Exploratory Wayfinding in Wide Field Ethnography

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Abstract

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This thesis focuses on what wayfinding means in Wide Field Ethnography (WFE), and how to improve wayfinding activities in WFE datasets. WFE datasets are too large, unstructured and complex for researchers to easily understand, navigate, browse, filter, annotate, and analyze. This thesis studies how frameworks and tools can help WFE researchers find their way through such large, complex, unguided, unstructured, unorganized, and continuously changing datasets to enable researchers to find phenomenon of interest in WFE datasets with relative ease and to use collaboration to uncover patterns. Using empirical data collected from observation sessions, this research identifies a set of WFE wayfinding challenges, and proposes approaches by which these challenges could be mitigated to improve WFE wayfinding. The data suggests that wayfinding in WFE datasets is largely exploratory in nature, leading us to define a new concept called Exploratory Wayfinding in WFE that aims to use tools to augment human capabilities to

discover otherwise undefined patterns, and help researchers navigate and explore WFE datasets. In particular, this thesis establishes an exploratory wayfinding framework whose purpose is to help WFE researchers explore phenomenon of interest by making sense of patterns to uncover landmarks. To help reason about wayfinding in WFE, and also to evaluate the efficacy of this approach, this thesis introduces a prototype tool for exploratory wayfinding in WFE datasets. The tool is based upon the exploratory wayfinding framework, and supports landmarking so that researchers can leave markers in the otherwise unstructured and unguided datasets. The research results suggest that tools can improve a set of exploratory wayfinding activities, and suggest that exploratory wayfinding could be used for other domains of inquiry beyond WFE.

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DEDICATION

I dedicate this thesis work to my family and close friends, who supported me throughout the process. A special feeling of gratitude to my parents and my brother. I will always appreciate all they have done. Special thanks to Mr. Arjun Cholkar for all his proof-reading, encouragement, and support throughout the entire master's program.

Chapter 1. INTRODUCTION

Imagine a researcher who wants to reason about how software development can be improved in an organization. This researcher might attempt to understand where software development time is spent; and identify opportunities to reduce ‘idle time’ [75], where developers are waiting for other tasks to be completed. Software development is a complex process that involves human interactions via speech, emails, documents, drawings, and so on. To understand this process, the researcher decides to explore documents, defect reports, diagrams, emails, meeting minutes, and code commits; and decides to attend daily standup meetings, sprint reviews, demos, and retrospectives, among other things. In this type of a complex environment where social interactions occur, gathering data widely using video recordings, wide-angle pictures and audio recordings, might help the researcher uncover patterns and issues. Her hypothesis is that if she can identify patterns where software developers are waiting on dependencies introduced by either other software developers or infrastructure components, or otherwise appear to be ‘blocked’ from doing their work, she can potentially create solutions. Those solutions might include discovering constraints that produce waste and bottlenecks in the software development process, and systematically improving those constraints until they no longer prove to be limiting factors. Exploration of such information to identify patterns that are otherwise not predefined or not visible without sense making, typically involves collating data across multiple mediums (meeting recordings, email, documents, diagrams, code repository, defect management system, etc.), and then searching through this data, manually, to discover and identify events of interest, patterns, and commonalities. Such exploratory activities can consume hundreds of hours of a researcher’s time. If data is gathered widely to enable a more extensive search across time, space, and modalities, this search and exploration activity for sensing patterns might consume even more time and effort.

How might the researcher more effectively find places to intervene? What types of tools might help? What could be automated? Which parts need human interpretation and sense making to uncover otherwise unguided patterns? These are the types of questions that motivated this thesis.

It is probable that the use of tools would help the researcher conduct her analysis more efficiently, with less frustration, and enable her to spot patterns that introduce ‘idle time’ faster. For instance, if she has access to tools that can help her view data from multiple sources (such as emails, recordings, documents, pictures) in a unified representation (like a map of a city that contains distances, points of interest, street names, etc. [8]), it may help her browse and navigate throughout this dataset more efficiently [94], and can narrow down her exploration space. If tools allow her to create and subsequently add markers (like flagging or tagging) to certain parts of her dataset, where markers identify events of interest, she or other researchers in her team can recall her previous analyses. Said another way, if she can use tools to find her way by exploring the data, and leave markers to help her and others (re)find their way the next time they explore the data, it might prove to be an improved experience for her compared to combing through the data set manually. Such tools may help her more effectively find her way through the collected data and assist with realizing her goal of reducing ‘idle time’ in the software development process.

Wayfinding, generically, refers to the user experience of orientation, and choosing a path within a built environment like a city or building [29]. In computer science, specifically, wayfinding refers to the experience of browsing, searching, and analyzing information contained within big datasets [61]. Being able to conduct rich inquiry into these datasets is useful for social science researchers and computer scientists, because they aim to understand the nature of interactions in complex environments [97]. These environments usually contain physical settings like offices, include social aspects of human collaboration, have interactions with cyber and digital facets (e.g. computers), and represent production of value from an economic perspective. Hence, we call such environments Physical-Social-Economic-Cyber (PSEC) systems [110], [111]. PSEC systems include teams and organizations, and therefore studying and understanding PSEC systems is useful for reasoning about social phenomena. For example, software engineering teams within a company that produce products and services, are PSEC systems, as are the organizations that use or consume those products and services [90].

This thesis focuses on reasoning about how researchers can potentially find their way in Wide Field Ethnography (WFE) [90] datasets collected from PSEC systems such as a software engineering teams, and if markers could be used to create a better wayfinding experience for such researchers. Wide Field Ethnography (WFE) refers to a way of gathering data widely to allow researchers to pursue a wide range of research questions about how people collaborate within their physical and social environment [97]. WFE, which we describe in more detail in the next chapter, includes gathering large amounts of unstructured data across different mediums, such as video, audio, and text.

WFE researchers currently have to manually explore, reason about, and analyze large and unstructured datasets for the most part [92]. As described in Chapter 5, our analysis of wayfinding in WFE revealed that majority of the time was spent in exploring the dataset because the dataset was not an entirely known, structured, organized and defined realm. The time spent included phenomenon such as searching for ‘one-off’ topics, navigating and orienting from one data type to another to discover patterns and place those patterns on the dataset to highlight, remembering the history and context of the analysis, reasoning about the relationships between different data types, and deciding on the path forward. These observations led to defining a concept called *Exploratory Wayfinding* (EW) that suggests the use of tools to augment human capabilities of sense-making that are used to uncover phenomenon, and help researchers *discover*, *navigate* and *explore* large cloud-based datasets collected from PSEC systems.

We used our knowledge of wayfinding to build a prototype tool for exploratory wayfinding in WFE in order to reason about exploratory wayfinding, evaluate exploratory wayfinding concepts in WFE, and understand if markers can potentially enhance the wayfinding experience for WFE researchers. We then assessed our wayfinding concepts and conjectures using a prototype tool. Chapter 7 describes this prototype tool in detail.

Throughout this thesis, we highlight concepts in italic and we underline important phrases to emphasize significance.

Chapter 2. WHAT IS WIDE FIELD ETHNOGRAPHY?

Consider a university classroom. The classroom has a physical layout; contains students, the instructor, digital equipment like laptops and projectors, non-digital equipment like notebooks, pencils. The classroom provides a medium for individuals to interact. Numerous interactions occur in this environment, i.e. communication, helping each other, agreement, conflict, etc. As an example, let us assume we are observing a literature course, where four students work together to deliver a group presentation. One of the students exerts little effort to participate in the team exercise, and his/her lack of contribution causes tension within the group. This common situation impacts the quality of the presentation and the inter-personal relationships between the students. During the class, the instructor surprises the class by requesting that they present their work in the next half hour. This request adds panic to the already strained inter-personal relationships within the team. At this point the group realizes that they have to wrap their findings and prepare for the presentation. In such cases the contributing team members may take steps towards completing the delivery, while the non-contributing team member may continue to not take responsibility. A classroom situation such as this is a common phenomenon that is studied by learning scientists [105]. These learning scientists want to explore and discover various types of social interactions within this relatively unstructured (multiple varieties of unorganized and large amounts of information) information source, and find similar interactions in other social settings, to reason about their relations to learning.

An approach for analyzing social situations that include collaboration in a complex (changing, adapting, multi-component) *environment* such as the classroom in our example, is to study data gathered from that environment, across multiple sources such as video cameras, audio recording devices, etc. Such data that might be collected continuously over the course of days or weeks or more, is then explored by researcher(s) to broadly analyze and discover the relationships, sequence, and reasoning for events of interest. This approach of gathering data widely to allow researchers to pursue a wide range of research questions about how people collaborate within their physical and social environment, is called Wide Field Ethnography (WFE) [97].

The data in WFE is multi-modal and multi-stream. Multi-modal in this context stands for the variety of data in the dataset; for instance, video, audio, screen capture, time-lapse photography, photos from a hand-held camera, field notes, text, software source code, infrastructure logs, interviews, and so on. Similarly, multi-stream in this context stands for dataset that contains a variety of recordings (e.g., audio, video, pictures, code commits, emails, etc.) streamed into dozens or thousands of files. WFE datasets are generally *large*, and may contain terabytes of information that represent the physical environment (e.g. classroom or office layout, teams meeting in meeting rooms, and physical actions), and the digital environment (e.g. software commits to version-controlled repositories, software design documents, email exchanges) spread across thousands of files. The collected data in a WFE dataset is akin to the researcher's dataset of the software development cycle (in Chapter 1), or the learning researcher's dataset of social interactions of a team in a class [71] (earlier in this Chapter). This data is mostly unstructured, unorganized, large, multi-modal, not correlated, and exploring this data to discover patterns typically proves to be a time-consuming activity.

The aspect of 'wideness' of WFE stems from researchers collecting <u>large</u> amounts of data in an <u>extensive</u> physical area, with <u>several</u> devices, over <u>long</u> durations. For example, the use of cameras with wide-angle lenses allows researchers to capture more context of the activity (e.g. a GoPro's 170-degree wide field of view) than cameras with a traditional lens that has a much smaller field of view. Additionally, data recorders might run for days or weeks, collecting data over a wide period of time and situations [96].

WFE often uses the technique of gathering videos of PSEC systems that allow researchers to analyze fine-grain details of how humans use their bodies (e.g., speech, gesture, gaze, body orientation), artifacts (e.g., tools, whiteboards, pencil, paper, mouse), and the environment (e.g., office layout, pair stations, student's desks) to accomplish work [98]. Such augmentation of ethnographically-informed research through video capture and analysis represents the 'ethnography' aspect of WFE. We claim that widely gathering and visually representing data makes phenomena more visible in their details, and provides more information for human exploration, discovery and interpretation [100] on unstructured realms.

WFE could be used to study many types of complex adaptive systems such as software engineering, computer supported cooperative work, human computer interaction, user research, human centered design, anthropology, sociology, education, etc. [97].

The problem with WFE, as we alluded to before, is that WFE datasets quickly become difficult and complex to search, navigate, and otherwise find one's way in, even for the person who collected the dataset due to their unstructured (not predefined, not guided, not marked) nature.

Chapter 3. WHAT IS WAYFINDING?

This chapter defines wayfinding by identifying common attributes based on a literature review of wayfinding in various physical and digital domains. Our conjecture is that to understand a phenomenon, it is useful to perceive its reasoning, relationships and usage in different disciplines. This understanding can then be used to uncover patterns that can be applied to Exploratory Wayfinding in WFE. While most wayfinding literature is focused on architecture and related disciplines, we wanted to understand wayfinding concepts and practices across a more diverse set of domains, and thus chose to make our research as expansive as possible within the constraints of this thesis. Our selected domains extend across different time spans (from ancient history to current state-of-the-art), social and scientific disciplines, digital and non-digital environments, defined and undefined structures, and intentional and observational wayfinding. Figure 1 illustrates this breadth of literature research. The horizontal axis in Figure 1 represents social and scientific disciplines, while the vertical axis represents digital and non-digital environments. We use the 'paper' symbol to represent intentional (guided) wayfinding and the 'sun' symbol to represent observational (exploratory) wayfinding. We use triangles to illustrate structured information spaces and twisted lines to illustrate unstructured information spaces. Literature references, and the period of the researched domain are included in Figure 1 as well.

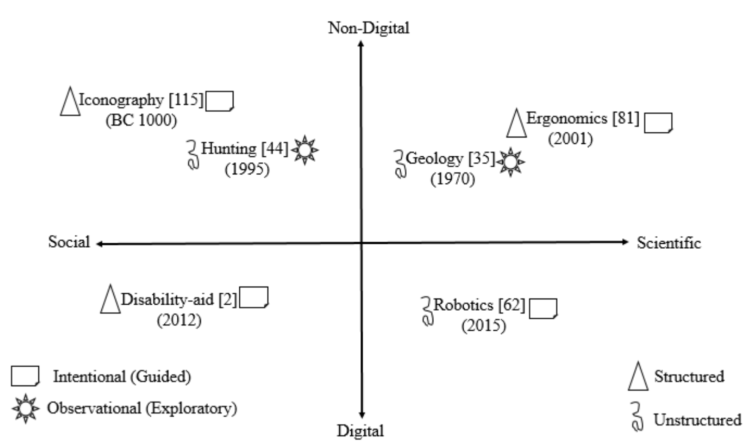

Figure 1. Breadth of wayfinding domains in literature review.

3.1 WAYFINDING CONCEPTS

Our literature study revealed common wayfinding concepts across most domains and time spans. To help illustrate these concepts, consider the wayfinding scenario in Figure 2. In this scenario: the intern is the *agent* (also called navigator or wayfinder), that is the actor that performs wayfinding; the company is the *environment* that is the medium in which the agent orients and navigates; the signs, signage, floor maps and directional arrows within the company building are *cues* that are mostly formal and authoritative symbols (marks) on the environment that guide the intern and help her narrow down her search scope and find her way; while finding her way, the intern references *landmarks* that are mostly informal, memorable and emergent symbols (marks) on the environment such as the location of the vending machine or the office coordinates of her team; the new hire orientation room is the *destination*, that is the intended goal for the agent whilst

Imagine an intern (*agent*) just started her internship in a big company (*environment*). In her first day, she needs to *find* where the onboarding session takes place, where she can get her badge, her laptop, how she can find her office, where the restrooms and cafes in the building are, where the stationary is, where IT support can be availed, the schedule for key places, where the break room is, how she can find documents for her task, who her manager/mentor is, etc. A big company is a *complex* environment that has various activities happening simultaneously. Our intern needs contacts to ask questions, *paths* to build and follow, and *tools* to help her to *orient* in this complex environment. Having a *map* of the building, seeing the *signage* for elevators, exits and restrooms, identifying her team's coordinates, facilitates the intern's questions about the physical layout of the environment. Setting up her login credentials, email account, and laptop configuration gives her access to the digital realm to *search* and *navigate* online material. In addition, knowing who to ask or call, when she gets lost, is important not to lose time. Our intern gets used to the environment in her second week since she starts to build a *mental map* of the physical and digital settings, and gets *familiar* with orienting in the environment since she has her *markers* that identify points of interest (e.g. café, restroom, etc.) for her. In the process of getting acclimatized to her new environment, our intern uses *cues* and tools available to her to *navigate* and search, communicates with the *dynamic* and complex environment, increases *experience,* and gets familiar with the settings over *time*; and builds her own understanding and experience of a new habitat, while *refining* the ways she finds her paths and destinations. Our intern keeps orienting in physical, digital, social, and economic environment as she learns and iteratively progresses doing her work.

Figure 2. Wayfinding scenario in digital and physical environment.

wayfinding, for the intern on her first day; the route from the new hire orientation room to her team's office location is the *path,* the journey that the agent takes during wayfinding, that the intern proceeds on whilst wayfinding; the building map and team wiki are the *tools,* devices that aid the agent to perform wayfinding, that help the intern find her way in the digital realm; and reaching her office on time is the intern's *intention,* the ultimate objective of the wayfinding exercise, within her context of interning in the company. We now describe these concepts (specified in italics) from the scenario in Figure 2.

Figure 3 summarizes the specified components of a wayfinding ecosystem, and shows that the interaction amongst its components is bi-directional. Typically, most wayfinding domains consist of these components in their ecosystems, and wayfinding activities in those domains are impacted by each element in the ecosystem [9].

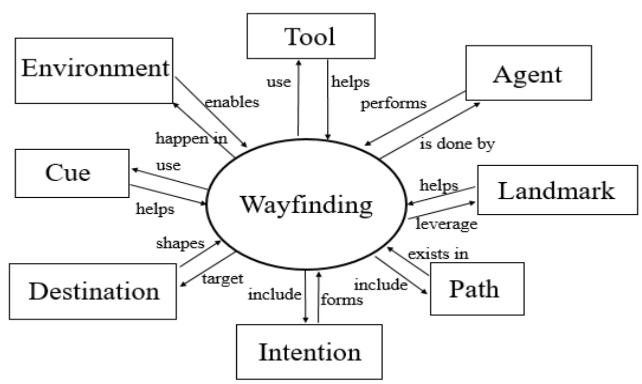

Figure 3. Wayfinding ecosystem and interactions of components.

