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The Standardized Coordination Task Assessment (SCTA)

A Method for Use-Inspired Basic Research on Awareness and Coordination in Computer-Supported Cooperative Settings

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Abstract

Today's modern world often affords individuals to form teams to work together towards shared goals and objectives. The need for tools to digitally support collaboration distributed in time and space increased over the past decades significantly with a recent sudden increase due to the Corona pandemic crisis. The research goal in the field of computer-supported cooperative work (CSCW) has always been to design systems that facilitate collaboration based on the understanding of groups and social interaction – especially on how people coordinate their work.

In the real-world coordination happens in a seemingly seamless and effortless way. However, the resulting mechanisms translated to digital systems often provide a clumsy and awkward experience as users lack the means for subtle and rich interaction beyond the spoken word. After numerous failures revealing system deficits and a large number of ethnographic studies, researchers identified *awareness* to become the support mechanism for effortless coordination in digital systems. Yet, instead of addressing the problem using appropriate methods and tools, researchers found themselves trapped in circular reformulations of concepts and evaluations of prototypes on the basis of disciplinary preferences ignoring the basic characteristics of the objects of interest. Even worse, the most basic design tensions stemming from a use-inspired perspective have not been resolved indicating a substantial problem with the evaluation of awareness and coordination support. Effortless coordination cannot be reached without being measured, thus not without an appropriate measurement approach.

This thesis introduces an appropriate assessment method for the efforts related to awareness and coordination support in cooperative settings – the STANDARDIZED COORDINATION TASK ASSESSMENT (SCTA). Applying a use-inspired basic research driven approach it creates and leverages an effort-based operationalization of the two constructs derived from literature and especially from a cognitive perspective. A highly automated and scalable framework delivers quantitative results to be used for hypotheses validations that allows a benchmark-based approximation of effortless coordination. At the same time the method opens the door for a lot more use-inspired basic research to resolve many of the still open design tensions and challenges.

Zusammenfassung

Die moderne Arbeitswelt von heute bringt es mit sich, dass immer mehr Menschen als Team im Rahmen gemeinsamer Ziele und Vorgaben zusammenarbeiten. Der Bedarf an Werkzeugen, die die digitale und damit die gleichzeitige räumlich und zeitlich verteilte Zusammenarbeit unterstützen, ist über die letzten Jahre stark gestiegen und erfuhr sogar in der jüngsten Vergangenheit eine zusätzliche starke Steigerung aufgrund der Corona Krise. Das Forschungsziel im Bereich Computer-Supported Cooperative Work (CSCW) bestand schon immer darin, die Zusammenarbeit auf Basis des Verständnisses von Gruppen und sozialer Interaktion im Rahmen von sozio-technischen Systemen zu gestalten. Ein Hauptaugenmerk liegt dabei immer auch auf dem Aspekt der Koordination.

Im Gegensatz zur digitalen Welt geschieht Koordination in der realen scheinbar mit Leichtigkeit und ohne große Mühe. Die für die digitale Welt entworfenen Möglichkeiten der Koordinationsunterstützung sind jedoch meist behelfsmäßig und eher ungünstig gestaltet, weil die Mechanismen für eine subtilere und reichhaltigere Interaktion, jenseits des gesprochenen Wortes, fehlen. Nach zahlreichen Fehlschlägen und einer Großzahl an ethnographischen Studien identifizierten Forscher „Awareness“ als zentralen Unterstützungsmechanismus für die mühelose Koordination in digitalen Systemen. Statt jedoch den Sachverhalt direkt mit geeigneten Methoden und Werkzeugen zu adressieren, fanden sich Forscher nach einiger Zeit in einem Zyklus der Reformulierung von Konzepten und der Evaluierung von Prototypen auf Basis von disziplinären Präferenzen wieder. Gleichzeitig wurden die Eigenschaften der Untersuchungsgegenstände häufig nicht beachtet. Zusätzlich wurden nicht einmal die grundlegendsten Forschungsfragen aus einer anwendungsinspirierten Perspektive beantwortet, sodass alles auf ein sehr grundlegendes Problem bei der Evaluierung von Awareness und Koordination hindeutet. Das Ziel der mühelosen Koordination selbst kann nicht ohne Messung erreicht werden und daher nicht ohne eine geeignete Messmethode.

Diese Arbeit stellt einen angemessenen Ansatz für die Bewertung von Aufwänden im Kontext der Koordination bei der digitalen Zusammenarbeit vor – das STANDARDIZED COORDINATION TASK ASSESSMENT (SCTA). Unter Anwendung eines anwendungsinspirierten Ansatzes zur

Grundlagenforschung wird eine aufwandsbasierte Operationalisierung der beiden Konstrukte, die zuvor auf Basis einer Literaturstudie insbesondere unter Berücksichtigung einer kognitiven Perspektive erarbeitet wurden, vorgenommen. Ein hoch-automatisiertes und skalierbares Rahmenwerk liefert quantitative Ergebnisse für eine Hypothesenvalidierung, die eine sukzessive Annäherung an die mühelose Koordination durch ein Benchmarking erlaubt. Gleichzeitig eröffnet die Methode Möglichkeiten für weitere anwendungsinspirierte Grundlagenforschung mit der viele der derzeit existierenden Gestaltungsprobleme angegangen werden können.

Acknowledgements

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1 out of 100

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1 Introduction

Nowadays, collaboration is key. Only few people achieve major results in their daily work completely on their own. The principle of the division of labor (Smith, 1776) has been introduced centuries ago, resulting in many different approaches like professional specialization, division of work within a company and between companies, or the split of work among man and machine (Bücher, 1893).

Figure 1-1. Collaborative work as a collocated team (Source: Pixabay, CC0).

With the advent of modern information technology (IT), collaboration lost its restrictions as to work together at the same time and place (cf. Figure 1-1). For instance, "more than 26 million Americans – about 16% of the total workforce – now work remotely at least part of the time (...) Between 2005 and 2015, the number of U.S. employees who telecommuted increased by 115%" (Greenbaum, 2019, p.54). There are further advantages and reasons for this trend besides the technical evolution: the hiring of distributed talent (not only the one closest to the office), hiring of staff outside expensive metropolitan areas, a gain in flexibility, time savings, reduction of transportation and child-care cost as well as a better work-life balance. Disadvantages of remote work especially include fewer opportunities to talk directly (i.e., fact-to-face) or to engage in side talks and to network or interact with colleagues.

The recent Corona pandemic crisis that has started in late 2019 gave the trend another major push towards remote work. For instance, by mid 2020 more than 60,000 out of 87,000 employees at Deutsche Bank worked from home or from elsewhere outside of the bank's facilities (Jones & Maisch, 2020) – a number many deemed impossible even shortly before the crisis. Large numbers of people, even those until that point unwilling, were basically forced into the situation of having to use applications for computer-supported cooperative work (CSCW) for their daily tasks. "We Live in Zoom Now", headlined an article in The New York Times in early 2020 (Lorenz et al., 2020).

Figure 1-2. Working in a distributed setting using Zoom (Source: Zoom Inc.).

ZOOM (cf. Figure 1-2) is a videoconferencing and collaboration tool offered by Zoom Inc.[1]. In detail it facilitates collaboration by providing the following functionalities:

- Integrated high definition (HD) video and audio supporting meetings up to 1,000 participants
- Recordings and transcripts generated using artificial intelligence (AI)
- Screensharing and annotations
- Calendar support for event scheduling
- Team chat
- Encrypted sessions and role-based security features

Its competitor named TEAMS (cf. Figure 1-3) by Microsoft Inc.[2] gained a large share of new users during this crisis as well.

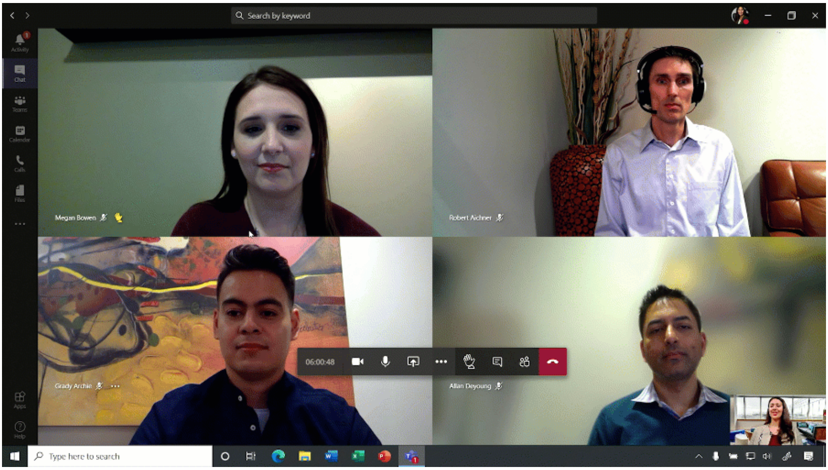

Figure 1-3. Microsoft Teams (Source: Microsoft Inc.)

1 https://zoom.us/

2 https://www.microsoft.com

Starting in 2017 as a chat-based workspace as part of OFFICE 365[3], it recently passed the mark of 44 million users (Spataro, 2020).

> “Over the last three years, thousands of organizations, small and large—including 93 of the Fortune 100—have discovered how TEAMS can be their hub for teamwork, helping them to stay connected and engaged. Industry leading organizations are rolling out TEAMS enterprise-wide. In fact, 20 customers have more than 100,000 employees actively using TEAMS, including Ernst & Young, SAP, Pfizer, and Continental AG, as well as Accenture, which has 440,000 employees actively using TEAMS” (Spataro, 2020).

Similar to ZOOM, TEAMS offers the following features for remote collaboration (Microsoft, 2020):

- Shared workspace and file storage
- Direct messages and group chat as well as channels for structuring threaded conversations
- Videoconferencing (instant as well as live events for invited people) including screensharing
- Integration into Microsoft’s OFFICE 365, e.g., to share documents, spreadsheets, calendars and emails

The third tool that has gained great popularity in this area (even before the crisis) is SLACK of Slack Inc.[4]. It appeared years before TEAMS and was conceived by Microsoft as its main competitor and source of ideas (Warren, 2017). Therefore, Microsoft developed very similar features like the one of threaded communication, mentioned in the feature list above. SLACK (cf. Figure 1-4) specifically allows the structuring of text-based instant messaging communication into threads (also referred to as channels) besides direct calls or multiuser conferences. Stewart Butterfield, creator and founder of Slack Inc., describes his tool as “all your communication in one place, instantly searchable and available where ever you go” (Hamburger, 2014). It integrates with a number of popular

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[3] https://www.office.com/

[4] https://slack.com/

applications (e.g., TWITTER[5], GITHUB[6] or DROPBOX[7]) on a channel basis. Originally SLACK even started out to “kill email” altogether (ibid.).

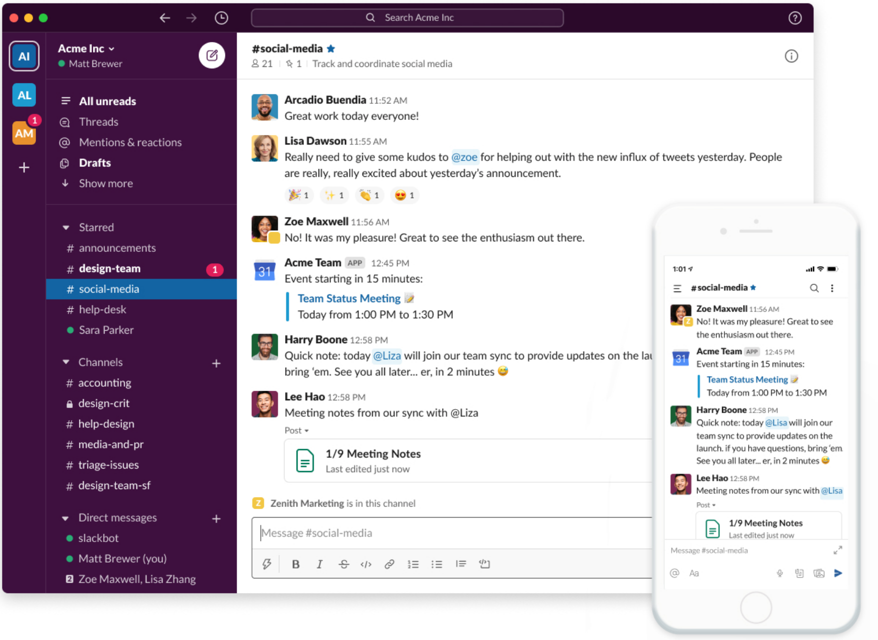

Figure 1-4. Slack mobile and desktop frontends (Source: Slack Inc.).

However, working with digital means to overcome separation and to collaborate across time and space introduces a lot of new challenges. It starts with technical issues, bad connections and security problems (as with the recent “Zoombombing”, i.e., the unwanted intrusion into a videoconferencing call causing disruption (Lorenz, 2020)) up to the overall issue of disembodiment (Bellotti & Sellen, 1993; Boyd, 2002; Heath & Luff, 1993; Kang, 2007; Tian, 2017): Though using beautiful colored icons, great

5 https://twitter.com

6 https://github.com

7 https://www.dropbox.com/

photos, high definition audio and video, i.e., the best that technology has to offer, the digital world only provides awkward and imperfect means for rich communication to express feelings, moods, attitudes or other social affordances. Opposed to the real world where people instinctively find ways to collaborate seamlessly and effortlessly, the digital world still needs to explicitly find additional means to support the social and cognitive act of collaboration as a whole – the centerpiece thereof being the support of effortless coordination in distributed settings.

The remainder of this chapter will provide a deeper background on the scientific context of this thesis, introducing the area of computer-supported cooperative work (CSCW) especially focusing on support functions to collaboration including their evaluation as part of the design of CSCW applications with the goal to achieve effortless coordination for the digital world. Further, this chapter provides the fundamental problem statement, hypotheses and research objectives of this thesis as well as an overview of its overall contribution before eventually outlining its structure.

1.1 Setting the Scene

This research falls within the field of computer-supported cooperative work (CSCW), a theme in the study of human-computer interaction (HCI). HCI itself is an area of research and practice that emerged in the early 1980s especially with the advent of graphical user interfaces and the following consumerization of computer equipment. It is the region of intersection between cognitive sciences, human factors and computer science (Carroll, 1997; Grudin, 2012; Myers, 1998).

CSCW attempts to achieve a deep understanding of group work and other types of social interaction to develop adequate technical concepts and tools for social interaction (cf. (Baecker, 1993; Greenberg, 1991; Gross, 2013)). In an early attempt, Wilson (1991) defined CSCW as "a generic term which combines the understanding of the way people work in groups with enabling technologies of computer networking, and associated hardware, software, services and techniques" (Wilson, 1991, p.1). In more detail, CSCW researchers are interested in the behavioral aspects of group activity (e.g. (McGrath, 1984)), the study of group interaction in the wild (e.g. (Heath & Luff, 1991)), the conceptualization and development of appropriate tools and their continuous evaluation and adaptation (Borghoff & Schlichter, 2000). The term CSCW itself was coined by Irene Greif at one of the first workshops in 1984 (Greif, 1988). The major difference between HCI and CSCW lies in the fact, there is not only one human-being involved but at least two or more trying to interact using their computers – or information technology (IT) devices in more general terms. Mixed systems of this sort which are to be supported technically, are also referred to as socio-technical systems (Trist & Bamforth, 1951). They typically consist of the four components that became the Leavitt Rhombus (Leavitt, 1958): humans, tasks, technologies, and organizations (cf. Figure 1-5).

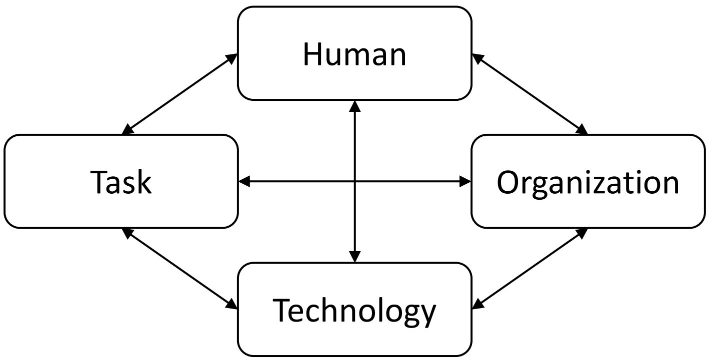

Figure 1-5. Components of group work aka Leavitt Rhombus (Leavitt, 1958).

Cooperative work itself, which is a central aspect of this thesis, differs in many ways with some forms requiring closer interaction than others. This can be expressed by the degree of required communication (Bair, 1989; Borghoff & Schlichter, 2000, p.110) (cf. Figure 1-6).

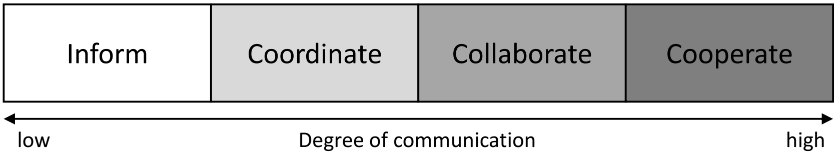

Figure 1-6. Inform, coordinate, collaborate, and cooperate indicating closer interaction from left to right (Bair, 1989).

There are four stages which at the same time serve as an indicator for the degree of work coupling (Neale et al., 2004):

- Inform: This is the general exchange of information (not only related to collaboration) indicating loose coupling.
- Coordinate: People coordinate the information flow and their activities, e.g., when using shared resources.[8]
- Collaborate People work together towards the same goal, yet, direct interaction remains sporadic, as they fulfill distinct and separate sub-tasks.
- Cooperate: People share common goals, a common plan, and data that supports coordination. The demand of direct interactions (e.g., fact-to-face) is especially high, as teams work on shared tasks of the same goal indicating tight coupling.

It is important to note that each stage requires the ones to its left (cf. Figure 1-6), i.e., cooperation and collaboration require coordination which requires information or better communication.

Progress in CSCW used to be driven by new means of technology or new tasks or task requirements (Borghoff & Schlichter, 2000). However, more recently CSCW appears to focus more on research that describes collaborative environments in practice instead of testing hypotheses or developing novel systems (Wallace et al., 2017). Moreover, CSCW is not limited to computers anymore but rather encompasses all kinds of information technology (IT) devices. That is why the Association for

[8] This actually represents only a limited view on coordination. A more precise picture will be elaborated later in section 3.2.

Computing Machinery's (ACM) CSCW conference generally focuses on "research in the design and use of technologies that affect groups, organizations, and communities" (Bietz & Wiggins, 2020). Actually, all other parts of the acronym CSCW advanced as well over the past decades (Wallace et al., 2017).

> "The terms computer, support, cooperative, and work have all been transcended. CSCW encompasses collaboration that uses technologies we do not call computers, collaboration in which technology plays a central rather than a support role, uses involve conflict, competition, or coercion rather than cooperation, and studies of entertainment and play" (Grudin & Poltrock, 2020).

The IT systems being developed in this area are commonly referred to as groupware. This term was first defined by Johnson-Lentz as "computer-based systems plus the social group processes" (Johnson-Lentz & Johnson-Lentz, 1982, p.47). This very generic conception gained more detail as Ellis et al. (1991) defined it as "computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment" (Ellis et al., 1991, p.40). Additionally, groupware systems are also commonly referred to as CSCW applications (Grudin, 1994a). Both terms are used synonymously throughout this thesis. ZOOM, TEAMS, and SLACK (cf. section 1) are all modern-day examples of CSCW applications or groupware.

Groupware or CSCW applications have been defined and classified in many ways. A prominent classification scheme is the *Time-Space Taxonomy* (Johansen, 1988) (cf. Figure 1-7), which was extended in many ways later on (cf. (Ellis et al., 1991; Grudin, 1994a) or section 5.2). It allows the differentiation of systems along the axes of their distribution in time and space.

Another classification relevant here is the 3C model (Teufel et al., 1995). It organizes CSCW applications according to their implementation of support functions for group activities: **C**ommunication support, **c**oordination support, and **c**ooperation support (cf. Figure 1-8).[9]

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[9] This follows the line of (Bair, 1989) renaming inform to communication, keeping coordination and grouping collaboration and cooperation.

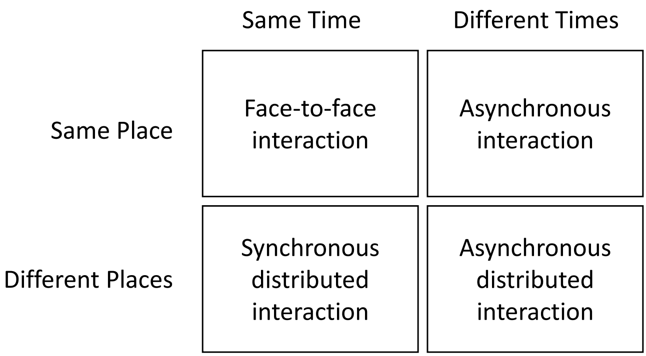

Figure 1-7. Time-Space Taxonomy (Johansen, 1988).

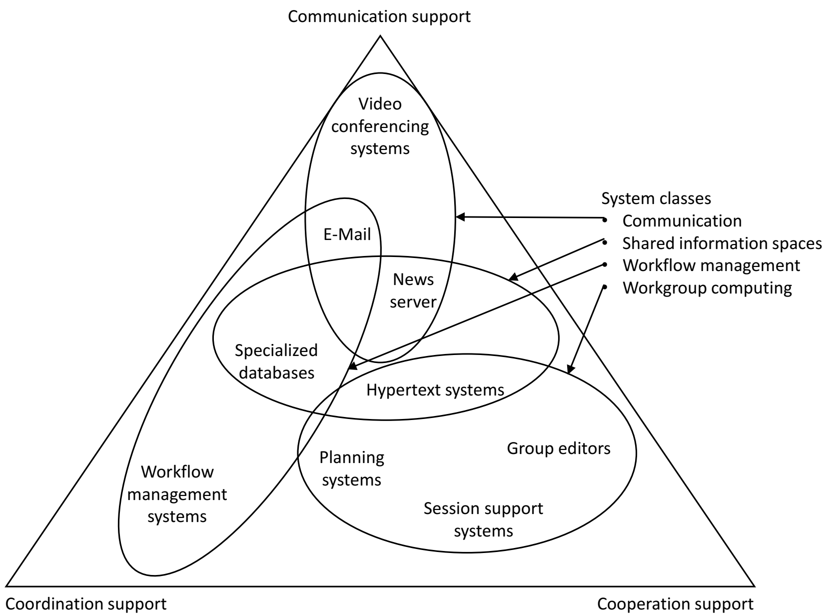

Figure 1-8. 3C model based on CSCW support functions (Teufel et al., 1995).

Support functions are required by group members in order to cooperate effectively and efficiently across time and space (and team members) and to counter the effects of disembodiment (cf. section 1). ZOOM, TEAMS and SLACK can be placed in the middle of the 3C model since they offer features for communication (videoconferencing and text messaging), cooperation (shared workspace and file sharing), and coordination (team calendar). Gross & Koch (2007) later expanded the classification of CSCW support functions from three to five different types (cf. Figure 1-9). Among these support functions are the concepts of coordination and awareness support. The term coordination is defined as "the harmonious functioning of parts for effective results" or "the process of organizing people or groups so that they work together properly and well" (Merriam-Webster, 2016c). Awareness in cooperative systems is the mutual knowledge of each other's presence and activities that has a positive effect on coordination (Dourish & Bellotti, 1992). Both concepts appear to work seamlessly and effortlessly in the real world (Schmidt, 2002, 2011a).

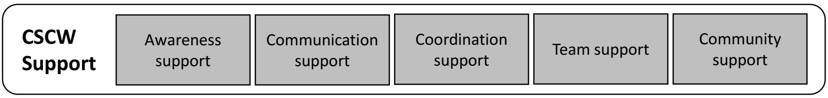

Figure 1-9. Classification of CSCW support functions (Gross & Koch, 2007).

The design and development of groupware and technologies that is based on the understanding of how groups cooperate (Bietz & Wiggins, 2020) tries to translate the same effortless experience of coordination to the digital world (Gross, 2013). The design typically involves an evolutionary process joined by users and/or entire teams in the lab as well as in the wild (Dourish, 1995; Schmidt, 2009; Tang, 1991). Evaluations are an essential and critical part of these development cycles. In CSCW, these should not only cover the user's main task but also the support functions for coordination and awareness – an issue unique to CSCW. The successful translation of *effortless coordination* would be proven by an appropriate evaluation in the form of before-after or A/B testing (Sauro & Lewis, 2012).

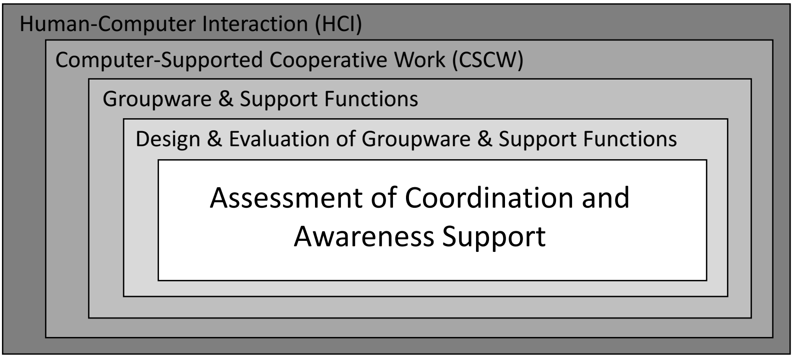

Figure 1-10. Research context of this thesis.

This is where the problem addressed by this thesis begins: the assessment of coordination and awareness support. Figure 1-10 summarizes the overall research context.

1.2 Problem Statement and Research Hypothesis

In general, a research problem in HCI and thus also in CSCW "is a stated lack of understanding about some phenomenon in human use of computing, or stated inability to construct interactive technology to address that phenomenon for desired ends" (Oulasvirta & Hornbaek, 2016, p.4960). HCI research is conceived as a problem-solving activity altogether. Scientific progress in this area improves the solution of problems related to human use of computing. This in turn leads again to new research problems (cf. Figure 1-11). All in all, Figure 1-11 describes the evolution of HCI (and also CSCW) research. The problem addressed by this thesis is that there is no appropriate evaluation or assessment method available to judge on the efforts involved with coordination in computer-supported cooperative settings. The effects are that CSCW researchers are not able to tell whether or not they reached their goal of effortless coordination and what caused it to be reached. This further implies that researchers currently do not know what causes more or less effort when users are engaged in an activity requiring coordination. Thus, it is unknown what preferred solutions are to typical design challenges – this implies that a lot of basic research is needed once a method becomes available.

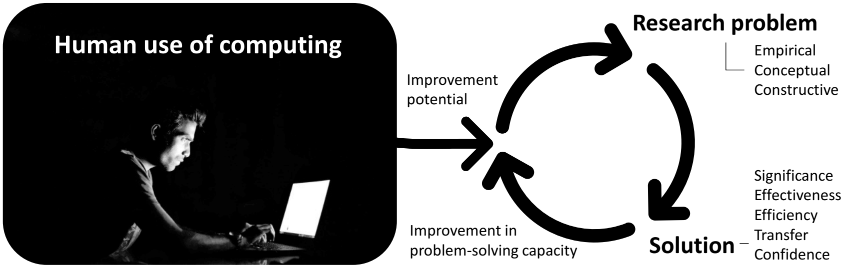

Figure 1-11. HCI research problems (Oulasvirta & Hornbaek, 2016).

From this situation, the following research hypothesis can be derived: in order *to reach effortless coordination in digital systems, coordination (and awareness) need to be made measurable and to be measured.*

This research involves a lot of literature, concepts and terms from cognitive sciences. It depends

> "on the development of viable constructs and principles to promote better understanding of human performance in complex systems (...) [It] puts forward theoretically based constructs and tests their generality through empirical studies in a wide variety of laboratory tasks, simulators, 'microworlds,' and actual work domains. A desirable feature is that the constructs and/or principles are quantifiable in the form of either mathematical or computational models" (Parasuraman et al., 2008, pp. 140).

The American Psychological Association (APA) defines constructs as an "exploratory model based on empirically verifiable and measurable events or processes – an empirical construct – or on processes inferred from data of this kind but not themselves directly observable – a hypothetical construct" (APA, 2020). Most of the constructs of cognitive psychology are hypothetical constructs. For the case of awareness and coordination this thesis connects the dots from previous work (main and helpful sidetracks) learning about their attributes and characteristics to form these constructs.

The above-mentioned research hypothesis will be investigated and tested by the research activities as part of the following research objectives:

- Objective 1: build a construct for awareness (conceptual operationalization). This objective will be met by reviewing existing literature on the subject from the area of CSCW gathering typical characteristics and underlying processes.
- Objective 2: build a construct for coordination (conceptual operationalization). This objective will be met by reviewing additional existing literature from the areas of CSCW, HCI and cognitive sciences.
- Objective 3: design a measurement approach to assess awareness, coordination and respective support systems. This objective will be met by suggesting a method and to demonstrate its applicability with reliable and valid results.

All of the work in this thesis builds on the following assumptions, some of which will be explained in greater detail in the course of this thesis:

- The progress in CSCW and more specifically with support functions is directly linked to how these means are designed and evaluated.
- CSCW design more specifically fails at the evaluation stage due to many reasons (e.g., preference-based measurement, application of inappropriate methods, lack of appropriate methods etc.).
- Awareness and coordination have not been sufficiently studied and explained by CSCW to reach their effortless state in digital systems.
- Both constructs are something mental and have to be studied as such. That is, appropriate constructs need to be developed, as it is done for instance in cognitive psychology.
- Awareness and coordination can be evaluated separately and even in early stages of the development cycle as their means of support are independent of a situated context.
- Awareness and coordination are even independent of a specific task as coordination activities depend on the coordination's interdependency type.

1.3 Scope

This thesis does not seek to create large amounts of design principles ready to be applied by practitioners and the industrial sector, though this might be the result of the application of the constructs and method developed as part of this thesis.

Another topic somewhat related but out-of-scope are context-aware applications (Dey, 2001; Gross & Specht, 2001; Schilit & Theimer, 1994). A system is considered "context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" (Dey, 2001, p.5). In the context of this thesis, awareness is a vital characteristic of a human-being, not of a system. However, this does not exclude context to be a key information as part of awareness and coordination support systems.

1.4 Contribution

According to Evans et al. (2014) there are four general areas of contributions:

1. Theory development
2. Tangible solutions
3. Innovative methods
4. Policy extensions

Circling back to the beginning of HCI research (cf. section1.2), its research problem-solving can be categorized into three subtypes (cf. Figure 1-12): empirical, conceptual, and constructive.

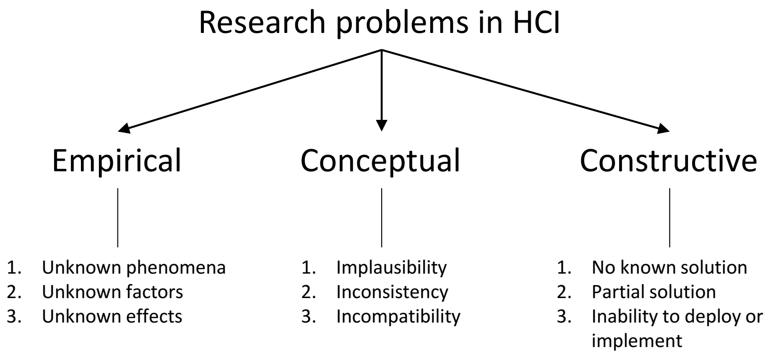

Figure 1-12. HCI contribution types (Oulasvirta & Hornbaek, 2016).

While empirical and conceptual types stem from Laudan's *Theory of Scientific Growth* (Laudan, 1978), the constructive type was added to HCI to represent engineering and design contributions. Further, "this typology is orthogonal to the well-known Pasteur's Quadrant which constitutes an attempt to bridge the gap between applied and basic research by suggesting 'use-inspired basic research' as an acceptable type"(Oulasvirta & Hornbaek, 2016, p.4958). Pasteur's quadrant (Stokes, 1997) (cf. Figure 1-13) is a classification of scientific research seeking a fundamental understanding of scientific problems, while also having immediate use. It bridges the gap between "basic" and "applied" research as coined by Bush (1945).

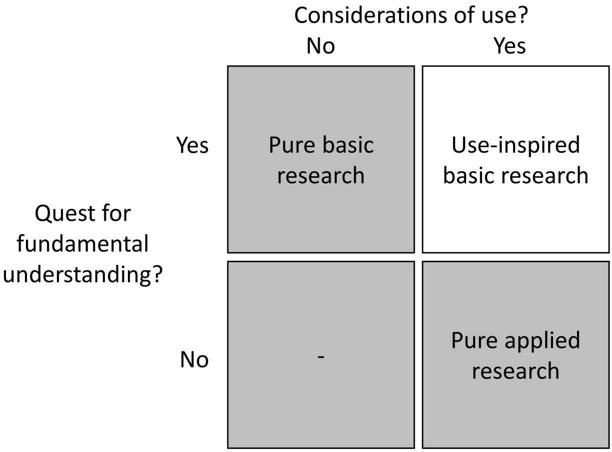

Figure 1-13. Quadrant model of scientific research: Pasteur's quadrant (Stokes, 1997).

In terms of these categorizations above, this thesis' contribution includes an innovative method (cf. Evans et al., 2014) comprised of a conceptual and constructive part (cf. Oulasvirta & Hornbaek, 2016), all of which belongs to the quadrant of use-inspired basic research (cf. Stokes, 1997) considering use while at the same time seeking a fundamental understanding of awareness and coordination support. In more detail, this contribution encompasses the following:

- A construct for awareness in CSCW (conceptual operationalization)
- A construct for coordination in CSCW (conceptual operationalization)
- A construct for the relation of awareness and coordination
- A quantitative evaluation method assessing the quality of awareness and coordination and their support in cooperative settings.
- A demonstration of the applicability of this method, especially in the context of forgetting and disruption in cooperative settings.

1.5 Structure

All of the above will be described and achieved using the following structure (cf. Figure 1-14):

- Chapter 1 introduces the basics for the term awareness, offering definitions and characteristics on the topic to build an initial construct extending on the introduction of CSCW (cf. section 1.1) and leading to the problems stated above (cf. section1.2). This chapter basically presents the story of awareness and awareness support as it can be found in standard CSCW textbooks. The chapter concludes with a discourse on issues that become apparent along the way.
- Chapter 3 adds the not so well-known aspects of cognition and coordination to the picture. This chapter establishes the construct of coordination also highlighting the differences to awareness as well as describing their relationship. It also closes with a discourse on some of the issues raised in this chapter.
- Chapter 1 continues taking a look at the design and evaluation of CSCW applications, also focusing on challenges and difficulties regarding the evaluation and assessment of groupware, especially for the cases of awareness and coordination. As the previous two chapters this one closes with a discourse as well.
- Chapter 1 introduces the (constructive) solution to the problem, the STANDARDIZED COORDINATION TASK ASSESSMENTS (SCTA). It describes the goals, construction, implementation, evolution, and its means of analysis. A small evaluation of the solution concludes this chapter.
- Chapter 1 extends on chapter 1 describing the method's applications and experiments including findings and results.
- Chapter 1 summarizes the work presented in terms of meeting the research objectives. It provides an overview of possible future work and next steps and eventually draws a conclusion on the achieved objectives.

Figure 1-14 depicts an overview of the structure.

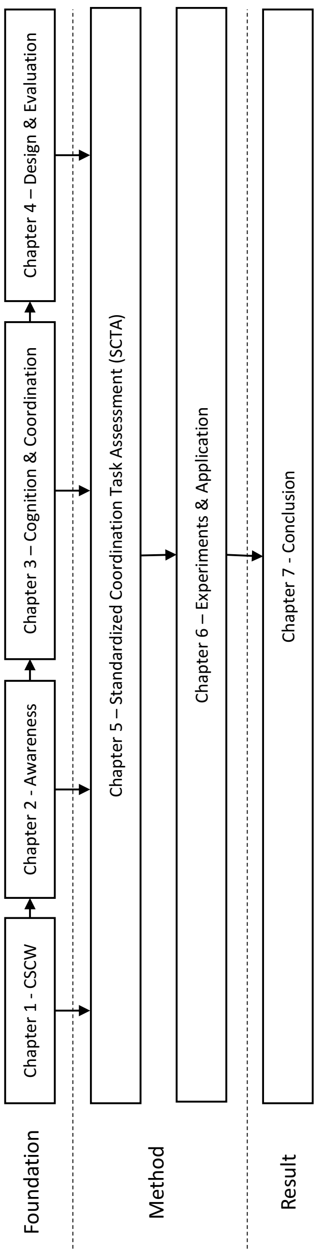

Figure 1-14. Thesis structure.

2 Awareness & Awareness Support

At a first glance, targeting effortless coordination and then starting with awareness and awareness support instead of topics focusing on coordination appears a little odd. Yet, this reflects how history evolved in the area of CSCW. Though actually discussing helpful coordination support functions researchers soon adopted the notion of making group members *aware* of the activities of the others. This is where it took off.

> "Not surprisingly then, the concept of 'awareness' has come to play a central role in CSCW, and from the very beginning CSCW researchers have been exploring how computer-based technologies might facilitate some kind of 'awareness' among and between cooperating actors" (Schmidt, 2002, p.285).

This chapter is the first step towards the announced construct of awareness (cf. section1.2). There are many ways to approach an introduction of awareness (cf. (Gross, 2013; Gross et al., 2005; Prinz, 2001; Rittenbruch & McEwan, 2009; Schmidt, 2002)). This chapter basically provides a brief wrap-up of the facts to be found in standard CSCW literature and publications that are considered to be commonly accepted CSCW research results.

Overall, this chapter has three main goals:

1. Present an overview of CSCW's research on awareness.
2. Create a basic understanding of what awareness is. This forms the basis for an appropriate operationalization required for the target construct.
3. Outline potential flaws and shortcomings in the current state of research. This forms the basis for improvements or redirects efforts towards a proper solution.

It starts with the term's origin and concept, then continues with the predominant dichotomy of ethnography and technology represented by studies, group characteristics and their tasks, as well as frameworks, and models. The chapter closes with a reflection on its contents outlining challenges and criticism of what is known at this point to derive a construct before eventually closing with a summary.

2.1 Conceptual Aspects

Simply checking a dictionary reveals that awareness is the state or quality of being aware, i.e., having or showing realization, perception, or knowledge of something happening or existing (Merriam-Webster, 2016a). There it is also said to be synonymous to the term consciousness which rather refers to being awake to the surroundings and one's own identity (Merriam-Webster, 2016b). However, the difference between the two terms becomes immediately obvious by using their antonyms: being unaware is truly something different than being unconscious. Conceiving it this way, it shows that consciousness is a prerequisite to become aware of something.

In CSCW, the term awareness first appeared in the late 1980s and at the beginning of the 1990s:

> "More specifically, the early harvest of ethnographic field studies in CSCW (e.g., Harper et al., 1989b; Harper et al., 1989a; Heath and Luff, 1991) indicated that cooperating actors align and integrate their activities with those of their colleagues in a seemingly 'seamless' manner, that is, without interrupting each other, for instance by asking, suggesting, requesting, ordering, reminding etc. others of this or that. As a placeholder for these elusive practices of taking heed of what is going on in the setting which seem to play a key role in cooperative work, the term 'awareness' was soon adopted" (Schmidt, 2002, p.285).

Henceforth, awareness became one of the central "hot" topics of CSCW research starting in the early days with researchers exploring ways on how to support awareness using audio and video equipment as well as computer-based technologies.

The first and most prominent definition of awareness, cited extensively in CSCW literature, stems from Dourish and Bellotti (1992): "Awareness is an understanding of the activities of others, which provides a context for your activity" (p.107). Yet, it was not the only definition around that time. Beaudouin-Lafon & Karsenty (1992) defined awareness in a similar way: „By this we mean that each user should be aware of what the others are doing, to facilitate coordination" (p.171). Over the years the term's precision increased. Sohlenkamp (1998) extracts three common characteristics from the above and other sources: "They all imply that awareness is a state of mind of a user ('understanding', 'knowledge', 'be aware of'), that it involves the activities of others, and that it provides a backdrop ('context') for own activities" (p.41). Yet, despite all the attention, no clear overall picture of awareness has yet emerged from the CSCW research community until this day (Gutwin & Greenberg, 2002; Schmidt, 2016).

As stated in the beginning of this chapter, awareness and its characteristics can be seen from various perspectives making it hard to grasp in its entirety: "Awareness, like attention, is one of the tricky and dangerous terms in psychology, easily leading to circular argumentations" (Pedersen & Sokoler, 1997, p.51) and diverse definition approaches. Schmidt (2002) recounts it this way:

> "The very word 'awareness' is one of those highly elastic English words that can be used to mean a host of different things. Depending on the context it may mean anything from consciousness or knowledge to attention or sentience, and from sensitivity or apperception to acquaintance or recollection" (p.287).

Research fields dealing with awareness range from anthropology and philosophy to human factors and psychology, each with a more or less different emphasis on certain details – yet all summarized under the very same term. Philosophers like Wolff depict awareness as the "conception of things" (Jacobs, 1973, p. 233). Yet, this is just one of its notions in the field of philosophy. For instance, the French philosopher Rene Descartes (1596 – 1650) describes awareness on the one hand as the knowledge of knowing, thinking, and imagining which corresponds to an unrestrained and abstract point of view (Descartes, 1637). In the same publication, he also refers to it as the knowledge of one's own inner mental states – a very restricted perspective demarcating the individual from its environment or the mind from matter thus fitting the classic cartesian dualism (Descartes, 1637). While the term's first version appears to be very abstract and comprehensive, the second is usually labeled "self-awareness" also due to its concrete notion closely related to Descartes' prominent statement "Je pense donc je suis" (Descartes, 1637) later translated into Latin as "Cogito ergo sum" – "I think, therefore I am".

However, this actually has only little to do with what is being described in the context of computer-supported cooperative work, eventually leading to the extraneous use of prefixes, to discriminate the term from the above by focusing on a particular function or characteristic (e.g., a part of a specific context). On the one hand, an overall encompassing and/or superordinate concept does not exist from which an appropriate sub-terminology can be deducted to be used in different research areas. On the other hand, this might exactly be what the term awareness is, as Sohlenkamp (1998) points out: “The term ‘awareness’ literally implies a broader meaning than actually intended by most related publications in CSCW literature. What is usually meant is ‘group awareness’ or ‘cooperation awareness’, being knowledge about the state of a cooperative effort of a group of people” (p.40).

2.1.1 Contents & Types

Currently in CSCW, the usage of awareness with prefixes (i.e., “xyz”-awareness) or as part of compounds adds its particular notion, thus also an idea of its content (e.g., self-awareness, presence awareness, social awareness, workspace awareness etc.). Doing so allows researchers to avoid two challenges: 1) to define an abstract term that fits all research as a common ground and 2) to integrate the own research with that of others as they marked theirs as something different. However, exactly this procedure eventually leads to the fragmentation of research to be described (cf. section 2.4.5). For a first glance, Table 2-1 provides a sample of commonly used awareness types in CSCW.

Table 2-1. Sample of awareness types found in CSCW literature.

Type	Description
Availability awareness	Involves knowing who is around, whether they are busy or not (Jang et al., 2000).
Activity awareness	Reveals what other team members are doing (Jang et al., 2000).
Background awareness	Provides “an overview of who was around and what was happening (and afforded the possibility of joining in)” (Bly et al., 1993; Rittenbruch & McEwan, 2009).
Collection awareness	Combines the aspects of document and people awareness, explained below (Cohen et al., 2000).
Contextual awareness	Tackles the questions what users should be made aware of and how they should be made aware of it (Liechti, 2000). The user’s current context demands for certain pieces of information while ignoring others.

Conversational awareness	"People continually adjust their verbal behaviour in conversation, based on cues picked up from their conversational partner (...) These cues provide a sense of awareness of what is happening in the conversation, awareness that helps us make adjustments and adaptations to keep things going smoothly" (Gutwin, 1997).
Document awareness	Refers to who sees the same document (e.g., a web page) at the same moment (Cohen et al., 2000).
Environmental awareness	Reveals all external information about activities and events in the agent's environment as opposed to information about himself referred to as self-awareness (Boyd, 2002).
General awareness	"This is a pervasive experience, one of simply knowing who is around and something about what they are doing: that they are busy or free, meeting or alone, receptive to communication or not" (Gaver, 1991; Bly et al., 1993).
Group awareness	It summarizes the knowledge about who is around and what they are doing, i.e., activity and presence awareness. (Dourish & Bellotti, 1992; Liechti, 2000).
Group-structural awareness	"Involves the knowledge about such things as people's roles and responsibilities, their positions on an issue, their status, and the state of various group processes" (Greenberg et al., 1996; Gutwin 1997).
Informal awareness	Represents the general knowledge of who is around in the work community (Greenberg et al., 1996). This type can also be found under the name people awareness (Cohen et al., 2000) or availability awareness (Jang et al., 2000). It "involves knowing who's currently around, whether they're available or busy, and what sort of activity they're engaged in" (Gutwin et al, 1996, p.205; Greenberg et al., 1996; Gutwin, 1997; Rittenbruch & McEwan, 2009) Knowledge of presence, activity and availability (p.30).
Intentional awareness	For instance, actively assess if a person is available (Pedersen & Sokoler, 1997).
Mode awareness	"Is the ability of a supervisor to track and to anticipate the behaviour of [mode-based] automated systems" (Gutwin, 1997, p.20).
Mutual awareness	(Benford et al., 1994) (Pedersen & Sokoler, 1997)
Organizational awareness	Is the knowledge of how the group activity fits within a larger purpose of an organization (Gutwin, 1996).
Passive awareness	Awareness information that is gathered along the way (Dourish & Bellotti, 1992; Dourish & Bly, 1992) (cf. unintentional awareness).
People awareness	Describes knowing who is around (Cohen et al., 2000) (cf. presence awareness)

Peripheral awareness	Rather denotes unobtrusive ways of presenting information, i.e., not requiring the focus of attention (Liechti, 2000). Weiser and Brown (1996) refer to means supporting peripheral awareness as "calm technologies" which engage both the center and the periphery of our attention, and in fact move back and forth between the two (Gaver, 1992; Bly et al., 1993; Benford et al., 1994; Pedersen & Sokoler, 1997).
Perspective awareness	Refers to what team members are thinking and why (Jang et al., 2000). It considers personal background, training, and institutional contexts. Thus, it is a partial aspect of group structural awareness.
Presence awareness	Provides information on who is around and available (Dourish & Bellotti, 1992; Handel, 2001; Nardi et al., 2000)
Process awareness	Has an analogue characteristic to organizational awareness in that it refers to an understanding of one's own work as part of a larger project or system (Jang et al., 2000).
Self-awareness	"Allows individuals to have a sense of who they are in relation to society and culture" (Boyd, 2002, p.21), i.e., understand their representation and role during interactions besides their environmental awareness.
Situation awareness	"Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p.36). "SA is not general knowledge (long-term memory for facts, procedures or mental models), which has a relatively long time constant, being acquired (and forgotten) over periods of hours, days, and years. SA, on the other hand, generally applies to more rapidly evolving situations. Long-lasting knowledge supports but is distinct from SA" (Parasuraman et al., 2008, p.145).
Social awareness	Refers to the information that a person maintains about others in a social or conversational context (Greenberg et al., 1996, p.30). "Social awareness includes information about the presence and activities of people in a shared environment" (Prinz, 1999, p.392; Greenberg et al., 1996; Fogarty et al., 2004; Tollmar et al., 1996)
Spatial awareness	"Is a pilot's understanding of her location in an airspace" (Gutwin, 1997, p.20).
Task-oriented awareness	"We consider task-oriented awareness as the awareness that is focused on activities performed to achieve a specific task. This kind of awareness can be promoted by change notifications or information about the state of a certain document or shared workspace. It allows users to coordinate their activities on the shared object." (Prinz, 1999, p.392).
Unintentional awareness	Maintained on others with no specific purpose (Pedersen & Sokoler, 1997).

Workspace awareness	Is "the up-to-the-moment understanding of another person's interaction with the shared workspace (...) workspace awareness is awareness of people and how they interact with the workplace, rather than just awareness of the workspace itself (...). [It] is limited to events happening in the workplace" (Gutwin and Greenberg, 2002, p.417). For Gutwin and Greenberg (2002) workspace awareness is a specialization of situation awareness since in this case the situation is defined by people's interactions within a shared workspace. Liechti (2000) describes workspace awareness as information about what artifacts are currently used by others, about their past changes, and who is around (Gutwin, 1997; Gutwin & Greenberg, 1999; Gutwin & Greenberg, 2002).

This collection does not claim to be exhaustive. It rather seeks to demonstrate that there is a large number of definitions with many of them sounding quite similar or even being synonymous. The following relationships can be observed:

1. There are types that comprise other types. For instance, presence awareness is part of group awareness, social awareness and workspace awareness.
2. There are mutually exclusive types, e.g., self- and environmental awareness or presence and document awareness.
3. There are types that differ in the degree of detail as with group awareness and presence awareness.
4. There are types that differ in scope. Workspace awareness has an inherent spatial limitation to its workspace. Self-awareness is limited to the respective self.

Gutwin (1997) created the following depiction identifying further subtype relationships (cf. Figure 2-1). He chose situation awareness (SA) to be the most generic of the awareness types. Therefore, it is shown at the top. SA originally stems from human factors and the research in the area of military aviation (Gutwin & Greenberg, 2002).

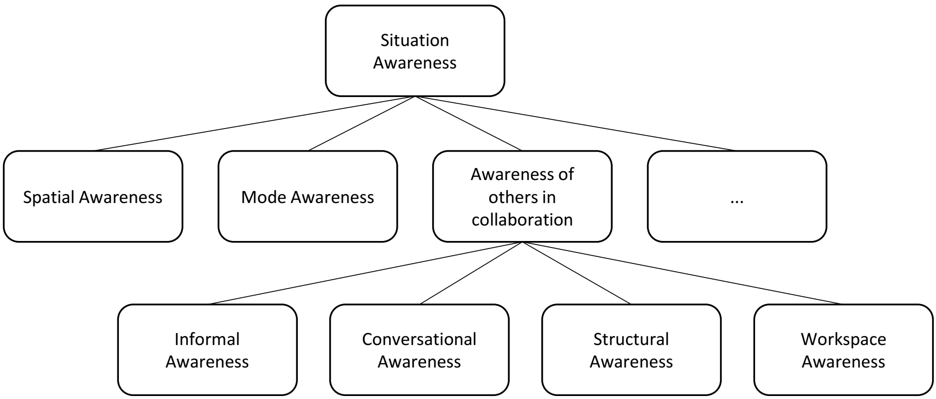

Figure 2-1. Situation awareness and subtypes (Gutwin, 1997).

Analyzing Table 2-1 in terms of what people are aware of reveals the following:

- People (others)
- Artifacts (e.g., documents, devices, shared resources)
- Events (i.e., what is happening in a certain context, activity of others, changes to documents and shared artefacts)
- Self (i.e., identity but also moods and feelings of oneself)

Figure 2-2 employs the above list and depicts the links between awareness types and their scope.

