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Ubiquitous Computing for Capture and Access

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Abstract

People may want to recall a multitude of experiences and information from everyday life. Human memory, however, has its limitations and can be insufficient for capturing and allowing access to salient information and important details over time. A variety of tools — primitive, analog, or digital — can complement natural memories through recording. Throughout history, in fact, record keeping and documentation have become increasingly important. In recent years, ubiquitous computing researchers have also designed and constructed mechanisms to support people in gathering, archiving, and retrieving these artifacts, a broad class of applications known as *capture and access.*

In this paper, we overview the history of documentation and recording leading broadly from primitive tools into the current age of ubiquitous computing and automatic or semi-automatic recording technologies. We present historical visions motivating much of the early

computing research in this area. We then outline the key problems that have been explored in the last three decades. Additionally, we chart future research directions and potential new focus areas in this space. This paper is based on a comprehensive analysis of the literature and both our experiences and those of many of our colleagues.

Contents

1

Introduction

Vannevar Bush was perhaps the first to write about the benefits of a generalized capture and access computing system. In his 1945 *Atlantic Monthly* article, he described his vision of the *memex* — a system intended to store all the artifacts that a person comes in contact with in her everyday life and the associations that she creates between them [23]. In pointing out the need to provide capture and access as a ubiquitous service, he noted that a "record ... must be continuously extended, it must be stored, and above all it must be consulted." His envisioned system includes a desk capable of instantly displaying any file and material that the user needs. Bush also envisioned other devices to support automatic gathering of information from other daily experiences for later retrieval, such as a camera that scientists wear on their foreheads to capture pictures during an experiment and a machine to record audio dictations. The goal of these imagined devices was to support the automated capture of common everyday experiences for later review, a concept reflected in much research since his article. Czerwinski et al. [37] more recently, reflected on Bush's vision within the context of modern recording technologies, identifying five reasons people capture digital versions of their lived experiences: memory, sharing, reflection and analysis, time management, and security.

In this paper, we briefly note the origins and natural human history of recording, providing only a selective overview of the extensive literature of note-taking, documentation, and the written word. We overview the early visions of computing systems designed and developed for these purposes and detail the myriad of research works in this area — broken down by domain of inquiry. We provide some information on information management and retrieval, but focus primarily on end-user applications of ubiquitous computing for capture and access of data surrounding lived human experiences. We close with an accounting of some of the near and long-term open questions for researchers.

There is no doubt that recording, whether of histories, rules, or data, has been a significant force in human history. From the early cave paintings and hieroglyphics, to the first Bibles printed for the masses using the Guttenberg press, to the Internet and publishing that is powered by the masses, the ability to record and then share information has changed the way people are able to interact, to empower themselves, and to spread knowledge. Certainly, accompanying the advances enabled through various recording media, sacrifices and losses have also impacted human history. Practices surrounding oral histories have been lost or reduced in many cultures. Documentation has sometimes replaced human rational thought in bureaucratic organizations. Peer-review and other quality controls have been lost in some arenas to the power of inexpensive, easy publication. Likewise, the advent of ubiquitous computing and the power of automated capture and access applications have continued the trend of recording as a core human need for which technology can be an important tool, support, and effecter of change.

Fernandez [53] provides a remarkable account of the way one lawyer in colonial America remained a welcomed member of an extremely conservative community, despite his unorthodox views of religion and morality. Thomas Lechford was most likely allowed to stay in the community despite his heretical views due to his role as one of the colony's "hired hands" paid to hand copy and to write legal documents. Ironically, these activities afforded him the power to insert several of his reforms, in particular around which elements of English common law to bring to American and which to leave as well as which elements Puritan

Jurisprudence might remain. The colonists were largely unable to read his reformation writings, and even if they could, they needed him to work as colonial copier, and thus tolerated reform activities that would normally have had him exiled. This single example demonstrates what many people know to be true intuitively: those who can document and share information have access to immense power and influence upon the society for which they are recording.

The power of records may also be discerned from the emphasis placed on them by certain professional fields [47, 157, 192]. Notes can serve as memory aids, decision-making tools, historical documents, backdrops for collaborative discussion and more. Furthermore, "record-keeping practices are a central means by which organizations demonstrate accountability" [192]. Thus, note-taking often can be a "requirement of professional practice" [157], governed by rules, regulations, and "best practices." However, many of the routines, procedures, and customs surrounding recording are in fact culturally and socially constructed. The context of the interaction has as much influence on the note-taking and record-keeping practices of the individuals as the content of these records.

Additionally, keeping records holds a significant historical place in the methods of the social sciences, many of which have been incorporated into HCI research. For example, Spindler and Spindler used films of research participants as "evocative stimuli" to encourage teacher reflection on classroom behavior, primarily their own [163, p. 19]. Goodwin described how videos could be used to develop a greater understanding of interactions by cataloging those interactions using similar methods to the cataloging of speech utterances by conversational analysts [64]. He also described the ways perceptions about those activities could be molded by the coding scheme used to catalogue and analyze them [63]. One goal of using video and audio records in some cases is to prevent some of the departure from reality that can be inherent to documentation manually recorded at the time of an incident or later. Even trained observers can make errors in judgment due to their own ingrained perceptions at the time of recording [163, pp. 219–221]. Video affords the possibility to return to those experiences at a later date for further analysis. Many education researchers have also examined the ways in which video can be used in teacher preparation and critique [105, 106, 121].

