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Requirements Elicitation and System Specification of Assistive Systems for People with Mild Dementia

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To my parents

Even though I walk through the
valley of the shadow of death, I
fear no evil, for You are with
me; Your rod and Your staff,
they comfort me.

Psalm 23:4

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Acronyms

AD Alzheimer's disease

ADL activity of daily living

AT assistive technology

CG caregiver

DL description logic

DSR design science research

MCI mild cognitive impairment

OWA open world assumption

OWL web ontology language

PwD person with dementia

SWRL semantic web rule language

Timisto time in storyboards

UCD user-centered design

UI user interface

Chapter 1

Introduction

1.1 Background

Dementia is a syndrome of serious decline of cognitive abilities that exceed age-related decline. Alzheimer's disease is the most common type of dementia. Forgetfulness, which is caused by episodic memory impairment, is an early symptom of dementia [1, 2]. Time in particular is an important aspect of dementia [3, 4]. There is an increased focus on early detection and diagnosis of Alzheimer's disease [5, 6]. A recent study commissioned by Alzheimer's Disease International [6] found that early diagnosis and intervention were beneficial to people with dementia.

The motivation for our research is to simplify the development of assistive technologies for people at the early stage of dementia. Assistive technologies can support people with dementia and their caregivers to cope with dementia. People with mild dementia can also use assistive technologies that are easy to use and not obstructive. Assistive technologies for people with dementia must therefore be tailored to individual users' context, in order to reduce cognitive load, without burdening users [7–9]. Designers who collaborate with people with dementia face many challenges in their effort to understand the requirements and needs of their users, who can often only provide vague and sometimes conflicting information [7, 9, 10].

Dementia affects about 4% of people over the age of 65 and 40% of people over 90. In Europe, at least half of the elderly population affected by dementia, have a mild form of dementia [11]. The organization

Alzheimer's Disease International estimates the cost of dementia worldwide amounts to USD 604 billion, or 1% of the global gross domestic product [12]. Unsurprisingly, Alzheimer's disease was dubbed the "coming plague of the 21st century" [1] for its social and economical ramifications [1, 2, 6, 12]. Alzheimer's disease has a profound effect both on the individuals who have dementia and on their social environment [2, 13–15]. Alzheimer's disease causes a progressive loss of higher cognitive abilities. Memory problems, especially episodic memory, are early symptoms. As cognitive impairment worsens, people with dementia can get lost in familiar places, find it difficult to recognize people they know and increasingly rely on others in their everyday life [1]. Dementia is especially devastating because it threatens the personal identity, the very core of being human [7, 13].

The availability of high speed Internet connections and the rapid dissemination of mobile computing devices is making assistive technologies viable for applications in dementia care outside medical institutions. While early developments in dementia care supported medical staff and personal caregivers, people with dementia are also starting to use to assistive technologies to cope with their symptoms [7, 16–18]. Developing assistive technologies that people with dementia and caregivers are willing to use in their daily lives is challenging. People with dementia are not a homogeneous group and customization is needed to adapt applications to meet individual requirements and needs [7, 9, 19].

1.2 Problem Statement

A characteristic of designing assistive technologies for people with dementia is the difficulty for designers to understand the users and produce an interactive system that helps people with dementia to live longer independently. People with dementia are more susceptible to change than cognitively unimpaired people. They may also be unaware of the full extend of their conditions. Furthermore, their abilities and emotional state can change. Designing assistive technologies is a challenging task for designers because what a person with dementia experiences is different from that of cognitively unimpaired users. Designers must be empathic towards the user and adapt the choice of design tools to the user's abilities and needs [7–9].

Literature suggests that storyboards helped people with dementia to participate in the design of assistive technologies [7, 20, 21]. A storyboard is a visual form of story telling that is used in user-centered design depict the context in which actors use an application [22]. Unlike textual description of scenarios or engineering models, understanding storyboards comes naturally to people because images do not require specific knowledge to decode [23].

A limitation of storyboards is that the design knowledge, i.e. the description user requirements and needs, is informal. The user requirements and needs must therefore be "translated" into more precise technical specification for further usage in the development process. A manual transition has several drawbacks: Tools cannot be used that would help designers to analyze the design knowledge and create technical specifications that represent the user requirements and needs. This also means that there is no explicit relationship between the technical specifications of the interactive system and the user requirements and needs. The motivation for our research is to facilitate the transition from informal design knowledge of the users to more precise technical specifications.

We aim to *1)* understand how dementia related-deficits translate into design specifications, *2)* explore how extract precise information about the context of use can be extracted from existing storyboards and *3)* how the precise information can help designers to analyze the user requirements and needs.

1.3 Research Questions

We adopted the design science research approach to develop this thesis. In the design science research paradigm, knowledge is gained through designing artifacts: inconsistencies in existing knowledge are identified and concepts are designed and developed to explore solutions, resulting in knowledge. This feedback-loop suggests that design science research incrementally improves the understanding of an object under study [24].

- **R 1 – Designing interactive systems with people with dementia:** Literature confirms the role of assistive technologies in dementia care but warns of the challenges inherent to designing and developing assistive technologies for people with dementia. The aim of the first research question is to analyze the design properties of assistive technologies for people with dementia as well as how to facilitate the involvement of people with dementia and their caregivers in the design process. The following questions were studied by reviewing context-aware assistive technologies in literature (Chapters 3 and 4):

- **R 1.1:** What are the characteristics of assistive technologies for people with dementia that were successful?
- **R 1.2:** How do dementia related deficits translate to design specifications?
- **R 1.3:** How can the involvement of people with dementia and their caregivers be facilitated?

• **R 2 – Representing requirements and needs of people with dementia:** The results from the first research question suggest to focus on the transition from user requirements and needs to the technical specifications of an interactive system. The aim of the second research question is to investigate how the design knowledge of the users (their requirements and needs) can be described in a precise and machine-understandable way. Literature is reviewed to address the following questions (Chapter 4 and 5):

- **R 2.1:** How can design knowledge be intuitively conveyed?
- **R 2.2:** How can informal design knowledge be captured, reused and exchanged?

• **R 3 – Extracting precise time information from storyboards:** The results form the second research question suggest that storyboards help people with dementia to discuss their requirements and needs. However, storyboards contain informal design knowledge, which is not accessible to computers. However, informal design knowledge can be additionally annotated with precise information to make it machine-understandable. The aim of the third research question is to extend existing storyboarding methods for people with dementia to provide precise time information. An ontology was developed to structure storyboards explicitly according to McCloud [23]'s work on comics. Furthermore, a temporal domain ontology for storyboards was developed to transform the informal temporal information in storyboards, as defined by McCloud for comics, into formal structures. The temporal semantics is based on Allen's temporal interval algebra [25] (Chapter 5):

- **R 3.1:** How is time currently described in storyboards?

  - **R 3.2:** How can time in storyboards be modeled unambiguously?

- **R 4 – Visualizing time information storyboards:** The aim of the fourth research question is evaluate and improve the concepts and method developed for the third objective. Tool support to annotate and visualize the time as timeline was developed and evaluated with users without cognitive impairment to study the following questions:
  - **R 4.1:** Which representation of the storyboard helps to improve the interpretation of time?
  - **R 4.2:** How can temporal semantics be exploited to visualize implicitly modeled application behavior?
  - **R 4.3:** Can temporal information in storyboards be visualized by mapping the content of a storyboard onto a timeline?

1.4 Chapters Overview

This thesis is organized in nine chapters:

- **Chapter 2 – People with Dementia and their Caregivers:** tries to put a human face on dementia. It discusses the effect of dementia found in literature, in particular Alzheimer's disease, on people with dementia and their social context, to gain a sense of the complexity of this disease.

- **Chapter 3 – Assistive Technologies for People with Dementia:** studies the role of assistive technologies as a non-drug treatment for dementia. The review studies assistive technologies from a context-aware perspective to represent the needs and requirements of people with dementia to the context dimensions activity, identity, location and time [26]. The review confirmed the value of assistive technologies for people with dementia and their caregivers but also stresses the responsibilities and challenges when involving people with dementia. This also explains why few research projects involved people with dementia.

- **Chapter 4 – Designing Applications with People with Dementia:** examines the difficulties of involving people with dementia in the design process. Empathy is imperative to collaborate with users who find it difficult to express their ideas and struggle to maintain their identity. This chapter argues that eliciting the users' design knowledge and coping with a variety of systems suggests to focus on knowledge management in application design and development.

- **Chapter 5 – Storyboarding for Requirements Engineering:** suggests to annotate storyboards, with precise time information to extract fine-grained temporal relationships between events in the storyboard. Storyboards are typical informal artifacts used in UCD. A formal ontology of McCloud [23]'s storyboard language is presented to structure storyboards. The structure of the storyboard visualizes the structure of time. A temporal domain ontology for storyboards, based on McCloud's description of time in comics [23] is developed. Its temporal semantics is grounded in Allen's temporal interval algebra [25].

- **Chapter 6 – Visualizing Time in Storyboards:** proposes to visualize time-related requirements as a timeline of the storyboard. The timeline reestablishes the time/space relationship that is an important property of comics [23] (and storyboards) by placing annotations that are adjacent in time adjacent in space. The timeline helps to analyze time-related requirements by revealing temporal relationships that were hidden by the presentation of the storyboard. A user evaluation was conducted to validate this approach.

- **Chapter 7 – Architecture and Implementation:** implements a prototype of the storyboarding environment. The architecture of the storyboarding application comprises of ontology centric modules that transparently manage the state of their ontologies.

- **Chapter 8 – Discussion:** discusses the benefits and limits of the conceptual part and reflects on the application of the storyboard environment in requirements engineering, particularly for dementia care.

- **Chapter 9 – Conclusion:** summarizes the findings of this thesis and outlines further research.

Chapter 2

People with Dementia and their Caregivers

This chapter is an introduction to the dementia syndrome, to motivate the use of assistive technologies by people with mild dementia. After an overview of the clinical features of Alzheimer's disease, the most common type of dementia, in Section 2.1, we focus on the human dimension of dementia. We discuss the personal and social implication of dementia for the patient in Section 2.2. In Section 2.3, we examine the role of caregivers in dementia care.

2.1 Alzheimer's Disease

Dementia is a syndrome of serious decline of cognitive abilities that exceed age-related decline. Dementia has different etiologies, of which Alzheimer's disease is the most common type. Other common causes are vascular dementia, frontotemporal dementia, primary progressive aphasia and dementia with Lewy body [2]. Forgetfulness is generally seen as the primary symptom of dementia; however, this is not necessarily the case for every pathology. Cognitive abilities usually progressively deteriorate and the underlying disease is incurable [1].

Dementia defines a disability threshold for cognitive abilities. Individuals can therefore exhibit a decline of cognitive abilities that do not meet the criteria for dementia [1, 27]. Mandell and Green [1, pg. 5] describe dementia as "a syndrome of *acquired persistent* intellectual impairments characterized by deterioration in at least three of the following domains: memory, language, visuospatial skills, personality or behavior, and manipulation of acquired knowledge (including executive function)". Alzheimer's disease is a neurodegenerative disease and the most common form of dementia [2]. Alzheimer's disease is commonly diagnosed after the age of 65, although brain damage resulting from Alzheimer's disease can start much earlier [28]. The causes of Alzheimer's disease is unknown. Memory problems that exceed age-related decline are early indicators. As Alzheimer's disease advances language difficulties, visuo-spacial impairment, confusion over time and space, misplacing and losing items as well as mood changes make it increasingly difficult for people with dementia to perform everyday tasks or interact with society [1]. Determining underlying causes for cognitive impairments is complex, since several cognitive processes are interconnected. For example several studies found that visual cues encouraged communication with people with dementia [3, 7, 20], even though visuo-spatial impairment is a symptom of Alzheimer's disease [1, 29, 30]. Tippett [30] argues that in most cases of Alzheimer's disease, visual processing impairment, can be attributed to the deterioration of other cognitive functions. She suggest that visual perception was impaired to a lesser extend than other cognitive functions [30].

The pathological process of Alzheimer's disease precedes the clinical process by ten to twenty years [28]. In response to an increased focus on delaying or preventing the onset of dementia, the National Institute on Aging and the Alzheimer's Association proposed a new framework of diagnostic criteria and guidelines for Alzheimer's disease that included preclinical stages of Alzheimer's disease [5, 28, 31]. Their model describes the progression of Alzheimer's disease in three stages:

- **Preclinical Alzheimer's disease:** Preclinical Alzheimer's disease measures changes to the brain and biomarkers of the pathological process of Alzheimer's disease. Research suggests that Alzheimer's disease begins 10 to 20 years before symptoms such as memory problems emerge. Alzheimer's disease will not necessarily cause dementia during the patient's lifetime.

- **Mild cognitive impairment due to Alzheimer's disease:** At stage of mild cognitive impairment due to Alzheimer's disease, cognitive functions impairment, especially episodic memory impairment, is

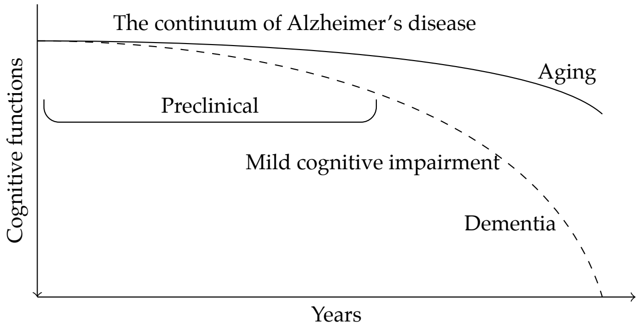


Figure 2.1: Model of the clinical trajectory of Alzheimer's disease compared to normal aging. Reprinted from Toward defining the preclinical stages of Alzheimer's disease: Recommendations from the National Institute on Aging–Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. Alzheimer's & Dementia 7 Sperling et al., 280–92, (2011), with permission from Elsevier

noticeable. However, abilities to perform activities of daily living (ADLs) are not restricted.

- **Dementia due to Alzheimer's disease:** At this stage Alzheimer's disease causes dementia.

Hodges [29] characterizes the clinical process of Alzheimer's disease as stages of patterns of impairment of the higher-oder cognitive abilities memory, attention and executive abilities, language, visuo-spatial and perceptual and praxis. The first stage, mild cognitive impairment, is prior to the dementia onset. The worsening of cognitive abilities is characterized by the stages mild dementia, moderate dementia and severe dementia [29]:

- **Mild dementia:** Mild dementia manifests itself mainly by a progressive degeneration of episodic memory and to a lesser extent semantic memory. Difficulties with attention and executive abilities also become evident. Working memory and remote memory as well as visuospatial and perceptual may also be affected. Individuals experience difficulties to perform perviously familiar activities. They may get lost in once familiar places and misplace items.

- **Moderate dementia:** Moderate dementia characterized severe episodic and semantic memory impairment. The working and remote memory also increasingly affected. Slight language difficulties become apparent. At this stage people with dementia start to depend on others for ADLs.

- **Severe dementia:** At the last stage of dementia all aspects of the individual's memory as well as attention and executive abilities are severely impaired. Language abilities have further declined. At this stage people with dementia are fully dependent on caregivers. They are unable to perform any previously familiar tasks, even dressing, without substantial help. Individual seem detached from others and it is very difficult to connect with them.

At the early stage of the clinical process, the rate at which abilities deteriorate vary from person to person. The later stages of dementia follow similar impairment patterns in most of patients. However the duration of each stage is individual. Alzheimer's disease affects several parts of the brain, the interdependency between disabilities is not fully understood [5, 29, 30].

The clinical perspective neglects personal and social facets and risks to reduce dementia merely to a medical condition and people with dementia to patients [13, 32–35]. The concept of personhood motivates a holistic view of people with dementia that includes their social, ethical, mental and spiritual dimensions. They are people who, with all their other characteristics, happen to have a condition that causes dementia [13]. The last two sections discuss how people with dementia and their caregivers experience dementia.

2.2 Living with Dementia

The dementia onset has a profound and mostly devastating impact on people with dementia and their social context. Being diagnosed with dementia is especially difficult, because it signals a disintegration of one's self, the essence of our existence. A person's past and current relationships strongly influences their identity [14, 35–37]. As dementia progresses and the short term memory declines, person with dementia draw more on their long-term memory to conceptualize their reality [35, 38, 39].

However, dementia does not reduce a person to an empty shell [13, 32–34]. Clare [34] found that people with dementia express their awareness is determined by their conceptualization of dementia, which determines how patients cope with it. She suggests a continuum for coping strategies that ranges from self-maintaining to self-adjusting:

- **Self-maintaining:** People with dementia who respond with self-maintenance try to normalize or hide the effects of dementia. For example, they can follow daily routines to establish a sense or normality, use tools mitigate cognitive impairment or use medication to treat the symptoms. People with dementia who follow a self-maintaining strategy are reluctant to attribute symptoms to the dementia onset and instead find other causes, such as age, for their difficulties.

- **Self-adjusting:** People with dementia who opt for a self-adjusting strategy accept that it is part of their lives. Self-adjusting strategies include acknowledging dementia, making separating the person and the illness learning about dementia. Some person with dementia take a combative stance towards dementia. They find a meaning in their life after the dementia onset, for example by contributing to dementia research.

People who are in early stages or in mild stages of dementia are capable of living independently, and have occasional need for help. They can benefit from digital and non-digital assistive technology to mitigate the impairments of dementia [16, 40, 41]. As the symptoms of dementia worsen, people with dementia are increasingly dependent on personal care. When the symptoms become too severe for people with dementia to use assistive technologies independently [10, 17]. People with mild or severe dementia can no longer live without personal care [41]. Assistive technologies for people with dementia is the subject of next chapter.