Leveraging Endsley's (1995b) definition of situation awareness (cf. Table 2-1), all of it can be generalized into three major components each embedded in a particular context or environment (cf. Figure 2-3):

- Elements (people and artifacts)
- Events (affecting the subject and the elements)
- Subject

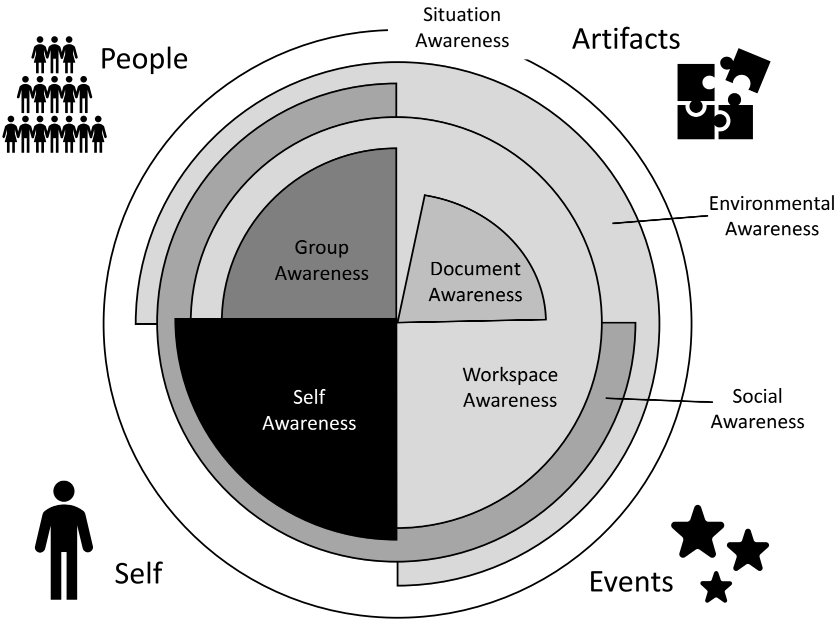

Figure 2-2. Scope of awareness types.

The subject, that is, the bearer of the awareness, needs to be added to Endsley's definition. Awareness cannot stand for itself. It is always bound to individuals. "The term 'awareness' is only meaningful if it refers to a person's awareness of something" (Schmidt, 2002, p.287). Thus, situation awareness is defined here as a subject's perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.

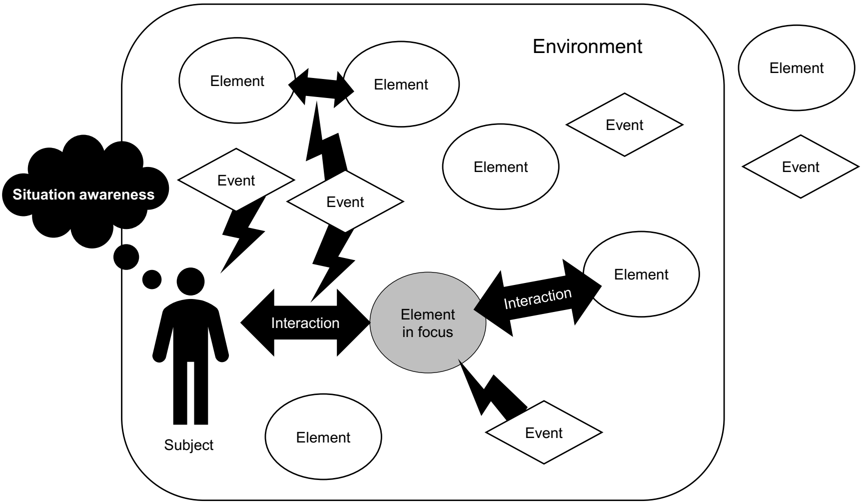

Figure 2-3. Elements and their relation in situation awareness.

2.1.2 Process and Mental Model

Most of the above-mentioned definitions of awareness obviously see it as something mental, dealing with perception, the processing and the result of what is being perceived. This leads to two ways awareness can be conceived (Gutwin & Greenberg, 2002, p.417):

1. Awareness just as mental model (narrow sense)
2. Awareness as mental model including the surrounding processes of perception and maintenance (wide sense)

Craik (1943) and other cognitive psychologists refer to mental models in general as internalized representations or constructions of some aspects of the external world. In his theory of mental models, Johnson-Laird (1983) finds that they are not one-to-one imitations of the real world but much simpler structural analogues. Yet, the model's similarity allows inferences and predictions for the real world to be made.

Integrating a mental model and its surrounding processes, Neisser (1976) developed the perception-action-cycle, a cognitive framework that shows the interdependencies of a person's memory, perception and action (Adams et al., 1995). It describes interactions of a person with the environment and differs from standard linear information processing models (e.g., Input-Processing-Output (IPO) (Forouzan, 2017)) by recognizing that perception is influenced and directed by existing knowledge suggesting the involvement of the long-term memory (LTM) (Gutwin & Greenberg, 2002).

In Neisser's model (cf. Figure 2-4), subjects have a basic understanding (knowledge) about interacting with the environment. This directs their actions and activities (exploration) during which they gain further knowledge about their surroundings. The feedback of their actions is perceived and integrated into the existing mental models. On this basis, subjects might adapt their future actions (i.e., the ones of the next cycle).

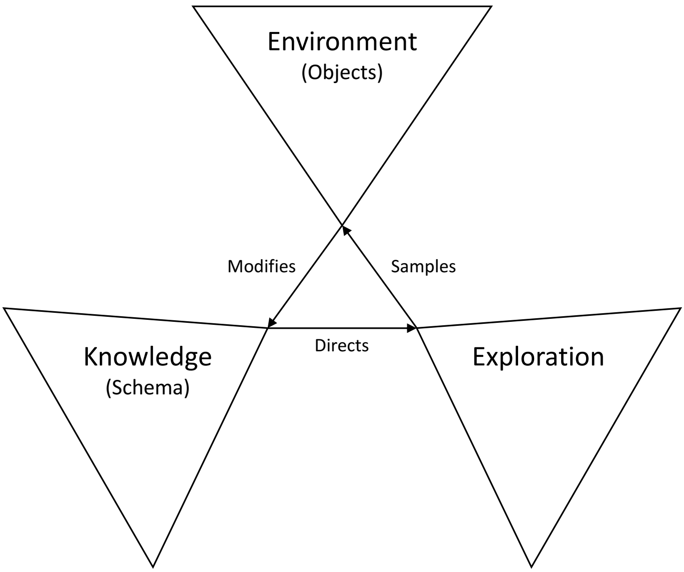

Figure 2-4. The perception-action-cycle (Neisser, 1976).

Based on the above the following characteristics of awareness can be summarized (Adams et al., 1995; Endsley, 1995):

- It is the knowledge about the state of an environment bound in time and space.
- The environment changes over time. Therefore, this knowledge needs to be maintained and updated.
- People interact with and explore the environment. Through this interaction the update of awareness is accomplished.
- Awareness is a secondary goal in the task. The primary goal is not simply to stay aware but to work on a cooperative task in the environment.

Already Endsley's definition of situation awareness (cf. Table 2-1) emphasizes that awareness is achieved through three different stages or levels (Endsley, 1995) (cf. Table 2-2):

Table 2-2. Situation awareness levels (Endsley, 1995).

Phase	Description
Level 1 SA	Involves perceiving the status, attributes, and dynamics of relevant elements of the environment
Level 2 SA	Comprehension of the situation based on Level 1 including an understanding of the significance of these elements
Level 3 SA	Projection based on Level 1 and 2 of the future actions of the elements in the environment near term

2.1.3 Interrelations and Perspectives

All types of awareness described in this thesis this far are unidirectional regarding the relationship of the subject and the surrounding elements, following the pattern "I know something about something". This unidirectional type is also referred to as first level awareness (Oemig, 2004). Yet, real life is more complex, especially when it comes to groups of people and social interaction that relies on norms and conventions. "It is through such individual feelings of accountability that norms, rules and customs become effective mechanisms for supporting coherent social behavior" (Erickson & Kellogg, 2003, p.19). Accountability in turn relies on awareness but not the unidirectional type. It builds upon knowing that the other person knows that one knows. This can also be described as the awareness about the awareness of another person and is referred to as second level awareness or social meta-awareness (Oemig, 2004). It describes the interrelation of the awareness of two individuals (cf. Figure 2-5). Thus, it differs from the previous mutual awareness (cf. Table 2-1) in that both individuals do not only know that they are around, for instance, monitoring each other without knowing of being monitored. They know from each other that each one of them knows that they are around.

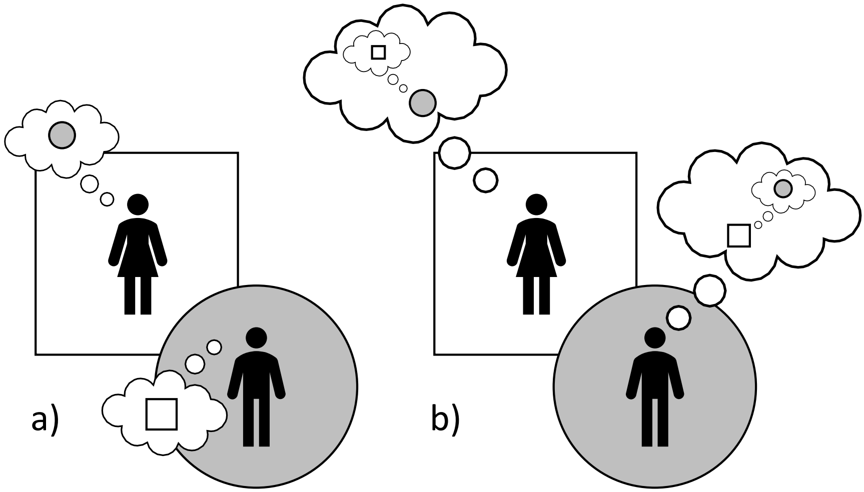

Figure 2-5. From mutual awareness a) to awareness about the awareness of others b).

Social meta-awareness relies on people's capability of taking perspectives. "The ability to take the perspective of another is critical for effective social functioning (...) and is an important component of the ability to empathize with another" (Sheldon & Johnson, 1993, p.320). Based on taking perspectives, Sheldon and Johnson (1993) distinguish eight types of social awareness (cf. Table 2-3).

Table 2-3. Eight forms of social awareness (Sheldon & Johnson, 1993).

Content	Self as Target		Other as Target	
	Perspective of Self	Perspective of Other	Perspective of Self	Perspective of Other
Experience (covert)	Own experience from perspective of self (privileged)	Own experience from perspective of other (non-privileged)	Other's experience from perspective of self (non-privileged)	Other's experience form perspective of other (privileged)
Appearance (overt)	Own appearance from perspective of self (non-privileged)	Own appearance from perspective of other (privileged)	Other's appearance from perspective of self (privileged)	Other's appearance from perspective of other (non-privileged)

Four out of eight forms are marked as "privileged" and four as "non-privileged". "Subjects indicated that they use the perspective of the other more often than their own only when it provides 'privileged' access to the relevant content of awareness – that is, when they think about the thoughts and feelings of the other or about their own appearance and behavior (...) The privileged perspective on covert experience is the experiencer's, and the privileged perspective on overt appearance is an external observer's perspective" (Sheldon & Johnson, 1993, p.320). In consequence, providing means for switching perspectives and objects facilitates the creation of empathy, self-and other-awareness effectively thus supporting accountability.

A similar path was picked up more recently when Tenenberg et al. (2016) introduced their notion of I-awareness and we-awareness. Previous concepts of awareness (cf. section 2.1.1) "are a first-person perspective that black-boxes the intentionality of others, focusing only on the actions, communication, and resources that are 'publicly available' (Robertson, 2002), what we call I-awareness" (Tenenberg et al., 2016, p.236). This basically refers to mutual awareness that was earlier described as unidirectional. In contrast, we-awareness corresponds to second level awareness. "Shared intentionality thus provides a basis for reconceptualizing awareness in CSCW research, building on and augmenting existing notions of individual intentionality. And it is just such a reconceptualization of awareness from 'mutual awareness of something' carried out seamlessly and effortlessly (Schmidt 2011), to a 'shared awareness of something that each recursively knows of the other' (...). Our key move is in going from first-person singular to first-person plural, from I-awareness to we-awareness" (Tenenberg et al., 2016, p.236).

2.2 Ethnographic Aspects

Ethnography is the study and systematic recording of human cultures (Merriam-Webster, 2019b). "As a method of data collection [it] entails examining the behaviour of the participants in a certain specific social situation and also understanding their interpretation of such behaviour" (Dewan, 2018, p.188). The following briefly takes a glimpse at the results of well-known ethnographic studies as well as insights on group tasks and the effects on the concept of awareness.

2.2.1 Studies

Introduced in the *Studies in Ethnomethodology*, Garfinkel (1967) substantially challenged sociology as a discipline. In CSCW, ethnographic studies gained greater popularity when Suchman (1987) published her thesis on *Plans and Situated Actions*. In her opinion, there are "two alternative views of purposeful action and shared understanding":

1. Cognitive science: views the organization and significance of action as derived of plans (to prescribe possible actions). These plans are triggered by recognizing intent, common knowledge and typical situations.
2. Social science: treats plans as derivate from situated action, i.e., ad-hoc responses to the action of others.

In the early days of CSCW many approaches to support cooperative work failed (Grudin, 1988; Lynne et al., 1990) due to a missing reflection on social interaction in groups and organizations (Galagher & Kraut, 1990). "There seems to be a focus on technology for the sake of technology, without much thought about what people need" (Henninger, 1991, p.28). That is why in the following years ethnographic studies gained a strong focus. For instance, Heath and Luff (1991) wanted to learn more about the subtleties of group work and focused on the Line Control rooms of the London Underground, a complex multimedia environment in transition where they observed the informal work practices and procedures whereby personnel systematically communicate information and coordinate a disparate collection of tasks and activities. The underground employees developed special mechanisms of “monitor & display” where they overhear their colleagues and provide certain information themselves, e.g., by talking out loud.

Another study (Bentley et al., 1992) was conducted at the London Air Traffic Centre where radar controllers and assistants implicitly coordinated their cooperative work. Also this study demonstrated that cooperative work involved careful attention to ongoing events and actions on the one hand and the directed disclosure of important information to others on the other (Gross, 2013). Interestingly enough, neither study used the term “awareness” in conjunction with these mechanisms.

2.2.2 Group Tasks and Group Dynamics

The activities in the context of collaboration happen rather implicitly and invisibly. Ethnographic studies showed “that the effort of displaying and monitoring awareness information should be low enough so it can happen in the background and does not interfere with the other activities of the actors” (Gross, 2013, p.430). This implies multiple tasks people are involved in during collaboration that might interfere with one another. Gutwin and Greenberg (2002) refer to these as domain and collaboration tasks (cf. Figure 2-6).

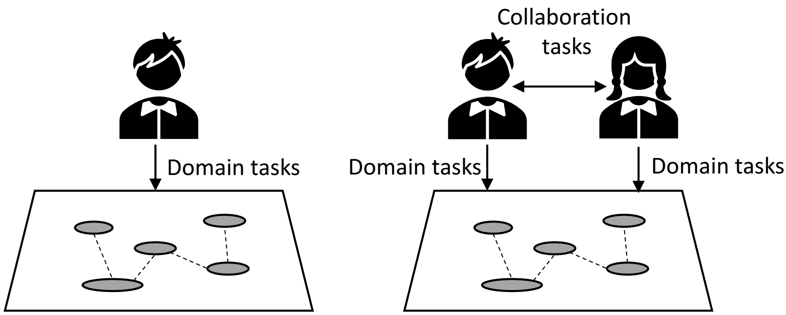

Figure 2-6. Domain and collaboration tasks (Gutwin & Greenberg, 2002).

However, other authors use different terms for these tasks. Besides domain and collaboration task, for instance, Pinelle and Gutwin (2002) speak of the following two “distinct kinds of work: *taskwork* (the actions that must occur to complete the task) and *teamwork* (the actions that group members must carry out in order to complete a task as a group)” (p.456). Prinz (1999) distinguishes two types of awareness related to different tasks, namely between task-oriented awareness and social awareness (the one being about artefacts the other about people).

These different tasks stem from the fact that not only one individual works on the task but multiple. Groups are “bounded, structured entities that emerge from the purposive, interdependent actions of individuals” (McGrath et al., 2000, p.95). However, “groups are not the same as teams. Groups have task structures with limited role differentiation, and performance depends largely on individual efforts. Teams, on the other hand, have members with specialized roles, and the team works together to accomplish common goals” (Hare, 1992; Neale et al., 2004) (cf. Figure 2-7).

Figure 2-7. Team or group? (Source: Pixabay, CC0)

The interdependence of tasks and their coordination are defining characteristics of a team.

McGrath (1984) is the one cited most when it comes to group tasks. His task typology goes far beyond the two above-mentioned task types. He organizes them into four quadrants that are subdivided into specific task types. In its entirety it is referred to as the *Group Task Circumplex* (McGrath, 1984) (cf. Figure 2-8). McGrath (1984) states that group interaction "not only takes place somewhere, it involves the group *doing something*. One very important aspect of all those settings just enumerated above is the 'task'" (p.14). Tasks always involve goals (e.g., generating ideas, executing tasks, problem solving etc.).

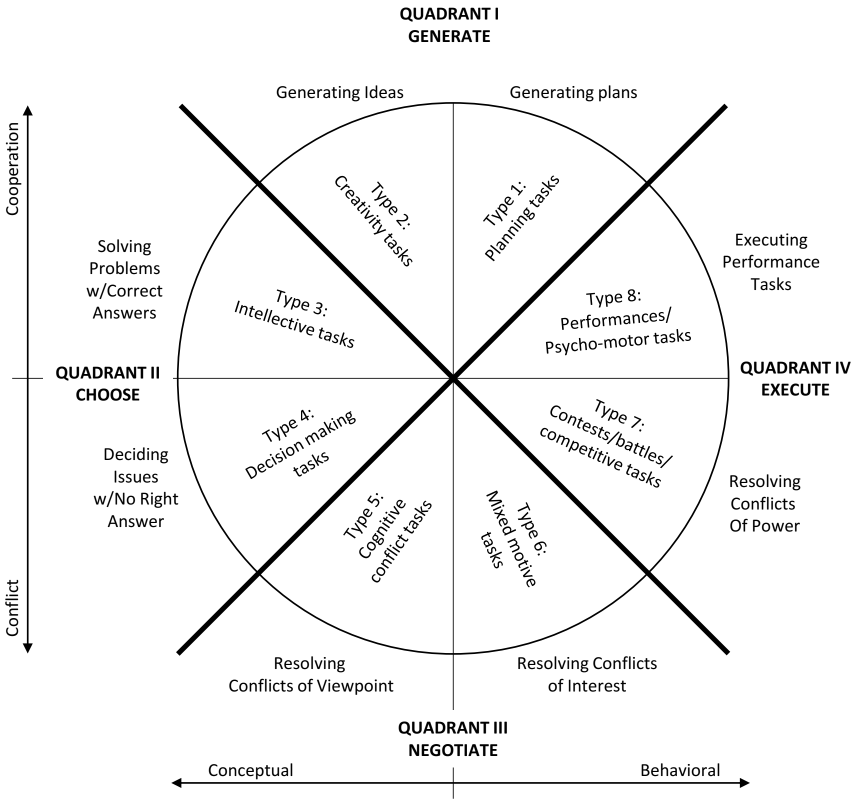

Figure 2-8. The Group Task Circumplex (McGrath, 1984).

The quadrants of the circumplex are defined as follows:

- Generate: contains tasks for structuring actions (planning activities) and for producing ideas (creativity tasks).
- Choose: contains intellective tasks for finding solutions to a problem (problem solving) and reaching a consensus over the solution (decision making).
- Negotiate: involves making choices in conditions of intragroup conflict, caused by opposing interests, as in bargaining (mixed-motive tasks) or by users systematically using different preference structures or viewpoints (cognitive conflict tasks).
- Execute: mostly physical behavior such as contests or battles deciding on winners and losers (competitive tasks) or performances that emphasize on coordinating manual tasks of multiple people (psycho-motor tasks).

Gutwin and Greenberg (2002) label the quadrants "Generate" and "Execute" as primary tasks that belong to the domain tasks. This thesis refers to everything that is part of the domain tasks as primary task and to the knowledge about the domain task as primary task knowledge. The primary task in the context of CSCW requires collaboration. Everything that relates to the collaboration task, i.e., tasks related to coordination and awareness are referred to as secondary task and the knowledge thereof as secondary task knowledge. The secondary task is required by the primary task in a collaborative setting. In section 2.1.2, Gutwin and Greenberg (2002) referred to awareness as a secondary goal.

Not all tasks of the *Group Task Circumplex* (cf. Figure 2-8) take place at the same time and not all of them are necessarily related to taskwork or teamwork. Some of them become relevant when it comes to the development of the team as a whole. They are not a secondary task to the domain task but triggered by the progress a team makes in terms of group dynamics. The term group dynamics itself goes back to Kurt Lewin (1890 – 1947), a German-American psychologist and later on director at the Center for Group Dynamics at the Massachusetts Institute of Technology (MIT). The term group dynamics describes how groups and individuals act and react to a changing environment (Lewin, 1939; Marrow, 1969). A first model to describe the stages of team development was developed by Tuckman

(1965) with the stages being forming, storming, norming and performing (Tuckman, 1965). This model was added an adjourning stage in 1977 (Tuckman & Jensen, 1977). Team members first need to orient themselves in the new structure, find their place, and setup standards for collaboration before eventually performing the domain task at a high-performance level. After being done with the purpose of their formation, the team adjourns or reorganizes. Another more complex model of this kind is the *Team Performance Model* (TPM) (Drexler et al., 1998) (cf. Figure 2-9). It is more fine-grained and uses seven stages to describe the development of a team over time. In the "Orientation" stage team members find out why they are there and start finding a place within the group (as in the forming stage). During "Trust Building" team members try to find out about one another, about their plans and expectations. In the "Goal Clarification" stage the team decides on what to do. Once the goals are clear a way needs to be determined to achieve them in the "Decision Making" stage (as in the norming stage). Then follows the "Implementation" addressing the sequence of work and who does what, when and where (i.e., coordination). During "High Performance" the plan is put into practice until the work is done and the team renews or adjourns.

Models of group dynamics show that the tasks related to the team change over time. In consequence, the need for certain information changes as well. This corresponds to Neisser's interaction with the environment (cf. section 2.1.2) with the information need changing the more is learned about it. That is, not only the domain tasks change over time, but also the information needs regarding a collaboration task.

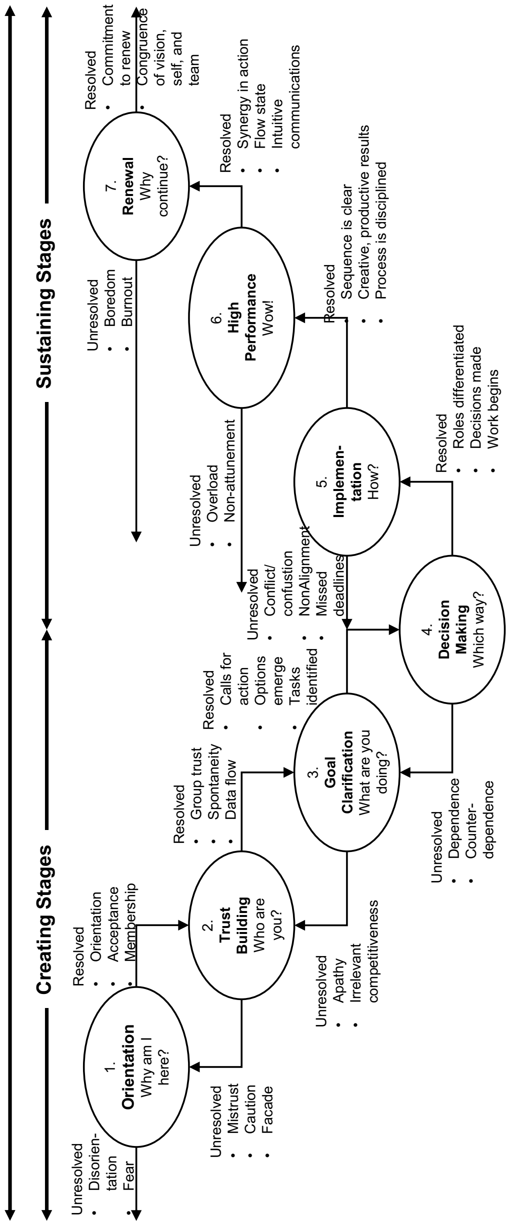

Figure 2-9. Team Performance Model (Drexler et al., 1998).

2.2.3 Heed versus Attention

One of Schmidt's (2011) key insights was to note that the term "awareness" has been used in two distinct but at the same time incompatible ways in CSCW research, which caused the terminological confusion (cf. section 2.1.1) (Schmidt, 2011b; Tenenberg et al., 2016). The two ways are referred to as the attention and heed concept:

- Awareness as a "attention" concept means being aware as being close to realizing or being conscious of or noticing. Already section 2.1 demonstrated the relation of awareness and consciousness with the latter being the prerequisite for being the former.
- Awareness can be described as a "heed" concept when it refers to the mutual heeding that skilled actors perform in a real-world setting. The skillful technique of "monitor & display" (cf. section 2.2.1) is the prime example for heeding which works in a seamless and effortless manner.

Heath et al. (2002) suggest "that awareness is not simply a 'state of mind' or a 'cognitive ability' but rather a feature of practical action which is systematically accomplished within developing course of everyday activities" (p.318). That is why researchers like Schmidt suggest to learn more about how these skillful practices for heeding are obtained by team members:

> "Instead of searching for putative intermediate mental states, we should try to identify the strategies competent cooperating actors employ to heed what colleagues are doing etc. How do they discriminate significant states, possible states, problematic states etc.? What do they monitor for in the setting? What is ignored as irrelevant, what is taken into account" (Schmidt, 2011b, p.35).

Obviously, ethnographers strongly favor the heed concept over the assumption of limited attentional resources that make it difficult to recognize that there might be forms of human activity in which an actor can attend to more than one thing while at the same time monitor the relevant activities of others. That is, Luff et al. (2008) critique conceptions of shared mental models, or the cognitive properties of individuals. As mentioned in the context of taking perspectives (cf. section 2.1.3), this is supposedly a reconceptualization of awareness from "mutual awareness of something" carried out seamlessly and effortlessly (Schmidt, 2011b) to a shared awareness of something that each subject recursively knows of the others based on shared intentionality to allow socially recursive inference.

2.3 Systems for Awareness Support

After discussing the conceptual and ethnographic aspects, this section turns to the technological side. Human beings adapted to their natural environment over thousands of years. Yet, in the digital realm they start over and are reduced to windows and widgets:

> "We live in a complex world, filled with myriad objects, tools, toys, and people. Our lives are spent in diverse interaction with this environment. Yet, for the most part, our computing takes place sitting in front of, and staring at, a single glowing screen attached to an array of buttons and a mouse. Our tasks are assigned to homogeneous overlapping windows. From the isolation of our workstations, we try to interact with our surrounding environment, but the two worlds have little in common. How can we escape from the computer screen and bring these two worlds together?" (Wellner et al., 1993, p.24)

Figure 2-10. Everything has to pass eventually the wire (Source: Pixabay, CC0).

In the digital realm, everything needs to be captured, encoded, mediated, decoded and displayed reducing the perceivable environment drastically (cf. Figure 2-10).

> "The difference of environments (being immersed in an environment or just having a window into it) implies that our natural mechanisms for gathering awareness information do not work in the digital world (...) computational analogues are mostly slow and clumsy" (Greenberg et al., 1996, p.31).

Before it becomes available, every piece of awareness and coordination support needs to be carefully designed and implemented and this can result in many different systems and technological solutions.

There are many ways to provide an overview of systems and prototypes supporting awareness. For instance, Rittenbruch and McEwan (2009) apply a temporal structure identifying three different phases of system development (p.3):

1. 1990-1994: Early explorations of awareness
2. 1995-1999: Diversification and research prototypes
3. 2000-now: Extended models and specialization

Over the decades CSCW research generated many types of systems especially to support awareness. The emphasis in the design of the early awareness support systems was largely on supporting peripheral monitoring, allowing people to see each other and their progress. Systems known as *Media Spaces* provided audio and video connections (i.e., high-fidelity awareness cues) to provide the distributed teams with a sense of who is around and their activities (Bly et al., 1993) (cf. Figure 2-11).

"Unfortunately, however, the expected benefits from these technologies never materialized" (Schmidt, 2002, p.285). Thereafter researchers introduced and worked on more abstract representations for the awareness of people and artifacts (Pedersen & Sokoler, 1997).

Other researchers joint the development of *Collaborative Virtual Environments* (CVE) like MASSIVE (Benford et al., 1994; Greenhalgh & Benford, 1995; Greenhalgh et al., 2000) where users completely immersed into their (virtual) working environment. However, "while impressive technical progress has been made, it is still not clear if and how these technologies could be used productively in cooperative work settings" (Schmidt, 2002, p. 286).

Figure 2-11. Media Space (Bly et al., 1993).

Another era that followed was the one of event notification systems. These are computational environments based on 'event propagation mechanisms' (Schmidt, 2002). They are used to provide information about the status of shared objects and the progress of collaborative tasks. Systems like GROUPDESK System (Fuchs et al., 1995), NESSIE (Prinz, 1999), KHRONIKA (Lövstrand, 1991) or ELVIN (Segall & Arnold, 1997).

Socially translucent systems (Erickson et al., 2002) are an example for the category of extended models and specializations. Their main feature is to make presence and social activity visible generating mutual awareness, which eventually reinforces accountability via taking perspectives and social meta-awareness (cf. section 2.1.3). Thus, researchers try to transfer typical social phenomena to digital systems.

Further specialization came from the area of dynamic awareness support. The idea here is that not only the information presented to the user changes over time, e.g., presence awareness switching from "available" to "away" due to inactivity. It is the information set that changes altogether due to group dynamics (cf. section 2.2.2) or switching tasks (Oemig &

Gross, 2007). For instance, in instant messaging (IM) the presence awareness indicator is not of interest when conversing. In this case the application shows a typing indicator instead to coordinate the texting. However, the IM client returns to its former state once the conversation is over.

There are about 30 years full of examples for CSCW applications supporting awareness, however, it is not the goal of this section to introduce each and every one of them.[10] It is rather the goal to provide an overview over existing common components and terminology as well as operationalizations introduced specifically by awareness models and frameworks that might help to build the required awareness construct.

2.3.1 Terms and Components

To build a system supporting awareness requires the term's operationalization to translate it to the digital realm. As noted earlier (cf. section 2.1) awareness is something that resides in the mind of the user – the bearer of awareness. It is important to understand that the user is the one who is aware of something – not the system. That is the reason why two more terms need to be defined on the system side:

1. Awareness information
2. Awareness cues

Awareness information "is all the information about existing objects and users within the system" (Antunes et al., 2001, p.33) or to stay with the definition of situation awareness (cf. section 2.1.1) it is all the information about the elements and events inside the subject's environment. "All information" can be specified more precisely as the information answering questions (who, where, how, what, why), their origin (real world or digital world) and the point in time when it was created or captured (Sohlenkamp, 1998) (cf. Figure 2-12).

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[10] For a more in-depth overview of these and corresponding details please refer to (Gross, 2013; Rittenbruch & McEwan, 2009) or (Markopoulos et al., 2009).

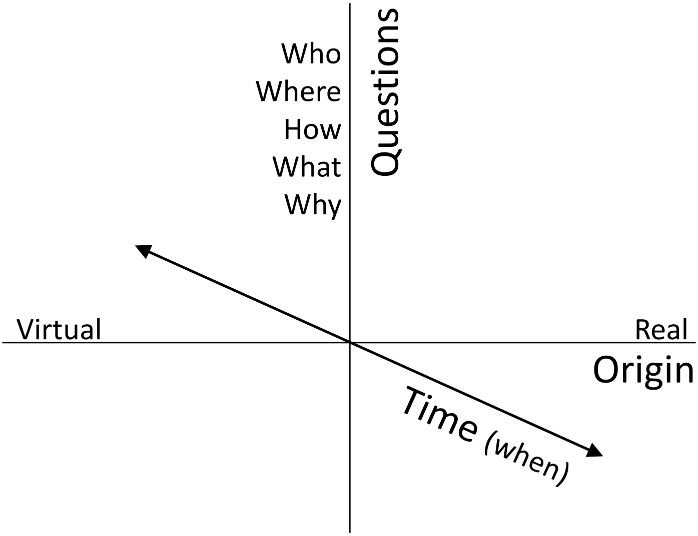

Figure 2-12. Three dimensions of awareness information (Sohlenkamp, 1998).

Fuchs et al. (1995) distinguish awareness information in terms of synchronicity and coupling (cf. Table 2-4). This resembles the *Time-Space Taxonomy* (cf. Figure 1-7 in section 1.1), but leaves out the aspect of spatial distribution.

Table 2-4. Synchronicity and coupling in terms of awareness information (Fuchs et al., 1995).

	Synchronous	**Asynchronous**
Coupled	What is currently happening in the actual scope of work?	What has changed in the actual scope of work since last access?
Uncoupled	What happens currently anywhere else of importance?	Anything of interest happened recently somewhere else?

In designing facilities that handle awareness information, four issues become extremely important (Donath et al., 1999):

1. Data choice (what is the data to be visualized?)
2. Data generation (where does the data come from?)
3. Data mapping (how is the data presented?)
4. The data's impact (how does the interface affect the dynamics of the group?)

On the other end, awareness cues are the user interface components to eventually trigger or causes the mental model in the user's mind:

> "The cueing and construction of such a model can be supported by the way in which information is presented to a user: form and content of information determine which existing models are cued, and how new information is mapped onto existing or new models through the mechanism of procedural semantics. Applied to HCI, this means that designers would have to identify suitable existing knowledge to be cued, and present relevant information about the system in the context and form which directs the model-building process toward the intended mental model" (Sasse, 1997, p.40).

In other words, "awareness cues are computer-mediated, real-time indicators of people's undertakings, whereabouts, and intentions" (Oulasvirta, 2009, p.125). Facilities presenting awareness cues are also referred to as awareness widgets (Gutwin & Roseman, 1996; Gutwin et al., 1996) Awareness cues are not limited to the screen. They may be physical objects like the "Dangling String" created by Natalie Jeremijenko that visualized the communication intensity of an ethernet cable (Weiser & Brown, 1996). There are high-fidelity cues (e.g., online audio and video connections as in Media Spaces (Bly et al., 1993) and low-fidelity cues using icons as abstracted visualizations as with Aroma (Pedersen & Sokoler, 1997).

2.3.2 Models

The models to be introduced here focus mainly on two aspects:

1. Awareness information dissemination
2. Determination of awareness levels

The models that are responsible for the dissemination of awareness information are usually structured as event pipelines. That is why they are often referred to as pipeline models (Fuchs, 1997; Rittenbruch & McEwan, 2009; Sohlenkamp, 1998). Figure 2-13 depicts typical parts capturing the information by the sender and eventually reaching the receiver.

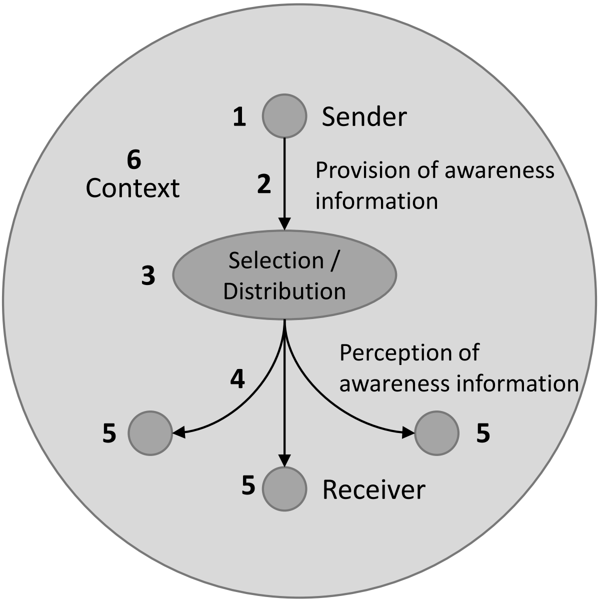

Figure 2-13. Pipeline to distribute awareness information (Luczak & Wolf, 1999).

Luczak & Wolf (1999) describe the following parts:

1. The person who provides awareness information (sender)
2. Specification and collection of awareness information
3. Selection and distribution of awareness information
4. Presentation of awareness information
5. The person who receives (and perceives) awareness information (receiver)
6. Context

Sohlenkamp (1998) developed a more elaborate version of the awareness information pipeline (cf. Figure 2-14) adding additional filters allowing the sender to control the outgoing information (privacy filter) and the receiver the incoming information (filter controlling disruption).

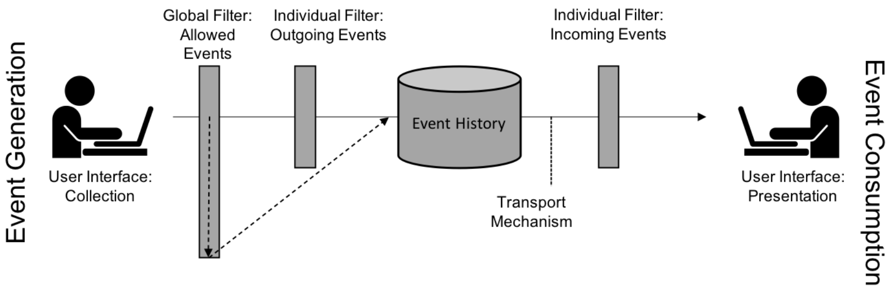

Figure 2-14. Awareness information pipeline (Sohlenkamp, 1998).

On the other end, there are models that help determine who becomes aware of what to what degree. For instance, the *spatial model of interaction* (Benford & Fahlen, 1993) is a model motivated by large virtual environments with an underlying spatial metaphor. It can be applied to all CSCW applications that use a spatial metric meaning a way of measuring position and orientation. The space is filled with objects (or elements, cf. section 2.1.1) that may represent people, information or other artifacts. The users control their interaction based on levels of awareness between them. These levels are determined by the interplay of the two of the following concepts, *focus* and *nimbus* (Benford & Fahlen, 1993, p.112):

- Medium: any interaction between objects occurs through a typical communication medium (e.g., audio, video, text etc.)
- Focus: subspace, "the more an object is within your focus, the more aware you are of it"
- Nimbus: subspace, "the more an object is within your nimbus, the more aware it is of you"
- Awareness: "The level of awareness that object A has of object B in medium M is some function of A's focus in M in relation to B's nimbus in M"

- Adapters: objects or tools to modify a subject's aura, focus and nimbus, e.g., a microphone
- Aura: a subspace which acts as an enabler of potential interaction, when two auras meet. An object may have different auras depending on the medium (audio aura bigger than visual aura).

Overall, the spatial model helps to facilitate interaction but is unspecific about what happens once a connection or link is established. How awareness levels are determined is show in Figure 2-15.

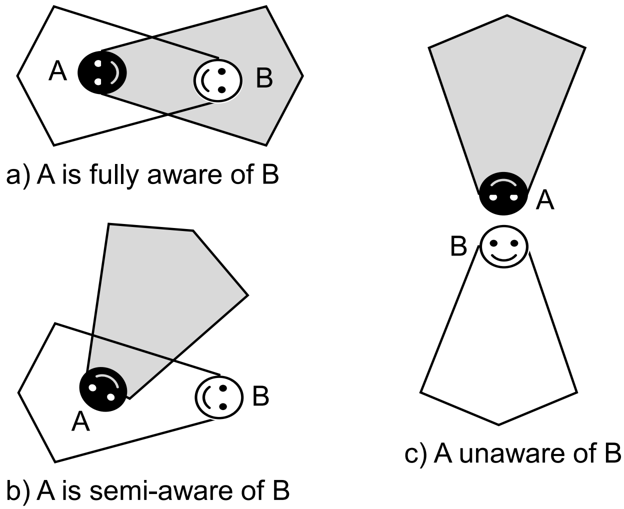

Figure 2-15. The spatial model of interaction (Benford & Fahlen, 1993).

The spatial model was applied in multiple systems, e.g., DIVE (Benford et al., 1995) and MASSIVE (Greenhalgh & Benford, 1995; Greenhalgh et al., 2000). It also provided the basis for many other models some of which are described in the following.

In his article *Populating the Application* (Rodden, 1996) describes a model of awareness based on the spatial model of interaction (Benford & Fahlen, 1993). "The model exploits the partitioning of space inherent within the spatial model to allow its application to non-spatial applications" (ibid., p.87). Like the spatial model it is used to provide notions of presence, sharing and awareness. The model aimed to be generally applicable across a variety of cooperative applications lacking a spatial metaphor. The model translates space into a simple "collection of objects shared by a number of users" (ibid., p.88).

AETHER (Sandor et al., 1997) was the name of a generic awareness engine that also extended and reinterpreted the spatial model. Similar as Rodden (1996), Sandor et al. (1997) reinterpret the spatial model to be of "general utility beyond the domain of shared virtual environments" (ibid., p.222). "Our goal is to recognize awareness at a fundamental system level and to build other functions on top of it" (ibid., p.222). Therefore, they distinguish between an application space and an awareness space (cf. Figure 2-16). CODESK (Tollmar et al., 1996) was the target system for their awareness engine.

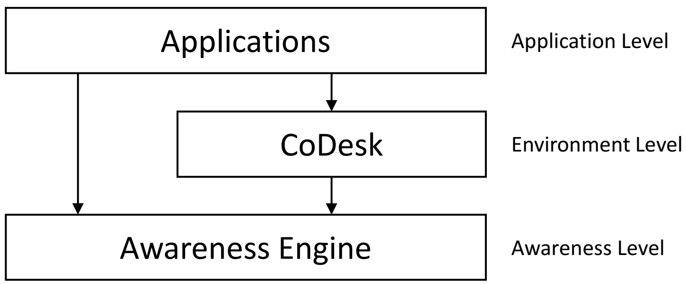

Figure 2-16. CoDesk awareness engine AETHER (Sandor et al., 1997).

The awareness engine itself can be found at the ground level of the system's architecture. At the second level CODESK provides functionalities for shared file access, access control, versioning etc. "The top level is the application level where specific awareness information is collated and presented to the user" (ibid., p.224). The application level may access the awareness engine directly or indirectly via the second level (cf. Figure 2-16).

Last but not least, the *Model of Modulated Awareness* (MoMA) (Simone & Bandini, 2002; Simone & Bandini, 1997) implements the so-called reaction-diffusion metaphor. Previous models focused on how awareness information is produced and perceived but not on how it affects the behavior of the objects. Simone and Bandini (1997) explain the components of the metaphor as follows:

> "Reaction refers to phenomena where two or more entities become in contact in some way and modify their state in consequence of this fact. Diffusion implies the existence of a space where the involved entities are situated. Reaction-diffusion refers to situations in which the entities modify their state together with their spatial position (...) The mathematical foundations of reaction-diffusion systems are due to A. Turing" (ibid., p.359).

The described interaction with the environment appears to be closely related to Neisser's (1976) perception-action cycle (cf. Figure 2-4 in section 2.1.2).

2.3.3 Frameworks

In 2002, Gutwin and Greenberg published their workspace awareness framework (Gutwin & Greenberg, 2002). The goal was to develop a descriptive theory of awareness for aiding the iterative design of groupware. The framework itself was developed iteratively over a longer period of time. Their research hypothesis states "that helping people to stay aware in groupware workspaces will improve a groupware system's usability" (p.412). It expands upon previous work (e.g., Neisser's (1976) perception-action cycle (cf. section 2.1.2) and the theory related to situation awareness from human-factors (Endsley, 1995)) on the term awareness and focuses on only one specific awareness type (cf. Table 2-1 in section 2.1.1): workspace awareness. The scope was restricted to real-time distributed groupware systems, that are systems that "allow people to work or play together at the same time, but from different places" (p.413). In part one of their framework, they defined the information that makes up workspace awareness (cf. Table 2-5 and Table 2-6). Here, they extend upon the characteristics of awareness information (cf. section 2.3.1) distinguishing elements related towards the present and elements related towards the past.

Table 2-5. Elements of workspace awareness relating to the present (Gutwin & Greenberg, 2002).

Category	Element	Specific questions
Who	Presence Identity Authorship	Is anyone in the workplace? Who is participating? Who is that? Who is doing that?
What	Action Intention Artifact	What are they doing? What goal is that action part of? What object are they working on?
Where	Location Gaze View Reach	Where are they working? Where are they looking? Where can they see? Where can they reach?

The elements towards the past are added two more categories, how and when.

Table 2-6. Elements of workspace awareness relating to the past (Gutwin & Greenberg, 2002).

Category	Element	Specific questions
How	Action history Artifact history	How did that operation happen? How did this artifact come to be in this state?
When	Event history	When did that event happen?
Who (past)	Presence history	Who was here, and when?
Where (past)	Location history	Where has the person been?
What (past)	Action history	What has a person been doing?

Part two of their framework focuses on how awareness information is gathered. They identified three main sources and three corresponding mechanisms to gather it (pp.423):

1. Bodies (source) and seeing and hearing activities, i.e., consequential communication (mechanism)
2. Artifacts (source) and feedthrough (mechanism, i.e., the feedback to the acting person that is used to inform others (Dix et al., 2004))
3. Conversation, gesture (source), and intentional communication (mechanism)

The third and last part of their framework describes how workspace awareness is used in collaboration. These activities are shown in Table 2-7.

Table 2-7. Usage of workspace awareness (Gutwin & Greenberg, 2002).

Activity	**Benefit of workspace awareness**
Management of coupling	Assist people in noticing and managing transitions between individual and shared work.
Simplification of communication	Allows people to the use of the workspace and artifacts as conversational props, including mechanisms of deixis, demonstrations, and visual evidence.
Coordination of action	Assists people in planning and executing low-level workspace actions to mesh seamlessly with others.
Anticipation	Allows people to predict others' actions and activity at several time scales.
Assistance	Assists people in understanding the context where help is to be provided.

In contrast to the spatial model of interaction which focuses on information selection and awareness levels the workspace awareness framework "is oriented towards small groups in medium-sized workspaces where it is more likely that participants are always interested in maintaining awareness of all the members of the group. Therefore, we see the focus/nimbus model as a higher-level complement to our framework" (p.440).

Further issues the workspace awareness framework does not consider are perspective taking and accountability (cf. section 2.1.3). However, these are regarded by the constraint-based awareness management framework or COBRA (Gross & Oemig, 2006a) that extends the model of the awareness information pipeline (cf. section 2.3.2) while replacing the filters with more sophisticated constraints to support awareness especially in socially translucent systems (cf. section 2.3).

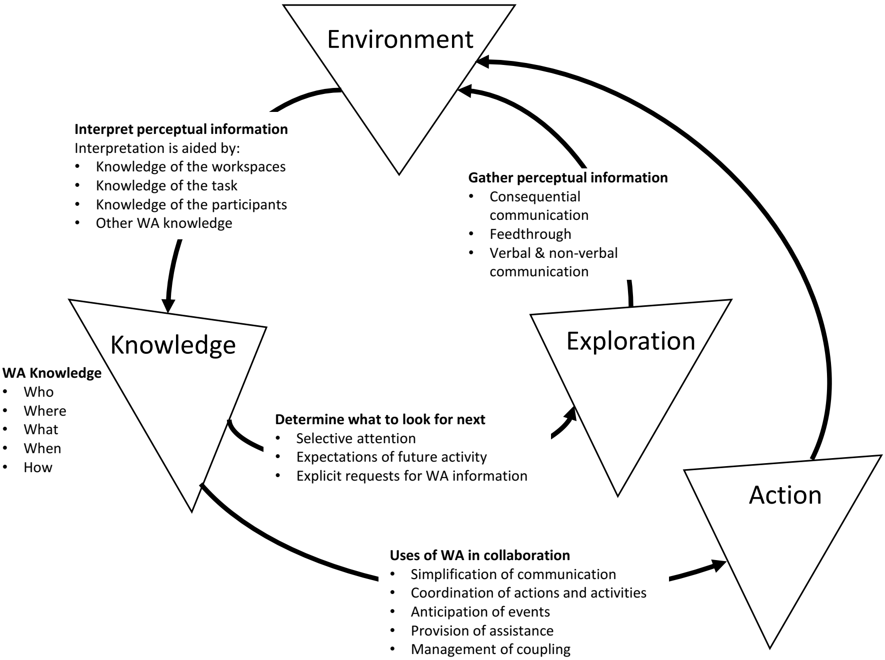

Figure 2-17. Overview of the workspace awareness framework (Gutwin & Greenberg, 2002).

Constraints represent circumstances and conditions that have an impact on our interaction by supporting or inhibiting specific behavior (Bürgy & Garrett, 2002). These constraints can be grouped into the following categories (Gross & Oemig, 2006a):

- Physical constraints (e.g., proximity, size, loudness etc.)
- Social constraints (e.g., politeness, moral, decency, norms etc.)
- Individual constraints (e.g., cognitive, logical, physiological etc.)
- Legal constraints (e.g., rules and laws)
- Organizational constraints (e.g., corporate culture)
- Technical constraints (e.g., limitations due to the equipment used)

Some constraints can be violated (e.g., social constraints) while other cannot (e.g., physical). COBRA does not just use one constraint but a so-called constraint pattern consisting of multiple constraints describing basically the context in which the interaction takes place (cf. Figure 2-18).

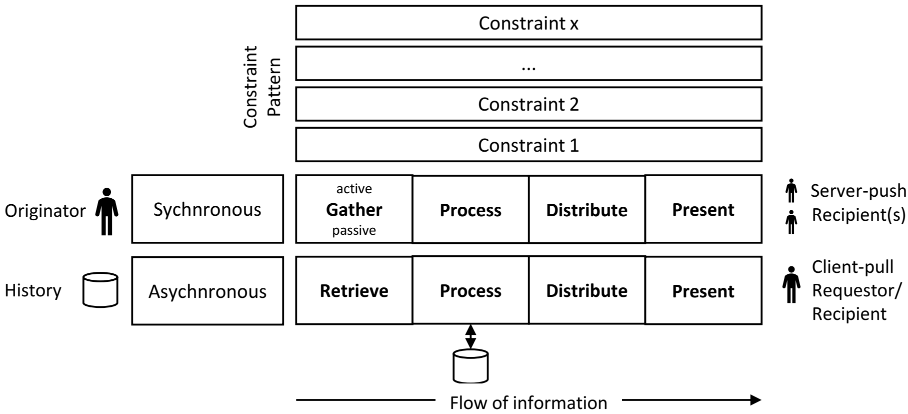

Figure 2-18. A constraint-based awareness management framework (Gross & Oemig, 2006a).

The spatial model (cf. section 2.3.2) can be implemented as physical constraint while perspective taking and accountability (cf. section 2.1.3) would serve as a social constraint. An implementation of the framework based on a social constraint was developed as part of the project PRIMIFaces (Gross & Oemig, 2006b) that focused on the selective dissemination of awareness information in the context of instant messaging applications.

