Figures 9.4 and 9.5). In addition to the series of photographs depicting a compass and a thermometer in nature, we also see desiccated plant samples, drawings of them, as well as photos of the plants as seen through a magnifying glass. Below the plant samples, there is a

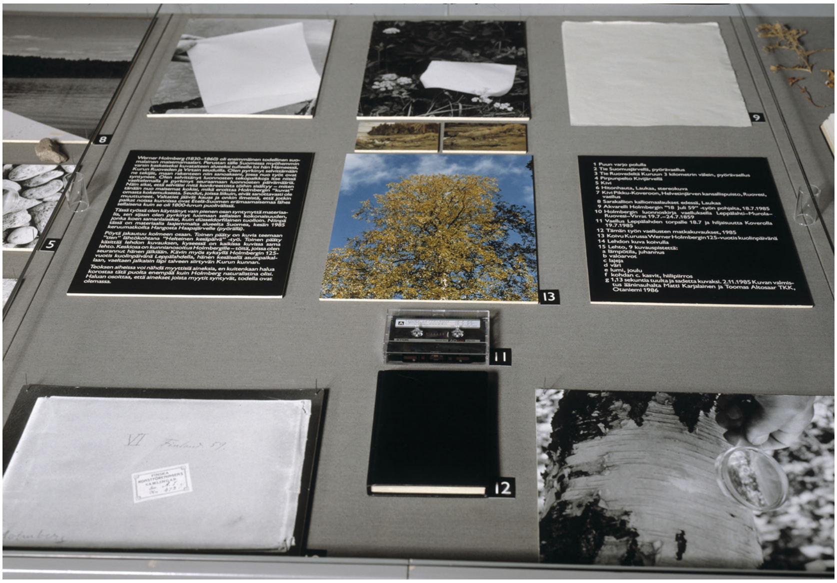

Figure 9.4 Lauri Anttila, *Homage to Werner Holmberg (Kunnianosoitus Werner Holmbergille)*, 1985–86, installation, black-and white photograph, colour photograph, drawing, text, books, dried plants, diary, 114.0 × 441.0 cm, Finnish National Gallery/Ateneum Art Museum. Photo: Finnish National Gallery/Jukka Romu. Reuse not permitted.

Munsell colour atlas opened to the green color chart, and below that a black and white photo of the same page of the colour chart placed in nature, in the middle of the plants. This section also includes the fragment, *Rain in the Grove on 2 November 1985 (Sade lehdossa 2.11.1985)*, which is made up of an audiogram produced by a computer and, above that, another cassette tape that contains the audio material the audiogram depicts. Additionally, the *Grove* section to the left of the diary includes a photo that shows the artist's hand holding a magnifying glass in front of the trunk of a birch tree, the magnifying glass reflecting the image of the grove (for a better rendition, see the lower righthand side of Figure 9.4).

Holmberg's painting, *Road in Häme (A Hot Summer Day) (Maantie Hämeessä [Helteinen kesäpäivä])*, has inspired the *Road (Tie)* section of the work on the left, although the painting draws from several places, viz., Kuru and Ruovesi as well as Suomusjärvi and Laukaa (Figure 9.6). In this *Road* section, Anttila has depicted the terrain he covered during his expedition: its inclines and declines with photos of a clock at different intervals along the span of three kilometres displayed side-by-side with

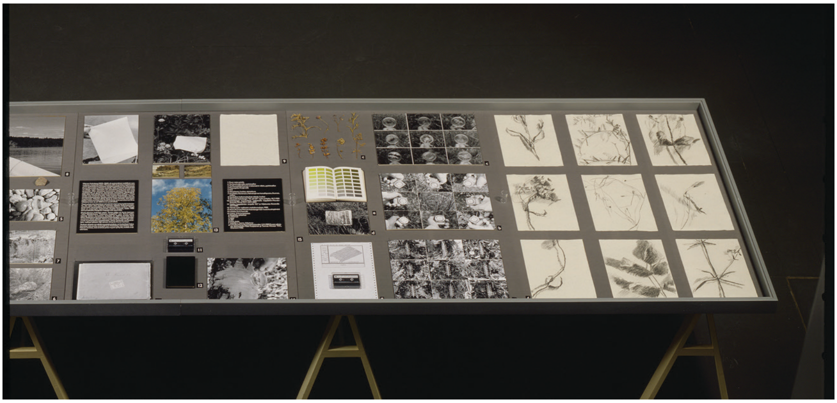

Figure 9.5 Lauri Anttila, *Homage to Werner Holmberg (Kunnianosoitus Werner Holmbergille)*, 1985–86, installation, black-and-white photograph, colour photograph, drawing, text, books, dried plants, diary, 114.0 × 441.0 cm, Finnish National Gallery/Ateneum Art Museum. Photo: Finnish National Gallery/Jukka Romu. Reuse not permitted.

the photos of the surface of the Kuru–Ruovesi road, also at intervals over three kilometres. Holmberg painted *Road in Häme (Maantie Hämeessä)* and *Mail Road in Häme (Postitie Hämeessä)* right after his last trip to Finland (he lived in Düsseldorf at the time). Next to the photos, we see pebbles that Anttila brought from his journey, which he placed next to the photos in the showcase. On the left in the *Road* section, there is, furthermore, a collage of five photos *The Shadow of a Tree (Puun varjo)* which, too, refers to the Holmbergian paintings; in particular, to the painting *Mail Road in Häme (Postitie Hämeessä)* (Figure 9.2), in which the trees cast their dark shadows onto the road.

We should note that Anttila's work has two chronological references. On one hand, the work follows Holmberg's routes and the places he visited in the Kuru and Ruovesi regions in the summer of 1859, which he depicted during his journey. Anttila sought to use various instruments to reproduce features typical of Holmbergian "outdoor" depictions: their sensitiveness to colours, the brightness of light, the humidity of the air and rain, and the material characteristics of the landscape. As Anttila put it himself, the work attempts to find contact with the concrete landscapes of Holmberg's paintings. "How did it feel to move in them; how did it sound?" (Anttila 2002, 31). On the other hand, Anttila recorded or traced his own experiences, observations, and impressions of the very landscape and nature where he walked during his journey—and tried to communicate them to the beholder the way they were, through various instruments

Figure 9.6 Lauri Anttila, *Homage to Werner Holmberg (Kunnianosoitus Werner Holmbergille)*, 1985–86, installation, black-and-white photograph, colour photograph, drawing, text, books, dried plants, diary, 114.0 × 441.0 cm, Finnish National Gallery/Ateneum Art Museum. Photo: Finnish National Gallery/Jukka Romu. Reuse not permitted.

and measurements. Thus, these sections in Anttila's work refer also to his own personal journey: the weather he experienced, the route that he travelled, and the changes in nature he witnessed during the journey.

These two chronological "levels" become conflated and carry on a constant dialogue in the various sections of the work. Regardless of which chronological "origin" we pay attention to, we, as beholders, are given one work: a showcase, which as an object in and of itself, concretely conveys both a scientific and an artistic approach. On one hand, it refers to the scientific collections and showcases in museums with their specimens and corresponding descriptive slips that explain what the specimens are.

On the other hand, it imitates—at a symbolic level—the table in Leonardo da Vinci's painting *The Last Supper*, which connects to Holmberg in an interesting way. A reproduction of Leonardo's painting was already on display in the Kuru church in the days when Holmberg lived; we can assume that Holmberg saw the painting as many of his works depict the Kuru church (see Anttila 2002, 31).

Thus, *Homage to Werner Holmberg* simultaneously attempts to depict the reality of both Holmberg's paintings and the reality of Holmberg and Anttila's journeys by showing the "objects" using different instruments and media. However, the various recording devices and other instruments and renderings Anttila used translate the Holmbergian landscapes and their sensuous qualities into new and more fragmented and abstract forms, making them amenable to scientific observation.

9.3 In Pursuit of a Scientific "Picture"

Anttila's goal of exploring the assumed certainty of science through his art resonates in an interesting way with the discussions on scientific representation from the last decades. These discussions, both within the fields of philosophy of science and science and technology studies, have challenged the assumption that science should represent its objects truthfully, casting doubt on the very idea of accurate representation. This questioning of representation has either radically forsaken the whole notion of representation or embraced a new, heretofore more pragmatic notion of representation. What has been typical of the representational legacy of philosophy of science is the assumption that knowledge consists of a collection of representations that more or less truthfully depict their outside reality. This requirement for truthfulness has often been understood in terms of a correspondence that raises the problem of how external representations in science (e.g., mathematical models, diagrams and pictures produced through the use of different instruments) can be compared to external states of affairs, beings, and processes—in other words, to reality.

As the title of Richard Rorty's famous criticism of representation, *Philosophy and the Mirror of Nature* (1980) insinuates, the idea of internal or external representations standing for and accurately depicting their real objects taps into phenomena like seeing and mirroring. John Dewey wrote about such "spectator theory" of knowledge as follows:

> The theory of knowing is modelled after what was supposed to take place in the act of vision. The object refracts light to the eye and is seen; it makes a difference to the eye and to the person having an optical apparatus, but none to the thing seen.
>
> (Dewey 1984, 19)

Such representationalist realism assumes that scientific representations could somehow reach the external world in the same way as our vision catches the objects in our field of vision, which means that our vision offers a model for knowledge. No wonder scientific representation is often approached through the metaphors of picturing, or mapping, that is, through various kinds of iconic signs, as well as the assumed structural or other kinds of similarities between scientific representations and real-world objects and systems (for critique, see Suárez 2003; Frigg 2006; Knuuttila 2005, 2011). The visual metaphors through which knowledge has been approached make a realistic (or, seemingly realistic) landscape painting an apt case for the study of scientific representation through artistic means.

The first thing to note when viewing Anttila's work, *Homage to Werner Holmberg*, as a study of scientific representation is the way it approaches the production of knowledge through the use of fragments and various media. The work dissolves a unified realistic picture or, rather, an illusion of it, into various renderings produced through different media. As we view Holmberg's works which serve as the starting point for Anttila's work, we see a uniform landscape that seems to reproduce an identifiable place at a certain time. Strictly speaking, no such landscape exists. As pointed out above, a great majority of Holmberg's paintings were put together from fragments following the conventions of the landscape painting of his times. For instance, a particular tree appears in many of his works, although the paintings appear to depict a certain identifiable landscape (and are named accordingly).

On the other hand, the individual fragments in Anttila's work, such as sketches of desiccated plants, directly refer to this process of assembly. The plants are detached from their habitat, drawn, and photographed, after which they are positioned as parts of the total work (Figure 9.5). Our attention is also drawn to the way Anttila's work employs the photograph; despite being a tribute to the *landscape painter,* the work refers to *scientific representation* through its fragments. Moreover, while the work displays technological instruments used in scientific research, it also comments on the scientific method by grouping, picturing, and serialising specimens, pictures, and drawings in different ways (Figures 9.5 and 9.6). The extensive use of the photograph in the work would seem to refer not only to the new media that arts increasingly employ, but also to the aims of science. A photo as an index-like sign, produced by a machine, is supposed to be in more direct contact with reality than a painting in its icon-like form created by an artist. Consequently, a photograph appears to refer to the ability of a scientific representation to depict reality in a more objective fashion than a painting.

It is fascinating to compare Anttila's work with constructivist science studies on scientific representation, which coincided with Anttila's work.

Constructivist science studies have attempted to show how scientific representations and results should be related to their social surroundings and technological media, being rich repositories of social actions. In doing so, it has challenged the traditional view of science as an endeavour that seeks to depict the world truthfully, or accurately. In what follows, we will put Anttila's work in dialogue with Bruno Latour's anthropological-philosophical essay, *The Pédofil of Boa Vista: A Photo-Philosophical Montage* (1995), with particular attention on the material processes of abstraction through which scientific representations are achieved.[5]

9.4 Latour in the Amazon

The French anthropologist and philosopher Bruno Latour has made expeditions to the sites of scientific work, both to laboratories and the "field"—comparable to the way that Anttila followed Holmberg's paths. Latour's article, *The Pédofil of Boa Vista: A Photo-Philosophical Montage* (1995), describes Latour's journey to the outskirts of the Amazonian rainforest with an interdisciplinary team of scientists. The trip led the scientists to write an article addressing the phenomenon of rainforest being turned into a savannah. Where Anttila follows Holmberg's alleged footsteps, Latour travels along with the scientists whose work he is studying. Like Anttila, Latour gives his own description of his objects' work and "origin", attending to the different media used.