Use of video as records in the social sciences has also been noted to have its downsides. Certainly, "the camera is selective" [163, p. 221]. In fact, so selective that Goodwin also described the ways coding techniques can be used to recreate "truth" from video within "socially situated, historically constituted" bodies of practice [63]. Thus, the old adage "seeing is believing" holds true. However, those who "see" using this constructed view of the video record, may see only what the constructor intends. The danger of acquiring a particular outlook regarding a setting either before or during the observation period can still be in place even when doing analysis of video records after direct observation. For example, Ochs [139] described the ways in which the process and style of transcription can influence the outcome of analysis. Significantly, she found this influence to be present whether the person doing the analysis was present for the initial observations or not.

The act of manual capture can also distract people from fully engaging in an experience. During the actual activity, people will not be able to devote full attention to the activity because they must devote time and effort towards the capture task. Conversely, when people wish to become engaged in the activity, they may not be able to take the time for recording enough details for later use. Bederson described the importance of using applications, like his NoteLens, to augment not to detract from human ability to stay in the moment [12] — in the "flow" of optimal human experience [35].

Recording adds extra challenges when considering storage of and access to that information over a long period of time. First, a large amount of information is generated, requiring intensive searching or browsing. Thus, a user's ability to easily access a specific piece of information depends on not only where the user chooses to store the information but also how it is organized. Retrieval then becomes a matter of how to index into the collection of captured information. The ability to index into captured information flexibly and to correlate pieces of that information is important because the salient features for triggering the retrieval of the desired information can be a portion of the content or the surrounding context. Accessing content also involves more than the simple retrieval of content. Depending on the situation, users may want to recall information at different level of details.

Additionally, vast amounts of information stored initially for particular reasons can be used in very different ways once compiled together, raising a host of concerns about appropriate information use [91, 138]. In Europe, current laws prevent use of data for any purpose other than that which originally collected [52]. In the United States, however, as of this writing, no such restrictions are present.

Despite the many flaws of recording technologies and processes, keeping records is a significant part of the production of scientific and practical knowledge. By enhancing the ways in which people can document information, we can work towards reducing some of these issues. Following on the Memex vision, in 1960, Licklider presented his vision of the "mechanically extended man," describing how man–machine symbiosis can augment the human intellect in the future by freeing it from mundane tasks [112]. He emphasized the importance of the separable functions between the user and the computer in the symbiotic association based on what humans are good at (e.g., synthesizing an experience, making associations between information) and what computers are good at (e.g., capture, storage). Although he and Bush shared very similar visions, the technological progression over the 15 years between their writings helped Licklider to ground his idea with an understanding of the relevant issues and challenges that needed to be investigated, such as how to store the information and how to provide natural, ubiquitous interfaces for input and output tasks [35].

Like Bush and Licklider, Douglas Engelbart also believed that technology could be used to augment human intellect [51]. However, Engelbart believed in more than merely augmenting individual memory. In his work at the Bootstrap Institute, he coined the term "Collective IQ" to describe how a group can "leverage its collective memory, perception, planning, reasoning, foresight, and experience into applicable knowledge" to solve problems. The key factor in Collective IQ is the quality of the group's knowledge repository. However, augmentation also depends heavily on the speed and ease of creating and retrieving knowledge. Engelbart demonstrated the importance of these factors through the simple example of how tying a brick to a pencil can de-augment users.

These early visions were (and remain) inspirational to many areas of computer science. However, it was not until the beginning of the 1990s that these ideas were explored away from the desktop computer. In his seminal 1991, *Scientific American* article, Mark Weiser describes a vision of *ubiquitous computing* in which technology is seamlessly integrated into the environment and provides useful services to humans in their everyday activities [186]. Weiser described several scenarios demonstrating the benefits of automated capture and access, such as:

1. *Sal doesn't remember Mary, but she does vaguely remember the meeting. She quickly starts a search for meetings in the past two weeks with more than 6 people not previously in meetings with her, and finds the one.*
2. *Sal looks out her windows at her neighborhood. Sunlight and a fence are visible through one, and through others she sees electronic trails that have been kept for her of neighbors coming and going during the early morning.*

These scenarios illustrate two interesting ways that information automatically captured on behalf of the user could be used later for two different environments — at home and at work. However, Weiser left out many important details to inspire others to investigate creative applications for automated capture and access. The first scenario describes the user searching through a list of captured meetings for a particular meeting that satisfies the salient context about it that she remembers. However, we can imagine other desirable access behaviors that could have also helped Sal, such as content-based retrieval or browsable summaries of meetings. The second scenario, in addition to capturing nontraditional data types, demonstrates a very short-term access of the captured information, where walk trails are displayed hours afterward. In this application, the captured information is used only a short time after it occurred; it is conceivable this captured information is useful even after a long period of time passes. This scenario also introduces interesting privacy concerns relevant to the area of automated capture and access.

