LifeLogging: Personal Big Data

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Contents

Abstract

We have recently observed a convergence of technologies to foster the emergence of lifelogging as a mainstream activity. Computer storage has become significantly cheaper, and advancements in sensing technology allows for the efficient sensing of personal activities, locations and the environment. This is best seen in the growing popularity of the quantified self movement, in which life activities are tracked using wearable sensors in the hope of better understanding human performance in a variety of tasks. This review aims to provide a comprehensive summary of lifelogging, to cover its research history, current technologies, and applications. Thus far, most of the lifelogging research has focused predominantly on visual lifelogging in order to capture life details of life activities, hence we maintain this focus in this review. However, we also reflect on the challenges lifelogging poses to an information retrieval scientist. This review is a suitable reference for those seeking an information retrieval scientist's perspective on lifelogging and the quantified self.

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Introduction

Lifelogging represents a phenomenon whereby people can digitally record their own daily lives in varying amounts of detail, for a variety of purposes. In a sense it represents a comprehensive "black box" of a human's life activities and may offer the potential to mine or infer knowledge about how we live our lives. As with all new technologies there are early adopters, the extreme lifeloggers, who attempt to record as much of life into their "black box" as they can. While many may not want to have such a fine-grained and detailed black box of their lives, these early adopters, and the technologies that they develop, will have more universal appeal in some form, either as a scaled-down version for certain applications or as a full lifelogging activity in the years to come.

Lifelogging may offer benefits to content-based information retrieval, contextual retrieval, browsing, search, linking, summarisation and user interaction. However, there are challenges in managing, analysing, indexing and providing content-based access to streams of multimodal information derived from lifelog sensors which can be noisy, error-prone and with gaps in continuity due to sensor calibration or failure. The opportunities that lifelogging offers are based on the fact that a lifelog, as a black box of our lives, offers rich contextual information, which has been an Achilles heel of information discovery. If we know a detailed *context* of the user (for example, who the user is, where she is and has been recently, what she is doing now and has done, who she is with, etc. . .) then we could leverage this context to develop more useful tools for information access; see the recent FNTIR review of Contextual Information Retrieval, Melucci (2012). This valuable contextual information provided by lifelogging to the field of information retrieval has received little research attention to date.

Before we outline the content of this review we will introduce and define what we mean by lifelogging, discuss who lifelogs and why they do so, and then introduce some of the applications and core topics in the area.

1.1 Terminology, definitions and memory

There is no universal or agreed definition of lifelogging and there are many activities which are referred to as lifelogging, each producing some form of a lifelog data archive. Some of the more popular of these activities include quantified-self analytics[1], lifeblogs, lifeglogs, personal (or human) digital memories, lifetime stores, the human black box, and so on.

In choosing an appropriate definition, we refer to the description of lifelogging by Dodge and Kitchin (2007), where lifelogging is referred to as"*a form of pervasive computing, consisting of a unified digital record of the totality of an individual's experiences, captured multi-modally through digital sensors and stored permanently as a personal multimedia archive*". The unified digital record uses multi-modally captured data which has been gathered, stored, and processed into semantically meaningful and retrievable information and has been made accessible through an interface, which can potentially support a wide variety of use-cases, as we will describe later.

A key aspect of this definition is that the lifelog should strive to record a totality of an individual's experiences. Currently, it is not

[1] http://quantifiedself.com

possible to actually record the totality of an individual's experiences, due to limitations in sensor hardware. However, we take on-board the spirit of this definition and for the remainder of this review, we assume that lifelogging attempts to capture a detailed trace of an individuals actions. Therefore, much of the lifelogging discussion in this review is concerned with multimodal sensing, including wearable cameras which have driven many first generation lifelogging efforts.

Because lifelogging is an emergent area[2], it is full of terminology that is not well considered and defined. Therefore, for the purposes of this discussion, we regard the lifelogging process as having the following three core elements:

- *Lifelogging* is the process of passively gathering, processing, and reflecting on life experience data collected by a variety of sensors, and is carried out by an individual, the lifelogger. The life experience data is mostly based on wearable sensors which directly sense activities of the person, though sometimes data from environmental sensors or other informational sensors can be incorporated into the process;

- A *Lifelog* is the actual data gathered. It could reside on a personal hard drive, in the cloud or in some portable storage device. The lifelog could be as simple as a collection of photos, or could become as large and complex as a lifetime of wearable sensory output (for example, GPS location logs or accelerometer activity traces);