Latour's explicit target is the representationalist idea that scientific illustrations in journal articles would be reproductions of some real objects through some relation of similarity. Latour had attacked this notion already in his earlier writings claiming that, in reading a scientific article, one easily forgets that their illustrations and diagrams are, in fact, the result of complex material and instrumental processes (e.g., Latour & Woolgar 1986 [1979]). Latour's photos of the group's work, which the text (philosophically) comments on, describe this very process: the natural object is turned, through a series of material and instrumental translations, into a successively more abstract phenomenon. In seeking to grasp the process through which scientific representations refer to their alleged objects, the real world, Latour uses the concept of *inscription*.

An inscription is any sign, for instance, a picture, a diagram, or a mathematical symbol, and an *inscription device* is any device or instrument that can transform material substances into signs. Prior to the start of the scientific exploration Latour joined in, complex inscriptions were already required. Among those inscriptions were maps of different kinds, through which the scientists can acquaint themselves with the place to be explored and even find their way there. The purpose of inscriptions is to mould the object, in this case, the outskirts of the rainforest, into a form more susceptible to knowing. Such processes of translation, utilising different inscription systems and instruments, have been analysed by ethnomethodologist Michael Lynch as mathematisation (e.g., Lynch 1985b, 1988). Lynch's analysis is influenced by Husserl's notion of *mathematisation* (Husserl 1970), but while mathematisation for Husserl describes the historical movement through which experience and proto-science transform into science, Lynch approaches mathematisation as those everyday procedures whereby a specimen, creature, or process is carefully prepared into an object of scientific analysis. From the perspective of Latour and Lynch, mathematisation is essentially a process of *abstraction through material translation*. To even embark on an exploration of a rainforest, for example, scientists need to place a coordinate grid over it by placing markers in a delimited area at regular intervals. This artificial Euclidian space makes it possible to register phenomena using a series of numbers assigned to the markers. In these series of acts, scientists start to transform the forest into a kind of laboratory, Latour observes.

What we call material translation is not reducible to a (potentially reversible) symbol-to-property mapping. If we were to view it as such, we would fail to appreciate the cognitive grounding of such abstractions. Moreover, as cognitive scientist David Landy (2006) shows, the abstractions involved in the transformation of a problem into a different material realisation are not about the "stripping" of properties, but about the "replacing" of features. According to Landy, by finding a new way to express a situation, one attains a different roster of affordances with new features—these new features may be useful in identifying patterns that were previously occluded and can also trigger different cognitive perceptions that could be helpful. Consequently, "abstraction is not (as the myth would have it) about removing features to isolate relations; instead, it's about managing features to get relational work done" (Landy 2006). The material enrichment taking place in abstractive translation enables the exploitation of the affordances of different material realisations. The point is that distinct material translations enable different kinds of sensorimotor (concrete) engagements that support different reasoning processes. In contrast, structural mapping assumes that the relevant properties and symbols are already available for scientists simply to map onto each other. In our view, the various kinds of material translations can be taken to *constitute* the process of abstraction. As Landy succinctly put it: "every abstraction is a concreteness somewhere else".

Science and technology studies have addressed the multitude of devices that configure, regulate, and institutionalise material translations that are crucial for abstraction. Scientific laboratories as habitats for the construction of facts and manifold representations have especially intrigued constructivist science studies (Latour and Woolgar 1986 [1979]). At the end of the 1970s and in the early 1980s, a number of so-called laboratory studies[6] appeared in science and technology studies with their published goal of "[d]irect observation of the *actual site of scientific work* (frequently the scientific laboratory) in order to examine how objects of knowledge are constituted in science" (Knorr-Cetina 1983, 117).[7] Later on, *the laboratory* became extended into a general concept covering those manifold instrumental-theoretical practices typical of scientific work, through which heterogeneous materials and socio-cultural elements are worked into fixed and stable facts and phenomena.[8]

Studying the process of rendering a field site into a laboratory, Latour traced the chain of inscriptions and instruments, which led from the rainforest to a diagram in the article published by the scientists. Plants were collected and dried, the soil was opened up to get soil samples, and the layers in the terrain were measured and analysed with different instruments. One of these instruments is Topofil Chaix, a device Brazilian scientists perversely call *pedofil*, which uses a running string to measure how far a scientist has walked. The same string can also bring a scientist who has perchance gone astray in the forest back to where he started from. This string provides Latour an apt metaphor for the chain of inscriptions that offers an answer to the traditional problem of representation: how is it possible that one entity (a diagram in a scientific publication) can represent a totally different entity (the Amazonian forest)? The diagram representing the forest is not similar to it, but the chain of inscriptions through which the diagram was created connects it with a particular part of the forest.

At one end of the chain is the forest; at the other end, the diagram on paper. In between are the measuring instruments and the different classifications through which the specimens and their properties are coded with different numbers and words. Inscriptions are created, arranged, and combined until the scientists finally arrive at a diagram, an abstract rendering of its object—the Amazonian terrain at the crossroads of the savannah and the rainforest—and are able to answer the question of which one is taking over the other.[9]

As can be observed from the two very different ends of the chain, it is the sequential translation of material realisations one unto another that best characterises the reference carried over. This chain of material translations can be understood as a process of abstraction in which the features of the object of interest (the ecological balance of the Amazonian rainforest) are literally re-presented in various material ways, each offering different affordances and enabling other translations. The soil samples are first analysed by rubbing them between palms and then describing their composition, after which they are coded using the Munsell colour chart. The Munsell code assigns the soil samples a number in accordance with their colour. After this, the soil samples are no longer needed, the soil has turned into signs, which can be transported on a piece of paper, losing the dirty hands, the heavy containers, and the confounding elements around the soil like plants and animals. What is more, the Munsell code allows for a standard comparison with other terrains.

At each step in the inscription chain, something of the elements is lost, but at the same time, they become renewed. Such renovation enables generalisations and connections that were not available in the original material realisation. The chain of inscriptions is a continuum that makes an ostensibly complex and opaque object into one known by a certain branch of science. In the transformation of the soil into numbers and other signs, a transfer takes place from natural objects into different documents and representations through subscription, experimentation, sampling, and substitution. This abstraction process generated through various inscriptions leans on the heterogeneous historical strata of other scientific disciplines, different instruments, languages, and practices. In this way, any scientific, artistic, or technological object always refers to the different times and places where the technological and other innovations were made that enabled its invention.[10]

As we have argued, the process Latour describes can be approached as an abstraction process. However, abstraction as translation is not reducible to the common notions of abstraction as omission, nor is abstractness opposed to concreteness in any simple way. Even though only a translated portion of the original situation is kept, it allows us to literally hold the transfer of the forest and the savannah in our hands. This abstract concreteness, we maintain, is characteristic of scientific work. With the help of combinability and comparability facilitated by concrete chains of inscriptions, we can get an overview-like understanding of the situation and manage it. The affordances of the different inscriptions and material realisations endow scientists with different sets of abilities, enabling them to take advantage of different affordances. These translations are also easier to move to other locations and scientific contexts—for instance, taking along the coded forest from the Amazon to Paris.

In the case examined by Latour, something of the original remains in the form of samples. The botanist in the group of scientists collected plants which serve as evidence. In the plants, we can see two features typical of scientific reference: on the one hand, an economic shortcut whereby we allow one individual to (metonymically) represent the others and, on the other hand, a grounding for the claims made. We can return to these dried plants, and they can be studied to justify scientific claims. One typical place where these kinds of specimens end up is a showcase. Indeed, the showcase of *Homage to Werner Holmberg* contains a compilation of samples (rocks and desiccated plants) as well as documents that were produced using different instruments and which refer to both science and the arts. This showcase is also like scientists' work-desks when it comes to its contents: it is full of specimens and inscriptions which bring the object, the landscape, to its beholders.

9.5 Material Translation in *Homage to Werner Holmberg*

Anttila's showcase demonstrates the common roots of representation in arts and science in their very mediality: in the inscriptions, media, and translations with which the scientific and artistic objects are created and displayed. As if visually anticipating Latour's observations in the Amazon, Anttila has juxtaposed several instruments or technologies used in scientific work, also superimposing them. In this work, which pays tribute to the landscape artist, the objects of depiction also seem significant. A great majority of the black-and-white photos are serial close-ups of the earth with no horizon, and they show practically nothing of the surrounding landscape. The technological and objective device, the lens of the camera, is focused on the ground or on another scientific or technological device placed on the ground, viz., a thermometer, a compass, a clock, a magnifying glass (Figures 9.5 and 9.6). These serial photos show the beholder the change in temperature, the passing of time, points of compass, and magnified details of the desiccated plants in the showcase. Whereas Holmberg created landscapes by combining spatiotemporally disjunct fragments of the world while still conveying a feeling of being in a particular place, Anttila dissolves the experience into seemingly random instrumentally mediated samples and slices. The fractured, recomposed, and translated nature of abstraction is present in both Holmberg and Anttila, though it is made visible by Anttila, quite like in Latour's analysis of the field expedition to the Amazon.

What *Homage to Werner Holmberg* makes evident is how instrumental and graphic paraphernalia have become rooted in our ways of seeing the world—and how their development can inevitably change what we are able to see. In this work, we can observe several chains of transformation where each change is accomplished by exploiting technological instruments. That corresponds to the way that science produces qualitatively new kinds of *visibility* through laboratory work and inscriptions. The *Grove* series provides perhaps the best example of scientific (or artistic) transformation of an object in Anttila's work. It depicts the many transformations and states of the grove in the form of different specimens and documents, executed through various media. The desiccated plants from the grove are placed in the showcase with a separate charcoal drawing of each, and they are photographed through a magnifying glass. In those photos, there are two media on top of each other: the photo and the magnifying glass, of which the magnifying glass both takes the beholder closer yet eventually also wipes out the object.

The *Grove* section also contains the Munsell colour chart book (Figure 9.5). Next to the book, is a black-and-white picture depicting plants and a colour chart book that is placed on top of the plants. This, too, represents various overlapping media and transformations. The photo refers to the possibility of comparing the colours of the vegetation with the colours in the book. Such comparisons enable classification, in giving codes, which *represent* the colours and maintain them in a symbolic form—only to do away with the sensual experience of the colours that is underscored by the black-and-whiteness of the photo depicting the Munsell chart on top of the vegetation.

The Munsell chart indeed provides a good example of a replacement in abstractive practices. While such an "inscription device," as Latour would call it, offers a translation of some properties (i.e., colour) of the collection of soil samples, it also strips the soil from its sensorimotor dimensions. Each of the soil samples becomes associated with a number that corresponds to the colour in the Munsell colour chart. What has been lost or gained in such translation? First, most of the other dimensions of the soil—texture, smell, volume, etc.—have been lost. Why is this not then just a case of abstraction as omission? Because the device does not just strip away these properties and leave *colour* but instead assigns the sample a *colour code* that allows the scientists to place the soil sample within a new context, affording for the comparison and alignment of the soil sample to inventories of other (translated) objects. This gesture signifies a loss, but it also involves an enrichment. In its new material realisation, the soil sample can be compared with other translated soil samples as well as other substances of many sorts. Several of these new epistemic possibilities are only available after the translation.

Second, the transformation via the Munsell chart is, in turn, the product of a concrete exploration. Munsell relied on photometrically tested value scales of the psychological experience of colour that he embodied in physical samples (Cochrane 2014, 36). Thus, while the process of creation of the Munsell System is grounded in particular experiences and experiments, such concreteness is compressed and black-boxed in the practice of using it. It is then crucial to note that there is no way back to the soil from the Munsell code. Instead, we have entered the forest of "circulating references".[11]

Perhaps the most complex series of references in Anttila's work is provided by the "picture of the grove on the birch", i.e., the grove reflected on the surface of the birch through the magnifying glass (Figures 9.4 and 9.5). The surface of the birch acts as the screen through which the photo, technologically produced with the help of a magnifying glass, appears to return to nature and, for its part, speaks of the chain of transformations that offer a chance to travel in different directions, yet always to an already transformed image. At the same time, this procedure bestows a metaphor for the mathematisation process whereby nature, changed technologically, is placed on top of nature proper.