2.3 Caring for a Person with Dementia

While dementia is immensely demanding for the person with dementia, it also puts enormous strains on the person with dementia's entourage. In a comparative study between caregivers of people with dementia and caregivers for non-dementia people, Ory et al. [42] found that the former was in almost all aspects more demanding than the latter. These people are therefore also victims of this disease. The main caregiver is usually the spouse and when he or she can no longer care for their loved one, children take over [43].

Preserving the person with dementia's personhood is also the main endeavor of their spouses and family members. In doing so, they protect themselves from dementia by maintaining their status as a the spouse of the person they care for [14, 34]. Caregivers spouses have a number of ways to support their husband or wife with dementia, which Perry and O'Connor [14] summarize as maintaining continuity, sustaining existing competencies, protecting the partner from incompetence and strategizing public encounters.

- **Maintaining continuity:** Coping strategies to maintain continuity mainly focus on preserving the person with dementia's personhood in their social context. Caregivers aim to maintain their spouse's social standing by giving outsiders a differentiated view that decouples the person from the illness. Caregivers draw on the past to construct their spouse's image. They either explain how the person with dementia was before the dementia onset, relate current behaviors to past characteristics to downplay the effects of dementia or point out which changes they attribute to dementia.

- **Sustaining existing competencies:** Caregivers who cope by supporting their spouse's competencies focus on the person with dementia's abilities. They encourage their partner to perform tasks themselves and assist to compensate for the deficits. The aim is to show that their spouse is, like other people, to a certain degree still independent.

- **Protecting the partner from incompetence:** Caregivers who try to protect their spouse from incompetence, foster their spouse's personhood by creating an environment that limits the room for errors and embarrassment. They try to protect their spouse from their illness by downplaying deficits and construct situations in which the person with dementia perceives to be successfully able to perform tasks.

- **Strategizing public encounters:** Caregivers who strategize encounters maintain their spouse's personhood in the wake of other people's reaction. They create a sense of normality by avoiding people who could react toward the person with dementia in a degrading way and undermine the person with dementia's dignity and integrity.

Assistive technologies can assist caregivers to care for a person with dementia. An early application of assistive technology were safety-related tasks, for example monitoring a person with dementia and alerting caregivers [44, 45]. More recent development also involve people with dementia, as we discussed previously for people with mild dementia. Even when dementia related symptoms do not allow for people with dementia to use assistive technologies on their own, assistive technologies can help caregivers to engage people with dementia in creative activities [46–49].

Chapter 3

Assistive Technologies for People with Dementia

The previous chapter introduced dementia and tried to portray its human side. In this chapter, we analyze the design of assistive technologies for people with mild dementia. Literature shows that the dementia syndrome itself does not thwart the use of digital assistive technologies, at least at its early stages [16, 40, 50]. To what extent people with dementia can benefit from assistive technologies depends on how well an assistive technology is designed to meet individual user requirements and needs [9, 40, 51]. In this chapter, we analyze the design characteristics of assistive technologies for people with dementia. The design and development of assistive technologies with people with dementia and their caregivers is the subject of the next chapter.

We conducted a literature review of assistive technologies for people with dementia to study the relationship between user requirements and need translate and the design of assistive technologies. The aim of this literature review is to inform designers in the early design stages of assistive applications how requirements and needs of people with dementia can be represented in a context-aware application. We discuss the design and development process of assistive technologies for people with dementia in Section 4.2.

We present the method for our literature review in Section 3.1. In Section 3.2, we analyze the requirements and needs of people with dementia regardingassistive technologies. A summary of each assistive technology in our literature review is given in Section 3.3. In Section 3.4, we use the context framework by Dey and Abowd [26] to analyze and classify the type of contextual information and context-aware services that we identified in literature. We summarize our lessons learned from the design and development of the assistive technologies in our survey with seven design recommendations in Section 3.5. We believe the proposed framework and these design recommendations can provide a tool for application builders and interface designers to accomplish an informed design of systems for people with dementia.

3.1 Scope of the Literature Review

Based on a systematic literature review, we elicit which context types are linked to the needs of people with dementia and their caregivers and how they are used in existing assistive applications in dementia care. Our focus is on applications evaluated and assessed with people with dementia. The context and context-awareness classification and our design recommendations presented are by no means a substitute for consulting medical professional and people affected by dementia. Our aim is to provide a tool to assist a preparatory investigation for the design and development of context-aware applications for person with dementia. The framework informs developers and designers about possible use of context for their applications. Validation with the target group remains the best approach, but given the condition of the test users it is extremely difficult to do actual user trials. Our framework builds upon previous research and development in this domain and makes the previous experiences in building such system more accessible for developers and designers creating a new system. When use cases are defined for a project, our reference framework helps to identify the (1) dimensions of context that need to be taken into account, (2) provide a set of examples of concrete implementations for these dimensions by referring to relevant research projects and (3) helps to uncover important context dimensions that might otherwise easily missed while designing an assistive application for people with dementia.

Because designing and developing assistive technologies for people with dementia is challenging, we focused on projects which evaluated their running applications with people with dementia. We further limited the scope to applications that react to context during runtime (in contrast to design time adaptation to contexts of use). Additionally, we considered only literature we could access from our university network or library.

In a first step, we searched the bibliographical databases of ACM, IEEE, ScienceDirect and PubMed. The search query specified the following criteria for the abstract or title of literature: (dementia OR alzheimer) AND (context OR location OR activity OR ambient OR situation) AND (person OR people OR individual OR adult). ACM gave 10 results, IEEE 34, ScienceDirect 5, PubMed 1. In a second iteration, we removed candidates that did not evaluate and assess their technical solutions with people with dementia. This clearly showed that very few of the research projects actually included user trials: ACM was left with 1 result [52], IEEE 0, ScienceDirect 1 [46], PubMed 1 [40]. The number of publications on dementia and context that also performed evaluations with end-users are very low and does not provide sufficient material to define a design space for creating assistive applications. However, we used these papers as a starting point and elaborated on the respective projects they originated from. In a third iteration, we therefore searched references for projects that focused on assistive applications in dementia care. This led to 3 additional Research and development projects [48, 53, 54].

3.2 Requirements and Needs of People with Dementia

Hughes et al. [13] emphasize the importance to respect the dignity of people with dementia. As discuss in Section 2.2, people with dementia face a threat to their own identity. Assistive technologies should be appealing to their users and not be perceived as stigmatizing [40, 51, 55].

For most types of dementia cognitive abilities degrade over time and at an individual rate (see Section 2). The design of assistive technologies must therefore be able to accommodate users even when their abilities change. Newell et al. [56] summarize requirements for user interface for people with dementia with "mitigate memory impairment, avoid cognitive overload" and "take into account individual characteristics of dementia". While to a certain degree these requirements are desired by all users, the reduced cognitive abilities of people with dementia and the emotionally very demanding situation makes these rules imperative.

To provide adequate support, the requirements and needs must be put into context of people with dementia and their caregivers's environment. Allan [3] suggests that "In common with us all, but probably to an even greater extent, the capacities of people with dementia and the ways they present and express themselves are affected by environmental factors. The general category of environmental factors can be further divided into those which are physical, social and temporal." Physical factors, such as noise or potentially unsafe configurations, can restrict people with dementia abilities. Social interaction is strongly related to personhood. Section 2.2 explained that people with dementia and their caregivers go through great lengths to preserve their identity in the face of others. People with dementia need to be reminded of future and past activities and events [10, 57]. Memory impairment also manifests itself as an increasing need for information about everyday issues. Hawkey et al. [10] cite an interviewee who wanted to know the role of the participating person (in this example a physician), the location of this person and the route, departure time, and what to wear. The authors also found that some participants had difficulties to relate with time or recognize people they know.

A cause for frustration was the increasing difficulty of some participants to use known devices and initiating or completing even simple tasks [10, 57, 58]. Wherton and Monk [58] analyzed the difficulties people with dementia are faced with when performing activities and how they can be assisted. They found that the difficulties were resulting from sequencing problems, problems finding things, problems operating appliances and incoherence. Sequencing problems occur when incorrect objects or actions for a given step are used. This was seen as a result of being unable to control stimulation from objects or affordances that are not relevant for that task.

The second cause for this problem is the degeneration of semantic memory. The impairment makes it harder for the person with dementia to distinguish similar objects types. Episodic memory problems led to forgetting steps that were already taken; hence, repeating them. Omissions of sub-goals were also reported, when the sub-goal was too similar to the overall goal. The problem finding items was seen for one as a result of episodic memory loss. The person with dementia would forget which places were already searched and repeat the search. The disability to identify visible items was also attributed to either not being able to subdue task-irrelevant stimulation or semantic memory impairment. The problem with using items was seen attributable the inability to comprehend the use of an appliance. The participants did not know when to use an appliance or found it too difficult to understand its functionality. This is seen as a result of not being able to select between action schemas or the inability to remember the actions that need to be performed. Incoherence is seen as the problem when person with dementia engage in activities that are not related to the overall goal.

The personal identity is embedded in their social context and determined by their role in social interaction. Social interaction is therefore vital for people with dementia, e.g. [4, 51, 57, 59]. However the increased difficulty to manipulate items and problems impairment rises the bar for the person with dementia to interact with their social environment. Being more and more confined to their residence also affects social activities [59].

Dementia aid is primarily situated within the residence of the people with dementia, not on activities outdoors. Even though people with dementia, at least at the early stages of their illness, appreciate outdoor activities [59]. However caregivers fear for their love one's safety and are therefore reluctant to let their protege leave their safe environment alone. People with dementia may also be anxious about getting lost because they are uncertain about their location and finding their way home [57, 59]. People with dementia feel more conformable in familiar places. Brittain et al. [59] found that people with dementia can use landmarks or ask other people to find their bearings. One interviewee would use photographs of older buildings to link the past memory with the current landscape. To reduce uncertainty about the person with dementia location, Wherton and Monk [4] suggest reinsure both parties by mutually sharing contextual information. Through mutual awareness, "the function of the technology becomes communication instead of monitoring" [4].

3.3 Context-aware Assistive Technologies for People with Dementia

We consider the context-aware properties as an inherent part of most assistive applications for people with dementia and their caregivers to accommodate the users' needs and requirements in a dynamic environment. The motivation for this work is to provide designers and developers with a tool to make an informed decision on the use of context and context-awareness. The following projects were selected for our literature review:

- **KITE:** The Keeping In Touch Everyday (KITE) [40] project developed an outdoor navigation and communication system for people with dementia. The person with dementia carries a mobile device. It has a call button to contact the caregiver and a navigation function. The navigation function presents the person with dementia with instructions to find their way home. Additionally, the mobile device tracks the person with dementia's position as well as the device and alert state. These contextual information is presented to the caregiver via a web interface.

- **COACH:** COACH [60–62] is an activity assistant for the hand washing process. The system visually tracks the user's hand movement and process relevant items. The system bases its decisions on current observations and the user's level of dementia and emotions. Emotions are referred to as attitude (dementia_level, awareness and responsiveness [60]). Only when the person with dementia experiences difficulties with the task, COACH presents the user with either visual or audio prompts. If prompts are ineffective and the person with dementia cannot resume the task, the caregiver is called. The user's comportment influences the attitude and dementia variables over time.

- **COGKNOW:** COGKNOW [21, 54, 63, 64] is a EU funded project to develop a comprehensive support system for people with mild dementia. COGKNOW extends the realm of the person with dementia's residence. The person with dementia accesses services either through a stationary touchscreen interface or a mobile device. Activities are supported with a context-aware reminder system, video recorded instructions for a set of activities and simplified access to services. The reminder system triggers time-based and event-based reminders. Reminders are set by a caregiver [64]. Simplified access to music, radio and communication service are presented by both stationary and mobile device. Outdoors, the person with dementia has access to reminders and communication on the mobile device. An additional navigation function to get home is presented. Social communication is provided with a simplified interface to the phone. The person with dementia is presented with pictures of each caregiver to call. A help button is provided to directly call the main caregiver.

- **Context-aware Wayfinder:** Chang et al. [52] developed a navigation system for people with cognitive impairments, including dementia. The system guides their users to a destination by presenting images of the next waypoint and overlaying directions for the user's route. User and caregiver can call if needed. The system records the route progress and compliance. It presents this monitoring information to an authorized person.

- **ExPress Play:** ExPress Play is an application for people with dementia to engage in a creative activity through music. The system provides a touch screen and an easy to use interface. Users can select their emotion (happiness, sadness and anger) which influences the music being played and the visualization of the sound. The users interact with the application by dragging a finger across the screen. The system draws shapes depending on the speed of movement and plays different sounds [46].

- **CPVS:** The Cell Phone Video Streaming (CVPS) system [53] is a mobile reminder for people with mild dementia. The system consists of a smart phone for the person with dementia and a workstation with video camera for the caregiver. Reminders are video clips that are presented to the person with dementia. The person with dementia's caregiver records and schedules the reminders for the user. The smart phone downloads videos and notifies the person with dementia at the given time. The person with dementia needs to confirm the reminder by pressing a button. Reminders' confirmation state is accessible to the caregiver via a web-based interface.

- **MemExerciser:** MemExerciser [48] alleviates episodic memory impairment by recording and later replaying a person with dementia's passed experiences. The system consists of three parts: mobile sensors for life-logging, the CueChooser application to create a narrative of the person with dementia's experiences and MemExerciser to replay the narrative. A person with dementia carries a mobile camera with tree-axis accelerometer (Microsoft SenseCam[1]), an audio recorder and a GPS. The camera and GPS record data in predefined time interval, the audio device records constantly. The recorded information is later preselected by the CueChooser application based on the context meta data. The caregiver further refines and tags the data to select good memory cues for the person with dementia. The person with dementia can partly compensate the memory impairment by "recalling" past experiences with the MemExerciser application.

[1] http://research.microsoft.com/en-us/um/cambridge/projects/sensecam/

3.4 Context and Context-awareness

Context-awareness is an accepted paradigm to adapt assistive technologies to known contexts of use during design time and can adapt to a dynamic environment during runtime to continue mediating between the user under new circumstances [65, 66].

This section presents the categories of context variables and context-aware behaviors for dementia care that were identified in literature. We use the definition of context and context-awareness as provided by Dey and Abowd [26]. Their definition is as follows: "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. [...] A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task.". This implies context is a fairly broad concept. Their definition does however provide helpful cues to determine if a piece of information is context or not: It puts contextual information within the scope of the interaction between the user and the system and it does not limit context-aware behavior strictly to context that is obtained during runtime.

Dey and Abowd propose four primary context dimensions to describe the situation of a subject [26]:

- **Activity:** the intrinsic properties that determine the state of an entity. E.g. feelings, tasks or status.
- **Identity:** the extrinsic properties that describe an entity independent of time and location. For example the name of a person, the phone number or personal relationships.
- **Location:** the location of an entity in a physical space.
- **Time:** the location of an entity in time.

Section 3.4.1 extends Dey and Abowd's categorization of context for assistive technologies in dementia care. We studied the research and development projects identified in the review and literature on the needs and requirements to elicit the second level context types that are relevant to provide services and information to people with dementia and their caregivers. Literature on needs and requirements drew our interest to identify context types that have not yet been used in current applications.

We also studied the runtime behavior of assistive technologies for people with dementia in literature that use context to provide relevant services and information to the user. Section 3.4.2 summarizes our findings as context-aware services.

3.4.1 Context Types for Dementia Care

In this section, we describe the type of context information that the assistive technologies in our literature review used to provide services to people with dementia. Symptoms of dementia relate to impairment of cognitive functions that process these context types. Assistive technologies can mitigate the effects of dementia by offering services that support impaired cognitive functions. Table 3.1 shows which context types assistive applications relied on to provide those services to their users. We used Dey and Abowd's framework to classify the before mentioned context types

- **Activity:** The activity context type describes the intrinsic properties of an entity [26], e.g. a person or a device. Dementia affects the ability of people with dementia to perform activities and influences their emotions. Their abilities and emotional state influence the dialog between a person with dementia and the assistive application. Activity also describes the capabilities and state of devices. The following context types were found:
  - **Emotion:** Dementia influences a person's emotions and their ability to control emotions [59] and anxiety [10, 59]. Rebenitsch et al. [67] reckon that frustration/fear, confusion and anger were influential emotions that indicate the onset inappropriate behavior. Hoey et al. [60] consider the variables dementia_level, awareness and responsiveness for their activity assistant.
  - **Capabilities:** Capabilities describe services or functionality of an entity. People with dementia expressed the desire to know more about whom they are interacting with [10], distinguish between similar items [58] or how to use a device [10, 58]. This value helps to define semantics of entities, including competencies of people, types of places, and device functionalities.
  - **Action:** The action describes the goal oriented process an entity is performing [61, 63, 68].

Projects	Activity					Identity		Location				Time		
	Emotion	Capabilities	Action	Status	Preferences	Name/Identifier	Personal Relationship	Orientation	Position	Relative Location	Semantic Location	Precise	Span	Semantic Time
KITE				×		×	×	×	×			×		
COACH	×	×	×			×	×	×	×	×		×		
COGKNOW		×	×	×	×	×	×	×	×			×	×	×
Context-Aware Wayfinder						×	×	×	×			×		
CPVS				×	×	×	×					×		×
ExPress Play	×											×		
MemExerciser								×	×			×		

Table 3.1: Context types in dementia care

– **Status:** The status describes the current state of an entity. For people, this context type can describe their availability [69]. For household appliances, the status can describe if they are on or off [63].

– **Preferences:** Assistive applications should consider the users' personal preferences [10]. This context type specifies stable personal preferences, meaning they are not subject to frequent change. Examples include language settings, date formats, or color settings; e.g. [63].

- **Identity:** Identity is needed to identify participants and their relationships. The name of an entity and Social relationship is of particular importance in dementia care. The social relationship context type links two or more persons. People with dementia are increasingly dependent on their social context for care and social activities, e.g. [4, 10, 59]. Furthermore, people with dementia may experience difficulty to recognize how they are related to some people in their social context [4, 10].