- A *Surrogate Memory* is akin to a digital library, it is the data from the lifelog and the associated software to organise and manage lifelog data. This is the key challenge for information retrieval, to develop a new generation of retrieval technologies that operates over such enormous new data archives. Given the term surrogate memory, we must point out that this does not imply any form of cognitive processes taking place, rather it is simply the digital li-

[2]Although lifelogging has been around for several decades in various forms, it has only recently become popular.

brary for lifelog data, which heretofore has been typically focused on maintaining a list of events or episodes from life;

It is important to consider that lifelogging is typically carried out *ambiently* or passively without the lifelogger having to initiate anything. There have been a number of dedicated individuals who are willing to actively try to log the totality of their lives, but these are still in the very significant minority. For example, Richard Buckminster Fuller manually logged every 15 minutes of activity from 1920 until 1983, into a scrapbook called the Dymaxion Chronofile, as described in Fuller et al. (2008). More recently Gordon Bell's MyLifeBits project, Bell and Gemmell (2007) combined active and passive logging by using wearable cameras and capturing real-world information accesses. Another example of active logging is Nick Feltron's Reporter app, which allows an individual to manually log whatever life activity they wish in as much detail as they desire. Reporter will periodically remind the user to 'report' on the current activities.

While such dedicated lifelogging is currently atypical, most of us often explicitly record aspects of our lives such as taking photos at a social event. In such cases there is a conscious decision to take the picture and we pose and smile for it. Lifelogging is different, in that by default it is always-on unless it is explicitly switched off and it operates in a passive manner. Therefore the process of lifelogging generates large volumes of data, much of it repetitive.Thus the contents of the lifelog are not just the deliberately posed photographs at the birthday party, but the lifelog also includes records of everything the individual has done, all day (and sometimes all night), including the mundane and habitual.

Compare this to the recently popular field of quantified self analytics. Quantified self is considered to be a movement to incorporate technology into data acquisition on aspects of a person's daily life in terms of inputs (e.g. food consumed, quality of surrounding air), states (e.g. mood, arousal, blood oxygen levels), and performance (mental and physical). While there is a level of ambiguity in terms of the cross-over between quantified self and lifelogging, this review assumes that the key difference between lifelogging and quantified self analytics is that quantified self is a domain-focused effort at logging experiences (e.g. exercise levels, healthcare indicators) with a understanding of the key goals of the effort, whereas lifelogging is a more indiscriminate logging of the totality of life experience where the end use-cases and insights will not all be understood or known at the outset of lifelogging.

Considering how to organise these vast lifelog data archives, we believe that lifelog data should be structured in a manner somewhat similar to how the brain stores memories. While a debate on human memory models is beyond the scope of this review, we select the Cohen and Conway (2008) model of human memory due to the fact that many other memory scientists who have ventured into the application of lifelogging; for example Doherty et al. (2012); Pauly-Takacs et al. (2011); Silva et al. (2013), all refer to this model. Cohen and Conway's model suggests that the memory of specific events and experiences should be called our episodic memory. It is autobiographical and personal, and can be used to recall dates, times, places, people, emotions and other contextual facts. Our semantic memory is different and is our record of knowledge, facts about the real world, meanings and concepts that we have acquired over time. While our episodic memory is personal, our semantic memory is shared with others and is independent of our own personal experiences or emotions since its contents can stand alone and are abstract. It is suggested that our semantic memory is generally derived from our episodic memory in the process that is learning new facts or knowledge from our own personal experiences, as described in Cohen and Conway (2008) For lifelogging, much of the focus thus far has been on supporting and generating surrogates of episodic memory.

Based on such a model, one would consider a typical day being segmented into a series of events of various durations. Figure 1.1 shows a timeline of a day with events represented by an image and various metadata sources. Dressing and self-grooming, preparing food, eating, travel on a bus, watching TV, listening to music, working on a computer, taking part in a meeting, listening to a presentation, doing gardening, going to a gym, and so on, are all examples of everyday events. Some of these events are regular and repetitive. For example, many of us eat the same or similar breakfasts each day at approximately the same time and in the same place. Going to a movie or attending a party is probably a rarer occurrence, perhaps weekly or monthly. While debate exists on the formation of human memories, the view presented in this review is that lifelogging creates a lifelog which is similar to the Cohen and Conway (2008) model of episodic memory. A lifelog captures the "facts" around the episodes in our lives but not their emotional interpretation.