Other parts of the *Grove* section are photos of instruments, i.e., the thermometer and the light meter, which are placed in the terrain, as well as the rain recorded on the cassette tape, the contents of which are visualised as an audiogram (Figure 9.5). In the audiogram, 1.16 seconds of the recording is transformed into a graphic picture of the wind and rain. These pictures are indubitably references to the gamut of sensations evoked by Holmberg's work. At the same time, they tell us how, in scientific terms, different sensations and observations are measured and transformed in visual form using technological instruments. The temperature and the amount of light are recorded with the measuring devices placed in the terrain. The sound of rain, on the other hand, has been turned into a diagram, which gives us information of an auditory phenomenon in visual form.

What is indeed typical of scientific representation are the machine-produced instrumental shifts from world to paper where "invisible" objects are graphically made visible. In studying the link between scientific visualisation and mathematisation, Michael Lynch has concentrated on this very process where transformations produced with different inscriptional instruments not only create but also mould the visibility of a scientific object (Lynch 1985b, 1988). Scientific representations do not just reproduce or simplify things, they also add visual features to the pictures and clarify, complete, expand, and identify different structures which are presumably latent in the original object. From this perspective, the process of abstraction does not just omit but also augments. For Lynch, visual displays in science supply an "externalised retina" where the natural object is transformed into a graphic one. The pictures in themselves, however, do not show the transformations on which the possibility of a picture to produce a sensual presence of a scientific object is based. Behind the pictures, there are different kinds of methodical practices, instruments, graphic inscriptions, and interactive processes that replace the mind as the traditional place where the object of knowledge is represented. For Lynch, vision is still a medium of knowledge, but it works in a different way from how the epistemological tradition conceives it. Scientific representations lay out the externalised retina, which is produced through the complex instrumental and inscriptive processes of linearisation, unification, and standardisation.

9.6 Objectivities Made and Lost

In following the work of scientists, Latour noticed that scientists trust their instruments and inscriptions much more than their cognitive abilities. Overlapping and parallel inscriptions, produced in different and independent ways, increase their reliability. Philosophers of science talk about *triangulation*—a process whereby the results produced through various independent means are compared to each other (Wimsatt 2007). The select objects in Anttila's work, the plants, the rocks, the scenery, the rain, and other atmospheric phenomena are all supposed to reinforce the natural experience created by the work. We must note, however, that the objectivity is created by the triangulation of different instrumentally produced inscriptions. In commenting on scientific objectivity, Anttila wrote in his article "Science in My Art":

> From the pursuit of scientific research, I have borrowed the method of making observations, its systematics, and the transformation of data into demonstrable reduced form. The object of study, which used to be a phenomenon in the starry sky, is now earthly. I have wanted to study the method itself and to find the concreteness in it. To set it against everyday life. I want to restore the connection between science and arts that was lost in the 1800s. I use the photo (now also the recorder) because it is granted "scientific" certainty, but the subject can be any ordinary phenomenon. To me, the camera is a measurement device. The whole picture comes into being only when the series is finished. What is unknown to me, behind the pictures, is exposed. Separate phenomena become parts of the whole.
>
> (Anttila 1989, 103)

The question is to what extent such artefactual renderings and translations remain artificial, and the unified picture illusory, at least to some extent. The preface to the Munsell colour chart indeed warns: "Rarely will the colour of the sample be perfectly matched by any colour in the chart. The probability of having a perfect matching of the sample colour is less than one in one hundred" (Munsell Color 1990, iv). This difficulty of matching is demonstrated by Charles Goodwin's ethnographic studies (1994, 2000) on the use of the Munsell colour chart. The colour chart is a cultural artefact, whose use must be learned with the help of trained scientists—alluding to the paradox of scientific objectivity. When we look at the various samples with the help of some coding system, the triangulation of mutually corresponding uniform observations becomes possible. The exactness of the coding system, nevertheless, conceals the preceding cognitive, and observation-bound uncertainties, and the situated and distributed scientific work. These uncertainties have, however, been bracketed in later documentation—through the coding—ingeniously commented by Anttila's black-and-white photo, positioned in the work just under the actual Munsell atlas. This photo taken of the vegetation on the top of which the atlas has been placed makes apparent how difficult it is to discern the plants' colours with the help of the colour chart, once the colours have been erased.

It is precisely the idea that such a loss of experiential qualities fosters objectivity that Anttila rightly parodies. In Anttila's reconstruction of the Holmbergian landscapes we have lost, via translational artefacts common in scientific practices, precisely what Holmberg wanted to produce: *an experience* of the landscape depicted. Holmberg was not interested in creating just a visual reconstruction of a landscape, but an experience of a landscape, despite its being one that as such did not exist (pace the names of geographical locations in the titles of his many landscape paintings). Anttila, in turn, is interested in giving us a scientifically translated experience of Holmbergian landscapes through the pieces, colours, and sounds of the environments that inspired Holmberg. Paradoxically, Anttila's work strips the specimens from the experiential dimension with the same gesture.

Homage to Werner Holmberg also casts an ironic light on the goal of science to create order. One of Anttila's salient ways of disturbing the production of objectivity is serialisation. The serialised photos of the road work in this manner. They suggest that their goal was to systematise the material, but at the same time, they seem to ask the beholder what this serialisation is based on. In the left-hand corner of the work, there is a series of five photos, which creates an "unbroken" picture of the shadow of the tree (Figure 9.6). The uniform picture is, first, accomplished with different pictures, but, second, instead of the tree, they piece together its *shadow*, so as to hint at the scientific method never reaching the tree itself. This series is followed by a series of photos of the road with a clock, where the pictures were taken at certain time intervals, underscored by the clock's different times. This series is in turn followed by a series of photos of the road which show a terrain of varied roughness. Next to each picture, there is a rock as a sample that functions also as a *guarantee* of the reference.

The serialised pictures and the overlapping and parallel fragments can be seen as an artistic expression of the chain of material references Latour refers to in his attempt to solve the problem of representation. The chain of inscriptions, along which one can move in different directions, substitutes and partly solves the problem of representation, viz., the question of the relationship between the picture and its object. What is essential in Latour's solution is, nevertheless, the fact that we, as beholders, must know how and why the transformations were made in order to effortlessly move along the referential chain back and forth. Both in science and art the specific knowledge and training, rooted in the tradition of a particular field, establish the ability to trace the chain of references through which it is possible to move from the representation to its source (though some spatiotemporal qualities of the source have been permanently lost).

Yet, *Homage to Werner Holmberg* appears to expose the fragility of these links. It offers us a series of references where the relationship of the signs with their objects is problematic. The work refers to Holmberg's paintings and work, but it does it through Anttila's own experiences, which, furthermore, are present in the work only in the form of fragmentary signs produced through various media. There is a disruption between all these references: series and specimens are apparently produced by random choice, with no ulterior motive. Moreover, a beholder who does not know that the work is a tribute to Holmberg is scarcely capable of determining this merely by looking at the work. In fact, the various parts of the work do not clearly, on their own accord, even refer to Anttila's own experience. These references cannot become evident merely by looking at the work, as the representational theory of knowledge presupposes. Although the work, in the tradition of natural history museums, displays numbered signs with "instructions" on how to read the work, they require not only knowledge of the arts and science but also of the intentions of the artist.

Irrespective of such knowledge, the work is nevertheless able to display its investigation of contemporary experience, which is increasingly scientifically and technologically mediated. The overall theme in *Homage to Werner Holmberg* does seem to be the twofold movement characteristic of representation that both makes present and distances. On one hand, Anttila's goal was to find something concrete, tangible, and permanent behind Holmberg's paintings. In order to do that, he returned to the same and similar landscapes and fetched—through the use of different media and materials, which crystallised those landscapes and conditions—*that* world. On the other hand, the work explores the act of distancing and losing the original experience through representation: what is present are only documents and samples left of the road or plants, and the multiple modalities of sensing, e.g., warmth, light, and sound, turned into numbers and diagrammatic displays. *Homage to Werner Holmberg* reveals, then, the paradox of mediality shared by both science and arts: science looks for the basic mechanisms and elements of reality, but to be able to do so, it is forced to invoke artificiality: complex devices and man-made classifications. Arts, on the other hand, typically look for an experience, which is basically subjective, but in order to supply this individual experience, is forced to resort to communal and shared representational means.

9.7 What Abstraction Leaves Behind

Artistic and scientific representations differ in how they work and what they aim at. If the traditional task of science has been that of depicting reality as exactly and as transparently as possible, especially modern art probes the inability of images to represent reality, or to reach that reality.

For this reason, the arts provide an excellent place to speculate on the materiality of images and representation, their lack of clarity as well as on the translations that mediate the relationship of the representation to external reality.[12] We have seen how both Anttila's and Latour's treks in the woods ironically led them to the space of artefactual displacements. Their humorous explorations in translation remind us of what is ignored in viewing abstraction simply as omission, or contrasting it to concreteness: the experiences, practices, and tools that enrich representations with new affordances, enabling novel insights, questions, and accomplishments.

There is still loss involved, of which Anttila is acutely aware. While Latour appears confident in scientists' ability to travel back and forth between the inscriptive chains, Anttila shows how abstraction does away with many, if not most qualities of experience, and going back might not be possible anymore. His is not the abstraction of many philosophers of science, who assume along with Jones (2005) that omission might still leave scientists with true, though partial representation. Anttila's serialisations, and overlapping and superimposed images, refer both to the production of objectivity, and the ambiguities and choices involved in it.

Another important lifelong goal of Anttila was to inquire into the deeper connections between arts and science. *Homage to Werner Holmberg* does that indirectly by commenting on scientific representation, which, in our culture, faces the requirement of clarity and truthfulness. Although the ostensible aim of Anttila's work is to depict external "reality", the passing of time, certain localities, and landscapes as accurately and exactly as possible, the work develops into a reflection of the inescapable mediality of representation—and experience. In employing both the forms of scientific depiction and artistic documentation, *Homage to Werner Holmberg* tears down the boundaries between science and the arts. It exposes the abstractive processes inherent in the material translations between different media, simultaneously pointing to the complex referential chains native to both scientific and artistic representation. At the same stroke, the work thematises the techno-scientific nature of our own sensual life-world that is increasingly mediated, measured, and curated: science and technology not only supply us with new and ever-refined observations and means to make our aims possible, they rather continually work on what we see, experience, and want.

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Notes

1 Some philosophers of science have resisted this reductive approach to abstraction (Radder 1996, 2006; Martínez and Huang 2011; Nersessian 2002; Gallegos Ordorica 2016; Jones 2018; Loettgers and Knuuttila 2022; Carrillo and Martínez 2023).
2 This is not the case in art that typically refers to its own material constitution.
3 *Homage to Werner Holmberg* (*Kunnianosoitus Holmbergille*) belongs to the collection of the Museum of Contemporary Art Kiasma, Helsinki.
4 Anttila's methods connect him to early contemporary art genres such as conceptual and land art.
5 See also "Circulating reference" in Latour, B. (1999) Pandora's Hope. Essays on the Reality of the Science Studies, Cambridge, MA; London, Harvard University Press, 24–79.
6 Three pioneering laboratory studies are Latour and Woolgar (1986[1979]), Knorr-Cetina (1981), Lynch (1985a). A good overview of them can be found from Knorr-Cetina (1995).
7 Italics of the original.
8 On the notion of a laboratory, see, e.g., Hacking (1992).
9 See also Lynch (1988).
10 See also Latour (1999, 174–215).
11 Latour's *The Pédofil of Boa Vista* has been reprinted in his book *Pandora's Hope* (1999) with a title "Circulating Reference".
12 E.g., Groys (2002).

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10 What If?

Rasmus Grønfeldt Winther and Marie Raffn

10.1 Asking *What If?* in Science and Art

In the initial conversation about abstraction between the authors at the café Kaf in Copenhagen, attention was suddenly drawn to the dotted glaze on the plate (Figure 10.1). Try an experiment: imagine that each dot on the plate represents a single star in outer space. The plate is then—potentially—a kind of map, a representation. Could the dots correspond, in their relative placement and size, to a real field of stars? Is there at least *one* vantage point in the universe from which the projection of visible stars onto a surface would produce the exact pattern on this plate?

How might we refine this thought experiment? Might it help to consider parallel universes or alternative realities? Could the dots represent worlds depicted through art or told through fiction, where our laws of physics might not apply, and stars—and planets—possess strange properties? The Kaf plate thought experiment opens up a multimodal space in your mind.