2.4 Challenges, Reflections and Criticism

As illustrated in the previous sections, research on awareness has been ongoing for quite some time. Many systems and prototypes have been designed and evaluated. However, there are still numerous issues that have not been resolved to this day. This section will deal with some of them more specifically. They are all organized in short sections for easier reference later.

2.4.1 No Basic Research

As elaborated in this chapter, one of the major goals of CSCW is to translate vital social mechanisms from the real world into technical concepts and means of support in the digital world. However, everything in the development of digital systems needs to be specified and implemented explicitly. Due to this reduced environment, a lot of information is simply lost or not even captured in the first place. On the other end, people are easily overwhelmed by a lot less information (Gutwin & Greenberg, 2002). Maintaining awareness thus becomes exhausting and stressful due to non-existent or awkward and imperfect mechanisms supporting it (Gutwin & Greenberg, 2002, p.415):

- Input and output devices only generate a fraction of the perceptual information that is available in rich face-to-face situations.
- A person's interaction with a digital environment creates much less information than in a physical environment.
- Many systems do not even present the limited awareness information that is available.

As a consequence, designing awareness support does not only mean to display information properly but also to gather it in sufficient ways leaving researchers with a large amount of design challenges small and large that never had to be dealt with in the real world. This implies that a lot of basic research or rather use-inspired basic research (cf. section 1.4) is required to catch up with reality as previously seamless and effortless routines suddenly require effort in a digital setup (cf. section 2.2.3). At the same time, this is the worst starting point for CSCW's goal of effortless coordination as researchers have to start at the very beginning. However, many researchers skipped ahead and left the basic part aside and developed systems with features insufficiently backed causing many groupware systems to fail altogether (Grudin, 1988, 1994b; Lynne et al., 1990). This was realized early on by other researchers complaining that "rather than looking at 'fancy' innovative functions for groupware systems, designers should be focusing on how to better solve the basic need" (Bullen

& Bennett, 1990; Henninger, 1991, p.294). Their overall assessment reads: “creeping featurism considered harmful to CSCW application” (ibid., p.28.).

2.4.2 (Un-)Resolved Design Tensions

As concluded in section 2.4.1, the research topic of awareness is full of design challenges. One of the most famous being the dual tradeoff between awareness and privacy and awareness and disruption (Hudson & Smith, 1996). Awareness and supporting awareness as part of a support function of a cooperative application has a positive effect on the cooperation itself. However, there is also a downside or at least something considered to be a tradeoff. After gaining some experience based on early CSCW applications, Hudson and Smith (1996) formulated the existence of the dual tradeoff between 1) awareness and privacy, and 2) awareness and disturbance. It basically states

> “the more information about oneself that leaves your work area, the more potential for awareness of you exists for colleagues. Unfortunately, this also represents the greatest potential for intrusion on your privacy. Similarly, the more information that is received about the activities of colleagues, the more potential awareness we have of them. At the same time, the more information we receive , the greater the chance that the information will become a disturbance to our normal work” (Hudson & Smith, 1996, p.248).

The first is a sending problem, while the second one is a problem of receiving too much information. Thus, there are design challenges at various levels from protecting data over to avoiding information overloading which is directly a result of the explicit effort to maintain awareness in the digital realm.

2.4.3 The Unserved Mental Entity

Awareness is described as mental model or knowledge or knowing something (cf. section 2.1). It is even described to reside in the user’s mind. Therefore, it appears extremely odd that CSCW avoids cognitive aspects while the issue overall appears indicative of a cognitive approach. Instead researchers remain in the dichotomy of the two-sided discussion on awareness research: “the technology-oriented side where awareness is often seen as technology providing information to users, and the ethnographically-informed side where awareness is often seen as the outcome of an activity of the user" (Gross, 2013; Schmidt, 2011b, p.427). Especially when seeking CSCW's goal of effortless coordination an operationalized cognitive construct is needed to measure efforts that suddenly appeared when translating real world mechanisms to digital systems (cf. section 2.4.1). Ethnographic studies are a useful tool but they will not help in this case. In the context of heed versus attention (cf. section 2.2.3) researchers even explicitly argued against cognitive approaches because of dealing with more than just a mental state or cognitive ability (Heath et al., 2002). "It does not make sense to conceive of 'awareness' as such, i.e., as a distinct (mental) entity. That is, the term 'awareness' is only meaningful if it refers to a person's awareness of something" (Schmidt, 2002, p.287). Maybe, previous cognitive approaches in HCI and CSCW had their flaws but those can be fixed. They do not require to ignore cognitive science entirely. A dogmatic preference on research methods (Neale et al., 2004) will not solve the design challenges at hand.

2.4.4 Design Implications from Ethnographic Field Studies

In CSCW, ethnography "has received serious attention as a method of informing system design, bringing a social dimension to the design process by focusing on how work is actually done rather than looking at these processes through some idealized organizational view" (Blythin et al., 1997, p.39). Researchers were quite certain that "empirical workplace studies, as much as they can provide specific design recommendations, are even more important to 'contribute to a respecification of key concepts, like awareness, that are critical to an understanding of how technologies are used and deployed in everyday environments" (Luff et al., 2008, p.408).

But the same way as ethnographers realized that "unfortunately, however, the expected benefits from these technologies [supposedly supporting awareness] never materialized" (Schmidt, 2002, p.285). The desire to provide design implications based on ethnographic studies did not materialize, either. Plowman et al. (1995) wonder "why so few ethnographic studies result in specific design guidelines" (Plowman et al., 1995, p.312) as proclaimed. In their opinion these studies belong to very unique settings so that their results are hardly generalizable. At this point CSCW seems to ignore the general scientific procedures of hypothesis generation and hypothesis validation, i.e., hypotheses being built on observations and qualitative research while hypothesis validation happens mostly on quantitative data that needs to be measured. Design implications result from validated hypotheses whereas initial ideas for hypotheses may stem from ethnographic studies – in other words, it is not going to happen.

2.4.5 The Problem with Awareness and the Big Hole

"Understanding, defining, and operationalizing the many roles of awareness in collaboration is a key problem for the success of CSCW systems" (Convertino et al., 2004; Gutwin & Greenberg, 1996). But nearly three decades after the initial findings, "nothing remotely similar to consensus about what the issue is and how to understand it has been achieved" (Schmidt & Randall, 2016, p.229). It appears to be even worse. Already in 2002, Schmidt published an article in the Journal of Collaborative Computing and Work Practices (JCSCW) titled "*The Problem with Awareness*" stating:

> "The term 'awareness' is obviously found ambiguous and unsatisfactory. The term 'awareness' of course refers to actors 'taking heed of the context of their joint effort. But this is hardly a concise concept by any standard. CSCW researchers are obviously far from confident with using the term and thus often use the term in combination with different adjectives (...). The proliferation of adjectives is a clear indication that the term 'awareness' is found to be equivocal, that researchers are aware that the term is being used in significantly different ways, and that it is in need of some qualification to be useful" (pp. 286).

The term itself was already described as being highly elastic (cf. section 2.1). "Interestingly enough, many authors discussing awareness issues rely on an intuitive notion of the term without giving any precise definition. Where definitions are given, they usually are subtly different from those of other authors" (Sohlenkamp, 1998, p.40).

For some reason researchers wish to distinguish themselves from others leading to the fragmentation of an entire research field as it was not only symptomatic for awareness alone. Schmidt (2009, p.223) diagnosed in his article *Divided by a Common Acronym: On the Fragmentation of CSCW* the following:

> "the required continuity of the program, the ongoing development of concepts and frameworks, is replaced by restless reformulation of the research problem, slapdash changes of scope, unaccountable redefinitions of key concepts, etc. Under such circumstances the progressive development of the conceptual foundation of technology is not possible."

Thus CSCW support functions are a prime example for the problem that surfaced eventually as the "big hole" in HCI (including CSCW) (Kostakos, 2015). In 2014 a bibliometric analysis was conducted (Liu et al., 2014) spanning 20 years (1994-2014) on HCI's flagship conference ACM CHI using co-word analysis (Callon et al., 1991; Callon et al., 1983). This type of study considers the keywords of papers, how these keywords appear together on papers and how their relationships change over time. Co-word analysis, a content analysis technique, has been conducted for various disciplines (e.g., psychology, sociology etc.) over the years. It yields two values for each analyzed item: its density and its centrality. The density (y-axis) reflects the internal cohesion of specific research theme. The centrality (x-axis) shows the strength of interaction between a specific research theme with others. Both are used to construct the strategic diagram (Callon et al., 1991) (cf. Figure 2-19).

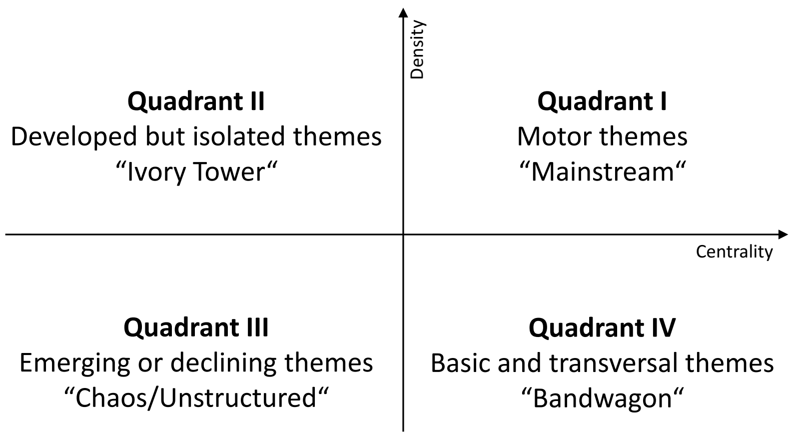

Figure 2-19. Strategic diagram of co-word analysis (Callon et al., 1991).

The resulting quadrants are described as themes in addition to a catchy phrase or term:

- Motor themes/"Mainstream" (quadrant I): research work here is internally coherent and central to the respective field.
- Developed but isolated themes/"Ivory Tower" (quadrant II): internally well-structured indicating that a group of researchers is actively working on them. Yet, there are unimportant external ties leading to specialized/peripheral work.
- Emerging or declining themes/"Chaos/Unstructured" (quadrant III): weakly developed with (yet) marginal interest from the research network.
- Basic and transversal themes/"Bandwagon" (quadrant IV): weakly structured themes. Topics here are strongly linked to research interests but weakly linked together. There is potential of considerable significance but work is under-developed as the research does not build on top of one another.

The result for the ACM CHI conference, serving as an indicator for HCI in general, was not very pleasing. There were almost no items in the first quadrant. HCI obviously lacks motor themes and the "analysis showed that most research themes at CHI remain at the Bandwagon or Chaos quadrants. *We simply roll from topic to topic, year after year, without developing any of them substantially*" (Kostakos, 2015, p.50). An accumulation of knowledge obviously does not take place. Liu et al. (2014) presume the following reasons:

> "Due to the rapid pace of technology designed for humans, however, knowledge in HCI tends to be highly contextual instead of universal like in the field of biology or physics. So, we argue that by nature HCI research is like nomads chasing water and grasslands, making it challenging for the community to accumulate knowledge (...) We can hypothesize this to be a consequence of technological development and the need for novel interaction techniques" (p.3560).

However, this statement rather sounds like an excuse instead of an explanation. On the other end, (Kostakos et al., 2015) make another point that potentially hits the mark: HCI research "completely overlooks the needs of fellow scientists and researchers. As a result, most research within HCI is not actually re-usable by other scientists" (p.3). This prevents progress in research. Further, many researchers do not consider the "implication of design", i.e., a mindset that places emphasis on re-usability for practitioners and the industrial sector. Research results need to be relevant to designing products – which implies that they are currently not in every instance. All in all, this leads to the *fragmentation of HCI* (Liu et al., 2014, p.3560).

The same co-word analysis of HCI also covers typical CSCW topics and places them in the fourth quadrant ("bandwagon") as weakly structured themes. That means they are strongly linked to specific research interests throughout the network but are only weakly linked together. In other words, CSCW themes are under-developed yet transversal, with potential to be of considerable significance to the entire research (Liu et al., 2014, p.3554).

Yet, ethnographic researchers see the problem in the concepts: "the difficulties in developing systems to support awareness do not simply derive from the limitations of technology, but rather from the ways in which we often characterize awareness and associated concepts such as mutual monitoring" (Heath et al., 2002, p.318). In Schmidt's (2009) opinion, the CSCW community even ignores ethnographic results and mainly focusses on technology to support group work alone:

> "One example will suffice to indicate the level of fragmentation. Take the review article in the HCI Handbook, entitled 'Groupware and computer-supported cooperative work' (Olson and Olson, 2003). (...) In fact, this review of CSCW completely ignores the substantial contribution of ethnographic or workplace studies to CSCW" (Schmidt, 2009, p.224).

However, in terms of Kostakos (2015), there are hardly any design implications, resolved design tensions or re-usable concepts for practitioners. As will be discussed later (cf. section 4.6.8), the real reasons appear to be something different.

2.4.6 Awareness versus Coordination

In section 2.4.3 awareness is described as something mental, yet cognitive science does not play a major role in CSCW as it has done in HCI. However, this is not the only curiosity that strikes the eye. Another one is that in many definitions awareness is said to support or facilitate coordination (cf. section 2.1). Even the overall goal refers to effortless coordination (cf. section1.2) and not effortless awareness. Early ethnographic studies did not even use the term awareness and rather spoke of "practices" like monitor and display to coordinate group work. The 3C model (Teufel et al., 1995) named coordination as an important support function of groupware (cf. section 1.1), the awareness support function was added years later (Gross & Koch, 2007). All in all, coordination appears to be the higher goal or the superior concept to awareness. This makes it even more surprising that a lot of research publications leave out coordination completely and focus solely on awareness.

However, focusing more on coordination could have spared the research community a lot of trouble and confusion: as mentioned in section 2.4.5, the problem with awareness started with the overloaded term itself which is also surrounded by large body of philosophical discussion blurring the sight towards the real thing. In comparison, the term coordination appears rather technical, straight-forward and almost non-philosophical overall.

2.4.7 Context-Independent Awareness Support

A fact mentioned earlier in this chapter that should not stay unnoticed is the one suggested by awareness models and engines in section 2.3.2: while the awareness of the subject itself is bound to a certain context (cf. section 2.1.1), the support system formed by awareness models and engines is not. Especially the AETHER model (Sandor et al., 1997) proposed a separation of application and awareness levels (cf. Figure 2-16 in section 2.3.2). While the application belongs to the subject's context, the awareness level contains the general means and mechanics[11] to support awareness in many different applications and thus also contexts.

A similar separation of context and mechanics can be found as part of the Clover model which also known as Clover architecture (Ellis & Wainer, 1994; Laurillau & Nigay, 2002). "The Clover design model provides a high-level partitioning for reasoning about the collaborative services a groupware application may support (…) a groupware application covers three

[11] These mechanics will be later referred to as the *mechanics of collaboration* (Gutwin & Greenberg, 2000).

kinds of services: production, communication and coordination" (Laurillau & Nigay, 2002, p.237):

- The production space refers to the objects produced by group activity or to the objects shared by multiple users.
- The communication space refers to person-to-person communication such as e-mail, relay chat media space.
- The coordination space covers activities dependencies including temporal relationships between the multi-user activities. It also refers to the relationships between actors and activities.

There are two CSCW design issues attached to it:

1. Not all groupware supports all of these spaces, e.g., media spaces (cf. section 2.3) lack a production space.
2. Coordination spaces are sometimes implemented as separate systems.

That it can be done this way is proven by the following: The spatial model of interaction (Benford & Fahlen, 1993) is said to be used in wide range of different applications (Simone & Bandini, 1997, 2002). This would not have worked if they were dedicated to a unique context or setup. The topic of context-independence will be picked-up again later in section 3.3.7 adding the perspective of coordination. For now, it boils down to: awareness is context-bound, the awareness support system is not!

2.4.8 The Underrated Self-Awareness

Reflecting on awareness and what has been said about it in this chapter reveals another underrated aspect in CSCW: self-awareness. Most definitions presented in Table 2-1 aimed at the knowledge of who is around and about the activity of *others*. Self-awareness has been described earlier in this thesis as the users' "sense of who they are in relation to society and culture" (Boyd, 2002) adding the notion of identity to the picture among moods and feelings.

In cooperative settings self-awareness also refers to the taskwork of oneself which is an important basis for coordination. Knowing one's own part is the basis for making inferences on possible next options. As such, self-awareness has hardly been studied in CSCW leaving it as another unresolved design challenge. Only in a few occasions it appeared, for instance, as part of Erickson's (2003) six claims demanding a third-person point of view:

> "Although it might be argued that users do not need feedback on their own activity since they know what they're doing, our experience is that this is quite important. People learn what elements of the social visualization mean by watching it over time, and , particularly, by seeing their own behavior reflected in it (...) Thus, a social visualization should show its users their own activity as others would see it" (Erickson, 2003, p.847).

By revealing to the users how their activities are shown to others, enables perspective taking which is a basis for the principle of accountability based on the awareness of the awareness of others (cf. section 2.1.3).

2.5 Summary

In order to support coordination in digitally supported cooperative environments, CSCW researchers found and used the concept of awareness. "Understanding, defining, and operationalizing the many roles of awareness in collaboration is a key problem for the success of CSCW systems" (Convertino et al., 2004; Gutwin & Greenberg, 1996). Reflecting on what has been achieved in terms of awareness, reveals many conceptual ideas and technical implementations (Gross, 2013; Rittenbruch & McEwan, 2009). After the initial failure of systems, researchers increasingly focused on ethnographic studies to better understand social interaction and user needs. Based on this knowledge they embarked in many directions with a constant reformulation of concepts and numerous unrelated technical prototypes each supporting a seemingly different type of awareness.

Yet, the situation is not as bad as it seems. Especially, after going through conceptual aspects, models and frameworks provided a good sense of what awareness is and to start building a construct for it.

The key findings in this chapter are:

- There is no coherent model or concept of awareness but when picking up the pieces it is possible to come up with a quite an extensive awareness construct.
- The CSCW contribution to the concept of awareness is rather fuzzy. A clearer picture stems from human-factors and surrounding psychological disciplines. Yet, these do not necessarily regard cooperative contexts. Situation awareness, a term stemming from human-factors, proved to be the most generic and comprehensive in terms of definition and explanation.
- Though being mental and for a starting point thus bound to the individual, awareness also develops a strong social impact, when introducing perspective-taking and meta-awareness.
- Seemingly effortless coordination based on awareness can be discovered but not explained by ethnographic field studies.
- Present awareness models appear to have a generic tendency splitting the awareness system from the application that fulfills a context-specific purpose. Typically, these models define components but no types of measurement of any sort.

The summary of awareness attributes and processes gathered in this chapter can be found in Appendix D1. As a next step the cognitive components and processes need to be understood and specified in greater detail. Another part that has to be addressed is coordination and with it a clarification or extension on how all of this relates exactly to awareness (to be addressed in the next chapter). Last but not least, especially "seemingly effortless coordination" remains an open issue. The word seemingly indicates that this finding stems from observation. "Effortless" means (almost) without effort. Diagnosing something as effortless requires an understanding of where the efforts lie and how to measure them.

3 Cognition, Coordination & Coordination Support

As shown in the previous chapters, awareness has truly been a CSCW topic as such. Chapter 1 provides the main research results in terms awareness and discusses related challenges and problems. Especially the latter raise the following questions:

1. If awareness is something mental (e.g.., a mental model), why have the cognitive details hardly been researched from a CSCW perspective?
2. If awareness is often defined as "facilitating coordination" (Beaudouin-Lafon & Karsenty, 1992) or as "fundamental to coordination" (Dourish & Bellotti, 1992) (cf. section 2.1), why has there been only limited research in the terms' relationship and meaning for one another?

This chapter provides the missing details on cognition to reveal further aspects related to the human mind (addressing question 1) and on coordination to learn more about it as a construct and its relation to awareness (addressing question 2). Like the previous chapter, this one contains a discourse on issues found through its sections followed by the chapter's summary where further characteristics of coordination are derived and gathered.

3.1 Cognitive Aspects

Section 2.1.2 showed that awareness can be described in a narrow and a wider sense: as mental model with and without the surrounding processes of perception and maintenance (Gutwin & Greenberg, 2002). HCI is known to be a field of applied cognitive engineering where insights from cognitive sciences (i.e., cognitive psychology, artificial intelligence, linguistics, cognitive anthropology, and the philosophy of the mind) inform the design of information technology for interaction (Norman, 1986; Wilson et al., 2013). It is "a type of applied Cognitive Science, trying to apply what is known from science to the design and construction of machines" (Norman, 1986, p.31).

On the other end, cognitive sciences were not that prominent in CSCW. Standard text books on CSCW (Borghoff & Schlichter, 2000; Gross & Koch, 2007; Schwabe, Streitz, & Unland, 2001; Beaudouin-Lafon, 1999) do not feature a chapter on cognitive psychology or cognition in collaborative contexts. Their focus is directed right away towards groups and teams and their characteristics where sociological and ethnographic studies are in the lead. Does that imply that there is no role for cognitive sciences in CSCW beyond the part already covered by HCI? Do cognitive aspects not change when moving from a single- to a multi-user setting (cf. section 2.2.2)? Do people stop using their perception and thoughts once in a collaborative context thus making cognitive sciences dispensable in CSCW? No.

Cognitive psychology "is the branch of psychology devoted to the scientific study of the mind" (Braisby & Gellatly, 2005, p.2). It especially faces the challenge, that nearly everything it deals with is unseen or not directly observable (e.g., thoughts or memories). Therefore, cognitive psychology has to help itself with modelling the concepts to come up with predictions tested in appropriate studies. Card et al. (1983) state: "An applied psychology that is theory-based, in the sense of articulating a mechanism underlying the observed phenomena, has advantages of insight and integration over a purely empirical approach" (Card et al., 1983, p.13) – as empirical approaches (like ethnographic studies, cf. section 2.1.3) rely on experience or observation without due regard for systems or theories (Merriam-Webster, 2019a). In the context of HCI (and probably also in the case of CSCW, as to be shown) the role of cognitive psychology is to specifically help with the evaluation of humans interacting with systems and technologies and deriving design guidelines thereof. One example of the latter is the well-known ground rule of system development: "Recognition over recall" (Budiu, 2014; Nielsen & Molich, 1990) or "Reduce short-term memory load" (Shneiderman & Plaisant, 2005).

One step further down, cognition itself is the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses or mental processes for short or just the product of these processes (Merriam-Webster, 2020). This sounds very familiar looking at the conception on awareness back at section 2.1.2. However, (Parasuraman et al., 2008) consider cognition which includes choice and knowledge as the broader concept of both. The term cognition dates back to the 15th century, where it actually referred to "thinking and awareness" (Revlin, 2012). Back then, early cognitive models (cf. Figure 3-1) were developed that even included gods ("deus") and angels ("angelos") besides more down-to-earth senses ("Auditus", "Visus", "Odorantus", "Gustus", "Tactus") as well as man's intellect and ratio.

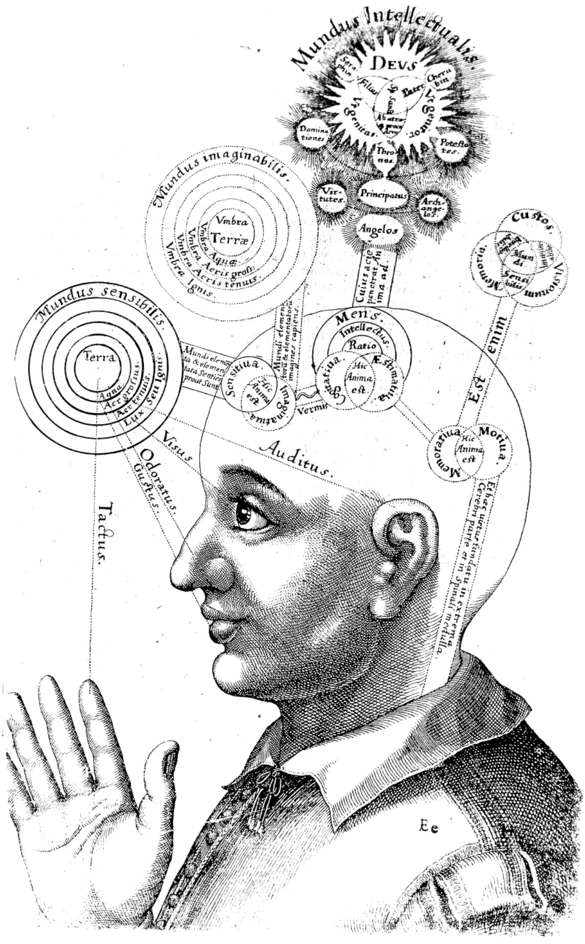

Figure 3-1. Cognitive model by Robert Fludd (1619).

The fairly similar definitions of cognition and awareness already indicate their close relationship, making awareness in cooperative settings even more eligible to be inspected from a cognitive point of view.

3.1.1 Cognitive (Sub-)System

Having cognitive psychology identified as an area of the "invisible", preferably working with systems and theories, it is time to dig deeper into this world. "It is natural for an applied psychology of human-computer interaction to be based theoretically on information-processing psychology, with the latter's emphasis on mental mechanisms" (Card et al., 1983, p.13). By naming it information-processing psychology, Card et al. (1983) underline its close relationship to computer science with its typical systems and components which will serve as a basic metaphor for their model: "A computer engineer describing an information-processing system at systems level (...) would talk in terms of memories and processors, their parameters and interconnections. (...) The human mind is also an information-processing-system, and a description in the same spirit can be given for it" (Card et al., 1983, p.24).

Having this in mind, Card et al. (1983) proposed the well-known Model Human Processor (MHP) in their seminal book *The Psychology of Human-Computer Interaction*. In this model they suggest three interacting subsystems (cf. Figure 3-2):

1. Perceptual subsystem: carries sensations of the physical world detected by the body's sensory systems into internal representations of the mind.
2. Cognitive subsystem: connects inputs from the perceptual system to the right outputs of the motor system.
3. Motor subsystem: translates into action by activating patterns of voluntary muscles.

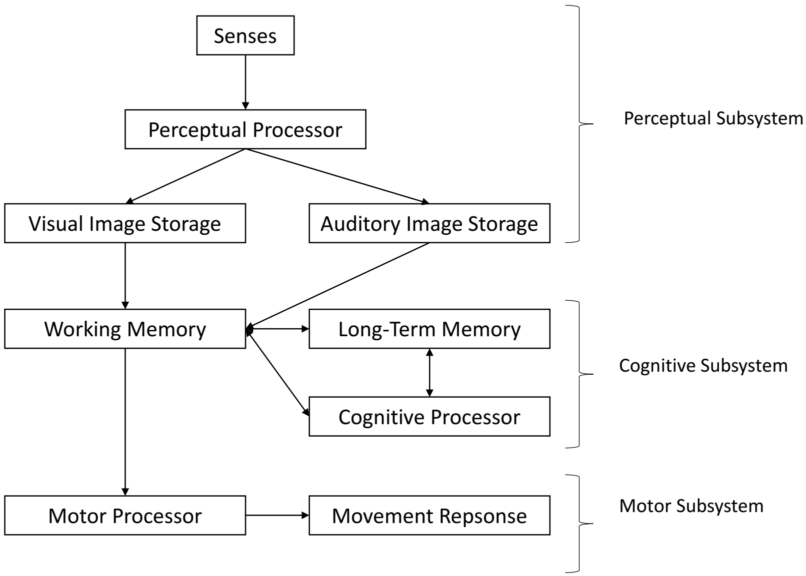

Figure 3-2. Model Human Processor (MHP) (Card et al., 1986; Card et al., 1983).

Each subsystem has its own memory/storage and processor. The system as a whole may operate in different modes. For some tasks the human must act as a serial processor, others require parallel operation of all three subsystems. The memory entities are described by the following parameters (Card et al., 1983, p.25):

- The storage capacity in items (μ)
- The decay time of an item (δ)
- The main code type (physical, acoustic, visual, semantic) (κ)

Whereas the most important characteristic for a processor is its cycle time (τ). The cycle time for the cognitive processor (τ_c) is "shorter when greater effort is induced by increased task demands or information load; it also diminishes with practice" (Card et al., 1983, p.42). Card et al. named this the *Variable Cognitive Processor Rate Principle*.

"The basic principle of operation of the Model Human Processor is the *Recognize-Act Cycle* of the Cognitive Processor (...) On each cycle of the

Cognitive Processor, the contents of Working Memory initiate actions associatively linked to them in Long-Term Memory; these actions in turn modify the contents of Working memory" (Card et al., 1983, pp.26). This comes close to the previously described perception-action cycle (Neisser, 1976) (cf. section 2.1.2).

However, the model of the MHP is a general description not specific to the context of CSCW or even awareness. On the other end, not dealing with aspects of CSCW is one of its limitations. The MHP is based on psychological sciences thus leaving out social or organizational aspects relevant in CSCW and cooperative contexts.

The following sections especially focus on the cognitive subsystem. It is comprised of the working memory, long-term memory, and the cognitive processor (cf. Figure 3-2). Card et al. (1983) characterize it as "fundamentally parallel in its recognizing phase and fundamentally serial in its action phase. Thus, the cognitive system can be aware of many things, but cannot do more than one deliberate thing at a time" (p.43).

3.1.2 Perception, Attention and Memory

Like awareness, perception is again a term with two meanings, one of the process and the other the result of that process. Perceptions enter through the visual, auditory, olfactory, gustatory or tactile sensory systems and trigger responses starting in areas of the brain dedicated to each sense (Johnson, 2010) (cf. Figure 3-1). The MHP reduces its perceptual system to auditory and visual perception (cf. Figure 3-2) that are considered the "most important buffer memories" (Card et al., 1983, p.24).

As to cope with this potentially large amount of information, the mind or more specifically the cognitive subsystem employs a filter mechanism named *attention*. "The human brain has multiple attention mechanisms, some voluntary and some involuntary" (Johnson, 2010, p.82). They focus our awareness on a very small subset of the perceptions and activated long-term memories while ignoring everything else, i.e., the opposite to attention is ignorance. From that perspective, awareness can be described as "our ability to maintain and constantly update a sense of our social and physical context. We do so in an apparently effortless manner and without being aware that we do so – at least until something happens that is out of order and makes us raise our level of consciousness" (Pedersen &

Sokoler, 1997, p.51). Humans shift their attention when needed. Taking (again) an information processing perspective, attention belongs to the memory management procedures that keeps the system from overloading as the human information processing system has a limited capacity (Baddeley, 1999; Chandler & Sweller, 1991). Attention is the mechanism that avoids that too much information enters the working memory. On the other end, there is another mechanism that purges the information from memory to release some capacity: forgetting (cf. section 3.1.3).

Cognitive processes are continuously taking place in your mind and in the minds in the people around you (Sternberg, Mio, & Sternberg, 2011) (cf. Figure 3-3).

Figure 3-3. The human mind - not the brain (Source: Pixabay, CC0).

It has to be noted that cognitive psychology always refers to this overall structure as the mind and not the brain which is a term from neurobiology (Braisby & Gellatly, 2005). Other cognitive scientists refer to the mind as the software of the brain (Block, 1995).

> "How does the mind work? Though this is, of course, the central question posed by cognitive science, one of the deepest insights of the last half-century is that this question does not have a single answer: there is no one way the mind works, because the mind is not one thing. Instead, the mind has parts, and the different parts of the mind operate in different ways: seeing a color works differently than planning a vacation, which works differently than understanding a sentence, moving a limb, remembering a fact, or feeling an emotion" (Firestone & Scholl, 2016, p.4).

Besides the cognitive processor the Model Human Processor introduces the working memory and the long-term memory as part of the cognitive subsystem (cf. Figure 3-2). In general, the term memory is used in multiple ways to describe the following (Ritter et al., 2014, p.123):

1. The mental function of retaining information about things (stimuli, events, images, ideas etc.) when those things are no longer present.
2. The hypothesized storage system of the mind where this information is stored
3. The information itself that is stored.

Structures for storage are typically called stores. The information inside of these is referred to as memory (Sternberg et al., 2011, p.193). There are three common operations applied to stores by the processor (Baddeley, 2002; Brown & Craik, 2000):

1. Encoding: sensory data is transformed into a mental representation
2. Storage: information is kept encoded in memory
3. Retrieval: pull out or use information stored in memory

Over time, multiple major models of memory (McAfoose & Baune, 2009; Murdock, 2003) were developed. William James (1970) distinguished two major types:

- Primary memory: temporary information
- Secondary memory: permanent or at least for a longer time

Atkinson and Shiffrin (1968) already used three store types. Their model became known as the traditional *three store model* (Sternberg et al., 2011):

- Sensory store: capable of storing limited amounts of information for brief periods
- Short-term memory (STM): capable of storing information somewhat longer but limited in capacity
- Long-term memory (LTM): capable of storing information for very long periods, large capacity

When it comes to short-term stores, Baddeley's working memory model is "probably the most widely used and accepted model today" (Sternberg et al., 2011, p.203). While Atkinson and Shiffrin (1968) suggested that the STM acts as a working memory responsible for a variety of control processes, Baddeley and Hitch (1974) explored and expanded their idea and concluded that STM is better regarded as a component of working memory (Braisby & Gellatly, 2005, p.313). Baddeley and Hitch (1974) originally suggested three major components (cf. Figure 3-4):

1. Visuo-spatial sketchpad: a system for maintaining and manipulating visual images
2. Phonological loop: an auditory store and rehearsal process
3. Central executive: an attentional control similar to the cognitive processor of the MHP

Later, a fourth component was added (Baddeley, 2000): The Episodic buffer, which is story based also drawing on information from the long-term memory. The central executive can be seen as the processor and the other components as distinct stores with a certain way of storing information.

> "The central executive of working memory is assumed to be a limited-capacity attentional system that controls the phonological loop and sketch pad, and relates them to long-term memory. The executive is almost certainly considerably more complex than either of the two slave systems, which makes it considerably harder to investigate" (Baddeley, 2013, p.66).

Further, an attentional system implies volatility: it focuses the attention on new information thus turning it away from some of what it was focusing on earlier. "If items in short-term memory don't get combined or rehearsed, they are at risk of having the focus shifted away from them"

(Johnson, 2010, p.84). The content is easily lost as it endures only as long as we are paying attention to it (Revlin, 2012).

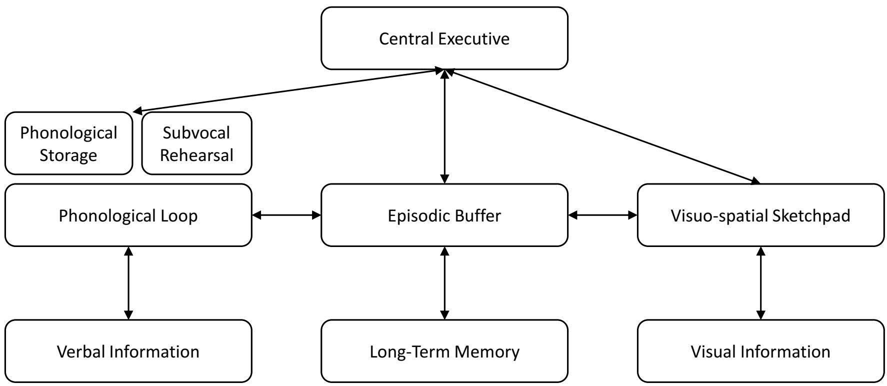

Figure 3-4. Working Memory Model (Baddeley, 2000; Baddeley & Hitch, 1974).

From a computer science and programming perspective this sound like a garbage collection mechanism that reclaims the storage associated with an object when it becomes unreachable, i.e., when nobody refers to it any longer (Bloch, 2018). This is another instance where human cognitive characteristics are similar to concepts in computer science – starting out with the MHP earlier in this section.

Already the MHP suggests a connection between awareness and the working memory (cf. Figure 3-2). The MHP and Baddeley's theory of the working memory both follow three assumptions (Mayer & Moreno, 2003, p.45):

1. Dual channel: Humans use separate information processing channels for verbal and visual material. It is a central theme of Paivio's dual-coding theory (Paivio, 1986, 1991) (cf. Figure 3-5). Here, there are not only two channels but signals coming in both ways are encoded in an associative manner making them easier to remember compared to the encoding in a distinct manner.
2. Limited capacity: each channel has limited capacity. Only a limited amount of processing can take place in the verbal or at the visual channel.

3. Active processing: Engaging in a task like learning requires substantial cognitive processing on both channels.

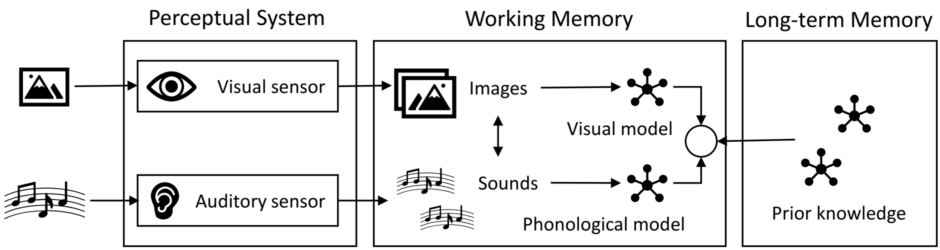

Figure 3-5. Dual-coding theory (Paivio, 1986, 1991).

More concrete evidence for the link between awareness and the working memory comes from Endsley (1995):

> "Once perceived, [awareness] information is stored in working memory. In the absence of other mechanisms (such as relevant long-term memory stores, most of a person's active processing of information must occur in working memory. New information must be combined with existing knowledge and a composite picture of the situation developed" (p.43).

Further, Endsley (1995b) integrated her conception of situation awareness (cf. section 2.1.1) into the cognitive system. This formed the model of situation awareness in dynamic decision making (Endsley, 1995) (cf. Figure 3-6). It contains stages of perception, cognitive processing and actions introduced in section 2.1.2. Self-awareness encompasses a subject's mental model of the situation upon which all of his/her decisions rely (Endsley et al., 1998).

As shown by Endsley (1995b) awareness involves a state of knowledge as well as dynamic processes of interaction with the environment. Awareness (the mental model) can be seen as a product of these processes and also as the "glue" connecting the three-staged process of perception, comprehension and prediction. Yet, there are different opinions on whether information acquisition and maintenance processes belong to awareness itself or not (Endsley, 2015).

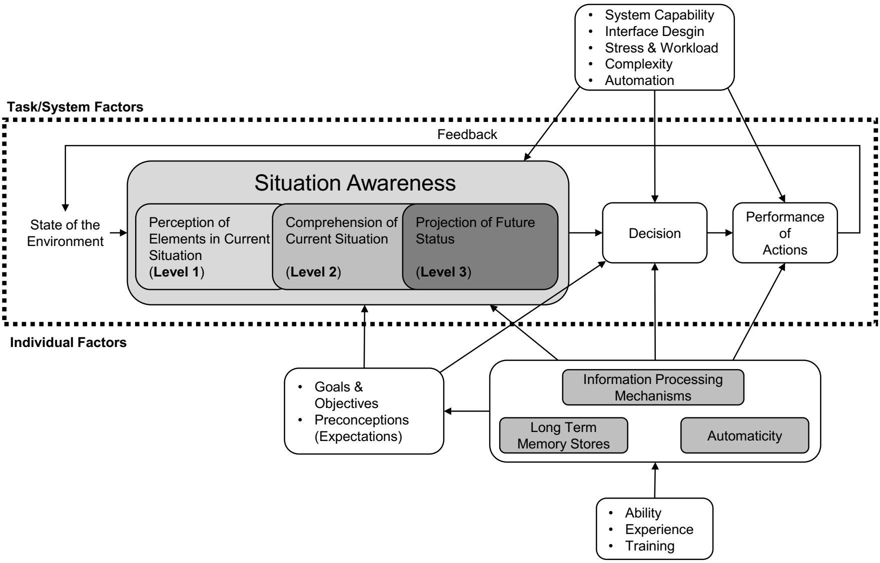

Figure 3-6. Model of situation awareness in dynamic decision making (Endsley, 1995).

3.1.3 Forgetting and Cognitive Artifacts

Forgetting is the inability to access information that was once stored and available to the subject (Ebbinghaus, 1885). Ebbinghaus sought to identify basic memory processes of the primary memory (i.e., the short-term memory, cf. section 3.1.2) that are independent of a subject's past knowledge (i.e., the long-term memory). To do this, he used nonsense syllables as the items to be remembered and determined how many runs through a list of these it would take to recite a list perfectly. Based on the number of syllables and the number of views he constructed a diagram known as his learning curve (cf. Figure 3-7). The curve showed that the number of views increased rapidly when the number of required syllables exceeded 7 items.

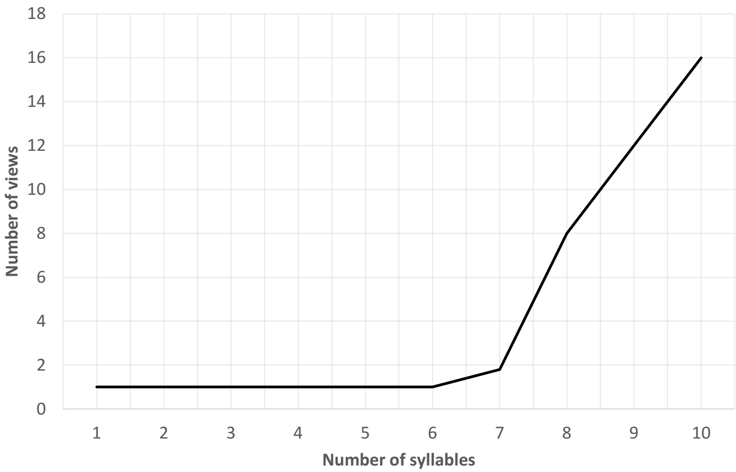

Figure 3-7. Learning curve (Ebbinghaus, 1885).

Another aspect he examined was forgetting for which he used another diagram – the forgetting curve (Ebbinghaus, 1885) (cf. Figure 3-8). The curve depicts the decline in memory retention over time when there is no attempt to retain it (e.g., by active recall/spaced repetition, better memory representation etc.). Ebbinghaus suggests repetitive rehearsals for better memory and especially emphasized the importance of sleep (Ebbinghaus, 1885). This precursor to implicit memory testing was, by the way, replicated successfully by researchers in 2015 (Murre & Dros, 2015).

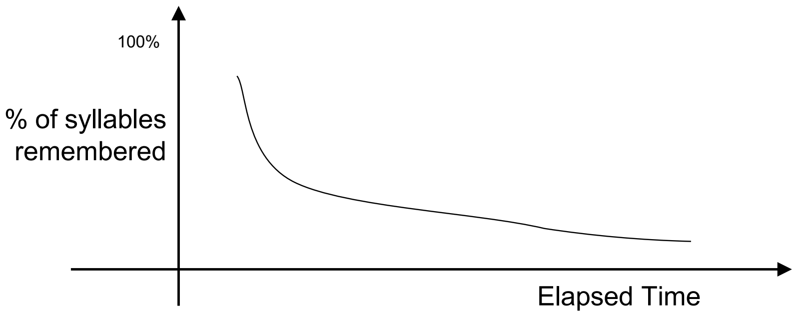

Figure 3-8. Forgetting curve (Ebbinghaus, 1885).

There are basically two theories to explain Ebbinghaus' observations and results, i.e., why people forget (Baddeley, 1999; Sternberg et al., 2011):

1. Decay theory: information gradually fades over time (this is shown by a forgetting curve)
2. Interference theory: information in memory is disrupted or obscured by subsequent activities following the initial perception. There are two kinds to be distinguished:
    a. Retroactive interference: newly acquired knowledge impedes the recall of older material. Here, the interference happens before the first recall.
    b. Proactive interference: material that was perceived or learned in the past impedes the perception/learning of new material.

The measure of how easily a piece of information or chunk can be retrieved from memory is called activation (Budiu, 2014). It is influenced by three different factors:

1. Practice/rehearsal: how many times a chunk has been used in the past
2. Recency: How much time went by since the information has been used and if it was the last or first in a larger amount of information (primacy/recency effect (Deese & Kaufmann, 1957))
3. Context: what is present in the subject's focus of attention

These factors are also the reason why one cannot actively forget something, no matter how hard they try as their trials are a kind of rehearsal that rather keeps things in memory.
Besides the above-mentioned internal factors there are other forms of memory aids. Cognitive artifacts can be defined as “those artificial devices that maintain, display, or operate upon information in order to serve a representational function and that affect human cognitive performance” (Norman, 1991). They are things made by man to extend our cognitive abilities like check lists, calendars or a handkerchief acting as a reminder (cf. Figure 3-9).

Figure 3-9. Cognitive artifacts (Source: Pixabay, CC0)

But these tools also easily influence the way tasks get done. According to Norman (1991), they can...

- ... distribute the task across time (precomputation).
- ... distribute the task across people (distributed cognition).
- ... change the actions required of the individuals doing the activity.

That is, they not only support memory but due to their externalized form support distributed collaboration (cf. section 1.1). Therefore, they will evolve to coordinative artifacts later in section 3.2.2. For now, cognitive artifacts "act as mediators between us and the world, both in execution (between actions and the resulting changes to the world state) and in perception (between changes in the world and our detection and interpretation of the state)" (Norman, 1991, p.18). In other words, they are central piece of Neisser's perception-action cycle (cf. Figure 2-4) described earlier (cf. section 2.1.2).

3.1.4 Problem Solving and Decision Making

Problem solving and decision making are two closely linked cognitive tasks that both form the second quadrant ("Choose") in McGrath's (McGrath, 1984) *Group Task Circumplex* (cf. Figure 2-8 in section 2.2.2). Problem solving in general "involves mentally working to overcome obstacles that stand in the way of reaching a goal" (Sternberg et al., 2011, p.484). Basically, it is finding solutions to problems – also in collaborative settings. "Problem solving occurs when users do not know what to do next" (Ritter et al., 2014, p.175). Finding solutions turns out to be quite dependent on the specific context. According to Sternberg et al. (2011), there are two different types of problems (Sternberg et al., 2011, p.447):

- Ill-defined problems: no specific goals nor clearly expected solutions.[12]
- Well-defined problems: allow for more initial planning, specific goals and clearly expected solutions plus a clear path to solution.

People usually develop a problem solving strategies as part of a problem solving cycle (Sternberg et al., 2011, p.444) (cf. Figure 3-10). In this cycle they will recognize the problem, define the problem, develop a strategy to fix the problem, organize the knowledge of the problem cycle, figure out the resources at their disposal, monitor one's progress, and evaluate the solution for accuracy in solving the problem.

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[12] Section 4.2 describes CSCW design later as *wicked problem* which is basically another term for ill-defined.

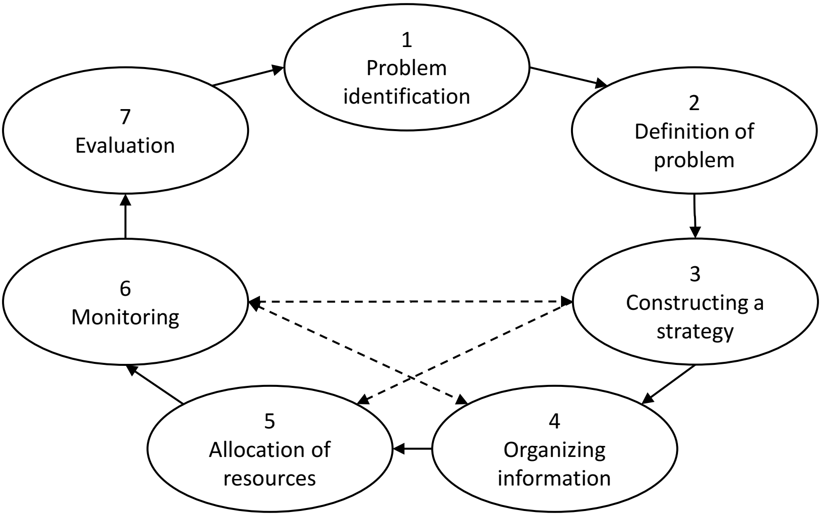

Figure 3-10. The Problem-Solving-Cycle (Sternberg et al., 2011).

On the other end, "decision-making is the result of problem solving" (Ritter et al., 2014, p.183). More commonly, the term decision is used to denote an important problem of choice among multiple options where much is at stake (Laux et al., 2014). In decision theory the term decision encompasses all acts of choice. Here, a decision defines all (sub-)conscious acts of choice among multiple alternatives for action no matter how big or how small. A decision-making problem can be characterized by the question "what option should be chosen from multiple alternative options?" One option might also be not to change anything maintaining the status quo (Laux et al., 2014). In order to solve a decision problem or to make a choice every option has to be examined regarding its benefits and risks. Results which can be reached with an option have to be projected and assessed on their impact. Options, results and impacts mark the field of decision making. Further, the goals and objectives of the decision maker are required to validate the options (Laux et al., 2014).

Decision making can be conceived as a specific kind of problem-solving process with the following steps:

1. Problem definition
2. Refinement of goals and objectives
3. Examination of options
4. Option selection
5. Realization of decision

In many situations the time to make decisions is critical. The Hick-Hyman Law (sometimes only Hick's law) (Hick, 1952; Hyman, 1953) describes the time to make the decision in relation to the number of options available. But the number of choices does not merely increase response times but it does so in a logarithmic way. Hick's law is already a concept that plays a role in HCI. It is usually used "to justify menu design decisions. For example, to find a given word (e.g., the name of a command) in a randomly ordered word list (e.g., a menu), scanning of each word in the list is required, consuming linear time, so Hick's law does not apply. However, if the list is ordered alphabetically and the user knows the name of the command, he or she may be able to use a subdividing strategy that works in logarithmic time" (Landauer & Nachbar, 1985). Decision-making basically comes with a speed-accuracy trade-off. One can either be very careful and slow but precise in making decisions or very fast but less accurate.

In this thesis, the decision-making is not to be seen as part of the primary task, i.e., the group's tasks to make a decision on a certain matter. Decision-making plays also small and mostly subconscious part in the secondary task of coordination! It is about deciding who is doing what next. Figure 3-6 shows how situation awareness facilitates decisions in order to decide what to do next. "Situation awareness forms the critical input to – but is separate from – decision making, which is the basis for all subsequent actions" (Endsley et al., 1998, p.1).

3.1.5 Capacity, Cognitive (Work-)Load and Effort

The MHP's cognitive subsystem (cf. section 3.1.1) consists of store and processor that can be described in terms of capacity (number of units) and cycle time (τ). The storage capacity can be determined by the number of items (μ) or as workload (relation of used capacity/available capacity).

The most important characteristic for a processor is its cycle time (τ) which denotes the amount of time needed to complete one task (e.g., retrieving information from memory). Also, the processor can be assessed in terms of load, especially if it is able to work on more than just one task at a time.

As mention earlier in section 3.1.2, “the primary characteristics of short-term memory are its low capacity and its volatility” (Johnson, 2010, p.82). Also, Ebbinghaus’ learning curve suggested a capacity limit. When it comes to memory and capacity almost every source of research refers to Miller (1956) and his chunks or rather the magical number seven plus minus two (Miller, 1956) whereas later research suggests rather four (Cowan, 2001). Miller concluded that the capacity of the short-term memory (STM) lies between five and nine meaningful items or chunks of information for a typical adult. In this case, the word “meaningful” refers to whether the person is able to find a way of relating the items to what he or she already knows. This process is called chunking (Sternberg et al., 2011). It decides if you see 1 4 9 2 or 1492 or the year Columbus discovered America (Revlin, 2012).