'Marks' are symbols about a place in wayfinding environment. There are two types of marks: cues and landmarks. The difference between cues and landmarks is that cues are more formal, authoritative and pre-defined signs in the environment, whereas landmarks are more informal, memorable, emergent reference points in the environment. Throughout this thesis, we use marks if we mean both cues and landmarks. During our literature review we realized there is not a consensus among wayfinding scholars about the definition of cues and landmarks. Thus, we use our own understanding of these concepts. For the rest of the terms, the definitions are more or less aligned in wayfinding literature.

3.2 WAYFINDING ENVIRONMENTS

Our literature study revealed that the environment in which wayfinding occurs can be distinguished by two dimensions, as shown in Table 1. The vertical dimension represents the ‘domains’ of wayfinding, which can be segmented into three categories: 1) Digital that represents automated and tool assisted wayfinding mostly in digital environments, 2) Physical that represents cue (sign, indicators, sensible signals, etc.) assisted wayfinding mainly in concrete (material layouts) environments, and 3) Conceptual that represents wayfinding in abstract domains. The distinctions between these three domains is not precise, but we attempted to place wayfinding disciplines according to their primary area of focus. For example, geology has been placed in the physical domain in Table 1 because a geologist’s exploration and discovery primarily occurs in nature (a physical environment). Yet we know that wayfinding in geology might be assisted by digital tools to collect materials or digital equipment in labs to classify findings.

The horizontal dimension in Table 1 represents the ‘nature’ of how wayfinding activities are carried out in that domain: Structured and Unstructured. This difference is largely about the information available for wayfinding in the domain, where the information could pertain to the environment, markers, tools, paths, destinations, intentions, and so on.

Table 1. Wayfinding Environments

	Structured	Unstructured
Digital	Aviation [55] Architecture [3] Virtual Reality [20] Disability-aid [2] Information Foraging [14] Network Architecture [31] Building Navigation [60]	Robotics [62] Augmented Reality [87] Astronomy [19] Human brain [34] Biology [41] Nautical [9] Informedia [116] WWT[36]
Physical	Museum Curation [72] Architecture [80] Emergency Management[83] Library orient [59] Urban Planning [46] Transportation [8] Ergonomics [81]	Hunting [44] Geology [35] Biology [13] Ancient Fisherman [26] Genetics [23]
Conceptual	Iconography [115] Symbolism [1] Signage [112]	Religious Study [119] Psychology [16] Zen Philosophy [68]

Structured wayfinding can be as simple as following a previously discovered path and signage to a known destination. For example, following maps and signage in a library to find the history section [59] is structured wayfinding in the physical domain. In structured wayfinding, an agent usually follows authoritative cues that have been previously defined [77], and are managed and operated by a known authority for that domain [72]. Examples of authoritative cues are highway signs posted by state officials, street signs and markers located by city officials, or floor maps posted by building management in a university campus [1]. We also refer to structured wayfinding as guided wayfinding because the available authoritative cues guide the agent along predefined paths [83] to her destination instead of having the agent derive, discover and create new solutions to explore the environment and build her cues, markers and paths along the way. Structured wayfinding involves following a mostly pre-defined wayfinding experience in known environments where the relation between wayfinding and the environment is defined using pre-defined markers (e.g. street names in a city, stop signs on crossroads, etc.) that identify the possible rules and possible paths to known destinations.

Unstructured wayfinding, on the other hand, is more of an observational and exploratory activity in complex environments where paths, directions, destinations might not be known and there are very few pre-existing markers, if any, in the environment. We also refer to unstructured wayfinding as exploratory wayfinding because in this type of wayfinding agent is most likely observing potential markers, and exploring an undefined environment to discover patterns. In unstructured wayfinding, the agent mostly builds solutions, paths, and even destinations as she is exploring the environment instead of following pre-defined guidance and authoritative cues. Thus, an agent discovers cues and markers by leveraging her observation and intuition to make sense of patterns that she encounters in the environment. Unstructured wayfinding is sense making and recognizing patterns since there is no defined signage or path. It is more of an empirical process and less driven by authoritative information. Unstructured wayfinding may be assisted by cues that emerge from other agents in the environment. For example, if 5,000 people using the Ways application suggest that a particular route is congested, the agent is likely to trust this information and search for an alternate route.

The combination of the ‘domain’ and ‘nature’ dimensions identifies six different ‘environments’ of wayfinding. We believe these six environments in Table 1 are a good way to describe the wayfinding design space. The fitting and placement in the table is not exact, and we can always argue where a domain truly fits. For example, a domain can present multiple natures, or can transition from one category to the other. In the following paragraphs, we explain each cell in the Table 1 with an example and highlight its predominant characteristics. These examples are meant to illustrate how we distinguish structured wayfinding (mostly intentional – where there is a defined intention to reach a known destination by following predefined instructions) from unstructured wayfinding (mostly observational – where the destination might vary based on the observed cue or phenomenon while simultaneously building paths according to an agent’s sense making and reasoning).

When a tourist finds her way to a train station, she follows already placed signs and maps [103] to find her destination [76] in the city (environment) she is navigating in. This is an example of structured and physical wayfinding. Structured and physical wayfinding, usually pertains to the set of ‘known-knowns’ domains. This means the destination, possible paths, cues, signs, rules, etc. are known, and an agent is expected to follow these markers instead of creating them.

Now consider a geologist who is trying to find her way in a forest, and does not have pre-built and placed signs or maps. She uses her observational (exploratory) intuition [34] to view phenomenon such as algae growth on rocks, or soil dampness to reason about her environment, path forward, and direction. This is an example of unstructured wayfinding in the physical domain. Wayfinding strategies can change based on the domain even if both domains represent physical and unstructured environments. Consider how wayfinding occurs in a swamp vs. a desert. Although these two environments are in the same cell (space) in our wayfinding framework, wayfinding decisions in a swamp are made one step at a time by feeling cues provided by the wetlands (e.g. whether to proceed or turn) [30], whereas in a desert wayfinding occurs by refraining from sand hills (which act as landmarks) and proceeding on primarily flat areas [48].

After an agent selects what to buy from the Amazon e-commerce webpage, the next steps of her digital wayfinding are mostly structured in nature. The website guides the agent towards checkout, selecting payment methods, picking shipment options, entering payment information, and so on. This is an example of structured wayfinding in a digital environment where options for an agent to explore are limited and markers and cues are imposed on the agent so that she mostly follows existing pre-defined paths.

In a digital wayfinding environment that has a mostly unstructured nature of wayfinding such as astronomy, which studies unknown galaxies [107], providing assistance to the agent to facilitate her exploration is more useful than providing her with a pre-defined path because we do not know a priori what the agent will discover by exploration. These types of design spaces of wayfinding would not benefit with just a map or signage system, and would most likely require the support of locating markers to enhance the wayfinding experience.

Wayfinding in an abstract domain like religious studies [109] is an inner journey to one's self, and the destination in such a domain can be an abstract and deep phenomenon like finding the universal truth [27]. In such domains landmarks are within one's soul, and these domains embody the same wayfinding attributes of other unstructured domains such as exploration, discovery of hidden markers, sense making to sense patterns, and induction and reasoning to build paths and determine destinations whilst wayfinding. Thus, wayfinding in such domains is conceptual and unstructured.

Ancient iconography provides abstract symbolisms to denote concepts like danger, food sources, family, etc. but still uses pre-defined cues, signs, drawings on walls in known locations so that they can be interpreted in a structured way by an agent that is attempting to wayfind.

Using the above insights gained from our literature research, and our proposed wayfinding framework, our conjecture is that wayfinding in WFE is unstructured in nature and is part of the digital domain. We evaluated this conjecture in our empirical work.

3.3 TOOLS USED IN WAYFINDING

Our literature research revealed that tools and techniques for wayfinding differ across the six design spaces outlined in Table 1. For example, wayfinding approaches in a digital environment like a virtual reality application [78] are different than wayfinding approaches in oceanography [39] because the characteristics of the environment, the intention of agent, the viability of tools, the nature of cues and affordances differ. For example, in virtual reality wayfinding auditory and haptic cues can be more important [20] but in oceanography wayfinding the depth of ocean can be dominant landmark. Another example is that in using arrows to point direction can be good enough for finding our way in a building [80], whereas providing light effects to the paths inside a plane could be the minimum requirement of wayfinding for finding our way in a plane.

3.4 WAYFINDING PATTERNS

In addition to defining wayfinding concepts (Section 3.1) and a wayfinding framework (Section 3.2), five patterns of wayfinding emerged from our literature study. To help illustrate these patterns, consider the wayfinding scenario in Figure 2 again. Pattern names are specified in italics in Figure 2.

Context Awareness: The intern in the scenario in Figure 2 is aware of her whereabouts. She observers and relates to her environment, her current presence in the environment, whether she is at her intended destination or not, how far she might be from her destination etc. We refer to this as context awareness. Specifically, an *agent* (the entity that attempts to wayfind in an environment) knowing their whereabouts (context) is called context awareness. Context awareness is an important concept in navigation because an agent knowing where she is, where she is not, and where she intends to be, helps her mentally draw a path to her destination [74]. This 'sense of place' is more than geographic self-location (spatial), and might include time, social, physical [86], economic parameters, along with relative orientation within the intended environment [68]. Using our intern scenario highlighted in Figure 2, an example of spatial context awareness can be the new hire orientation room in the company building. Similarly, an example of temporal context awareness can be the time for her face to face meeting with her manager, or social context awareness for that intern can be knowing the rules of conduct within the, or economic context awareness can be knowing the affordances of tools available to the intern such as using the bus to commute to her company, or orientation context awareness can be knowing relative distance and direction from the current office location to the next meeting's location.

Environment complexity: In our wayfinding scenario illustrated in Figure 2, the company that the intern works in comprises a part of the *environment* where her wayfinding activities take place. As highlighted by Table 1, the complete environment of the intern is not just physical, but also includes the digital aspects such as source code repositories, wikis, etc.; and conceptual aspects that captures inter-personal relationships and team dynamics. An environment, in general, can be physical, digital or conceptual such as New York City (NYC) [64], a hospital [22], an airport [47], the Pacific Ocean [63], the human brain [73], the Canadian forests [44], galaxies in space [19], and WFE datasets [89]. These environments can be large and complex, and the destination or path that the agent is following or creating in the environment is not always obvious (not only visually, but also perceptually). Complexity in these examples has multiple contributors such as time, size, social, diversity, etc. An environment can be a complex adaptive system [45] that is a combination of partially connected components that has dynamic interactions and system characteristics that mutate over time to adapt to changing events. The complexity in the environment can also change in reaction to occurred events.

An agent can view an environment to be more complex or less complex depending on the experiences of that agent in the environment, and the actions of wayfinding might vary based on this view. This phenomenon is well represented in the Cynefin framework that is a decision-making framework to decide on which actions to take under which circumstances by considering complexity and the conditions of situation. Cynefin framework consists of five domains [88]: Simple, Complicated, Complex, Chaotic and Disorder and suggests that each domain requires deciding on different actions and data to act upon. The Cynefin framework divides the domains into two broad categories. Simple and Complicated domains are referred as 'ordered' and Complex and Chaotic domains are referred as 'unordered'. The fifth domain is itself called 'disordered'. These domains are not about inherent qualities about a system; instead they are about how a person or set of people relates to a particular system in which they are making decisions. Different people may relate differently to the same system and thus place the same system into different Cynefin domains. The simple domain represents known knowns. In this domain, it is accepted that cause-consequence relationships and rules are mostly known and the use of defined and proven best-practices are suggested in decision making. The complicated domain represents known unknowns. In this domain, some analysis and expertise is required to understand the relationship between cause and consequence, and selecting from a set of good practices is suggested in decision making. The complex domain represents unknown unknowns. In this domain cause and consequence can be inducted by sensing, uncovering and recognizing patterns, and the underlying causal mechanism may be changing invisibly, so there might be multiple right answers, so emergent practices are suggested in decision making. The chaotic domain represents a complete lack of understanding of cause and consequence relations. In this domain events are considered too confusing to use knowledge-based processes; instead quick, reactive and decisive novel practices are suggested in decision making. The disorder domain represents a system that the person or set of people have thought about to even consider how they relate to that system.

In wayfinding, each agent's viewpoints create customized wayfinding methods and experiences. For example, an agent that visits NYC for the first time, might find the environment to be in the Chaotic domain of the Cynefin framework, with no discernable organization; while another agent that visits NYC regularly might find the environment to be in the Complicated domain, requiring expertise to navigate effectively [60]. Similarly, the intern in our scenario described in Figure 2, might need different wayfinding approaches on her first day vs. her third month in the company. Likewise, a researcher, who has not studied a particular WFE dataset previously might find the dataset more complex to navigate, than a researcher who gathered the dataset and was physically present in the environment. When complexity increases, sometimes it is not feasible to use traditional approaches and tools to decide on actions, and humans might use their qualitative and exploration skills to create novel approaches. Additionally, when complexity increases, humans can collaborate and use their previous experiences in the environment to wayfind.

Sensing cues: Our intern in the scenario described in Figure 2 might need to interpret and use some information to find her way to reach points of interest to her (e.g. the Exit sign, the Restroom label, etc.). Sensory *cues* [24] (visual, auditory, haptic indicators that help the agent orient in an environment) are a common theme in wayfinding. These cues can be highway signs [11], signage in a hospital [58], auditory alerts [87] in a virtual reality (VR) environment [55], a bird's song in the Amazon forest [106], the feeling of water or the feeling of sunlight on the skin of visually-impaired people [2], and so on. For example, hunters in Nova Scotia [44] decide their next path by sensing and combining multiple cues: tracks of smaller animals, the proximity of a river, migratory direction of birds, sounds made by the wind, wetness of soil, etc. In our intern's case, these cues include signs in the building, the map of campus, elevator sounds in the corridors, etc. In a WFE environment, cues can be *tags* in a dataset, transcripts of videos, visual representations of human activities, and annotations of meta-data that highlight the things that can help WFE researchers reason about the environment. Cues, primarily aid the agent in the exploration of, and navigation within, an environment [26], with relative ease [13]. The agent is an integral part of wayfinding, and we can claim that there is no wayfinding without an agent's intention and decisions. Wayfinding is agent-centric, and requires intention of an agent to be performed. For instance, in a WFE analysis session we observed (see Chapter 4) that researchers used their cognition to reason about elapsed time, semantics, and human behavior, and hypothesize which events occurred before two developers in the WFE dataset reached their pair station. These researchers identified it was early morning, and the developers in the dataset had just finished a standup meeting. Using this information, the WFE researchers used sense-making to understand possible scenarios and used abductive reasoning to conjecture that the developers in the video might have taken a coffee break prior to walking to their pair programming station.

Landmarking: Wayfinding is usually not limited to following maps or signage. Wayfinding can use human senses to continuously interact with the environment to create new experiences, and points of reference [23]. For example, the intern in the wayfinding scenario described in Figure 2, might try to choose a different elevator to go to cafeteria based on the number of people that are waiting to get onto a particular elevator. This information becomes a point of reference for the intern, and she uses it to make elevator choices in the future. This concept is called Landmarking. Landmarking also emerges for known places in a physical environment. For example, the restaurant where the intern celebrated her birthday is a known place, and because she can distinguish it from other places she has visited, the restaurant now becomes a landmark for her. Wayfinding involves an ecosystem of multiple continuous decisions that result from getting input from the environment, and leaving landmarks or *markers* as the output. These markers can be used by the agent that creates them or by other agents that come across them (collaboration) [82]. For instance, in WFE wayfinding, researchers can mark portions of their dataset as being useless (e.g. if visibility is very poor in the video), so that they themselves and other researchers do not waste time in downloading or viewing that portion of dataset again.

Continuous Change: Environments are dynamic and continuously changing because there are multiple components like people, people's cognition, tools used, their interactions [45], etc. that are changing. Wayfinding therefore involves continuous orientation to find, decide, change, and adapt a path towards the destination. This mechanism is similar to Boyd's Observe-Orient-Decide-Act (OODA) Loop [65], as illustrated in Figure 4, wherein the results of one step (e.g. Observe) forms the input to the next iterative loop (e.g. Orient). For example, in wayfinding, an agent *observes* her location and orients herself mentally to realize that she is not at her destination. Then she *orients* herself in the environment in such a way that she believes is progressing on a way forward that will lead her towards her intended goal. Along the path of her journey she checks in at various points to check and *decide* whether she has reached her destination. If she does not complete her intended goal, she *acts* to take the required next steps to re-orient her towards her intended destination. In wayfinding domains with unstructured nature, this circular progression loop of observe, orient, decide, and act repeats very frequently, and a number of times since unstructured wayfinding calls for exploration and discovery in unknown environments.