Imagination and fantasy are necessary for asking *what if?* We invite you to ask how our world might be different if, as individuals or societies, we could inspire behavioral change via new ideas and art-making across fields with the aim of getting us to rethink and act anew in our lives. This approach could help us address many small issues as well as giant ones—even the anthropogenic mass extermination of life on Earth.

What if?-thinking is standard practice in scientific modeling and map-making. To represent the world theoretically, we have to imagine how we could simplify and idealize it as if it contained just a few kinds of processes and objects. What would evolution look like if it only occurred at the individual level, or gene level? What if a gas mixture consisted of vanishingly small, inelastic atoms or molecules bouncing around that neither attracted nor repelled each other? Scientific experiments are also a form of *what if?*-thinking: What if we simplified material processes by including only a few types of objects and their interactions in a controlled and randomized manner (in a beaker, on an inclined plane, in a fruit fly breeding design)?

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Figure 10.1 A Kaf plate. This plate, used at the Nørrebro, Copenhagen café Kaf, is a Stonecast design by Churchill China in England. Authors' image

Even alternative realities can be built with *what if?*-thinking. New ontologies need not be based on the actual world. In this regard, the creative explosion of asking *what if*? serves particularly well in art and fiction.

Drawing on choice scientific and artistic achievements, as well as on our own previous philosophical and artistic work, we show how *what if?*-thinking provides a unique and powerful lens—both a telescope and a microscope—onto matters of abstraction and representation (and imagination and even the spiritual).

This is an experimental and fully collaborative chapter resulting from conversations, exhibition visits, and studio visits. In this contribution, both authors access and emphasize their respective subject matter—philosophy of science and contemporary art—from a somewhat outsider perspective. How we draw these boundaries is itself ripe for *what if?*-thinking. We may question how our lives are circumscribed and closed in by the assumption that each of us already occupies what Winther has called a "world navel."

Whatever collective we are part of—say, the academic ivory tower or the contemporary art world—isn't, after all, the *entire* world (Winther, 2014a, 2020a, 2020b).

We have tried to make the text modular and therefore more digestible to readers who may zoom in on different sections. Even if this approach might make the text a bit jumpy, it is meant to facilitate your efforts at asking how our shared world could be different.

10.2 Marie Tharp as a Scientific *What If?* Thinker

Let us move from the stars to the oceans. "Could the waters of the Atlantic be drawn off," says 19th-century American oceanographer M. F. Maury, "the very ribs of the solid earth, with the foundations of the sea, would be brought to light, and we should have presented to us at one view the empty cradle of the ocean" (Heezen, Tharp, and Ewing, 1959, epigraph, p. iv). Cartographer, oceanographer, and geologist Marie Tharp (1920–2006), along with her scientific partner Bruce Heezen, took the indisputably biggest step toward this vision of the exposed ocean floor of anyone in the 20th century. Tharp did this by pairing *what if?*-thinking with tools of abstraction and representation. "First," she says, "there is only one proper way to sketch or to contour the ocean floor and that is to present it as it actually exists *as it would be seen if* all the water were drained away" (Tharp, 1982, p. 22, emphasis added). What would the ocean floor look like if we could draw off or drain the oceans?

Tharp's skilled hand visualized the ocean bottoms for us.[1] In 1952, she discovered, properly and systematically, the rift—also referred to as the median rift, rift valley, graben, or V-shaped cleft—along the Atlantic Mid-Oceanic Ridge. It "took a whole year" to convince Heezen of the rift's existence (Tharp, 1996; cf. Wertenbaker, 1974, p. 144). As a logical extension of this discovery—and using data about earthquake epicenters that closely correlated spatially with the rift—Tharp, together with especially Heezen, suggested that there was effectively a long, continuous ridge—with a median rift—that "went all the way around the world for forty thousand miles" (Tharp, 1997). Discovering and establishing the Atlantic median rift, and inferring, with Heezen, a global mid-oceanic ridge system were two immense accomplishments, requiring creativity and fortitude. Tharp accomplished this despite encountering sexism and personal style harassment (Winther, 2019), including not being mentioned in the publication announcing both the proper discovery of the median rift along the mid-Atlantic Ridge and the inference of a global ridge system (Ewing and Heezen, 1956).[2]

Perhaps more memorably, Tharp's work with Heezen at Lamont-Doherty Earth Observatory at Columbia University gave us abstract

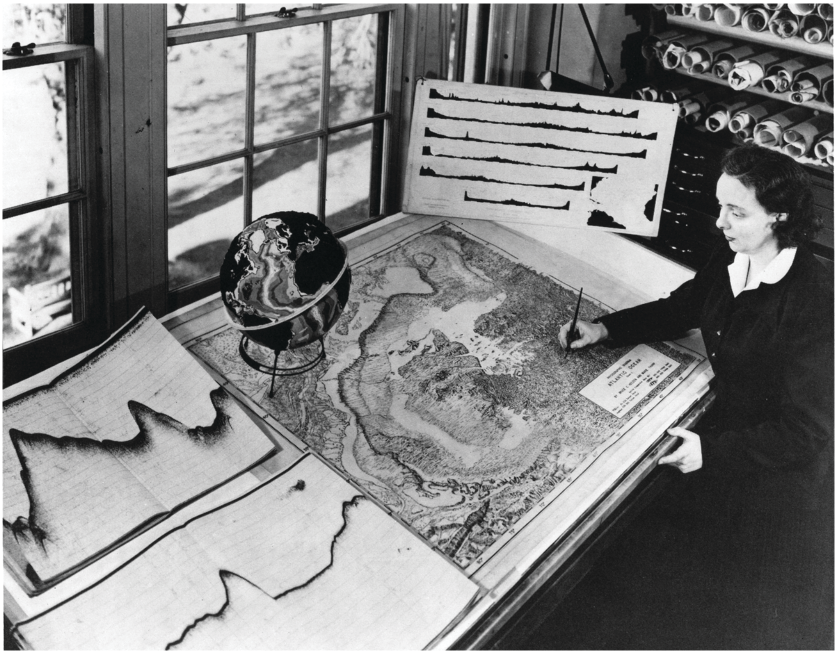

Figure 10.2 Marie Tharp at the drafting table. Tharp paints or touches up the left half of the North Atlantic physiographic diagram in what is almost certainly a staged photograph, likely from 1961.[28] The map cartouche discussed in note 4 can be found under her arm. On her right is plate 22 of Heezen, Tharp, and Ewing (1959), "Six Trans-Atlantic Topographic Profiles." These were made by comparing and collating countless echograms or fathograms, ideally PDR (precision depth recorders) readouts—developed at Lamont (Luskin et al., 1954)—two of which are shown on her left. In her own words: "To make the map, we first plotted lines of soundings taken by ships tracking across the ocean. Then we converted the sounding lines into two-dimensional profiles of the seafloor. Then we made three-dimensional sketches based on the profiles and plotted them along the ship tracks. Finally we sketched in areas with no soundings by extrapolating trends observed in profiles made by actual soundings. In other words, we made educated guesses to fill in the dataless gaps" (Tharp, 1999). More poetically, and also in her own words: "Deep sea soundings obtained along a ship's track … were as a ribbon of light where all was darkness on either side" (Felt, 2012, Loc. 1721). Behind her, note the rolled-up maps and other visual resources, perhaps PDR readouts "tens of meters long" (Higgs, 2020, p. 234). Finally, the globe was likely made with "acrylic applied to a basketball" (Doel, Levin, and Marker, 2006, note 72, p. 625), painted "in blacks, blues, grays, and browns, brushing dark colors over the tasteful pastels already there. Red had always been reserved for the rift valley" (Felt, 2012, Loc. 1986). Reproduced with kind permission of Lamont-Doherty Earth Observatory and the estate of Marie Tharp.

representations—maps—forged in *what if?*-thinking: What if the ocean floor exhibited an unexpectedly rich and variegated structure, with flat abyssal plains as well as seamounts, and with wild ridges? What if there indeed was a continuous mid-oceanic ridge system running along the ocean floor? These two questions have major implications for geological theories about the origin and structure of continents and oceans, including the theory of plate tectonics as a mechanism for continental drift. In addressing these questions, Tharp's imagination and desire to inspire the map reader "contributed to a revolution in geological thinking. Because now they're using the ocean and plate tectonics to redo the geology on the land" (Tharp, 1997).[3]

In creating all of her maps, Tharp used standard cartographic generalization and abstraction protocols, such as selection (scale, projection), simplification, and exaggeration (Winther, 2019, pp. 101–109). Even so, Tharp's best known maps are the ones she co-produced with Heezen and the Austrian painter Heinrich Berann, which were published by *National Geographic* (Tharp, 1997; Felt, 2012, Loc. 2810). Much of the literature on Tharp has emphasized these maps because of their dramatic beauty and public influence. As for Tharp's more scientific maps, commentators have focused on the physiographic diagrams of, for example, the North Atlantic (first published in 1957[4]; reprinted in Heezen, Tharp, and Ewing, 1959 as an inset; and deemed an "abstract view of the sea floor …[which] can be seen in no other way but in the mind's eye" by Heezen and Hollister, 1971, p. 7) and Indian (Heezen and Tharp, 1964) oceans. We are the first to comment on Tharp's scientific maps beyond the physiographic diagrams.

The scientific maps of Heezen and Tharp (1965) are exercises in the two *what if?* questions discussed immediately above. Among Tharp's papers with Heezen, this one is the most theoretically sophisticated and contains the widest variety of fascinating and detailed maps of the ocean bottoms (e.g., Figure 10.3).[5]

The two aims of Heezen and Tharp (1965) are: (1) empirically, a summary of prominent features—recorded and inferred—of the bottoms of the Atlantic and Indian oceans; and (2) theoretically, an evaluation of what they thought was an uneasy fit between the theory of continental drift and the complexity of the Indian Ocean. Heezen in particular believed that the Indian Ocean, with its "scattered linear micro-continents" (p. 94; e.g., Madagascar and the Seychelles) could not be easily explained or predicted by continental drift.[6] The authors declaim, "the Mid-Oceanic Ridge appears to be a feature created by extension of the Earth's crust and the emplacement of new material from the mantle below" (p. 100). This sentence can be read both from a continental-drift-via-plate-tectonics perspective (or "convection current hypothesis") *or* from Heezen's own favored continental-displacement-via-an-expanding-Earth perspective (p. 105).

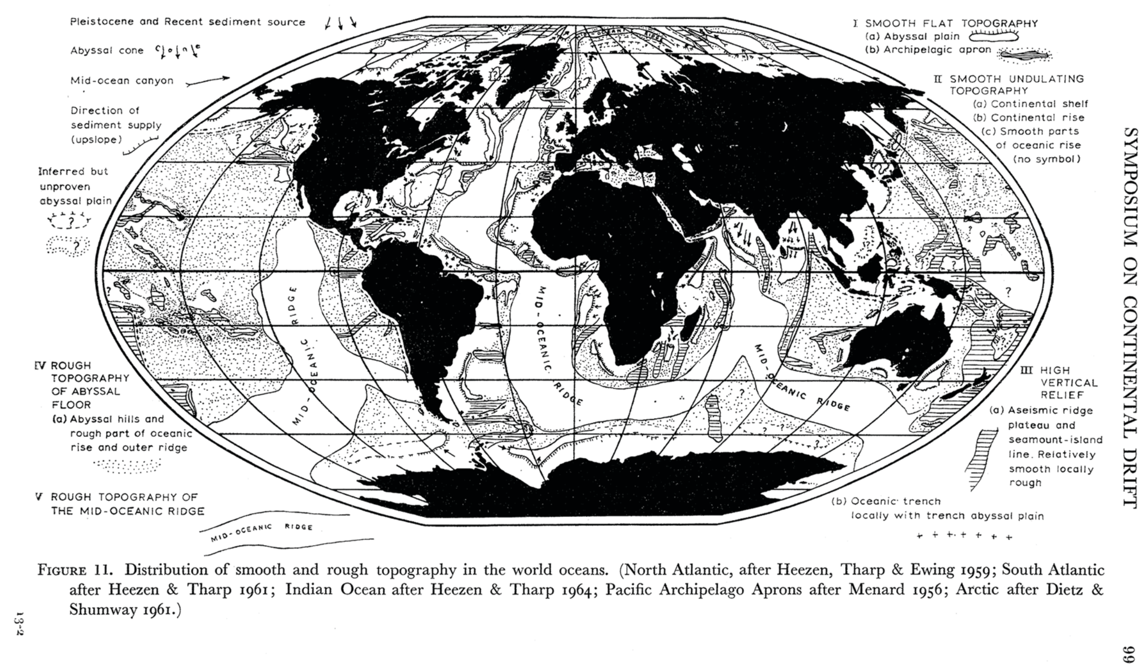

Figure 10.3 "Distribution of smooth and rough topography in the world oceans" (Heezen and Tharp, 1965, p. 99). Tharp drew this map from scratch, possibly on a Denoyer Semi-Elliptical projection,[29] using new data as well as the various sources cited. The entire article page is here reproduced to give the reader contextual information. Reproduced with kind permission of The Royal Society (UK), from Tectonic Fabric of the Atlantic and Indian Oceans and Continental Drift by Heezen, B. C. and Tharp, M. in *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences*, volume 258, issue 1088, 1965; permission conveyed through Copyright Clearance Center, Inc.