Turning to the cognitive processor, “one way of measuring [the central executive’s] capacity is through the working memory span task, which correlates with the comprehension capacity” (Baddeley, 2013, p.69). The *working memory span* is a task devised by Daneman and Carpenter (1980) (cf. Appendix C) which “involves presenting the subject with a series of sentences. The subject was required to read each one and then, after the final sentence, recall the last word of each sentence. Some people have difficulties remembering more than two, others easily remember four” (Baddeley, 2013, p.67).

On the other end, “at the most general level, mental workload can be described as the relation between the function relating the mental resources demanded by a task and those resources available to be supplied by the human operator” (Parasuraman et al., 2008, p.145). The relation is expressed by two figures of capacity: the used capacity divided by the available capacity (both in numbers of items) which yields a percentage.

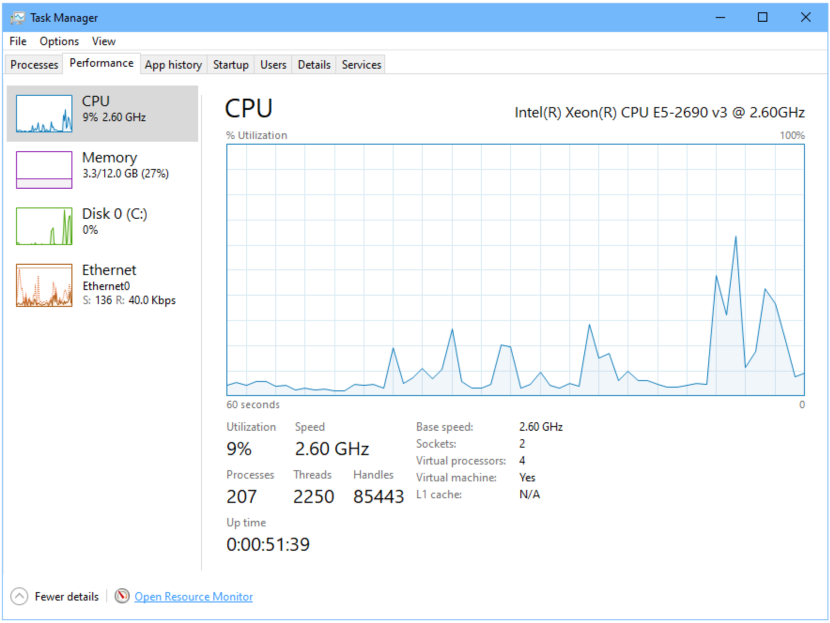

Figure 3-11. Capacity and workload displayed in Windows task manager (Source: Christoph Oemig).

This is also the third occasion where this thesis draws on a metaphor from computer science. This time the memory capacity is measured in Gigabyte (GB). For instance, the Windows task manager (cf. Figure 3-11) shows both, load 2.49/4GB and capacity of 4 GB. The workload of a CPU is calculated by the number of possible threads and how many of them currently work as opposed to the other fraction being idle.

According to Mayer and Moreno (2003) there are three types of cognitive demands that influence the cognitive workload (p.45):

1. Essential processing: cognitive processes required to pick up, make sense and integrate presented information
2. Incidental processing: cognitive processes that are not part of the essential ones, that deal with additional, unnecessary or redundant information (waste of resources)
3. Representational holding: cognitive processes aimed at holding a mental representation in working memory over a period of time due to the suboptimal presentation of information

Especially humans are subject to cognitive overload where the subject's intended cognitive processing exceeds the subject's available cognitive capacity (Mayer & Moreno, 2003). "Reducing cognitive load can involve redistributing essential processing, reduce incidental processing, or reducing representational holding" (ibid, p.43). This corresponds to the Cognitive Load Theory (Chandler & Sweller, 1991) where essential processing is called germane load, incidental processing is extraneous load, and the representational holding corresponds to intrinsic load. Awareness and coordination belong to the group of essential processing.

Last but not least, talking about effortless coordination involves the term *effort* which can be defined as "the conscious exertion of power or total work done to achieve a particular end" (Merriam-Webster, 2017). The typical unit for effort is time or more exactly time per one unit that is available to work on something though in many cases the effort is expressed as total effort (O´Regan, 2017). It is also not to be confused with the duration of something. For instance, if a task takes a total effort of twelve hours and there is one unit available then the duration is twelve hours and the effort per unit is also twelve hours. If there are two units available the total effort is still the same but the duration is split by two as well as the effort per unit.

3.2 Coordination Aspects

In general, the term coordination is defined as "the harmonious functioning of parts for effective results" or as "the process of organizing people or groups so that they work together properly and well"(Merriam-Webster, 2016c) (cf. Figure 3-12).

Figure 3-12. Working together to achieve a common goal requires coordination (Source: Pixabay, CC0).

Coordination takes place when a group of people act or interact together to achieve something (Preece et al., 2015, p.118), i.e., they either collaborate or cooperate as described in section 1.1 where cooperation requires more coordination and communication than collaboration.

The symptoms of poor coordination include "people bumping into one another, duplicating actions that another person has just completed, or attempting to take shared resources at the same time" (Gutwin & Greenberg, 2000, p.118).

3.2.1 Coordination Theory

The definitions above serve as a first introduction. But as previous definitions of awareness, they are hardly the definition of a construct, i.e., a lot more details are required. However, for the case of coordination as opposed to the one of awareness, there is an extensive concept known as *coordination theory* that formulates a construct of coordination. Its authors, Malone and Crowston (1990) (also later in Crowston et al. (2006)) describe this theory as

> "a body of principles about how activities can be coordinated, that is, about how actors can work together harmoniously. (...) In its attempt to find generalizations that apply across disciplines and across levels of analysis, coordination theory resembles earlier work on systems theory and cybernetics" (p.358).

Overall, coordination theory is the "body of principles about how the activities of separate actors can be coordinated" (Malone, 1988, p.6). As part of this theory they define coordination as "the act of managing interdependencies between activities performed to achieve a goal" (Malone & Crowston, 1990, p. 361). As shown for the case of awareness (cf. section 2.2.2), coordination is another example of a secondary task: "Coordination is distinguished from production: (...) We divide goal-relevant tasks into two categories: coordination task and production tasks" (Malone, 1988, p.5). Coordination tasks are information processing tasks performed due to interdependencies. Production tasks are all the other tasks that are performed in order to achieve the goal. Interdependencies and goals are two of the following components of coordination:

- Goals: coordination is always directed towards achieving a certain goal.
- Activities: the goal is decomposed into activities which have to be coordinated.
- Actors: activities are assigned to actors who execute them.
- Interdependencies: those are the goal-relevant relationships between activities.

Interdependencies are the vital part of the theory that cause the need for coordination.

> "In our previous work, we defined coordination as something that occurs only when multiple actors are involved, Since then, however, we have become convinced that the essential elements of coordination listed above arise whenever multiple, interdependent activities are performed to achieve goals – even if only one actor performs all of them (...) If there is no interdependence, there is nothing to coordinate" (Malone & Crowston, 1990, p.362).

Further, the authors identify three types of generic interdependencies (cf. Table 3-1):

Table 3-1. Interdependency types.

Kind of interdependence	Common object	Example in manufacturing	Example of coordination process
Prerequisite	Out of one activity which is required by the next activity	Parts must be delivered in time to be used	Ordering activities, moving information from one activity to the next
Shared resource	Resource required by multiple activities	Two parts installed with a common tool	Allocating resources
Simultaneity	Time at which more than one activity must occur	Installing two matched parts at the same time	Synchronizing activities

In another step Malone and Crowston (1990, 2006) specified the processes underlying coordination on different levels with coordination being the top-level process (pp.364) (cf. Table 3-2).

Table 3-2. Processes underlying coordination (Crowston et al., 2006; Malone & Crowston, 1990).

Process Level	Components	Examples of Generic Processes
Coordination	Goals, activities, actors, resources, interdependencies	Identifying goals, ordering activities, assigning activities to actors, allocating resources, synchronizing activities
Group decision-making	Goals, actors, alternatives, evaluations, choices	Proposing alternatives, evaluating alternatives, making choices (e.g., by authority, consensus, or voting)
Communication	Senders, receivers, messages, languages	Establishing common languages, selecting receiver (routing), transporting message (delivering)
Perception of common objects	Actors, objects	Seeing same physical objects, accessing shared databases

The above table shows that decision making is a vital aspect of coordination.

> "Many coordination processes require making decisions that affect the activities of the group. For instance, in sharing resources a group must somehow 'decide' how to allocate the resources; in managing task/subtask dependencies, a group must 'decide' how to segment tasks" (Malone & Crowston, 1994, p.99).

The group decision-making processes in turn

> "require members of the group to communicate in some form about the goals to be achieved, the alternatives being considered, the evaluation of these alternatives, and the choices that are made. This communication requires that some form of 'message' be transported from senders to receivers in a language that is understood by both" (Malone & Crowston, 1990, p.364).

Malone and Crowston (1990) describe communication as interacting with the environment which comes close to Neisser's (1976) perception-action-cycle (cf. Figure 2-4 in section 2.1.2).

Overall, this layered approach of coordination processes fits the one in the beginning of this thesis where collaboration builds on coordination which builds on communication (cf. Figure 1-6 in section 1.1). This will also play an important role later in chapter 1.

3.2.2 Coordination Practice

Now that is known what coordination is it is time to shift over to how coordination is actually done. "In general, collaborative activities require us to coordinate with each other (...) In particular, we need to figure out how to interact with one another to progress with our various activities. To help us we use a number of coordination mechanisms" (Preece et al., 2015, p.118).

Primarily, these include (Preece et al., 2015):

- Verbal and non-verbal communication
- Schedules, rules and conventions
- Shared external (i.e., physical) representations

The coordinative practices found by ethnographic studies, named "monitor and display" (cf. section 2.2.1) are a prime example for verbal coordination mechanisms. An example for non-verbal communication is a conductor of an orchestra or marching band (cf. Figure 3-13).

The conductor's baton and his movements are the means to display the necessary information to all the musicians involved. At the same time this is an example of the interdependency type simultaneity as the conductor synchronizes the activities of each individual musician.

Figure 3-13. A conductor coordinates the sounds of the orchestra using hand signals for non-verbal communication (Source: Pixabay, CC0).

As another example, our daily traffic, i.e., a large number of drivers and their respective vehicles, is coordinated by rules and conventions. These rules and conventions are implemented as traffic signs and traffic lights along the streets (cf. Figure 3-14). As traffic lights synchronize the ongoing driving at an intersection, they are another example of the interdependency type simultaneity.

Figure 3-14. Traffic lights as coordination mechanism implementing rules for traffic (Source: Pixabay, CC0).

In general, the interdependency type simultaneity deals with resources that are potentially used by multiple users at the same time. On the other end, the interdependency type shared resource deals with resources that can only be used by one user at a time requiring a coordination mechanism that enforces asynchronous utilization. For instance, the emergency intercom system in German regional trains allows only one participant to talk at a time – a transmission mode referred to as half-duplex (Couch, 2013). Whether a participant may talk is signaled by a traffic light metaphor using red and green lights in addition to a white push-to-talk (PTT) button (cf. Figure 3-15).

Figure 3-15. Intercom system in German regional trains using a half-duplex transmission mode. The user is required to wait with the red light and may talk when the green light flashes (Source: Christoph Oemig).

Another example of a coordination mechanism are schedules which can be found, for instance, at airports, train stations or at schools telling people where and when to go (cf. Figure 3-16).

Figure 3-16. A schedule as coordination mechanism (Source: Pixabay, CC0).

Recipes in a cook book (cf. Figure 3-17) are a different type of plan. These define the ingredients and the sequence of steps, i.e., the ingredients are not all added at the same time (indicating simultaneity) but in distinct steps one after the other following a pre-defined order. Thus, one step is the prerequisite for the next making it an example for a verbal coordination mechanism for the interdependency type prerequisite.

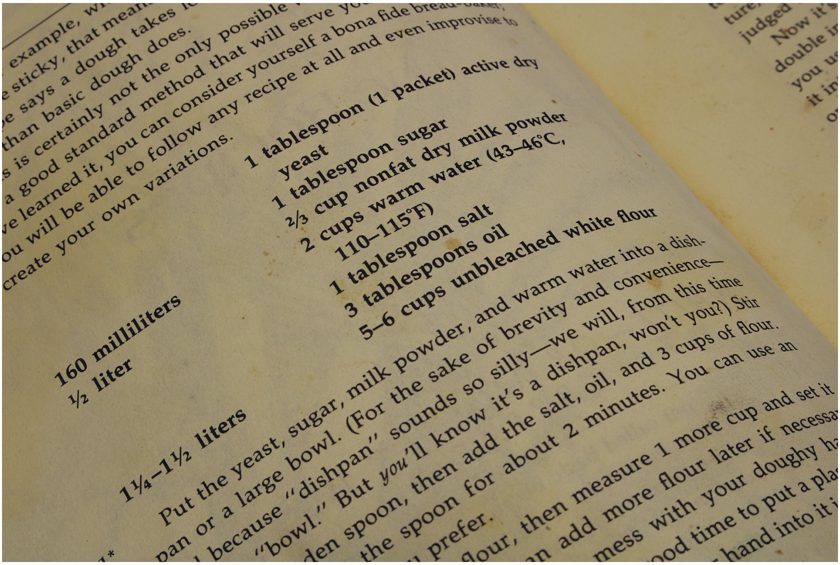

Figure 3-17. Recipe using verbal communication as coordination mechanism for the interdependency type prerequisite (Source: Pixabay, CC0).

Other examples of coordination mechanisms use physical representations (later referred to as coordinative artifacts). For instance, the key board at a hotel's reception helps the manager to coordinate the hotel's rooms as shared resources (cf. Figure 3-18). The key chain is a physical representation for one particular room identified by a room number.

Figure 3-18. Hotel keys as physical representation for the rooms (Source: Pixabay, CC0).

All in all, this shows that a coordination support system (e.g., the traffic light) may implement multiple coordination mechanisms to address one interdependency type (cf. Table 3-3).

Table 3-3. Coordination mechanism examples per interdependency type.

	Interdependency type		
Coordination mechanism	Prerequisite	Shared Resource	Simultaneity
Verbal/non-verbal communication	Recipe, Process description	Reservation list	Conductor, Traffic lights
Schedules, rules, and conventions	Recipe, Process description	Flight schedule	Conductor, Traffic lights
Shared external representation	Recipe, Process description	Hotel keys	Conductor, Traffic light

The above describes a number of real-world coordination support systems. In the area of computer-supported cooperative work computational coordination support is used.

> "In cooperative work settings characterized by complex task interdependencies, the articulation of the distributed activities requires specialized artifacts which, in the context of a set of conventions and procedures, are instrumental in reducing the complexity of articulation work and in alleviating the need for ad hoc deliberation and negotiation" (Schmidt & Simone, 1996, p.162).

A computational coordination support system (as opposed to the ones shown above) should be conceived as a specialized piece of software interacting with the user articulating work-related information (i.e., awareness information via awareness cues, cf. section 2.3.1) using specific coordination mechanisms (Preece et al., 2019):

> "a coordination mechanism is a construct consisting of a coordinative protocol (an integrated set of procedures and conventions stipulating the articulation of interdependent distributed activities) on the one hand and on the other hand an artifact (a permanent symbolic construct) in which the protocol is objectified" (Schmidt & Simone, 1996, p.165).

In more detail, a coordinative protocol is the part of a coordination mechanism that supports situated action by reducing "complexity of articulating cooperative work by providing a precomputation of task interdependencies which actors, for all practical purposes, can rely on to reduce the space of possibilities by identifying a valid and yet limited set of options for coordinative action in any given situation" (Schmidt & Simone, 1996, p.174). On the other hand, the other part of a coordination mechanism is the artifact that is used to "to objectify and give permanence to the coordinative protocol so that its stipulations are unceasingly publicly accessible" (Schmidt & Simone, 1996, p.176). This means it is a proxy, representing the state of the protocol.

As indicated above, this basically makes awareness cues coordination mechanisms. In other words, coordination mechanisms in the digital world are nothing but a part of a coordination support systems for which Schmidt and Simone (1996) defined the subsequent requirement: they have to be flexible. "It must be constructed in such a way that actors are supported in controlling the propagation of changes to the protocol with the cooperative work arrangement" (ibid., p.187).

The role of coordinative artifacts appears to have become topical in more recent years. For instance, in architectural practice (Schmidt & Wagner, 2002) they are part of the material work settings. They populate them playing "a crucial role in the seamless and effective coordination and alignment of cooperative work" (ibid., p.257). They are similar to but at the same time exceed the aforementioned cognitive artifacts (cf. section 3.1.3) by not just being "vehicles for information" (ibid., p.257) or for memory aids.

Redaelli and Carassa (2015) studied coordinative artifacts at an Italian airport. In doing so, they tried to understand "the role of plans in supporting coordination at work by proposing an approach that focuses on how the plan's capacity to anticipate interdependencies at work is maintained in face of changes in surroundings to ensure stability in the coordination of different stakeholders" (ibid., p.165). They found that artifacts anticipate future ways of performing activities. Anticipation itself plays a key role in coordination.

Bardram and Bossen (2005) studied how people in a hospital coordinate their work using a wide range of non-digital artifacts like whiteboards, schedules, examination sheets etc. "The role of these artifacts in collaborative work is to lessen the amount of 'articulation work'" (ibid., p.169). *Articulation work* (Strauss, 1985) is the effort of coordination tasks and responsibilities between distributed collaborators. This type of work can be reduced by developing divisions of work, conventions and by the use of coordinative artifacts.

Recently, Zaitsev et al. (2020) conducted a case study on coordination artifacts in agile software development. Here, coordination artifacts were used to mitigate coordination challenges. They identified four different types of coordination artifacts that vary in terms of their information richness and mutability:

1. Foundational
2. Projective
3. Exposition
4. Indicative

3.2.3 Systems for Coordination Support

Already the introduction of this thesis defined coordination support as a standard support function for computer-supported cooperative work. The 3C Model (Teufel et al., 1995) defines the group of systems closest to this area as *workflow management systems* (cf. Figure 1-8 in section 1.1). These are systems “where work activities are given a formal representation in terms of some workflow model which often stipulates how the contributions of different participants are to be coordinated” (Sandor et al., 1997). Malone (1988) and later Grudin and Poltrock (2020) refer to these systems that help people to coordinate their activities as “coordination technology”.

> “Coordination technologies employed in the workplace such as meeting support systems, group calendars, workflow management systems, and computer-aided software engineering systems were an early focus of CSCW. They gave way to studies of how people coordinate in the absence of (or despite) coordination management technologies. For example, Bowers et al (1995) studied the problems that deployment of workflow technology created in a large printing enterprise. Social networking also enables a new generation of coordination technologies whether mobile and location-aware real-time” (Grudin & Poltrock, 2020).

Abbott & Sarin (1994) describe two different types of workflow systems:

1. Document-oriented workflow: The definition of routes is attached to shared documents.
2. Activity-oriented workflow: The processes are modeled as sequence of activities and documents are attached to activities.

Further, Gross & Koch (2007) distinguish two kinds of coordination support (p.91):

1. Explicit coordination support (automation): The system is in charge of coordinating resources, i.e., the system decides, the user follows (cf. the traffic light in Figure 3-14).
2. Implicit coordination support: The system offers (awareness) information and the users make the decisions following a social or technical protocol.

The degree of automation is basically a design choice which has to be carefully made.

> "Other systems acknowledge the need for basic coordination mechanisms by providing locking and versioning of shared documents based on check-in- and check-out operations performed by users. These systems do not dictate behaviour, but simply coordinate concurrent access and provide status information about other users' activities" (Glance et al., 1996, p.180).

Based on Malone's coordination theory (cf. section 3.2.1) three types of coordination support systems can be derived (Gross & Koch, 2007, p.91):

1. Task sequencing systems (workflow management systems) addressing the interdependency type of prerequisite.
2. Access to shared resources: optimistic/pessimistic locking as well as concurrency control. When missing it could lead to thread interference and memory consistency errors. Badly implemented synchronization leads to thread contention, starvation, livelocks, and deadlocks (Dix et al., 2004; Lea, 1999). All of the above refers to the interdependency type of shared resource.
3. Activity synchronization is needed in the case of the interdependency type simultaneity. Systems in this area introduced a range of floor control mechanisms such as chair people, reservations and token-passing (Cook & Lunt, 1992; Crowley et al., 1990; Sarin & Greif, 1988). Also the spatial model introduced in section 2.3.2 sought to minimize hard-wired constraints of traditional floor control (Benford & Fahlen, 1993, p.111).

Last but not least coordination support systems can be split in two groups depending on whether they can be used synchronously or asynchronously (as a reduced form of Johansen's (1988) Time-Space Taxonomy, cf. Figure 1-7 in section 1.1). As with awareness support systems (cf. section 2.3.2) there appears to be an application level and a coordination level, meaning that there are basic coordination mechanisms like floor control, that can be implemented and provided in different ways in different applications, yet always with the purpose of activity synchronization. Again, this makes these basic mechanisms independent of the application context!

When it comes to actual systems that support coordination it becomes obvious that most of them exist already outside of CSCW research (e.g., workflow management systems, calendar applications etc.). For instance, the three tools from the introductory section of this thesis use multiple mechanisms to address the different interdependency types of coordination. The following systems serve the purpose of pointing out further aspects when dealing with coordination support. They do not aim to provide a complete list of tools.

When it comes to coordination support, a by this time quite old but often cited example is the COORDINATOR (Flores et al., 1988). It is a speech-based system (not to be confused with systems like Amazon Alexa[13]) that helps people make and keep track of requests and commitments to each other. It thus supports "mutual agreeing", an important part of the task assignment process. Therefore, it uses language related to the underlying theory of speech acts (Searle, 1969). Communication is the primary unit to interaction (cf. section 1.1). "In COORDINATOR, users add structure to their messages based on conversational moves and actions, such as 'request' and 'notification'" (Henninger, 1991, p.25). The intention is to lead the user to think about what s/he is doing and then to characterize a particular communication as one of several choices (e.g., make a request, make a promise etc.). However, the system failed: It imposed to many restrictions and users did not use the system as intended. In most cases they only used the first menu option "request" (Bullen & Bennett, 1990).

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[13] https://alexa.amazon.com

Another system well known is this area was LOTUS NOTES[14] which was available as a commercial system. It was a document-based system for which flexible workflows could be implemented. Both were bundled as applications inside LOTUS NOTES providing developers a high degree of flexibility. One type of these documents were emails for which NOTES provided a tight integration. While being one of the most flexible systems, LOTUS NOTES failed as well:

> "the findings suggest that where people' mental models do not understand or appreciate the collaborative nature of groupware, such technologies will be interpreted and used as if they were more familiar technologies, such as personal, stand-alone software (e.g., a spreadsheet or word processing program). The findings further suggest that where the premises underlying the groupware technology (shared effort, cooperation, collaboration) are counter-cultural to an organization's structural properties (competitive and individualistic culture, rigid hierarchy etc.) the technology will be unlikely to facilitate collective use and value" (Orlikowski, 1992, p.362).

Halloran et al. (2002) found similar issues when their students simply rejected the tool in favor of others, they were familiar with. The tool's high degree of flexibility (as opposed to the COORDINATOR's restrictiveness) was the reason for its failure. In many companies LOTUS NOTES was reduced to a simple email tool because that was what people were familiar with.

Another more recent commercial tool is JIRA, probably the #1 software development environment used by agile teams by Atlassian Inc.[15] (cf. Figure 3-19).

JIRA's core concept is that of an issue tracker. The key component is an issue that might be a task, user story, defect or service request. Each issue has its own workflow attached to it, that is, it uses an activity-oriented workflow model (Abbott & Sarin, 1994).

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[14] Lotus Notes was procured by IBM in 2013, then renamed to IBM Notes. In 2019 IBM sold Notes to HCL.

[15] https://www.atlassian.com/software/jira

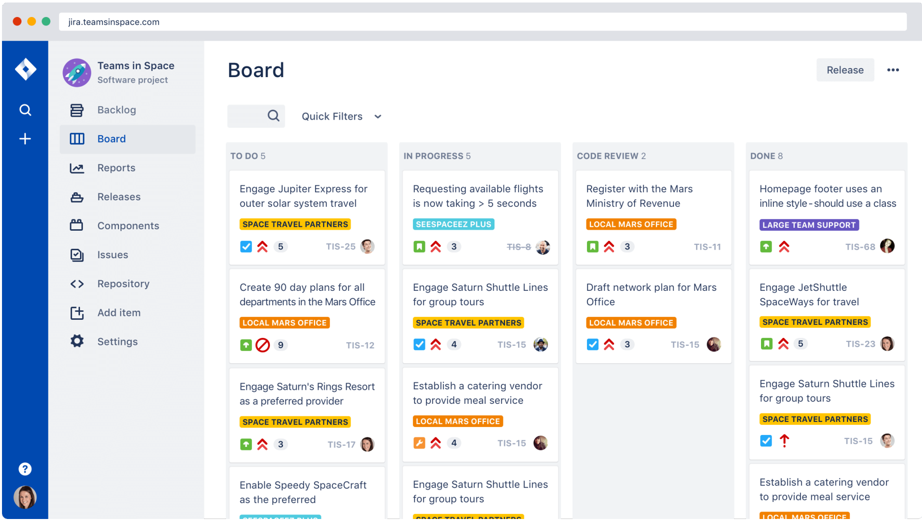

Figure 3-19. JIRA von Atlassian Inc. (Source: Atlassian Inc.).

The remainder of the tool consists of powerful filters based on a distinct but intuitive query language and sets of issues like boards, sprints, reports and releases. The basic mechanisms are provided, yet, these follow the users' concepts and language. Additionally, they are flexible enough to be used in many situations.

Last but not least comes an example of a very lightweight coordination support systems that helps during synchronous conversations (thus supporting the interdependency type simultaneity): the typing indicator (cf. Figure 3-20). It helps to coordinate the turn-taking in a conversation using an implicit coordination support approach (Gross & Koch, 2007). I.e., though the indicator shows, that the other is typing one can start typing as well. If it was an explicit coordination support approach the application would probably block all others, when somebody starts typing.

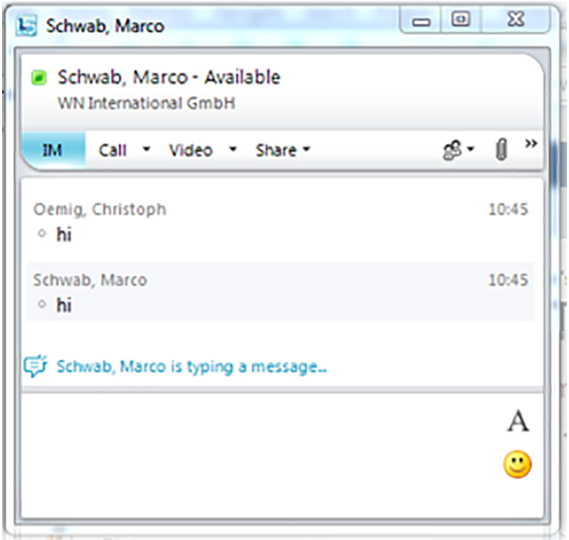

Figure 3-20. Coordination of synchronous communication (Source: Christoph Oemig).

3.3 Challenges, Reflections and Criticisms

As in the previous chapter, there are some issues in this chapter worth discussing or for taking a second look. They are all organized in short sections for easier reference later.

3.3.1 Forgetting versus Overfitting

In most cases forgetting has not a positive reputation as it is connected to information, memory or data loss. Memories are lost typically due to illness, accident or simply age (Sternberg et al., 2011). However, forgetting is a vital function to the mind's health and well-being as it basically solves its capacity problems. Information not needed becomes inaccessible to make room for newer memories (cf. section 3.1.3). Overall forgetting is an important memory function that keeps humans from overloading (Johnson, 2010).

At the same time, it also keeps the memory from overfitting. This is another finding from computer science explaining cognitive issues, this time from the field of artificial intelligence (AI). It describes the state "when a mathematical model is so good at matching the data it has been programmed with that it is unable to predict which data might come next" (Gravitz, 2019). Recent research even suggests Alzheimer being a problem of forgetting and not remembering (Gravitz, 2019) also relating it to overfitting.

The prediction of future states is a core element of situation awareness (cf. section 2.1.2) and of coordination (cf. section 3.2.1). Thus, overfitting imposes also a threat to these capabilities. On the other hand, awareness and coordination support becomes the key technology to prevent it.

> "Unlike previous communication technologies, however, the new computer-based technologies also have the potential to transfer information more selectively. Thus (...) new coordination technologies have the potential to help reduce information overload by directing information more accurately to people who want to know it without overloading others" (Malone, 1988, p.13).

The design goal of awareness and coordination support must not be to help people to remember everything, but to remember the right things at the right time. This becomes even more important when dealing with dynamic awareness and coordination support (cf. section 2.3). Here, it raises the following questions: What information is needed when? What is the best type of transition between contexts? What is the effort of such transition? Again, these are all use-inspired basic research questions.

3.3.2 Shared Capacity

Section 3.1.5 talks about the memory's capacity and workload from a generic perspective. Section 2.2.2 in the previous chapter introduced primary and secondary tasks for the context of cooperative work. Combining the two in terms of capacity, reveals a major difference between single user tasks and group tasks (cf. Figure 3-21).

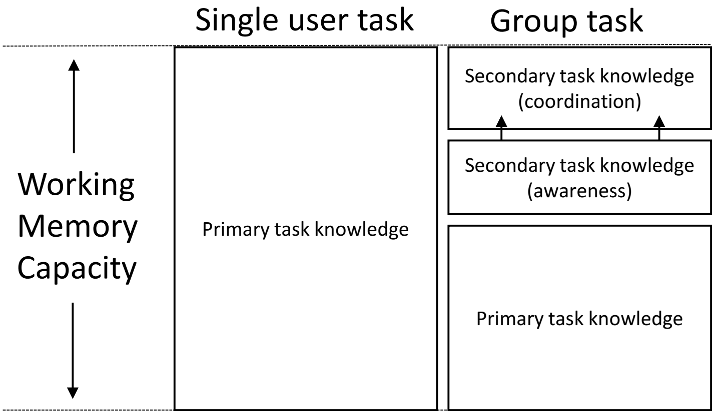

Figure 3-21. Working memory capacity for single user task and group task.

While in single user tasks the primary task knowledge may occupy nearly the entire capacity alone, it has to share this capacity with the knowledge for the secondary tasks of awareness and coordination during a group task no matter if the scenario is a computer-supported setting or not. This raises questions like what is the memory ratio in terms of primary to secondary task knowledge? Another aspect is (again) forgetting – as just mentioned in the previous section. How does forgetting affect primary and secondary task knowledge? Do the same mechanisms apply for all knowledge types (primary and secondary) the same way or are they treated differently? Again, these are further use-inspired basic research extending upon section 2.4.1.

3.3.3 Working Memory and Long-Term Memory

Earlier in this thesis, awareness was said to be a mental model (cf. section 2.1.2). However, while awareness is said to be stored in the working memory (cf. section 3.1.2) the previous statement appears odd as mental models originally belonged to the long-term memory construct (Craik, 1943). In hindsight, these statements appear hard to be matched. Endsley

(2000) admits: “to view SA as a function of either working memory or long-term memory would probably be erroneous” (Endsley, 2000, p.14). However, there actually is research, e.g., (Johnson-Laird, 1983), that proclaims mental models being part of the working memory. Other, more recent research (Jones et al., 2011) acknowledges both positions and accepts them as equally true. Endsley explains her insight (and deviation from her earlier statement (cf. section 3.1.2)) with the decay of memory that did not strike in tests although expected and with an alternate model of cognition that conceives the working memory to be an activated subset of the long-term memory (Cowan, 1988) (cf. Figure 3-22).

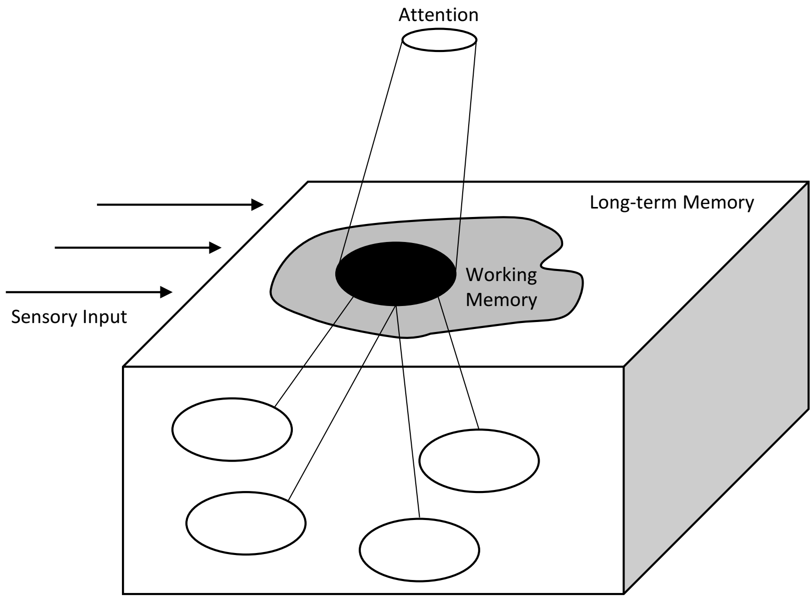

Figure 3-22. Mental model: working memory versus long-term memory (Cowan, 1988; Endsley, 2000).

> “An increasing number of alternative accounts has emerged subsequently (...) One of the principal questions concerns the relationship between working memory and LTM. Baddeley and Hitch (1974) assumed that the two were separate systems. However, a number of authors take a different view, maintaining that working memory corresponds to an activated region of LTM” (Braisby & Gellatly, 2005, p.316).

As of today, this does not contradict the current working memory construct by Baddeley (2000, 2012) anymore as the component of the episodic buffer was introduced in 2000 which has a link to the long-term memory (LTM) (cf. Figure 3-4). In terms of the assessment approach described later in this thesis the exact construct at this level makes no difference.

3.3.4 Cognitive versus Social Science

All the cognitive concepts and ideas of this chapter make sense for the context of awareness and coordination. How come that there appears to be a problem with cognitive science in CSCW? Especially in its early days, cognitive science earned itself a reputation of only dealing with single users in laboratories, i.e., artificial settings. “Much evaluation of the past was concerned with the cognitive functioning of a single user sitting alone in front of a computer display” (Neale et al., 2004, p.112). This especially was criticized in the context of CSCW where early systems failed and social aspects became increasingly dominant, for instance, through ethnographic studies (cf. section 2.2.1). “Indeed, in the last few years the caricature of HCI notions of isolated ‘users’ and tasks’ has become a popular form of critique both in the social sciences and among disillusioned persons within the HCI community itself” (Rogers & Ellis, 1994, p.121). Extending on section 2.4.3, this might explain why there is hardly any cognitive research as part of CSCW.

> “With the emergence of the new field of CSCW in the mid-to-late [19]80’s, the problem of how computer systems should be designed to support groups of people communicating and working together came to the forefront of research on system design. Cognitive psychologists, however were left behind. Simply, the cognitive models and task analytic tools developed in HCI were unable to be applied in this context because of the constraints that follow from their inherent individual-based focus. Sociologists and anthropologists attempted to fill this lacuna and thus began to make their mark in this area of research. Inspired by the influence of Suchman’s work in the HCI community, a number of social scientists started to conduct ethnographic studies of technology-mediated collaborative work” (Rogers & Ellis, 1994, p.122).

Social and organizational concerns then dominated the research agenda for studying collaborative work and CSCW. With the cognitive researchers protesting: “On the one hand they assume a decontextualised model of the actors while on the other they neglect the cognitive capabilities of these actors" (Rogers & Ellis, 1994, p.119).

> "the omission of cognitive aspects in these analyses is, we propose, a grave mistake. Given that much work activity is inherently cognitive (e.g., people need to think, solve problems, predict, make decisions and so on) it is argued that there needs to be an understanding of how work activities are performed at this level of analysis in order to design computer systems that can support both cognitive activities and social interactions. The problem, however, is how one might start to analyse the cognitive activities of people in their working environment rather than the workings of the isolated mind of a single individual. To this end, the alternative approach of distributed cognition is proposed" (ibid, p.123).

In the following, cognitive scientists suggested a new approach analyzing and explaining collaborative work known as distributed cognition (Hutchins, 1995; Hollan et al., 2000):

> "[It] attempts to overcome the limitations of existing single-disciplined frameworks, for studying collaborative work, by traversing conventional disciplinary boundaries. In particular, it is intended to explain socially distributed, cognitive work activities that are mediated by the rich assortment of technological artefacts found in the workplace" (Rogers & Ellis, 1994, p.125).

However, this approach got rejected as well:

> "Following recent developments in the psychology of work, we might conceive of this organisation as a form of 'distributed cognition'; a process in which various individuals develop an interrelated orientation towards a collection of tasks and activities (cf. Hutchins 1989, Olson 1990, Olson and Olson 1991). And yet, even this relatively radical reconceptualisation of the relationship between the individual, his or her activity and the system, does not quite capture the situated and socially organised character of cooperative work (...) Whether one subscribes to a theory of distributed cognition or a more sociological conception of cooperative work, it is clear that we need to move away from laboratory studies of cognition, 'which have deliberately stripped away the supporting context of the everyday world, in an effort to study 'pure internal processes' (Olson 1990), and begin to explore task coordination and computer support in real world everyday work settings" (Heath & Luff, 1992, p.71).

The argument of not understanding social details followed the allegation of irrelevant and commonsensical research results lacking practical implications on the other side:

> "Many of the approaches advocated by social scientists [cf. section 2.2.1] for informing CSCW design similar to those that have been applied by the cognitive sciences to interface design for single user systems in HCI, such as design recommendations and building software prototypes and evaluation tools. So far there have been very few attempts to translate findings from workplace studies beyond the provision of a few general design recommendations. Moreover, fieldworkers were only too aware that their practical offerings are meagre and commonsensical compared with their rich and poetic accounts of the workplace. Whereas HCI researchers have found numerous ways of transforming their findings into practical implications and formal prescriptions that, arguably, have proved useful for designers, CSCW researchers are finding it more difficult to follow suit" (Plowman et al., 1995, p.320).

Following this dogmatic battle, it is hard to find further cognitive work in CSCW. In 2002, the social research agenda found itself stuck with the "Problem of Awareness" (Schmidt, 2002) (cf. section 2.4.5). In 2004, Neale et al. found the "the evaluation of distributed CSCW systems has been too frequently method driven by various disciplinary preferences, rather than driven by frameworks that get the appropriate questions answered" (p.112). "Reconsidering Awareness" in 2016 Schmidt and Randall (2016) diagnose a lack of consensus regarding awareness and coordination resulting in a research field exhibiting a fragmented state (Schmidt, 2009) others referred to as "The Big Hole" (Kostakos, 2015).

On the other end, cognitive science today employs "theoretically based constructs that are evaluated in their generality through empirical studies in a wide variety of laboratory tasks, simulators, 'microworlds', and actual work domains" (Parasuraman et al., 2008, p.140) – yet all outside of CSCW.

3.3.5 The Problem with Explicit Coordination Support

Supporting coordination has its limits. Especially when the system is to take over (e.g., as with traffic lights) as done with explicit coordination support (cf. section 3.2.3), designers have to be careful: "When designing coordination mechanisms, it is important to consider how socially acceptable they are to people. Failure to do so can result in the users not using the system in the way intended or simply abandoning it" (Preece et al., 2015, p.122). The rigid mechanisms of coordination support were one of the reasons why CSCW applications failed (Grudin, 1988). "A key part is getting the right balance between human coordination and system coordination. Too much system control and the users will rebel. Too little control and the system breaks down" (Preece et al., 2015, p.122). This reveals a classic design tension. For instance, coordination facilities with the COORDINATOR were experienced as excessively rigid (Winograd & Flores, 1986). But the COORDINATOR is not the only system where this occurred. Glance et al. (1996) strive for an explanation:

> "The promise of workflow solutions for coordinating organizational processes is currently being obscured by strong criticism of the rigidity of their work representation. This rigidity arises in part from viewing work processes as unfolding along a single line of temporally chained activities. In reality, work evolves both horizontally, in the cooperation of causally unrelated, but information-sharing tasks, and vertically, in the coordination of causally-dependent activities" (Glance et al., 1996, p.180).

However, as will be shown later, there are further reasons why explicit coordination support should be avoided especially in cooperative contexts.

3.3.6 Awareness as Support Function to Coordination

This thesis started out with collaborative settings, then added coordination and coordination support to the picture (cf. section 1.1). When researchers in CSCW took over, they introduced the concept of awareness to facilitate coordination without going into further details about their relationship. "Awareness aids both fine and coarse-grained coordination, since it informs participants about the temporal and spatial boundaries of others' actions, and since it helps them fit the next action into a stream" (Gutwin, 1997, p.54). However, this chapter showed how awareness is the basis for coordination because it feeds the problem-solving and decision-making processes of coordination with the information needed. For the case of implicit coordination support, the coordination is then done by the subject which provides a high degree of flexibility. In case of explicit coordination support, the awareness information would be used by the system to coordinate the activities.

Another aspect was the degree of coupling which was also used to explain the difference between collaboration and cooperation or the difference between workgroup and workflow systems (Neale et al., 2004; Piepenburg, 1991).

> "In contrast [to workflow systems], in many awareness-oriented systems, the coordination between different activities is supported by giving participants an awareness of what each other are doing or have done so that participants can coordinate their work themselves. Many researchers would hope that, not only does this provide a 'truer' and more 'lightweight' sense for 'support', but would also make for more flexible applications which are not liable to the usability criticism that can be made of more procedural-oriented approaches to CSCW" (Sandor et al., 1997, pp.221).

Taking a closer look reveals that the above-mentioned flexibility has also something to do with the distribution of tasks among system and user as the user is always the more flexible. That means, if the highest degree of flexibility is needed then the problem-solving and decision making of coordination is left to the user. Handing problem-solving and decision making over to the system takes away flexibility (cf. section 3.2.3) – but also effort! Finding the right degree of how to distribute coordination work among user and system is another design tension indicating (again) the need for more use-inspired basic research (cf. section 2.4.2). This is especially worth considering when trying to reach effortless coordination in cooperative systems because the lowest common denominator when building coordination support is to support awareness. The AETHER model did exactly offer this (cf. Figure 2-16 in section 2.3.2) by allowing direct and indirect access to its awareness engine.

In summary, coordination is the higher goal and awareness supports especially the user to reach it. From that perspective awareness is a support function to coordination (either done by the users themselves or by the system) which is a support function to cooperation.

3.3.7 Mapping Awareness to Coordination

The insights from the previous section, i.e., the general connection between awareness and coordination, allows further conclusions: If awareness is a support function to coordination then there is...

1. ... no awareness without the purpose of coordination.
2. ... an explanation or mapping for each type of awareness (cf. section 2.1.1) using the coordination interdependency types (cf. section 3.2.1)

The mapping of awareness types to coordination interdependency types is shown in Table 3-4.

Table 3-4: Mapping awareness to coordination interdependency types.

Awareness Type	**Coordination Interdependency Type**
Availability awareness Background awareness Collection awareness Environmental awareness General awareness Group awareness Group-structural awareness Informal awareness Organizational awareness Peripheral awareness Presence awareness Situation awareness Task-oriented awareness Workspace awareness	Shared resource
Activity awareness Conversational awareness Document awareness Group awareness Mode awareness People awareness Perspective awareness Presence awareness Self-awareness Situation awareness Spatial awareness Task-oriented awareness Workspace awareness	Simultaneity
Background awareness Collection awareness Environmental awareness General awareness Group awareness Group-structural awareness Informal awareness Organizational awareness Peripheral awareness Presence awareness Process awareness Situation awareness Task-oriented awareness Workspace awareness	Prerequisite

Only the awareness types of (un-)intentional awareness, mutual awareness and passive awareness could not be placed in the table as they are rather related to attention than awareness (cf. section 3.1.2).

Another issue that becomes obvious is the relation of the coordination interdependency types to the *Time-Space Taxonomy* (cf. Figure 1-7 in section 1.1) and synchronous and asynchronous awareness information (cf. Table 2-4 in section 2.3.1). The types of prerequisite and shared resource are relevant in asynchronous modes independently of the location. On the other hand, simultaneity is relevant in synchronous modes, yet also independent of the place of interaction (cf. Figure 3-23).

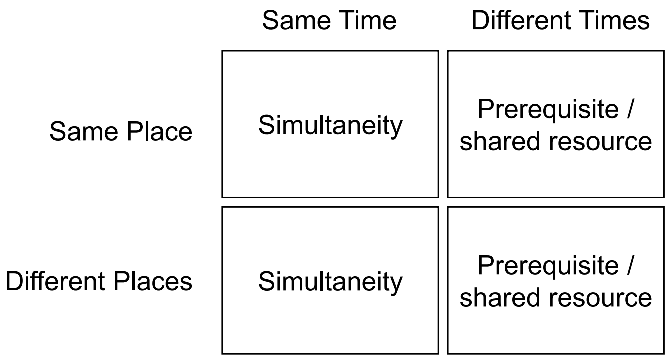

Figure 3-23. Interdependency types related to time and space.

All in all, it was shown that awareness support (cf. section 2.4.7) and coordination support (cf. section 3.2.3) are independent of application context. What both depend on is the interdependency type!

3.4 Summary

This chapter picked up the two most important sidetracks that belong to the foundation of this thesis: cognition and coordination. Awareness and coordination have constantly been described as mental models and surrounding processes. This chapter uncovered what that actually means. While CSCW remains on the level that “awareness facilitates coordination” this chapter elaborated their more detailed connection and relationship. This chapter provided the main clues to a measurement of efforts in this context which is required when trying to reach the goal of effortless coordination. All of this underlines the importance of cognitive science to CSCW.

On the other end the term coordination is backed up by a solid theory which was used to identify the main attributes and process. The resulting construct of coordination can be found in Appendix D2.

This chapter's main findings are:

- The limited capacity of the working memory is shared among primary and secondary tasks (awareness and coordination).
- Awareness and coordination are two distinct secondary tasks that share common cognitive features like the working memory thus splitting further the available capacity.
- There are links to both working memory and long-term memory that provides information or input to problem-solving and decision making.
- Though the conception of cognitive science has been attacked in the past especially concerning its contribution to the field of CSCW, this chapter shows that cognitive science offers a solid contribution which helps to escape the problems caused by solely focusing on social issues.
- Awareness is a support function to coordination which is a support function to collaboration and cooperation.
- Especially coordination support provides a new design challenge as it can be implemented on the system or user side, i.e., resulting in the system or the human making the decisions. Early systems already revealed that systems taking over coordination (explicit coordination support) is not well liked by users.
- All coordination activity and thus also all awareness efforts are directed towards one out of three interdependency types: simultaneity, shared resource or prerequisite.
- This extends the notion of the previous chapter were the awareness support system is independent of the context of use to that the awareness support system is dependent on the coordination interdependency type.

Last but not least: as much as the term awareness was a hyped topic in CSCW and at the same time a highly elastic term causing a lot of reconceptualization up to highly philosophical discussions, the opposite is true for the term coordination which appears to be a lot more solid and sound.

The missing link that is left towards a measurement approach for coordination and awareness is provided by the next chapter that takes a deeper look at the design and evaluation of their respective support systems.

4 Design & Evaluation of Cooperative Applications

As stated at the beginning of this thesis, the design of groupware lies at the core of CSCW (cf. section 1.1). In general, "CSCW should be conceived as an endeavour to understand the nature and requirements of cooperative work with the objective of designing computer-based technologies for cooperative work arrangements" (Schmidt & Bannon, 1992, 2013, p.11, p.351).

The design and evaluation are typical steps in a software development life cycle (SDLC). This development life cycle may differ in the process model being used: "the primary functions of a software process model are to determine the order of the stages involved in software development and evolution and to establish the transition criteria for progressing from one stage to the next" (Boehm, 1988, p.61).

As already mentioned, design and evaluation are two examples of these stages. Yet, this has not always been the case. One of the earliest process models is the code-and-fix model (Boehm, 1988). It contained only two steps: write code and fix code. "The order of the steps was to do some coding first and to think about the requirements, design, test, and maintenance later" (Boehm, 1988, p.62). The problems that came along with it were poor structures, a mismatch to user needs, and expensive fixes as they typical resulted in also fixing the overall suboptimal structure. This led to the development of staged models like the waterfall model (Royce, 1970) (cf. Figure 4-1). It uses a set of linear sequential stages, where each stage depends on the deliverables of the previous one. Every stage corresponds to a specialized activity like analysis, design or testing. Although Royce described this process model as one of the first, he never used the term "waterfall model" himself (Royce, 1970).

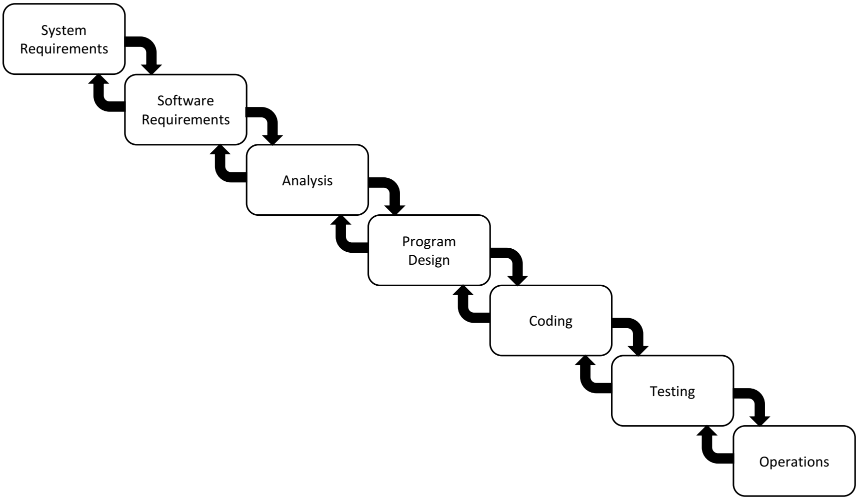

Figure 4-1. The stages of the waterfall model (Royce, 1970).

Yet, also the waterfall model has its problems: the requirements analyzed in the beginning turn out to change over time as more is learned about a topic or when users discover their real needs once a first version of the resulting product or service becomes available. These requirement changes thus become a risk to a project's success.

Therefore, process models evolved further into iterative, incremental models (also referred to as evolutionary models (O´Regan, 2017)) like the spiral model (Boehm, 1988) (cf. Figure 4-2).

> "The major distinguishing feature of the spiral model is that it creates a risk-driven approach to the software development process rather than a primarily document-driven or code-driven process. It incorporates many of the strengths of other models [like the code-and-fix model, and the waterfall model] and resolves many of their difficulties" (Boehm, 1988, p.61).