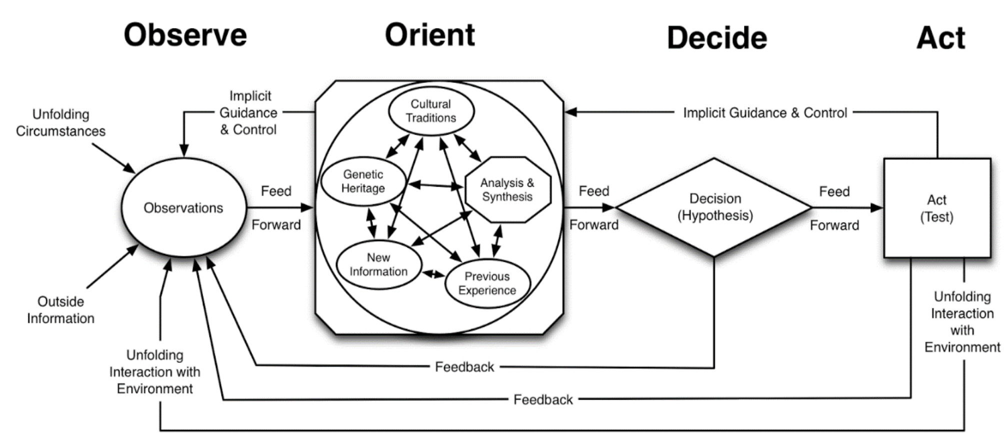

Figure 4. OODA modeling of wayfinding activities.
(courtesy of http://www.edgefirearmstraining.com)

Wayfinding, usually, is not limited to a static and pre-defined set of paths. The environment and set of possible paths are continuously changing. Example of change in environment variables include changes of the roads in a city [79], and the network architecture of a big infrastructure system [32]. Oceans, forests, etc. change due to seasons, erosion, construction, and so on. A visually impaired person who uses an auditory wayfinding application [38] on the phone can change his/her way when he/she feels that there is ongoing construction on the pavement. If an intern's team moves to another building, she needs to adapt her understanding of wayfinding activities to the new environment. Similarly, in WFE, the wayfinding path can change over time as more markers are added to the dataset. If markers are visible and an agent can search/filter the markers, she can explore the complex environment with relative ease.

Another example of continuous change is that the chosen path might change depending on the human (agent) in the loop [63] per the agent's background, gender, experience, culture, age [85], current state, perceptions, biases, etc. [16] [57]. Even the same agent in the same environment can explore a different path depending on other factors like time, mood, experience, etc. [14]. The intern in our scenario described in Figure 2 might need different wayfinding approaches in her second year of internship or in an internship with another branch office of the company. Similarly, a researcher who was physically present at the location where the data was collected vs. another researcher who was not, might have different understandings and producing different outcomes while wayfinding in the dataset. As the understanding of the agent about her environment increases over time, and as the agent builds a mental image of the environment, her wayfinding experience changes.

Using the above patterns extracted from our wayfinding literature analysis, and the wayfinding framework we created, we define wayfinding as:

> an *agent* being aware of her current *context* and deciding to navigate through a *complex environment* by interacting with the environment, tracking *sensory cues*, and orienting

herself towards a *destination* with an *intention* using available *tools*, wherein that intention and path might *dynamically and continuously change* based on feedback from the environment; and during the journey she enhances her understanding and experience of the environment and creates new *markers* as the unfamiliar environment transitions itself to a more familiar environment for the agent by the use of *landmarking*.

Chapter 4. UNDERSTANDING WAYFINDING IN WFE

This chapter describes an empirical study of the current state of wayfinding in WFE. This study revealed: a) the general nature of WFE wayfinding, b) a set of problems that WFE researchers commonly face while wayfinding in WFE datasets, and c) the highly exploratory nature of WFE wayfinding.

We chose to study wayfinding in the WFE domain because the scarcity of conceptual frameworks and tools in the relatively nascent field of WFE makes it difficult for researchers to easily navigate the large and diverse WFE datasets. We expect WFE datasets to be larger and more diverse in the future, and this will exacerbate a WFE researcher's difficulties in wayfinding. To understand how wayfinding can be performed more efficiently in the future, it is useful to understand how wayfinding is currently conducted in WFE datasets.

In order to generate insights and reason about wayfinding in WFE [101], we used the following methods [10] to study the phenomenon of wayfinding in WFE: a) performed six observation sessions [17], b) held three interviews with WFE researchers, and c) analyzed videos of nine WFE sessions that covered twenty hours of video.

The six observation sessions involved either observing a set of WFE researchers analyzing WFE datasets (observatory), or participating in the WFE analysis (participatory) [12]. Table 2 shows the details of the six observation sessions, including the participants, session duration, and the intent of the session. In the table, 'Active' means that the participant was actively analyzing the dataset [18], whereas an 'Observatory' participant means that the participant's involvement in the session was limited to taking notes and pictures [52].

Table 2. Details of Observation Sessions

Session No.	No. of Participants	Duration (hours)	Intent
1	Active: Socha, Arisoy Observatory: Al-Sughayer	2	Analyze the scalability discussion
2	Active: Socha, Al-Sughayer Observatory: Arisoy	1	Find interactions between pairs of programmers
3	Active: Socha, Dowe Observatory: Arisoy, Al-Sughayer	2	Find moments of laughter
4	Active: Arisoy, Al-Sughayer	4	Analyze videos captured from Session 1 to understand challenges in WFE Wayfinding
5	Active: Arisoy, Al-Sughayer	3	Find moments of Wayfinding
6	Active: Arisoy	1	Analyze videos captured from Session2 to understand how researchers conduct Wayfinding

The environment that afforded the analysis [104] in these sessions included three GoPro cameras and two smart phones. The three GoPro cameras were set to record at the beginning of each session and run concurrently until the end of the session. Two GoPro cameras were situated on the desk (GoPro3 and GoPro9) and one was located on a shelf (GoPro4). The smart phones were located on the table (Camera1 and Camera2), and the smart phones were used to only take pictures. This layout is shown in Figure 5. Figure 6 shows an actual image of the environment for Session 1. In the particular instant during which Figure 6 was captured, only one observer was present (instead of 2 as depicted in the layout in Figure 5). Figure 6 has been captured via GoPro4 and hence the perspective is rotated by 90-deg clockwise compared to Figure 5.

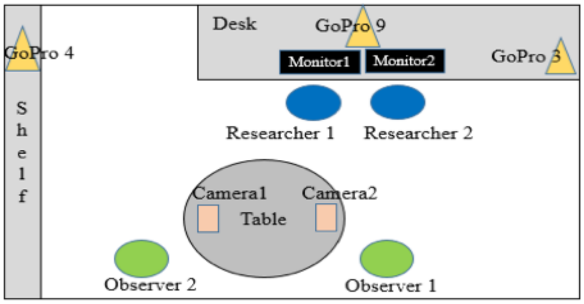

Figure 5: Observation session layout.

Figure 6: An observation session.

To illustrate our approach to analyzing the six observation sessions, we only describe how Session 1 was analyzed because the remaining five sessions were analyzed in a similar manner. The dataset being analyzed in this session (Session 1) is called BCResearchers. BCReseachers is a dataset that contains video recordings captured from a workshop in Victoria B.C., Canada, in which WFE researchers were analyzing another dataset called BeamCoffer [89]. BeamCoffer, is a dataset that captures three weeks of video recordings of programmers working in a software development company in Seattle, WA, USA. We also use BeamCoffer as a pseudonym for the software company where the dataset was captured. BeamCoffer is an example of a PSEC system mentioned in Chapter 1. In Session 1, the researchers goal was to analyze the dataset with the initial intention of finding when the word 'scalability' was first used. Thus, the destination was known to the researchers.

Session 1, had the following three WFE researchers:

- DS (Dr. David Socha): My thesis advisor who gathered the BeamCoffer and BCResearchers datasets specified above. This researcher was physically present in the locations where the data was gathered, and therefore had some prior experience to the dataset.

- AA (Aytul Arisoy): Me, the author of this thesis, and one of Dr. Socha's students. This researcher is an active participant in this session.
- FA (Fida Al-Sughayer): Another one of Dr. Socha's students, who is an observatory participant, and is taking notes on, and pictures of, the other two researchers' actions and behaviors.

4.1 ANALYZING VIDEOS OF WFE SESSIONS

The first step in our video analysis was to transcribe the session, where the transcript contained observations of activities that were related to the wayfinding concepts and patterns identified in Chapter 3 of this thesis, rather than what was said by the study subjects (researchers). These notes helped us classify, define, and differentiate tasks that were done during wayfinding in the WFE dataset so that we could reason about the varieties, durations, and challenges of wayfinding in WFE.

The following is a small portion of our transcript of Session 1. Appendix A contains additional transcripts. The values in the left column are time in offsets (mm:ss) from the beginning of the video. The underlined words represent activities that we felt would be useful for understanding wayfinding moments. Using italics, we highlight wayfinding concepts that we defined in Chapter 3.

10:23: DS and AA (*agents*) are <u>turned</u> towards their monitors (*tools*) as illustrated in Figure 7, and initiated their wayfinding activities (*path*) (to detect the first utterance of the word 'Scalability' (*intention*) in the BCReseachers data set (*environment*)).

10:23: DS (*agent*) grabs the mouse (*tool*) in front of him (Figure 7), and directs his gaze to the monitor in front of him. That monitor is the *tool* to access the *environment* (dataset) and conduct his wayfinding activity.

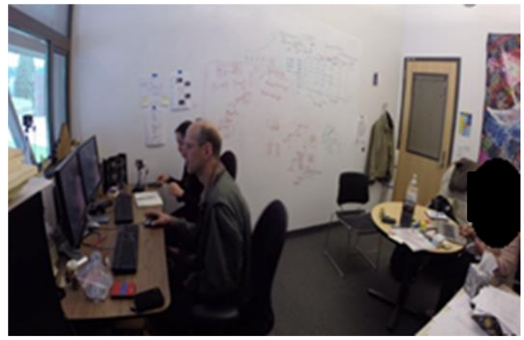

Figure 7. Initiation of wayfinding.

DS and AA were the two WFE researchers that were analyzing the session. DS and AA were the *agents* in that environment. The *environment* was the dataset of BCResearchers that resided in cloud storage as well as on an external hard drive. The computer, monitors, mouse, paper, notebook were the *tools* that the agents used for their wayfinding activity. In this session, the agents' *intention* was to find the moment where the Victoria workshop researchers used the word 'scalability'. Their *destination* was the point of video in the dataset where they would detect this intention. Their *path* started from where they initiating their navigation in the dataset, and extended to where they would find their destination. *Landmarks* were available because of DS's prior experience with the workshop, in which he knew that the discussion about scalability would likely have happened on the second day of the workshop, and that the discussion happened when all the Victoria workshop researchers were present in the workshop room. *Cues* in this session were the audio fragments that agents heard [62] while viewing the videos of the workshop, and the visuals they watched in the videos.

Turning to the monitors in front of them was an act of initiation for the researchers to start searching through the dataset (BCResearchers). By initiating their wayfinding activity, the researchers started searching for their context and *intention* for the session. They changed their attention from the discussion that occurred between the three researchers (Figure 6), to start orienting themselves towards the environment in the computer to locate the dataset that was to be navigated (Figure 7). Such initiation is analogous to explorers taking their first step on the first day of their expedition. The WFE researchers then turned towards their monitors and computers because they had an understanding that they could access the search *environment* (dataset) via those *tools*.

10:24: DS asks 'What are we doing?' (*context-awareness*), and at the same time launches the Start menu of the computer(*tool*) in front of him. He is already performing a task (which later analysis of video captured by GoPro3 showed to be opening TrueCrypt to reach the hard drive of the dataset (*environment*)), and initiating a route (*path*) for exploration.

This initiation of the wayfinding activity and subsequent steps in navigation were similar to the OODA loop descried in Figure 4 of Chapter 3. Their first step was to observe their context, identify where they were in the dataset (current place), and reason about what their next step could be. Before going to the next step (orient), these two agents wanted to reason about their current place as well. Since WFE wayfinding is mostly unstructured in nature (as defined in the wayfinding framework in Chapter 3), these agents were not operating in a guided manner for the most part; and by trying to understand more about their current location, recalling their intention, and reasoning about their potential destination, these agents were trying to explore and discover the otherwise unknown environment.

10:28: AA (other *agent*) replies, 'Victoria Session??' (*content-awareness*)

Here AA seems to be answering, and by observing DS's action of initiating an exploration, she seems to be assuming that his question is a rhetorical one. The intonation at the end of her sentence, sounds as if she is also questioning. AA meanwhile follows the cursor of DS's mouse (*tool*), and follows the movement on the monitor of the computer in front of DS to see the dataset (*environment*). (observe action in OODA loop, context awareness pattern in Chapter 2)

The WFE environment was complex because the dataset was large, unstructured, had multiple types of data in it, and was not organized beyond having folders that represented the camera name and the date of recording. Thus, in an unstructured, digital and complex environment where there were no pre-located signs to denote paths in WFE dataset, these agents tried to create new solutions cognitively to identify signs, cues, and potential paths by interacting with each other and with their environment. For example, to narrow down her exploration space, one agent (AA) kept asking questions to the other agent (DS) because he was physically present in the dataset when the recordings were captured. Her objective in questioning the other agent was to make sense and spot patterns about when the workshop started, the day the scalability discussion occurred, the time of the scalability discussion (morning or afternoon), and the members present in the room when the scalability discussion was held. Since these agents did not have a pre-defined map or destination, or pre-located markers to gain context, they used their sense-making, intuition and inductive reasoning to discover phenomenon, explore highlights, and build a path to their intended destination.

By studying the above observations and subsequent steps in the transcripts of Session 1 and the other five sessions, we saw the following general patterns for wayfinding in WFE datasets: The *agent* (WFE researcher), first oriented herself into time, space, and other dimensions of the WFE *environment*, which in our specific case meant that she connected to the network, accessed the dataset folder, and set her intent to study a particular dataset for a particular day. To achieve this orientation, she related to (communicated with) the complex environment (used *tools*, and her interpretation), used familiarity with such data sets, and built her mental model of the environment. The agent, monitored where she was to understand her sense of place and context, how much she had progressed in her analysis, and what phenomenon she *intended* to find. This WFE researcher checked data from various data sources, investigated visualizations, built correlations and used her sense-making to decide next steps, based on her prior experience. Based on the information she gathered in her activity, the agent evaluated between continuing the activity, diversion to another route, or starting over; and then decided on her next step. Next, the WFE researcher explored the environment (WFE system and dataset), and started analyzing a different time slice of a different day in the dataset because she may have believed that the new *path* would take her closer to her desired outcome and *destination* [56]. As the researcher continued her navigation through the system, she discovered *landmarks* that were important for her phenomenon that helped her generate insights that aided her orientation. In general, WFE researchers (including our observed researcher mentioned above) tended to access data indicated by landmarks, and check if the accessed data was what they expected, by trying to recognize and validate their assumptions. Our observations showed that this eight-step cycle (illustrated in Figure 8) is iterative for most wayfinding activities in WFE, and occurs within each category of WFE wayfinding activities as wayfinding changes *dynamically*. We call this iterative and cyclic continuation of wayfinding activities as ‘Wayfinding Loop’. Since there is no signage to follow, no map to locate the destination, no route to calculate the distance, and no landmarks that can be referred to, the agent doing wayfinding in WFE datasets explores the dataset to discover otherwise hidden components like landmarks, cues, and paths.

In our observations, we also saw that WFE researchers repeatedly cycled through a set of 'mini-tasks' that we categorized into eight themes: 1) Orient, 2) Monitor, 3) Decide, 4) Explore, 5) Discover, 6) Access, 7) Recognize, and 8) Validate. In guided or structured wayfinding

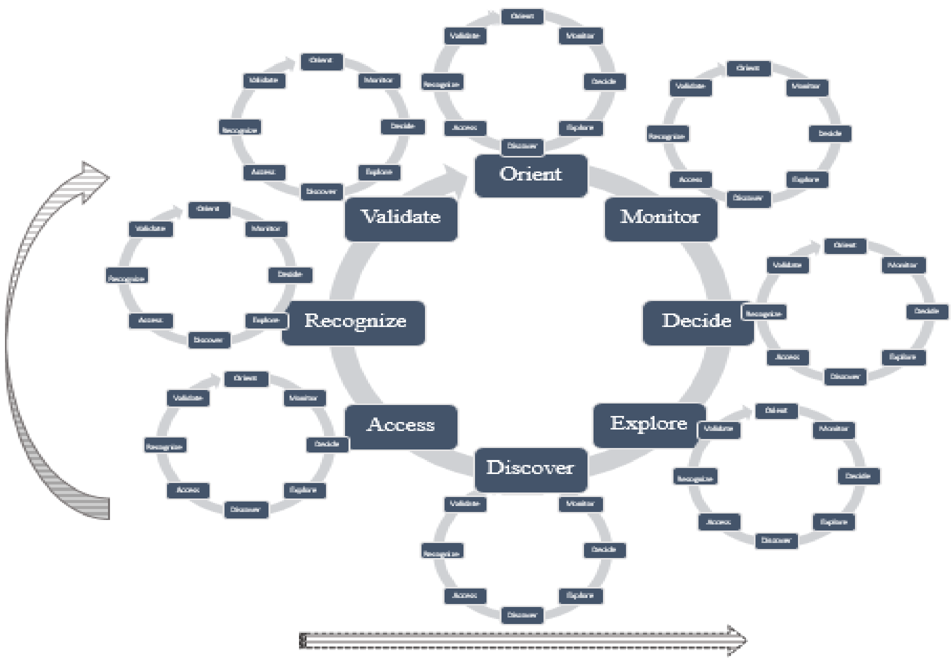

Figure 8. Eight dominant themes in wayfinding loop.