The article deploys *what if?*-thinking, dialectically considering what possible kinds of ocean floor topographic, sedimentation, or general geological features continental drift or continental displacement theories would suggest, and which actual features fit better with which of the two theories. While interestingly granting concessions to continental drift—"a northward drift of India is suggested by palaeomagnetic measurements" (p. 100)—the article cautiously defends a now-discarded expanding Earth theory. Still, this defense was not unreasonable, and the article was a sophisticated descriptive and theoretical intervention in the literature.[7]

Tharp's maps are instrumental to the article's effectiveness. Even just a list of the map names from Heezen and Tharp (1965) provides a glimpse into the richness and diversity of scientific maps Tharp created (Table 10.1). Elsewhere, Winther has classified five types of Heezen–Tharp maps: physiographic diagrams, profiles, perspective panorama maps, angled panorama maps, and absolute panorama maps (Winther, 2019, p. 116). Only the first two types are scientific, while the last three describe the maps co-produced with Berann. To be complete, this typology would have to be extended to include geographic and geological maps, with new kinds of semiotics. Setting this complexity aside, a too-brief exploration of only one of these figures, Figure 10.3, will have to suffice.

Table 10.1 Maps Drawn by Marie Tharp in Heezen and Tharp (1965)

- "Bathymetric sketch of portions of the Chain and Romanche Fracture Zones." (Fig. 3, p. 91; reprinted from Heezen, Bunce, Hersey, and Tharp (1964), p. 14—the 1964 figure caption concludes thus: "contours by Heezen")
- "Topographic profiles in the vicinity of Vema Fracture Zone." (Fig. 4, p. 92; reprinted from Heezen, Gerard, and Tharp (1964), p. 736)
- "Fracture zones in the equatorial Atlantic." (Fig. 5, p. 93)
- "Bathymetric sketch of Atlantis Fracture Zone." (Fig. 6, p. 93)
- "Arabian Sea, Red Sea, and Gulf of Aden. … portion of the Physiographic Diagram of the Indian Ocean" (Fig. 7, p. 95)
- "Madagascar Ridge, Mozambique Ridge and Mid-Oceanic Ridge. … portion of the Physiographic Diagram of the Indian Ocean" (Fig. 8, p. 96)
- "Northwest Indian Ocean." (Fig. 9, p. 97)
- "Diamantina Fracture Zone, Broken Ridge, Ninetyeast Ridge in the east central Indian Ocean. … portion of the Physiographic Diagram of the Indian Ocean" (Fig. 10, p. 98)
- "Distribution of smooth and rough topography in the world oceans." (Fig. 11, p. 99; Figure 10.3)
- "Organic productivity of the world ocean; a generalized interpretation based largely on oceanic circulation patterns." (Fig. 12, p. 102)
- "Sediment thickness." (Fig. 13, p. 102)
- "Tectonic chart of the world." (Fig. 14, p. 104, on a Mercator projection)

Note: Original captions, truncated.

The semiotics of Tharp's topographic oceans map are exquisite (Figure 10.3).[8] First, ocean floor topography is classified into five general types: "smooth flat," "smooth undulating," "high vertical relief," "rough… abyssal floor," and "rough… mid-oceanic ridge." It is almost as if there are three semiotic moments here: –, |, and ^^^. That is, the first two types are basically horizontal, flat, and smooth (i.e., –), the middle one vertical (i.e., |), and the last two rough (i.e., ^^^). Second, abstract dots, lines, and closed shapes are combined in different ways to mark off different areas of the ocean floor (e.g., abyssal plains such as those off the African west coast or off several mid-oceanic ridges). In this way, the limits of knowledge are also accepted, and extrapolation and interpolation called out, with symbolization for "inferred but unproven abyssal plain." Finally, the subtlety of some of Tharp's abstract signs and symbolic implications is sublime, including: "c↓o↓n↓e" for abyssal cones; the remarkable absence of any structure in the white void labeled "mid-oceanic ridge"; and, in a moment of oceanic revenge, the implicit plea to the reader to not pay any attention whatsoever to the solid black void of the continents. What if you focused your mind's eye on those parts of the ocean bottom that are much harder for you to imagine, beyond the mid-oceanic ridges (e.g., the Indian Ocean Ninety East Ridge or the vast abyssal floor of the Pacific Ocean)? We invite the reader to procure a magnifying glass and closely study Figure 10.3 for your own enjoyment.

Thus, Heezen and Tharp (1965), and in particular Figure 10.3, serve as a snapshot of *what if?*-thinking and abstraction in Marie Tharp's opus. Tharp's highly diverse maps tell many a story about the ocean; her semiotics involve significant consideration and sophistication; and her deft hand created highly informative and beautiful maps, synthesizing the scientific and artistic.

10.3 *What If?* in Visual Arts

Scientists such as Tharp make the world visible using data secured by microscopes, telescopes, and echosounders (cf. Wise, 2006). Artists also show us invisible worlds, often by depicting or accentuating features of the real world. In art, the process of abstraction is even more imaginative than in science or the philosophy of science. The abstract in art, a product of the artist's imagination, draws us in to participate in the artwork—to use *our* imagination. The artwork can be a portal to our own inner world and to alternative realities—not just utopias, but also states and spaces without a purpose other than the viewer's experience. The abstract in art implores and strongly invites the spectator to engage in *what if?*-thinking.

10.3.1 The Abstract in Visual Arts

In depictive, figurative or representational art—say, Dutch Golden Age painting or 19th-century Realism or Naturalism—we have a common ground: namely, a desire to faithfully reproduce our shared world, as presented to the senses. Viewers do not have to say out loud that a chair is a chair or a face a face. In contrast, the abstract in art invites unlimited possibilities in its visual language. In our desire to categorize and decode, one association will turn into the next, and the next, and so on. Abstract art issues in mystery and potential. In simplifying creatively, the abstract in art includes geometrical forms, the void, sheer color, and, in general, semiotic codes. For instance, a painter in a dialogue by Piet Mondrian says: "In painting you must first try to see *composition, color, and line*, and not the representation *as representation*. Then you will finally come to feel the subject matter a hindrance" (Mondrian, 1992/1919, p. 283; emphasis in original). What is essential here is not an exact 1:1 match with the physical world but the invitation to open alternative realities (cf. the Kaf plate).

The abstract in art is subjective—it will be experienced differently from viewer to viewer. Higher degrees of abstraction will leave more to individual interpretation. Many abstract artists active during the period of Minimalism in the 1960s (e.g., Agnes Martin and Robert Ryman) wished for the spectator to experience the artwork with their body, rather than to decode it. The spectator's mindset and imagination are co-creative of the artwork, even if its theoretical and temporal context, the artist's intentions and artwork title, and the role of art historians and theorists in communicating about it also remain essential aspects of the artwork. Indeed, the viewer's experience of the abstract invites a wide range of *what if?* questions: What if the artwork implored you to imagine alternative, previously invisible worlds? What if the artwork did this by depicting formal structures gleaned from the visible world and deployed in surprising ways?[9] The abstract is generous.

Thinking of abstract art may call to mind its best known form: the early 20th-century work of Wassily Kandinsky, Piet Mondrian, and Kazimir Malevich, among a few select others (but see below), as well as American Abstract Expressionism of the mid-20th century. But we will deliberately start further back and out than this obvious apotheosis of abstraction, appealing also to, for instance, Cubism and Minimalism.

Consider the geometrical forms associated with early 20th-century Cubism.[10] Cubism captures harmonic beauty with a multi-perspectival geometrical reconstruction of reality premised on collapsing or projecting—and recreating—regular three-dimensional space and experience onto the canvas' two dimensions (cf. Ozenfant, 1992/1916, p. 224), an act reminiscent of our Kaf plate thought experiment. For cubists, geometry permitted an aesthetic *what if?* decomposition and recomposition of the world: "geometry is to the plastic arts what grammar is to the art of writing" (Apollinaire, 1992/1912, p. 181). Furthermore, "avantgarde artists and art theory in the years up to World War I" considered "abstraction, anti-mimetic form-language and especially geometrical figures" to be "a significant method to express the metaphysical and spiritual sides of the world" (Schou, 2019, p. 63; Winther's translation).

Abstraction is not just operative in art that is traditionally called abstract: What if an apparently depictive scene turns out to contain surprising elements of the abstract? Furthermore, abstraction may reach beyond our mind: What if an abstract artwork is an entrance to an alternative reality and imaginary world? Such worlds may be spiritual, as we shall see with Caspar David Friedrich (1774–1840; who discovered avant la lettre key elements of the abstract in art) and especially Hilma af Klint (1862–1944; perhaps the first abstract artist, sensu stricto). Such worlds may also be secular, teeming with formal structures with open-ended semiotics. For instance, in contemporary art, Marie Raffn's artworks are frequently motivated by *what if?*-thinking, inviting the spectator to commune simultaneously with the mystical and with the formal and quasi-mathematical. By exploring the work of Friedrich, af Klint, and Raffn, we expand our understanding of *what if?*-thinking as characteristic of the abstract in art.

10.3.2 Abstract Elements in C. D. Friedrich

We have moved from the stars to the ocean floor and now, with German Romantic landscape painter Caspar David Friedrich, to the mysterious sky and frozen sea. While it might seem surprising to find elements of the abstract in art so early on, Friedrich's work contains abstract elements such as the void—glossed both as empty space and as a sense of present absence—and cubistic forms.

A monochrome sky fills approximately 80% of the painting *Der Mönch am Meer* (Friedrich, 1808–1810). The grandeur is exalted by a small figure standing on the beach sand with his back toward us while he is looking at a dark sea. According to art historian Dea Schou, *Der Mönch am Meer* "speaks through two channels—one representational and one abstract." The first channel is the "figurative scene with the monk and the beach," the latter "the background and the sky… characterized by an abstract, blurred, and material mode, composed of colors, clear texture, and impasto brushstrokes" (Schou, 2014, p. 83; Winther's translation). Dialectically then, this artwork represents a literal monk on a beach and simultaneously deploys the abstract void—i.e., the empty space and present absence of the painting's sky, clouds, and light—to invite the spectators into mystery through its depiction of something impalpable, beyond rational comprehension: sublime nature, the spiritual, and God. Art historian Alice Kuzniar points out this potential of the void: "An early anonymous reviewer of 1804, for example, remarks that Friedrich, rather than paint the rays of the sun, leaves it to the viewer to imagine them" (Kuzniar, 1988, p. 368). The spiritual was important to Friedrich, so clearly alluded to in the figure of the monk:

> Because Friedrich… imposed upon everything he drew and painted an explicit or implicit sense of supernatural power and mystery in nature, it becomes especially difficult to categorize his various works as either religious or secular in character. They are, in fact, both.
>
> (Rosenblum, 1975, p. 25; cf. Harvey, 2022, p. 82)

Thus, with the abstract void, and its depiction of absence, the viewer is invited in to reflect on and perfect the painting, thereby making it whole and experiencing the spiritual, almost as if we were standing side by side with the monk on the beach.