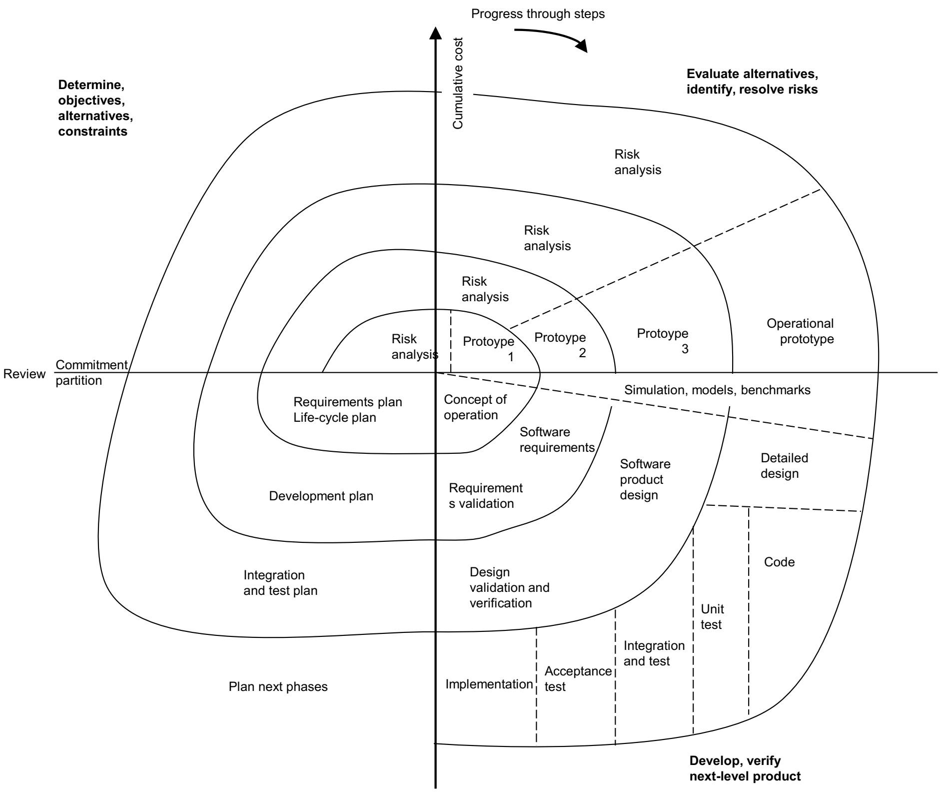

Figure 4-2. Spiral model (Boehm, 1988).

Iterative and incremental process models are the basis for mostly any type of human-centered design approach in HCI or CSCW (Gross & Koch, 2007). In the following, this chapter takes a look at how single-user applications and then more specifically groupware is designed and evaluated this way. It outlines existing common procedures and then dives deeper into the area affecting the support functions of awareness and coordination. For these especially the limitations of current approaches are discussed. This chapter, as the previous ones, concludes with a critical reflection on the overall topic in the context of awareness and coordination before summarizing its key insights.

4.1 From Participatory to Human-Centered Design

HCI, CSCW and this thesis focus on systems intended to be used by humans, i.e., socio-technical systems (cf. section 1.1). "The design of single-user applications translates users' tasks and needs into a functional description which directs the overall design and development of the application" (Ehrlich, 1999, p.2). Especially HCI developed two answers to the aforementioned risk of changing user requirements:

1. The utilization of an iterative and incremental process model developing one group of requirements at a time while checking the validity of others.
2. The active engagement of users in the development process to regard their insights and feedback as early as possible.

While the first aspect was already known from the spiral model, the second part evolved from a procedure initially outside of HCI known as participatory design (Muller & Kuhn, 1993; Ross et al., 1995):

> "The field of participatory design (PD) spans a rich diversity of theories, practices, analyses, and actions, with the goal of working directly with users (and other stakeholders) in the design of social systems including computer systems that are part of human work" (Muller & Kuhn, 1993, p.24).

PD is also referred to as the *Scandinavian approach* or as *cooperative design* or *co-design* (Preece et al., 2019). It is an overarching design philosophy not only limited to the design of IT technologies (Gregory, 2003).

In the area of HCI (especially from the angle of (again) cognitive psychology) participatory design evolved into its more IT-related counterpart of user-centered design (UCD). Norman (1988) describes it in his well-known book *The Psychology of Everyday Things* (POET) as "a philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable" (Norman, 1988, p.188).

With the third edition of his book and a slightly changed title to *The Design of Everyday Things* (DOET), the approach also evolved to its current incarnation of human-centered design (HCD): "Human-centered design (HCD) has emerged since the first edition, partially inspired by that book. (…) although looking back, we see that the entire book [POET] was about HCD" (Norman, 2013, p. xv). Further, he defines HCD as "an approach that puts human needs, capabilities, and behavior first, then designs to accommodate those needs, capabilities, and ways of behaving" (Norman, 2013, p.8). The subtle difference in names indicates that HCD is not only limited to users but also regards other stakeholders. Further, HCD introduced another concept which goes beyond the "understandable and usable": the user experience (UX) (Norman, 2013, p. xiii). It can briefly be defined as "a user's perception and responses that result from the use and/or anticipated use of an interactive system" (UXQB, 2020, p.12).

In HCI it is nowadays commonplace to apply the human-centered design process (or one that encompasses the same steps but uses a different name like the interaction design process in Dix et al. (2004) or Preece et al. (2019)). Today, the process is specified by the norm ISO 9241-210 (ISO, 2019) which was released in its second edition in 2019. Briefly, its stages encompass the understanding and description of the context of use, specifying the user requirements, designing a solution on the basis of those requirements, and the evaluation of the design (cf. Figure 4-3).

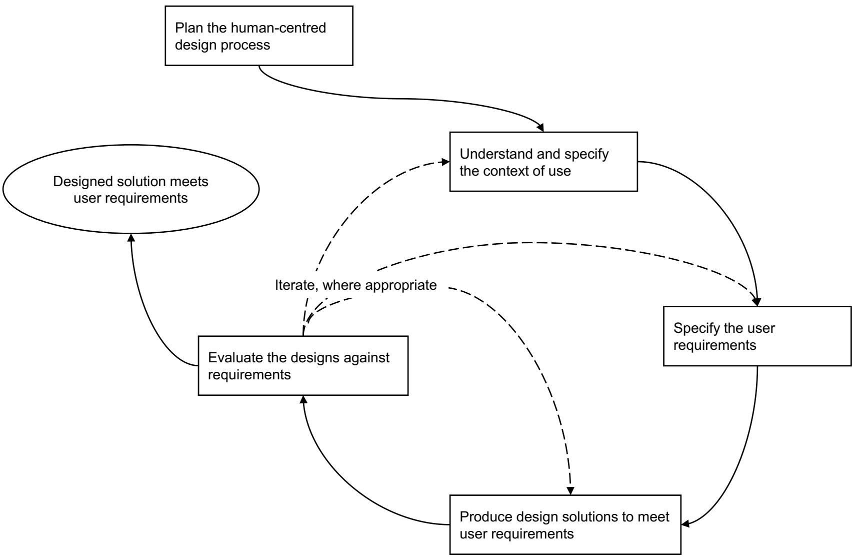

Figure 4-3. Human-centered design process as defined in ISO 9241-210 (ISO, 2019).

However, this model does not indicate what it means by design or evaluation, i.e., it is agnostic of the methods eventually used – and there are many possible ones to fill these gaps (to be shown in section 4.3). This in particular is the case where the process is expected to be different between HCI and CSCW. Further, its depiction (cf. Figure 4-3) understates the model's incremental nature. There are early stages, phases, or increments and later ones that truly affect the techniques and methods to be used, i.e., there is a dependency between the stage of the process and the applicability of a certain method.

The human-centered design process can be applied straight forward in commercial software development but also as a research approach. The contribution section of this thesis (cf. section 1.4) described HCI as an example scientific discipline for use-inspired basic research. "Science is essentially a problem-solving activity" (Laudan, 1978, p.11) and the problems in science are typically resolved using the scientific method (Encyclopaedia Britannica, 2019) that includes the following procedure (cf. Table 4-1):

Table 4-1. Steps of the scientific method.

Step #	Description	Area
1	Define a question	Hypothesis generation
2	Gather information	
3	Formulate hypothesis	
4	Test experiment	Hypothesis validation
5	Analyze data	
6	Interpret data and reformulate hypothesis	

Steps 1-3 are also referred to as hypothesis generation whereas steps 4-6 belong to hypothesis validation.

Adding humans to the picture for the case of HCI, the scientific method resembles the human-centered design process to a very high degree. The problems to be solved in HCI (and CSCW) (cf. section1.2) are typically framed as design challenges (open question – how can we design an easy to use application?) or design tensions (either-or question – is it better to either use recognition or recall?) (Tatar, 2007). HCI as a field for use-inspired basic research (Stokes, 1997) allows not only to develop fully functional systems but to create prototypes of partial or isolated setups or trials to understand the basic working of a certain research aspect or construct (e.g., awareness support) or mechanism. The very same accounts for CSCW.

4.2 The CSCW Design Challenge – A Wicked Problem

Being an iterative and at the same time incremental process for designing interactive systems in general, the human-centered design process is also eligible for the development of cooperative systems. However, creating CSCW applications differs notably from developing single-user applications.

> "In contrast to single-user applications which support peoples' tasks, groupware supports peoples' work. Tasks are often explicit, observable and concrete. Work is often tacit, invisible and amorphous. The challenge in developing a groupware application lies in understanding, explicating and then supporting the invisible work" (Ehrlich, 1999, p.1).

Neale et al. (2004) consider it "a paradigm shift toward socially centered design from past eras of system-centered and user-centered design" (Neale et al., 2004, p.113; Stanney & Maxey, 1997). At a minimum, different and additional requirements need to be considered when designing CSCW applications (Wilson, 1991):

- Individual human characteristics (e.g., communication patterns)[16]
- Organizational aspects (e.g., organizational structure)
- Design of cooperative work together with the users, including support functions
- Group dynamics and processes

Ehrlich (1999) suggests a phased approach consisting of the steps requirements, design and deployment, yet, leaving out evaluations (Ehrlich, 1999). To understand work practices, she and others suggests the set of ethnography, participatory design, and action research (Wulf & Rohde,

[16] It is intersting that cognitive capabilities are left out here.

1995). All of this should occur in an iterative process (Tang, 1991) or cycle of design (Dourish, 1995).

However, the design and evaluation of CSCW applications often failed mostly due to the following reasons (Grudin, 1988, 1994b; Lynne & Connolly, 1990; Bullen & Bennett, 1990):

1. The disparity between those who benefit from an application and those who must do additional work to support it.
2. The breakdown of intuitive decision-making.
3. Underestimated difficulty of evaluating CSCW applications, prevents learning from experience.

Later this list was extended to the overall number of eight challenges (Grudin, 1994b) with the additional ones being:

4. Critical mass and prisoner's dilemma problems. Groupware is only useful to all when reaching a critical mass or it may fail because it is never of use to anyone.
5. Disruption of social processes. Groupware may require activities that violate social norms and standards in the area of its application.
6. Exception handling. Group activities are more complex making the exception handling also more complex.
7. Unobtrusive accessibility. "Features that support group processes are used relatively infrequently, requiring unobtrusive accessibility and integration with more heavily used features" (ibid., p.97)
8. Adoption process. CSCW applications require a more careful introduction in the workplace as more individuals need to agree to the new style of working.

Cockburn and Jones (1995) generalize the above into three levels of failure: system-use, system-design, and system-evaluation. In addition to that, they present four groupware design principles to avoid the above mentioned problems altogether (Cockburn & Jones, 1995):

1. Maximize personal acceptance (to encourage individuals to adopt new systems)
2. Minimize requirements (reduce disparity of groupware cost and benefits as well es minimize efforts to collaborate). This also includes effortless coordination.
3. Minimize constraints (avoid inflexible and constraining style of use) (this is in line with the problem of explicit coordination support, cf. section 3.3.5)
4. Maximize external integration (this is what SLACK does, cf. section 1)

The early failures were the reason to use ethnographic studies extensively (cf. section 2.2.1). Due to the complexity of the issue demonstrated by all these failures, Fitzpatrick (1998) even considers the design of CSCW applications overall a true (design) challenge because "designing CSCW systems is a 'wicked problem'" (Fitzpatrick, 1998, p.11). A wicked problem is a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize (Rittel & Webber, 1973). In section 3.1.4 about problem-solving the same was also referred to as an *ill-defined problem*. It stands for an idea or problem that cannot be fixed or where there is no single solution to the problem. The use of the term 'wicked' denotes resistance to resolution, rather than evil (Rittel & Webber, 1973). Wicked problems require an ongoing iterative dialogue between problem and solution to understand either. This corresponds to cycles of design and evaluation. Requirements change rapidly. Each step in the design might change the possible usage of the solution:

> "The design of new technology is always an intervention into an ongoing world of activity. It alters what is already going on – the everyday practices and concerns of a community of people – and leads to a resettling into new practices, which in turn create new future design possibilities" (Flores et al., 1988, p.154).

Therefore, CSCW research is indicative of an evolutionary human-centered design process. Having chosen one to address the wicked problem of CSCW design and evaluation now raises the question of how to equip that process for the use in the context of CSCW. Plowman et al. (1995) "have constructed a diagrammic overview to show the various ways in which work studies have been used to inform system design and facilitate the implementation of CSCW in organisations” (Plowman et al., 1995, p.319). Their overview (cf. Figure 4-4) is divided into three merging phases (initial research & implications, design & change phase, evaluation & development), each showing the kinds of research activities that take place at that particular stage in the design cycle as well as their potential outcomes. Overall, the process is in line with the human-centered design process, though the naming of the phases appears a little odd.

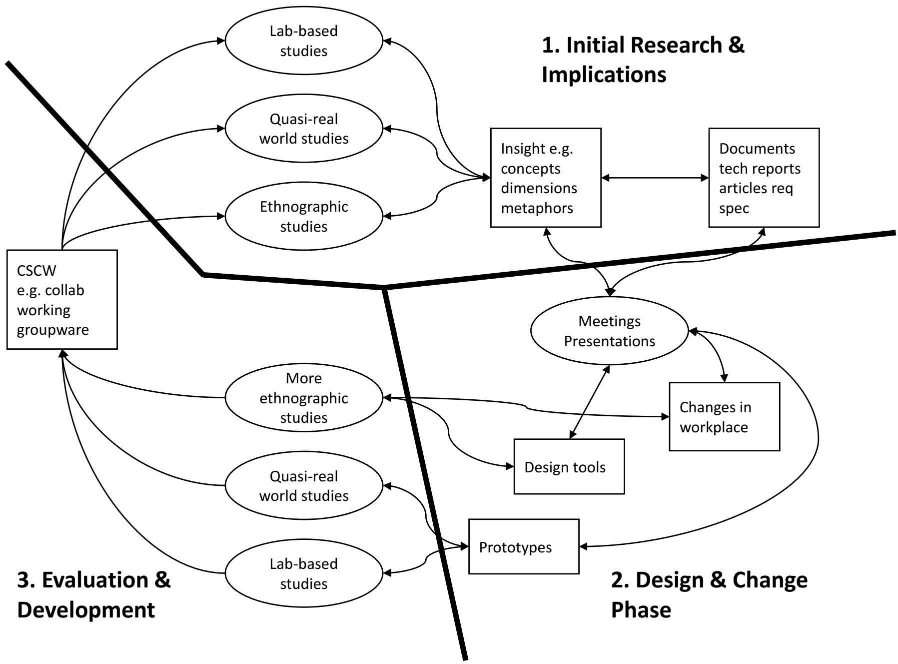

Figure 4-4. Role of studies in CSCW design and implementation (Plowman et al., 1995).

Their overview is also one of the first assigning methods to process stages in the context of CSCW. Yet, they make no further mention of early and late design cycles.

More recent and stemming from the angle of wicked problems, Design Thinking (DT) is another approach to cope with wicked problems (Buchanan, 1992; Dolata & Schwabe, 2016):

> "Many see the primary impact of Design Thinking in the area of industrial innovation. Given the engineering background of the methodology, this is definitely the most straightforward approach, with its practice-oriented nature. We claim, however, that Design Thinking – defined as the mindset as well as the toolset – can significantly contribute to the success of academic research in the information systems area" (Dolata & Schwabe, 2016, p.67).

Design Thinking is a human-centered design approach that also facilitates multidisciplinary teams and collaborative workspaces (GDTA, 2018). There are multiple variations of its design process (cf. Figure 4-5) describing 5 to 7 steps as part of an evolutionary model going back and forth between design and evaluation or hypothesis generation and validation. The model is also agnostic of the actual methods being used in each phase making it ready-for-use also in the area of CSCW to tackle its own wicked problems.

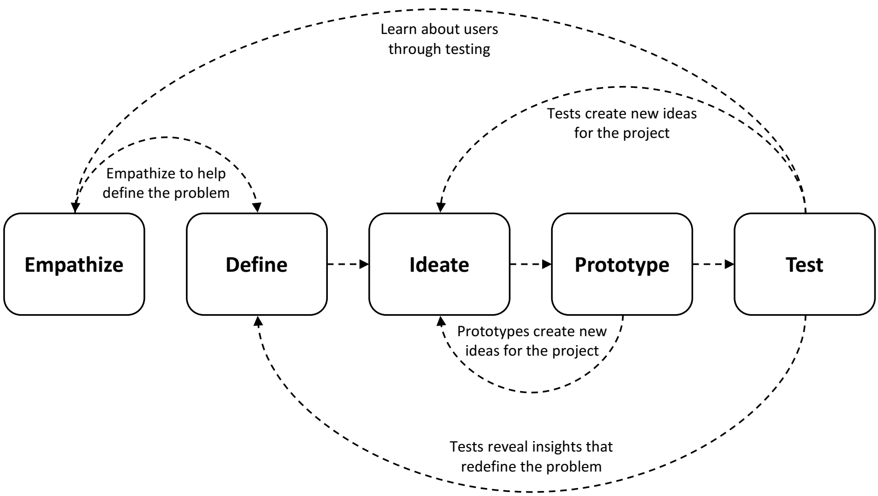

Figure 4-5. 5 step design process of Design Thinking (Hasso Plattner Institute, 2010).

4.3 Evaluation in General

This section focuses especially on the evaluation (or test) stage as part of an iterative and incremental process. It is one of the core steps of many development processes but in particular of the human-centered design process. Yet, in most cases this happens without defining any concrete method on how to evaluate anything.

As part of their research, Twidale et al. (1994) came up with 9 different definitions of evaluation (a term they use synonymously with the term assessment) (Twidale et al., 1994, p.442):

1. An assessment of the overall effectiveness of a piece of software, ideally yielding a numeric measure by which informed cost-benefit analysis of purchasing decisions can be made.
2. An assessment of the degree to which the software fulfills its specification in terms of functionality, speed size or whatever measures were prespecified.
3. An assessment of whether the software fulfills the purpose for which it was intended.
4. An assessment of whether the ideas embodied in the software have proven to be superior to an alternative, where that alternative is frequently the traditional solution to the problem addressed.
5. An assessment of whether the money allocated to a research project has been productively used, yielding useful generalizable results.
6. An assessment of whether the software proves acceptable to the intended end-user.
7. An assessment of whether end-users continue to use it in their normal work.
8. An assessment of where the software fails to perform as desired or as is now seen to be desirable.
9. An assessment of the relative importance of the inadequacies of the software.

A valid number 10 would have been the validation of research hypotheses. The items above describe 'what' and partially 'why' something is examined as part of an evaluation. According to Dix et al. (2004, p.319) evaluation has three main goals:

1. To assess the extent and the accessibility of the system's functionality,
2. to assess the users' experience of the interaction, and
3. to identify any specific problems with the system.

Once the goal is clear, an appropriate evaluation procedure needs to be determined. Most testing done in HCI is usability testing. In general, "there are generally two types of usability tests: finding and fixing usability problems (formative evaluation) and describing the usability of an application using metrics (summative evaluation)" (Sauro & Lewis, 2012, p.10).

Figure 4-6 depicts the 'how', i.e., the way something can be evaluated, by identifying different evaluation types. Pinelle and Gutwin (2000) distinguish four types depending on the setting and degree of manipulation (McGrath, 1995; Pinelle & Gutwin, 2000).

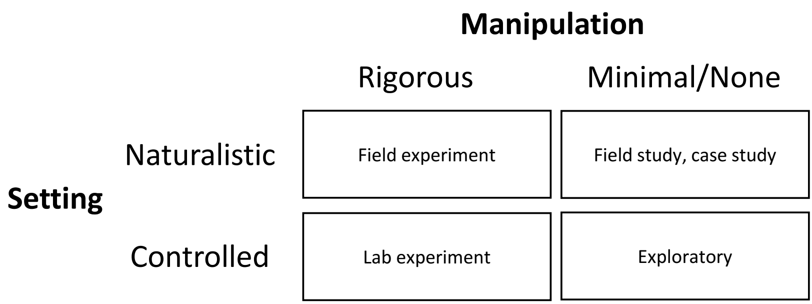

Figure 4-6. Evaluation types (Pinelle & Gutwin, 2000).

Preece et al. (2019) use a slightly different approach: "We classify evaluations into three broad categories, depending on the setting, user involvement and level of control" (p.500). They distinguish:

- Controlled settings directly involving users (usability labs, research labs): User activities are controlled to validate hypotheses and measure or observe certain behavior. The main methods are usability testing and experiments.

- Natural settings involving users (e.g., online communities, field studies): There is little or no control of the users' activities to determine how the product would be used in the real world. The main method used is field studies.
- Any setting not directly involving users: inspections, heuristics, walk-throughs as well as models and their analysis.

All of the above shows that there are many different dimensions to evaluation and its respective techniques:

- Point in time (of the development cycle) when it is to be used (from early to late) (Pinelle & Gutwin, 2000)
- Effort and cost caused by the approach (Baker et al., 2001)
- Formative testing (finding and fixing usability problems) or summative testing (describing the usability of an application overall) (Sauro & Lewis, 2012)
- User participation or expert-driven inspections (Molich & Nielsen, 1990)
- Natural or artificial settings (McGrath, 1995)
- Degree of manipulation (McGrath, 1995)
- Degree of disruption during evaluation (McGrath, 1993; McGrath et al., 2000)
- Evaluation of single aspects (e.g., satisfaction) or multiple/combined aspects as in usability (i.e., effectiveness, efficiency, and satisfaction)
- Single instance or comparative setups (A/B or split testing) (Sauro & Lewis, 2012)
- Targeting a user's attitude or behavior (Nielsen, 2001)
- Resulting in quantitative or qualitative data (Sauro & Lewis, 2012)
- To validate or generate hypotheses (cf. Table 4-1 in section 4.1)

There are many pros and cons of each category. Lab-based studies are good at revealing usability problems, but they are poor capturing the context-of-use; field studies are good at demonstrating how people use technologies in their intended setting, but they are often time consuming and more difficult to conduct (Rogers et al., 2013). Modeling and predicting approaches are relatively quick to perform, but they can miss unpredictable usability problems and subtle aspects of the user experience (cf. section 4.1). Similarly, analytics are good for tracking the use of a website but are inappropriate for finding out how users feel about a new color scheme or why they behave as they do. The following takes a quick look at the most common evaluation types: experiments, field studies and inspections.

An experiment is a procedure carried out to support, refute, or validate a hypothesis (cf. scientific method in section 4.1). They may take place in the wild or in the lab and they prefer highly controlled settings to control independent and dependent variables in order to judge on cause and effect. They are run for the following reasons (Dean et al., 2017):

1. To determine the principal causes of variation in a measured response.
2. To find the conditions that give rise to a maximum or minimum response.
3. To compare the responses achieved at different settings of controllable variables.
4. To obtain a mathematical model in order to predict future responses.

"Observations can be collected from observational studies as well as from experiments, but only an experiment allows conclusions to be drawn about cause and effect" (ibid, p.1). Experiments especially help with validating hypotheses.

Ethnographic field studies (cf. section 2.2.1) have been the center piece in CSCW research especially allowing the following (Blythin et al., 1997):

- Find new ways for developing new products
- Evaluate existing socio-technical systems
- Find ideas for the specification of designs

Field study-based methods are mostly used for hypotheses generation as they are mostly based on qualitative measures. Yet, they have been criticized for being less appropriate for producing design solutions (cf. section 2.4.4).

Last but not least, inspection is a generic term for a set of methods where evaluators (experts, not the users) inspect an application's user interface to spot usability problems:

- Heuristic evaluation (Nielsen & Molich, 1990)
- Cognitive Walkthrough (Polson et al., 1992)
- Formal usability inspection (Nielsen, 1995)
- Pluralistic walkthroughs (Nielsen, 1995)
- Feature inspection (Nielsen, 1995)
- Consistency inspection (Nielsen, 1995)
- Standards inspection (Nielsen, 1995)

Overall, the evaluation method used in the end strongly depends on factors like the research goal, type and subject. Additionally, in terms of development cycles all of them will not work at any time!

For instance, when it comes to the evaluation of the user interface there are currently four possible ways (Nielsen & Mack, 1994; Nielsen, 1995):

1. Automatically: usability measures computed by running a user interface specification through a program, e.g., the number of clicks a user needs to fulfill a task.
2. Empirically: usability assessed by testing the interface with real users.
3. Formally: using exact models and formulas to calculate usability measures, as with GOMS (Card et al., 1983).
4. Informally: based on rules of thumb and the general skill and experience of the evaluators.

However, "under the current state of the art, automatic methods do not work and formal methods are very difficult to apply and do not scale up well to handle larger user interfaces" (Nielsen, 1995, p.377). That is why empirical and informal methods are most likely to be used. Due to some of the disadvantages (e.g., cost and time) and the need of something without a high degree of precision led to the development of discount usability engineering techniques (Nielsen, 1994). All of the above evaluation techniques focus on the interaction between humans and computers.

They let the evaluator judge on the interaction in three dimensions that comprise the definition of usability (ISO, 2019):

1. Efficiency
2. Effectiveness
3. Satisfaction

When to use which user experience method, depends on the following factors:

1. Stage of development and who participates (cf. Figure 4-7)
2. User information intentionally provided or given off (attitude/behavior) versus data requirements (quantitative/qualitative) (cf. Figure 4-8)

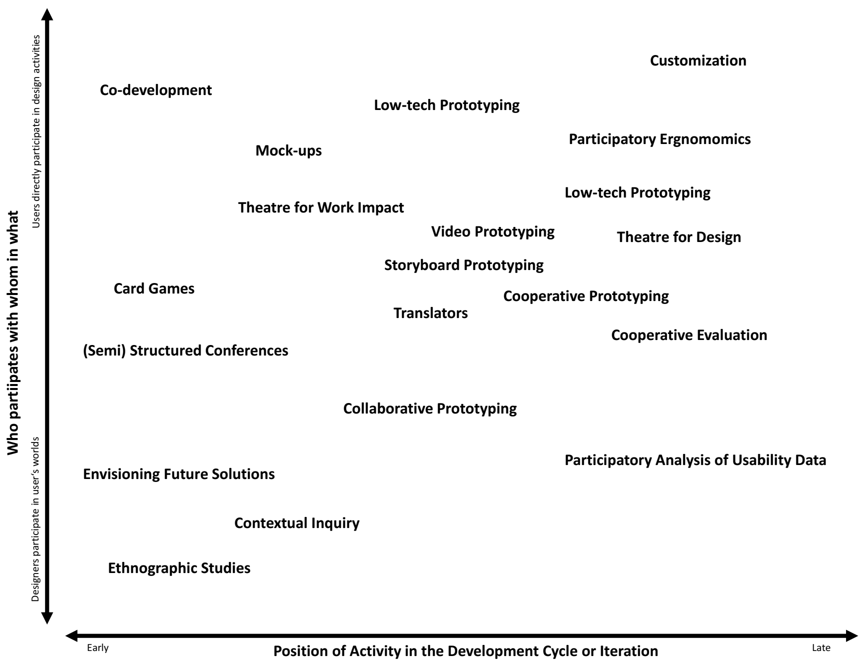

Figure 4-7. Methods for participatory design (Muller & Kuhn, 1993).

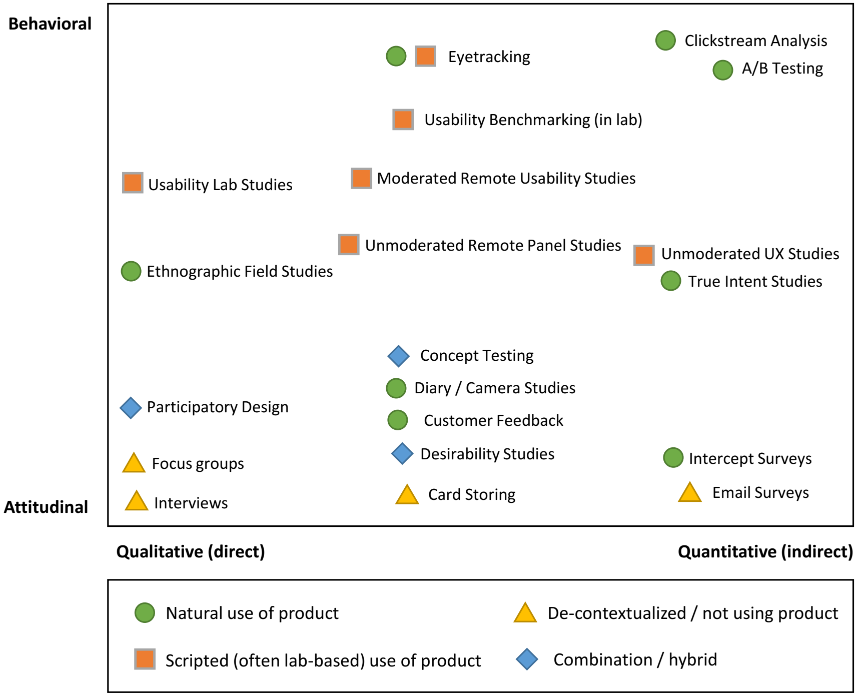

Figure 4-8. User research methods (Rohrer, 2014).

4.4 Evaluation in CSCW

Evaluation also plays an important role in CSCW. "Few practitioners in CSCW would wish to contest the importance of evaluation work. In principle, evaluation should be a significant check of a system's capacity to deliver what is required of it" (Twidale et al., 1994, p.441). Yet, already more than 20 years ago, CSCW researchers suspected that evaluations are not necessarily trivial: "Our problems in finding an acceptable basis for 'validating' the system led us to suggest there is a pressing need for the reappraisal of evaluation philosophies and techniques" (Twidale et al., 1994, p.441).

The difficulty with the evaluation of groupware has been known from the very early days of CSCW(Grudin, 1988; Ross et al., 1995) (cf. section 4.2). One of the reasons is the tight entanglement of social and technical aspects which is typical for socio-technical system (cf. section 1.1). The predominant assumption is that the technical cannot be tested without the social (Gross & Koch, 2007). "The evaluation of CSCW applications requires a very different approach, based on the methodologies of social psychology and anthropology" (Grudin, 1988, p.87). Researchers have constantly been facing the intellectual challenge of the gap of what must be supported socially and what can be support technically (Ackerman, 2000). Further, it became quickly obvious that CSCW evaluations are different from those conducted in HCI.

> "Much evaluation of the past was concerned with the cognitive functioning of a single user sitting alone in front of a computer display. Users were modeled as vigilant, task-oriented workers operating in relatively narrow contexts over short time periods without regard to their broader functioning as social members of larger groups and communities" (Neale et al., 2004, p.112).

But besides the initial differences, the problem with evaluation in CSCW is complex.

> "CSCW evaluation has been, in general, more broad in nature, but it often has been ill-defined, time consuming, labor intensive, difficult to implement, difficult to interpret, and largely ineffective at producing formative data that is needed if groupware applications are to succeed" (ibid, p.112).

Neale et al. (2004) identified the following major issues:

1. Logistics of data collection in distributed settings
2. Number and complexity of variables
3. Validating re-engineering group work

In the field of CSCW, evaluation frameworks fall into three different categories (Neale et al., 2004, p.114):

1. Methodology-oriented frameworks: they describe the types of experiments and methodologies available to CSCW researchers. They provide an overview but no further help on when to choose which method.
2. Conceptual frameworks: describe the group factors that need to be considered during evaluation but they do not describe the methodology on how to achieve that.
3. Concept-oriented frameworks: focus on specific aspects of group behaviors or concepts, such as communication or coordination. They are more limited but offer specific help to focus on isolated aspects of group interactions.

It has always been an issue whether groupware can be evaluated only using ethnographic studies (cf. section 2.2.1). Other researchers "believe that it is more practical to evaluate groupware through usability inspection methods" (Steves et al., 2001, p.125). For the most part, these inspection methods have been translated and adapted from the context of HCI:

- Basic inspection (Steves et al., 2001)
- Groupware Walkthrough (Pinelle & Gutwin, 2002)
- Heuristic evaluation (Baker et al., 2002)
- Collaboration Usability Analysis (CUA) (Pinelle et al., 2003)
- Lab simulation (Humphries et al., 2004)

On the other end, field studies have been criticized for being less appropriate for producing design solutions (Neale et al., 2004; Plowman et al., 1995). Further they require a functioning groupware system running in the actual workplace (Neale et al., 2004). Therefore they do not integrate well in the iterative design process inherent to interactive system design (Dix et al., 2004) (cf. section 4.1) as they cannot be deployed at the early design stages. At the evaluation stage most studies focus on groupware usability (Wainer & Barsottini, 2007). Groupware usability is roughly defined as the "degree to which a groupware system supports the activity of collaboration" (Gutwin & Greenberg, 1999, p.247). This includes taskwork and teamwork (cf. section 2.2.2). They typically employ indirect measures of the following (Olson et al., 1995; Olson et al., 1992):

- Product measures: (taskwork elements) measure aspects of the outcome of a task. Assumption: usability positively influences the group's success completing the task.
- Process measures: (teamwork elements) look for patterns in behavioral and verbal activity during a collaborative session to judge on effectiveness and efficiency (observation, visual recording).
- Satisfaction measures: (both teamwork and taskwork) subjective experience of the individual user with the groupware system (questionnaires, interviews).

As part of their groupware usability testing Gutwin and Greenberg (1999) particularly selected the following five measures (p.243):

1. Task completion times (task work): group activities relate to performance, effectiveness
2. Communication efficiency: number of words spoken related to subject (a coordination practice referred to as articulation work in section 3.2.2)
3. Participants perceived effort: activities of collaboration
4. Overall preference: satisfaction measure, assumes the relationship between usability and preference; users prefer a system that better supports their collaborative activities
5. Strategy use: how groups choose to solve the task

4.5 Evaluation of Awareness & Coordination Support

When it comes to the evaluation of awareness and coordination support, especially later in terms of effort, there is only little that was developed in the area CSCW. The major part stems from the study on human-factors. Overall, it is not a trivial task:

> "Because SA is an internalized mental construct, creating measures to adequately assess and describe it is not an easy task. Metrics of SA generally approach the issue either by inferring SA from other constructs that are easier to assess, or by attempting to obtain a direct assessment of the operator's SA" (Endsley & Jones, 2004, p.259).

This especially underlines the need to develop new evaluation techniques to be used prior to real workplace evaluations in order to make them more practical in terms of time and cost and to eliminate many problems early on thus improving the overall efficiency of evaluation (Pinelle & Gutwin, 2000). However, this cannot be reduced to simply using discount techniques from HCI.

> "Within the field of human-computer interaction (HCI), many low-cost evaluation techniques have moved out of the research arena and into accepted practice (...) [yet, they] have problems when we try to apply them verbatim for the purpose of evaluating groupware" (Baker et al. 2001, p.124).

The *mechanics of collaboration* (Baker et al., 2001; Gutwin & Greenberg, 2000; Pinelle et al., 2003) are a methodology-oriented framework (Neale et al., 2004) suggesting an evaluation scheme that is well apt to "occupy a middle ground between brittle experimental techniques and time-consuming field techniques, where they will provide the kind of formative information valuable in an iterative groupware development process" (Gutwin & Greenberg, 2000, p.120). The mechanics of collaboration are the low-level actions (communication, coordination, planning, monitoring, assistance and protection) and interactions that must take place when completing a task as a team. Their main characteristic (and advantage) of these mechanics: they are independent of the social context! This fits the picture previously drawn in this thesis about awareness and coordination support (cf. sections 2.4.7 and 3.2.3). The downside of this framework is that it lacks the concrete means of measurement for each of the mechanics. "Aside from gross descriptions like laboratory or field studies, it is difficult to determine how these factors should be studied, and it is difficult to determine what methods are best suited to which factors" (Neale et al., 2004, p.114).

Therefore, starting with CSCW and having established a background on evaluation, the next step is to take a look at examples of evaluations in CSCW dealing with awareness or coordination to see whether and how other researchers have approached the issue and to understand where things might have gone wrong in the past. In fact, there are many evaluation approaches and techniques in CSCW originating from various research areas like interviews, questionnaires (social psychology), ethnographic studies (sociology), conversation analysis (ethnomethodology) etc.

(Ross et al., 1995). Pinelle and Gutwin (2000) conducted a review especially focusing on groupware evaluations:

> "We reviewed all papers from the ACM CSCW conference (1990-1998) that introduced or evaluated a groupware system. Forty-five papers were included in the review. The main findings are that almost one-third of the groupware systems were not evaluated in any formal way, that only about one-quarter of the articles included evaluations in a real-world setting, and that a wide variety of evaluation techniques are in use" (p.86).

Most notably: 7 out of the 10 most severe usability problems of groupware related to coordination and awareness. In order to briefly outline what researchers actually did during their evaluations the following selects a small sample of publications with different approaches. The goal here is not to compile an exhaustive list of all evaluations but to select different approaches that were actually used for the purpose of evaluating awareness and/or coordination. For each of these publications it is checked if the aspect of effort is addressed, if a comparative approach is used, and if researchers regarded awareness or coordination characteristics (ephemeral, subconscious etc.) in their setups.

The first publication is from Dourish and Bellotti (1992) who showed that awareness in group editors has positive effects on the coordination in work teams. They used an experimental approach conducting a lab study with a shared text editor. The limitations of the editor imposed further restrictions to the settings. They used a task-based evaluation and observed their participants as the sessions were videotaped. Further, they conducted a post-task interview. The study rather served the purpose to get a general understanding of a cooperative context and the role of awareness in it in terms of qualitative feedback. The goal was not to improve awareness as it was not operationalized further for measurement. There was no quantitative verification or comparative approach.

In another publication, Gutwin et al. (1996) conducted a usability study (combined aspects as compared to Gross (2013)) of awareness widgets. They used post-task questionnaires and interviews, that were audiotaped. Awareness itself was not operationalized. Participants were asked directly for their feedback and consent regarding the widgets. Thus, the authors provided an insight on their users' attitude which is valuable to build hypotheses – that need to verified quantitatively. It was not proven by any numbers that their users could coordinate better using a particular widget, indicating a certain implementation's superiority to others (to resolve a certain design tension).

In another study, Convertino et al. (2004) used a new approach of field studies informing the design of lab experiments for the case of activity awareness. They used a task-driven approach applying the Think Aloud technique (Nielsen, 1994) to learn what users were thinking while completing a task thus imposing an even higher load on the working memory. They especially focused on awareness breakdowns using multiple session in between which they requested informal feedback (contextual inquiry). Further, they used a post-task questionnaire. Two researchers subsequently assessed the level of awareness post-task by judging on the degree of inconsistencies being noticed (i.e., expert judgement).

The approach reported by Antunes et al., (2014, 2010) to review the quality of awareness support in collaborative applications is based on a checklist comprised of 54 design elements and six awareness types. The list is created by experts to be provided to developers as a guide in the early stages of development. Yet, they did not operationalize awareness or coordination in terms of effort. They do not measure the user's effort but rate the application based on expert knowledge. Further, they did not provide explicit before and after results of an application checked using their method.

All of the above used a mixture of multiple evaluation techniques. Most of them used either high-fidelity prototypes or fully developed applications as test objects, that is, they were not at the very beginning of the development process. Only one had a comparative setup (not in terms of before/after but A/B). None of the above focused on efforts imposed by coordination or awareness. The applied techniques were mostly borrowed from HCI, some with slight adaptations to be used in the context of groupware. Most of them do not specifically regard or even ignored the characteristics of awareness or coordination as outlined above. For instance, post-task questionnaires and interviews tend to query the users' attitude about issues they have not consciously thought about at a point in time when the knowledge is typically gone.

Turning to human-factors, reveals a more advanced approach in terms evaluating situation awareness (SA). As described earlier, researchers developed a model for situation awareness (cf. section 2.1.2) and the great advantage when having this kind of model is, that it is a lot easier to develop measurement and evaluation approaches based on it. “In general, evaluation metrics can assess user processes, cognitive states, and performance at different stages” (Endsley & Jones, 2004) (cf. Figure 4-9).

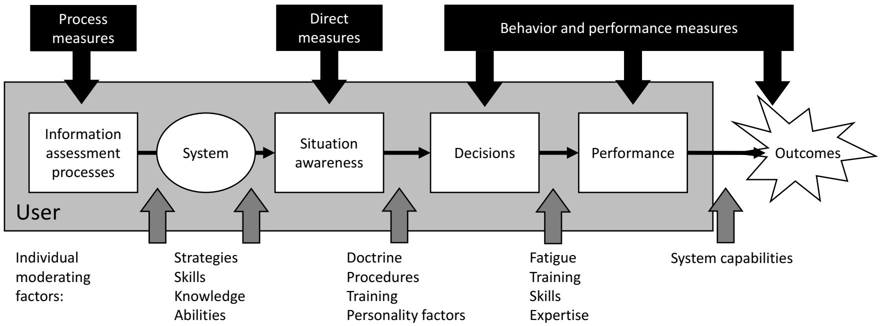

Figure 4-9. Areas of evaluation (Endsley & Jones, 2004).

Further, researchers believe that “direct and objective measurement of SA is the best way to approach the evaluation of a system design” (Endsley & Jones, 2004, p.260). For this to occur they suggest the following measures:

- Subjective measures: qualitative data, users rating their SA on a certain scale revealing that something happens and why
- Objective measures, i.e., collecting data from users and their perception of the context compared to what is actually happening in that context. In detail there are:
    - Measures of effectiveness
    - Measures of performance

- Process measures – including eye tracking, information acquisition, and communication analysis
- Workload measures
    - Physiological measures (EEG/ECG)
    - Subjective measures
    - Performance measures including task error measures and measures of spare capacity using concurrent secondary tasks

When it comes to workload measures, there is an interesting observation to be made as far as the measurement outside the context of cooperative work is concerned:

> "One of the most widely used techniques to measure workload is the secondary task. This technique requires an operator to perform the primary task with that task's specified requirements and to use any spare attention or capacity to perform a secondary task. The decrease in performance of the secondary task is operationally defined as a measure of workload" (Gawron, 2008, p.94).

The above covers the theory. Talking about the practical measurement of situation awareness two well-known techniques from human factors are the *Situational Awareness Rating Technique* (SART) (Taylor, 1990; Taylor et al., 1998; Endsley et al., 1991) and the *Situation Awareness Global Assessment Technique* (SAGAT) (Endsley et al., 1998).

SART is an approach using subjective metrics. It assumes, that subjects "use some understanding of situations in making decisions, that this understanding is available to consciousness and that it can readily be made explicit and quantifiable" (Taylor, 1990). The method clusters 10 constructs into three broad domains:

1. Attentional demand: situation stability, variability and complexity
2. Attentional supply: arousal, spare mental capacity, concentration and division of attention
3. Understanding: information quantity and quality as well as familiarity

Especially 1 and 2 are associated with workload which is seen as an integral part of SA (Taylor, 1990).

The Situation Awareness Global Assessment Technique (SAGAT) (Endsley et al., 1998) is an objective metric used across a variety of domains like air traffic control, power plant operations, teleoperations, driving and military operations. SAGAT seeks to assess a subject's SA by asking questions and comparing the results to reality. This is done during a simulation exercise where

> "at randomly selected intervals, the simulation activity is briefly halted, the displays are blanked, and a battery of queries is administered to the participant (...) Data collected by the simulation computer and by subject matter experts are used to score the participant's responses as correct or incorrect based on what was actually happening in the scenario at that time" (Endsley & Jones, 2004, p.271).

After answering the question, the simulation resumes. Major disadvantages or limitations of the technique are that it requires a situation to be stoppable which is likely not the case in many real-world settings. Another is the creation of appropriate questions that fit the environment.

Objective measures like SAGAT typically face the following challenges:

- Appropriate timing for the queries; asking the subject in the end provides the subject's SA at the point when the activity ended (this is also the problem with subjective questionnaires).
- Appropriate questions to ask related to the subject's task of interest.
- The questions must not alter the subject's SA by asking for circumstances the subject is not aware of.
- Creating questions that cover the entire range of relevant issues to SA.

The choice of metrics for an evaluation depends largely on the goals of the evaluation, the characteristics of the medium available for testing, and the expertise of the personnel performing the study. "How well a measurement technique addresses these challenges provides a benchmark for assessing the utility of the tool" (Endsley & Jones, 2004, p.283).

Disadvantages of SARS and SAGAT are that they leave out coordination and cooperative contexts completely. They require tremendous manual configuration and setup and ask users about awareness related items directly.

4.6 Challenges, Reflections and Criticism

As in the previous chapters, there are some issues in this chapter worth discussing or for taking a second look. They are all organized in short sections for easier reference later.

4.6.1 The Toughest Question

What is currently the best awareness support? This is a question that no CSCW researcher is currently able to answer. What is meant by "best"? Even a more relaxed variant thereof like "Is awareness support A better than B?" and "Why?" are equally tough. An earlier section talked about design tensions (cf. section 2.4.2), however, many of them stay unresolved as there are many hypotheses on how good or better awareness support might be like (i.e., the hypothesis generation was done) but there is hardly a method to validate these hypotheses. And the problem is not what is meant by good, better or best. For instance, "is it better to provide awareness cues inside the task screen or separate?" is a simple question which lacks a quantitative basis to answer it. Most evaluations use the usability criteria of effectiveness, efficiency and satisfaction (Frøkjær et al., 2000; Gutwin & Greenberg, 2000). Yet, what especially is effectiveness and efficiency in terms of awareness and coordination support? Both are closely related to the issue of effortless coordination. There is an issue with evaluation to be explained in greater detail in section 4.6.8. For now the argument ought to show that more basic research is required (cf. section 2.4.1), which is for the case of awareness and coordination use-inspired basic research (Stokes, 1997). However, this in turn requires methods that can be used for hypothesis validation.

4.6.2 False Consensus

Groupware designers, as many other designers, easily fall into the trap to make decisions for the user based on their own preference. What is bad practice for single-user application becomes worse for groupware:

> „The design process fails because our intuitions are poor for multi-user applications – decision makers see the potential benefits for people similar to themselves, but don't see the implications of the fact that extra work will be required of others" (Grudin, 1988, p.86).

For a CSCW application many different characters from different perspectives need to participate in the design process in order to achieve a successful design. If not makes CSCW applications easily susceptible to the false consensus effect (Ross et al., 1978):

> "False consensus exists when people's won choices, attitudes, or beliefs bias their estimates of those of other people, leading them to view their own reactions as relatively common while viewing alternative reactions as relatively uncommon. False consensus is revealed when people making a particular choice consider this choice more common than do people making the opposite choice" (Kunda, 1999, p.397).

4.6.3 The Problem with the Study of Groups

If the problems with awareness and evaluation were not troubling enough, there comes even another one. In his reflection on the study of groups McGrath et al. (2000) draw the following conclusion:

> "By concentrating our empirical research (and our subsequent theoretical formulations) on studies with these features, we have denied ourselves the opportunity to envision groups in ways that more accurately reflect our own experience in groups – namely, that groups are complex, adaptive, and dynamic systems – and to find ways to incorporate such a viewpoint in our empirical and theoretical research" (p.97).

They especially argue against laboratory studies as these study groups as simple systems isolated from their context as static entities without past, present or future.

This thesis takes quite the opposite direction as awareness and coordination mechanics allow to abstract their use from a particular context (cf. section 2.4.7 and section 3.2.3). It is hard to study social dynamics but, in this case, it is not the goal!

4.6.4 Hypothesis Generation versus Hypothesis Validation

There are methods that are primarily apt to make observations upon which hypotheses can be build. For these usually empirical studies yielding qualitative data are applied. Once observations to be checked are formed into hypotheses it is time to make a switch towards hypothesis validation. This step typically applies another set of methods either yielding further qualitative data or quantitative data that can be statistically analyzed.

Ethnographic studies are the best choice to make observations (cf. section2.2.1) but not a good choice to validate them as they usually do not yield to much quantitative data that can be used for validation.

4.6.5 Don't Listen to Users

This claim is one of the most famous of Jakob Nielsen (Nielsen, 2001) when being asked for the number one rule in usability research. It strikes the issue of user behavior versus their attitude. Users simply do not do what they say from which Nielsen concludes that he does not listen to them but rather observes their actions. For instance, in the COORDINATOR system they found that the "'wonderful' functions often cited by users were not actually used by those users" (Bullen & Bennett, 1990; Henninger, 1991). This also becomes important when evaluating an awareness or coordination support system. Asking users about their opinions or attitudes does not help:

1. They actually might use the system in a different way then articulated.
2. It does not matter what they say as it would refer to a secondary task that works mostly subconscious and unintentional (cf. section 2.5).
3. Especially asking users about awareness after a common task makes no sense as the knowledge was not only mostly subconscious but already gone and forgotten by that time anyway (cf. section 2.5).
4. Targeting effortless coordination efforts cannot be measured this way.

That means that all approaches evaluating awareness and/or coordination support should find another way than asking users directly about it.

4.6.6 Assessment versus Approval

Another problem related to asking users or customers is the difference between a true evaluation and asking for approval. In 2009, the US company Walmart asked its customers: “Would you like Walmart to be less cluttered?” The customers agreed.

> “So, Walmart cleared out space and reduced inventory and customer satisfaction shot up. However, same-store sales plummeted, by Phil Terry’s estimate, by $1.85 billion, and now Walmart has fired the team that put the idea into place and is spending hundreds of millions to undo what they spent hundreds of millions doing. But wait! Weren’t they listening to their customers? Why weren’t they rewarded? It was a costly mistake that required lots of overhaul and refurbishing. 15% of inventory was removed from the stores. End caps were slimmed. Shelves got shorter. Gone were the big pallets of stuff stacked in the middle of aisles. Ah, it was more clean and open, more like Target – the strategy was put into place by a former Target exec, who is now a former Walmart exec – and sales dove. How could this be?” (Popken, 2011)

Walmart’s goal was to listen to its customers, however, they “came up with the answer first, then asked customers to agree to it” (Popken, 2011). While the customers liked the increase in space inside the Walmart stores, the approach completely ignored what mattered most to the company: its vast selection of cheap items to create revenue. Many experiments mentioned earlier used questionnaires for awareness evaluations running the risk of easily falling into the trap of rather asking for approval than conducting a real assessment.