(explained in the wayfinding framework in Chapter 3), these eight steps and iterative cycles of wayfinding activities do not always take place or take place to a much lower extent. Rather, the most observed action set is Access, Recognize, Follow, and Validate. Additionally, guided wayfinding does not include the exploration part found in exploratory wayfinding, where the agent tries to discover unknown patterns and then decides whether those patterns can be used to compute her wayfinding path.

Table 3 illustrates the variety of activities that occur over a 5:02 minute portion of a WFE analysis session, and shows the classification of these activities using the eight themes described above. This classification was done by two WFE researchers in a joint analysis session. Our analysis identified 66 different mini wayfinding tasks within those 5:02 minutes that closely resemble multiple nested OODA-type loops. In Table 3, the Theme column specifies the classification of the wayfinding mini-task based on the eight themes in Figure 8. Distribution, in Table 3, shows the frequency at which the mini-task is observed. The values Uniform, Random, and Clumped are used to denote the Distribution. Co- balance, in Table 3, describes how the mini-task is shared between agents. High (H), Medium (M), Low (L) is used to denote co-balance. In Table 3, Duration represents the total time taken by a mini-task within the total duration of video. Mini-tasks that occur more than 10 times are highlighted with a green background, and mini- tasks that occurred more than 5 times are highlighted with a blue background.

Table 3. Wayfinding Sub-activities

Theme	#	WF Activity	# of Times	Distribution	Co-Balance	Duration	Definition	Example
Explore	1	Co-looking	54	Uniform	H	3.4	Collaboratively and actively viewing an object	Two agents are looking at folder in drive, to AWS, to video
Decide	2	Talking	46	Uniform	H	4.2	An agent is speaking	Either S or A is saying something, nodding and gesture is excluded
Orient	3	Multi-tasking	43	Uniform	H	5	An agent is doing multiple tasks: talking, looking, using tools	S talking, pointing cursor, opening folders at the same time
Explore	4	Asking	19	Uniform	L	2.1	An agent is asking a question, not proposing or questioning e	A is trying to understand the estimated time of scalability discussion
Access	5	Using tools	18	Uniform	L	4.6	Using mouse, pen, cell phone, etc	S is using cursor to point a file
Discover	6	Pointing	17	Uniform	H	2.3	Pointing to an object - monitor or notebook by finger or pen	A is pointing to active monitor by her finger to emphasize a proposal
Explore	7	Answering	16	Uniform	L	1.9	An agent is answering a question	S is answering A's question about drive usage
Recognize	8	Thinking	14	Random	H	2.4	An agent takes time to respond, answer, act - eyes up etc	S is saying umm and looking at ceiling putting his hand to his chin
Orient	9	Navigating	13	Random	M	3.6	An agent is navigating in the environment, folder to file, etc	S is opening drive and Victoria folder Oct 22
Explore	10	Questioning	9	Random	M	1.1	An agent is suspiciously questioning to get convinced	A is questioning the video they view is first day morning
Recognize	11	Indicating	8	Clumped	M	1.8	An agent suggests pointing out a way	S is indicating the word scalability was used previously
Validate	12	Confirming	7	Random	M	1.2	An agent confirm a proposal or idea	A is confirming the session purpose
Explore	13	Proposing	7	Random	M	1.4	An agent recommends another way	A is proposing to work on AWS
Orient	14	Searching	7	Random	M	2.9	An agent is trying to find an object	S is trying to find the drive
Decide	15	Listening	6	Random	H	3.1	An agent is listening to the other agent	A is listening to where transcripts are
Access	16	Tracking	6	Random	H	4.1	An agent is following a cue	S is tracking the discussion of first video
Recognize	17	Agreeing	5	Clumped	H	2.2	An agent concur or consent a proposal or idea	S aggrees to open the cloud folder to search data
Recognize	18	Disagreeing	5	Clumped	M	1.5	An agent does not concur or consent a proposal or idea	A disagrees to only search for scalability in one context
Decide	19	Guessing	5	Clumped	M	1.4	An agent is not depending the thinking on fact but supposes	S guesses the conversation was on the second day
Access	20	Highlighting	5	Clumped	M	2.6	An agent emphasizes an idea	A indicates researchers arrived from one place together
Explore	21	Locating	5	Random	M	2.2	An agent finds the whereabouts of an object	S finds the hard disk as a source of data
Decide	22	Taking notes	5	Clumped	L	1.1	An agent is taking notes in notebook or laptop	A takes notes of the file name as a landmark
Discover	23	Claiming	4	Clumped	M	1.3	An agent makes an assertion	A claims the interactions of researchers
Orient	24	Orienting	4	Clumped	L	1.5	An agent locates their location w.r.t other objects	S moves the cursor to the next day's folder
Access	25	Writing	4	Clumped	L	2.1	An agent is writing in keyboard, notebook, phone etc	S types the location of second days GoPro folder
Validate	26	Approving	3	Clumped	M	1.3	An agent confirms a proposal or nods	S confirms to search for next video
Validate	27	Checking	3	Clumped	M	1.6	An agent is controlling the validity of an assumption	A checks the number of researchers in the video
Access	28	Configuring	3	Clumped	L	2.4	An agent is setting up tools to use	S is configuring Wifi setting of GoPro
Explore	29	Expediting	3	Clumped	H	2.1	An agent is exploring the subset data	A is exploring the cloud folders to locate Victoria session
Discover	30	Finding	3	Clumped	L	1.7	An agent is discovering a thing	S is finding the lunch time of the session of second day
Explore	31	Moving	3	Clumped	M	2.6	An agent makes a move to direct another direction	A is moving to second monitor to view videos
Monitor	32	Repeating	3	Clumped	L	1.4	An agent iterates wat he/she said before	S repeats the likelihood of finding Scalability in 2nd day
Validate	33	Verifying	3	Clumped	M	1.3	An agent is confirming a thing	S confirms the word was used when room was crowded
Explore	34	Clarifying	2	Clumped	L	1.5	An agent expaining an assumption	S explains the layout of Victoria workshop to A
Access	35	Committing	2	Clumped	L	0.8	An agent deciding to act	A committing to continue on external disk path
Discover	36	Confusing	2	Clumped	M	0.6	An agent struggling to decide	S confused on the time of the session
Explore	37	Opening	2	Clumped	L	0.8	An agent accessing a data to explore	S opening the Victoria folder
Recognize	38	Planning	2	Clumped	L	0.4	An agent thinking to move	A planning to narrow down the search scope
Orient	39	Preparing	2	Clumped	L	0.6	An agent planning to move	S preparing the configuration for analysis
Validate	40	Struggling	2	Clumped	M	1.2	An agent confused for next path	A is confused on where to find the word in day-1
Explore	41	Analyzing	1	Clumped	L	1.5	An agent evaluating the current path	S is assessing the behavior of researchers
Decide	42	Assessing	1	Clumped	L	1.3	An agent trying to compare the destination point	A is evaluating whether to fast-forward images
Decide	43	Assuming	1	Clumped	L	0.7	An agent accepting a thing to move forward	S is assuming researchers came from breakfast
Explore	44	Comparing	1	Clumped	L	0.5	An agent comparing two points of location to decice	S is comparing the sunshine in the analysis room
Access	45	Denying	1	Clumped	L	0.2	An agent disagrees on the act of move	A is disagreeing to select first instance of the word
Discover	46	Directing	1	Clumped	L	0.9	An agent leading the path to progress	S is leading the path to the second day of workshop
Explore	47	Discussing	1	Clumped	L	1.3	Two agents trying to clarify a situation	S and A trying to understand the reason of researcher's move
Recognize	48	Doing	1	Clumped	M	0.5	An agent performing a task manually	S is reaching his pocket to find his phone to configure
Orient	49	Entering	1	Clumped	L	0.4	An agent opening a dataset to access	S is entering password to open encryption
Validate	50	Estimating	1	Clumped	L	1.1	An agent guessing the path to destination	A is guessing the dialogue will not long more than 2 videos
Explore	51	Following	1	Clumped	M	1.6	An agent following the lead of the other agent to the destination	A is following the proposal of S to move forward on video
Decide	52	Getting data	1	Clumped	M	1.4	An agent is collecting data from a source like hard disk	A is getting information from S about the day-2
Orient	53	Hearing	1	Clumped	M	1.1	An agent is getting audio input from the videos	A is hearing the word scalability from one of the researchers
Explore	54	Ignoring	1	Clumped	L	0.4	An agent ignores the suggestion from the fellow researcher	S is ignoring A's request to move to cloud
Access	55	Implying	1	Clumped	L	0.9	An agent meaning to say a thing	A is implying there might be more than one word mention
Discover	56	Initiating	1	Clumped	L	0.8	An agent starting a move to the path	S is starting to orient in next day's video
Explore	57	Invalidating	1	Clumped	L	0.2	An agent verifying a thing is not true	S is saying the first day started in the afternoon
Recognize	58	Misguiding	1	Clumped	L	0.3	An agent leading the fellow researcher to a mis-cue	A is insisting to follow miscue to look at day 1
Orient	59	Negotiating	1	Clumped	L	0.3	An agent discussing the next step with fellow researcher	A is negotiating to search second folder
Monitor	60	Observing	1	Clumped	M	0.7	An agent monitoring the progress of the path	A is monitoring the sequence of event in video 1
Orient	61	Proceeding	1	Clumped	M	0.6	An agent progressing on the path	S is progressing on the third video in same day
Discover	62	Processing	1	Clumped	L	0.5	An agent thinking about a proposal with input data	A is assessing the likelihood of cause-consequence of BC
Explore	63	Progressing	1	Clumped	M	0.4	An agent progressing towards the destination (positive)	A is proceeding to listen to BC dataset information in video
Recognize	64	Reaching	1	Clumped	L	0.4	An agent accessing a data to explore	A is accessing mouse to point where researchers do not exist
Orient	65	Triggering	1	Clumped	L	0.3	An agent initiating a path to destination	S is initiating to open next day's video
Orient	66	Unlocking	1	Clumped	L	0.2	An agent uncovering and opening a new data source	A is realizing the workshop was 1,5 days not 2

To recap, we observed that agents reason about their context, try to uncover sensory cues, locate markers on points of interest for them, and dynamically change their direction, path or destination using feedback they sense from the environment. While doing these activities, agents use the tools that are available to them (computer, notebook, pencil, etc.) to help their exploration. Yet, they use their own interpretation to drive the decision loop by evaluating the data they get from the environment.

During the process of this thesis, our empirical data disproved a few hypotheses. For example, during literature research on wayfinding in different domains, we generated a conjecture that in group wayfinding activities there is generally a leader and a set of followers. We captured this concept as pilot and co-pilot during orientation. That hypothesis was built on the assumption that while navigating in a transportation vehicle (car, motorcycle, bus, etc.), there is one steering wheel or one active control plane. Thus, we were under the impression that there will be one leader in a group-based wayfinding activity. Similarly, in WFE, we presumed that the agent who holds the mouse and uses the active monitor would be the leader while the other researchers would be followers. We also wrongly assumed that in a pair station, even though there are two monitors and two mice, at a single point in time (t), there would be only one active event that occurs, and the two researchers would not be able to use the two mice at the very same moment, on the very same monitor (i.e. one active control plane). Yet, after six observation sessions of two WFE researchers trying to wayfind in a WFE dataset, we realized that this conjecture did not capture reality, because the ‘driver’ (pilot), and the navigator (co-pilot) swapped roles frequently. We saw role swapping frequently in WFE wayfinding, even though one of the researchers could be the mentor, could be more experienced with the dataset than the other researchers, and could have more authority due to teacher-student dynamics. This observation is similar to the pair programming results [93] from literature [112], [113]. Additionally, we observed that the orientation and progress in wayfinding depended on both researchers. For example, the relatively novice researcher (AA), kept asking questions to narrow down the scope of her inquiry (‘when was the discussion - day or night?’, ‘first day or second day?’, ‘was everyone present?’, ‘where were you sitting?’, etc.). In addition, the novice researcher also proposed multiple alternate paths, some of which, were pursued by the collective research group (‘let’s try AWS’, ‘let’s check the previous day’, etc.).

4.2 WFE WAYFINDING CHALLENGES

The analysis of WFE sessions (Section 4.2) revealed a set of challenges [28] that WFE researchers encounter. The main challenges noted during our six observational sessions were:

1. There was no visual data representation of the WFE dataset which was the wayfinding environment.
2. Last state was not saved, so researchers had to remember the context of the previous session prior to initiating a new wayfinding session.
3. Data tracking was complex, difficult and spread over large number of settings. Agents needed to open and view data from sources and tools spread over technologies and mediums (e.g. Excel, video, Google Drive, AWS, hard drive, paper, notebook, post-it, etc.) making it hard for them to correlate the data. Thus, agents lost time going back and forth across the large number of tools and data sources. In essence, there was an absence of a unified or well-interconnect interface to visualize and navigate the variety of data.
4. Perception of layout, distance, and field of view (360-degree or fish-eye) was absent making it difficult for agents to understand the proximity, interaction and relationships between entities (i.e. PS A is next to PS B).

5. Agents lost time opening each video sequentially, when they were searching for a phenomenon, whose location in the dataset was unknown.
6. Agents took notes of their mental markers in their notebooks or cloud drives, but could not represent their markers digitally on the dataset.
7. Unsynchronized streams of data made agents' wayfinding harder, because these agents spent time correlating data across multiple streams (e.g. videos to pictures).

These challenges present an opportunity to evaluate if tools could help with wayfinding in WFE datasets, an opportunity that we take up further in Chapter 7 where we discuss a prototype tool we created to aid wayfinding in WFE.

Chapter 5. EXPLORATORY WAYFINDING

After conducting the empirical study described in Chapter 4, we realized that some parts of wayfinding in WFE appeared to be qualitatively different than most wayfinding methods described in literature. Instead being about signage and getting assistance to a known destination through common paths, WFE wayfinding appeared to be mostly about exploring large amounts of unstructured data to search for unknown-knowns. In WFE wayfinding there is limited signage to follow, limited maps to locate destinations, limited routes to calculate distances, and limited landmarks to refer to; because of which, the agent (WFE researcher) was seen to explore the dataset to discover hidden components of a WFE ecosystem such as landmarks, cues, and paths. WFE wayfinding was seen to be mostly unstructured in nature and therefore unguided, and appeared to be about reaching an unknown destination in an unstructured dataset, where paths could vary widely per agent and intention. In our observations of WFE researchers analyzing WFE datasets, we saw these agents to be usually very observant, seeking any potential markers, trying to discover patterns, creating solutions and paths forward, and even identifying destinations, instead of following pre-defined guidance and authoritative cues. Thus, WFE wayfinding appeared to be a more emergent and a more empirical activity compared to guided wayfinding. In our observations, WFE wayfinding used more interpretation and intuition to make sense of patterns to uncover hidden landmarks. Collaboration amongst researchers was also observed during WFE wayfinding, where they used their respective knowledge, experiences, and interpretations for making sense of potential cues. WFE researchers usually took notes of session details that included any observed interesting phenomenon surfacing their use of markers (landmarking) whilst wayfinding. These aspects led us to define ‘exploratory wayfinding’ as distinct from ‘guided wayfinding’.

There are several important differences that we observed between guided wayfinding and exploratory wayfinding. First, exploratory wayfinding encourages the agent to try to discover unknown patterns and then decide if those patterns could be used to generate markers in the wayfinding path. Guided wayfinding on the other hand encourages the agent to follow pre-defined paths through the use of authoritative cues and landmarks. Next, agents that perform exploratory wayfinding have the flexibility and freedom to create new paths, cues, destinations, and landmarks because most of these components either do not exist or are not known in the environment. In contrast, guided wayfinding does not always provide a flexible set of options to the agent, and mostly focuses on providing paths that authorities intend agents (wayfinders) to follow. Finally, exploratory wayfinding relies on the agent being more active in her environment, and using her cognitive capabilities to apply inductive reasoning to cues gathered from the environment and abductive reasoning to choose a good enough path to forge forward. Conversely, guided wayfinding expects the agent to play a more passive role in her environment and use the available and pre-located authoritative cues to follow paths to the pre-determined destination [4].

Similar to the wayfinding definition in Chapter 3, we define exploratory wayfinding in WFE as:

> an exploration where the *destination* can be the discovery of specific phenomena relating to a general idea of interest on the part of the wayfinders, where *agents* (researchers) repeatedly navigate in the dynamic and complex *environment* of WFE datasets using available *tools* as they reason about the environment, their *path* and the *cues* embedded in it, while sometimes discovering or adding *landmarks* that help their exploration.

We evaluate the efficacy of this definition after we gather the prototype tool insights [53] [91] (see Section 7).

A WFE dataset is an example of a complex and unstructured digital *environment* [99] *(Table 1 upper right hand side space)*, where *agents* (WFE researchers) find their way using reasoning with sense-making to identify cues and paths. In WFE, researchers often continuously explore the dataset to uncover phenomena of interest to them. Based on data extracted from viewing several hours of videos pertaining to WFE analysis of three different datasets, by three different set of researcher groups, observing three WFE analysis sessions in person, and participating in three WFE analysis sessions [15], we observe that exploratory wayfinding starts with an agent knowing where she is located (which dataset, which folder, which day, etc.), where she wants to go (what needs to be found in this session, what needs to be studied in this dataset, etc.), and what her initial *path* to navigate should be (which camera view does she start with, does she start with videos or thumbnails, etc.). Therefore, context-awareness not only includes location and whereabouts, but also time, intention, and objective. For example, in WFE studies, a researcher can start her wayfinding with a query like 'How can I find the points in a set of videos that capture conflicts one week prior to the release date of the product'.