The abstract nature of Friedrich's work is emphasized by art historian Robert Rosenblum, who with the term "the abstract sublime" drew parallels between the vast void in *Der Mönch am Meer* and the painting *Light, Earth and Blue* (1954) (almost 150 years later) by Mark Rothko, a painter associated with Abstract Expressionism (Rosenblum, 1961). Over a decade later, Rosenblum started his book thus: "The alpha and the omega of this eccentric Northern route that will run the gamut of the history of modern painting without stopping at Paris may be located in two works," namely, Friedrich's *Der Mönch am Meer* and Rothko's *Green on Blue* (1956)—the "emptiness" or "nothingness" of these two works "bewildered" and "disconcert[ed]" their audiences (Rosenblum, 1975, pp. 10–11).[11]

Das Eismeer (Friedrich, 1823–1824) (Figure 10.4) can be productively interpreted as an early experiment in abstract, cubistic style.[12] Schou observes:

> One can regard *Das Eismeer* as an abstract investigation into the painting and the boundaries of the painting. The ice fragments have become geometrical forms and are made up of triangles, squares and straight lines—a surface-oriented construction of an iceberg; pure and abstract. By painting abstract, geometrical forms with a meticulous, detailed, extremely naturalistic painting style, Friedrich blends two principles and two spatial figures: the three-dimensional and the surface-oriented. Our gaze oscillates between seeing a depiction of a

Figure 10.4 Friedrich, C.D. (1823–1824) *Das Eismeer*. H 96.7 × W 126.9 cm. Oil on canvas. In *The Sea of Ice* (English title), an entanglement of ice fragments almost hides a presumably smashed shipwreck in the Arctic on the right side of the painting. *Das Eismeer*. (2023, January 5). Reproduced from: https://en.wikipedia.org/wiki/The_Sea_of_Ice by Caspar David Friedrich—The Yorck Project (2002) *10.000 Meisterwerke der Malerei* (DVD-ROM), distributed by Directmedia Publishing GmbH. ISBN: 3936122202. Public Domain.

> realistic ice sea, where the mimetic ship becomes an important detail in the pictorial space for creating depth and space, and to see an abstract representation of pointed, broken, white geometrical shapes in an unidentifiable space, which refers back to the [canvas] surface on which the illusion emerges.
>
> (Schou, 2014, p. 53; Winther's translation)

The complex entanglement of ice fragments, roughly horizontal in the lower third of the painting, and practically vertically oriented in the upper two-thirds, almost hides what could have been the central focus of the painting: the eerily tilted and presumably smashed shipwreck on the right side. Indeed, the geometrical center of *Das Eismeer*—one could even say its central subject, drawing our attention—is *not* the off-center shipwreck, but the immense and abstract, cubistic cornucopia of ice fragments over which sunlight breaks.

What happens when we perceive an object, in this case a field of ice, from multiple points of view at a single moment? How can three-dimensional space be collapsed onto the canvas' two dimensions neither through smooth, continuous, and literal metric distortions as in cartographic projections (from the globe), nor in (later) surrealistic spatial distortions, but through abstract and geometrical elements—namely, the ice fragments?[13] Through *what if?*-thinking, we can thus complete the painting and experience nature's sublime power, fearing for the souls on the wrecked ship.

In these two artworks by Friedrich, the void and geometrical forms, respectively, help awaken potential, curiosity, and imagination. Through *what if?*-thinking, we connect to the sublime in nature and even to the spiritual. Rosenblum states: "Friedrich's search for new symbols to elicit transcendental experience was so intense that it converted almost all earlier categories of secular painting into a new kind of religious painting" (1975, p. 32). Friedrich himself apparently said:

> Close your physical eye, so that you may see your picture first with the spiritual eye. Then bring what you saw in the dark to the light, so that it may have an effect on others, shining inwards from outside. … A picture must not be invented, it must be felt.
>
> (Bell, 2012)

10.3.3 The Spiritual in Hilma af Klint

The spiritual aspect of abstraction can also be understood through the important work of the Swedish artist Hilma af Klint, who was "a pioneer of abstraction" (Wivel, 2004, p. 12; Birnbaum, Noring, Kittelmann, and Stals, 2013, p. 15; Müller-Westermann, 2013, p. 33; *Beyond the Visible–Hilma af Klint*, 2019). In November 1906, she started painting the series *Primordial Chaos*, initiating the cycle *Paintings for the Temple* (Voss, 2022, p. xii, for the paintings; see, e.g., af Klint, 1906–1907 and Guggenheim, 2018). This was abstract art "several years before Wassily Kandinsky, Piet Mondrian, Kazimir Malevich and František Kupka" (Müller-Westermann, 2013, p. 33).[14] Hilma af Klint's "visual worlds" evolved over time, from "organic abstraction" into "geometrical" abstraction; the red thread in this shifting work is the "attempt[] to give shape to invisible contexts and make them visible" (Müller-Westermann, 2013, pp. 33, 45). With sheer colors, sharp forms, balanced composition, and a guided brush, af Klint made visible hidden, spiritual worlds.

In fact, Hilma af Klint believed she communed with spiritual beings from other dimensions. She was influenced by contemporaneous spiritual and occult movements such as spiritualism, theosophy, and anthroposophy (Weise, 2023). In af Klint's own words: "The pictures were painted directly through me, without any preliminary drawings and with great force. I had no idea what the paintings were supposed to depict; nevertheless, I worked swiftly and surely, without changing a single brushstroke" (Müller-Westermann, 2013, p. 38, note suppressed). Indeed:

> If Romantic artists felt like mediums for God, Hilma af Klint felt like a medium for the departed souls that return during spiritualist meetings.
>
> (Wivel, 2004, p. 12; Winther's translation)

> Since 1906, [af Klint] had been attuned to a broader cosmos described by spirals, snails, swans, letters, and abstract figures, with Askets and Vestals. She had spiritual friends called Gregor and Ananda, names from disparate cultural contexts.
>
> (Voss, 2022, pp. 275–276)

What if we could experience and access the spiritual, thereby transcending the limitations of what our senses are able to register in the physical, material reality of everyday life? Hilma af Klint's abstract visualizations, also inspired by complex, living nature and even by the latest science of invisible electromagnetic waves, are a portal—"an opening with no interpretation" (Wivel, 2004, p. 12; Winther's translation)—to other worlds and alternative realities.

Across fields and time periods, Caspar David Friedrich, Hilma af Klint, and Marie Tharp share a fascination and dedication to making the invisible visible through the use of their hand. What if we could render visible the ineffable sublimity of God in Nature, the wisdom of the spiritual beyond, or the dizzying beauty of the ocean floors?

10.3.4 **What If?** ***in the Contemporary Art of Marie Raffn***

Contemporary art is often permeated by abstract elements and abstraction, as well as by the desire to invite spectators to engage in imaginative *what if?*-thinking. Much can be said about art in our times, but we will be zooming in on the work of Raffn, with which we have first-person familiarity. This approach also gives us an opportunity to consider sculpture. Raffn's sculptures are three-dimensional works which nevertheless, like paintings, have two-dimensional interpretations.

Minimalism is a form of abstract art that emerged in the USA in the late 1950s and 1960s (e.g., Carl André, Agnes Martin, Richard Serra, Eva Hesse, Charlotte Posenenske, and Fred Sandback). A number of minimalist artworks consisted of "simple geometric shapes based on the square and the rectangle" (Tate, 2023). Minimalists often used commercial materials and manufactured their art industrially; color was deployed to mark and define space rather than to capture sentiments, let alone spirit (in stark contrast to Friedrich and af Klint). They also cared about viewer engagement, including the ability of the viewer to move through some of the artworks (Wolfe, 2019). The same applies to land art (inspired by, e.g., Minimalism and Conceptual Art)—the movement of the spectator's body through space is essential to experiencing the artwork. For land artists such as Robert Smithson (1938–1973), shapes tended toward the organic, and the artistic transformation of geology and ecology was a significant driver.

The current Danish artist Marie Raffn is influenced by Minimalism[15] with strands or overtones of Cubism and a playfulness found in Dadaism and concrete poetry "objects composed of words, letters, colors, and typefaces, in which graphic space plays a central role in both design and meaning" (Aube and Perloff, 2017). In her solo exhibition *an oval, a vowel, an e* (Raffn, 2021a; Figure 10.5), concrete forms are rooted in concepts and questions concerning dimensionality in a physical meeting with the body.[16] The press release for *an oval, a vowel, an e* opens with *what if?*-thinking and embraces the more-than-human:

Figure 10.5 Raffn, M. (2021a) *an oval, a vowel, an e*. Vestjyllands Kunstpavillon, Videbæk, Denmark, June 26–July 18, 2021. Curated by Paola Paleari and Anne Zychalak Stolten. Photo: Jacob Friis-Holm Nielsen. Dimensions variable. Steel, plaster, pigment. @ Marie Raffn 2021. Installation view of organic line formations with embedded dyed reliefs in grouped compositions that could resonate with a drawing, a notational score or a scribble from a distance.

> What if one found oneself, in body and mind, within a cubist, polysemic universe—within an abstract language? … [the exhibition] leads our thoughts and associations towards a spatial, enlarged, fragmented drawing. A kind of three-dimensional, pluralistic and fractal translation of two-dimensionality. … We all reduce dimensionality in our own fashion; and somehow depict and understand the world cubistically, in different ways. Some species emit sounds and orient themselves by following echoes from surrounding objects. Can the works in the room detect each other and establish a similar relationship?
>
> (Paleari, Stolten, and Raffn, 2021)

In this way, "with an experimental approach, Raffn distorts the given uniformity of language" (Bhullar, 2022).

The geometrical sculptures, in the large installation, are three-dimensional but feature prominent, two-dimensional surfaces inviting inspection (similar to Friedrich's ice fragments). The outlines of the spatial wavy lines and the sculptural, dyed sheer color reliefs change significantly depending on the angle from which they are viewed, creating various formations and compositions. The cubistic "preference for discrete, palpable objects" (Rosenblum, 1975, p. 192) and multi-perspectival geometrical reconstruction of reality comes to the fore here: "my sculptures are rooted in material and textual worlds," Raffn says. "New connections… arise through associations and games that welcome other ways of understanding" (Raffn, 2021b). The abstract reveals itself as a metaphysical layer of higher-level-thinking, which may equate to an enigmatic kind of mysticism.

Whereas the installation *an oval, a vowel, an e* spreads over physical space, the sculpture *Untitled (VEAAVI)* (Raffn, 2023) (Figures 10.6 and 10.7) is an open-ended steel collage of the signs of the notational system of Raffn (2019), where each sculptural fragment is a "movement notation" somewhere between a letter, a sign, and a drawing. The capital letters in the title *Untitled (VEAAVI)* are taken directly from those signs that resemble letters in the lower "row" of the sculpture (Figure 10.6), emphasizing how something concrete and simultaneously open and formal turns into an increasingly abstract language. As with Hilma af Klint, this is an exploration of the potential of what signs or symbols could mean, rather than the search for one specific answer.

Raffn's engagement with concrete poetry again elevates visual form and the spatial composition of words in addition to semantic, meaning-laden output. This applies to her spatial installations as well as to her artist books:

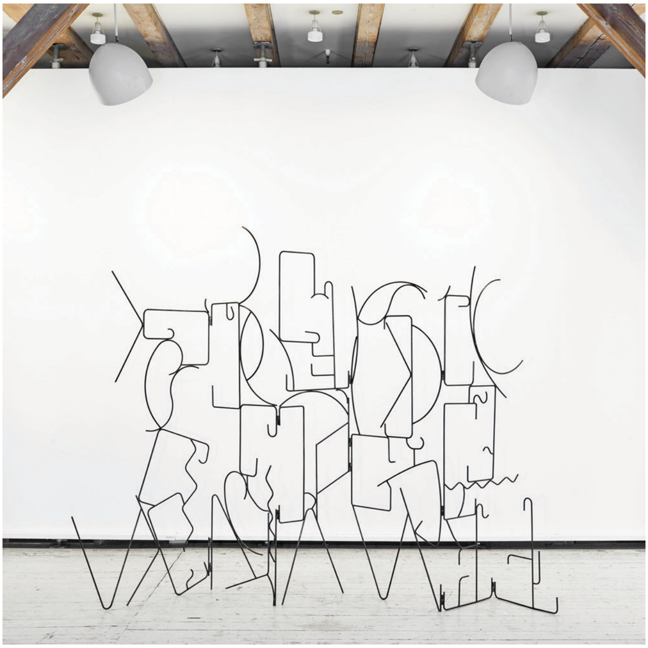

Figure 10.6 Raffn, M. (2023) *Untitled (VEAAVI)*: frontal view. Approx. H 240 × L 75 × W 290 cm. Steel. @ Marie Raffn 2023. The Danish Art Workshops, Copenhagen, Denmark. Photo: Jenny Sundby. The sculpture has a slender construction rising upwards that appears both loose and tight, constructed by fragments in a compressed composition.