4.6.7 Situated Action versus Artificial Environments

Section 3.3.4 already discussed the cognitive versus the social science. “A factor contributing to the failure to learn from experience is the extreme difficulty of evaluating these applications (...) these complex applications introduce almost insurmountable obstacles to meaningful, generalizable analysis and evaluation” (Grudin, 1988, pp.85). This section continues the argument which extends to how designers should evaluate their work. For instance, a study (Suchman, 1983) examined how existing office technologies were being designed in relation to how people actually work. She found that designers would be much better positioned to develop systems that could match the way people behave and use technology, if they began by considering the actual details of work. Suchman later underlined her arguments highlighting the inadequacy of basing the design of an interactive system purely on an abstract user model, when she analyzed the use of a help system for a photocopier showing the impact of unique details of the situation at hand (Suchman, 1987). This quite old study still fires the discussion on what evaluation type is appropriate for CSCW applications.

On the other end, real life scenarios are complex, hard to reproduce and conclusions to be drawn too specific to be generalized. In other words: these studies are not very helpful to the general design of systems. "Evaluation of CSCW applications requires a very different approach, based on the methodologies of social psychology and anthropology (...) And the required methods are generally more expensive, more time-consuming, and less precise" (Grudin, 1988, p.87). Others state that it is difficult or impossible to create a group in the lab that will reflect the social, motivational, economic, and political factors that are central to group performance (Malone, 1985). Group interactions or group dynamics unfold over days or weeks (cf. section 2.2.2). There are many statements, also as part of this thesis, that workplace studies are essential und more of them need to be conducted. Schmidt emphasizes their importance (Schmidt, 1998) even before writing about "The Problem with Awareness" in 2002.

Yet, there are also different opinions. For example, Bardram (1996) states:

> "From the very beginning, workplace studies have played a prominent role in the research field of CSCW. They are used to understand and shed light on work and interaction happening in a workplace (...) and as such [have provided] an important insight into the subtleties of (...) socially constructed work practices. Within CSCW the value of these insights into the social nature of work activities, gained through such workplace studies, is unquestionable. However, there has been an ongoing dispute in the field (...) [as] to the exact value of these often very detailed and specific investigations of the workplace. Questions like: how effective is the field study approach for informing the design of CSCW systems? How can typical ethnographic field studies which take months or years, be done with the fast pace of systems development? What should be used for within the design process? Are they economical or even practically desirable in a complex design process? Is it possible to generalize such detailed and narrow studies into applicable design recommendations?" (p.613)

Bardram and Hansen (2010) later add: "Most studies of plans and situated work have applied ethnographic methods and thus fail to provide any quantitative insight into the extent of this phenomenon" (Bardram & Hansen, 2010, p.331). Further problems:

- Social studies yield no design guideline, no practical impact (cf. section1.2) revealing a gap between results and their applicability.
- There is no transfer between studies and application design due to separate groups of researchers (Plowman et al., 1995).

Later other approaches to the evaluation of groupware entered the discussion:

> "Many researchers believe that groupware can only be evaluated by studying real collaborators in their real contexts, a process that tends to be expensive and time-consuming. Others believe that it is more practical to evaluate groupware through usability inspection methods. Deciding between the two is difficult, because it is unclear how they compare in a real evaluation situation" (Steves et al., 2001).

Other researchers mention that "most discount methods rely on some understanding of the context in which the groupware system will be used" (Pinelle et al., 2003, p.281). However, others suggest the application of the mechanics of collaboration (Gutwin & Greenberg, 2000) for exactly these discount methods which make them potentially independent of the social context. All in all, it strongly depends on what is meant by context and how much you need of it. That is, the goal of the evaluation should decide on the method being used and not only if it is a group context or not.

4.6.8 The "Evaluation Crisis"

The previous section and section 3.3.4 on the cognitive versus the social science describe the core movements that lead to the "evaluation crisis" (Neale et al., 2004). "The evaluation of distributed CSCW systems has been too frequently method driven by various disciplinary preferences rather than driven by frameworks that get the appropriate questions answered" (Neale et al., 2004, p.112). Further, looking at a typical development cycle reveals that without proper evaluation no design activity can be finished successfully. Research in CSCW due to its evaluation disputes is basically confined to its first development cycle and thus with hardly any progress possible. The dichotomy of ethnography or technology drove out cognitive science and tries to hinder research happening in rather context-independent approaches. Especially cognitive engineering seeks constructs or concepts to understand human performance. It "puts forward theoretically based constructs and test their generality through empirical studies in a wide variety of laboratory tasks, simulators, 'microworlds', and actual" (Parasuraman et al., 2008, p.140). "By empirical evidence, we mean controlled experimental studies and/or validated computational models and not just subjective observations, analytical exercises, or personal opinions" (Parasuraman et al., 2008, p.143). The design of CSCW applications or groupware fails at the evaluation stage due to the lack of appropriate methods. In the long run, this has already caused the fragmentation of the entire research field on the large scale (Kostakos, 2015; Liu et al., 2014; Schmidt, 2009).

Wallace et al. (2017)'s more recent study does not indicate any improvement in this matter:

> "Our review shows that research methods at CSCW have changed with the emergence of social networking and Post-PC devices over the past decade, but that these changes have followed rather than anticipated technological advances. In particular, CSCW now places most emphasis on research that describes collaborative work environments in practice, as opposed to work that develops novel systems in the laboratory or tests scientific hypothesis" (Wallace et al., 2017, p.2).

That is, the evaluation crisis is not yet over and will not be soon, unless: "The choice of evaluation methodology – if any – must arise from and be appropriate for the actual problem or research question under consideration" (Greenberg & Buxton, 2008, p.111).

4.7 Summary

The development of CSCW applications which includes their design and evaluation is a complex task. It was shown how CSCW researchers go about the risks and issues employing an evolutionary design process equipped with methods for the particular research context.

This chapter's key findings are:

- The CSCW design challenge is a wicked problem. Therefore, the development requires an evolutionary design process involving users already at the early stages avoiding the risk of changing requirements and the users being influenced by the resulting system.
- There are a lot of evaluation approaches but only a few come close to the requirements afforded by the characteristics of awareness and coordination. For instance, using a post-task questionnaire is likely not to capture the right values as secondary task knowledge is ephemeral by nature.
- The evaluation of awareness and coordination requires this secondary task knowledge to be still present.
- Awareness and coordination cannot be judged in terms of effort by directly asking users about it or by observation as it is mostly a subconscious and unintentional activity resulting in ephemeral knowledge quickly gone when not needed.
- Most evaluation techniques can be used for hypothesis generation, but only very few for hypothesis validation.
- The usage of evaluation approaches in general depends on the development stage (early, late).
- CSCW currently suffers from an evaluation crisis as most evaluation methods are chosen upon disciplinary preference instead of appropriateness and many of them do not allow for hypothesis validation which is, however, required to finish a design cycle. A design cycle is incomplete without a proper evaluation. Thus, CSCW fails at the evaluation stage of the design process.
- As coordination and awareness support mechanisms are context independent features it is appropriate to study these as part of dedicated laboratory studies as only those allow the connection of cause and effect.
- Measuring efforts in the context of awareness and coordination requires a quantitative approach that focuses on the behavior and not the attitude of a user.

However, there is no one size fits it all approach. McGrath (1995) states that researchers are always trying to maximize generalizability, precision, and realism. Yet, this cannot usually be done in a one-step approach applying a single method. Multiple methods must be used in combination with others to balance their shortcomings (Neale et al., 2004).

When it comes to evaluations the guiding principle should be following: "The choice of evaluation methodology – if any – must arise from and be appropriate for the actual problem or research question under consideration" (Greenberg & Buxton, 2008, p.111).

5 Standardized Coordination Task Assessments (SCTA)

This section presents a new approach to the selective, early and appropriate assessment of awareness and coordination support. This chapter starts with the definition of the research goals and objectives connecting the approach with a rationale. Then it takes look at the method's concept by discussing high-level requirements, the ideas and related work that led to the eventual design of the method. Next, this chapter takes a look at how awareness and coordination can be operationalized in terms of effort based on the characteristics gathered in chapter 1 and 3. The sections describing the approach focus on the structure of the method and what components are used as well as its overall procedure. In the following section, the implementation of the approach is described including technologies used for its realization also drawing a little history on how the approach itself evolved over time. Finally, this chapter presents possible means of analysis based on this approach. It concludes with a short evaluation of the method itself with respect to its scientific reliability and validity as well as to its initial goals and mission statement.

5.1 Rationale

As mentioned numerous times throughout this thesis, one of the major goals of CSCW is to translate vital social mechanisms from the real world into technical concepts and means of support in the digital world: "CSCW should be conceived as an endeavour to understand the nature and requirements of cooperative work with the objective of designing computer-based technologies for cooperative work arrangements" (Schmidt & Bannon, 1992, 2013, p.351). As part of this endeavor, researchers found that team members coordinate their activities seamlessly and effortlessly in the real world and thus tried to translate this to digital system. Gross (2013) framed the term effortless coordination as follows:

> "the concept of effortless coordination – that is, the question whether and how team work can be coordinated and a mutual understanding in the team can be gained and maintained, while still keeping the team members' coordination effort to a minimum" (Gross, 2013, p.427).

But how and when can coordination be considered effortless in digital systems? This is a tough question which cannot be answered directly but has to use an approximation and benchmark approach consisting of the following steps:

1. The coordination support is built based on a certain hypothesis (e.g., derived from ethnographic studies).
2. The effort is measured.
3. The results are compared to previous results (benchmark).
4. If the effort is lower (approximation) it appears to be a hypothesis worth pursuing (new benchmark) otherwise it created more effort than previous approaches and does not help towards the goal.

These are exactly the steps of the scientific method introduced in section 4.2. However, the problem is that there is currently no way to measure or assess efforts related to coordination (and thus also related to awareness) in CSCW.

From this situation, the following research hypothesis for this thesis was be derived: in order to reach effortless coordination in digital systems, coordination (and awareness) need to be made measurable and to be measured.

This hypothesis was broken down into three objectives:

- Objective 1 – make awareness measurable: build a construct for awareness (conceptual operationalization). This objective will be met by reviewing existing literature on the subject from the area of CSCW gathering typical characteristics and underlying processes.
- Objective 2 – make coordination measurable: build a construct for coordination (conceptual operationalization). This objective will be met by reviewing additional existing literature from the area of CSCW, HCI, human-factors and cognitive sciences.

- Objective 3 – create a measuring method: design a measurement approach to assess awareness, coordination and respective support systems. This objective will be met by suggesting a method and to demonstrate its applicability with reliable and valid results.

Objective 1 and 2 have been addressed earlier as part of the previous chapters. This chapter especially focuses on objective 3: Find a way to measure efforts in coordination and also awareness as it is closely related to it. Here, the goal is to design a new method that properly regards the characteristics of the constructs of awareness and coordination in order to gain deeper insights into how the constructs can be translated successfully to the digital world to render them effortless here as well.

In order to do so, the constructs need to be understood precisely, i.e., there is a need for the fundamental understanding of both constructs, yet, with a strong consideration of the eventual use already in mind. This intersection of fundamental understanding and consideration of use are the characteristics of use-inspired basic research, also known as research in Pasteur's quadrant (Stokes, 1997) (cf. section 1.4). The above-mentioned goal is considered to be reached once a method is found that delivers reliable and valid results in terms of effort for awareness and coordination.

5.2 Concept

This section undertakes the next steps from the aforementioned objectives to the concept, i.e., describing the *what*, of the desired measurement approach. In a first step, high-level requirements are gathered and derived from the previous objectives (cf. section 5.1). The next section takes these and describes ideas and major influences they are based upon. A section on the concept's scope describes which of the ideas are realized to what extent as part of this thesis.[17] The following sections then outline the operationalization of the constructs and further thoughts on the research design.

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[17] Out-of-scope parts can be found as part of the future work section in chapter 7.

5.2.1 High-Level Requirements

The following high-level requirements for the measurement approach were gathered throughout this thesis and derived from the research objectives (cf. Table 5-1).

Table 5-1. High-level requirements.

ID	Title	Description
1	Comparative Approach	As described in section 5.1 the approach requires a before/after or split (i.e., A/B) procedure to allow approximation and benchmarking.
2	Approximation and Benchmarking	Both are required in order to approximate effortless coordination.
3	Inexpensive	Field studies are quite expensive and a quantitative approach should be inexpensive due to potentially high volumes of participants.
4	Formative evaluation	The approach must be able to be applied in settings where the solution is not yet finished.
5	Easy replication	Retries and results of the approach shall be easily replicable in order also to be reproduced by other researchers.
6	Quantitative measure	The approach must use a quantitative approach in combination with an observation and measurement of the users' behavior.
7	Distributed assessments	The approach must allow for distributed and colocated testing. Especially distributed settings are an obstacle to current ethnographic studies (Neale, 2004).
8	Environment integration	In order to quickly integrate into existing environments or to quickly setup its own for conduction experiments, the approach must not require any software installation on the participants device. All integration must be done as configuration.
9	Device independent	The approach's implementation must not be dependent on a specific device type.
10	Operating system independent	The approach's implementation must not be dependent on a specific operating system.
11	Distinct levels for coordination and awareness	The approach must measure distinct levels of secondary task knowledge on awareness and coordination.
12	Appropriate consideration of awareness and coordination constructs	The approach must consider awareness and coordination appropriately according to their characteristics outlined in their constructs.

13	Early stages of development	The approach must be applicable in the early stages of development of awareness and coordination support systems.
14	Hypothesis validation	The approach must be usable for hypothesis validation as part of a human-centered design approach.
15	Iterative, incremental application	The approach must allow to be applied numerous times without being affected by the effects of repeated use (e.g., learning).
16	Re-usable/sharable results	The approach must allow to (re-)use and share results with other researchers in order to allow replication.
17	Scalability	The approach must allow the assessment of various group sizes in a configurable number of assessments.

5.2.2 Idea and Major Influences

The initial idea of the approach was conceived in 2011 (Oemig & Gross, 2011). The idea is comprised of an easily replicable, standardized primary task to be solved by a team which is interrupted by a configurable number of freeze probes to query the participants about their secondary task knowledge. Based on this, the approach received its name: STANDARDIZED COORDINATION TASK ASSESSMENT (SCTA).

The SCTA is a concept-oriented framework (cf. section 4.4), i.e., it defines a method to measure specific concepts (in this case awareness and coordination). The concepts have been specified in detail in chapter 1 (awareness) and chapter 3 (coordination). The following subsections briefly describe the ideas and major influences behind the approach.

5.2.2.1 Context Independence

The first idea builds on the independence of awareness and coordination mechanics from a specific context (as shown in sections 2.4.7 and 3.3.6) as they are part of the mechanics of collaboration (Gutwin & Greenberg, 2000). It thus basically allows awareness and coordination mechanics to be tested outside and independently from the original group or task context that there was so much discussion about (cf. section 4.6.7). This especially allows the implementation of requirements #3 and #15 (cf. Table 5-1).

The idea itself is heavily influenced by stack-based approaches from computer science where the lower layers are agnostic of the context of the higher layers as in the TCP/IP or DoD stack (Cerf & Cain, 1983) or the ISO OSI model (ISO, 1994) (cf. Figure 5-1).

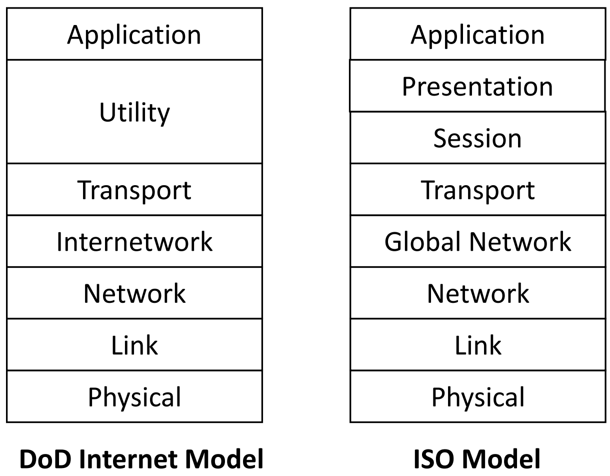

Figure 5-1. DoD model (Cerf & Cain, 1983) and ISO OSI model (ISO, 1994).

These stacks are the role model to build a stack using the layers of communication, coordination and cooperation/collaboration (cf. Figure 5-2). A stack of underlying processes was as also suggested by coordination theory (cf. Table 3-2 in section 3.2.1).

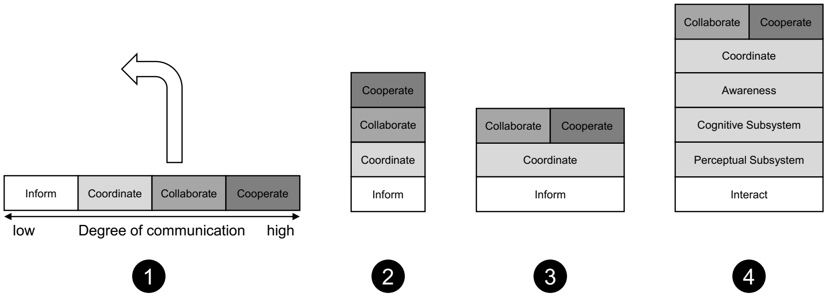

Figure 5-2. The stack underlying cooperation and collaboration. (1) (Bair, 1989)'s horizontal chain from inform to cooperate has to be flipped to a vertical position (2). As people either collaborate or cooperate based on their coordination, both are set to the same level (3). Step (4) then adds the different layers for the coordination layer, based on the MHP (Card et al., 1983) and the findings from this thesis with regard to the relationship of awareness and coordination (cf. section 3.3.6).

As part of the stack, the STANDARDIZED COORDINATION TASK ASSESSMENTS especially focus on the two mechanics of collaboration for awareness and coordination (cf. Figure 5-3).

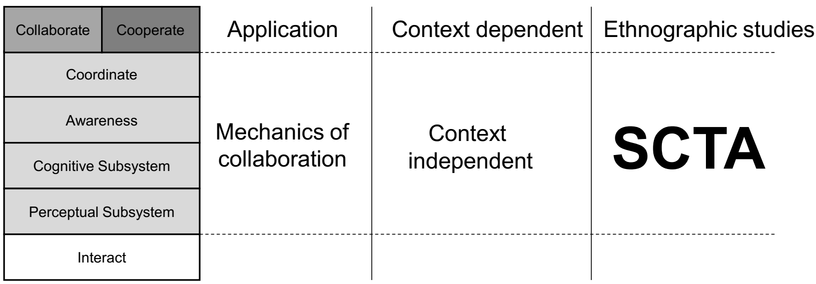

Figure 5-3. SCTA area of application.

5.2.2.2 Interdependency Type Dependency

The second idea to be introduced here builds on the interdependency types of Malone and Crowston's (1990) coordination theory (cf. section

3.2.1) and the previous insight, that awareness is a support function to coordination and that each awareness type can be matched to a coordination interdependency type (cf. section 3.3.6). This allows an even stronger focus (meaning a shift from context independent to being dependent on the interdependency type). That is, there are overall three generic contexts that awareness and coordination mechanics can be observed and evaluated in. For these three generic contexts three applicable primary tasks need to be defined to assess the resulting secondary task knowledge. These generic primary tasks are also referred to as *coordination games* as SCTA experiments use a game-like setup. From another angle these coordination games are the standard tasks the name of the method refers to.

5.2.2.3 Cognitive Approach

The next idea described here is to use a cognitive approach, as awareness and coordination are based on mental processes and models. Card et al. (1983) state: "An applied psychology that is theory-based, in the sense of articulating a mechanism underlying the observed phenomena, has advantages of insight and integration over a purely empirical approach" (p.13). Additionally, cognitive approaches like Card et al.'s (1983) MHP (cf. section 3.1.1) are partially based on metaphors borrowed from computer science like the one that sees the human mind as information processor. Especially talking about workload and effort again suggests a metaphor like a task manager of an operating system displaying current loads and capacities (cf. Figure 5-4).

The second part of the idea regarding a cognitive approach is the previous measurement of workload in other settings outside of CSCW and computer-supported cooperation.

> "One of the most widely used techniques to measure workload is the secondary task. This technique requires an operator to perform the primary task with that task's specified requirements and to use any spare attention or capacity to perform a secondary task. The decrease in performance of the secondary task is operationally defined as a measure of workload" (Gawron, 2008, p.94).

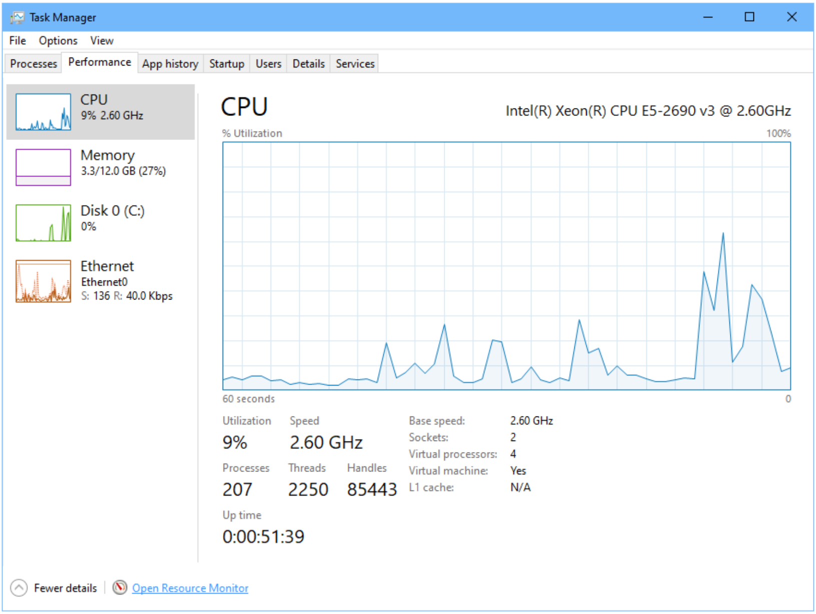

Figure 5-4. Task manager metaphor from computer science applied to psychological concepts of workload and capacity for a human information processor (Card et al., 1983).

For the context of SCTA this approach is basically turned upside down. The SCTA uses an arbitrary primary task (or better one, that fits one out of the three interdependency types) that creates an initial workload and especially the need for the secondary task (i.e., awareness and coordination). The primary tasks can be tuned up, if needed, but in general they serve as the base load to make experiments comparable and to have equal or very similar workloads across all of them. That allows then to change only one variable in the experiment (the awareness/coordination support) and to observe the effects on the mental effort.

Last but not least the setup of the first primary task was also borrowed from cognitive psychology, where especially memory experiments were conducted using abstract syllables or letter combinations (cf. section 3.1.3). More details on this are described in the next section.

5.2.2.4 Subliminal Messages and Letter-counting

The idea for the first coordination game for the interdependency type of simultaneity was borrowed from the context of subliminal messages (Karremans et al., 2006; Stern, 2015). Here, researchers also used an arbitrary letter counting activity (i.e., participants were counting Bs on a screen while being exposed to subliminal messages). The basic idea for this research stems from a private market researcher named James Vicary, who claimed in a study to increase sales of beverages and popcorn by using subliminal messages in movie theatres (cf. Figure 5-5).[18]

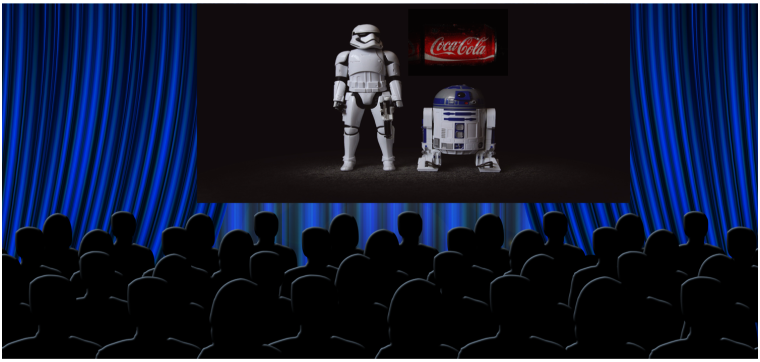

Figure 5-5. Vicary's idea of subliminal messages in movie theatres (Karremans et al., 2006).

5.2.2.5 Automation and Probing

Automation and probing actually refers to two separate ideas, yet their effect basically comes as one. Automation is the answer to the requirements of being inexpensive and replicable providing similar workloads for the primary task when running a set of experiments. The automation creates the letter counting task. By using all letters of the alphabet, a large number

[18] Vicary's study was obviously a hoax, however, the context here does not refer to his study but to the idea of using letter counting when trying to replicate his suggested findings (Karremans et al., 2006).

of different primary tasks can be created instantly using a random letter generator. But not only the task is generated automatically. The questions as part of the probing are automatically generated as well based on previously entered results from the participants.

The probes used are similar to the ones used in SAGAT (Endsley, 1988, 2019; Endsley et al., 1998) (cf. section 4.5). The idea is to also blank the screens of the participants multiple times during the task delivering questions about the task. The major differences to SAGAT are, that the questions address coordination and awareness indirectly and that the questions are completely autogenerated based on letter counting results.

5.2.2.6 Standardization

The idea of standardization is to allow the sharing and replication of research results.

> "A standardized questionnaire is a questionnaire designed for repeated use, typically with a specific set of questions presented in a specified order using a specified format with specific rules for producing metrics based on the answers of the respondents" (Sauro & Lewis, 2012, p.185).

Advantages of standardized approaches (Sauro & Lewis, 2012, pp.185) are:

- Objectivity: standardized measures allow other researches to independently verify the results of others.
- Replicability: replication of other and own results is easier with standardized procedures.
- Quantification: standardized approaches allow researchers to report results in finer detail and to apply statistics to their results.
- Economy: standardized approaches cause great effort in their development but are very economical to reuse.
- Communication: it is easier to communicated standard measures as the rules of their creation are available to all.
- Scientific generalization: standardization is essential for assessing the generalization of results.

5.2.3 Scope

The scope of the method for the purpose of this thesis is reduced in two ways:

1. Awareness/Coordination support/mechanics are independent of the application that is used in a particular context. Thus, they can be dealt with in an isolated fashion. The SCTA focusses only on the coordination space described as part of an Clover architecture (cf. (Ellis & Wainer, 1994; Laurillau & Nigay, 2002) or section 2.4.7).
2. The implementation of the method starts with the coordination game for the interdependency type simultaneity.

In order to explain the second scope reduction of the approach it is best to use a mixture of the Time-Space Taxonomy (Johansen, 1988) introduced in section 1.1 and the interdependency types of coordination as part of the coordination theory (Crowston et al., 2006; Malone & Crowston, 1990, 1994) introduced in section 3.2.1. Figure 5-6 shows that interdependency type simultaneity predominantly occurs in settings where the team members work at the same time (either co-located or remote), whereas the other two types of prerequisite and shared resource handle the time in-between multi-user sessions.

	Same Time	Different Times
Same Place	Simultaneity	Prerequisite / shared resource
Different Places	Simultaneity	Prerequisite / shared resource

Figure 5-6. Time-Space Taxonomy coordination interdependency types.

This reduction in scope has an impact on the results later to be applied to applications like the following: Google Docs[19] by Google Inc. (cf. Figure 5-7) is a shared word processor. Here, multiple users may create or co-edit shared documents at the same time while their presence and the activity is indicated by colored cursors.

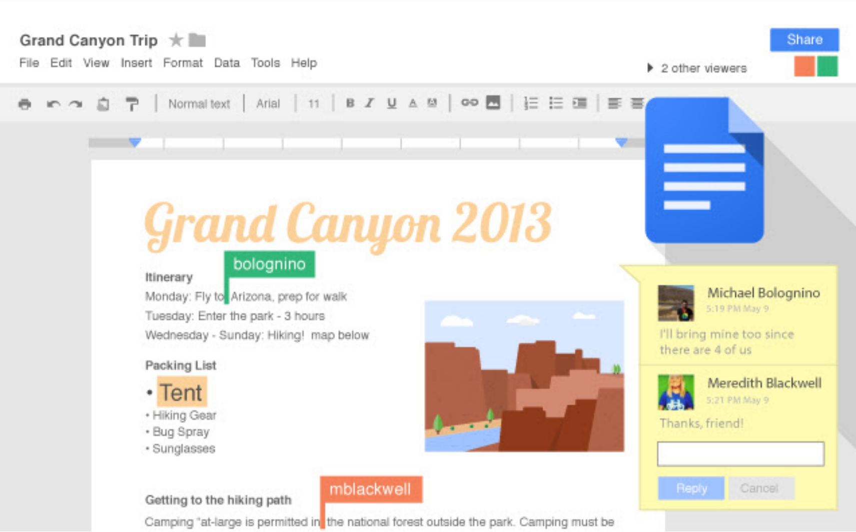

Figure 5-7. Google Docs. Multiple users are indicated by colored cursors (Source: Google Inc.)

Another example for the case of simultaneity are multiplayer games like Star Wars™ Battlefront II by Electronic Arts Inc.[20]. Here multiple users may play together on a common mission with the activities and whereabouts of the others indicated by an awareness widget named radar view (cf. section 2.3.1 and Figure 5-8).

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[19] https://docs.google.com

[20] https://www.ea.com

Figure 5-8. Multiplayer games like EA's Battlefront use radar views (in the lower left) for coordination (Source: EA Inc.)

5.2.4 Operationalization

This section briefly describes the constructs' operationalization for the usage as part of the STANDARDIZED COORDINATION TASK ASSESSMENTS (STCA). The starting point is the stack-based model in Figure 5-9 which was introduced in section 5.2.2.1.

The part covered by the SCTA reaches from the perceptual system to coordination. Starting from the bottom, the perceptual subsystem and the cognitive subsystem were described as part of the Model Human Processor (MHP) in section 3.1.1.

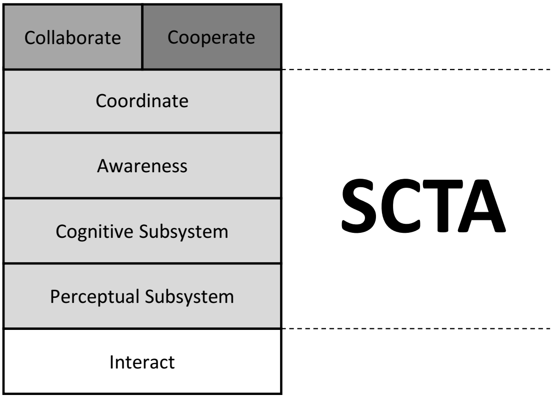

Figure 5-9. The stack-based model.

Here, the memory entities are described by the following parameters (Card et al., 1983, p.25):

- The storage capacity in items (μ)
- The decay time of an item (δ)
- The main code type (physical, acoustic, visual, semantic) (κ)

Whereas the most important characteristic for a processor is its cycle time (τ). Overall, Card et al. (1983) even published values for these parameters (cf. Appendix B). However, for assessing the effort of coordination the values alone at this level do not suffice. As mentioned earlier, the starting point for the operationalization of awareness and coordination, was the single aspect of effort as in 'effortless coordination' (Gross, 2013). Effort (cf. section 3.1.5) can be defined as "the conscious exertion of power or total work done to achieve a particular end" (Merriam-Webster, 2017). Basically, it expresses the amount of rigor and energy a user needs to spend when dealing with his secondary task knowledge which competes with the primary task knowledge for the limited capacity of the working memory. As described in section 3.1.5, effort is measured in terms of time.

In the real world, *articulation work* (Strauss, 1985) is the effort of coordination tasks and responsibilities between distributed collaborators. This type of work can be reduced by developing divisions of work, conventions and by the use of coordinative artifacts (Bardram & Bossen, 2005). As far as the stack in Figure 5-9 is concerned it reveals three *areas of effort*. An area of effort is a specific region of the construct for which the effort can be determined separately. Two of them, the secondary tasks of awareness and coordination, are in scope for the SCTA. The third one, that is the primary task or the cooperative/collaborative task, is not the main focus here but is also measured. This is due to the fact that primary and secondary task knowledge share the same memory capacity (cf. section 3.3.2) and if the secondary task affords too much effort then this could be observed in the performance of the primary task.

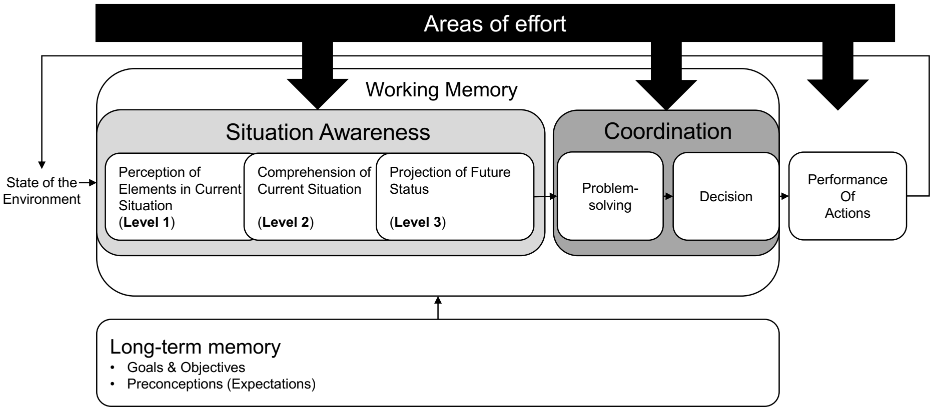

Figure 5-10. Three areas of effort: awareness (secondary task), coordination (secondary task) and the performance of actions (primary task).

The effort area of awareness covers the perception of elements, the comprehension of the current situation and the projection of future status. “When we are talking about ‘awareness’ we are talking about the phenomenon that actors align and integrate their activities with the activities of others without interrupting the current line of action and in a seemingly effortless way” (Schmidt, 2002, 2011b, p.162).

The effort area of coordination includes problem-solving and decision-making efforts (cf. Figure 5-10). “Situation awareness forms the critical input to – but is separate from – decision making, which is the basis for all subsequent actions" (Endsley et al., 1998).

The idea of how to actually measure the effort in the above-mentioned areas stems from the following quote: "These practices appear effortless because the indicators of states or state changes in the field of work and of colleagues' intentions are ready-at-hand or are easily made ready at-hand" (Schmidt, 2011b, p.194).

For the effort area of awareness, this leads to the following assumptions:

1. If I am aware about something, I can answer probe questions about it quickly and correctly.
2. The longer the answer takes, the more effort is involved.
3. The effort needed to answer the probe question is proportional to the regular effort during the task without a probe.

The assumptions basically ask for how long it takes to retrieve the respective information or to make a certain decision which corresponds to the effort in that particular area. But there is already an additional aspect in these assumptions: the quality of awareness information. Besides the effort, the fact whether the information was stored and retrieved correctly soon became another aspect for the quality of awareness and coordination. For the case of awareness, the above assumption was formulated that if somebody is aware of something, then they can answer questions about this something not only quickly (relating to effort) but also without error (relating to information quality). Quick and correct answers being an indicator of low effort as the information can be retrieved easily from the working memory. This something people need to be aware of as part of the assumption refers directly to the elements of awareness (cf. section 2.3.1). However, not all of the elements are equally important at the same time. Their importance is determined by the interdependency type (cf. section 3.2.1) of the coordination required. Consequently, this accounts for three sets of awareness elements to focus on for the interdependency types prerequisite, shared resource and simultaneity. For instance, for the type shared resource, the user requires knowledge about its availability and whereabouts while for the type of simultaneity this need is replaced by the one for current activities. These shifts in significance of awareness information requirements induced by interdependency type changes can be observed for example in instant-messaging applications (Oemig & Gross, 2007): not conversing the user relies on presence and availability information (interdependency type: shared resource). Once conversing the information shifts to a typing indicator that helps to avoid collusions in communication (interdependency type simultaneity). This shift reverses once the conversation is concluded.

Coordination and awareness are two different concepts. While awareness relates to the present and past to provide a basis for coordination, the latter is rather about the future and decision making. This has to be reflected as part of the operationalization. The core assumption regarding coordination builds again on the aspects of effort and correctness, yet, it is about selecting options for future actions. That is, for the effort area of coordination, a different set of assumptions is used:

1. If I know my options, I can make correct and quick probe decisions.
2. The longer a decision takes, the more effort is involved.
3. The effort needed to make the probe decisions is proportional to the regular effort during the task without a probe.

Getting the above information requires asking users during a collaborative task about their secondary task knowledge. The answers should measure the response time and whether the answer was correct or not.

5.3 Approach

This section describes how the operationalization (cf. section 5.2.4) is transferred into practice by using some of the ideas mentioned in section 5.2.2 while at the same time regarding the high-level requirements (cf. section 5.2.1). As mentioned in the scope description (cf. section 5.2.3) the subsequent approach only covers the interdependency type of simultaneity. This section first describes the structure of the approach and then its procedure.

5.3.1 Structure

The structure of the approach is comprised of the primary tasks, the probes and questions as well as the overall organization in runs, sessions, and traces.

5.3.1.1 Primary Task

In order to implement the questioning of subjects regarding their secondary task knowledge requires a primary task. This task is something the subjects work on in a collaborative manner as the task requires simultaneous cooperation. Inspired by the letter counting activity as part of the research on subliminal messages (cf. section 5.2.2.4), this approach uses a letter counting activity as well. A team of people is asked to jointly count all letters presented to them. This approach differs in a number of ways from the one used by Karremans et al. (2006):

- It is a shared collaborative task as opposed to a single-user task in the context of subliminal messages.
- The goal of the primary task workload is to cause secondary task knowledge and not to divert participants from outside influences like subliminal messages.
- It uses all letters of the alphabet instead of just one that is to be counted.
- The set of letters is automatically created using a random generator assuring an equivalent effort required by participants when running the experiment.
- Due to the changes to the set of letters subjects may participate multiple times in the experiment as the presented letters are always different as opposed to the task with subliminal messages.

The counting activity and the required coordination creates the mental load to be measured in terms of the effort-based operationalization outline earlier (cf. section 5.2.4)

5.3.1.2 Probes and Questions

The counting activity is interrupted by multiple freeze probes (cf. section 5.2.2.5). They focus on the user's secondary tasks, i.e., why actual counting results are not the most important aspect. The SCTA uses four dedicated question types—two concerning self-awareness and two concerning group awareness (cf. Table 5-2). The questions focus either on people or artifacts (i.e., letters) (cf. section 2.1.1). They are directed towards the past as awareness is the knowledge of the past that provides the basis for future decisions. The difference between the types SELF_WHO-GROUP_WHO and SELF_WHAT-GROUP_WHAT is the letter that is being asked for. The SELF_WHO always probes for letters a user himself has counted – hence questioning the users about their own activities. The GROUP_WHAT always questions for letters counted by another team member while the SELF_WHAT always asks for letters that have been counted by the subject being asked.

Table 5-2. Question type overview for awareness.

Question type	Focus	Time	Target	Example
SelfWhoQuestion (SELF_WHO)	Team	Past	Self-awareness	Who counted As? (counted by self)
SelfWhatQuestion (SELF_WHAT)	Artifact	Past	Self-awareness	Was the letter A counted? (counted by self)
GroupWhoQuestion (GROUP_WHO)	Team	Past	Group awareness	Who counted As? (counted by others)
GroupWhatQuestion (GROUP_WHAT)	Artifact	Past	Group awareness	Was the letter A counted? (counted by others)

For the case of coordination, it works in a similar way (cf. Table 5-3). Yet, there is no distinction in perspective.

Table 5-3. Question type overview for coordination.

Question type	Focus	Time	Target	Example
CoordinationWhatQuestion	Artifact	Future	Coordination	May As be counted next?
CoordinationWhoQuestion	Team	Future	Coordination	Who will count As next?

One or multiple sets (s={SELF_WHO, GROUP_WHO, SELF_WHAT, GROUP_WHAT}) of these four questions are used to query the participant—always in random order. At the time of writing the questions regarding coordination could be added as an option. No two users are asked the same questions, since all questions have to be personalized to the respective participant (at runtime) always taking into account current counting results.

The questions are generated by the engine fully automated based on previous counting results and on an individual basis as the questions rely on the perspective of the individual user: If user 1 counted As, then it is user 1 self-awareness that s/he did. At the same time, it is user 2 group awareness as s/he did not count the letter.

The questioning engine records the response times and determines the correctness of the answers. After answering the freeze questions, the team continues with the primary task until they are interrupted again by another freeze probe. The number of freeze probes is configurable, yet the number of freeze probes is typically set to at least three.

5.3.1.3 Runs, Sessions, Traces

The assessments are organized in runs, sessions, and traces:

- Run: a single counting task with a configured duration where a version of a prototype is evaluated with a set of users. A run is interrupted by a configurable number of freeze probes (cf. section 5.3.2.2).
- Session: a set of multiple runs using the exact same prototype. The results are aggregated and displayed as circle inside the 4I diagram (cf. section 5.4.2).
- Trace: a set of multiple sessions. While each session represents a certain version of a prototype, the trace depicts the evolution over time as each session may employ another increment. Thus, a trace visualizes the evolutionary path of a prototype and its corresponding hypotheses.

5.3.2 Procedure

The SCTA procedure consists of the stages preparation and sign up, counting and probing eventually followed by the aftermath (i.e., clean-up and analysis).

5.3.2.1 Preparation & Sign-up

Before any user can start with the counting activity, the SCTA administrator has to create a run (cf. section 5.3.1.3) using the SCTA Administration Console (cf. Figure 5-11).

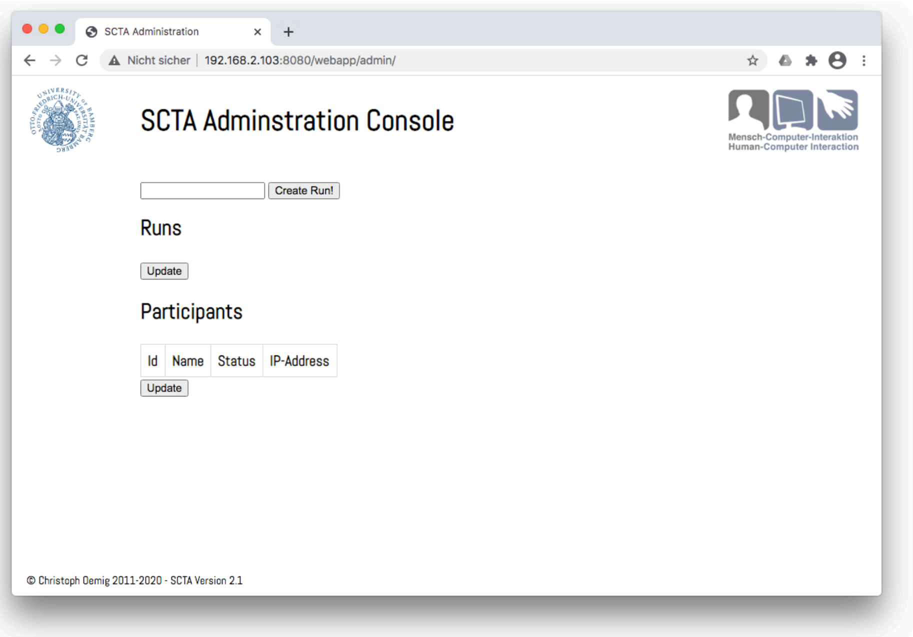

Figure 5-11. SCTA Administration Console at start-up.

Once created (cf. Figure 5-12) the new run appears in the run list of the SCTA Administration Console. The run is still not open to participants as the administrator needs to open it using the button in the action column.

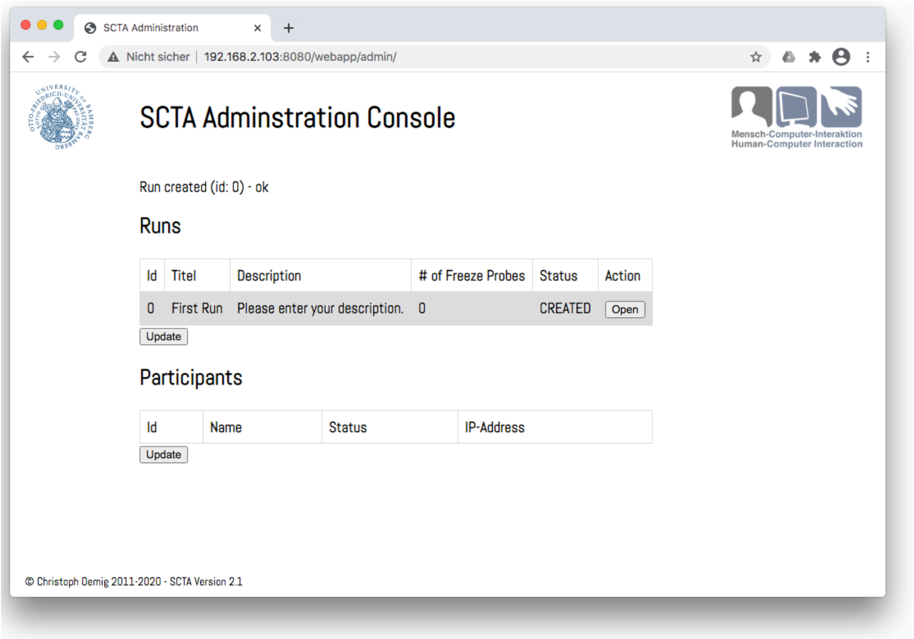

Figure 5-12. First run created, not yet opened.

While not open participants accessing the SCTA Participant view are shown the “no-run available wait screen” (cf. Figure 5-13) denoting that there is no open run currently available.

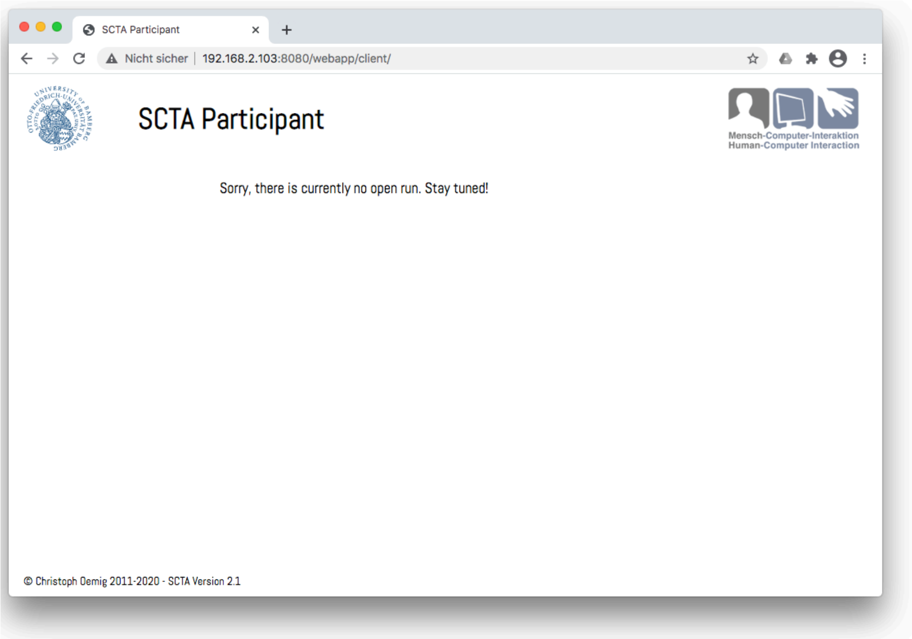

Figure 5-13. Waiting participant when there are no open runs.

Once the administrator opened the run, participants are able to sign-up for it (cf. Figure 5-14). They may choose a simple name as identifier.

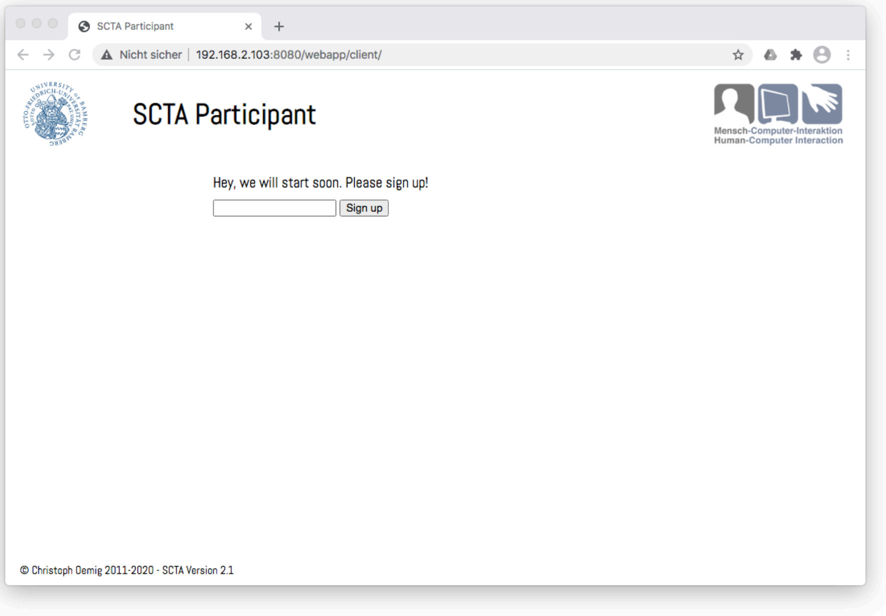

Figure 5-14. Participant registration once a run is open.

After their registration, the registered participants appear in the list for the next run in the SCTA Administrator Console (cf. Figure 5-15).

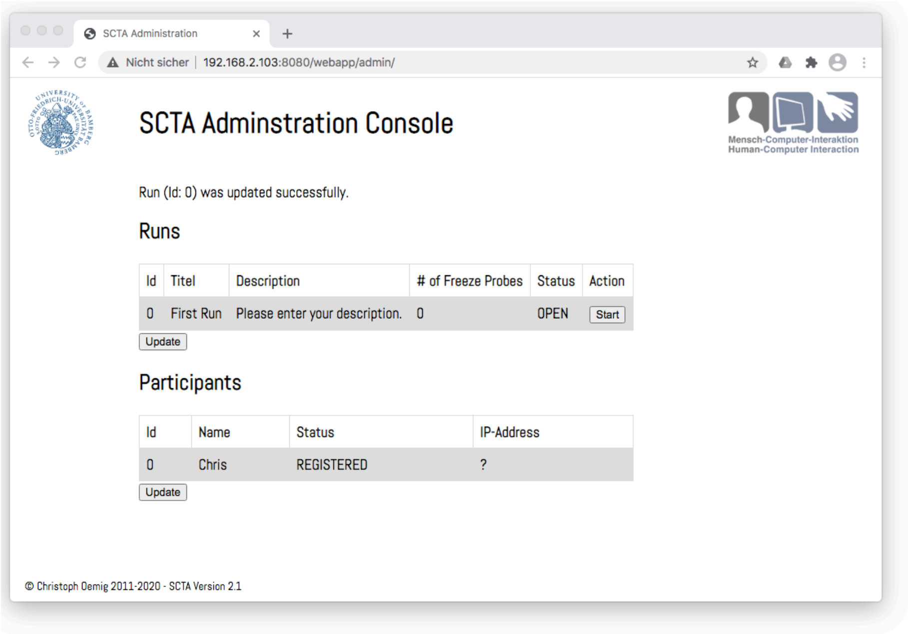

Figure 5-15. List of registered participants in the SCTA Administration Console.

Further participants may sign up to the open run until the target number of participants is reached. In the meantime, participants are shown another wait screen (cf. Figure 5-16).