In the process of exploratory wayfinding, the agent (researcher) might leave *markers* (in our prototype tool we model them as '*tags*') thereby potentially guiding future wayfinding (for herself and/or future researchers) in that environment (dataset). These markers can be in the form of annotations, tags, colors, and transcripts, and could support the addition of incremental information by other researchers. This is similar to foraging in nature, where ants leave identifiers that point to food or shelter, so that the colony can find these later [82]. This phenomenon is known as *stigmergy*, which relates to self-organization and indirect and/or unplanned coordination in an environment between agents [25]. For example, ants follow an identifier (pheromone) left by other ants, to build a path when they are wayfinding (usually searching for food). The principle of stigmergy suggests that actions of agents simulate actions of other agents in an environment [69], and these actions reinforce and build upon each other to build a more complex and wide system [70]. In computer science, stigmergy has been applied in techniques called ‘ant colony optimization’ [114], which query, search, and explore solutions to complex problems, by leaving ‘virtual pheromones’ along paths that appear to be useful. In the scenario described in Chapter 3, wherein the agent is interning at a large software development company, principles of stigmergy might apply to how the intern uses the Do’s and Do Not’s suggested by previous interns at her company. Similarly, in exploratory wayfinding, we suggest that researchers might leave identifiers (markers) that other researchers could use to build upon, and enhance their enquiry, paths, and maps. Leaving markers and sharing landmarks with other researchers is an aspect of collective wayfinding because markers might enable researchers to learn from each other, and use the strength of collaboration while performing wayfinding. Thus, encouraging stigmergy [43] can be one of the goals of a framework and set of tools that support wayfinding in WFE.

Chapter 6. CONCEPTUAL FRAMEWORK FOR EXPLORATORY WAYFINDING

This chapter builds a conceptual framework for exploratory wayfinding using results from our study of exploratory wayfinding in WFE domain. In Chapter 5, we defined exploratory wayfinding in WFE as the system by which researchers (agents) know their current context and intention, interact with the dynamic and unstructured digital environment, guide themselves through the WFE environment by exploration of the unknown, and enhance their understanding, perception and experience of the WFE dataset.

Agents perform wayfinding with a purpose (intention), and we claim that there is no wayfinding without a purpose including activities that may appear or seem purposeless to someone who observe the wayfinder. Even a tourist with an abundance of free time [76], has a purpose – to see and explore the city [46]. From ancient times, people and animals have been wayfinding with tangible purposes such as to hunt in order to feed themselves, to find new lands in order to seek safety, etc. [106]. Similarly, a WFE researcher's purpose while wayfinding in a WFE dataset could be to reach a concrete goal (e.g. 'When did this discussion start?'), or familiarize herself with the dataset, or uncover patterns of a social phenomenon, or build the mental map of the environment [54]. Additionally, the agent's intention while performing exploratory wayfinding in WFE can change multiple times during the wayfinding journey.

In wayfinding, the agent (WFE researcher in our research), the environment (WFE dataset), and the intention (objective of WFE researcher) are mostly mandatory variables. Experience with the environment could be optional because wayfinding can be performed with or without prior experience with the environment (i.e. the agent's mental map of the environment can relatively empty or full, but does not prevent her from wayfinding). Experience in this context is not binary but rather a spectrum of information that may contain variable amounts of insights that could be used at a particular moment in wayfinding. Our literature research and our observations showed that time and familiarity (factors that contribute to experience), could be attributes that affect wayfinding. The more familiarity the agent has in navigating the environment, the more efficient the agent's wayfinding activities are likely to be [41]. Consider three WFE researchers: the first is analyzing a dataset for the first time (almost empty mental map), the second has been analyzing the dataset for weeks (likely to have a mental map, landmarks, points, etc.), and the third has been analyzing a dataset that he/she captured (was present in the environment, and has more experience in the environment compared to the other two researchers). These three WFE researchers might have different wayfinding experiences, and their wayfinding activities can yield different outcomes.

As we mentioned earlier, wayfinding methods can vary across different domains and natures as illustrated in Table 1. For example, guided wayfinding in a physical domain like a hospital building might require more procedural methods [34] like route knowledge, maps, directions, signage, arrows showing landmarks, announcements, and so on. Procedural methods like pre-located and pre-defined authoritative signs, cues, signage, and landmarks can be useful in guided (structured) wayfinding to enable agents to follow a defined path to reach a defined destination. Wayfinding used in the disability-assistance area might require dynamically changing and safety-focused methods to aid the agent. These kinds of wayfinding areas use more declarative methods to aid the agent by providing landmark information that facilitates navigation and awareness of the present place, intended destination, and path. Wayfinding activities in unstructured domains which are also digital in nature, such as genetics studies, might need more cognitive methods to aid agents, where these methods could be mental spatial maps that facilitate the selection of a path to a destination depending on the intent, context, time, task, and resources.

Our conjecture is that exploratory wayfinding in WFE is mostly a combination of cognitive and declarative methods (and less procedural), wherein cognitive methods are more predominant at times. We arrived at this conjecture because we observed that researchers in multiple observation sessions depend on their intuition and inductive reasoning to decide on wayfinding actions, rather than just following given paths and cues. Guided wayfinding, on the other hand, does not always encourage agents to interpret the environment and use sense-making to uncover otherwise hidden cues to decide on their paths and methods. In fact, one of the design principles of guided wayfinding (see Section 6.1 for more of these principles) suggests that agents should not be given too many choices while wayfinding. In exploratory wayfinding, an agent usually needs to be aware of the context, have a sense of place, have an intention, have an initial estimated path to the destination in her mental map even though the path may not actually exist, can dynamically change the path as exploration and discovery continues, uncovers landmarks, and then uses those landmarks to narrow down the search scope as she navigates through the dataset, and adapts to uncover patterns by changing her selected tasks, resources, and priorities based on sense-making.

6.1 DESIGN PRINCIPLES TO IMPROVE EXPLORATORY WAYFINDING

Given that exploratory wayfinding is different from the wayfinding found in most literature, in this section we study what design principles to improve the exploratory wayfinding experience in WFE are that are distinct from design principles of other types of wayfinding found in literature (primarily guided wayfinding). Consider, for example, the following wayfinding design principles [31], [32], which we call guided wayfinding design principles (GWDPs):

GWDP 1: Create a discriminatory marker at each location that is different from all others.

GWDP 2: Provide landmarks to give orientation cues and memorable locations.

GWDP 3: Create well-structured paths.

GWDP 4: Create regions of differing visual character.

GWDP 5: Don't give the user too many choices in navigation.

GWDP 6: Use survey views (give navigator's a vista or map).

GWDP 7: Provide signs at decision points to help wayfinding decisions.

Some of the GWDPs are also applicable to exploratory wayfinding. For example, creating regions of differing visual character can be applicable and useful for unstructured and digital environments. However, other GWDP do not fit well with the essential characteristics of exploratory wayfinding. Thus, we propose a set of exploratory wayfinding design principles (EWDPs) whose intent is to improve the exploratory wayfinding experience in WFE. Our proposed set of exploratory wayfinding design principles is as follows:

EWDP 1: Provide the researcher with an environment that can be explored easily.

EWDP 2: Enable researchers to create, discover, and view landmarks.

EWDP 3: Enable researchers change scope as they desire.

EWDP 4: Enable researchers add as many marks as they desire to the environment.

The first exploratory wayfinding design principle, provide the researcher with an environment that can be explored easily, relates to freedom. In exploratory wayfinding, the researcher should have the freedom and flexibility to orient herself in the dataset, and be able to incrementally generate a path to reach his/her emergent destination, thus avoiding a phenomenon that is analogous to operating in a maze (usually referred to in digital wayfinding literature as 'getting lost in hyper-space' [40]). This is different than guided wayfinding design principles, where the agent is given well-structured paths (GWDP #3), landmarks to provide cues (GWDP #2), and signs at decision points (GWDP #7); and has limited flexibility in charting a path of its own (GWDP #5) [3]. Exploratory wayfinding is more of an act of active discovery by the agent as opposed to following authoritative signs. Thus, it is better for an exploratory wayfinding environment to not mandate authoritative paths that limit the agent's creative process of wayfinding. In order to provide a navigable dataset to researchers, exploratory wayfinding design principles should also incorporate a means by which researchers are aware of their location within the overall dataset. In addition to providing context-awareness (sense of place), researchers should be able to undertake their desired wayfinding activities such as day, date, or video selection. We provide such capabilities in our prototype exploratory wayfinding tool.

The second exploratory wayfinding design principle, enable researchers to create, discover, and view landmarks, relates to landmarking concept. Landmarks are an important concept in wayfinding, and represent notable phenomena that are easy to see, remember, and identify on a path to a destination. Landmarks are not confined to visual signage, and any phenomenon that helps an agent identify a point of location can be considered as a landmark. For example, in avionics, when weather conditions reduce visibility, the pilot depends on the plane's Instrument Landing Systems (ILS), and the airport control tower's auditory directions, as landmarks, to find her way [106]. Similarly, in WFE research, the video time offset in a particular dataset, where the word 'triage' has been used, can be used a landmark. During our observation sessions, we identified the need for WFE researchers to be able to mark points of interest (POIs), so that they can view, access, remember, and share those POIs or landmarks. Landmarks in the context of our prototype tool are called 'Tags' that researchers can use to highlight the uncovered phenomena, and can later filter and search for those phenomena. Agents that are performing exploratory wayfinding in WFE need the ability to create landmarks in the dataset that is different than the design principles of landmarking in guided wayfinding, wherein landmarks should be provided to the agent (GWDP #2).

The third exploratory wayfinding design principle, <u>enable researchers to add marks at whatever scope they desire</u>, relates to what a mark can be attached to. A system of landmarks helps to organize and define an information space. The frequency and level of detail in landmarks are important parameters that need to be thoughtfully planned. Less frequent landmarks that provide cursory or high-level information might fail in their intended use to identify phenomenon of interest in an environment; whereas more frequent landmarks that provide too much detail can lose their essence of highlighting important phenomenon. Thus, the placement and definition of landmarks needs to be adjusted based on an agent's wayfinding needs and environment. In a physical environment, the agent is present in the environment herself and cannot easily 'zoom' out to 10000-feet view and then zoom in to seeing inside the room of a house. In a digital environment, however, it is much easier for an agent to zoom in and zoom out and thus apply marks at different levels of detail.

The fourth exploratory wayfinding design principle, <u>enable researchers add as many marks as they desire to the environment</u>, relates to the quantity of marks. In physical environment, locating too many marks (landmarks and cues) is not encouraged and allowed [35]. In wayfinding literature, locating a large number of signs in a street is considered to be a failure of wayfinding signage. Nor is physically possible to locate huge numbers of signs in a small amount of physical space, such as along one block of a street [66]. In digital wayfinding, however, adding as many marks as an agent desires is encouraged and allowed. It might be possible to add thousands or millions of marks to large and complex datasets, such an WFE dataset. This principle also affords crowd-sourcing of adding marks and voting on marks.

6.2 RELATED WORK

While there is currently no prior research on exploratory wayfinding for WFE, we found two studies in alternate domains that are similar to our approach: 1) the World Wide Telescope (WWT), and 2) Carnegie Mellon University's (CMUs) Informedia Research project.

1) World Wide Telescope (WWT) [36] is a visualization environment that functions as a virtual telescope, bringing together imagery from ground and space based telescopes to enable guided explorations of the universe. It blends terabytes of images, data, and stories, from multiple sources over the Internet, to create a rich experience. Their mission is described as aggregating scientific data from major telescopes, observatories, and institutions, and making temporal and multi-spectral studies available through a single, cohesive Internet–based portal. It uses the method of leaving data pointers over time, on the dataset.

The WWT environment, and our wayfinding efforts in WFE, are both geared towards helping users (researchers) explore, navigate, browse, and query large, multi-dimensional, multi-modal datasets (in terabytes). Both tools allow researchers to add and view landmarks or markers in the dataset, so as to help researchers build a digital path in the dataset. However, our research is different from WWT because our technique, exploratory wayfinding, relies on the exploratory data analysis principles, in which agents (researchers) use their mental maps and sense-making to uncover patterns, in addition to annotations provided by exploratory wayfinding tools, to accomplish wayfinding in WFE. WWT relies mostly on confirmatory data analysis principles, and depends on validating the gathered data to reach facts (e.g. conducting quantitative studies to measure whether a student using WWT enhances her knowledge of astronomy). In WWT, we see that EWDP 1 and 3 are applied.

2) CMU's Informedia Research [107] was built to achieve machine understanding of media (audio, video, film media, broadcast media, etc.), including browsing, search, retrieval, and visualization in contemporaneous and archival content collections. It combines speech, image and natural language understanding to automatically transcribe, segment and index linear video for intelligent search and image retrieval. Its next version, Informedia-II [108] seeks to improve the dynamic extraction, visualization, and presentation of distributed video; automatically producing 'collages' and 'auto-documentaries' that summarize documents into one single abstraction. Researchers currently use it in the domains of education, healthcare, defense intelligence, and understanding of human activity. Their goals are to apply existing functionality and capability for textual information retrieval [37], to video [21], and leverage temporal and visual qualities for richer information delivery [5].

Informedia is similar to our efforts because of its capabilities for multi-modal media browsing, navigation, search and visualization, over large, multi-dimensional, multi-modal datasets. Both systems aim to provide a single abstraction to the user to facilitate and support navigation activities. However, Informedia is based purely upon automation and machine learning techniques; and our hypothesis states that wayfinding in WFE needs human agents (researchers) that use their mental maps and sense-making, in addition to digital tools, to proceed with wayfinding. Another difference between Informedia and our research is the intent of the two systems that translates to what the systems are designed to afford. In Informedia project, we see that EWDP 1 and 3 are applied.

Chapter 7. TOOLS AND ARTIFACTS

In this chapter, we describe a prototype tool that we built to better understand wayfinding in WFE, and to evaluate some of our design principles to improve exploratory wayfinding in WFE defined in Chapter 6. The requirements for the tool were generated using a combination of insights captured from our observational sessions, the conceptual framework built based on our literature review, and input from WFE researchers (Dr. David Socha, Fida Al-Sughayer and Wei Wang). This tool is a prototype and was only tested by one user, who is the author of this thesis.

7.1 SCOPE OF WORK

The wayfinding experience described in the Socha & Tenenberg paper [96] is about researchers studying sketching and design [84] within a software organization in which hundreds of hours of video of development activity in situ was captured, and researchers searching to identify moments of sketching by viewing thumbnail-sets to reason about what sketching is [95], when it occurs, and where it occurs. Understanding the aid of a thumbnail-set view enabling researchers to find their way in the dataset aligns with our conceptual framework and design principles. In the paper, researchers scan thumbnail-sets in order to quickly browse dozens of video files to identify sketching [33]. For example, using thumbnail-sets of the videos they can identify the points where a green-shirted software developer sits at the developer station quicker than using the actual videos. Using this insight, we conducted an experiment with our prototype tool to understand, 'Does visually representing thumbnail-sets of videos and providing tools to manage thumbnail-sets help WFE researchers perform better exploratory wayfinding?'. In our prototype exploratory wayfinding tool, we chose to let researchers create and locate landmarks (tags) in thumbnail-sets that capture 26 minutes of video content. We did not create the ability to allow researchers to create landmarks on each individual thumbnail given the limited time we had, but we hypothesized that landmarking entire thumbnail-sets would be good enough to start with. Additionally, we used insights from our analysis of challenges faced by researchers performing exploratory wayfinding [7] in a WFE environment (Chapter 5), to choose the following features to test our conjectures of exploratory wayfinding in WFE:

- Search or filter based upon a dataset date, timeframe within the data, and set of tags (to address Challenge-6, Chapter 5)
- Save and share tags with other researchers (to address Challenge-4 and Challenge-7, Chapter 5)
- Provide visual cues on the physical layout and field of view (to address Challenge-5, Chapter 5)
- Thumbnail set views of corresponding videos (to address Challenge-8, Chapter 5)

Some scholars refer to 'quality of wayfinding' as the ease with which agents are able to understand the environment and find their way to a particular destination <u>without delay or undue anxiety</u> [81]. In our tests, we measure one of the parameters (delay) in the above reference to the 'quality of wayfinding' as the duration between a researcher's intent to find a phenomenon, and the researcher finding the phenomenon (i.e. 'I want to find X' and 'I found X'), and compare wayfinding durations with and without the tool.