- **Location:** people with dementia experience difficulty to orient themselves physical space, even in once familiar places [10, 59]. They may not recognize their current location or remember how to reach a certain destination, for example their home. We identified the subtypes: orientation, position, relative location and semantic location. Orientation shows the direction in which to move from one place to another. The position determines the current location, for example for navigation assistance or monitoring. A semantic location denotes the meaning of a place. For example a "bakery" is a place that has a bread service. Hence, if the person with dementia's semantic location is "bakery", this person is in that place.

- **Time:** Dementia affects episodic memory and temporal orientation [4, 10]. People with dementia find it increasingly difficult to recall recent events, plan activities and how to relate to time. Precise time, time span and semantic time were identified. Precise time and time span are used to set reminders, either precise or within a certain threshold. Semantic time refers to an event entity in the user's context, for example lunch time or the time to watch the evening news.

3.4.2 Categories of Context-aware Services

Assistive technologies can help people with dementia to cope with the symptoms of dementia by offering services for the tasks that they find increasingly difficult to do on their own. Table 3.2 shows who the users were, the types of context-aware services they used and where the applications were deployed (i.e. indoors or outdoors). The assistive technologies in our survey offered the following services:

Project				Category					
Name	Reference	Users	Settings	Activity Assistant	Reminder	Life-Logger	Information Provider	Communication	Navigation
KITE	[40]	People with mild to moderate dementia, caregivers	outdoor					×	×
COACH	[60–62]	People with moderate-to-severe dementia	indoor	×				×	
COGKNOW	[54, 63]	People with mild dementia, caregivers	indoor, outdoor	×	×		×	×	×
Context-Aware Wayfinder	[52]	Mental retardation, epilepsy, organic depression, Parkinsonś Disease, dementia, schizophrenia, organic brain syndrome	indoor, outdoor					×	×
CPVS	[53]	People without cognitive impairment, people with mild dementia, caregivers	indoor, outdoor		×			×	
ExPress Play	[46]	People with mild to moderate dementia	indoor	×					
MemExerciser	[48]	People with mild cognitive impairment, mild Alzheimer,moderate Alzheimer, caregivers.	indoor, outdoor			×			

Table 3.2: Categories of context-aware applications in dementia care

- **Reminder:** A reminder system is a memory assistant to plan and structure future events and activities. The system triggers reminders when certain conditions are met (e.g. time or location is reached). A notable example of context-aware reminders is the CybreMinder [70]. In dementia care, HYCARE [64] supports setting reminders with several context types.

- **Activity Assistant:** While reminder systems remind users when activities are due, activity assistance tells users how to perform activity of daily living (ADL). Activity assistants vary in activities they support, and the type of support they provide. The COGKNOW DayNavigator [63] displays video sequences that show how to perform a task. The user interacts with a touch screen to play a sequence. Automatic activity assistants delve in the realm of artificial intelligence. The user's context is monitored to intervene when the user is deviating from the plan to complete the task (e.g. [46, 61, 68]). The development of intelligent activity assistants still faces many challenges [61]. The COACH system is seen as the most sophisticated ADL assistant [61]. It guides a person with dementia through the hand washing process [61] .

- **Information Provider:** Information providers use context to present relevant functions or information objects to the user. For example the COGKNOW DayNavigator offers a simplified access to in-house devices and other services. The functions available change when the person with dementia is outdoor. An example for the latter are 'information appliances' [10]. These applications provide people with dementia detailed information about previous, ongoing, and future activities.

- **Communication and awareness:** Communication and awareness systems extend social relationships and awareness beyond time and location. Communication is either asynchronous or synchronous. For example, the COGKNOW DayNavigator has a picture-based interface to a stationary and mobile phone. The awareness function makes one entity's context visible to others. An application of awareness in dementia care is monitoring. For example the KITE system [40] shows the location of the person with dementia to the caregiver. A context-aware system for people with dementia was proposed by Mahmud et al. [69]. The person with dementia uses a mobile phone to communicate with his social network. The system stores the type of social relationship for each contact and their availability. The personal caregiver can monitor the person with dementia 's current location and schedule.

- **Navigation:** A navigation system guides a user through physical space to a desired destination. The projects COGKNOW [54] and KITE [40] both have a guidance function to help the person with dementia find their way home. A navigation system that considers location and time was proposed by Mahmud et al. [69]. Todo items are placed in the person with dementia's time, location and social context. The navigation system helps the person with dementia to find the location of a given todo list item in a timely manner.

- **Life-Logging:** Life-Logging complements a person's memory function. It records a constant stream of information during the day as images, sounds, location and time. The information is later processed to reconstruct the user's experiences [48].

3.5 Design Recommendations

The purpose of our work is to help designers to map the needs and requirements of people with dementia to the context dimensions activity, identity, location and time [26]. Our literature study shows, that this field is drawing a lot of interest from the research community, which is reflected by several large scale research projects. However, only few applications were tested with the actual target group. This is not surprising, given the following two reasons. First, developing and testing for people with dementia is a cumbersome process. A detailed discussion of a design and development process of assistive technologies for people with dementia is given in Section 4.2. In short, the specific disease does not allow a traditional user-centered approach that designs for archetype representations of users. Designers who collaborate with people with dementia face a number of challenges in their effort to understand the requirements and needs of their users [7, 9, 10]. They must develop systems that are tailored to individual users' context to reduce cognitive load, without putting users under pressure, who often provide only vague and sometimes conflicting information [7, 9]. Second, there is no "user with dementia" archetype a designer can aim for. While people with dementia share many characteristics, the advancement of the dementia syndrome is different for each person. Also the people with dementia and their caregivers's coping strategies will differ from case to case [14]. Designers must therefore not only consider the person with dementia's cognitive abilities, but also personal and social aspects. This was the main reason our survey focused on projects in which people with dementia participated as users. A challenge during our survey was to determine whether a piece of data is context, as defined by Dey and Abowd [26] or not. During the study of assistive software for people with dementia, the perspective of context and context-awareness provided us with a first impression of the role of context in the design process.

We summarize these findings as a set of basic design recommendations here. The recommendations are distilled from the practices presented by the projects and papers we studied for this survey. We listed good practices that occurred in one or more sources, and labeled them with a fitting title. With these design recommendations we want to provide a set of general guidelines and rules that lead to informed design for assistive applications for person with dementia. Since performing user evaluations with this specific user group is complex and often undesirable, having these guidelines can be of great help to create accessible assistive applications tailored according to the target group.

- **REC 1 Represent time explicitly:** Person with dementia rely on a concrete notion of time and progress in time to alleviate the impacts of episodic memory impairment. Time is therefore an important non-functional requirement, which is present in all the services we studied. Time is often combined with other context information. E.g. a reminder for medication may also consider the location to present reminders when the person with dementia is in the right room. Or an activity assistant may adapt the triggering of prompts depending on the person with dementia's mood. An appropriate interactive system should schedule events in the interface and display reminders and other information as well as recording time stamps in live logging for later retrieval.
  - This recommendation is based on: Wherton and Monk [4], Hawkey et al. [10], Dröes et al. [57]
  - This recommendation has been applied by Robinson et al. [40], Riley et al. [46], Lee and Dey [48], Chang et al. [52], Hoey et al. [61], Davies et al. [63]
- **REC 2 Label temporal events:** Temporal impairment can be alleviated by giving a meaning to temporal events. People with dementia

find it increasingly difficult to make sense of time. This is referred to as semantic time in Table 3.1. Semantic time is inherently linked to other context dimensions. For example "lunch" is the time when a person eats at home, normally around 12:00h.

  - This recommendation is based on: Wherton and Monk [4], Hawkey et al. [10], Dröes et al. [57]
  - This recommendation has been applied by Donnelly et al. [53], Davies et al. [63]

- **REC 3 Make location data accessible at all times:** Use location in the dialog with people with dementia to mitigate topological and geographical disorientation. A typical service for the person with dementia is a navigation system that guides the person from its current location to a destination. Location also provides tracking capabilities to locate the person with dementia and trigger alerts. Semantic location is a location in combination with other context information. For example a shop or a rendezvous point, i.e. a place where two or more people are to meet at a given time. Location also manifests itself in the interface as choices of information of functionalities that are presented to the user. For example a controller removes access to the radio once the person with dementia leaves the house.

  - This recommendation is based on: Hawkey et al. [10], Dröes et al. [57], Brittain et al. [59]
  - This recommendation has been applied by Robinson et al. [40], Chang et al. [52], Donnelly et al. [53], Davies et al. [63]

- **REC 4 Explicitly and uniquely identify all people, concepts and objects in the user interface:** To avoid confusion, label all concepts, people and objects that might be accessed through the user interface. This needs to be done in an unambiguous way to avoid confusing the person with dementia. E.g. when to contact someone using a contact list, people with similar names could cause confusion. In this situation extra information needs to be added to increase the discrepancy between similar items. Person with dementia tend to misplace objects or be unsure which object to use. Activity assistants and reminders need to know which objects the person with dementia needs for their tasks. Identity can also be combined with subtypes of activity, such as the status of kitchen appliances.

  - This recommendation is based on: Wherton and Monk [4], Hawkey et al. [10], Dröes et al. [57]
  - This recommendation has been applied by Robinson et al. [40], Chang et al. [52], Hoey et al. [61], Davies et al. [63]

- **REC 5 Put the social network central:** The first line of help comes from other people: caregivers, other relatives, medical professionals and friends. The interface can reassure person with dementia that there are people they know reachable for help by including a contact list. For example: one presentation of social relationships is an address book that lets a person with dementia call a contact. An alerting service uses social relationship to send notifications and escalate alerts to multiple contacts is an example for a background service. Additional information about the contacts, such as competencies or availability, can help to route notifications to contacts that are the most likely to help.

  - This recommendation is based on: Wherton and Monk [4], Monk [51], Dröes et al. [57], Brittain et al. [59]
  - This recommendation has been applied by Robinson et al. [40], Chang et al. [52], Donnelly et al. [53], Hoey et al. [61], Davies et al. [63]

- **REC 6 Show the current activity at all time:** The assistive application should show what the currently planned activity is at all times. This relies on an agenda that is available with the person with dementia daily activities. We found "user activity" is, together with time, the most important but also the most demanding to incorporate into the system design. Preferably, the previous activity and next planned activity are included in the user interface design.

  - This recommendation is based on: Wherton and Monk [4], Hawkey et al. [10], Wherton and Monk [58], Brittain et al. [59]
  - This recommendation has been applied by Robinson et al. [40], Donnelly et al. [53], Hoey et al. [61], Davies et al. [63]

- **REC 7 Foster Personal Identity:** People with dementia and their caregivers are very sensitive about how they are perceived by others. Maintaining their personal identity, respect and dignity is vital for people with dementia and their caregivers. Assistive applications should be appealing to their users and not be perceived as stigmatizing. In addition to functional requirements, the design must therefore consider the individuals' preferences and blend into their environment.

- This recommendation is based on: Hawkey et al. [10], Hughes et al. [13], Monk [51], Newell et al. [55], Dröes et al. [57], Brittain et al. [59]
- This recommendation has been applied by Robinson et al. [40], Riley et al. [46], Donnelly et al. [53], Davies et al. [63]

Chapter 4

Designing Applications with People with Dementia

In this chapter, we consider the design and development process of assistive technologies for people with dementia. In the previous chapter, we established a set of design recommendations. These design recommendations serve as basic guidelines. They are no substitute for involving people with dementia in the design process. In Section 4.1 we aim to outline some of the challenges that designers can face when collaborating with people with dementia. Section 4.2 discusses the steps in the design and development of assistive technologies for people with dementia. The difficulty for members of the design team is to understand the user's requirements and needs and establish adequate technical specifications for an interactive system that will help the users. In Section 4.3, we therefore propose to use a model-based approach that allows to concentrate efforts on conceptual modeling.

4.1 Collaborating with People with Dementia

Involving people with dementia and their caregivers in the design process requires empathy for the users and awareness of their abilities, needs and to their environment [9, 51, 71]. People with dementia are usually older people who are affected by age related degeneration of physical abilities such as vision, hearing or tremor [10, 20]. The rate of decline of cognitive functions differs from person to person [5]. Also the degree to which people with dementia are aware is individual [10, 34]. Dementia also has a disruptive effect on the person with dementia's social context [42, 43, 72]. The primary caregiver, often the spouse or another close relative, take an important role in supporting the person with dementia [43]. Caregivers are therefore also vital stakeholders in the design process. They hold considerable sway over the person with dementia and need to be convinced of the project's merits [7, 10, 21, 73].

Obtaining informed consent from people with dementia is especially difficult for several reasons. Giving consent may be a legally sensitive issue for a person with dementia [73–75]. Furthermore, caregivers may be unwilling to expose their loved one to an unknown and potentially stressful situation. The design team must therefore clearly communicate the aim of their involvement and that they can quit at any time [73, 74].

Requirements and needs are established in multiple iterations in collaboration with users [21, 40]. Literature may provide additional information to prepare workshops or complement findings [9, 17]. Aside from needs and requirements that concern the user group, the situations of individual people with dementia and their caregivers should also be considered [21]. A person's past and current relationships strongly influence their identity [14, 35–37]. As dementia progresses and the short-term memory declines, people with dementia increasingly conceptualize their world based on long-term memories [35, 38, 39]. Caregivers too base present decisions on their memory of people with dementia before the dementia onset [14, 74]. Maintaining the people with dementia "personhood" is one of the main endeavors of their caregivers [14]. This dependence on previous events reflects itself in the collaboration with people with dementia and their caregivers. Having background information on the stakeholders helps to better connect with the stakeholders [35].

A design team is faced with a number challenges when preparing workshops with people with dementia and their caregivers. It is difficult for designers who have no previous contact with person with dementia to grasp the complexity of such users. Yet people with dementia's contribution is important to gain an understanding of their unique needs and requirements [40, 75]. As Stalker et al. [75] point out, if the person with dementia is the user, then "Reliance on carers for this information is foolhardy".

To elicit the people with dementia requirements needs, designers must be able to interpret vague and contradictory information [3, 7]. Direct questions should be avoided because people with dementia could think they are being tested and they must answer the question correctly [3, 74, 75]. Empathy and an understanding of the users are therefore essential to interpret non-verbal information, such as the person with dementia's reaction to questions [7, 10, 76].

Narrative-based methods are an accessible way for people with dementia to communicate their own perspectives. Narratives are centered around the personal identity and personal experience [8, 35, 74, 77]. Hence by using methods to that allow readers to feel personally involved, the users are being portrayed as individuals instead as subjects [35]. Visual objects can provide salient cues to steer the conversation flow and encourage the discussion with people with dementia [3, 7, 35, 63, 77].

The aim of this thesis is to extract more precise time information from storyboards that the behavior of an application. Storyboarding is a visual, narrative-based method and an established tool in user-centered design (UCD) to elicit user requirements and needs. The graphical notation used for creating storyboards makes complex details comprehensible and allows to add contextual information.

Storyboarding also enabled people with a mild form of dementia to take part in the design of assistive technology. With storyboards, people with dementia could provide useful comments on user interface mockups discuss their daily activities and context of use with storyboards [7, 21, 40]. Allan [3] explains that people with dementia the environmental factors that affect people with dementia most were physical, social and temporal, precisely the type of information that is found in storyboards. The language of storyboarding for designing interactive systems is discussed in detail in Chapter 5.

Sellen et al. [78] name several reasons that suggest the suitability of communicating in narratives and using storyboards. They analyzed how narratives were perceived when using storyboards compared to videos. They found that storyboarding worked favorably for elderly users. The current availability of all related panels supported participants' memory. Users could navigate in time and space of the story. This, the authors argue, is also advantageous for stakeholders with memory problems. Furthermore, elderly users to felt more involved with storyboards [78]. This is in line with McCloud [79] work on comics, who explains that the abstract nature of characters in comics lets users "fill" the blanks in the message with their own personal content. The ability to self-reference is therefore a weighty argument for storyboarding as collaboration tool with people with dementia, because it accommodates their own personal views.

4.2 Design and Development Process

User-centered design (UCD) is a type of multi-stage process for the design and development of interactive systems. In a UCD process, user requirements and needs are the driving force for the design. The aim is to adapt a system to the users, instead of users having to change their way of work to accommodate the system. Designers use descriptions of archetype users make design choices for the characteristics, goals, tasks and operating environment of archetype users. Each stage ends with an evaluation of the results with final users. A UCD design process, until the final product adequately represents the user requirements and needs [80].

Traditional UCD techniques are suitable for people without cognitive impairment. However, designing and developing assistive technologies with people with cognitive impairments requires current practices to be extended to account for users specific abilities and needs [7, 19, 55, 81]. Even though people with dementia do share common traits, each user has individual abilities, requirements and needs that must be considered in the design process and in the final product [7, 21, 82].

It is also very difficult to design and develop products that people with dementia are willing to use in their everyday lives, without a profound understanding of the users. There is a huge difference between the designers life-experiences and that of people with dementia. Designers must therefore discuss the design with users since they cannot on their intuition to design for a fictive person with dementia [7, 9].

A challenge for designers who collaborate with people with dementia is to build a relationship with them. Designers must show empathy to their users and accommodate the users' their current abilities and need [7, 9]. Furthermore, assistive technologies are designed for use in a social context and for every day activities. The design must be "fashionable", especially for users who struggle to maintain their identity and fear to be stigmatized [40, 51, 55].

Figure 4.1 shows the UCD process that was used for the COGKNOW project [19]. Similar approaches were also used in other projects of assistive technologies for people with dementia, e.g. [7, 76, 83]. The emphasis of design and development of assistive technologies for people with dementia is on the translation of user requirements and needs to technical specifications of the interactive system. This underlines how important and challenging is to involve people with dementia and their caregivers in the design process [7, 9, 19].