Ubiquitous computing technologies also can begin to remedy the selectivity and ambiguity of human memory. People often have difficulty foreseeing the value of information [188] or predicting when an event of significance (e.g., baby's first steps) might occur. Automated capture technologies can enable models of recording in which a person can determine the value of information about an event *after* that event rather than *before*.

As ubiquitous computing technologies improve, they can also reduce errors and challenges in external recorded memory as well. For example, we can reduce the selectivity of the camera by providing multiple fixed views of particular interactions. We can reduce the selectivity of coding of media by keeping the media and allowing access to varied coding schemes. Larger and more complex data provenance schemes can work towards ensuring the authenticity of the original record.

A large number of ubiquitous computing research projects focus on or incorporate technologies for capturing details of a live experience automatically and providing future access to those records. This theme of ubiquitous computing research is commonly referred to as *capture and access applications* [5]. We define *capture and access* as the task of preserving a record of some live experience for future review. Capture occurs when a tool records data that documents an experience. The *captured data* are recorded as *streams of information* that flow through time. The tools that record experiences are the *capture devices*; and the tools used to review captured experiences are the *access devices*. A *capture and access application* can exist in the simplest form through a single capture and access device or in a more complex form as a collection of capture and access devices [177]. Four common goals exist across ubiquitous computing applications focused on capture and access functionality:

1. *Capture should happen naturally*: The usefulness of this service often lies in its ability to remove the burden of recording from the human to support focusing attention on the live experience [5]. As a result, capture must be supported unobtrusively and should require little or no additional user effort. This behavior typically has been supported by (1) capturing raw audio and video of an experience and processing it later for additional semantic information or (2) augmenting the

devices that the user normally uses during an activity to log salient data.

2. *Information should be accessible with minimal effort*: The design of capture and access applications involves more than the development of unobtrusive capture services. The usefulness of these services becomes evident in the access phase when users need to review the information. Brotherton previously defined successful *access* as situations in which information can be found at the proper level of detail (as accepted by the user doing the access) with minimal effort [19]. Additionally, as Abowd and Mynatt point out, these information access services are most useful when they are ubiquitous [5]. Together, these two points indicate that users require interfaces that support access whenever, wherever, and however they need.
3. *Records should be cross-indexed by content and context*: Over a long period of time, automated capture results in the recording of a large amount of information. This amassing of data may cause users to experience difficulty in finding desired points of interest in the captured streams. To help users better navigate through these streams of information, applications often support many forms of indices so a user can jump directly to relevant points in a stream [127]. Additionally, access tools should be able to easily correlate and compute over events across streams and levels of detail, as motivated by user retrieval needs. For example, a person might remember a portion of the content or the surrounding context; as such, records should be cross-indexed by content as well as context.
4. *Records should be created, stored, and accessed in socially, ethically, and legally responsible ways*: Development of ubiquitous computing, database, and storage and processing technologies has led to a new "recording age," in which immense quantities of data about everyday life are being amassed. To ensure that users maintain a natural experience, capture technologies must be created in ways that

reflect their comfort levels with them. Likewise, to ensure appropriate protections against misuse and other social and societal challenges, storage and access portions of capture and access systems should ensure these same requirements are upheld.

These requirements stem not only from formative, philosophical, and analytical inquiries into capture and access technologies but also from a review of successful applications of ubiquitous computing technologies to the problem of large scale and naturalistic recording. In the previous work, we also identified five dimensions in the design space for capture and access applications (see Table 1.1). These dimensions are explored in more depth in the summary section as a means for understanding the applications overviewed in this paper.

In this paper, we outline the history of such projects from early visions at the dawn of computing to current and future trends. We divide these technologies and applications initially by domain area: workplace (Section 2), educational and scientific (Section 3), and personal (Section 4). This division enables the reader to follow how specific human problems have motivated and driven many researchers to design,

Table 1.1 Key dimensions in the design of capture and access applications.

Dimension	Description
When & where capture occurs	When and where does capture occur — how ubiquitous is recording? • Fixed locations vs mobile or wearable • Continuous, at scheduled times, or only when explicitly specified?
Methods for capturing and annotating the live experience	How is recording activated? How are annotations and other meta-data associated to the raw data?
Number of devices	How many and what types of recording devices are associated with the capture application? How many and what types of storage devices are associated?
Techniques for reviewing captured information	How do users access search, browse, index, and retrieve captured content?
Length of time captured information persists	How long will data persist? How will it age (e.g., automatic deletion, user-assisted deletion, time-based degradation)?

develop, and deploy capture and access technologies. In Section 5, we describe the techniques for capture and access across these domain problems, with a more explicitly technological focus. In Section 6, we close with a summary of the design space and some indication of the major open challenges that remain in this research area.

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