7.2 WFE SYSTEM

The infrastructure for the WFE system resides in the cloud (Amazon Web Services (AWS)). The input devices used for gathering raw data comprise of GoPro cameras, smart phone cameras, other cameras and recording devices, time-lapse devices, notes; and therefore, the raw data includes files with that are stored in mp4, mov, jpeg and PNG, wav, avi, docx, and pdf formats. Raw data collected from the WFE environment layout is stored in AWS's cloud datastore - Simple Storage Service (S3), with server-side AES256 encryption. Figure 9 shows the folder structure of the datasets in the AWS Console. Each dataset (e.g. BeamCoffer, or BCResearchers) is denoted as a 'bucket' in S3 and each individual file within the dataset (i.e. video file, picture, text, etc.) is represented as an object in the bucket. When a researcher tries to find a thing of interest, she needs to navigate through the folder structure illustrated in Figure 9. We illustrate the S3 folder view of the dataset to denote in which setting we navigate and browse in WFE wayfinding activity.

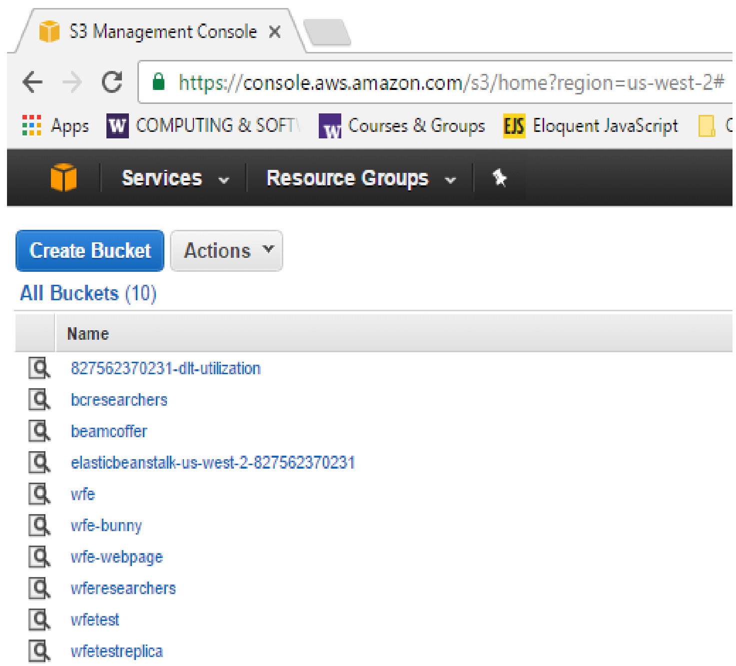

Figure 9. WFE dataset view as S3 buckets.

Code repository for the overall WFE project was GitHub (shown in Figure 10). Source code is open source with an MIT license. There are 20 repositories in all, within the WFE project, of which one belongs to our prototype wayfinding tool's source code.

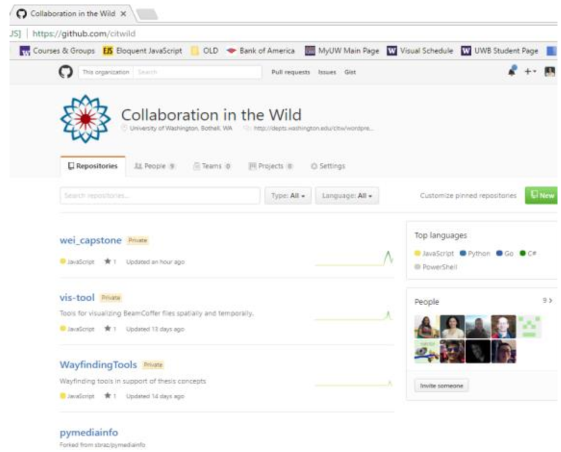

Figure 10. View of WFE code repository.

7.3 TOOL DESIGN AND IMPLEMENTATION

The objective of our research is to augment the interpretation and sense-making capabilities of WFE researchers via tools to enable them explore WFE datasets more easily. To test our conjecture that improving on challenges faced by researchers in the six WFE analysis observation sessions might support our objective (mentioned in the first sentence of this paragraph), we created the following features in our prototype tool to assist with exploratory wayfinding in the BeamCoffer and BCResearchers datasets:

- Provide visualization to unify and correlate data from different sources
- Generate thumbnail-set views showing frames of a video content to quickly scan video segments
- Allow researchers to leave markers (tags) on the data segments (thumbnail set)
- Allow researchers to search/filter the markers (tags) associated with data segments (thumbnail-sets)

Using the above feature list we created a prototype tool [102] that displays thumbnail-sets of the BeamCoffer dataset with date and time scale, includes information such as name, and location of the thumbnail-set, provides a mechanism to view meta-data information such as filename, offset of time, and directory where the thumbnail-set is located, provides a mechanism to the user to indicate where they found phenomenon, provides a text field to enter the tag (landmark), associates video that corresponds to the thumbnail-set, provides a mechanism to swap between modes: 4x3, 5 column, etc., and gives a capability to search added tags.

The tool includes a web server, a web client, and a database that interact with the WFE system metadata stored in a SQLite database, to retrieve data such as file paths of data stored in S3. Figure 11 denotes the data flow between the main tool entities: EW tool web server, EW tool web client, EW tool Database (DB), the WFE metadata database, and AWS storage (S3). The bold and green highlighted parts are components of prototype tool that we built within the scope of this thesis. The DB stores tag information and tag metadata used in all tag management operations.

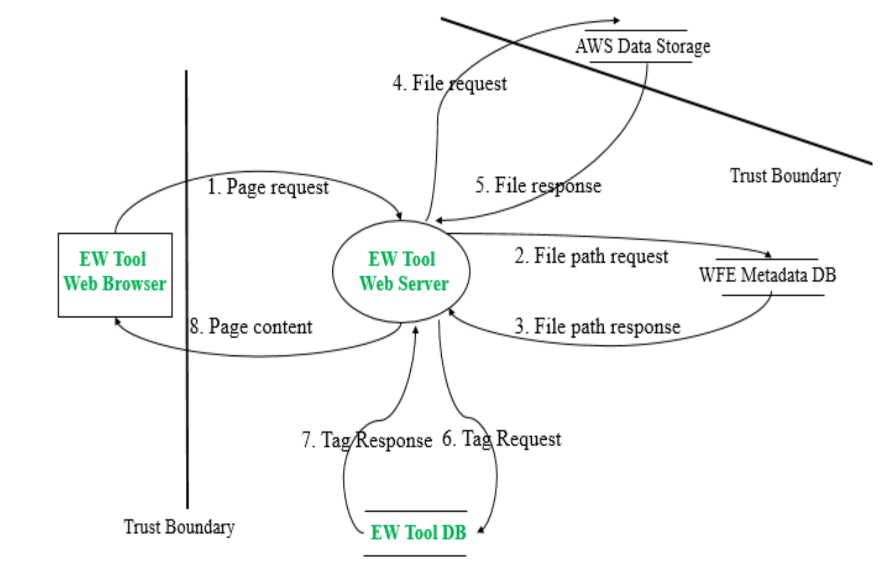

Figure 11. Level 0 data flow diagram of EW tool.

Our prototype tool allows a WFE researcher to use a web browser to view the duration of the video duration, the nominal date selection (temporal) such as February 15, 2014, and the camera location selection (spatial) such as PS A. Also, the tool visually shows the floor plan, thumbnail-set views in both 4 x 3 (a set of images arranged in a two-dimensional matrix of 16 columns and 16 rows, where each image is taken every 6 seconds, as show in Figure 13) and 5 columns (a set of images arranged in a two-dimensional matrix of 5 columns and 52 rows where each image is taken every 5 seconds, as illustrated in Figure 12) formats.

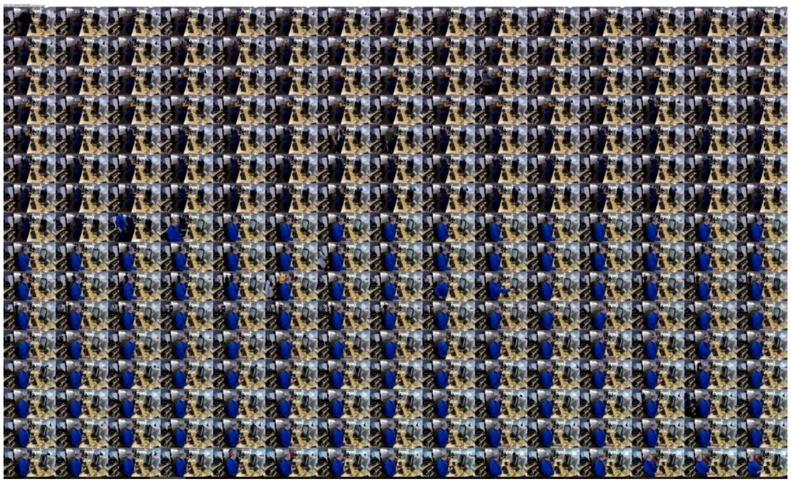

Figure 12. 4 by 3 thumbnail example.

Figure 13. 5 column thumbnail example.

We used Node.js, HTML, and CSS, JavaScript (programming language), JSON (data type), and SQLite (DB), to create the tool. The web interface (web page) for the tool is displayed in Figure 14, wherein different aspects of the tool are highlighted with circles and a number next to them. These aspects are as follows:

1) The Dataset Date: WFE researchers can choose the dataset to be analyzed, by date, using the calendar view.
2) Shows the data source (e.g. PS A, PS B, etc.), where in the data source has the location embedded in its name. For example, PS A stands for the GoPro camera that is located next to Pair Station A.
3) Shows an actual time, where each grey rectangle (denoted by: 4) in the swim lanes illustration represents the duration of a particular video file mapped to the actual time on the timeline

above. The width of each rectangle depends on the length of the captured video segment, and in instances where a camera was not recording anything, empty spaces, show up in the time sequence on the tool.

4) Represents captured video file.
5) Shows the viewing window of the thumbnail set within the page (thumbnails can also be viewed opening in another page) that corresponds to the selected video (grey rectangle) from the temporal and spatial selector (swim lanes which are the combination of grey rectangles that form the horizontal parallel lines in the bottom of the webpage). The name of the dataset, the nominal date, camera name, and file name, is displayed, to provide context. For example, Figure 14, shows the thumbnail set viewer window displaying the BeamCoffer | 02/12/2014 | PS A | GOPR0040 dataset. Providing such context is useful, because it enables WFE researchers to become context and place aware.
6) Shows the Tag Window. Tags are used as landmark information to help WFE researchers locate their markers in the environment (dataset). The start and end time for the duration of the thumbnail set is displayed in the tag management window, to add context to the Tag. Start and end times are actual times in PST (e.g. Figure 14 shows 09:59:37 to 10:25:42), and this duration information was requested explicitly by our stakeholder to help them be more context aware. The keywords displayed in the Tag window are Tags that researchers added until that point in time, and are associated with the thumbnail sets and visually represented to be added on the video duration representation on the swim lanes. The smallest unit of tagging functionality is on the entire thumbnail set that corresponds to approximately 26 minutes in this dataset.

7) Displays the selected video slice (grey rectangle) on the swim lane, and the camera location information (i.e. PS A) to provide additional context to the researcher. Tag icons are present

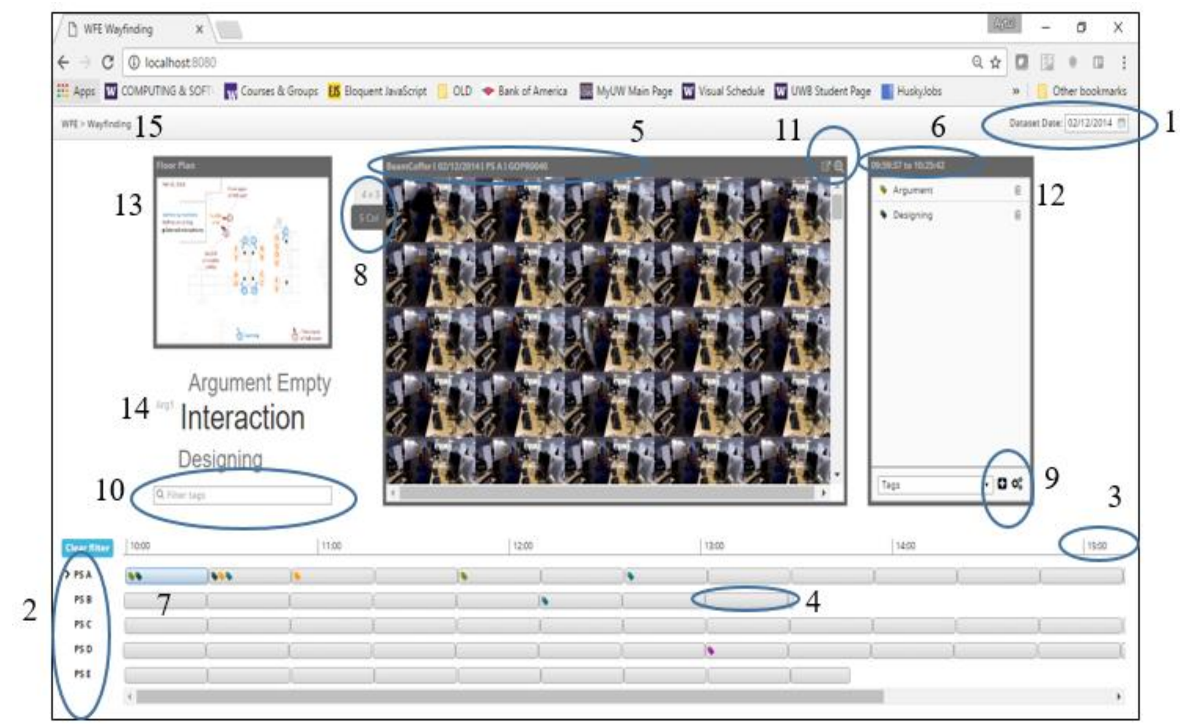

Figure 14. Snapshot of built EW tool.

on video slices that have Tags associated with them. We describe the details of the Tagging feature in the next section.

8) Gives a vertical list for the two different formats (4by3 and 5col) of thumbnail files so that researchers can have the option to view the format according to their needs.

9) Shows the tag management feature of the tool where researchers list, view, add, delete and locate tags in the environment.

10) Displays the search and filter functionality of the tool, where the researchers can type the tag in the text box (they can type first letter, first two letters and tool search functionality will highlight all matching tag records) and the matching tags are displayed in the tag cloud above.

11) Denotes the zoom and open in new page options for viewing the thumbnail sets. In second HCP loop we ran with the stakeholder, this requirement was requested to provide more fine-grain viewing of the thumbnail sets.

12) Shows the deletion option for tags in the tag window. For any selected thumbnail set, researchers can view the tag and quickly delete the tag from the tag window.

13) Represents the static floor plan so that researchers can have an idea of the big picture of environment layout (i.e. which pair station is next to which, where do the cameras actually locate, what direction the cameras facing, etc.,) so that they can have a zoom out higher level view of the data collection layout. At this point, the floor plan is a static view, yet for future work, the floor plan can be made dynamic (changing angles as thumbnail sets are selected) and interactive (showing tags on the floor plan view as tags are added).

14) Shows the tag cloud we mentioned before. The function of tag cloud is when we search and filter a tag, the tag is highlighted on the tag cloud and we click that tag to view on which thumbnail set duration the tag was stored in the swim lanes. Number 15 shows the bread crumps or the webpage since for future work, the WFE system can easily integrate the EW tool in the main WFE infrastructure.

In the next section we will go into details of features to provide the capabilities of tool and how it relates to our conceptual framework, patterns and principles.

7.4 TOOL FEATURES

In this section, we will go into more details of prototype EW tool features. As illustrated in the circled highlight on Figure 15, WFE researchers can click on the calendar icon on the right-hand side of the Dataset Date section and view which days on the calendar contain collected data. In our

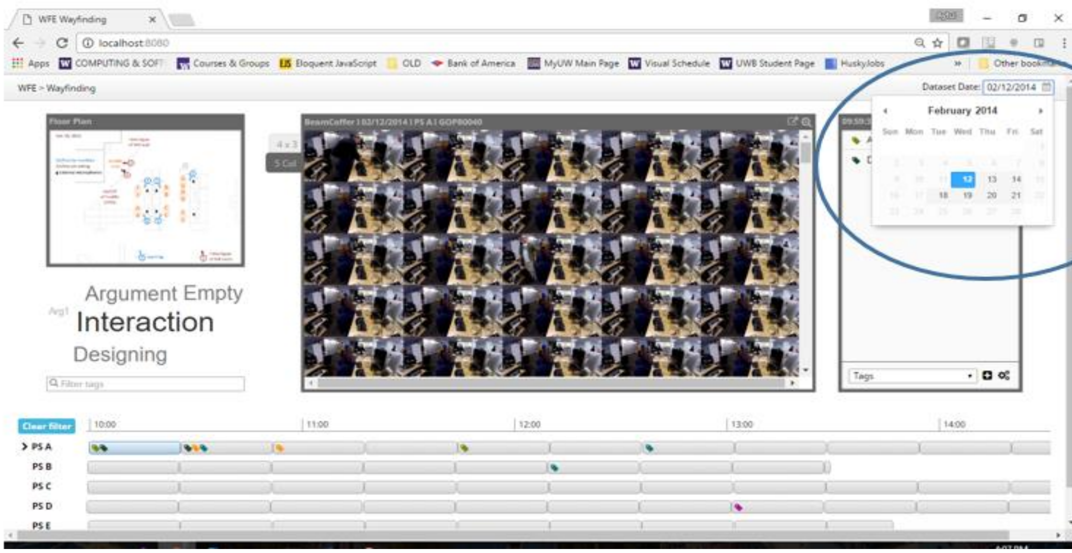

Figure 15. Dataset date selection in EW tool.

example illustration on Figure 15, we can see 7 days are highlighted as bold on February month of year 2014. This capability provides researchers, browsing and navigation approach as well as visually representing dataset as we mentioned both in patterns and principles. Without such a tool, researchers need to go to AWS console, open S3 buckets, select dataset, select associated folder structure (i.e. compressed), and traverse into the days manually and sequentially when they were searching for a specific visual of a phenomenon. As we will mention in our result section, this capability might reduce the duration of browsing time based on three tests we performed.