The COGKNOW design and development process includes four steps,

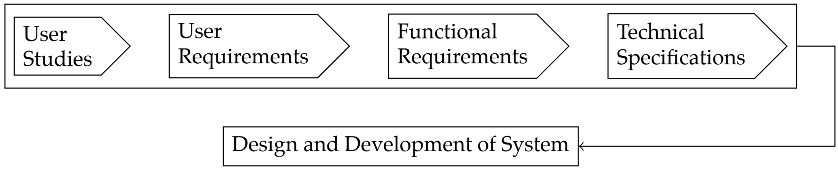


Figure 4.1: Design process of the COGKNOW project to translate user requirements and needs to technical specifications of an assistive technology. "Supporting People with Dementia Using Pervasive Health Technologies,2010, 101-111, Managing the Transition from User Studies to Functional Requirements to Technical Specification, Hettinga et al., With kind permission from Springer Science+Business Media"

user studies, user requirements, functional requirements and finally technical specification, to gradually establish the requirements and needs and later develop a set of technical specifications of the final application. Each step may require several repetitions.

- **User studies:** In the first step, the design team conducts workshops with users to gather information about the everyday life of their users and problems they struggle with. Storyboards can help people with dementia to understand and comment on role of technology can play to prolong independent living [7, 21].

- **User requirements:** Next, the design team analyses how technology can mitigate the negative effect of dementia and help users to cope with the symptoms of dementia. The results are summarized as a set of user requirements. The design recommendations, presented in Section 3.5, can inform designers on the type of information and services that assistive technologies can provide to people with dementia.

- **Functional requirements:** Functional requirements is an intermediate step between the user requirements and the technical specifications. The resulting catalog of functional requirements describes how the system will address the user requirements and needs. The framework, discussed in Section 3.3, provides a tool to can inform the process of how user requirements and needs can be translated into technical specifications.

- **Technical specification:** The functional requirements are translated to technical specifications for the final system. Technical specifications contain conceptual models, e.g. process models or data models, as well as technology specific descriptions of user functional requirements.

4.3 Model-based Approach for Assistive Technologies

In the next phase, the assistive technology is implemented based on the technical specifications. We suggest to use a model-based approach to create the final application. A model-based approach is suitable for assistive technology for several reasons: The challenge in designing and developing lies in eliciting the users' design knowledge, i.e. their requirements and needs, and providing people with dementia with personalized assistive technologies [7, 21, 65, 84]. The main activities of designers and developers in a model-based approach is to create formal conceptual models of the user requirements and needs. Based on the conceptual models, designers and developers use tools to create the assistive technology. Models can also be adapted during runtime to dynamically adjust the application to changing user requirements and needs [85–88]. A model-based approach therefore allows to create personalized assistive technologies from the same conceptual models [65, 66, 89]. Models make design knowledge reusable. Knowledge management techniques can be applied to extract generalizable design knowledge and encoded as pattern [90, 91]. The representation of user interfaces as formal conceptual models allows to integrate other knowledge sources into the interface design process and map domain knowledge to user interface models [92].

In this thesis we model design knowledge as web ontology language (OWL) [93] ontologies. OWL is the recommended world wide web consortium standard to model complex knowledge representations. The formalism of OWL is based on description logic (DL). Formal logics such as DLs allow to verify the consistency of the knowledge base and to discover implicit modeled knowledge by reasoning on the knowledge base. A reasoner infers the structure of the knowledge based on the on known class and property descriptions. DL is domain independent and suitable for conceptual modeling. This makes it ideal to formalize knowledge in the requirements phase [94]. Because OWL ontologies are codified in formal and machine-understandable way, knowledge can be shared and combined [95]. OWL ontologies are being developed in knowledge intensive domains such medicine, physics or biology. Several of open and closed source software libraries, editors (e.g. Protégé[1], KAON2[2]) and reasoners (e.g. Pellet[3], FaCT++[4]) are available [96, 97].

Ontologies provide a common vocabulary to formally describe a domain of interest. A generally accepted definition of ontology in computer science was developed by Gruber: "An ontology is an explicit specification of a conceptualization".

The main building blocks of an OWL ontology are classes, properties and individuals. In DLs, classes are also called concepts and properties as roles [99]. A class is a set individuals. Individuals are characterized by their properties; data properties are relationships between individuals and primitive data types, such as string or integer values. Object properties are relationships between individuals. OWL supports the relationships subsumption, equivalent, disjoint and union between classes and between roles [100]. OWL has different sub languages, also called species, to make the tradeoffs between expressiveness, scalability and efficient reasoning. OWL Full is the most expressive species but is undecidable. OWL DL was designed to provide maximum expressiveness while guaranteeing computational completeness. OWL Lite is the least expressive sub language. The formal semantics of OWL DL and Lite is grounded in DL[5]. The forthcoming version is OWL 2 [100]. It adds new features to OWL 1.1 and is backward compatible. OWL semantics is based on the open world assumption (OWA), which assumes that the knowledge base is incomplete [96]. DL distinguishes between primitive and defined concepts. A primitive concept is a set of individuals that exhibit characteristics inherent to their being. Formally, a primitive concept definition has only necessary conditions. A defined concept is declared by necessary and sufficient conditions [96]. Instances of a defined concept may change over time. Consider the following example for people with dementia and caregivers: Person is an a primitive concept. Caregiver and person with dementia on the other hand are defined concept. Individuals are only caregivers as long as they care for someone in need and an individual is only a person with dementia if it is a person who has dementia. Also in this example caregivers are not necessarily humans.

Ontologies enable to exchange and reuse of knowledge by abstracting

[1] http://protege.stanford.edu/

[2] http://kaon2.semanticweb.org/

[3] http://pellet.owldl.com/

[4] http://owl.man.ac.uk/factplusplus/

[5] For the remainder of this thesis we refer to OWL DL as OWL.

details and relating general and specific ontologies across abstraction levels. Upper-level ontologies contain abstract concepts that independent of specific domains. They model the connections between several domain specific ontologies.

OWL ontologies can be complemented with rule-based languages to model knowledge that cannot be expressed in OWL. In the DL syntax, axioms do not explicitly use variables. For example it is not possible to express two relationships between only two individuals [96]. The rule-based modeling paradigm describes knowledge as "if [premise] then [conclusion]" statements. For this thesis, we use the semantic web rule language (SWRL) [101]. SWRL is a combination of datalog and OWL. Both OWL and datalog are sublanguages of first-order logic and are therefore compatible [96]. SWRL can be extended with user-defined built-ins. The core built-ins add mathematical and string manipulations abilities to SWRL. For example the following SWRL states that if an interval begins when the other finishes, both intervals meet:

$$\forall i, \forall j : (\text{Interval}(i) \land \text{Interval}(j) \land \text{to}(i) = \text{from}(j) \rightarrow \text{meets}(i, j))$$

SWRL rules cannot add or remove individual members or alter the value of data types. Rules can however make new property assertion but not to remove properties or to add or remove individuals. An implication of the OWA is that negation as failure is generally not supported. Under the OWA, the domain is assumed to be infinite, unless explicitly stated otherwise. The reasoner cannot negate a test, because the knowledge base is to be incomplete.

Chapter 5

Storyboarding for Requirements Engineering

Engineering an interactive software system is essentially a creative activity that needs input from both technical and non-technical people. However, we are facing many difficulties getting these typical multi-disciplinary teams involved [19, 102, 103]. Current notations and tools often follow a strict separation of concern strategy in which members of such a team use the notations and tools they are accustomed with. Given the wide diversity of notations and tools, synchronizing the various efforts is cumbersome [104].

Informal design artifacts are very accessible to non-technical people and often only require pen and paper to make [105, 106]. Storyboarding is such an informal technique that is frequently used for the design of interactive systems [22] and that will be the basic notation for the contributions described in this thesis.

In Figure 5.1 a storyboard is shown that describes a setup for an exhibition. We use McCloud's works on comics [23, 107] as a reference framework for analyzing storyboards. Like comics, storyboards are a visual form of storytelling. Graphical depictions of imaginary or real things such as places, people or ideas are used to illustrate and convey ideas. Furthermore, drawing comics or storyboards is inherently spatial. The physical space that is used by sequences of drawings often visualizes the progression of the story in time. The sequence of images, their size, and the distance between images help the reader to move through time by

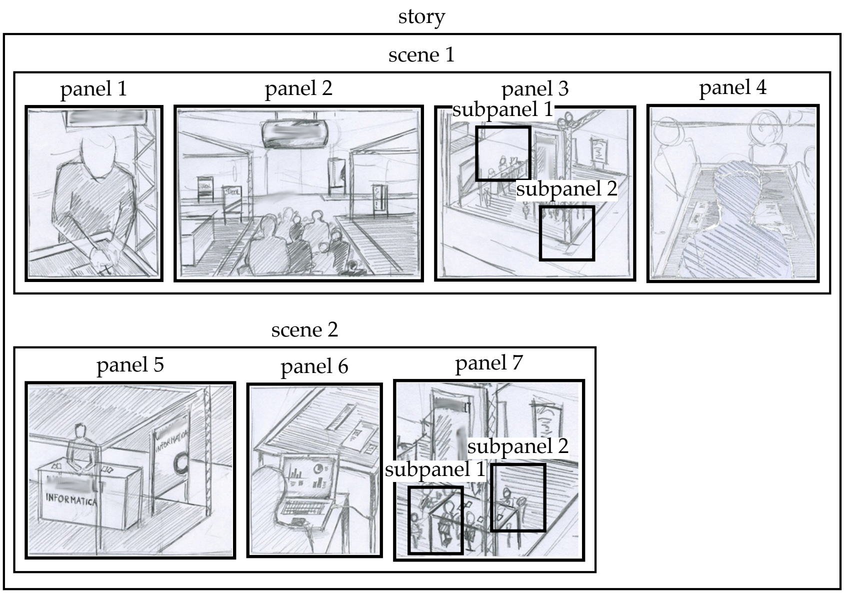


Figure 5.1: A storyboard presenting an interactive multi-touch system for exhibitions or fairs in seven panels

moving through space. Panels have a special role in comics. They are snapshots that explicitly show moments of the story. The story evolves between the panels and is developed further in the reader's imagination.

Unlike textual description of scenarios or engineering models, understanding storyboards comes naturally to people because images do not require specific knowledge to decode [23]. McCloud provides a comprehensive framework for comics, which is also useful for storyboarding. Because storyboarding is frequently used in early stages of the design process, storyboard languages and methods were developed to provide storyboard-specific terminology [102, 108–110].

A limitation of storyboards for further usage in an engineering process is that they are informal and subjective. There is no explicit model that is agreed upon, and the information in storyboards is therefore not accessible to computers. Further comments or graphical annotations can be added to improve understanding among members of the design team [105, 108, 109].

Yet without formal semantics, the content remains difficult if not impossible to process by a computer [111, 112]. Providing tool support that would allow to automatically infer new information from the knowledge base for the analysis of user requirements or transform model to other modeling languages is therefore complex and not possible [105, 106, 111, 112].

We claim there is already much temporal information readily available in storyboards that can be extracted automatically. Although this information is often still incomplete or even subject to change, most of the expected behavior of the software can already be deduced from the storyboard. We focus on extracting fine-grained temporal relationships from storyboards, a typical informal artifact that is used during the early design phase of an interactive system. Since time-related aspects are in general important requirements in the design of interactive systems, they should be elicited with users early in the design process [113]. Accordingly, we call our approach time in storyboards (Timisto).

Timisto will not constrain the creativity and freedom during storyboarding; we will use an informed, conservative translation that takes advantage of typical structures used for drawing scenario's. Informed means we use both the storyboard structure as well as special purpose annotations, conservative indicates we do not apply any other heuristics to deal with vague information in our algorithm. We show this translation is the cornerstone for linking informal artifacts and (more) formal artifacts in the engineering cycle. We argue that the behavior of interactive software is determined by the possible orderings of user actions over time that is supported. Exactly these orderings can be found in a storyboard.

In Section 5.1, we introduce the storyboard language for the Timisto approach. Timisto does not provide concepts to describe the content. Rather, the content is described by linking storyboard annotations to concepts of domain specific ontologies, that can be chosen freely to suit the designers and users needs. Annotations define the type of content that an image or group of image contains. Actors, for example can be described with personas or FOAF [114] user profiles.

In Section 5.2, we suggest that storyboarding and explicit time annotations provide an accessible way to implicitly model explicit time-related aspects of interactive systems. This is still an open issue in storyboarding [109]. Our survey of assistive technologies for people with dementia confirmed that time is an important context type and used in all the projects we surveyed. Three of our design recommendations, REC 1, 2 and 6, are related to temporal information.

We introduce a temporal domain ontology to structure the time implied by a storyboard. The formal semantics is based on Allen's temporal interval algebra [25]. With a special purpose algorithm, we calculate the temporal relationships in a storyboard in terms of Allen's temporal interval algebra and these relationships to visualize the passage of time in storyboard as a timeline.

A demonstration of how storyboarding in combination with explicit references to time can describe time-related requirements is given in Section 5.3. Time is an important part of storyboards, because the physical structure and layout of the storyboard visualizes the structure and passage of time. In Chapter 6, we explain how the temporal annotations allows to visualize to map the storyboard content onto a timeline. The timeline helps designers and users to visually analyze how users image they would use an interactive system over time and discover implicitly modeled relationships between different parts in the interaction such as parallel interaction. We also provide tool support to annotate digitized storyboards with precise information about the passage of time. The Timisto application is discussed in Chapter 7.

5.1 Storyboard Language

Storyboards are often drawn on paper, or if composed on a computer, images are assembled on slides with programs such as Powerpoint. Our interpretation of storyboards is strongly inspired by McCloud's work on comics [23, 107]. He defines comics as a "sequential art" or more verbose as "juxtaposed pictorial and other images in deliberate sequence" [23, pg. 9]. By defining a storyboard language, we want to clarify the way a storyboard provides information by means of images and structure. This combination of images and structure is very powerful to specify temporal information in storyboards.

The representation of a storyboard can be compared to a comic and presents images that are shown in a sequential order. These images are called panels. The meaning of the term panel will be explained below, but first we will give an example of a storyboard and its panels. The storyboard in Figure 5.1 on page 42, presents an interactive multi-touch system for exhibitions or fairs in seven panels. On the one hand, the system presented by the storyboard provides information to visitors of the booth at the exhibition. On the other hand, it allows visitors to enter their personal data to be contacted by the exhibitor afterwards. Panels 1 and 4 of Figure 5.1 zoom in to the multi-touch system and its users, panels 2,

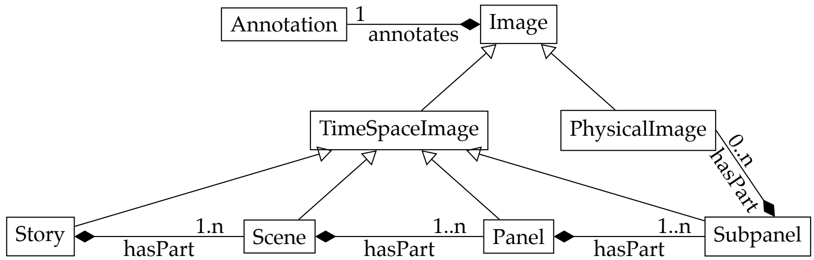


Figure 5.2: A storyboard contains images to visualize the passage of time as well as physical items. The passage of time is visualized by the structure of the storyboard and the size of images

3 and 7 provide an overview of the booth at the exhibition and panels 5 and 6 visualize the representative of the booth behind a desk, collecting information of the visitors that was entered into the multi-touch system.

Besides the aforementioned structure that is clearly visualized by the panels in a storyboard, other information can also be inferred from a storyboard. To make use of this inferred information for specifying temporal information in tool support, we propose to annotate basic elements of a storyboard. These annotations concern scenes (a group of related panels), panels (images in a storyboard) and subpanels. The relationship between them is shown in the storyboard model depicted in Figure 5.2. The characteristics of the storyboard's structural elements can be summarized as follows:

- **Scene:** A storyboard is drawn as one or more scenes by physically grouping panels of a storyboard that are related to each other in time or in space. In some comics, the author tries to fit all panels of one scene to a page to improve the readability of a comic. However, authors of comics can also present two different scenes in successive panels, just to emphasize significant distances between time or space [79].

- **Panel:** A panel is a window into a moment of the story, that shows what is happening during that time. The size of a panel often refers to the time the panel takes. Inside a panel, an actor performs an action during that moment that implies the advancement of time. An action is visually depicted as "motion" or "sounds". Although it is difficult to visualize motions or sounds in still images, there are several techniques to realize this [23]. Panels also steer the reader's

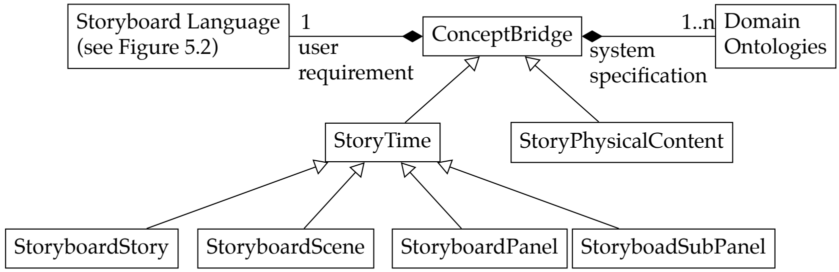


Figure 5.3: The storyboard is an interface to the design knowledge. The concept bridging ontology acts a mediator between the informal design knowledge in the storyboard and the formal design knowledge

interpretation of the story with the angle through which the reader views the story, the level of detail and the placement of objects within the panel.

- **Subpanel:** According to McCloud, a panel with more than one action implies more than one moment. A subpanel captures a specific action inside a panel, thus mostly shows one or more users performing an action. For each action that occurs in a panel a separate subpanel is used.