> I have chosen to tell you about the artists' book from a Swedish perspective but without stopping at any borders. My method has not primarily been chronological. The history running from Asger Jorn and C O Hultén up to Marie Raffn and Lina Nordenström has not been hung on a timeline, quite simply because that would give the impression that one thing leads to the other. This rarely happens. The history is much more interesting than this, with threads, thoughts, expressions crossing, mixing, combining.
>
> (Millroth, 2021, p. 29)

Viewed head on, *Untitled (VEAAVI)* looks almost two-dimensional (an uncanny appearance since this would make it impossible for it to balance) (Figure 10.6). In the sensory encounter with the spectator's moving body,

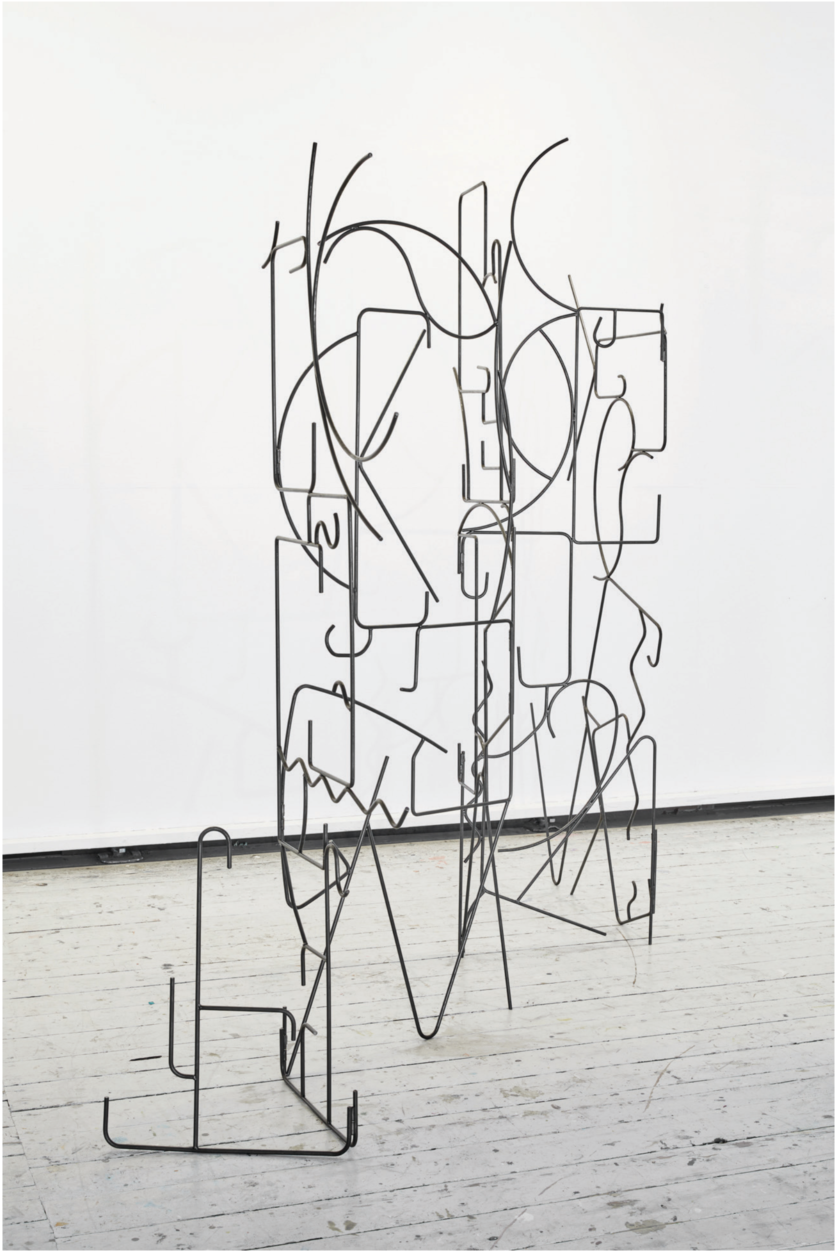

Figure 10.7 Raffn, M. (2023) *Untitled (VEAAVI)*: 45-degree angle view. Approx. H 240 × L 75 × W 290 cm. Steel. @ Marie Raffn 2023. The Danish Art Workshops, Copenhagen, Denmark. Photo: Jenny Sundby. The sculpture has a slender construction rising upwards that appears both loose and tight, constructed by fragments in a compressed composition.

the artwork's lines dissolve into geometrical, organic fragments overlapping in a cubist manner, and a bewildering number of voids emerge. Especially when viewed from the narrow side, the sculpture appears almost kaleidoscopic in its infinity (Figure 10.7).

From a distance, Raffn's works could read as drawings, notational scores, or scribbles. There is a consistency. Ocean. Something fluid? A visual poem. The unexplainably abstract. For instance, at the vernissage of *an oval, a vowel, an e* on June 26, 2021, selected sculptures served as a graphical score, read and interpreted by a violinist. The abstract relationship and translation between image and sound was also important to Kandinsky, as Müller-Westermann (2013) reminds us: "Synaesthetic perception became crucial for him: colors evoked tones and in turn, tones evoked colors" (p. 45). Furthermore, Wivel (2004) points out, a "cardinal point" in Kandinsky (1977/1912) is that the "visual arts should mimic music" (p. 13; Winther's translation). Likewise, abstract expressionist Agnes Martin desired her paintings to be a kind of music:

> It's not about facts, it's about feelings. It's about remembering feelings and happiness. A definition of art is that it makes concrete our most subtle emotions. I think the highest form of art is music. It's the most abstract of all art expression.
>
> (Beasley, 2021)

Raffn's *an oval, a vowel, an e* expresses a different, more liberated and perhaps less obsessive kind of vibrating humming than what is found in the immense, impressive installations of handwritten notations by conceptual artist and minimalist Hanne Darboven.[17]

> [N]umbers, words, and dates fill Darboven's grids to the saturation point. Often using the simple, reduced means of pencil and paper, she copies out by hand vast sequences so that "The writing fills the space as drawing would." And if a line from one of Darboven's works that is a letter to Sol LeWitt reads "writing writing"—as if "writing writing" were the fundamental operation of the work itself—then could we not see Agnes Martin "drawing drawing"?
>
> (Fer, 2006, p. 184, note suppressed)

To spiral back: the uncomfortable and incomplete synesthesia of sound, drawing, and sculpting were woven together at the vernissage of *an oval, a vowel, an e*.

If *an oval*, *a vowel*, *an e* captures dynamic, cubistic perspectivism—an abstraction from the world's entangled processes—then *Untitled (VEAAVI)* embodies the empty and present absence void within and between the signs of one communication system among many—an abstraction of pure semiotics. The feminine invisible in these artworks is yet to be made visible and analytically explicit.[18] Again, with absolutely no pretensions of even scratching the (flat? curved? fragmented?) surface of contemporary art, we turned to Raffn's 2021 installation and 2023 sculpture as subtle cases of geometrical forms, the void, and the mystical, not to say spiritual, in the abstract in (contemporary) art.

10.3.5 Integrating Abstraction through Robert Smithson

Robert Smithson's *Map of Broken Glass (Atlantis)* (Figure 10.8; Smithson, 1969a), an installation that "occupied a beach in Loveladies along the New Jersey coast… for twenty days in July 1969" (Hailey, 2020), permits us to sharpen up themes in Tharp, Friedrich, and Raffn.[19] Smithson was taken by the idea of a lost continent of Atlantis: "[there are many] hypothetical arguments in favor of Atlantis. Conjectural maps that point to this non-existent site fill many unread atlases. … From Plato's *Timaeus* to *Codex Vaticanus A* the documents of the lost island proliferate" (Smithson, 1996/1969, p. 133). What if such a place had existed? One sketch for this artwork, *Map of Broken Clear Glass (Atlantis)*, also from 1969, presents a large outline—with zigzag lines inside, representing glass shards—similar in shape to the outline of Atlantis from a map in Lewis Spence's *The History of Atlantis*, which is affixed to the sketch's upper-right hand corner (Smithson, 1969b). Another drawing from December of the same year, *A Surd View for an Afternoon* (Smithson, 1970/1969), shows another planned, immense project, in context: "The drawing's eccentric epicenter is *Island of Broken Glass*, which rests at the origin of an Archimedean spiral" (Hailey, 2020). As a minimalist working with land art, Smithson's work was suffused with maps and mapping (Wood, 2010, pp. 207–208; Siegert, 2023).

Much like Tharp's maps, Smithson's *Map of Broken Glass (Atlantis)* attempts to make visible the invisible ocean floor, in this case the fictive, even spiritual, *Atlantis*. His submarine topography was rough and sharp, hers rough or smooth. The artwork's glass shards are reminiscent of Friedrich's cubistic ice fragments, and the work's void, whether on a beach in New Jersey or cradled in a white cube, is the air above the installation representing several kilometers of frigid ocean water over the lost continent.[20] In *A Surd View for an Afternoon*, *Island of Broken Glass* is shown sitting at the center of a spiral *and* a "triangulated spiral".[21] Raffn is inspired by Smithson—*an oval, a vowel, an e* resonates with his work's fragility, mapping between two-dimensional and three-dimensional space, and ambiguous semiotics. Might large shards represent rocky outcrops while small shards along the edges are a kind of mathematical device

This figure has been removed from the OA ebook version of this book at the request of the rightsholder.

Figure 10.8 Robert Smithson, *Map of Broken Glass (Atlantis)*, 1969. Dia Art Foundation; Partial gift, Lannan Foundation, 2013. © 2023 Holt/Smithson Foundation/Licensed by Artists Rights Society (ARS), NY. Photo: Florian Holzherr, courtesy Dia Art Foundation, New York. H 48 × L 240 × W 192 in. Glass. Smithson's artwork consists of turquoise-tinted glass shards of different sizes pressed against each other, with surprising vertical effects, and likely in the outline of Lewis Spence's Atlantis. The image is available online at www.diaart.org/collection/collection/smithson-robert-map-of-broken-glass-atlantis-1969-2013-027

where groups or sets of glass infinitesimals asymptotically approach a smooth topography? We are here far from the regimented semiotic codes of Tharp's maps.

The elements of the abstract that we have considered are represented in Smithson's *Map of Broken Glass (Atlantis)*:

- the mapping and abstraction of topography in various ways (e.g., selection, simplification, and exaggeration protocols);
- geometrical, cubistic forms (including circles and spirals);
- the void;
- the play between the two-dimensional and the three-dimensional;
- manufactured and raw materials;
- semiotic codes.

Should we imagine these elements as simultaneous layers of abstraction, or is each an independent, particular form of abstraction? Can and should we use lessons from the history of art and art theory to illuminate the abstract—and abstraction practices—in philosophy of science?