The second feature we will explain is tag management. Tag management works in the following flow: i. Researcher lists to view already entered tags by clicking the down arrow in drop down menu as illustrated in circle shape highlighted area in Figure 16, ii. if researcher wants to add a new tag he/she clicks the pinion icon next to the plus sign that opens the tag management division as illustrated in circle shape highlighted area in Figure 17, iii. in the new opened tag

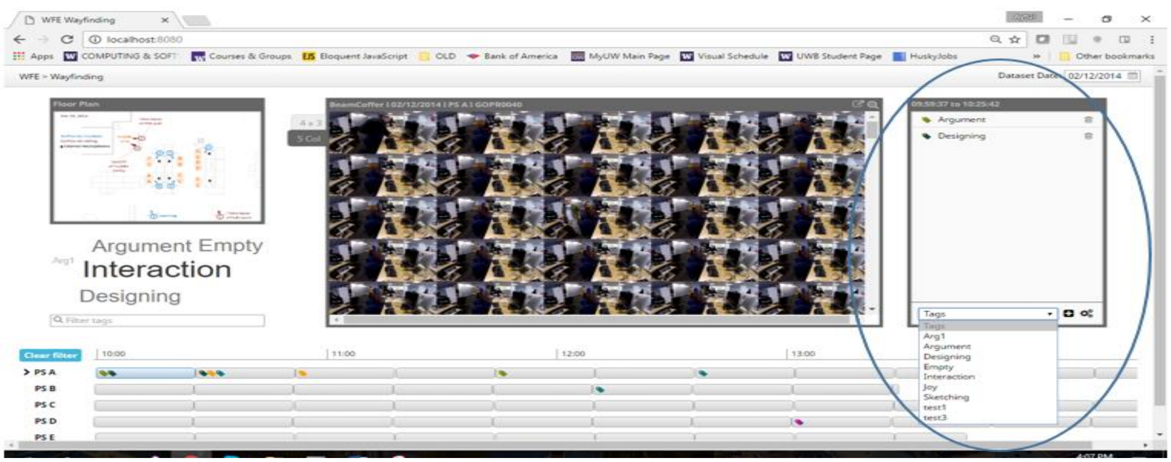

Figure 16. EW tool tag management.

management window researcher types a tag text in the text box that has the default 'Enter new tag' text and presses plus to enter the tag to tag list and immediately views the tag in the tag list.

As seen in Figure 17, Tag Manager window opens on top of the web page while making only the tag manager window highlighted as a hover view and makes the rest of the webpage passive.

After the tag is added to the tag database by the help of tool user interface, the researcher can select a thumbnail set segment as illustrated in grey rectangles that show the associated video duration in the swimlanes, expand the drop-down menu (as seen in Figure 16 highlighted with

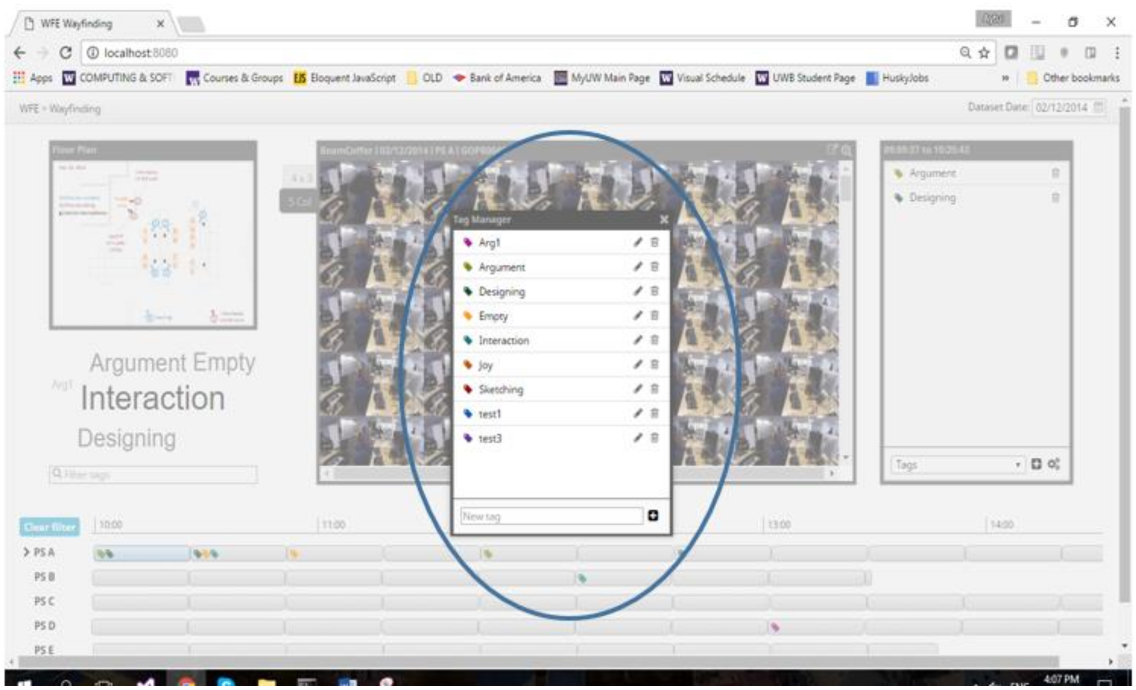

Figure 17. Tag management user interface.

circle shape) to view all entered tags and click the plus sign in the tag window to add the tag to the corresponding file. Then researcher can see the tag on top of the grey rectangle in the swim lanes. The tags are illustrated in Figure 16 as different colored universal tag icons on top of the grey segments representing durations taken from camera locations. We used color-coding as another visualization approach to enable differentiating on tags in a simple way. We used the universal tag icon so that our user can relate to the sign and find their way easier while understanding and using the tool.

Another feature we added is to search and filter tags. As illustrated in Figure 18 in the highlighted circle, we placed a tag cloud since it was easy to implement and search box under the floor plan map area. The purpose of the search box that has the universal search icon and default text ‘Filter Tags’ is to find the tags entered to the system matching the tag the user typed and list them in the tag cloud area above the search box. After the searching for the tags is done, user can see the matching tags displayed in the tag cloud and user can click on the tag that he/she wants to filter in the dataset files. Figure 19 shows how filtering function operates in the tool. When the user clicks on a matching tag on the tag cloud, the tool filters only the files where that tag was added and does not display the rest of the files in the swimlanes. In the example of Figure 19, we searched for the tag ‘Interaction’. Work flow is, we typed ‘inter’ in the search box, the search function found ‘Interaction’ as a matching text and displayed it in the tag cloud. Then we click the ‘Interaction’ text in the tag cloud as highlighted in circle box in Figure 19, in the swimlanes only three files are displayed that has this tag that has blue color tag icon. The filtering view is highlighted in Figure 19 with the arrows pointing to filtered files.

The reason for providing an extra layer of filtering and viewing capability is because we identified not being able to filter was one of the challenges that impacts WFE researcher's exploratory wayfinding experience.

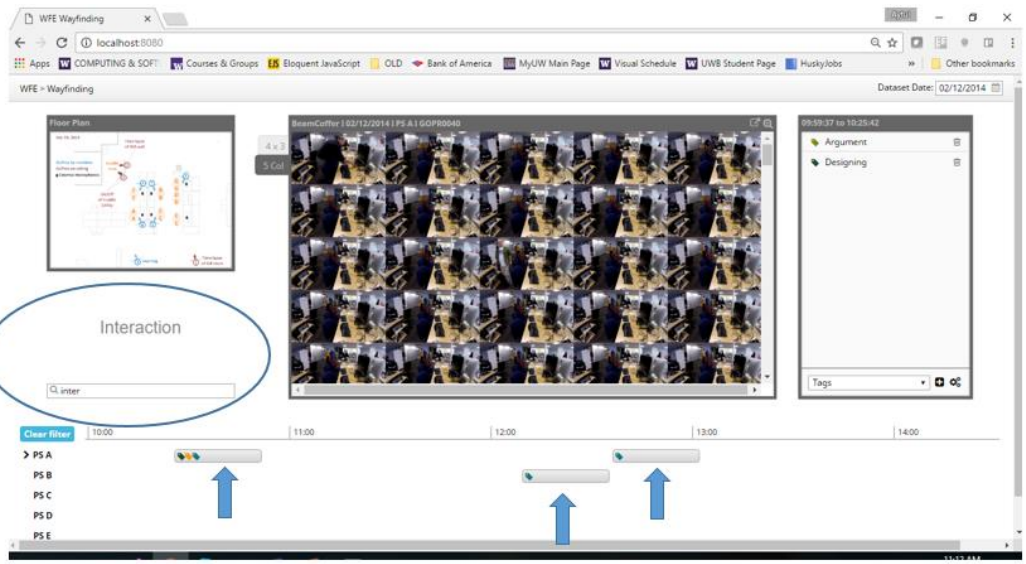

Figure 18. Tag filtering capability in EW tool.

Another feature is we display the metadata of the files in the swimlanes when mouse hovers over them. Although we know the camera location, date and dataset information displayed on the webpage, we wanted to provide the file name, duration, start time information on each file slice in the swimlane to provide more data about where our researcher is within the dataset. This feature also aims to supply context and sense of presence. We can see in Figure 19, where mouse is over a file, a darker grey box appears including the meta-data information we mentioned above.

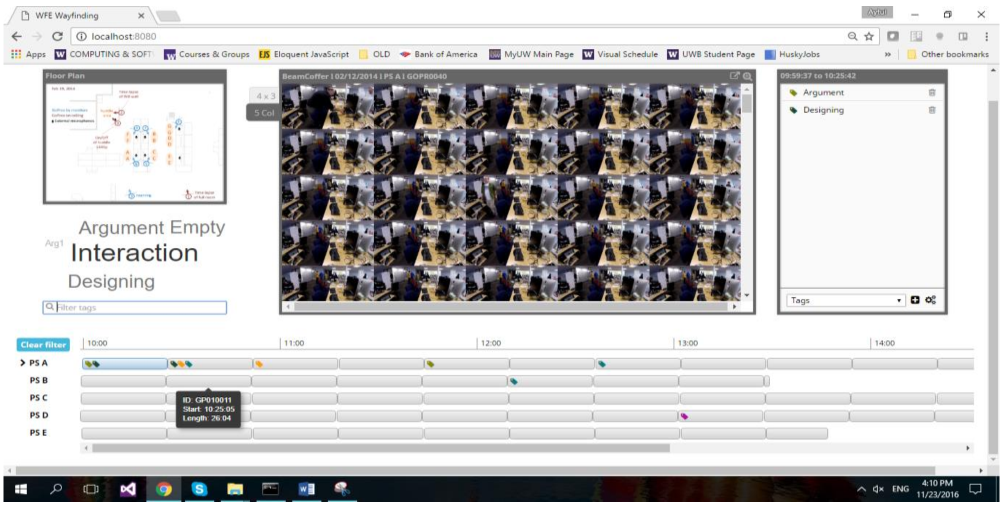

Figure 19. Displaying file metadata.

Another functionality we added per generated insights is, since researchers sometimes used summary view like thumbnail set, sometimes they wanted to see the fine-grain details of the pictures during the analysis sessions. Thus, we added zoom feature to the thumbnail set view

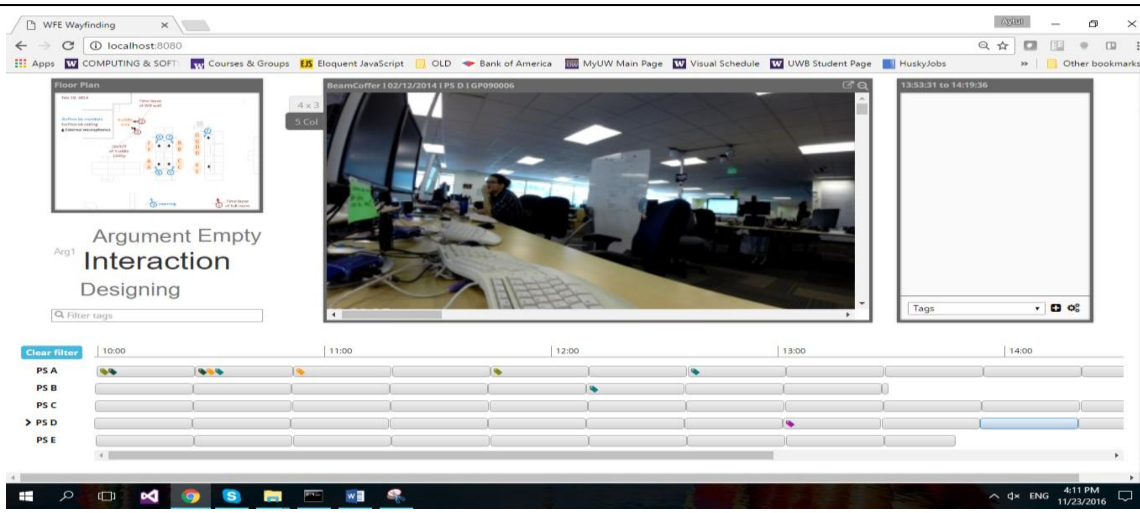

Figure 20. EW tool zoom functionality.

window. Figure 20 displays the view on the thumbnail set view division when we click zoom icon on the right land side of the division.

On the thumbnail set view division, we also added an 'open in another page' icon so that researchers are not limited to the thumbnail set division size and as illustrated in Figure 21, when the open in new page icon is clicked, the thumbnail set (either 4by3 or 5 col) will be displayed in another page. In the new opened page, researchers can also zoom into the thumbnail set when they want to view more details of the thumbnail set as illustrated in Figure 22.

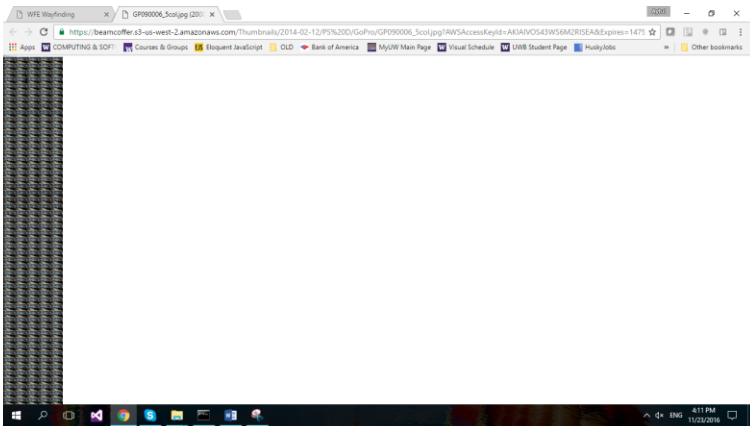

Figure 21. EW tool view file in new page.

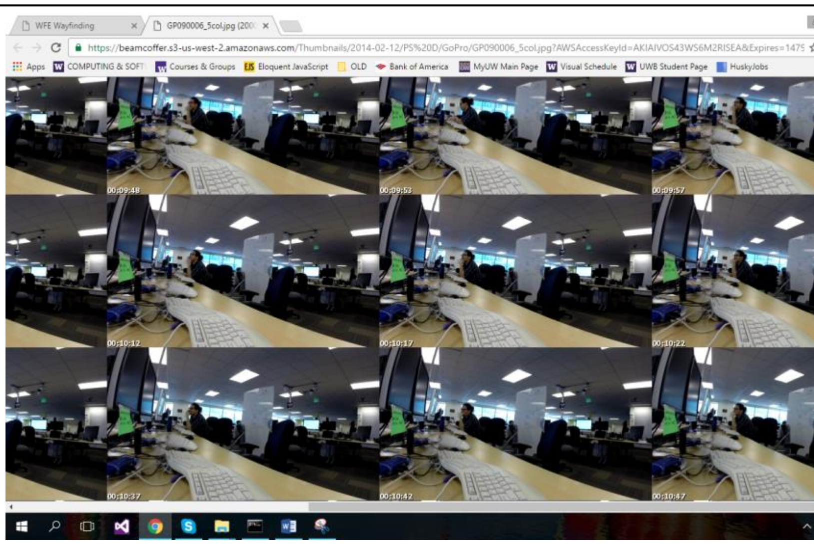

Figure 22. EW tool zoom file in new page.