We provide an ontology, called storyboard ontology, to use the storyboard language for tool support to annotate the structure of digitalized storyboards and describe the content. The storyboard ontology consists of the storyboard language and a separate ontology that links each element of the storyboard language to one or more domain ontologies. We refer to this ontology as the concept bridging ontology, because it acts as a bridge between the informal concepts in a storyboard and their formal peers in the knowledge base.

The storyboard language ontology, shown in Figure 5.2, is used to annotate the storyboard and assign each annotation to an element of the storyboard language. An annotation consists of two coordinates that mark the place of the annotation on the storyboard.

The concept bridging ontology defines the vocabulary to describe the content the storyboard. Concept bridge classes connect one storyboard structural element with one or more domain concepts to describe the content of the annotation. This is shown in Table 5.1. The concepts Story, Scene, Task and Action are the terms to describe passage of time in a

Concept Bridge	userRequirement	systemSpecification
MetaData	Story	StoryEvent
StoryboardScene	Scene	SceneEvent
StoryTask	Panel	TaskEvent
StoryAction	Subpanel	ActionEvent
StoryObject	PhysicalIcon	A physical object

Table 5.1: Each concept bridge type defines one or more domain concepts for each structural element type of the storyboard language

storyboard. These are defined in the temporal domain ontology storyboards, discussed later in this chapter. Additional ontologies can be used depending on the type of information that has users want to describe.

5.2 Time and Space in Storyboards

Time is an integral part of storyboards, which make storyboarding an accessible tool to describe concrete examples of how users interact with an application and the context of use. However, the way time is visualized in a storyboard is not precise enough when concrete information about the passage of time is needed. Truong et al. [109] found that explicit depictions of time can affect a reader's understanding of a story. They argue that "time passing was a significant element needed to understand particular storyboards" [109]. In their study, participants initially felt that time is implied from the storyboard language and explicit depictions of time were unneeded. Yet after the authors added explicit references to time in the storyboard, 36% participants who had previously read the storyboard, changed their interpretation of the time. The visualization of time is also distorted when a storyboard spans several pages, because adjacent moments are not adjacent spaces [107].

5.2.1 The Timisto Approach

The Timisto approach builds on the findings of Truong et al. to add an additional layer of precise temporal information on existing storyboards:

(1) we extract temporal relations from a storyboard based on structure and content in combination with annotations for more precision and (2) when these temporal relations are incorrect we provide feedback to the user. Timisto does therefore not impose a new storyboarding paradigm on users. Annotations are carefully selected to require a minimum of work to add a layer of precise information on the storyboard so that it does not interfere with the normal storyboarding practices. In fact, these annotations can be selected once the creative process of storyboarding is finished and the storyboard is ready to be used for the further engineering of an interactive software system. Annotations of the structure of the storyboard have their time made explicit by defining precisely the time when they start and the time when they end.

For example, panel 1 in Figure 5.1 on page 42 can be annotated with specific timestamps that show it lasts from 11:40AM to 11:55AM. During that time the exhibitor checks the multi-touch system and observes the newly arrived visitors. Panel 2 starts at 11:41AM, when the group of visitors arrives at the exhibition, and ends at 11:46AM. In panel 3, both visitors interact with the multi-touch table: one group from 11:47AM to 11:55AM and a second group from 11:53AM until 12:00PM. These interactions represent two sub panels of panel 3. Panel 3 therefore lasts from 11:47AM to 12:00PM. Panel 4 looks over the shoulders of one of the visitors while using the multi-touch system from 11:53AM to 12:00PM.

Timestamps are provided by users and designers to discuss the progression of the story. These values are estimates and the precise timing is not important. What is important however are the temporal relationships between elements in the storyboard that users implicitly describe through the precise time stamps. For example, in panel 1 the exhibitor observes a group of visitors, who just arrived in panel 2. After having arrived, visitors gather around the multi-touch table in panel 3. This means that the action of observing visitors occurs when new visitors arrive. Furthermore, visitors must first arrive before the visitors can access the multi-touch table. With the precise timestamps, such temporal relationships between different parts of the storyboard can be automatically inferred.

5.2.2 Allen's Temporal Interval Algebra

We make use of Allen's temporal interval algebra [25] to describe temporal relationships in storyboards. This algebra has thirteen disjoint relationships that are presented in Table 5.2. The five basic relationships are before, equals, overlaps, meets and during. The relationships starts and

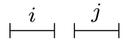
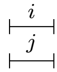
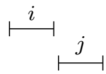
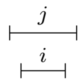
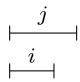
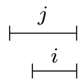
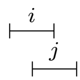
Relation	Inverse	Symbol	Definition	Example
before	after	$<, >$	$i^+ < j^-$	
equal		$=$	$i^- = j^- \wedge i^+ = j^+$	
meets	met-by	m, mi	$i^+ = j^-$	
during	contains	d, di	$j^- \leq i^- \wedge j^+ > i^+$ $j^- < i^- \wedge j^+ \geq i^+$	
starts	started-by	s, si	$i^- = j^- \wedge i^+ < j^+$	
finishes	finished-by	f, fi	$i^- > j^- \wedge i^+ = j^+$	
overlaps	overlapped-by	o, oi	$i^+ > j^- \wedge i^+ < j^+ \wedge$ $i^- < j^-$	

Table 5.2: Temporal relationships defined by Allen [3]. i and j are two distinct temporal intervals, where $i^- \leq i^+$ and $j^- \leq j^+$. $-$ represents the *from* value of an interval; $+$ the *to* value

finishes are two special cases of during. Each relationship has an inverse relationship (except for equals).

The temporal relationships between the first three panels of Figure 5.1 that were informally introduced for the example in the pervious section, are as follows: "Exhibitor observes" overlaps "Visitors arriving" (Panel 1 and 2). "Visitors arrive" before "Gathering around the multi-touch table" (Panel 2 and 3). Allen's temporal relationships are transitive: "Exhibitor observes visitors" before "They gather around the multi-touch table". Allen's temporal interval algebra is suitable for specifying time in storyboards for several reasons:

- Allen's temporal interval algebra is a generic algebra for specifying time and thus usable within most application domains and a good fit for how time is described in other artifacts in the engineering cycle. Temporal intervals can represent instances of events, which are the case for storyboards, or event types, which are the case for e.g. process models or dialog models.

- Allen's temporal interval algebra works with relative time, so the emphasis is on orderings and overlaps instead of the exact timing. Allen's temporal interval relationships provide a precise framework to describe temporal relationships in a way that is natural to people.

- Allen's temporal intervals can be nested, i.e. an interval can contain other intervals. This is suitable to model the relationship between types of events at different levels of detail.

5.2.3 Temporal Domain Ontology for Storyboards

Events are time-related concepts that organize and structure the story into meaningful parts. "Event" is used on other fields, such as physics, mathematics, or programming, but does not necessarily have the same meaning. We use the term "event" to refer to a time interval, not a point in time. Allen's temporal interval algebra [25] thus provides the suitable formal framework. A story consists of a sequence connected of events. Events can further contain subevents. Terms for events to distinguish between events types based on their level of granularity and the type of context information belonging to an event. For example, "Scenes" are high-level events that occupy a section in time or space. Scenes help to divide a story into concluding sections. A scene contains subevents that are "actions" of actors. An action may consist of sub actions. However, the terminology and properties of events in comics and storyboarding are informal and unclear [23, 110]. They are intended for a human audience and are not precise or detailed to easily translated into a precise model.

The aim of this thesis is to extract more precise information about how authors of a storyboard conceptualize the time. It is therefore important represent the structure and semantics of events in a more formal way. StoryboardML [111] defines temporal relationships for storyboarding based on Allen's temporal interval algebra. However, StoryboardML contains high-level storyboard language elements and two types of events, scene and action. When we developed the storyboard language for Timisto, mainly based on McCloud's work on panels and transitions between panels [23], we proposed for types of storyboard language elements, each type containing different context information. The storyboard language

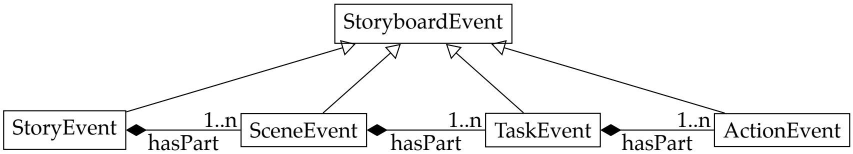


Figure 5.4: The partitioning of time in a story in a storyboard into scene events, task events and action events

is inherently temporal, hence each storyboard language element can be seen as a type of event with its own context information.

Event recognition in videos provides useful guidelines that can also be used to describe events in storyboards more precisely. Lavee et al. [115] studied the semantics of video events in applications such as surveillance, semantic video analysis, interactive systems. They found a lack of a common terminology, with terms such as event, action, behavior, activity often referring to the same or similar concepts, which they attribute to the ambiguity in the common language. The different terms refer to context that belongs to an event and to the position of an event in the event composition. Lavee et al. [115, pg. 491] summarize the common properties of events as:

- Events occupy a period of time.
- Events are built of smaller semantic unit building blocks.
- Events are described using the salient aspects of the video sequence input.

In addition to the type composition, events are also composed by time and content. Temporal composition refers to how events are related in time. Content composition refers to how events are abstracted from the video stream.

We present an ontology that can be used to describe the physical layout of the storyboard in terms of the type composition of time-related concepts (subevents and superevents) and how different events in storyboards can be situated w.r.t. each other in time and content. Figure 5.4 shows the main concepts that are part of this ontology and how these are related. Our ontology attempts to represent McCloud's [23] description of time concepts in comics, and thus storyboards, in a more explicit way. Our ontology is to describe time information that can be extracted

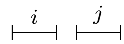
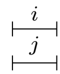
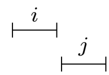
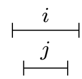
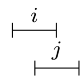
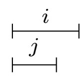
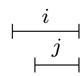
Relation	Rule	Example
before	$\text{to}(i) < \text{from}(j) \rightarrow \text{before}(i, j)$	
equal	$\text{to}(i) = \text{to}(j) \wedge \text{from}(i) = \text{from}(j) \rightarrow \text{equals}(i, j)$	
meets	$\text{to}(i) = \text{from}(j) \rightarrow \text{meets}(i, j)$	
during	$\text{from}(i) \geq \text{from}(j) \wedge \text{to}(i) < \text{to}(j) \rightarrow \text{during}(i, j)$ $\text{from}(i) > \text{from}(j) \wedge \text{to}(i) \leq \text{to}(j) \rightarrow \text{during}(i, j)$	
overlaps	$\text{from}(i) < \text{from}(j) \wedge \text{to}(i) < \text{to}(j)$ $\wedge \text{to}(i) > \text{from}(j) \rightarrow \text{overlaps}(i, j)$	
starts	$\text{from}(i) = \text{from}(j) \wedge \text{to}(i) < \text{to}(j) \rightarrow \text{starts}(i, j)$	
finishes	$\text{to}(i) = \text{to}(j) \wedge \text{from}(i) > \text{from}(j) \rightarrow \text{finishes}(i, j)$	

Table 5.3: The rules for the temporal relationships of Allen's temporal interval algebra [25]. Variables are universally quantified at the rule level. Inverse relationships are omitted

from storyboards to analyze user requirements or generate high-level engineering models. How the drawings are structured using scenes, panels, subpanels and even specific icons is used to drive the extraction process. Our ontology focuses specifically on storyboarding to describe the context of use of an interactive system. It therefore uses different terms for events, depending on their place in the composition hierarchy.

As discussed above, the physical layout of a storyboard illustrates the structure of the time. The content composition is therefore established by linking events to annotations on the storyboard that makes the structure explicit. The temporal composition is established with a set of rules, shown in Table 5.3 that infer Allen's temporal relationships based on the start and end of each event.

Our ontology is equivalent with the web ontology language (OWL)-Time ontology [116], but separate to specifically accommodate our research that might have required differentiation from the OWL-Time ontology. Since both use Allen's temporal interval algebra as the foundation for time specification, full equivalence is guaranteed and we can now use both our custom ontology as well as the OWL-Time ontology. By maintaing equivalence with other standard ontologies we ensure compatibility with other services and tools that use these ontologies. Before explaining how the actual extraction of temporal information is done, we define five event types that need to be considered for storyboards:

- **Storyboard Event:** A storyboard event defines the time span as an interval with the values *from* and *to*, i.e. the time beginning and the end of the event i, where $\text{from}(i) \leq \text{to}(i)$. Furthermore, each interval is unique and it is assumed that all events are known. This is needed because the semantics in OWL are based on an open world assumption (OWA) and without explicitly specifying all individuals of a class, negation cannot be answered. Note that storyboard events do not describe the "event domain" [115], i.e. other characteristics to specify what events are. Allen's temporal intervals only represent the occurrence in time [117]. The hasPart relationship represents the content composition of events. This is shown as the annotation nesting on the storyboard. If an event contains other events on the storyboard, its *from* value is set to that of its first descendant and the *to* value to that of its last descendant.

$$\text{hasPart}(i,j) \wedge \text{from}(i) > \text{from}(j) \rightarrow \text{from}(i) := \text{from}(j)$$

$$\text{hasPart}(i,j) \wedge \text{to}(i) < \text{to}(j) \rightarrow \text{to}(i) := \text{to}(j)$$

- **StoryEvent:** A story event represents the time of the entire story. It consists of the sequence of scenes that lead up to one or more actor achieving their goal and ending the story. A story event states how long a story took.

- **SceneEvent:** A scene event represents the time of a scene. It is what Lavee et al. [115] calls a "general event", i.e. an event which occupies a specific duration and consists of semantic building blocks. A story event would then be a superevent In the storyboard, a scene is most likely a group of panels on a page or a very large panel. Figure 5.1 contains two scenes: The first scene informs the reader that the main setting is an exhibition and the actors are an exhibitor and visitors. It shows a newly arrived group of visitors who gather around a multi-touch table. The second scene shows the exhibitor using a remote monitoring tool to analyze how the multi-touch table is used.

- **TaskEvent:** A task event is the time during which one or more subjects perform one or more actions to reach a goal. A task event is associated with one or more panels. A task event describes during what time someone did something at a location. Where is described by a location ontology. In the first panel of Figure 5.1, the main task of the exhibitor is to watch newly arrived visitors. His goal is provide information to visitors if they have questions.

- **ActionEvent:** An action describes the time of an image that visualizes motion or sound that advance the story in time. An action states when a subject does a task. The type of action is described by another ontology. Who is described for example in a persona. Again in the first panel of Figure 5.1, the action of the exhibitor is watching newly arrived visitors to be able to assist if needed.

5.3 Example of the Timisto Approach

In this section, we provide example of the Timisto approach by describing the time in the second scene of the storyboard in Figure 5.1. Figure 5.5 visualizes the relationship between the storyboard, the storyboard annotations, the concept bridging object and the events that describe the time in the second scene. This example is continued in Chapter 6 to explain how the temporal information can be used to render a timeline from the storyboard. The Timisto application, presented in Chapter 7, provides tool support to draw annotations on digital images of storyboards and specify time of the annotation.

An annotation delimits an image in the storyboard to which precise temporal information is added. Each annotation is described by an annotation object (rectangle) that specifies the structural element type according to the storyboard language (Figure 5.2 on page 45) of the image it annotates. The dotted lines represent the annotates relationship between annotation objects and the images. Annotation objects from a hierarchy of structural elements.

An event (rectangle with rounded corners) is created for each annotation. It contains the time of the annotated image as a [*from*,*to*] value pair.