10.4 Art, Science, and Abstraction as *What If?*-Thinking

Recall the Kaf plate with which we began this chapter. This everyday object can play multiple roles. We can eat a pastry on it, for instance. But we can also employ *what if?*-thinking and imagine it as an abstract object, in at least two senses. (The reader could undoubtedly imagine more.) It could allude to artwork such as Jackson Pollock's abstract expressionist paintings. The plate could also, you will recall, be imagined as a star map. In that role it invites many open-ended investigations and even paradoxes about space, cartographic projections, and existence. It also invites us to an important meta-question: *What if we thought of abstraction as what if?-thinking?*

In this chapter, we have drawn on examples from art and science to show that different kinds of abstraction result from different kinds of *what if?*-thinking. Reconfigured in this way, our analysis of abstraction and the creative practices it invites can be seen as substantively contributing to the philosophy of science literature on representation, broadening those debates beyond questions of how a representation fits data or matches the world. The account of *what if?*-thinking we propose here is in line with the *multiple representations account*, recently developed by one of us in the context of cartography and philosophy of science (Winther, 2020a; see further developments by Walsh and Rupik, 2023 and Rupik, 2024). The multiple representations account:

> explores the process of how map *becomes* world. …the first stage or moment is *ontologizing,* when we make the abstraction the world. The second moment is *merely-seeing-as*, when we are aware that our abstraction is not the world. Practice enriches theory in the third, synthetic moment of *pluralistic ontologizing*. Here a scientific community or the lay public uses various representations to measure, change, or understand the world, with the ability to test different representations for these purposes side by side.
>
> (Winther 2020a, p. 128; note suppressed)

According to this account of representation, one can proceed through different stages of representation, first conflating representation and reality, then refraining from doing so, then finally taking up different representations and experimentally employing them to understand, and intervene in, the world. Winther's multiple representations account asks: What if different scientists developed a variety of models about the same, as it were, system or part of the world?[22] These models or maps themselves originate in prior processes of abstraction involving *what if?*-thinking.[23]

Our open-ended exploration of abstraction as *what if?*-thinking in art and science has shown that abstraction can neither be reduced, without conceptual harm, to a philosophical moniker, nor can it be reduced to a single relation or practice—e.g., "omission," "distortion," or "simplification," as some in philosophy of science would have it. Roughly put:

> *Abstraction is a cognitive, aesthetic, and social process of analyzing, creatively adding to, and what-if?-thinking about (1) the actual known, shared world; (2) alternative realities that may still be actually existent (e.g., scientific experiments); or (3) artistic or fictional imaginary worlds—eventually presenting (in language, mathematics, visual representations, music, etc.) and storing (in the mind, as computational data, on a canvas, etc.) information about salient (in a particular context, for a particular question) aspects of such worlds.*

This is our rather imprecise, rule-of-thumb characterization of abstraction, which we will call *creative abstraction*.[24] Let us distill it more:

> *Abstraction is a creative deconstruction (analysis) and reformulation (synthesis) of worlds, which may be motivated by asking what if?*

Abstraction both conserves and challenges existing thinking. Even in standard cartography, abstraction involves a subtle tension between representing and questioning the status quo. It is tempting to believe "that which is mapped, *is*, and that which *is*, can be mapped"; on the other hand, and asking *what if?*: "Can cartographic reason re-create our world? Can it bring forth new worlds?" (Winther, 2022; emphasis added).

We have seen how different visual creators bring forth new worlds by abstracting with *what if?*-thinking. First, Tharp abstracts *cartographically-scientifically* by asking: What if we could remove the seawater above the ocean floor, and thereby visualize with maps the otherwise invisible seafloor? Friedrich abstracts *sublimely* by asking: What if an immense and monochrome sky or a field of ice fragments could open our imagination to a metaphysical world? Af Klint abstracts *spiritualistically* by asking: What if I could use color, shape, and composition in serving as a medium to the world of spiritual beings? Raffn abstracts *synaesthetically* by asking: What if the spectator could walk among colorful and enigmatic signs, and experience how sound, drawing, and sculpting are entangled in a fragmented and pluralistic world? Smithson abstracts *cartographically-artistically* by asking: What if open-ended, disjointed, or physical maps could point toward realms of mental potential?

If Winther (2020a) explores how cartography could enrich philosophy of science, this chapter, and perhaps this edited volume in general, seems part of an investigation into how art, art history, and aesthetics could teach philosophy of science. What if philosophers of science looked to entire other domains of human expression—e.g., cartography and art—to understand science? *When Maps Become the World* was premised around the map analogy: "a scientific theory is a map of the world" as explored in its Chapter 2: "*Theory* Is to *World* as *Map* Is to *Territory*" (Winther, 2020a, p. 29, pp. 28–57). At least implicitly, our chapter also points to an analogy that can be stated via *what if?*-thinking: *What if mathematics is to the natural sciences as abstract art is to depictive art?*[25] Just as abstract art is non-depictive, systematic, mystical, and even spiritual, so mathematics is transcendent, imaginative, and explores the possible—both are steeped in creating alternative worlds.[26] They are paradigm cases of *what if?*-thinking.[27] In contrast, perhaps like depictive art, the natural sciences aim at representation, and, like depictive art, are also constrained by our given, shared, and experienced world.

In short, in so far as abstraction involves rethinking and redoing the status quo, abstraction involves *what if?*-thinking. Such creative abstraction helps us make multiple representations that attempt to track the world, and it helps us produce artistic works opening up worlds of imagination. In that sense, our characterization of creative abstraction captures abstraction in science and art.

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Notes

1 See Wertenbaker (1974), Oreskes (1999), (2021), Barton (2002), Doel, Levin, and Marker (2006), North (2010), Felt (2012), Winther (2019), (2020a), (2022), and Higgs (2020) for parts of Tharp's biography and context.

2 Higgs (2020), p. 238 presents a thought-provoking counterfactual history pointing to an alternative reality in which invisible women scientists are made visible (cf. Oreskes 1996). Elsewhere, Winther will track in detail, in the contemporaneous scientific literature, the general lack of recognition Tharp received for her 1952 proper, systematic discovery of the mid-Atlantic Ridge

rift (preliminary text available upon request). Theberge (2014a, 2014b, and 2014c) and Oreskes (2021), pp. 194–231 trace the discovery to earlier efforts.

3 Regarding Tharp's imagination: "I also wanted to include mermaids and shipwrecks, but Bruce would have none of it" (Tharp, 1999).

4 The physiographic diagram map was found in Elmendorf and Heezen (1957) "in envelope inside rear cover" (p. 1061). The map cartouche clearly indicates "Bruce C. Heezen and Marie Tharp" as the creators; states a "vertical exaggeration about 20:1"; and codifies four different categories of "fathom relief," from relatively smooth to strikingly vertical along the mid-oceanic ridge. A rift valley along the middle of the ridge is drawn on the map.

5 Heezen and Tharp (1966) is much shorter; more descriptive; lacks any significant theoretical discussions; and has a lower diversity of scientific maps. We also set aside the scientific maps of Heezen, Tharp, and Ewing (1959) because that volume has been discussed elsewhere, at least in general, and is much more methodological, containing many more profiles than significant maps, as it was their first attempt to map the ocean floor (cf. Figure 10.2). Heezen, Bunce, Hersey, and Tharp (1964) and Heezen, Gerard, and Tharp (1964) are highly descriptive papers filled with figures—including topographic profiles and temperature profiles as well as photographs of the ocean bottom—many of which are not standard maps. Even so, these figures deserve further exploration, particularly figures 1, p. 13, and 6, p. 20, of Heezen, Bunce, Hersey, and Tharp (1964), with their rich symbolization and semiotics.

6

> In an ocean such as the North Atlantic or South Atlantic the nearly precise symmetry of these oceans and the lack of any extensive aseismic ridges make such a [mantle "convection cells"—i.e., continental drift] pattern indeed attractive. However, in the Indian Ocean the existence of such divergent trends and the scattered ancient micro-continents make such explanation extremely difficult.
>
> (Heezen and Tharp, 1965, p. 101)

7 Heezen (1959) was the first presentation of Heezen's version of the expanding Earth theory (see especially Heezen, 1959, pp. 295, 300, 302, and the Q&A on pp. 302–304). Heezen was not the only defender of this theory (e.g., Carey, 1975). The theory was an imaginative, if ultimately unsuccessful, use of *what if?*-thinking.

8 While there is no reference to the "Distribution of smooth and rough topography in the world oceans" map (Figure 10.3) in the text of Heezen and Tharp (1965), there are ample qualitative descriptions of different regions and features visualized on this map. The map works as a visual summary.

9 There are also questions pertaining to cognitive science or even transcendental philosophy here: What if the abstract in art can show us how the eye's vision is constituted by innate cognitive structures? What if abstraction is a way of representing the mind's powers of abstraction to the mind?

10 A term which, according to art historian Nicholas Wadley, "originated from criticisms of the angular volumes in some of [Georges] Braque's paintings of 1908" (Wadley, 1970, p. 12). In collecting roughly 200 paintings that either fall under the style or school or movement of Cubism or are influenced by Cubism, Wadley (1970) serves as a window to Cubism.

11 What counts as a precursor? In "Kafka and His Precursors," Borges (1999/1951) writes, "the fact is that each writer *creates* his precursors. His work modifies our conception of the past, as it will modify the future" (p. 365, emphasis in original, note suppressed). The subsequent existence of artists, art styles, or art critics (e.g., Rosenblum, Schou) births the conception of an earlier artist or artwork as a precursor. For Rosenblum, it is the "dilemma" or dialectic between the sacred and the secular that provides the connecting thread "between Friedrich's *Monk by the Sea* and a painting by Rothko" (Rosenblum, 1975, pp. 10, 12, 218).

12 Relatedly, Nielsen (2022) discusses "The Cubistic Iceberg" in relation to the Anthropocene.

13 We believe that most surrealistic paintings depict figuratively with distortions, while Cubism works with abstract objects. In addition, we here set aside discourse about Cubism and the spatial "fourth dimension" (e.g., Wadley, 1970; Henderson, 1983; and Ambrosio, 2016).

14 Hilma af Klint's biographer, art historian Julia Voss draws an alternative history making invisible women artists visible (Voss, 2022, pp. 305–306). As with Marie Tharp, there is a larger cultural historical context—both then and now—diminishing the work and existence of women pioneers in science and art. Resonating with Higgs (2020) and Voss (2022), our chapter is also a *countermap* (Winther, 2020a) to standard historical narratives.

15 However, the imprint of the hand is present in her work, and although you will find commercial materials (steel, fiberglass, etc.) as well as (mathematical) systems, variations, and repetitions in her artworks, these are freer and more organic than what is typical of Minimalism.

16 When the exhibition title is said out loud, there is something Dadaistic and rhyming about the flow, emphasizing the play with language and semiotics in the installation.

17 Some of Darboven's handwritten writings on paper—e.g., the numbers and dates of Opus 17—were also composed into music, which she called "mathematical music" (Darboven, 1996; cf. Spice, 2015).

18 We are particularly keen and curious to do this by resonating with Cixous (1976), Irigaray (1991), and Niemanis (2017).

19 Smithson is perhaps best known for *Spiral Jetty* (1970). The ocean was rarely far from his imagination (see also his *World Ocean Map, 1967*—on display here: *Robert Smithson: Abstract Cartography*, 2021).

20 The Gambia Abyssal Plain, labeled on Heezen, Tharp, and Berann's classic 1968 *National Geographic* foldout map is approximately 5 kilometers deep, and would roughly be the southern edge of Spence's, and Smithson's, Atlantis.

21 Müller-Westermann (2013) observes that "the spiral permeates Hilma af Klint's entire œuvre" (p. 42). On the esthetic and epistemic import of spirals, see Didi-Huberman (2021).

22 Cf. Winther (2020a, pp. 253–254); Chapter 5 of Winther (2020a) articulates the multiple representations account as one philosophical account, among several, of scientific representation.
23 Winther (2014b) and Chapter 3 of Winther (2020a) contain extensive treatments of abstraction, which have served as hidden anchors for our analysis. Ohlsson and Lehtinen (1997) and Radder (2012) are also sui generis inspirations.
24 We are glad to acknowledge resonances between our "creative abstraction" analysis and the category of "generative abstraction" developed by Michael Stuart and Anatolii Kozlov (this volume) as well as, mutatis mutandis, the notion of "creative similarity" found in Sánchez-Dorado (2019).
25 There is so much to say about the relation between mathematics and the natural sciences. Two favorites: Gowers (2002) and Hacking (2014).
26 Elisa Caldarola (this volume) remakes the fragile distinction between the abstract and the depictive—we agree that this distinction is not absolute, but are here engaging in *what if?*-thinking.
27 We could further explore our *what if?* analysis by turning to one of our effective precursors, Walton (1990) (cf. note 11). But our project differs from his in multiple ways, including that we start with abstraction rather than with representation; we are honest to a systemic history of art; and we focus on artistic (and scientific) practices rather than on epistemology: How could the abstract in art inspire and expand our philosophy of science horizon? Ultimately, Walton's make-believe and our *what if?*-thinking continue resonating today.
28 Likely date confirmed by Marian V. Mellin of the Lamont-Doherty Earth Observatory (pers. comm. July 5, 2023).
29 Checked by Tobias Jung (pers. comm. July 5, 2023, Jung, 2023).

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