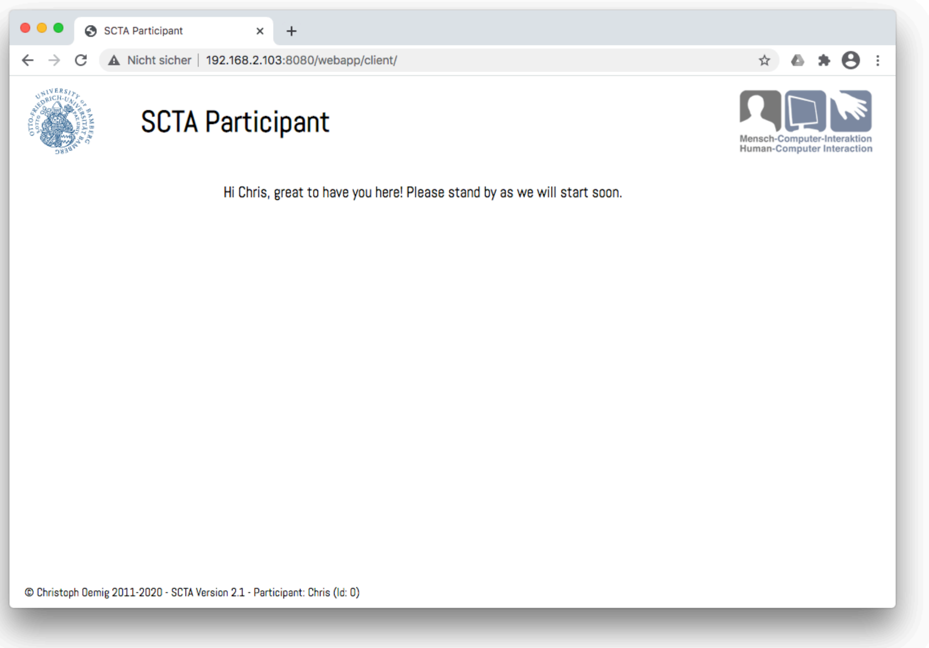

Figure 5-16. Another wait screen shown to registered participants when the opened run has not started, yet.

All participants registered appear in the SCTA Administration Console (cf. Figure 5-17)

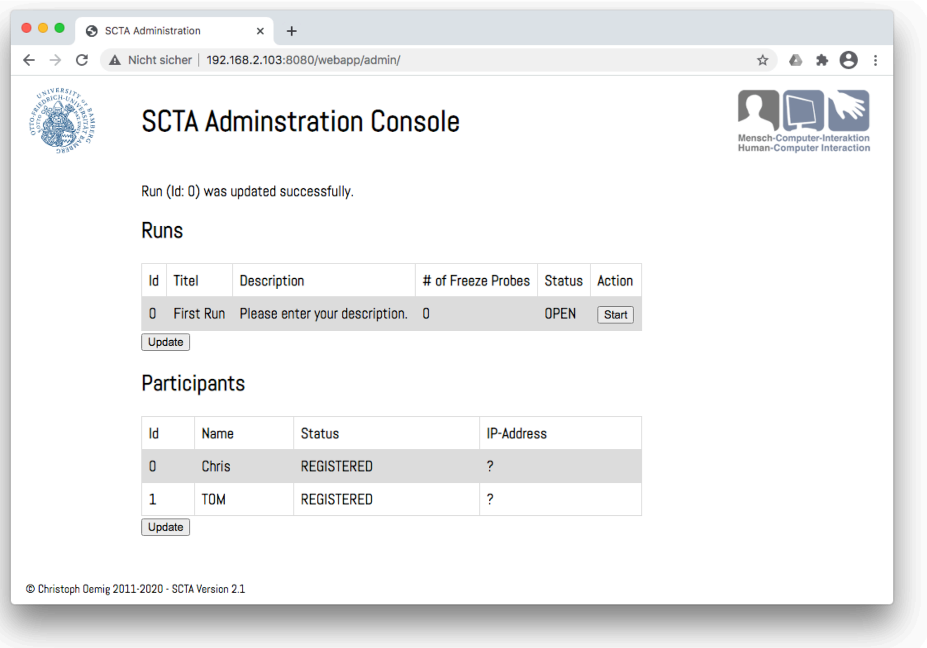

Figure 5-17. Two participants registered for the currently open run that has not started, yet.

In order to start the run the administrator needs to push the start button. After doing so, the run's status changes to RUNNING (cf. Figure 5-18)

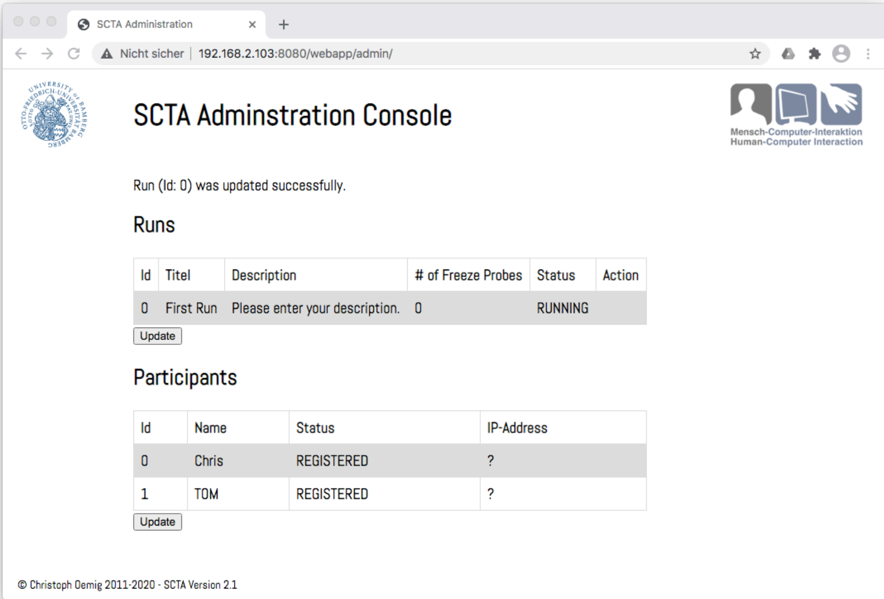

Figure 5-18. Run started in the SCTA Administration Console.

5.3.2.2 Counting and Freeze Probes

Once the run was launched, the so-called document screen is show to all participants (cf. Figure 5-19). This screen has a small section at the bottom where participants can enter their counting results. Depending on the setup of the run, further input options may be present, for instance, capturing the intention of the participants (e.g., "I will count Ds next."). Another part not shown in Figure 5-19 is the coordination or awareness support system under test implementing a certain hypothesis. For instance, an additional window may be shown listing the counting results that other users typed in at the bottom of their screen. This is where the ideas of researchers and developers start in implementing new features or concepts as awareness or coordination support system.

The number of letters shown is a configuration value. It is usually changed depending on the size of the group working on the task.

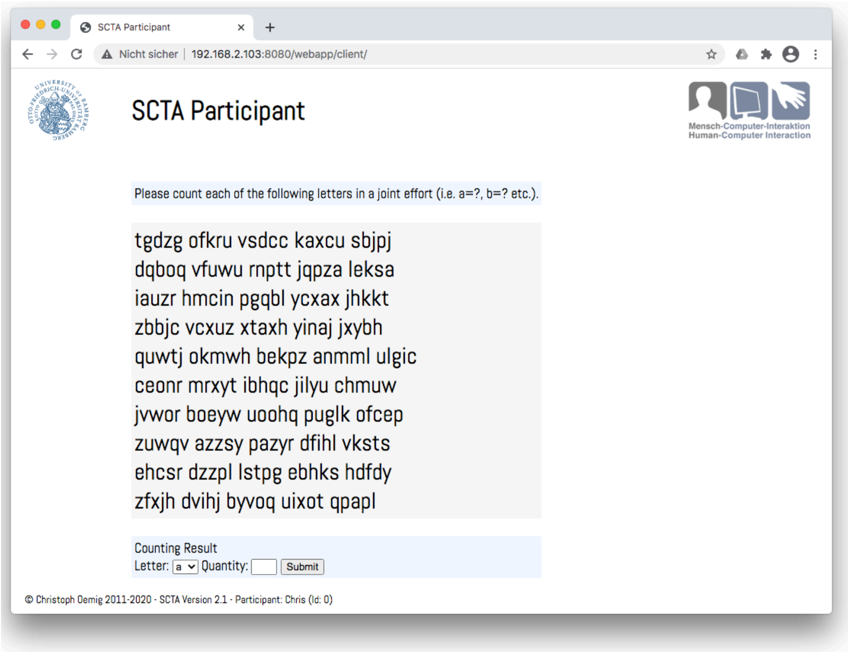

Figure 5-19. Document screen showing the counting task to the participants who joint the run.

After a configurable duration, the run switches into the freeze probe mode, presenting personalized question to each participant (cf. Figure 5-20). The questions (cf. section 5.3.1.2) being asked are created by the question engine. They query the participant about his status and knowledge regarding the collaborative task at hand.

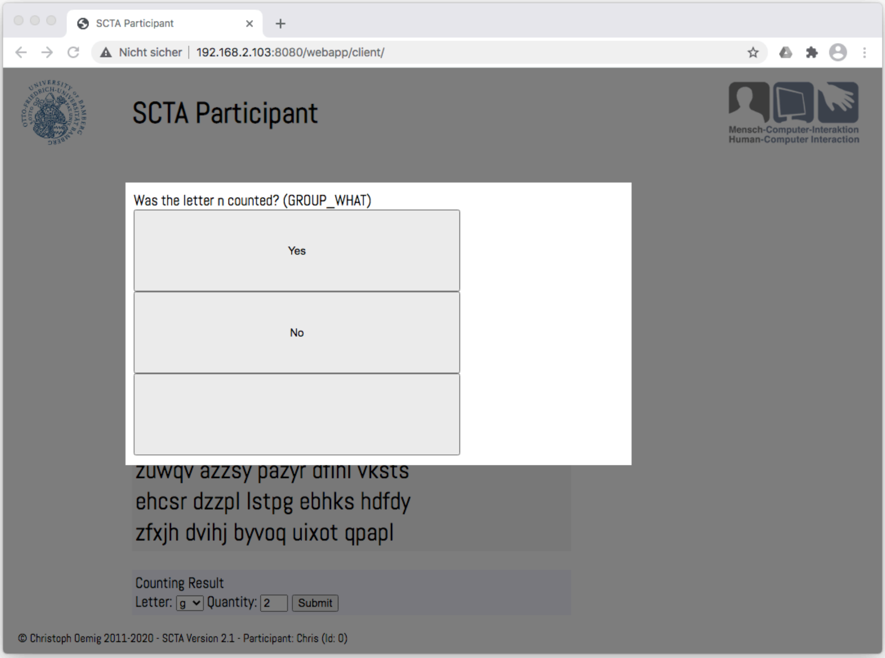

Figure 5-20. Freeze probe using a GROUP-WHAT question.

Freeze probes can also be seen from the SCTA Administrator Console (cf. Figure 5-21).

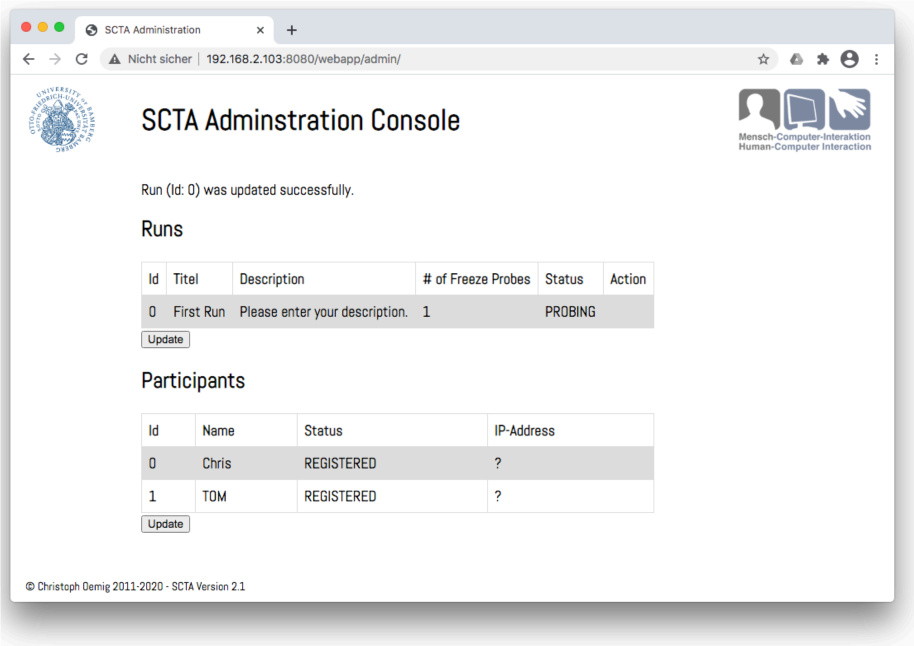

Figure 5-21. SCTA Administrator Console during a freeze probe.

Further question types of the question set (cf. section 5.3.1.2) are asked during the freeze probe using a random order (cf. Figure 5-22).

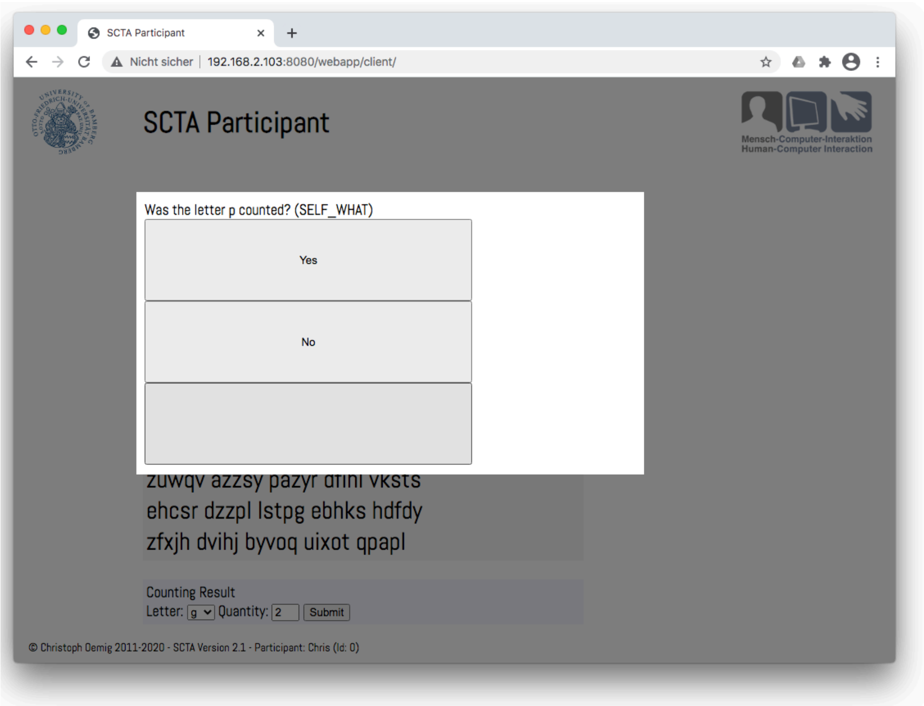

Figure 5-22. Freeze probe question SELF-WHO.

After finishing all questions of the probe, the participant is shown another wait screen (cf. Figure 5-23) that serves to synchronize activities as some participants might answer the questions quicker than others ready to continue the counting task while the remainder of the group is still busy answering the questions of the freeze probe.

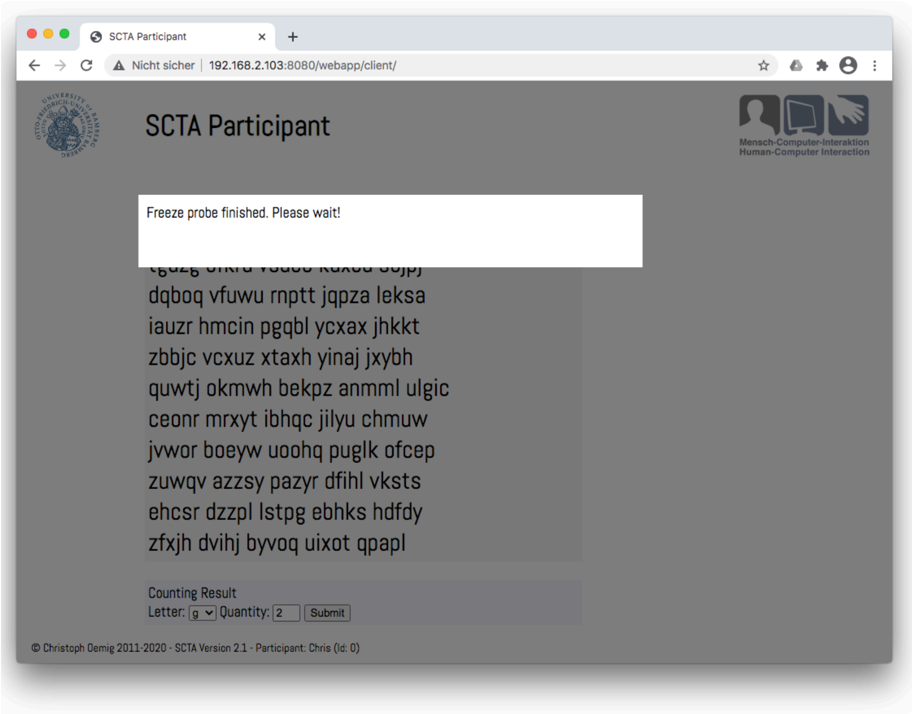

Figure 5-23. Participant finished the questions and needs to wait for the other participants to finish as well.

Once synchronized, participants resume the counting task using the document screen and the provided awareness and/or coordination support facilities. As mentioned before, the number of freeze probes is configurable as was as the overall duration of the run. Once every participant has completed the questions from the last freeze probe, the run is over (cf. Figure 5-24).

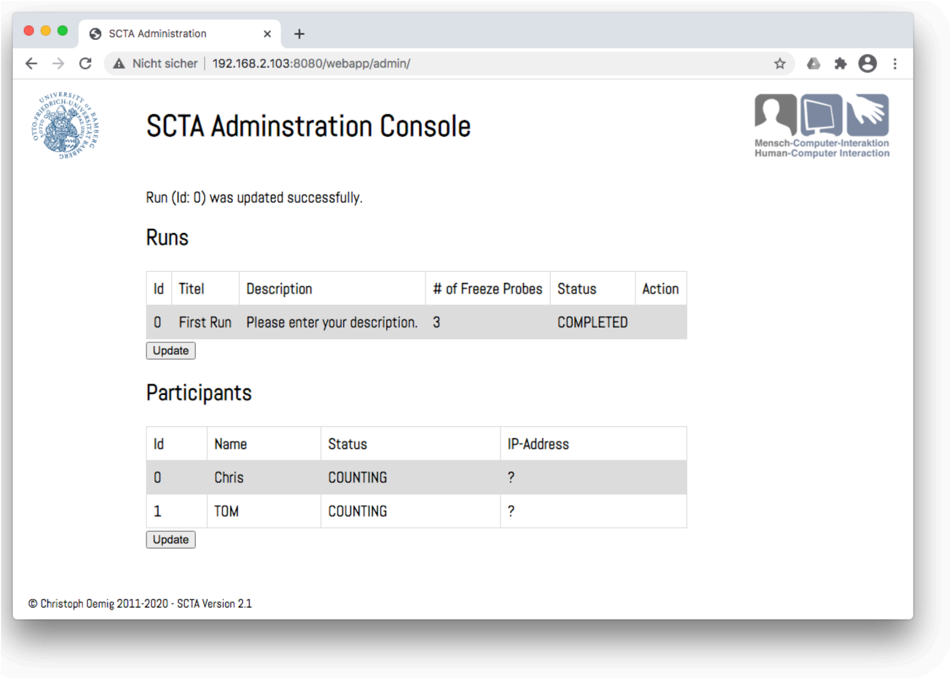

Figure 5-24. Run completed.

5.4 Means of Analysis

The above operationalization allows to derive different means for analyzing the data collected by SCTA runs:

1. Key Performance Indicators
2. The 4I-diagram
3. Patterns

5.4.1 Key Performance Indicators (KPI)

Having operationalized awareness and coordination the way as described in section 5.2.4 allows to derive a number of KPIs that may be used for further analysis or benchmarking.

Response-Forget Ratio (RFR)
Average response time/forgetting time ratio is defined as the arithmetic mean of all response times of all runs belonging to one session in relation to the configured forgetting time. It is derived from the response data.

$$RFR = \frac{\frac{1}{n}\sum_{r=1}^{n} responsetime_r}{forgetting\ time}, \{r_1 \dots r_n\} \in s$$

Error Rate (ER)
The Error Rate (ER) is defined as the quotient of the total number of incorrect answers of all runs belonging to one session divided by the total number of all answers of all runs belonging to the same session. It is derived from the response data.

$$ER = \frac{\sum_{r=1}^{n} incorrect_r}{\sum_{r=1}^{n}(incorrect_r + correct_r)}, \{r_1 \dots r_n\} \in s$$

Coordination Error Rate (CER)
The Coordination Error Rate (CER) is defined as the arithmetic mean of the number of multiple counts of the same letter by different users divided by the number of all letters counted per run. It is derived from the count data.

$$CER = \frac{1}{n}\sum_{r=1}^{n} \frac{multi\ count_r}{count_r}, \{r_1 \dots r_n\} \in s$$

Performance (P)

The Performance (P) is defined as the arithmetic mean of the number of letters counted per run divided by the configured assessment run time. It is derived from the count data and configuration.

$$P = \frac{\frac{1}{n}\sum_{r=1}^{n} count_r}{run\ duration}, \{r_1 \dots r_n\} \in s$$

5.4.2 4I-Diagram

The data gathered from the assessment runs contain response times and an information about the correctness of the answer. The combination of these two aspects provides us four typical settings depicted in Figure 5-25.

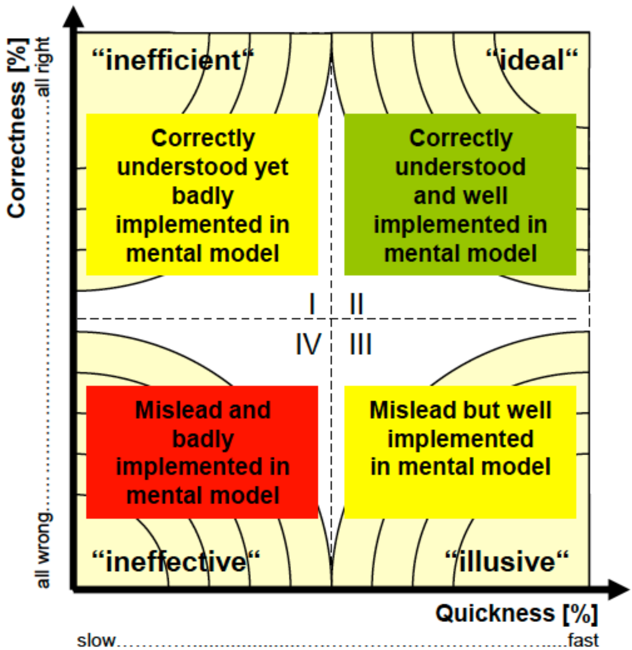

Figure 5-25. The combination of speed and correctness provides four typical scenarios provided as part of the 4I-diagram.

While one quadrant represents the desired state, the other three offer rather suboptimal cases. Each of these settings received a distinct headline:

- Ideal: in this case the users provide quick and correct answers as the knowledge appears to be well implemented in their mental model.
- Inefficient: while still answering correctly, it takes the users a long time, that is, it causes them a high effort to retrieve that information.
- Ineffective: the answers from the users come slow and are incorrect indicating that they have been misled by something and it is also hard to retrieve that information from memory.
- Illusive: in this case the users provide quick but all wrong answers. The retrieval obviously causes low effort but they have been misled by something completely.

Since all quadrant titles start with the letter "I" the diagram is also referred to as the 4I-diagram. In terms of the above-mentioned assumptions, an evaluation yields two of these diagrams: one diagram for awareness and another one for coordination. This later extends to even more when the perspective of self and others and further drill-down options are included.

The 4I-diagram is used to depict traces consisting of multiple sessions that are aggregated from multiple runs (cf. Figure 5-26) (cf. section 5.3.1.3). Thus, it illustrates the evolution of a prototype that represents a certain hypothesis.

It is important to note that the above does not tell researchers why the answers come either slow or fast or why something is correct or incorrect. It merely reflects the current state. It is left to the researcher to judge on the reasons and to evaluate different or slightly adapted hypotheses regarding awareness and coordination support to find out. This demonstrates the use of the SCTA as a comparative approach.

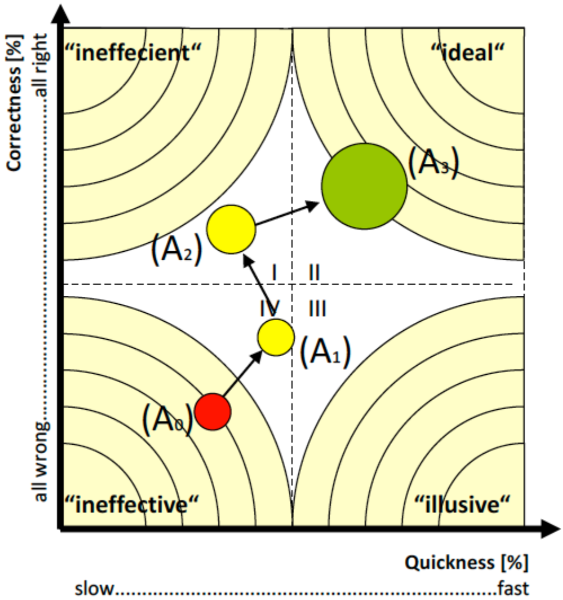

Figure 5-26. Depiction of a trace in a 4I-diagram.

5.4.3 Patterns

The 4I diagram usually depicts measurement results for self and group awareness in one aggregated value. However, as indicated in section 5.3.1.2, response time and correct or wrong answers of questions regarding the self-perspective (SELF_WHAT, SELF_WHO) can be used to calculate the x- and y-coordinates for the average self-awareness circle in the diagram. The same can be done with the answers of questions for the case of group awareness (GROUP_WHAT, GROUP_WHO). Additionally, the performance indication (circle radius) can be applied to the two circles respectively, yielding a typical set of patterns (cf. Figure 5-27).

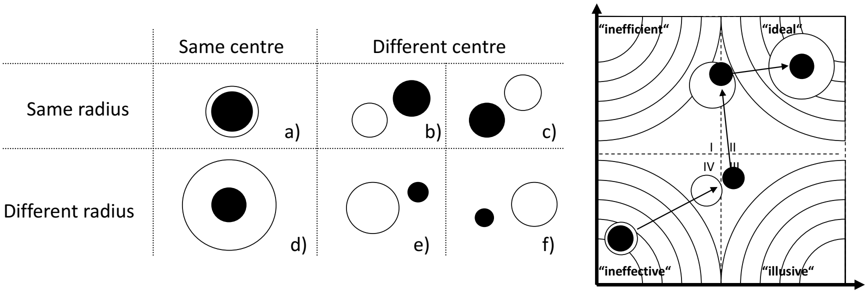

Figure 5-27. Patterns of positions and proportions depicting levels of self and group awareness.

Due to the detailed questioning concept the radius of the self-awareness circle shows the average individual performance. The radius of the group awareness circle depicts the average group performance. As a basic validation check the group's performance has always to be greater than or equal to the individual's performance (in this case with the maximum coordination error, i.e., all letters were counted by all participants). Another expected behavior is that the farer apart the circles get from one another, the more the radiuses of both are likely to assimilate. In other words: the greater the quality gap of self and group awareness becomes, the more the group's performance deteriorates—due to coordination problems. Overall, both circles together allow observing patterns of positions (circle centers) and proportions (circle sizes) (cf. Figure 5-27). Pattern a) shows no displacement but equal radiuses (eclipse) indicating severe coordination problems since individual and team performance are nearly the same, knowledge of own and other activities has the same quality; b) shows a displacement with the same circle size indicating severe coordination problems since individual and team performance are nearly the same. The knowledge of own activities is better than about group activities. Pattern c) is nearly the same as b) but with knowledge of group activities being better than about own activities. d) shows no displacement (same quality of knowledge about group and individual activities) and group performance is greater than individual performance indicating very few or no coordination problems. e) contains a displacement (knowledge quality about individual activities better than about group activities) and group performance greater than individual performance indicating minor coordination problems. Eventually, f) shows a displacement (knowledge quality about group activities better than about individual activities) and the group performance greater than individual performance indicating minor coordination problems.

5.5 Implementation

The following section share some deeper insights into the implementation of the approach which originally started out as a Java fat-client which was later migrated into a web application.

5.5.1 Java Fat-Client

The SCTA Tracer (Oemig & Gross, 2012) (cf. Figure 5-28), a combination of administration console and client for participants, was developed using the Java programming language.[21] Its overall architecture works according to the mediator pattern (Gamma et al., 1994). This pattern belongs to the object-based behavioral patterns. In this pattern a central controlling instance, the mediator, promotes loose coupling by keeping the collaborating objects (called colleagues) from referring to each other directly. The mediator controls and coordinates interaction and represents the software's overall behavior. Colleagues obtain a reference of the mediator from a central registry. The mediator is responsible for sending/receiving information to/from the respective colleagues.

[21] https://www.java.com

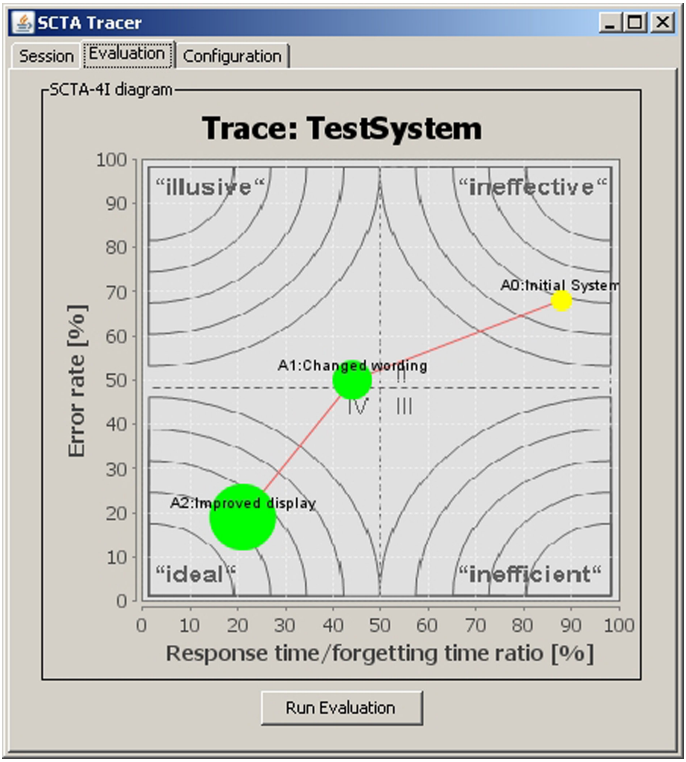

Figure 5-28. SCTA-Tracer (Java implementation).

The first to login automatically becomes the administrator of the experiment. The subsequent logins will be assigned the participant role. All participants are show in the list of the administrator screen (cf. Figure 5-29). Once a sufficient number of participants is present, the administrator launches the run.

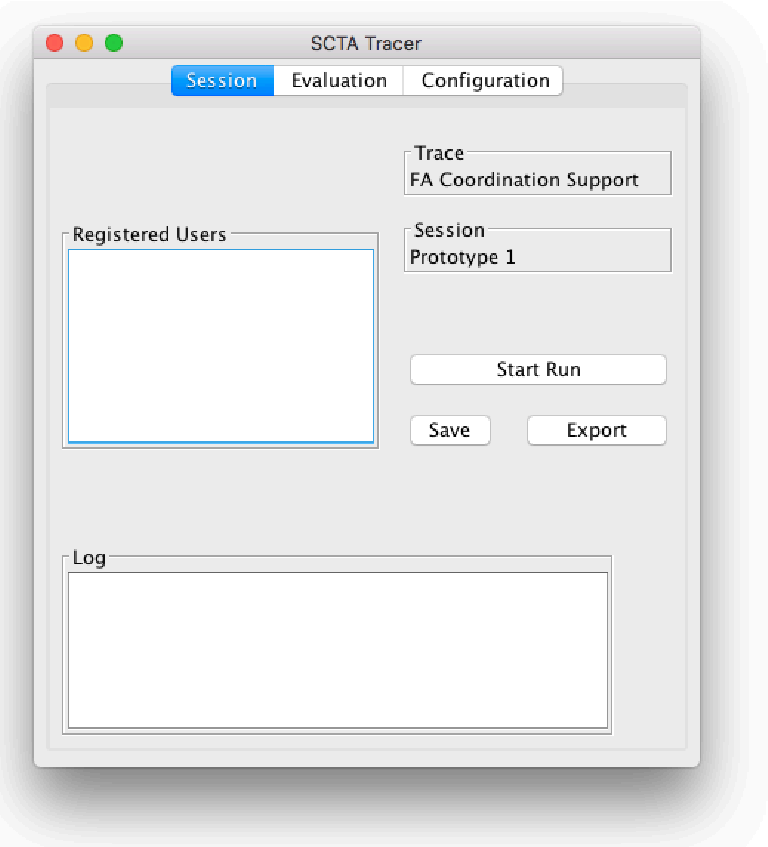

Figure 5-29. SCTA Tracer administrator screen.

Once launched participants get to see the document screen (cf. Figure 5-30) where they start with the counting activity. Also, in this implementation the counting is interrupted by freeze probes asking the already known questions from a question set. At this point of the implementation the question set only contained questions regarding awareness (cf. Table 5-2). Response times and correctness are recorded once a user answers the probe questions.

Figure 5-30. Document screen show the counting task.

5.5.1.1 Architecture

As described in the introduction, the architecture of this implementation follows the mediator patter (cf. Figure 5-31).

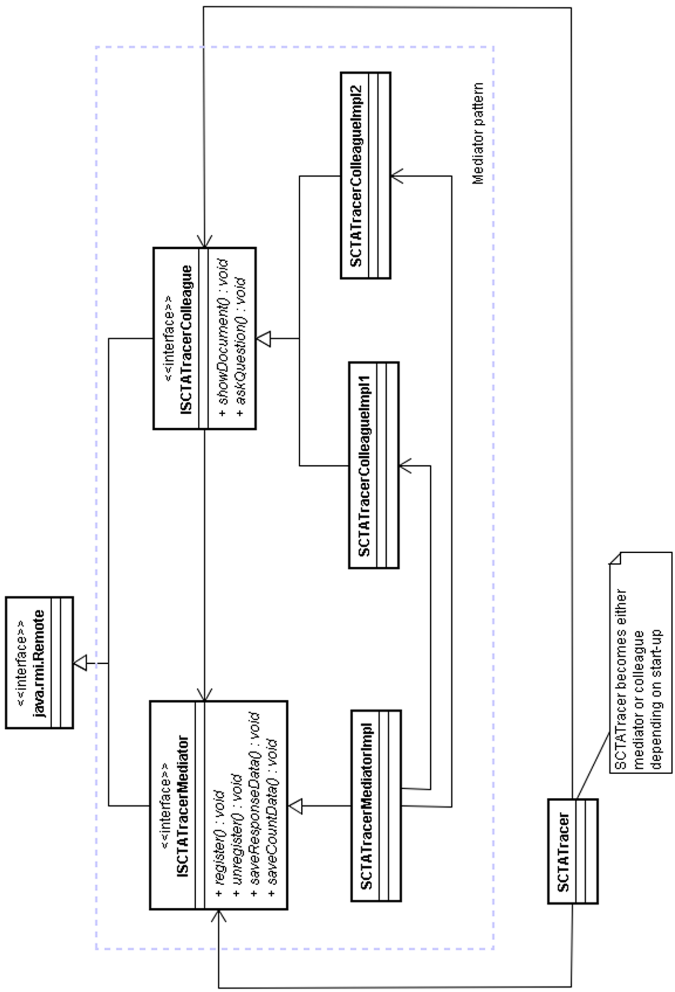

Figure 5-31. UML class diagram using a mediator pattern.

There are two interfaces named `ISCTATracerMediator` and `ISCTATracerColleague`. Java's Remote Method Invocation (RMI) was used to allow the distributed use of the software, the two interfaces are Java Remote Interfaces at the same time.

At start-up the first `main()` method creates an `ISCTATracerMediator` instance of the remote object implementation (the stub) and tries to bind that instance to the name `SCTATracerMediator` in a Java RMI registry. When registered successfully, this instance launches the administration screen (cf. Figure 5-29). Further instances try to do the same, but their registration as `SCTATracerMediator` will fail, due to an already registered instance. Therefore, these further instances will create objects of the `ISCTATracerColleague` interface. These colleague instances obtain a mediator reference using a RMI registry lookup. Now they are able to use the mediator's `register()` method to place their remote interface references there. Thus, the setup of the mediator pattern is complete. In the following the colleague instances setup the wait screen for their users. The mediator controls the colleagues using the `ISCTATracerColleague` interface – for instance, when the assessment run starts, questions of the freeze probes are to be shown, or when the assessment run is over. The colleagues use the `ISCTATracerMediator` interface to (un-)register for assessment runs, to send counting results, and to answer freeze probe questions.

5.5.1.2 Persistence

For the initial version of persistence, a lightweight approach know as XML data binding was selected. This allowed accessing XML data using objects rather than using DOM or SAX. The Java Architecture for XML Binding (JAXB) allows mapping Java classes to XML representations. It provides two main features: the ability to marshal Java objects into XML and the inverse, that is to unmarshal XML back into Java objects. JAXB allows storing and retrieving data in memory in any XML format, without the need to implement a specific set of XML loading and saving operations. JAXB is part of the Java SE platform.[22]

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[22] https://www.java.com

The storage format was defined as XML Schema (cf. Figure 5-32). The plan was to use one XML file per assessment trace. Therefore, it became out top-level element in the schema. It only has a name attribute. A trace element may contain multiple session elements, which also have a name attribute. The session element may contain multiple run elements. A run element holds the information about the participating users, counting information and response data from the freeze probes.

The binding compiler `xjc` is used to generate a set of Java classes that represent the schema. These classes are filled by the application with the data collected. When the administrator chooses to save the current status of the trace then this data structure with its top-element class Trace is handed over to the Marshaller object to create the XML file. On the other hand, at application start-up an existing XML file can be chosen from which the Unmarshaller object creates a data structure to be used by the application.

5.5.1.3 Charts

Pushing the button "Run Evaluation" on the evaluation tab (cf. Figure 5-28) creates a 4I-diagram using an extended version of JFreeChart[23]. It is an open-source Java framework allowing the creation of complex charts of various types like XY charts (line, spline, and scatter), pie charts, Gantt charts, and bar charts (horizontal, vertical, stacked and independent). Besides the creation of charts, JFreeChart allows the placement of various markers inside the resulting diagrams. However, in the case of the 4I-diagram custom chart was needed. Fortunately, JFreeChart proved to be easily extensible for this situation also due to the availability of its source code. Error rate and response time/forgetting time ratio are used as standard x- and y-coordinates. However, the need to influence an item's diameter and color by the values of performance and coordination error rate required customization. Additionally, an individual label was needed for each item of a series to be shown while standard JFreeChart allows only

23 https://www.jfree.org/jfreechart/

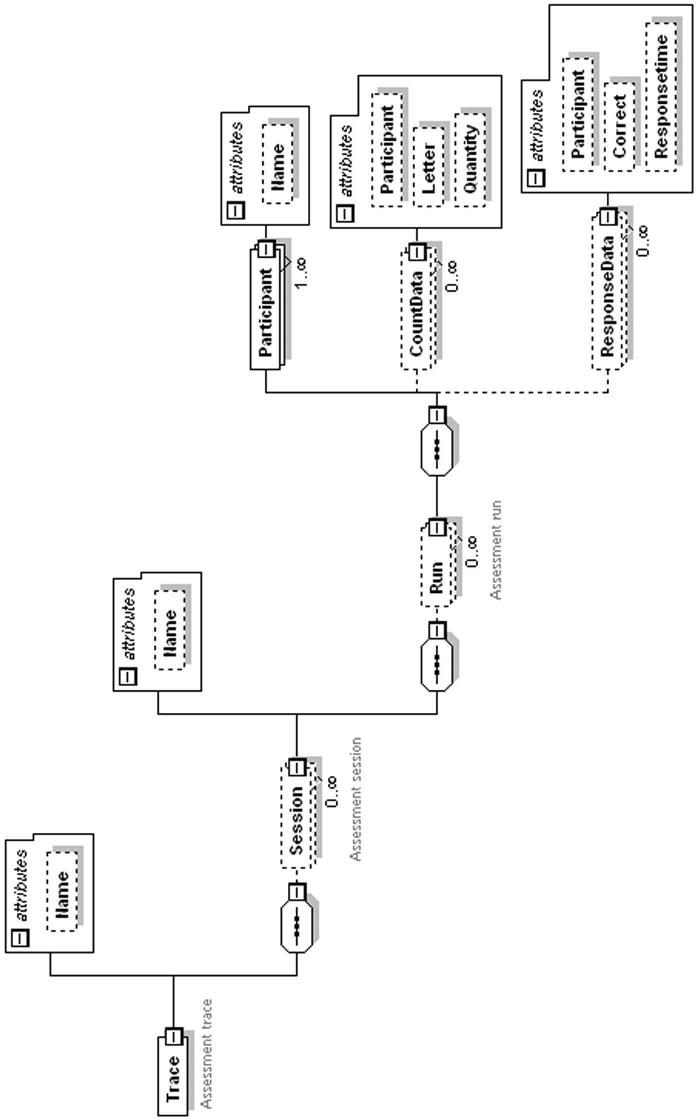

Figure 5-32. Trace structure (XML Schema).

labels per series (which corresponds to an assessment trace; a series of items corresponds to an assessment run). First, a new dataset type was defined that is able to contain all four measures per item (i.e., a 4-tuple, or quadruple) in addition to a session label. This dataset, named `SCTADataSet`, extends JFreeChart's `XYDataset`. In order to deliver the data on the screen a custom renderer needed to be defined that displays the dataset's content as 4I-diagram. The `SCTARenderer` extends JFreeChart's `XYLineAndShapeRenderer` class to do the job. The generation of proper labels required a customized `SCTAItemLabelGenerator`. The JFreeChart object is finally added to a standard Java Swing container.

5.5.2 Web Application

The Java fat-client implementation had a couple of major disadvantages.

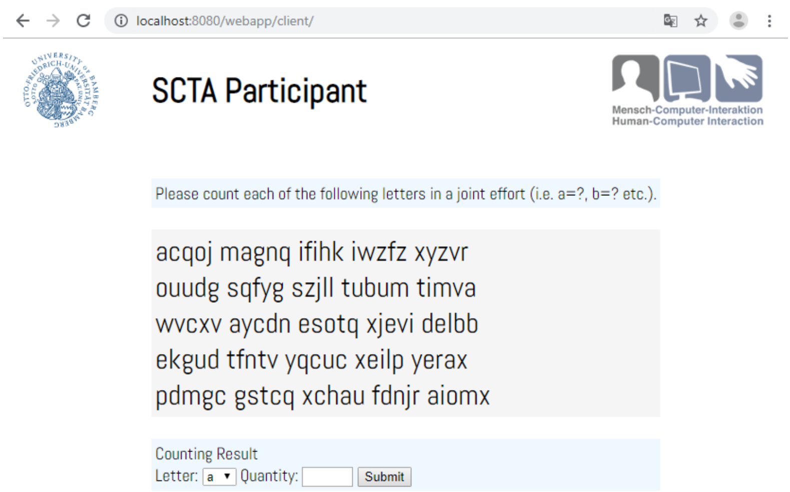

Figure 5-33. REST-based implementation showing the DocumentScreen.

It was hard to install at a site to conduct experiments as it required the installation of software (Java runtime, SCTA Tracer etc.). Another problem was that it only could be run on PCs or comparable IT devices. For instance, it was not possible to run the SCTA Tracer on a smartphone. That was also the main reason why its front-end implementation was eventually replaced by a web-based application (cf. Figure 5-33). Overall, this made the setup at an external site extremely easy. Typically, a smartphone was used to setup a mobile hotspot. The Internet connection was not needed but every device connecting to the hotspot thus became part of a spontaneous shared WLAN. Participants could connect with their own devices or with locally provided ones. They only required a current browser on their machine or device (cf. Figure 5-34).

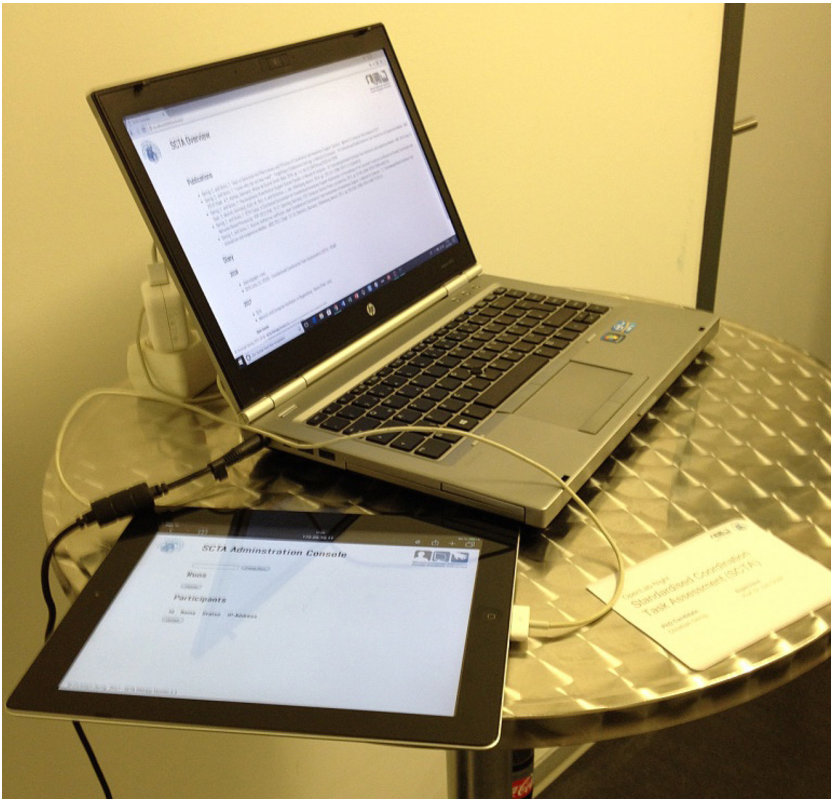

Figure 5-34. Web-based application running on different device types.

The administration console was usually run from a tablet as it was easier with it to move around and maybe assist with connection problems. Thus, the entire issues with software installations, configurations and firewall connections could be avoided. The only problem were older PCs that did not have a Wi-Fi connector.

5.5.2.1 Architecture

The architecture reused many former components, especially the questioning engine. These components were wrapped by an API layer which provided the access to the core components via RESTful webservices. The front-end was replaced completely with a single-page application (SPA) using a new JavaScript library based on JQuery[24]. The former mediator pattern was completely removed.

5.5.2.2 Persistence

The persistence layer described in section 5.5.1.2 remained unchanged.

5.5.2.3 Charts

The JFreeChart library cannot be used inside a browser. Therefore, it was replaced by GoogleCharts[25] which seamlessly integrates with JavaScript.

5.6 Solution Evaluation

According to (Oulasvirta & Hornbaek, 2016) the outcome of research (i.e., the solution) can be evaluated in terms of its contribution to problem-solving capacity which is defined by following five criteria:

1. Significance: means that an approach addresses a problem that is important to the stakeholders of the research. The significance of the presented approach was derived from literature as shown in the early chapters of thesis and by publishing papers to peer reviewed conferences (cf. section References).

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24 https://jquery.com

25 https://developers.google.com/chart

2. Effectiveness: refers to the solution being able to solve the stated problem. This foreshadows the closing chapter of this thesis, but the presented approach found a way to measure efforts related to coordination and awareness thus providing a way to maybe reach effortless coordination one day.
3. Efficiency: refers to the cost of applying the solution compared to the gain. This is a part where the SCTA especially stands out as it uses a very low-cost procedure that is highly scalable and which provides decent results (as to be demonstrated in the next chapter).
4. Transfer: refers to the fact how well the solution transfers to other problems of the same kind. This is also a capacity the approach developed in this thesis is very good at (as to be demonstrated in the next chapter). The SCTA can be applied in various scenarios and settings where dealing with a standard primary task to learn something about the secondary (e.g., effects of disruption, forgetting, switching contexts or dynamic awareness support). With further coordination games for the interdependency types of shared resource and prerequisite, the approach may be applied to even more problems.
5. Confidence: deals with the concerns about a method's reliability and validity. Reliability, i.e., the consistency of measurement can be proven in several ways, for instance, by test-retest or split-half reliability (Sauro & Lewis, 2012). This was done and recorded basically on every occasion as a warm-up activity using the test-retest method. Once more results become available, the reliability method will be switched to Cronbach's alpha coefficient (Nunnally, 1978). On the other end, the validity, i.e., the measurement of the intended attribute can easily be observed with the numbers for the effort going up when the counting task is made more complex, that is, by introducing larger syllables which are harder to remember. This correlation can be reproduced easily, yet, it remains to be mathematically proven.

5.7 Summary

This chapter introduced the Standardized Coordination Task Assessment (SCTA). It described its rationale, the concept starting with the high-level requirements and the ideas that influenced its creation. The transfer of the awareness and coordination constructs was described as part of the operationalization which uses simple questions to query a subject about his/her knowledge on the primary task at hand. The overall procedure was outlined followed by an overview of the means of analysis. Further, this chapter provided some insights of the implementation of this approach before eventually closing with a brief evaluation of the solution.

The SCTA is a simple and powerful tool that opens the door to many research issues related to CSCW's overall goal of effortless coordination. It is the first approach that truly allows to measure these and to put them in perspective with other measurements, thus allowing to approximate the most minimal effort possible.

6 Application, Experiments and Extensions

This chapter presents a number of sample experiments to demonstrate the capabilities of the approach.

6.1 No Support

This is a special type of test as it does not provide any type of awareness or coordination support. It uses a co-located setup (cf. Figure 6-1). Participants are simply explained the task and may talk to one another on how to proceed with the task in which they eventually engage in. They receive a standard counting task with three freeze probes.

There are many reasons to use this kind of procedure:

1. At the beginning it was a test for the overall procedure. It could be observed how well participants get along with the provided tools and the provided task. Thus, little misconceptions could be fixed very easily. Another important aspect was the sizing of the task itself for a certain number of people and finding an appropriate duration for the task.
2. Observations: in this scenario the actual engagement in the task was not in focus but how people actually communicate and negotiate (also in terms of group dynamics, cf. section 2.2.2). Of special interests were also the strategies participants used as a common ground to solve their tasks. These observations are helpful for designing initial awareness and coordination support mechanics. That is, this procedure can be used for hypothesis generation as well.
3. Calibration and reliability testing: this procedure was also used to discovery how the approach behaves in terms of reliability (consistency of measurement) and which configurations are the most appropriate for testing.