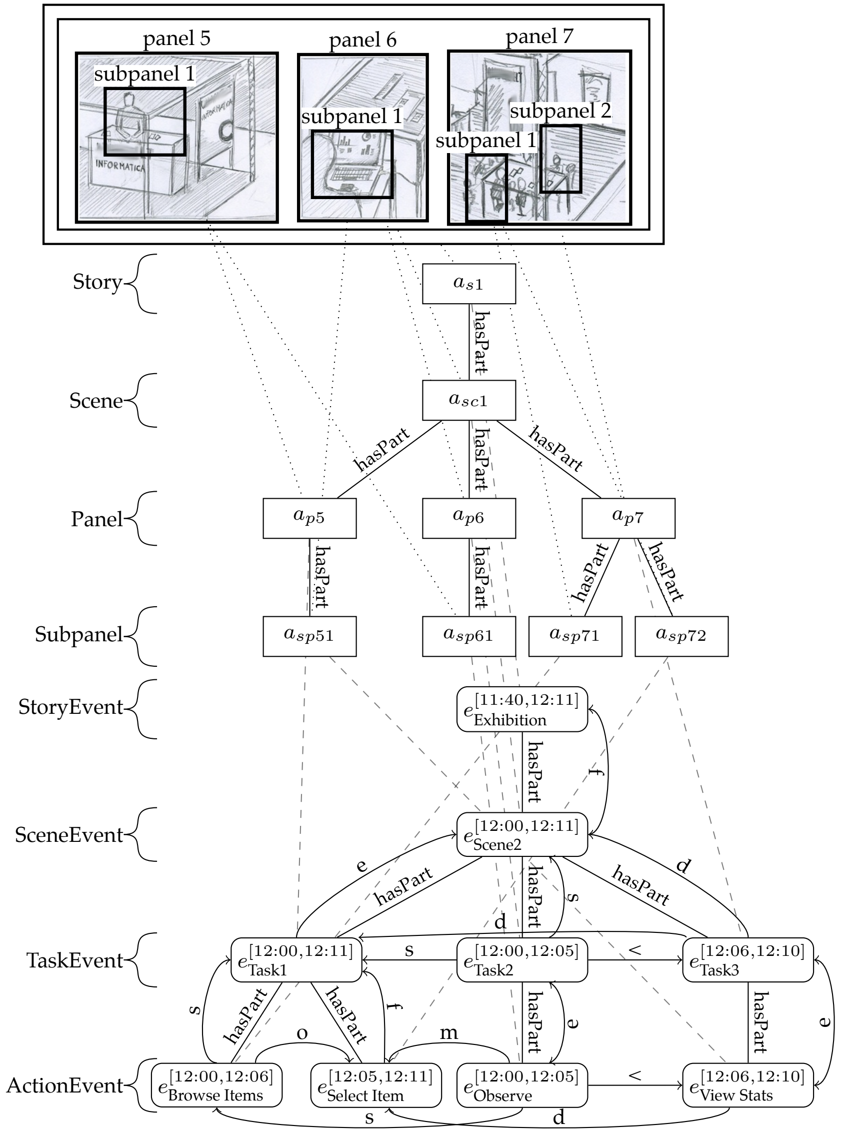


Figure 5.5: The structure of the second scene in Figure 5.1 is annotated and the time of each image is specified and stored as a storyboard event. Structural element and event types are indicated left. Dotted lines relate images to their annotation objects. Dashed lines represent the concept bridging objects. Temporal relationship symbols are explained in Table 5.2

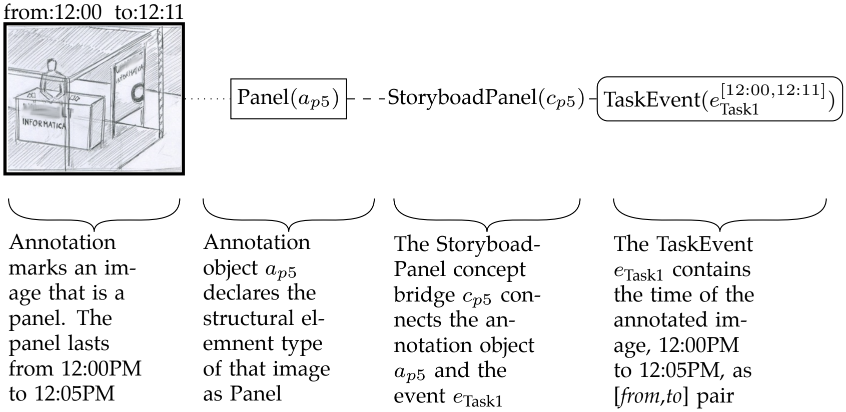


Figure 5.6: A detailed description of the annotations for panel 5 in Figure 5.5

The rules to infer temporal relationships are discussed in Table 5.3. For example, the rule

$$\text{from}(e_{\text{Task2}}) = \text{from}(e_{\text{Task1}}) \wedge \text{to}(e_{\text{Task2}}) \leq \text{to}(e_{\text{Task1}}) \rightarrow \text{starts}(e_{\text{Task2}}, e_{\text{Task1}})$$

creates the relationship e_{Task1} during e_{Task2}. Inverse and transitive relationships are omitted in Figure 5.5. The symbols for the temporal relationships are explained in Table 5.2.

The Timisto approach uses the concept bridging ontology to connect informal user requirements in the storyboard and the precise representation of the user requirements as technical specification (Figure 5.3 on page 46). Concept bridging objects are represented as dashed lines from annotation objects to events. A concept bridging subtype specifies the event type for one structural element type (Table 5.1 on page 47).

Consider the detailed example in Figure 5.6 for the image labeled panel 5 in Figure 5.5. The type T of an object o_i is written as $\text{T}(o_i)$. The annotation object a_{p5} is at the third level in the annotation hierarchy. According to the storyboard language, the structural element type of panel 5 is a Panel. The event in panel 5 starts at 12:00PM and ends at 12:05PM. This information is stored in the TaskEvent e_{Task1}. The relationship between the annotation object and the story event is established by the StoryPanel concept bridging object c_{p5}. The StoryPanel type defines that the event type for a Panel annotation object is TaskEvent.

Chapter 6

Visualizing Time in Storyboards

In this chapter, we propose to visualize the passage of time in the storyboard by mapping the content of the storyboard onto a timeline. A timeline is a common visualization of time-coded data. Events are shown in chronological order to create the impression of narrative and relate events to other contextual information [118].

In Chapter 3, we established seven recommendations for the design of assistive technologies for people with dementia. Three of the seven design recommendations discuss the relationship between temporal information and the design of an interactive system.

REC 1, represent time explicitly, suggest that time is an important non-functional requirement. For example, a digital agenda should remind the person with dementia when to take medication. Prompting even though the person with dementia already took the medication or prompting too early might be frustrating.

REC 2, label temporal events, suggests that an assistive technology can help a person with dementia to better orient in time by providing additional context information for past or future events. For example, a birthday or a grandchild can include a picture of the child and a brief history.

REC 6, show the current activity at all time, discusses activity detection. For example, an assistive technology that can understand what the person with dementia is currently doing, can help the person with dementia to complete a difficult task.

We believe that tool support to visualize how people with dementia and their caregivers expect their assistive technology to behave and conceptualize time is helpful for the design team to analyze user requirements and needs. Timelines are used in several domains to visualize data, especially where time-coded data can be presented in as a narrative. For example, the social network site Facebook maps user information and content onto a personal "social timeline" to visualize activities throughout a member's life [119]. eStory [120] is an application for emergency management based on information posted on the internet. A timeline and scenario-based interface visualize about incidents as events. ChronoViz [121] is a tool that provides a timeline interface to navigate, analyze and annotate data related to events.

Section 6.1 presents the timeline algorithm that we developed to map the storyboard onto a timeline. In Section 6.2, the timeline algorithm is applied to the annotated storyboard of Section 5.3 to make a concrete example of how the timeline algorithm works. We evaluated our approach with five different storyboards that we collected. We discuss the results in Section 6.3.

6.1 Time Extraction and Visualization Algorithm

In this section we present the algorithm we designed for extraction temporal relations from a storyboard and, simultaneously, create a graphical overview of these temporal relationships. For the sake of reproducibility, we provide an in depth description of the algorithm alongside an example of execution of the algorithm.

Based on the precise time, the time in storyboards (Timisto) application can render a timeline of the storyboard to visualize the passage of time. It will split the storyboard in subparts according to the storyboard event types linked to annotations and present a graphical timeline with these subparts of the storyboard ordered on top of the timeline. We believe this is an important feature of our approach, since during storyboarding a visual and detailed representation of the temporal relationships within a storyboard also inform the creators of the storyboard. It allows additional adjustments and to detect ambiguities about the time during the storyboarding phase.

The `createTimeLine` function receives an event, *event* and a boolean value, *addLane*, that states if a new lane for its direct descendants has to

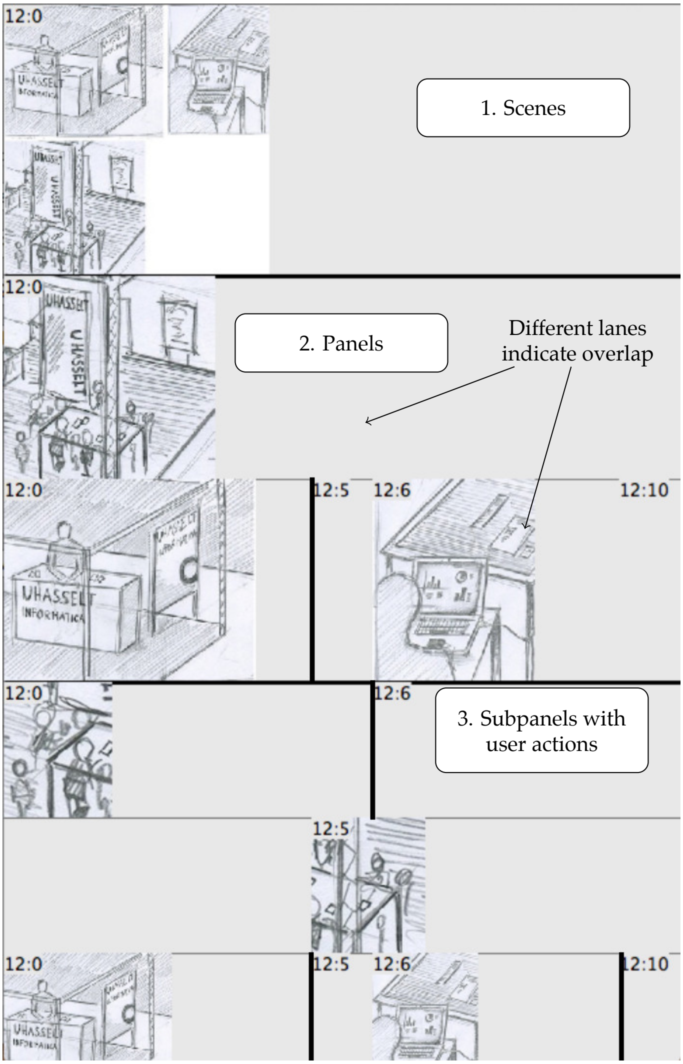


Figure 6.1: The second scene of the storyboard in Figure 5.1 is mapped onto a timeline. The temporal information to render the timeline is annotated as explained in Figure 5.5. The top level shows the entire scene. The second level shows the panels. Some panels overlap in time and are placed on separate lanes. The third level contains subpanels. Several subpanels overlap and are therefore placed on seperate lanes. Time evolves from left to right. The timeline corresponds to step 3 in Figure 6.3

be created or an existing lane can be used. A lane is one horizontal layer that can be seen in Figure 6.1, so it is a graphical division that represents a timeline for a specific level of detail.

Function createTimeLine(event,addLane)

```
levels ← {{}, {}, {}, {}}, level ← 1;
begin
    if addLane then
        lane ← {};
        add(levels [level ],lane)                // Add propagated lane;
    else
        lane ← last(levels [level ])             // Use existing lane;
    end
    descendants ← {};
    cType ← descendantTypeConstraint (event);
    if cType ≠ null then
        descendants ← ∀i ∈ cType: hasPart(event,i);
    end
    sort(descendants);
    foreach descendant ∈ descendants do
        level ++;
        createTimeLine(descendant,addLane);
        add(lane,descendant);
        conflict ← ∀i ∈ descendants :overlaps(descendant , i)∨contains(descendant
        , i)∨equals(descendant , i);
        if |conflict| > 0 then
            lane ← {};
            add(levels [level − 1],lane);
            addLane ← True                       // Propagate new lane;
        else
            addLane ← False                      // Set existing lane;
        end
        level −−;
    end
end
```

To create a timeline, the first argument is the topmost event, i.e. the story event, and *addLane* is set to true to add a new lane to each level below the story level (level 0). createTimeLine first prepares a lane in the timeline on which direct descandants of *event* will be placed. Next, it processes the direct descendants of *event* in chronological order. createTimeLine is called for each direct descendant, with *addLane* as argument. *descendant* is then added to the previously prepared lane.

The algorithm then verifies if the next sibling of *descendant*, which will be processed in the following iteration, overlaps with the current descen-

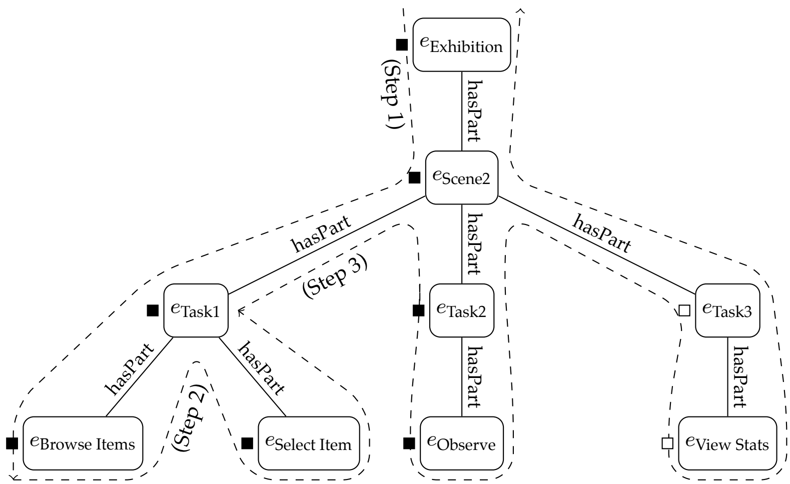


Figure 6.2: When createTimeLine passes left of an event, it adds a lane to the level below that event. When createTimeLine passes right, the event's descendants are added to the lane. The square left of an event shows the value of *addLane*. A full square is true and a new lane is added. An empty square is false, and the event will be placed on the same lane as its previous sibling. Figure 6.3 shows the construction of the timeline for step 1–3

dent. If there is no overlap, that event can be placed on the same lane as *descendant* and *addLane* is set to false. However if the next direct descendent overlaps with *descendant*, subsequent direct descendants will be placed on a new lane below. Because the time of an event depends on its first, respectively last descendent, a new lane is also propagated to lower levels by setting *addLane* to true.

The recursive implementation of createTimeLine means that an event is added to the timeline once all its descendants have been added. The first event to be added is therefore the first action event that starts the storyboard. The timeline is finally rendered by substituting temporal events with their annotations.

6.2 Example of the Storyboard Timeline

Consider the timeline in Figure 6.1 on page 59 that was rendered from the annotated storyboard in Figure 5.5 and the event hierarchy in Figure 6.2. To create the timeline, the createTimeLine on page 60 was called with the values *event* = $e_{\text{Exhibition}}$ and *addLane* = true as arguments. The dashed line with arrow in Figure 6.2 shows the path createTimeLine takes to traverse the event hierarchy to place each event in the right order and level on the timeline.

Steps 1 to 3 in Figure 6.3 show the variable *levels* during the execution of createTimeLine. Once the timeline contains all the events, events are replaced with the annotated image which they represent in time, as shown in Figure 6.1.

- **Step 1:** createTimeLine is called for the event $e_{\text{Exhibition}}$, with *addLane* true. This adds a new lane to the scene level (Lines 3–5 in createTimeLine on page 60). Because createTimeLine is not called recursively, the story event will not be added when createTimeLine exits (Line 18). Next, the list of its direct descendants, i.e. those events related by hasPart and are of the event type of the next level, is sorted in chronological order (Lines 10–14). Its first and only direct descendant is e_{Scene2} (Line 15). It increments *level* by one to descent one level and calls createTimeLine for e_{Scene2} (Lines 16–17). This is repeated for e_{Scene2}, which first calls createTimeLine on e_{Task1}, and e_{Task1}, which calls createTimeLine on its first descendant, $e_{\text{Browse Items}}$.

- **Step 2:** $e_{\text{Browse Items}}$ has no descendants. It is added after createTimeLine exits, to the first lane in the action level (Line 18) by createTimeLine for e_{Task1} . Next, the algorithm verifies if the second descendant of e_{Task1}, $e_{\text{Select Item}}$, can be added to the same lane (Line 19). $e_{\text{Select Item}}$ overlaps $e_{\text{Browse Items}}$ and would therefore cover part of the image of $e_{\text{Browse Items}}$ (Line 20). A new lane is created and added to the action level for $e_{\text{Select Item}}$. *addLane* is set to true, so that any descendants of $e_{\text{Select Item}}$ would also be added to a new lane (Lines 21–23). Next, *level* is decreased to ascent one level (Line 27) and increased again by one for $e_{\text{Select Item}}$ (Line 16), the next descendant of e_{Task1}. After createTimeLine exists for $e_{\text{Select Item}}$, $e_{\text{Select Item}}$ is added to the action level and *level* is decreased to point to the task level. createTimeLine exists for e_{Task1}, e_{Task1} is added to the task level.

- **Step 3:** The next direct descendant of e_{Scene2}, e_{Task2} overlaps with e_{Task1}. A new lane is therefore added to the task level and *addLane* is again set to true so that e_{Observe} is also added to a new lane. After e_{Observe} and e_{Task2} are added to their respective levels, *addLane* is set to false (Line 25), because e_{Task3}, the next and last direct descendant of e_{Scene2}, does not intersect with e_{Task2}. $e_{\text{View State}}$ and e_{Task3} are both

Figure 6.3: State of the array *levels* (white boxes) as createTimeLine traverses the events hierarchy in Figure 6.2 to generate a timeline of the storyboard in Figure 5.5. Grey lanes contain events. Two or more lanes in one level are added to avoid placing events that intersect in time on top of each other. Step 3 shows the events for the timeline in Figure 6.1

added to existing lanes in their levels. createTimeLine for e_{Scene2} exits and createTimeLine for $e_{\text{Exhibition}}$ adds e_{Scene2} to the scene level.

6.3 Case Studies

In order to evaluate our approach, we collected five different storyboards and used our approach to generate timelines. Each storyboard was created by different researchers that were asked to provide us with an existing storyboard or to create a realistic storyboard for one of their applied research projects. There were no restrictions with respect to the style and the size of the storyboard. The number of scenes of the resulting storyboards varied from 5 to 8 and the application contexts included health care, cultural heritage and public interactive displays for exhibitions. The five storyboards differed in level of detail: some storyboards contained more superficial drawings, while others used very concrete drawings or even pictures. The authors of the storyboards also specified the start and duration of each task that was depicted in a storyboard scene. Describing each storyboard in detail would be beyond the scope of this paper; we will highlight the most important findings.

Besides assessing the correctness of our algorithm and tool support, we also verified the scope of the temporal storyboard ontology to express initially vague descriptions and to visualize them in the timeline presentation. We annotated the storyboards that did not include full time annotations based on the time information we received from the authors. We assessed consistency of the temporal composition and ordering of the storyboard in the timelines with respect to the time information that the participants provided. A study on the appropriateness of the current visualizations is planned as future work since our scope is on getting the temporal relationships formalized from a storyboard for further usage. An exploration of appropriate timeline visualization designs is beyond the scope of this work.