7.5 RESULTS

One of the results of this thesis is our reasoning about wayfinding in WFE. Our first classification of wayfinding was to identify six spaces that capture different types of wayfinding as physical, digital, conceptual, structured (guided, authoritative) and unstructured (exploratory, emergent). After our study on the empirical observations and conceptual framework, our claim is exploratory wayfinding in WFE is mostly in the digital and unstructured cell of Table 1.

Other threads that we revealed with our study is, WFE wayfinding is mostly exploratory wayfinding and landmark information can be useful to provide context in facilitating researcher's wayfinding experience. We can say exploratory wayfinding is mostly in complicated domain in Cynefin framework thus we might need emergent practices since sensing patterns might be useful in this domain.

Our understanding for exploratory wayfinding in WFE is that the agent is more active compared to guided wayfinding, that is, agent might need to create her own cues, landmarks, paths, signs by pattern management, instead of following a structured signage along a known path to go to a known destination. exploratory wayfinding in WFE can be either an individual or collective effort; have priorities such as accuracy, speed and privacy; uses cues that are visual (video or still images), sound and texts (no haptic cues at this point, etc.); and happens mostly in a digital environment.

After building the framework and the prototype tool, we did total six tests to answer our second research question that is 'How can a framework and system help enable WFE researchers do wayfinding' using the prototype tool. To do this, author of this thesis ran three test loops with similar search topics with and without the prototype tool. In the first test, which we call 'color test', author of this thesis analyzed 180 mins of video to first find someone with a red outfit without the tool and then find someone with a green outfit with the tool and measured how long it took to find that phenomenon in each test. We alternated the turn of using tool in the tests to try to reduce the bias or impact between measurement results. In the second test, which we call 'pair station test', we first measured the duration to find when one of the developers of a pair are not present in pair station using the prototype tool and then we measured the duration to find when there is an additional person interacting with the two developers in pair station without the prototype tool. On the third test, which we call 'gender identification', we first measured the duration to find when there is a female developer in the video/thumbnail set without the prototype tool and then we measured the duration to find when there is a male developer in the video/thumbnail set with the prototype tool. We realize the preciseness and sample set of the tests are open for discussion, yet the six test results supported our conjectures about visualization and landmarking for exploratory wayfinding. Insights from the test show that visually representing the dataset and landmarking reduced the duration to find phenomenon in these limited test scenarios performed only by the builder of the tool as illustrated in Table 4. Table 4 is explained in more detail in below paragraphs.

Visually representing the map of the environment with landmarks which might be tags, transcripts, annotations, notes, filmstrips / thumbnails, time/location data, related research papers, team roster, etc. provides a more improved understanding of the environment.

Also, using the empty tag, that is tagging a video segment empty, was useful in that it enabled eliminating data that cannot be useful, e.g., video with no lights on (thus black image) or after everyone has gone home so when the author of this thesis started using tool the next time she did not lose time to analyze those segments of dataset. Our conjecture is that tagging might also help afford 'attractors', e.g., finding either moments of a) breakdowns, or b) insights / excitement - both places where people make visible to each other. Table 4 illustrates the summary of test loops and measured values. The video files were analyzed from February 19, February 20 and February 14 dates of BeamCoffer dataset.

Table 4. Test Results

	Test Date	Video Stream	Duration of Analyzed Videos	Search Phenomenon	Duration to Find	
					With Tool	**Without Tool**
Test 1	November 11	February 19 PS C	180 mins	Red Outfit / Green Outfit	42 mins (first test)	18 mins (second test)
Test 2	November 24	February 20 PS A	120 mins	One developer in Pair Station / Three developers in Pair Station	39 mins (second test)	14 mins (first text)
Test 3	November 18	February 14 PS A	150 mins	Female Developer / Male Developer	41 mins (first test)	15 mins (second test)

Chapter 8. DISCUSSION

In this chapter, we challenge and discuss our findings and results, the limitations of our approach, alternative approaches, and possible future work.

8.1 EXPLORATORY WAYFINDING VS THE LITERATURE

Our results show that exploratory wayfinding in WFE is qualitatively different from the wayfinding described in the literature. One of the differences is that wayfinding literature primarily talks about wayfinding in physical domains where the destination is known or predefined (i.e. intentionality aspect of wayfinding that we mentioned in Chapter 3). The majority of the exploratory wayfinding we observed in WFE was exploratory in which the destination was largely unknown or not well defined.

Most wayfinding literature is about following maps or signage, whereas exploratory wayfinding in WFE can be more complex than that. In exploratory wayfinding in WFE, following a map might not be enough because what the researcher is searching for can be unknown. In exploratory wayfinding in WFE, researchers might look for abstract things like social phenomenon, for which it might be difficult to generate a map, especially because of the variety in the social phenomenon [67], or the undefined and unknown nature of the destination and path.

Guided wayfinding or structured wayfinding mostly focuses on searches that have been done by many agents before; it is about how to get another agent to a goal that has been visited by many before. On the other hand, exploratory wayfinding in WFE is mostly about exploring a space in a context where the type of phenomenon being sought is much less defined, perhaps because no wayfinding history exists, or perhaps because of the nature of the phenomenon itself. In our literature research, we observed that guided wayfinding is mostly about helping agents navigate a specific 'space' in a way that is known to be a common or useful way to navigate the environment. Thus, guided wayfinding is mostly about known-knowns. However, exploratory wayfinding in WFE is an example where wayfinding can be about unknown-knowns, and unknown-unknowns.

In the majority of exploratory wayfinding in WFE that we observed, we found that researchers were trying to locate a social phenomenon. Locating such social phenomena also required human interpretation because humans could recognize complex concepts and inner meanings using their very nature, instead of using specialized computer programs. For example, even if an algorithm provides moments of interaction in a team, human interpretation can distinguish real collaboration in those interactions vs. perceived collaboration. Guided wayfinding mostly focuses on getting to the goal and is less interested in providing discovery and exploration capabilities to support pattern management along the way. exploratory wayfinding in WFE recognizes that providing context in WFE analysis is often a valuable part of the activity, so tools for exploratory wayfinding in WFE should focus on providing wayfinding assistance and letting researchers do analysis when and where desired [6]. Again, this is about being in a space where the unknowns are important. Most wayfinding in literature is mostly focused on tools giving procedural and authoritative guidance on defined paths - GPS, compass, applications, maps - that are intended to reduce human errors, or improve resource usage (time, fuel, etc.). In exploratory wayfinding in WFE, human interpretation can be a tool in itself. Most WF techniques found in literature use visual cues, but our limited exposure to exploratory wayfinding in WFE via the conducted observation sessions and tool tests, suggests that uncovered patterns or discovered landmarks can also serve as useful cues for wayfinding in WFE datasets.

Our study within the scope of this thesis, provided us with examples of wayfinding in WFE where wayfinding mostly represented the analysis of data to reach a social phenomenon (e.g.

collaboration, interruption, conflicts, social laughter, etc.), and most of the analysis was done by a group of researchers. Even if one researcher held the mouse at all times, the real wayfinding activity was performed by the sense-making, interpretation and experience of multiple agents (researchers). In this thesis, we observed researchers doing collective wayfinding that we believe can be an interesting topic for research. However, time constraints prevented us from pursuing this concept further, and we nominate this topic as a candidate for future study.

8.2 LIMITATIONS

Our research has several limitations that may impact the extent of the validity of our findings. Our observational results are based upon a small sample size of WFE researchers, we have repetitive researcher sets performing wayfinding in the dataset, and researchers were working on the same datasets. In addition, our tests only involved one person who is the author of this thesis. The tool is a simple prototype and probably will never be used for any real WFE analysis. Also, the relationships among group members (e.g., advisor/advisee) may have influenced some of the findings in the analysis sessions.

8.3 APPROACHES TO AUGMENT EXPLORATORY WAYFINDING

An approach to augment exploratory wayfinding in WFE could be to transcribe all contents of the dataset into text, i.e. transcribing video content, audio content, etc., into a textual representation [49], and then build search algorithms to browse for keywords of interest using text-based search and filtering. A drawback of this approach, however, could be that it does capture subtle things like body gestures [50], non-speech audio [42], a person's gaze, etc. In this thesis, we did not afford this method of study.

8.4 FUTURE WORK

Areas of possible future work could include studying exploratory wayfinding concepts and tool approaches in other datasets and researcher groups in WFE studies (i.e. math class analysis in universities), or in domains other than WFE, or studying similar wayfinding approaches in non-human agents (i.e. analyzing penguins' interaction on the South Pole).

During our research, we changed our research questions multiple times and we generated more questions. While we do not list all the questions we produced based on insights of our research study, we do want to list two that we find interesting and valuable to pursue further.

One question that was generated was 'how to measure success of exploratory wayfinding?' Metrics to assess the efficacy of particular wayfinding practices is an area for future work. This is a challenging area given the diversity of the types of 'goals' that agents may have during exploratory wayfinding. For example, if an agent stops her wayfinding activity before she has found what she was initially looking for, because she found an even more interesting phenomenon, would that be considered successful or unsuccessful wayfinding? This topic is complex and can be an area of research by itself.

The other question was, 'what are the affordances of exploratory wayfinding in domains like augmented reality?'. In an augmented reality environment, where the agent is using a head-mounted display, and can have an augmented set of visual, auditory, and haptic cues, a study on whether exploratory wayfinding concepts identified in this thesis hold true, would be an interesting area of research.

The prototype tool can also be expanded to be a real tool that might be used in real WFE analysis. To do this several tool features that need to be designed, implemented, tested and deployed. We also see that the current tool could be extended to include other data sources such as text, videos, and IoT based data. Additionally, the definition of tag (tag has a duration, tag has a stream, tag has a context, etc.), and the tag metadata can be extended. Tests insights for our tool suggest that enabling researchers to add context while using the tool can also be another desirable feature. Also, at this moment, the tags on thumbnail sets are text keywords. In the future, researchers might want to add tag entries of different data types such as picture, audio, or video. Furthermore, the thumbnail-set could be divided into equal 5 second (for 5col format) or 6 second (for 4 x 3 format) frames, and in the future, the tagging functionality could be extended to cover the duration that is selected by the researcher rather than the entire thumbnail-set. Finally, the tool could be integrated into the main WFE infrastructure, and could provide support for playing videos, searching datasets, and roles with authenticated access.

Chapter 9. CONCLUSIONS

In this thesis, we addressed two questions that form the primary focus of our research: ‘What is wayfinding, especially in the context of WFE?’ and ‘How can a framework and system help enable WFE researchers do wayfinding?’ To accomplish this, we undertook literature research to understand how wayfinding is accomplished in other existing domains, and classified our findings into a wayfinding design space with two dimensions – one axis was called ‘nature of wayfinding’ (Structured, and Unstructured), and the other axis was called ‘wayfinding domains’ (Physical, Digital, and Conceptual). Our empirical work, analysis, and observations revealed that wayfinding in WFE falls primarily in the digital and unstructured design space, and that wayfinding in a WFE environment is primarily an exploratory set of actions that WFE researchers take using their intuition, inductive, and abductive reasoning. We call this process *Exploratory Wayfinding*. The result of our empirical work, analysis, and observations, wherein we observed six sessions of WFE researchers searching for specific phenomenon in a WFE dataset, revealed that wayfinding in WFE datasets is exploratory wayfinding.

We established an exploratory wayfinding framework based on challenges and insights generated from our observations and test runs [51], and hypothesized that allowing WFE researchers to better visualize the WFE datasets, and supporting <u>landmarks (markers with context)</u> in these datasets, can help WFE researchers find their ways with less challenges. To understand exploratory wayfinding in WFE better, and to evaluate this hypothesis, we built a prototype tool that provided a <u>visual representation</u> of captured videos in the WFE dataset in a thumbnail-set view, and allowed <u>tags</u> (landmarks) to be added to the WFE data; and ran it through six tests. The results of these very limited six tests were promising for our hypothesis because wayfinding sessions with the tool took less time to find phenomenon of interest compared to wayfinding efforts without the tool.

We acknowledge these results may vary between WFE datasets, WFE research teams, and other PSEC criteria. Thus, more detailed and specific study may be required on top of our research, to ascertain the broader applicability of our findings to other PSEC systems. Also, we realize our exploratory wayfinding results are not precise and might vary from domain to domain that include non-PSEC attributes. Thus, while further research can be done on the conceptual framework, we propose that our findings on exploration (discovering undefined patterns in an unknown environment), visualization (visually representing data in a unified and coordinated manner), and landmarking (allowing agents add markers to unknown environment along the way of their exploration) will be applicable to other domains that fall into the design space of mostly a digital and unstructured nature.

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GLOSSARY

Agent: A human who is getting oriented in the environment with a specific goal.

Environment: The medium where the agent is navigating.

Cues or Markers: Symbols, and landmarks that help in narrowing down the search scope and facilitate wayfinding. Cues are distinguishers and leading aspect of wayfinding studies.

Dataset: The resultant WFE information that contains varieties of data that is collected continually and simultaneously over the course of a time period to be analyzed by researcher(s).

Destination: End of the search space for wayfinding. It can be a place, location, phenomenon.

Path: The journey the navigator takes during wayfinding.

Tools: Aids used by the navigator to perform wayfinding.

Goals: The objective (intention) that the navigator plan to gain from the navigation.

APPENDIX A

Transcripts in Chapter 4

The following is a larger portion of transcripts of Session 1 mentioned in Chapter 4.

10:23: AA grabs her pencil and notebook, as if she is preparing to take notes of what she sees.

10:23: AA does not grab the mouse in front of her or does not look at the monitor in front of her at that moment

10:24: Both DS and AA look at the monitor in front of DS as wayfinding starts (exploration, and initiation as both agents direct their gaze to the environment) (Figure 7).

10:24: DS opens a folder of the dataset (via Start - > TrueCrypt - > Victoria Session folder).

10:26: DS opens Start menu on the computer in front of him. ('complex environment' pattern and 'exploration')

10:24: DS asks 'What are we doing?', and at the same time starts opening the Start menu of the computer in front of him. He is already performing a task (which later analysis of video captured by GoPro3, concluded to be opening TrueCrypt to reach the hard drive of the dataset), and initiating a route for wayfinding exploration.

In this transcript, we see that agents want to confirm their understanding of their context and sense of place. They are trying to explore the affordances that are available to them to orient themselves in the environment in order to perform wayfinding activity.

10:29: DS asks, 'So, what do you mean about scalability? We are trying to figure that out?' DS answers as if he is trying to confirm AA's understanding of the intention of the session.

10:31: AA responds, 'Mm huh', while she nods. ('context awareness', 'interaction' patterns)

10:32: DS appears like he is confirming with an 'OK'. DS is not looking to AA's side but he can make out through his peripheral vision that she is nodding. In some cultures, this movement represents approval, while in some cultures this movement represents refusal. In this case, this movement is a common gesture for approval. ('dynamism' pattern, sense-making and exploration)

10:32: Meanwhile, FA touches the laptop's touchpad as if she intends to unlock her laptop.

10:33: DS looks below the table as if he is checking something as seen in Figure 8. ('complex environment' pattern and exploration)

(10:33 to 10:35) AA two second gap is observed before the next word from agents is heard. Meanwhile, exploration continues, in which, DS is opening the 'Victoria' folder from the hard drive, and AA is tracking DS's cursor movement on the monitor in front of him.

10:35: AA says, 'It doesn't necessarily need to be 'what do you mean by scalability?' Can we track (making a hand gesture as if to represent a tracking movement) scalability as a word?' Here, AA asks to take another approach for exploration. ('dynamism' pattern, sense-making and exploration)

10:43: DS replies, 'No.' ((as if dissenting)). 'I mean' *(laughs)* 'how?' *(laughs)*. DS keeps using the mouse and keyboard to locate the folder of interest from the hard drive. ('interaction' and 'complex environment' patterns, exploration)

10:44: FA grabs her pencil and notebook, and puts them in front of her, as if she intends to take notes during the session.

10:45: AA responds, 'No', (one second elapses in what appears to be, thinking), 'maybe in the lunch you also said scalability about' (another second elapses in what appears to be - trying to find an example) 'restaurant catering' ('dynamism' and 'interaction' patterns, exploration and sense-making)

DS keeps using tools like computer, mouse, monitor, external drive, AWS folders to try to open the Victoria workshop dataset. They do not have a quick way to reach the data in one single interface so they open seven different tools such as external drive1, AWS S3 folder, external drive2, Google Drive, excel spreadsheet, former visualization of BeamCoffer dataset, word document, notebook, etc. One of the reasons for this tendency is WFE wayfinding is a complex system and data is spread across multiple sources. Researchers try to view the raw data to understand the analysis session.

10:50: FA writes something in her notebook.

10:56: DS appears to be carrying out a search and navigation task on his screen while responding 'Umm, let me just get the one, I hope has enough..'. DS also makes a gesture that appears to be about searching something and puts his hand on his chin. He seems to need a moment for orienting, and not open to multi-tasking. ('complex environment' pattern, exploration)

DS keeps opening folders to locate the Victoria session dataset. He navigates through external drive to find the location of dataset. Agents are exploring the physical and digital realms of the environment (including dataset, office, tools, etc.) since the location of dataset is not clear to them when they start. AA and FA take notes on their respective notebooks to remember the location of dataset, the meta-data about the visited videos, the interesting points in the analyzed portions of videos.

VITA

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