Figure 6-1. Simple assessment setup at the Mensch und Computer 2017 conference in Regensburg (Oemig & Gross, 2017) (Source: Christoph Oemig).

6.2 Forgetting of Secondary Task Knowledge

Another example of the approach's application was the experiment on forgetting regarding secondary task knowledge (Oemig & Gross, 2016). The difference between the forgetting of primary and secondary task knowledge is an issue that has not been researched at all, as appropriate measurement approaches were missing.

The human memory and its subsystems have had a strong influence on Human-Computer Interaction (HCI) research and resulting systems. This was especially shown with the sections on cognition where the Model Human Processor (MHP) was discussed (cf. section 3.1.1). As also shown, the working memory plays an important role as it is limited by its capacity (cf. section 3.3.2) which is even shared among primary and secondary task. On the other end, forgetting was shown to be a natural mechanism to face this limitation (cf. section 3.1.3). In other computing contexts, forgetting algorithms were designed for a wide range of purposes, for instance, they help filtering instant messages (Seifert et al., 2007) or facilitate the calculation of interest curves as part of recommender systems (Chen et al., 2014). Forgetting even became a core feature of the currently popular social app SNAPCHAT[26] (Bayer et al., 2016). Here, it contributes the major incentive to conceal personal information.

Forgetting curves (cf. section 3.1.3) illustrate the memory's retention over time. Yet, collaborative settings have never been analyzed using forgetting curves. These settings are known to introduce the secondary task of coordination right next to the primary task itself. Consequently, the capacity of the working memory is not only limited but has to be shared among primary and secondary task knowledge. However, rehearsing, as Ebbinghaus (1885) suggests, is not an option here. Additionally, interruptions and interferences have a devastating impact on its recall (cf. section 3.1.3). The general idea in this experiment was to gain a solid understanding of forgetting in collaborative settings. These insights may help with the design of collaborative systems and coordination support systems.

6.2.1 Approach

Ebbinghaus (1885) himself never considered secondary task knowledge as he was not dealing with cooperative systems. Creating secondary task knowledge requires a collaborative task. For primary and secondary task knowledge the approach needs to measure how much of each knowledge type is lost over time. The result will be depicted as forgetting curve (one for each type of task knowledge). To gain even deeper insights the secondary task knowledge can be subdivided into knowledge about a user's own activities and the knowledge about the activities of others (cf. section 5.4). The SCTA helped to provide the primary task for this experiment. A group of participants has to count individual letters inside a shared document. During the task the group has to coordinate its counting efforts. The participants are also required to share their results with the group. These are recorded using the letter, timestamp, and participant name. To determine

[26] https://snapchat.com

the status of forgetting the counting task was suspended to query each participant. As in the original SCTA approach, the questions are based on the recorded counting results. Here, the participants were asked to complete a list of letters stating how many of a certain letter were counted (primary task knowledge) and by whom (secondary task knowledge). To make it more difficult the list also contained letters that were not counted at all (secondary task knowledge). Since the results also recorded who originally counted the letters, the list of answers returned by the participants could be analyzed in terms of self and group knowledge. The regular freeze probe questions were not answered by the participants as the number of freeze probes was set to zero and an external timer was used to trigger the paper-based probes. Yet, in contrast to the original SCTA the response times were not recorded as the focus was not on effort but on correctness after a certain period of time. Another difference were also the questions regarding the primary task knowledge. This was done to be able to compare the forgetting curves for primary and secondary task knowledge. The forgetting curve diagram itself shows the percentage of correct answers on the y-axis and the time elapsed since the start of the task on the x-axis.

6.2.2 Smoke Test & Findings

For a smoke test on the entire procedure, a mixed setup was chosen using the SCTA for the counting task and collecting the results whereas the questioning was done on paper setup.

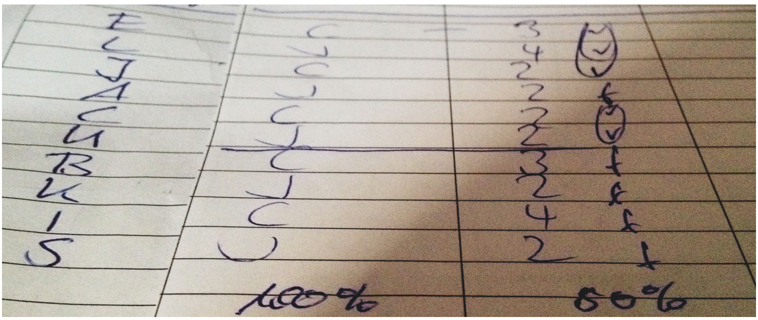

Figure 6-2. Filled questionnaire.

The reason also being to find a proper approach to be implemented at a later point in time. Four participants (age 28 to 45, 50% male, 50% female) were invited to engage the counting task in pairs. They were allowed to coordinate and to take notes. They were also expected to share their results. The times the experiment was suspended were a) in the middle of the task, b) directly after finishing the task, c) 30 minutes afterwards, and d) 2 hours afterwards (cf. Figure 6-3).

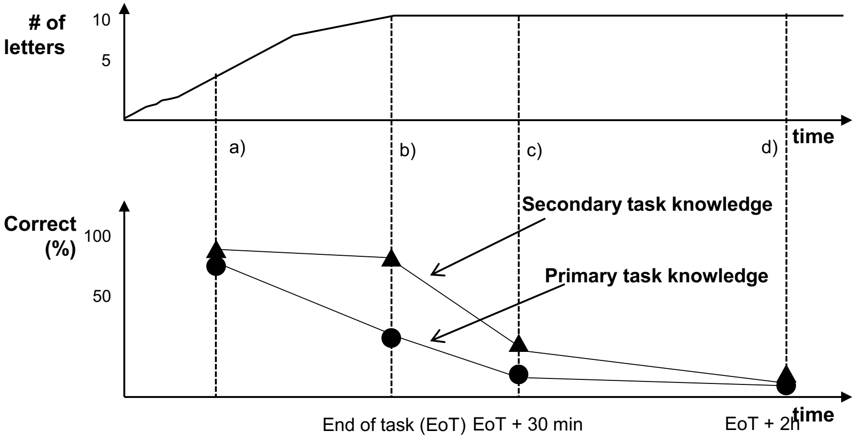

Figure 6-3. Forgetting curves for primary and secondary task knowledge.

At point a) four letters were counted. The recall of primary and secondary knowledge was the highest here. The recall of secondary task knowledge worked better than that of primary task knowledge. At point b) ten different letters were counted in total. While the recall of secondary task knowledge still worked well, there was a significant drop for the primary task knowledge. Reaching point c) the primary task knowledge was nearly gone and also the secondary task knowledge was at lower levels. At point d) both knowledge types were nearly gone.

A short interview following the test revealed that most of the participants agreed that they still knew who counted the letter but they forgot how many of them. That is, the secondary task was still there while primary task knowledge was gone. They stated that they told their partner the counting result, wrote it down and forgot about it. They had no further use for this information while the secondary task knowledge still helped them to coordinate. Another statement made by one participant regarding the secondary task knowledge was that “I knew I did not count that letter, therefore it had to be him”. This basically explains why the levels of self and group knowledge have been nearly equally high throughout the test. A larger group of participants will probably eradicate the opportunity of this kind of conclusion. Overall, taking notes obviously relieved the working memory from primary task knowledge leaving more room for the secondary. The reason for high values for the primary task knowledge at point a) is likely to be sufficient capacity of the working memory (in accordance with Miller’s 7+/- 2 chunks).

6.2.3 Discussion

This small experiment showed, that the secondary task knowledge stayed longer in the working memory than the primary task knowledge, since it was continuously useful for coordination while maintaining its small memory footprint. Yet, the experiment also revealed room for improvements: the group size for the counting task needs to be increased at least by one so that the knowledge about the group cannot be directly inferred from the knowledge of one self. Another issue not covered at this point were interruption and/or interference. As secondary task knowledge is not stored intentionally it is expected to be highly vulnerable to interruptions (cf. section 3.1.3). This also the basic idea for the experiment described in section 6.4. Overall, this experiment showed that being able to measure the impacts on secondary task knowledge sets the ground for explicitly answering the questions on how to rehearse or cue secondary task knowledge to let computer-supported cooperative work be more successful and efficient.

6.3 Going to Extremes

This experiment rather describes a classic application of the SCTA which was also done partially due to calibration purposes, that is, to learn about the approach’s behavior under extreme conditions. Doing so the awareness-/coordination-support system paradox was found (Oemig & Gross, 2014). An experiment was designed contrasting a very simplistic awareness support strategy and an automated coordination support strategy. Additionally, a control group participated with no support at all.

6.3.1 Setup

Three types of settings were defined for measuring. The first setting introduced a simple awareness support system. It implements a simple awareness strategy that notifies the user about what letter another user is about to count (i.e., their intention) and about actual counting results (shown as “awareness display” in Figure 6-4).

The second setting utilizes an automated coordination support strategy, that was learned from the “no support” experiments (cf. section 6.1): the total number of letters was simply divided by the number of participants. Each user was assigned a respective fraction thereof. Once a letter is counted it was dashed in the coordination support window (shown as “coordination display” in Figure 6-4). Thus, the user does not need to know what the others are counting. It is the implementation of an explicit coordination support system (cf. section 3.2.3) that actually coordinates the counting effort. As they have been reported as too rigid (cf. 3.3.5) at least some type of reaction was expected later to be found in the post-task interview. Yet, in terms of effort it is expected to be at a minimum in this case.

A third setting, the control group received no treatment at all. In order to avoid or minimize cofounding influences the experiment setting is selected by random for a single experiment run (i.e., the counting task). In the next step, the participants are assigned to the run randomly as well.

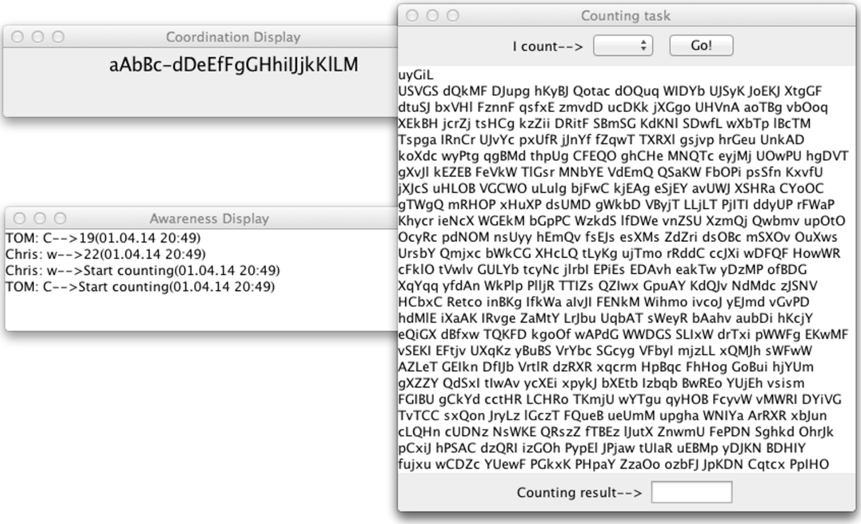

Figure 6-4. SCTA counting task (old Java client) with awareness support and coordination support show at the same time. Only one of the left-hand windows was shown to participants, depending on the group they were in.

There was a total number of 24 participants, 34% female and 66% male in a range of 17 to 40 years with the majority drawn from a computer science class (including the teacher) of a German High School. The focus was on dyads, i.e., from the total number of participants groups of two were arranged. They used individual computers separated by blinds so they could not see each other. This time they were not allowed to talk or to communicate by other means outside the provided tools. Since multiple counting tasks took place concurrently, participants did not even know with whom they were actually working (no real names were used). A counting task lasted 10 minutes interrupted by three freeze probes. These asked the participant two questions concerning group awareness, two questions concerning self-awareness and two questions regarding coordination (cf. section 5.3.1.2). Thus, a total of 18 questions had to be answered by a participant during a run. Besides the performance (total number of counted letters) the coordination error rate (duplicate letters) was measured and recorded.

6.3.2 Results

This section briefly describes some of the most important results of this type of experiment. These are derived from the response time diagram (cf. Figure 6-5) and the success rates, performance and coordination errors shown in Table 6-1.

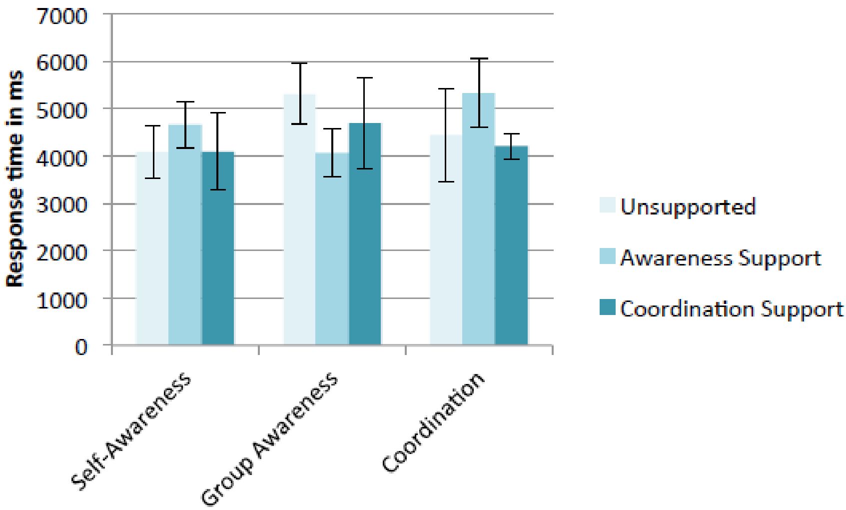

Figure 6-5. Mean response times per question area for each experiment type including standard error.

The experiment without any support type was the winner in the self-awareness category (4s, 95%) the only support participants had in this group was their knowledge about their own activities. Not surprisingly the awareness support experiment type was the most successful and fastest (4s, 75%) in the category of group awareness. Last but not least the coordination support type experiment performed best (4.2s, 95%) in the coordination category. But the most interesting lies beyond the expected, which rather proves that the approach generally appears to work.

Table 6-1. Success rates (percentage of correct answers), performance (total number of letters counted), and coordination errors (number of letters counted multiple times).

	Success Rate (%)			Performance (Avg)	Coordination Errors (Avg)
	Self Aw.	Group Aw.	Coordination		
Unsupported	**95%,**	38%,	25%	6	1
Awareness Support	88%,	**75%,**	70%	6	0
Coordination Support	75%,	63%,	**95%**	7	0

However, in the coordination category the awareness support group was not the fastest (5.2s) and created some errors (success rate 70%), which might be due to its indirect nature in supporting coordination as mentioned in the concept. Only the direct coordination support performed better (4.2s, 95%), while the results for coordination of the unsupported type suggest that the participants were simply guessing (4.5s, 25%).

Furthermore, the data suggests that the coordination support does not require the user to have superior levels of self- and group awareness. Participants answered slower and increasingly wrong but overall performed best indicating that they do not really need this specific types of knowledge. This effect was named the awareness-/coordination-support system paradox: while awareness support facilitates coordination support the latter has not necessarily a need for the former. As expected, the third setting (no support) shows the highest number of coordination errors. Yet, all types showed nearly the same overall performance. This version of the SCTA used a large number of different countable letters (whole alphabet, small and capital letters) and a large quantity of each single letter. Therefore, also the coordination errors were low requiring the reduction of the number of different letters in future experiments to provoke a larger number of coordination errors.

6.3.3 Discussion

The experiment revealed some new insights and new problems regarding the goal of effortless coordination:

- The awareness-/coordination-support system paradox: this effect described above has the consequence that when developing a coordination support system, it needs to be carefully reviewed which awareness information is still needed by the user. This adds another possibility to create more efficiency but this has to be done very carefully.
- Effortless coordination's anti-social tendency in digital systems: driving efficiency to the extreme may sacrifice social subtleties for its own purpose. Though performing best some participants mentioned that they did not like the explicit coordination support experiment type. They could not see what their partner was doing or if s/he needed assistance. Reducing efforts to the minimum also contradicts general design principles of human-work. The consequence is not only to measure response times and errors but also include means to measure satisfaction (cf. section 7.2.2). This is also mentioned as part of the mechanics of collaboration (cf. section 4.5).
- Self-awareness obviously needs no support: the unsupported experiment type actually removed all efforts concerning perception and comprehension from the user without offering a substitute. However, according to the measurement, participants performed even better in the category of self-awareness. As a consequence, self-awareness does not need to be supported releasing screen estate and other resources for other information. Yet, it needs to be verified if this remains true for more complex settings.

The experiment further created insights regarding the SCTA approach:

- The twofold letter problem: there were too many letters in too high quantities making it easy for the participants to avoid coordination errors. Further, this fact reduced the total number of letters counted since the participants spent longer times counting a single letter. This in turn reduced the effort needed to coordinate the situation. As a consequence, future experiments have to dramatically decrease the number of letters and their quantities.
- Don't know/don't care answer options: Another point mentioned by participants was that for some questions they would prefer an "I don't know" answer option instead of being forced to some other answer. This can also be derived from the results: the "I don't know" answers are those where there is a quick wrong or deliberate answer while producing an overall high performance. However, it needs to be discussed if an "I don't know" answer is sufficient or if an "I don't care" needs to be introduced as well since some of the knowledge is really not needed as the found paradox implies.
- Freeze probes killing counting results: Another aspect mentioned by participants is that the freeze probes prevented them sometimes from finishing their counting. Since there were only a few letters counted but those at high quantities this might have a large impact which can be avoided by smaller quantities for each letter and again reducing the number of letters overall.

6.4 Effects of Disruption on Secondary Task Knowledge

This section reports on another experiment (Oemig & Gross, 2019) which especially aimed to expose secondary task knowledge to disruption to study the effects. Secondary task knowledge is stored subconsciously and due to its ephemeral nature, it is easily compromised by interruption and interference which cause information to be lost (cf. section 3.1.3). Related work suggests a strong effect of interruptions on a collaborative task due to the impact on the secondary task knowledge located in the working memory. Yet, the major effort of scientific work focused on minimizing the disruptiveness (Cutrell et al., 2001), i.e., finding the right time and manner for interruptions, or understanding the role of context on the cost of interruption (Mark et al., 2008). However, from a SCTA perspective interruptions can hardly be avoided or optimized entirely. The approach rather seeks to support the finding of new ways helping users to recover the best way possible from various types of interruptions during their collaborative task using appropriate support mechanisms and cues. As there are different types of interruptions (some of which we introduce later) this at least calls for adaptive coordination or awareness support mechanisms (cf. section 2.3) as a counter measure.

This experiment used the SCTA method where participants are provided a standard letter counting task and they are queried using a specific set of questions to assess the status of primary and secondary task knowledge by determining and recording levels of correctness and speed related to these questions. In addition to that, observations during that experiment revealed different modes of recovery and social nuances on how participants dealt with the results of interruptions. These insights will serve as the basis for the next series of experiments evaluating different ways to restore secondary task knowledge after interruptions depending on the type of interruption thus informing the design of adaptive coordination support systems.

6.4.1 Approach

Gaining a deeper understanding of the impacts of disruption on a participant's secondary task knowledge requires its measurement before and after these interruptions. Assessing the process and state of recovery requires at least a third measurement. Additionally, an appropriate primary task is required in order to create a need for coordination that in turn creates secondary task knowledge that can be observed and assessed as part of a standardized assessment. That is, what the SCTA is used for in this scenario.

8 participants (age 29 to 47, 6 males, 2 females) were invited to engage in the counting task in pairs. In terms of variables, four types of interruptions were used as independent variable and observed their effect on the secondary task knowledge (dependent variable). The four types are based on the two dimensions of duration and interference (retroactive interference, cf. section 3.1.3):

- Scenario 1 uses a short interruption with no interfering content (i.e., content not related to another counting task).
- Scenario 2 draws again on a short interruption but this time with interfering content.
- Scenario 3 introduces a long interruption with no interfering content, while
- Scenario 4 again uses interfering content in combination with a longer interruption.

The participants were collocated in one room and were allowed to take notes and to share their results verbally, but neither their screens nor notes. The overall duration of one experiment was limited to four minutes counting time (plus the time required by the freeze probes and interruption that varied in length). The text to be analyzed covered 250 characters. Three freeze probes were configured: one before the interruption to capture the pre-interruption state, one after the interruption to capture the post-interruptions state and one shortly before the end of the task to learn about the recovery state of the interrupted participant (cf. Figure 6-6). Each run of the experiment started with a briefing, followed by the counting task which was concluded by a short interview of the participants, asking them how they experienced the task. A short debriefing finalized the experiment.

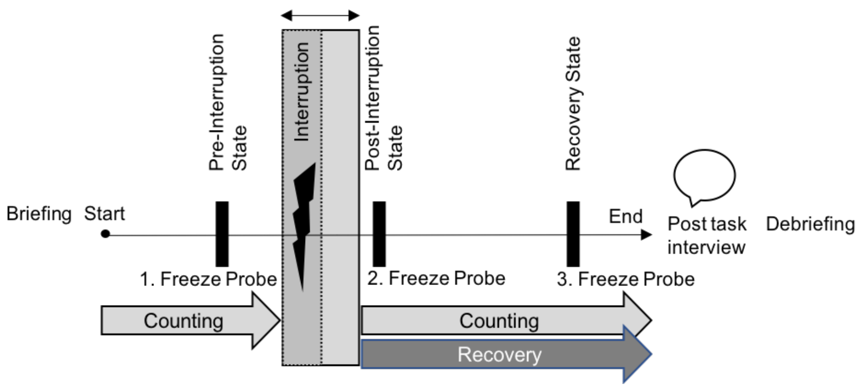

Figure 6-6. Experimental setup of interruption and freeze probes.

For each counting task two participants were chosen randomly. The small sample size required participants to take part in multiple runs, yet, always with a new counting task. To learn more on interruptions and their impact on secondary task knowledge, it was decided to assign the chosen couple to one out of the four aforementioned scenarios. In total four measurements per scenario (i.e., 16 measurements in total) were used. Interruptions were mimicked as phone calls. Short interruptions only contained a single question. In case of interfering content, it asked a question like “How many Ts contains the name Tottenham Hotspurs?”. In case of non-interfering content, it asked for the weekday or some personal information. Long interruptions were made up of 10 questions like the single ones above depending on the need to be interfering or not. Only one participant is interrupted, the other is explicitly allowed to continue counting or to stand-by and wait. Following the interruption participants were required to synchronize upon the interrupted participant’s return to the task. The focus of the measurements in this experiment is on the interrupted person. As part of the experiment participants were also observed especially in the recovery phase which followed the post-interruption freeze probe in order to gain some insights on how people restore their secondary task knowledge.

6.4.2 Results

As to be expected all scenarios showed a similar pattern in the pre-interruption state with equally high levels in terms of speed and correctness regarding the answers to the questions asked during the freeze probes. The most significant changes can be found in the post-interruption state and recovery state. The largest impact could be found with the long interruption with interfering content. The interruption also appeared to impact the speed more than the correctness for each scenario. As all experiments had the same length, the impact was also visible in the recovery state. Obviously, participants needed more time to recover from long and interfering disruptions than from shorter and non-interfering ones. The results are depicted in Figure 6-7.

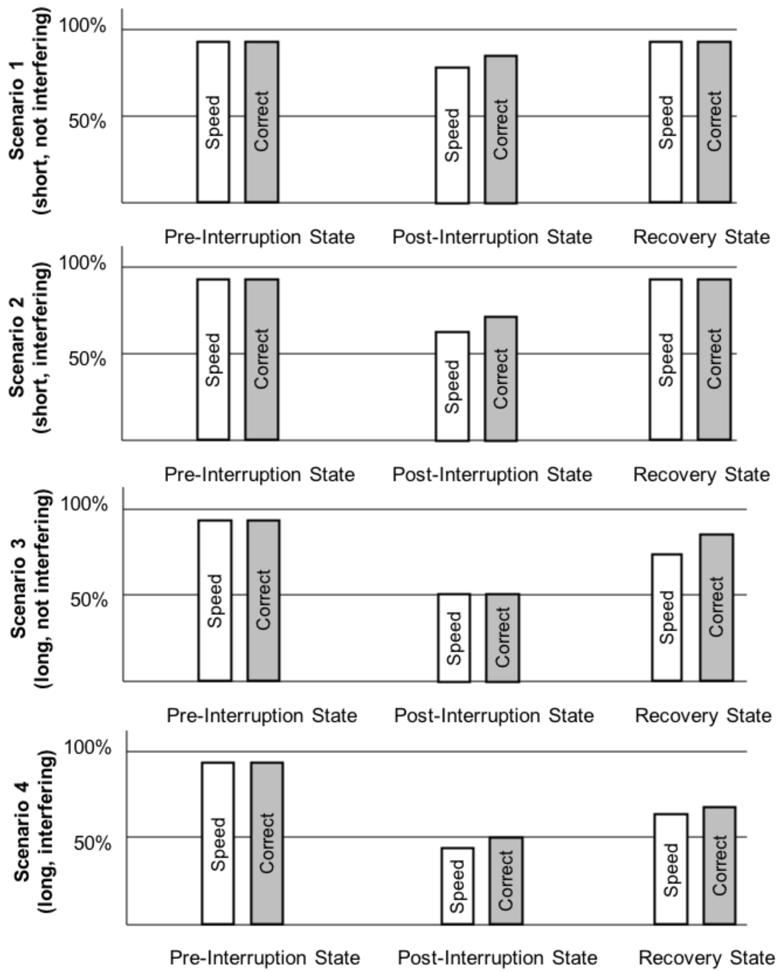

Figure 6-7. Results for the four scenarios.

The impact on speed rather than correctness is possibly due to participants having to think longer but eventually recalling the correct answer, suggesting a greater effort to do so. The increased timespan needed to recover from long and interfering disruptions can be explained by the observations during the experiment's recovery phase where two types were found: quick and long recovery modes. Participants shifted their recovery mode especially after long and interfering interruptions. While they used a little thinking by themselves ("Ok, just a second, where was I.") for short interruptions in the quick recovery mode, they actively engaged their companion to help them recover ("Can you help me out, what did you count?") for the long recovery mode.

Another significant observation during the recovery phase was that though the non-interrupted participants were told to be free to choose whether to stand-by or to continue counting, nearly all of them chose the stand-by mode, i.e., they waited for their partner to return to the task. Being asked for the reason revealed the social nuance that they did not know how long the interruption would last and that they did not feel comfortable in leaving their fellow participant behind. In this case individual preferences clearly overrode a team's performance (a finding also described by Nielsen and Levy (1994) in his work on the correlation of efficiency, effectiveness and satisfaction in usability evaluations and also found in a slightly different form in earlier experiments on awareness and coordination support, cf. section 6.3). Future work on the experiment includes a larger sample size and a systematical analysis of the variances within and between the different scenarios.

On the other end there was the initial suspicion that the applied freeze probes themselves might be perceived as interruptions. However, they did not turn out to be a serious confounding variable. They were perceived by the participants as short interruptions without any interference since they dealt with the knowledge of the same task. A possible experiment that could expand on this issue could include the chaining of multiple freeze probes thus checking their influence on one another. Here, the confounding effects appear to be smaller than those of the interruption in Scenario 1.

Next steps after this experiment could include some variations of this experiment: they could use a longer task with more letters and more participants. Variations could also be created by introducing even longer interruptions or in placing the interruption not only near the beginning but also more to the middle or end of the task, again observing the effects on the recovery activities. Another option could be to study the effects of multiple interruptions, especially ones disrupting the recovery phase. Finally, other experiments could focus on the participants not being interrupted directly observing their activities during their time waiting for their partner to return. As part of an adaptive coordination support system, they would need to be supported differently than their interrupted counterpart.

6.5 Crowdsourced Extension

This section reports on an extension to the SCTA which has the goal to create a basis for sharing research results more openly and freely with other scientists to make use of them. This basically opens the door to crowdsourced research as in FoldIt (Cooper et al., 2010; FoldIt, 2020) which aimed to determine the crystal structure of the Corona virus through a crowdsourced approach using a computer game, sharing and collecting ideas even from non-scientists (cf. Figure 6-8).

Figure 6-8. Crowdsourcing versus Coronavirus, https://fold.it/portal/node/2008963

The SCTA's feature to export data is the foundation for the extension introduced below named *Traceland*. It offers an additional level on top of the SCTA offering facilities for analyzing, annotating, publishing, and sharing awareness and coordination research results (cf. Figure 6-9).

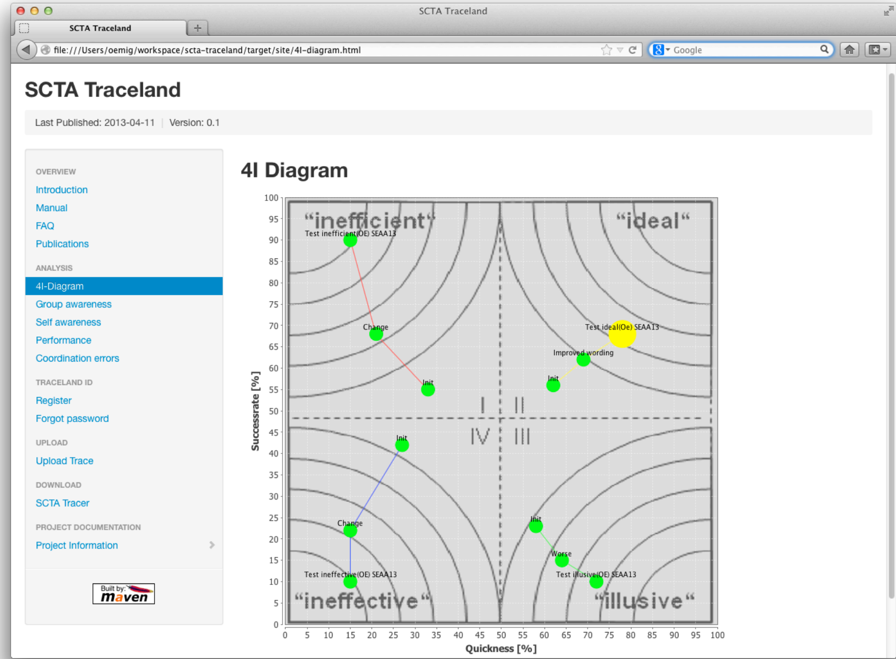

Figure 6-9. Traceland.

While the regular SCTA application is used to track the evolution of a single development effort, Traceland acts as a contribution facility to a larger body of knowledge. It is able to visualize multiple trace files placing results into a larger context to which volunteers and professional researchers may contribute. This type of joint approach is also known as crowdsourcing (Howe, 2008) which is by definition "a business practice that means literally to outsource an activity to the crowd". Contributors are especially motivated by earning credits for their work. Traceland offers a coherent set of methodology, infrastructure, and tools basically open and available for anyone interested in coordination support research. Researchers are offered an additional stage to present their work and to earn credit as well as a platform to share ideas and to compare their results.

Conceptually, as a next step trace files will be separated per team size (aka *trace leagues*) since the coordination effort increases with the team size making it hard to compare SCTA results. Socially, the trace owners will also be allowed to tag their traces with further meta-data (e.g., comments like “for this improvement we realized a user interface with green buttons instead of yellow ones” or bibtex references to papers). This potentially helps other researchers to understand what went right and what went wrong and where to find out about the details. Another idea also in spurring the competition is to introduce nominations in categories like ‘best performing trace’ or ‘highest improver per session’. This especially makes sense after introducing the aforementioned trace leagues. In order to identify the champions further key performance indicators are needed. All in all, maybe this becomes another incentive for researchers participating in crowdsourced scientific projects contributing to the body of CSCW research in the sense Schmidt (2009) argued for in the beginning of this thesis.

6.6 Summary

This section provided some insights into a small collection of experiments leveraging the principles and concepts of the SCTA. It underlines that though the method’s scope is currently limited to the coordination interdependency type simultaneity, that there is a large number of open questions and topics potentially to be addressed by this method. It demonstrates the versatility of the letter counting technique. Even without researching a specific awareness or coordination support mechanism, the method can be used for inspiring observations just by providing participants a shared counting task.

7 Conclusion

The goal of the research field of CSCW is to design systems to support collaboration in digital settings based on an understanding on groups and social interaction. As part of that collaboration requires coordination in order to run smoothly. In the real-world coordination happens in a seemingly seamless and effortless way. However, the resulting mechanisms translated to digital systems often provide a clumsy and awkward experience as users lack the means for subtle and rich interaction beyond the spoken word. After numerous failures revealing system deficits and a large number of ethnographic studies researchers identified “awareness” to become the support mechanism for effortless coordination in digital systems. Thus, the “understanding, defining, and operationalizing the many roles of awareness in collaboration is a key problem for the success of CSCW systems” (Convertino et al., 2004; Gutwin & Greenberg, 1996).

Yet, instead of addressing the problem using appropriate methods and tools, researchers found themselves trapped in circular reformulations of concepts and evaluations of prototypes on the basis of disciplinary preferences ignoring the basic characteristics of the objects of interest. “The evaluation of distributed CSCW systems has been too frequently method driven by various disciplinary preferences rather than driven by frameworks that get the appropriate questions answered” (Neale et al., 2004, p.112). This was then referred to as the *evaluation crisis* (cf. section 4.6.8).

Even worse, the most basic design tensions stemming from a use-inspired perspective have not been resolved though some researchers even urged for it: “rather than looking at ‘fancy’ innovative functions for groupware systems, designers should be focusing on how to better solve the basic need” (Bullen & Bennett, 1990; Henninger, 1991). CSCW research thus became subsequently fragmented. All of this indicates a substantial problem with the evaluation of awareness and coordination support. On the other end, the goal of effortless coordination cannot be reached without evaluation, i.e., without being measured, thus not without an appropriate measurement approach.

One of the goals of this thesis that spans decades of CSCW research was to deliver this specific evaluation approach. The remainder of this chapter describes what exactly has been reached in terms of this thesis' objectives and in regard to its core hypothesis. After that, remaining open issues and future work are identified complementing the overall picture and indicating the future direction of this approach. Eventually this chapter finishes with a few closing remarks.

7.1 Research Objectives Results

As stated in the introductory chapter, this thesis derives its objectives from the following research hypothesis: in order to reach effortless coordination in digital systems, coordination (and awareness) need to be made measurable and to be measured.

This hypothesis was investigated and tested by the research activities as part of the research objectives described below also indicating their results in the subsequent sections.

7.1.1 Objective 1: Build a construct for Awareness

Objective 1 was to create a construct for awareness (conceptual operationalization). This objective was met by reviewing existing literature on the subject from the area of CSCW gathering typical characteristics and underlying processes. The resulting construct can be found in Appendix D1. It provides a very good point of reference unseen before in this form in CSCW research. On the other end, it may be a starting point as the method introduced as part of objective 3 allows a lot more use-inspired basic research potentially revealing a lot more details now that respective hypotheses can be validated on a quantitative basis. A part currently missing in the construct are resulting guidelines and design implications derived from the presented characteristics.

7.1.2 Objective 2: Build a construct for Coordination

Objective 2 was to create a construct for coordination (conceptual operationalization). This objective was met by reviewing additional existing literature from the areas of CSCW, HCI and cognitive sciences. The resulting construct can be found in Appendix D2. Also, this construct shares a collection of characteristics and processes thus providing a very good point of reference. Coordination has never been analyzed this way and context though the underlying coordination theory provides a solid basis while lacking especially the connection to awareness. A part also currently missing here are resulting guidelines and design implications. But as with the previous objective, these will sooner or later result from the measurement approach's application.

7.1.3 Objective 3: Design a Measurement Approach for Awareness and Coordination

Objective 3 entails the design of a measurement approach to assess awareness, coordination and respective support systems in terms of effort and maybe more. This objective was met by suggesting an appropriate research method and its demonstration in multiple scenarios proving its applicability with reliable and valid results. However, as mentioned in the scope of the approach (cf. section 5.2.3) the focus was reduced to one of the coordination interdependency types, namely the type of simultaneity. The other two types (prerequisite and shared resource) have not been covered by this thesis leaving them as possible future work. Besides that, there have been numerous further details discovered along the way of the approach's development, some of which are presented in the next section as well.

7.2 Open Issues and Future work

This section provides some insights on possible next steps derived from open issues that have been left aside during the fulfillment of the objectives (left-overs) and other aspects encountered as part of the literature study on awareness, coordination and cognition.

7.2.1 Coordination Games

As mentioned above, the scope of the approach developed in this thesis was reduced to the interdependency type of simultaneity. For this type a coordination game, i.e., a primary task that generates the need for coordination activities matching this interdependency type, was created. For the part of this thesis, a letter counting activity was selected (cf. section

5.2.2.4). As part of the future work alternate coordination games should be examined.

On the other end, there is still the need to find the initial coordination games for the other two interdependency types of prerequisite and shared resource.

7.2.2 Rate, Reuse, Recommend

Another item on the list for future work is the integration of satisfaction measures in a way not yet determined. Currently, post-task interviews are conducted after experiments but adding satisfaction to the list of measures would make the SCTA a true usability measuring approach, as it is the only dimension that is currently missing.

7.2.3 (Un-)Blanked Freeze Probes

One example of the smaller open issues is the blanking of screens during freeze probes (cf. section 5.3.2). Currently the blanked modus is used, that means the questions displayed on the screen cover the means for coordination and awareness support. However, this might turn the questioning into a free recall exercise as the existing cues that support recognition are temporarily unavailable. It would be interesting to observe the impact of not blanking the screen during freeze probes allowing for recognition to take place. However, this requires more screen estate or a different mechanism for presenting the questions during a freeze probe. One of these alternate mechanisms is suggested in section 7.2.5.

7.2.4 Extensions to Meta-Awareness

Meta-awareness was shown to result from perspective-taking (cf. section 2.1.3) eventually providing the basis for further social mechanisms like accountability. One of the next steps could be to extend the existing questioning framework (cf. section 5.3.1.2) to include questions regarding subject's meta-awareness. This might be used to explain specific behavior as this level of awareness imposes social constraints (cf. section 2.3.3).

7.2.5 Integration of Virtual Assistants

Another aspect interesting to be looked into is the integration of voice-controlled virtual assistants like Amazon's Alexa[27] (cf. Figure 7-1) for the purpose of questioning the participant.

Figure 7-1. Amazon Echo Dot (Source: Pixabay, CC0)

This releases the screen estate needed to display the questions covering parts of the needed awareness and/or coordination support system (cf. 7.2.3). In a complete different approach these types of assistants also could be used as awareness indicators, i.e., the voice assistant becoming part of an awareness and/or coordination support system.

27 https://alexa.amazon.com

7.2.6 Cognitive/Coordinative Artifacts

Further exploration would be also of great interest in the area of cognitive or coordinative artifacts (cf. section 3.2.2). Here, CSCW research has barely scratched the surface with more and more technical gadgets becoming available for instance as part of smart home technology.

7.2.7 Advanced Means for Statistical Analysis

Another possible next step is the extension of the SCTA's currently available means of analysis (cf. section 5.4). Here, the idea is to realize a direct interface to SAS or R[28] for the statistical analysis of the results (Dean et al., 2017). This would help to extract the math out of the code and to arrange it in an area where it belongs and where there are more powerful tools within close range.

7.2.8 Artificial Intelligence

Last but not least it was shown that cognitive science and artificial intelligence are two closely related topics worth inspecting a little deeper in this context. This could especially help potential awareness/coordination support systems to avoid overloading and overfitting (cf. section 3.1.3).

7.3 Closing remarks

Overall, the research hypothesis of this thesis could be positively validated creating an approach to get closer to the goal of effortless coordination. Going through decades of CSCW and HCI research, let the question arise if the fragmentation of CSCW research could have been avoided if there had not been the dogmatic debates on the "proper" or the "one-and-only right" research approach. It was clearly shown in this thesis that cognitive science can make a tremendous contribution and a difference in research. In hindsight the thesis' reference list reads like the who-is-who of cognitive psychology with names like Baddeley, Sternberg, Miller, Ebbinghaus, Johnson-Laird, Neisser etc.

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28 https://www.r-project.org

Hopefully, CSCW regains its science curiosity instead of putting tribe before truth (Kahan, 2018) by continuing to follow disciplinary preferences. CSCW's point of pain is its evaluation. And this is exactly the point where the "choice of evaluation methodology – if any – must arise from and be appropriate for the actual problem or research question under consideration" (Greenberg & Buxton, 2008, p.111).

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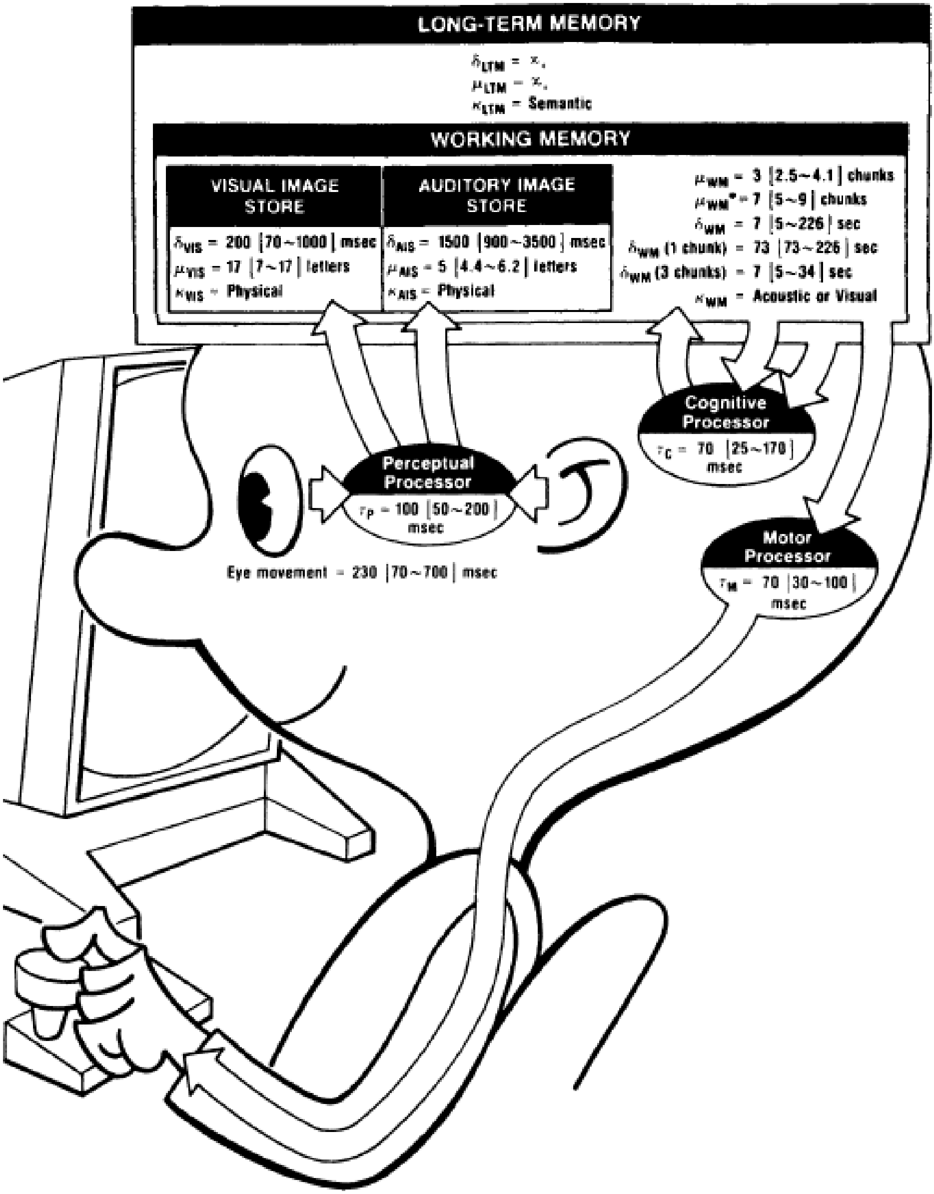
Appendix A – Abbreviations

ACM	Association for Computing Machinery
AI	Artificial intelligence
APA	American Psychological Association
COBRA	Constraint-based Awareness Management Framework
CPU	Central Processing Unit
CSCW	Computer-Supported Cooperative Work
CVE	Collaborative Virtual Environments
DOET	The Design of Everyday Things
DT	Design Thinking
GB	Giga Byte
GOMS	Goals Operators Methods Selection
HCD	Human-centered design
HCI	Human-computer interaction
HD	High definition
HTML	Hypertext Markup Language
IEC	International Electrotechnical Commission
IM	Instant Messaging
IPO	Input-Processing-Output
ISO	International Organization for Standardization
LTM	Long-term memory
MHP	Model Human Processor
OCS	Office Communicator Service
OSI	Open System Interconnection
POET	The Psychology of Everyday Things
POM	Persistence of Memory
RMI	Remote Method Invocation
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situational Awareness Rating Technique
SCTA	Standardized Coordination Task Assessment
SDLC	Software Development Life Cycle
STM	Short-term memory
TPM	Team Performance Model
UCD	User-centered design
UX	User experience
UXQB	User Experience Qualification Board
WIMP	Windows, Icons, Menus, Pointers
XML	Extensible Markup Language

Appendix B – Model Human Processor (MHP)



Appendix C – Working Memory Span

The *working memory span* is a task devised by (Daneman & Carpenter, 1980) which "involves presenting the subject with a series of sentences. The subject was required to read each one and then, after the final sentence, recall the last word of each sentence. Some people have difficulties remembering more than two, others easily remember four" (Baddeley, 2013) (p.67).

Try it yourself using the sentences below, covering each one as soon as you have read it:

- The greengrocer sold many apples and oranges.
- The sailor had been around the world several times.
- The house had large windows and a massive mahogany door.
- The bookseller crossed the room, scowled and threw the manuscript on the chair.

Now recall the final word of each sentence. How many did you get right?

Appendix D - Constructs

Appendix D1 Construct of Awareness

Attributes

Name	Description
Subject-bound	Awareness is bound to a single subject or person; thus, it cannot be found by itself. Artifacts have no awareness.
Individual	Awareness is individual resulting only from individual perception.
Unique	Awareness of two people might be similar but never identical.
Multidimensional	Awareness is knowledge about a person's environment bound in time and space. Besides answering the questions when and where, further dimensions answer the questions what and who, thus introducing identity and responsibility.
Requires updates/dynamic	Environments change over time; hence awareness is knowledge that must be maintained and kept up to date.
Requires interaction	The maintenance of awareness is accomplished through interaction with and the exploration of the environment.
Secondary task	Awareness is a secondary task. A subject's primary task is not to maintain awareness but to pursue another one in the environment (i.e., the domain task).
Product and process	Awareness is comprised of a mental model and its surrounding processes
Adaptive and cyclical	The process of acquiring and maintaining awareness are adaptive and cyclical. Awareness forms a person's actions (cf. Neisser cycle).
Multivariable	There are numerous external and internal factors impacting awareness.
Not instantaneous	Awareness is not acquired instantaneously, but over time.

Not symmetrical	Awareness is not necessarily symmetrical. Just because someone is aware of something else does not mean it is aware of oneself the same way.
Knowledge directed towards the past and present	Awareness is knowledge about present and past activities, artifacts and events in a specific context.
Context-bound	About environment bound in time and space and it switches when switching context as different information becomes important.
Multiple perspectives	Leverages empathy
Prerequisite Consciousness	Subject needs to be conscious in order to perceive information to become aware of something.
Intentional/Unintentional	Not always controlled by will, but in some cases gathering subconsciously, automatic.
Subconscious	(Pedersen & Sokoler, 1997) "We do so in an apparently effortless manner and without being aware that we do so" (p.51)

Processes

Name	**Description**
Perception	Data intake, interaction with the environment.
Comprehension	Integration into mental model.
Projection	Future impact basis made on decisions for future interaction with the environment.

Appendix D2 Construct of Coordination

Attributes

Name	Description
Goal-driven	Coordination is goal driven as cooperation aims towards a common goal.
Decision-making	In order to coordinate decisions among possible options have to be made.
Problem-solving	Decision making is the result of problem-solving done as part of coordination.
Secondary task & knowledge	Like awareness coordination is a secondary task with corresponding knowledge that is to support the primary task.
Individual part as with situation awareness	As with awareness coordination covers the individual part in a situation.
High level activity	Coordination is a higher-level activity compared to awareness as it requires awareness information to be present for problem-solving.
Directed towards the future	Coordination makes decisions on future actions and is thus directed towards the future.
May be based on awareness	Coordination may be based on awareness but does not have to be. It might use rules and conventions instead to make decisions (e.g., the traffic light, may use a strict schedule or a sensor to see if any cars are waiting).
Resides in working memory and LTM	As awareness coordination resides in the working memory with connections to the long-term memory. From these sources it receives the information the problem-solving is based upon.

Implemented by human or system	The problem-solving and decision making as part of coordination may be implemented on the system side (then the user needs a coordination support system) or on the human side (then the user needs all awareness information as part of an awareness support system to make the problem-solving and decision making himself.
Phased	Card et al. (1983) characterize it as "fundamentally parallel in its recognizing phase and fundamentally serial in its action phase. Thus, the cognitive system can be aware of many things, but cannot do more than one deliberate thing at a time" (p.43).
Interdependency of activities is the cause for coordination not the number of actors	This was found as part of the coordination theory. Thus, the coordination of one's own activities also affords coordination. It does not require a context with multiple actors.

Processes

Name	**Description**
Problem-solving	Problem-solving in general "involves mentally working to overcome obstacles that stand in the way of reaching a goal" (Sternberg, 2011, p.484). It is finding solution to problems.
Decision-making	Decision-making is the result of problem-solving. It also denotes a problem of choice among multiple options.

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Today's modern world often affords individuals to form teams to work together towards shared goals and objectives. The need for tools to digitally support collaboration distributed in time and space increased over the past decades significantly with a recent sudden increase due to the Corona pandemic crisis. The research goal in the field of computer-supported cooperative work (CSCW) has always been to design systems that facilitate collaboration based on the understanding of groups and social interaction – especially on how people coordinate their work.

In the real-world coordination happens in a seemingly seamless and effortless way. However, the resulting mechanisms translated to digital systems often provide a clumsy and awkward experience as users lack the means for subtle and rich interaction beyond the spoken word. After numerous failures revealing system deficits and a large number of ethnographic studies, researchers identified awareness to become the support mechanism for effortless coordination in digital systems. Yet, instead of addressing the problem using appropriate methods and tools, researchers found themselves trapped in circular reformulations of concepts and evaluations of prototypes on the basis of disciplinary preferences ignoring the basic characteristics of the objects of interest. Even worse, the most basic design tensions stemming from a use-inspired perspective have not been resolved indicating a substantial problem with the evaluation of awareness and coordination support. Effortless coordination cannot be reached without being measured, thus not without an appropriate measurement approach.

This thesis introduces an appropriate assessment method for the efforts related to awareness and coordination support in cooperative settings – The *Standardized Coordination Task Assessment (SCTA)*. Applying a use-inspired basic research driven approach it creates and leverages an effort-based operationalization of the two constructs derived from literature and especially from a cognitive perspective. A highly automated and scalable framework delivers quantitative results to be used for hypotheses validations that allows a benchmark-based approximation of effortless coordination. At the same time the method opens the door for a lot more use-inspired basic research to resolve many of the still open design tensions and challenges.

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