Figure 6.4 on page 66 shows one of the storyboard we collected. This storyboard was created for a cultural heritage project. The storyboard depicts a typical family visit that uses a mobile device that acts as a museum guide. This project explored the use of location-based services (LBS) and social networking, specifically how both these aspects interact with a typical family visit. The image on the left in Figure 6.4 shows only the first scene in the storyboard. The solid lines are the temporal relationships between events. Although in the left image we added the arrows ourselves, the actual temporal relations are calculated by our algorithm. The image on the right shows the generated visualization similar to Figure 6.1. During the first task, the users enter the reception of the cultural heritage site and shortly afterwards launch the mobile guide. The scene is started by the first task and is finished by the first and the second task (starts and finishes are subsets of during). The second task, which is related to the mobile device, begins after the first task has started and ends at the same as the first task, therefore also finishing it. At the action level, the user interacting with the device and the dialog occurs during the same time and is therefore related as equal in time.

Our algorithm generated the temporal relationships for all five storyboards. These results were consistent with the time information we received from authors. Based on the output of the algorithm, we analyzed the relationships that were most commonly used for expressing temporal relations. We found four interesting practices that reoccured in the different storyboards:

- The most used relationships were before and meets, indicating that most authors preferred to construct their story as a linear sequence of separated scene.
- The contains relationship was commonly used to indicate that users interact with a mobile device.
- The during relationship is often used for monitoring systems that are active in the duration of the story.
- We noticed most storyboards also specify concurrent actions, of which at least on action might be still valid during the next scene in the storyboard. However, these types of temporal relationships are often included without making them explicit. Our approach helps to find these more complex temporal relationships.

Although we expect the findings above are probably general storyboarding practices, our sample set is too limited to make this conclusion. Our approach can facilitate a study on how time is typically specified in storyboards.

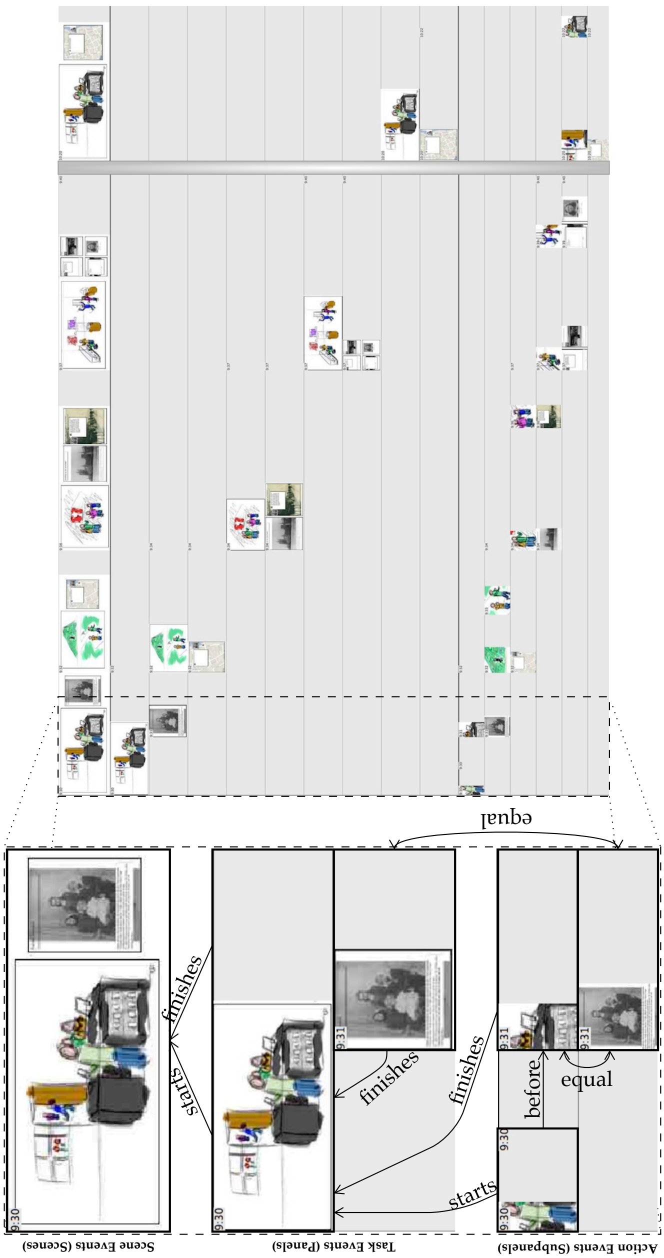


Figure 6.4: A storyboard for a context-aware mobile museum guide for family visits. The shaded area in the storyboard right represents an idle time period. The image left shows the first scene. The solid lines are the temporal relationships. Inverse and transitive relationships are omitted

Chapter 7

Architecture and Implementation

In this chapter, we discuss the prototype of time in storyboards (Timisto) application, that provides tool support for the Timisto approach to annotate and visualize the time in storyboards. We present the architecture in Section 7.1. In Section 7.2, we discuss how the modules of the Timisto application interact when an image in the storyboard is annotated. In Section 7.3, we present the user interface of the Timisto application.

7.1 Architecture of the Timisto Application

The architecture of the Timisto application comprises three ontology centric modules (Figure 7.1). Each module provides an interface to its ontology. A module transparently manages the state of its ontology during the annotation description. For this application, we used the ontology editor Protégé 4.2[1] and Pellet reasoner[2]. Our application uses the Java OWL-API[3] to access ontologies. Drawing storyboards is not part of the user interface (UI)'s functionality.

The storyboard client is the UI to annotate a storyboard. The dashed line shows the path through the modules when the user draws an anno-

[1] http://protege.stanford.edu/
[2] http://pellet.owldl.com/
[3] http://owlapi.sourceforge.net/

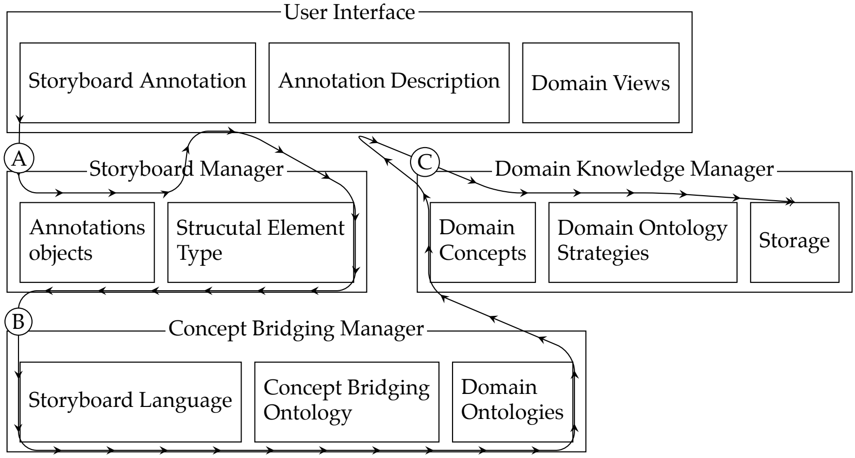


Figure 7.1: The architecture of the Timisto application. The line with arrows shows the path taken to formalize the storyboard content. A: The user draws annotation, B: The annotation is assigned to a structural element of the storyboard language, C: The user adds the content. The UI is shown in Figure 7.9

tation on the storyboard and specifies its content:

- **Step A:** The user draws an annotation around an image on the storyboard, for example an action inside a panel.
- **Step B:** The storyboard structural element of the annotation is set, for example an action is annotated with a subpanel. The application then looks-up the domain concepts that the concept bridging ontology specifies for the storyboard structural element and presents a list properties of the domain concepts. For a subpanel, it creates an ActionEvent and displays two fields, *from* and *to*.
- **Step C:** The user sets the duration of the annotation by entering the *from* and the *to* value and saves the content and the annotation.

The **storyboard manager** keeps an internal representation of the annotations of the storyboard in memory. It offers an interface add annotation objects and update the current annotation object. Figure 7.2 shows the lifecycle of an annotation object. S_0: the annotation object is created when the user annotates an image. S_1: the space of the annotation on the storyboard is stored as a pair of coordinates. S_2: the storyboard structural element type of the annotation is set in step B. S_3: the annotation

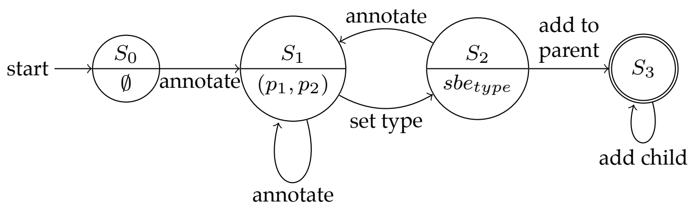


Figure 7.2: An annotation is ready when the annotation is drawn and a storyboard element type is set

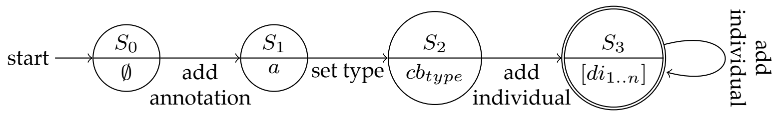


Figure 7.3: A concept bridge is ready when it has an annotation, its type is set and it connects one or more domain individuals to its annotation

can be redrawn until it is saved and added to its parent. Once it is stored, it is ready to be described in step C and to accept child annotations.

The **concept bridging manager** mediates between the storyboard manager the domain knowledge manager. The concept bridging manager uses the concept bridging ontology to match the storyboard structural element type of the annotation to domain concepts. When a new storyboard annotation object is ready, the concept bridging manager creates a concept bridging object. Figure 7.3 shows its lifecycle. S_0: the concept bridging object is instantiated. S_1: it receives a pointer to the current annotation object from the storyboarding manager. S_2: based on the storyboard structural element type of the annotation, the concept bridging concept type is set. S_3: the concept bridging object is complete when one or more domain concept individuals are added in step C. The concept bridging object will permanently keep the storyboard annotation object connected to its domain concept individuals.

The **domain knowledge manager** is the gate to the knowledge base of the Timisto application for steps A, B and C. It is the only module that can modify OWL files on the filesystem directly. The domain knowledge manager keeps track of the domain concept individuals for the current concept bridge. It then creates domain concept individuals and asserts properties. Additional domain ontology specific modifications to the knowledge base are either described as semantic web rule language (SWRL) rules or in Java in domain ontology strategies.

(a)

(b)

Figure 7.4: The list of possible storyboard structural elements (step B)

7.2 Message Exchange

This section explains the message exchange between the three modules when the user annotates the storyboard. In step A, the user draws a rectangle around an image on the storyboard. In Figure 7.5 on page 71, the storyboard manager creates a new annotation object and stores the coordinates. The storyboard manager sets the storyboard element as pending and notifies its observers. The concept bridging manager ignores the message because the storyboard structural element type is no yet defined. The UI requests the list of valid storyboard structural elements for the annotation. The storyboard manager determines the valid types as follows:

1. The list of annotations is sorted by surface size in ascending order.

2. The sorted list is traversed until a storyboard structural element is found which has a surface size greater than the surface of the pending annotation.

3. The surface size of each annotation in the remaining sublist is compared to the surface size of the pending annotation to find the annotation with the smallest surface that fully encloses the pending annotation.

4. If an annotation is found, the incomplete annotation is set to the next storyboard structural element type that is defined in the storyboard ontology.

In step B, Figure 7.4, the storyboard structural element type is selected.

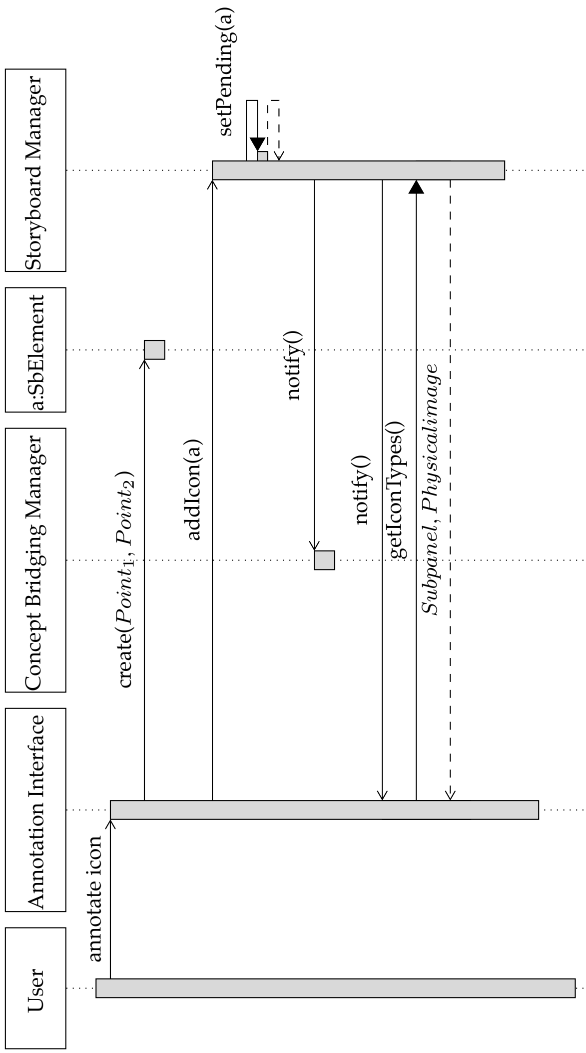


Figure 7.5: Drawing an annotation (step A)

(a) (b)

Figure 7.6: Specifying the time of an event (step C)

Figure 7.7 on page 73 : The storyboard manager updates storyboard structural element type of the annotation and adds it to the knowledge base. The storyboard manager again notifies its observers. The concept bridging manager reacts to the notification message, since the annotation is now complete:

1. A new concept bridging object is created. It will maintain the connection between the annotation object and the domain concept individuals that represent the annotation content.

2. The concept bridge object is set to the concept bridging type that corresponds to the storyboard structural element type of the annotation object. For the subpanel annotation, the concept bridging object is a StoryAction.

3. The properties of the domain concepts to describe the content are returned presented as input fields in the UI. In this example, the annotation is a subpanel and the domain concept is an ActionEvent. The user specifies the time of that event by specifying when the event starts and when it ends.

4. The concept bridging object and the domain concept individual is saved in the knowledge base.

The concept bridging manger notifies its observers. The UI requests the list of properties and creates a property widget for each property (Figure 7.6 on page 72).

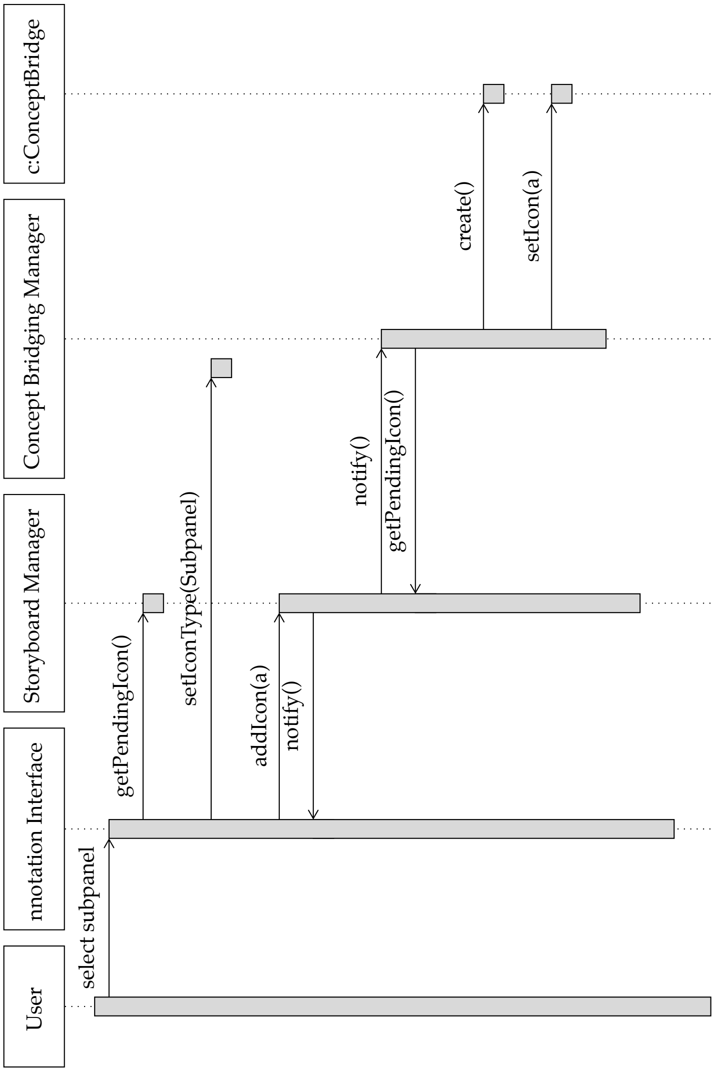


Figure 7.7: Setting the storyboard structural element type of the annotation (step B)

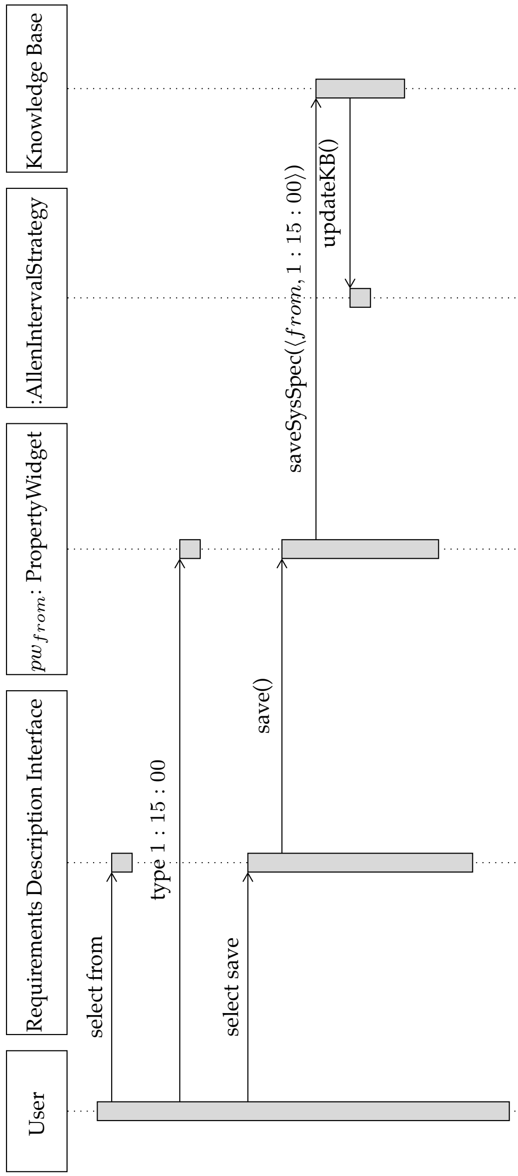


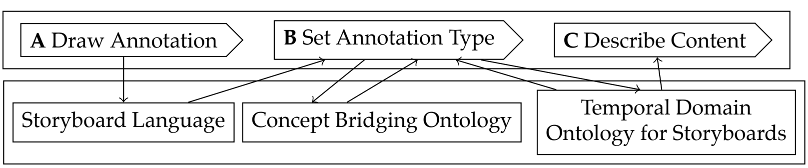
Figure 7.8: Describing the time of the annotated image (step C)

In step C, Figure 7.6b on page 72 , the designer specifies the property values. Figure 7.8 on page 74 : when the properties are saved, the resource description interface fires each property widget, which in turn send their (property,value) pair to the knowledge base.