A lifelog does not typically capture or store semantic memory, so when we want to know the capital city of Azerbaijan (Baku) or the winners of the 2000 FA Cup (Chelsea), we don't ask a lifelog, we go to Wikipedia or we search the web. As of now, we do not refer to a lifelog for such semantic facts. Therein lies one of the real challenges in lifelogging: how to search a lifelog for relevant information given that the IR techniques we have developed over the last several decades are developed to search semantic rather than episodic memory. We shall return to this point later.

Other use-cases of lifelogging are broad and varied, such as the ability to detect and mine insights from our daily lives, in a Quantified Self type of analysis. We will return to a detailed discussion of the use-cases later. Whichever use-cases we employ, in order to maximise the potential of lifelogging (as with any technology), we should map this new technology into our lives and develop the technology in support of, rather than to try to change, our lives around the technology. Thus at the outset we should ask ourselves what are the characteristics and structures which form the organisation of our lives where we can use lifelogging to build upon.

1.2 Motivation

Lifelogging is becoming more accessible to everyone due to data capture becoming more feasible and the availability of inexpensive data storage technologies. Gordon Bell from Microsoft was one of the first to fully embrace digitising his life as part of the MyLifeBits project (Gemmell et al. (2002, 2006)) at Microsoft Research and this helped raise the profile of lifelogging. Lifelogging alone can generate large volumes of

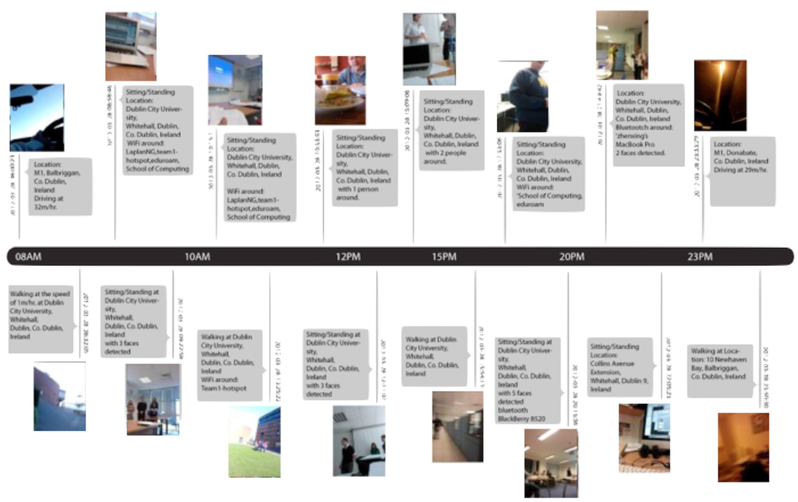

Figure 1.1: An event timeline showing key images with associated metadata from a lifelog.

data on a per person basis and a sense of this can be found when we examine the amount of information in the world in general, and also in our own personal lives, as recently discussed in The Economist (2010). When we factor in the possibilities of linking our personal lifelogs with "external data" in order to semantically enrich our lifelogs, then as an information management task it becomes a challenge to maximise its potential. Lifelogging is not a new idea, and it is not new in practice either, but apart from the media coverage generated by projects like MyLifeBits it has recently become popular for several reasons, including the following:

1. Computer storage has become incredibly cheap, both on the cloud or as personal storage. In fact we have seen exponential growth in disk storage capacity over the lifetime of digital storage;

2. We are seeing advances in sensors for sensing the person as well as sensing the person's environment which are making such sensors cheap, robust and unobtrusive;

3. There is growing social interest in the phenomenon of sens-

ing and recording oneself, the so-called quantified-self movement. Sometimes this is driven by applications like sports and health/wellness, other times it is sensing just because we can;

4. We can observe an increased openness to storing and sharing information about ourselves as can be seen in social networks.

5. New technologies such as Google Glass has brought lifelogging to the fore as a topic for public discussion.

These contributing factors evolved independently and some came together with the CARPE (Continuous ARchiving of Personal Experiences) workshop, Gemmell et al. (2004), in 2004 which brought together for the first time those whom Steve Jobs would have called the rebels, the square pegs in round holes, people like Steve Mann, Kiyoharu Aizawa, Gordon Bell, Jim Gemmell and others. This workshop in 2004 was the first real gathering of those who previously had been working independently or in isolation and suddenly as a result there was a lot of sharing of tools and experiences and lifelogging emerged as a research area.