7.3 User Interface of the Timisto Application

The UI of the Timisto application is shown in Figure 7.9. When the designer draws a rectangle on the storyboard to annotate an area in step A, the user interface activates the storyboard elements that are valid for the annotation in step B. After the user has assigned the annotation to a storyboard element in step B, the user interface presents domain concept properties to further describe the annotation in step C. In this example, the designer has to specify the duration of an action in a panel segment to complete step C.

(a)



(b)

Figure 7.9: User Interface to annotate and describe information in a storyboard. A, B, C in (a) show the process steps in (b)

Chapter 8

Discussion

This thesis was motivated by the following goals: *1)* understand how dementia related-deficits translate into design specifications, *2)* explore how to extract precise information about the context of use can be extracted from existing storyboards and *3)* how the precise information can help designers to analyze the user requirements and needs. In this chapter we reflect on the benefits and limit of our work. We discuss the first goal in Section 8.1, the second in Section 8.2 and the third goal in Section 8.3.

8.1 Design for People with Dementia

The following research questions are related to this research questions: R 1.1, R 1.2, R 1.3

Benefits

Assistive technologies can help to prolong the time that people with dementia are able to live at home independently. People with dementia find it increasingly difficult to think abstractly and to express their point of view. Therefore, the design process as well as the final application have to accommodate individual users requirements and needs to reduce cognitive load. Several projects [7, 9, 21] developed design and development methods to allow people with dementia to take part in the design process. They emphasize the need to involve people with dementia and their caregivers, though collaborating with people with dementia is challenging. We analyzed how these projects translated user requirements and needs into technical specifications of assistive technologies. Our aim was to allow designers who intend to collaborate with people with dementia to build on the experience of previous projects. To that end, we extended Dey and Abowd [26] context and context-awareness model to classify assistive technologies according to type of context-ware services that they offer and the type of contextual information that those services rely on. We summarize our findings with seven design recommendations that can inform designers how the design of an assistive technology can accommodate the user requirements and needs of assistive technologies.

REC 1, represent time explicitly, suggests that proper timing of behavior is important to help people with dementia cope with episodic memory impairment. REC 2, label temporal events, explains that an assistive technology can be designed to help people with dementia understand what events mean, by making relevant information easily accessible. People with dementia also experience semantic memory impairment, and can therefore be confused about time-related concepts such as lunch time or a doctor's appointment. REC 3, make location data accessible at all times, addresses the increasing difficulty of people with dementia to go outdoors because they forget where they are or how to get home. REC 4, explicitly and uniquely identify all people, concepts and objects in the user interface, explains that an user interface (UI) must be designed to reduce cognitive load. This means reducing room for error, displaying only functionality that the person with dementia can use and making information easy to understand. REC 5, put the social network central, explains that assistive technologies can help people with dementia to counter social isolation. For example by making it easy to call relatives or allowing a person with dementia and caregiver to access each others' status when they are not at the same place. REC 6, show the current activity at all time, suggests to incorporate the user's activities into the design. This recommendation is related to REC 2, activities are a type of events. Whereas REC 2 is concerned with making information about events accessible to users, for REC 6 the assistive technology has to "understand" the activity in the context of the user and react accordingly. REC 7, foster personal identity, is to emphasize that the design that assistive technologies should not only be functional but also appealing to people with dementia.

To reflect on our design recommendations, we briefly examined the latest development in assistive technologies for people with dementia since we conducted our literature review. We found several projects that investigate activity detection, either to assist a person with dementia to perform task, e.g. [122–125] or for monitoring and safety, e.g. [126, 127]. The design recommendations that apply those project are REC 3, the assistive technologies need to understand the objects in the environment, REC 6, since the activity is part of the design, as well REC 7, because the assistive technologies must be likable and respect the users' dignity. For activity assistants, REC 2 can also be applied, since they provide the people with dementia with additional information about the current time. Safety systems additionally use REC 5, to know who to alert when the person with dementia needs assistance.

Projects to investigate life-logging have also been proposed, e.g. [128, 129]. These systems record a person with dementia's context of use to compensate with episodic memory impairment. The design recommendations that apply are REC 1, REC 2, REC 3, to record the precise time, events and location, to record events and REC 5 if caregivers are involved. REC 7 also important for privacy reasons, because life-logging amounts to surveillance.

Limitations

The analysis framework and our design recommendations are not a substitute for consulting medical professional and people affected by dementia. Our aim is to provide a tool to assist a preparatory investigation for the design and development of context-aware applications for people with dementia. The analysis framework informs developers and designers about possible use of context for their applications. Validation with the target group remains the best approach, but given the condition of the test users it is extremely difficult to do actual user trials.

8.2 Extract Precise Information from Storyboards

The following research questions are related to this goal: R 2.1, R 2.2, R 3.1, R 3.2

Benefits

Storyboarding is an established method in user-centered design (UCD) to involve users in the design of interactive systems [105, 106]. Storyboarding was used in several projects to involve people with dementia

Project	Terms	Method	Best Practices	Formal Model	Tool	Visualize
Kantola and Jokela [110]	×	×				
Truong et al. [109]			×			
Greenberg et al. [108]	×	×	×			
Luyten et al. [111], Haesen et al. [130]	×	×	×	×	×	
Timisto				×	×	×
Sellen et al. [78]		×	×			

Table 8.1: Related storyboarding applications and projects

and their caregivers in the design and development of interactive systems [7, 21, 40, 77]. A storyboard contains information about actors, the places where actors are located and their actions. This makes storyboarding a useful tool to elicit the type of information with users that are related to all seven design recommendations.

Several methods have been proposed to provide storyboarding languages and methods [102, 108, 110]. They also introduce a new terminology, which contains terms to describe the storyboard medium as well as terms to describe the content. A formal metamodel simplifies the integration of informal storyboards with conceptual software-engineering models was presented by [111]. Best practices for storyboarding in the design of interactive systems were proposed by [78, 109, 130].

The purpose of the Timisto approach is to allow designers and users to make time information in existing storyboards more precise and store in a machine-understandable format. People and their relationships can be described for example with personas and location with location-specific ontologies. Storyboards are inherently temporal. However, the way time is described in storyboards is insufficiently precise to be extracted automatically and be used for the design of interactive systems. To our knowledge, this is still an open issue. The Timisto approach allows to add more precise time information on existing storyboards. It does therefore not change how storyboards are used with people with dementia. Table 8.1 shows how the Timisto compares to storyboard approaches mentioned above.

A story consists of a sequence of events and subevents [115]. The structure and arrangement of storyboards (and comics) visualize the structure of time. Storyboards describe the high-level event types, such as "scene" and "activity". A scene describes a timespan and a location. An activity describes an activity of an actor and occurs during a scene [102, 108–110]. When we developed the storyboard language for Timisto, which we mainly based on McCloud's work on panels and transitions between panels [23], we found that each storyboard language element can be seen as a type of event with its own context information. We therefore developed a temporal domain ontology for storyboards to represent the different types of events that the physical storyboard structure represents, based on McCloud's [23] description of events.

Limitations

The event types of the temporal domain ontology for storyboards describe the time of individual events in a specific story. The classification groups events that contain particular context information. However, event types do not formally describe what these events are [117]. For example, an event called "select file i" of the type ActionEvent describes when a user did a "select file" action. The term "select file" is a textual description of the "event domain" [115], i.e. the action type definition. A formal specification of the action type is needed to use the temporal information to generate for example process models.

8.3 Analyze User Requirements and Needs

The following research questions are related to this goal: R 4.1, R 4.2, R 4.3

Benefits

We use the precise temporal information to inter temporal relationships based on Allen's temporal interval algebra [25] between events in the storyboard and visualize the time by rendering the content of the storyboard on a timeline. The timeline helps to visualize how users thought they would use the application. The timeline is a natural presentation of time-driven information [119–121].

We developed the Timisto application to provide tool support for the annotation and visualization of the time in storyboards. The prototype application consists of three loosely modules. Each module provides services to one specific ontology. The modular approach allows to interface the design knowledge with other design artifacts, without having to modify other parts of the system. The information is stored as web ontology language (OWL) ontologies. The storyboarding environment uses the OWL-API to interact with ontologies and the knowledge base, and the Pellet-reasoner to infer temporal relationships. The Timisto application also provides an interface to add knowledge that cannot written in OWL or semantic web rule language (SWRL), as Java code.

Limitations

A limitation of our approach is how temporal relationships and events are formally represented. Events and temporal relationships in Allen's temporal interval algebra are crisp [25, 131]. For example two events occurring in close succession are simply related by before. before does state whether they are a second or a year apart, although this difference may matter for the design of interactive systems. For this thesis, this information is sufficient, because the timeline places images relative to the position of their events and the human reader can intuitively make that distinction. One approach is to make temporal relationships more precise are fuzzy events and relationships [131].

Our prototype would need additional functionality to make it useable by other users. Exception handling is very limited and the storyboarding environment makes only tentative attempts to optimize the execution time.

Chapter 9

Conclusion

We conclude this thesis by answering the research questions in Section 9.1 that guided our work and propose future research topics as a continuation of our work in Section 9.2.

9.1 Summary

The motivation for our work was to develop assistive technologies to prolong independent living of people with mild dementia. The most common type of dementia is Alzheimer's disease. Alzheimer's disease a neurodegenerative disease and is commonly diagnosed after the age of 65. Common symptoms of dementia are memory problems, difficulties to perform familiar tasks, impaired judgement, language deterioration, and mood changes. Dementia is especially traumatic both for people with dementia as well as their social context, because it threatens the personal identity of the sufferer and, to a certain extent, also that of their family members. In many aspects, caring for someone with dementia is considered to be more demanding than caring for someone without dementia. Especially since Alzheimer's disease cannot be cured, a multi-faceted approach of drug and non-drug treatments is needed to prolong independent living.

> R 1.1 What are the characteristics of assistive technologies for people with dementia that were successful?

Literature confirms that assistive technologies can be involved in an effective treatment strategy, provided the user needs and requirements are adequately reflected in the system design and behavior.

> R 1.2 How do dementia related deficits translate to design specifications?

As dementia progresses, the cognitive abilities of people with dementia change. People with dementia are more influenced by their physical and social environment than able bodied people. This information can be represented as requirements that influence the dialog between the user and the system. Episodic memory impairment is a dominant characteristic of the clinical process of dementia. The is therefore an important context type. The context-aware paradigm views applications as intermediates between the user and their environment. Functional and non-functional requirements can be represented as context dimensions and context-aware behavior.

> R 1.3 How can the involvement of people with dementia and their caregivers be facilitated?

To understand how assistive technologies can contribute to treatment strategy, collaborating with people with dementia and their caregivers is necessary. The sensitivity and complexity surrounding collaboration with people with dementia can hardly be overstated. It is particularly difficult for the design team to understand what their users really need. The design team is forced to find intuitive ways to elicit the users' often vague design knowledge. However designers also have to specify a system that limits room for errors and reflects the people with dementia perception of the world.

> R 2.1 How can design knowledge be intuitively conveyed?

Informal design artifacts are accessible to non-technical users because they impose little formal restrictions. Storyboarding was found to be an accessible way involve people with dementia in the design process. Storyboards are a visual form of storytelling and a natural way to visualize the social, physical and temporal context. The type of information that is important for the design of assistive technologies in dementia care. The drawback of informal design artifacts is that in the absent of formal semantics, the design knowledge is inaccessible to computers.

> R 2.2 How can informal as well as formal design knowledge be captured, reused and exchanged?

Literature suggests that a model-based approach is suitable for assistive technologies. Model-based design focuses on conceptual modeling instead of technology specific development. We suggest that combining informal design artifacts and formal annotations could also be suitable to make design requirements accessible for people with dementia. We use web ontology language (OWL), the world wide web consortium standard to model design knowledge. OWL is a description logic (DL), and, being widely used, provides access to a large body of available ontologies.

> R 3.1 How is time currently described in storyboards?

In storyboards, time is represented by the size of panels and by their grouping. By definition, adjacent panels are adjacent moments. But this relationship is being distorted when comics (and storyboards) are segmented into pages.

> R 3.2 How can time in storyboards be modeled unambiguously?

The storyboarding ontology structures the informal storyboard content and allows to integrate the content with the formal design knowledge. The storyboard temporal domain ontology provides the time information to make implicit temporal relationships in storyboard explicit. We propose a method to implicitly model time-related requirements by annotating when each action in the storyboard starts and when it ends. Each start and end timestamp is stored as a event. Action events are entailed in task events which in turn are entailed in scene events. A set of semantic web rule language (SWRL) rules infer temporal relationships between intervals.

> R 4.1 Which representation of the storyboard helps to improve the interpretation of time?

Prior to print, the physical presentation of the content mimicked the temporal order of images. The placement of images visualized the flow of the story. By moving through space, the reader also moves through time. Additionally, explicit time indicators, for example a clock, also improved understandability.

> R 4.2 How can temporal semantics be exploited to visualize implicitly modeled application behavior?

The temporal semantics allows to visualize temporal relationships that are hidden in the storyboard by presenting the content of the storyboard on a timeline.

> R 4.3 Can temporal information in storyboards be visualized by mapping the content of a storyboard onto a timeline?

To evaluate our approach, we conducted a preliminary user study with human-computer interaction researchers. We studied how the authors of the storyboards thought the application would behave. They often had a linear understanding of their application time, which reflects the presentation of storyboards.

9.2 Future Work

In this section we present possible directions for future work.

- **Event Domain:** The temporal domain ontology for storyboards describes the time of events, i.e. when events occur in time. It does however not contain explicit information about what these events are. For example a story action event "select item" could contain as input a selected item and as precondition that the user who wants to perform this action has the necessary credentials. The properties of events are described in the event domain. A formal event domain is required to transform the time information in the storyboard into conceptual models which model the relationships between classes of individuals, such as process models or task models.
- **Context:** Additional domain ontologies to describe the social and physical context could be added. This would allow to provide a more accurate description of the user requirements and needs. The time in storyboards (Timisto) approach is designed to include other domain ontologies.
- **Improve Timisto application:** The Timisto application is a prototype. It needs additional functionality, such as error handling, storyboard file management and plugins for additional domain ontologies. Furthermore, the Timisto could be integrated into the COMuICSer tool[1].
- **Business Process Modeling:** The problems we tried to tackle are also present in other domains, for example business process modeling [132]. Misrepresentation of the stakeholder requirements and needs are more likely to be the cause for failing to meet project goals than technical obstacles [132]. We suggest to use the Timisto

[1] http://research.edm.uhasselt.be/~kris/research/projects/StoryBoardML/tools.html

approach to describe business processes with users. Furthermore, storyboarding could also be used with process mining to describe processes that are not supported by information systems. Process mining is a technique to analyze and extract business processes from log files [133–137].

9.3 Scientific Contributions

The research for this thesis was published in the following papers:

Nadine Fröhlich, Andreas Meier, Thorsten Möller, Marco Savini, Heiko Schuldt and Joël Vogt. LoCa – Towards a Context-aware Infrastructure for eHealth Applications. In *Proceedings of the 15th Int'l Conference on Distributed Multimedia Systems*, DMS '09, pages 52–57. Knowledge Systems Institute Graduate School, 2009

Joël Vogt and Andreas Meier. An Adaptive User Interface Framework for eHealth Services based on UIML. In *Proceedings of the 23rd Bled eConference*, pages 409–422. Bled eConference, 2010

Nasim Mahmud, Joël Vogt, Kris Luyten, Karin Slegers, Jan Van Den Bergh, and Karin Coninx. Dazed and confused considered normal: an approach to create interactive systems for people with dementia. In *Proceedings of the 3rd Conference on Human-Centred Software Engineering*, HCSE 2010, pages 119–134. Springer, 2010.

Joël Vogt, Kris Luyten, Jan Van den Bergh, Karin Coninx, and Andreas Meier. Putting Dementia into Context. In *Proceedings of the 4th Conference on Human-Centred Software Engineering*, HCSE 2012, pages 181–198. Springer, 2012.

Joël Vogt, Kris Luyten, Mieke Haesen, Karin Coninx, and Andreas Meier. Timisto: A Technique to Extract Usage Sequences from Storyboards. In *Proceedings of the 5th ACM SIGCHI symposium on Engineering interactive computing systems*, EICS '13. ACM, 2013

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