While most of the interest in lifelogging is in either the technologies we can use, or the applications that lifelogging can be usefully used for, these do represent sizeable challenges in their own right. From an information science perspective, lifelogging presents us with huge archives of personal data, data with no manual annotations, no semantic descriptions, often raw sensor data (sometimes error-some), and the challenge is to build tools for semantic understanding of this data, in order to make it usable.

This has similarities to the early days of content-based image retrieval, but it is different in that the multimodal sensory information which forms part of the lifelog can be used to make this an opportunity for *big data* analytics. "Big data" is an often mis-used term and is unfairly associated with huge volumes of information, hence the use of the term "big". In fact "big data" isn't just about volume, it is equally about veracity (the accuracy and correctness of data which may have been eroded due to things like calibration drift in sensors), velocity (the shifting patterns and changes in data over time) and variety (the heterogeneous sources from which data is gathered). Big data is a contemporary problem and is about mining and cross-referencing information from diverse sources in order to discover new knowledge. The opportunity with lifelogging is to do this on a personal rather than on an enterprise level. Personal lifelogging can also be regarded as a new search challenge, with new use-cases defining new search and access methodologies, and providing a new opportunity to re-examine contextual IR, as described recently in Melucci (2012), with new data sources from lifelogging.

1.3 Who lifelogs and why ?

As with any new technology, there are pioneers of lifelogging like those mentioned in §1.2, and there are early adopters who take lifelogging into new applications. These applications exhibit the main advantage of concentrating on better understanding of an individual's *life* interactions, not just their activities on social media or their past search behaviour on electronic commerce sites or search engines.

However, in order to move beyond this and into a more mainstream and sustainable contribution to society, lifelogging needs to show successful application in different domains. We return to the point regarding lifelogging and quantified self analytics. The question of whether lifelogging when focused in a narrow domain is actually lifelogging is a topic for discussion, but as we will describe, the first set of lifelogging applications that are getting market traction are focused quantified self applications, perhaps because of the immediate value that can be mined from the focused data.

At the present time, there are already a large number of such applications which show successful inclusion of lifelogging technologies and concepts. Many of these are based around some form of personalised healthcare or wellness. There are already several relatively cheap products on the market which log caloric energy expenditure and types of human physical activity being performed such as the FitBit One™worn as a clip-on device on the belt or trouser pocket, the Nike FuelBand™worn as a bracelet, or the Lark™, also worn as a bracelet[3] These have built-in accelerometers and gyroscopes and with a fairly simple algorithm employed, can be used to count the number of steps the wearer takes in a day. They are quite accurate at measuring some activities like walking but not so good for other activities like cycling, contact sports or swimming. They are popular because they provide real-time feedback to the user on their physical performance or they have been embedded into a gamification model and integrated with social network thereby allowing for league tables and comparisons against the self and against peers is used to incentivise exercise or even change behaviour, Barua et al. (2013).

Monitoring sleep patterns and quality has also become a consumer-level product in recent times. These sense even the most minute movements we make when we pass through the various stages of the circadian rhythm as we sleep and from that they can compute an indicator of sleep quality. Given our recent realisation of the importance of sleep as a health indicator as well as its all-round restorative properties, its no surprise that a market has quickly grown up around this. Sleep sensing devices are typically made up of a combination of accelerometers and gyroscopes, fabricated onto a small, self-contained device worn on the wrist which detects, logs and stores timestamped movement information. Alternatively, there are apps on smartphones which do the same thing but not as accurately and there is a technology which emits low-power radio waves and measures its refraction as we breathe or move, its advantage being that it is contactless and it is built into a device marketed as the Renew SleepClock from Gear4.

Healthcare self-monitoring has other, more significant applications besides a desire for personal analytics. Smoking cessation, diet monitoring for weight loss or tracking sugar intake for monitoring diabetes all have apps to record our activity, some of them to record manually and some semi-automatically. Moving to fully automatic applications, these become very challenging, because even with wearable cameras, it is difficult to automatically sense and detect what you eat and it is easy to cheat such a system. Hence most of these apps use manual lifelog-

[3] `http://www.fitbit.com`, `http://www.nike.com/fuelband` and `http://www.lark.com` respectively.

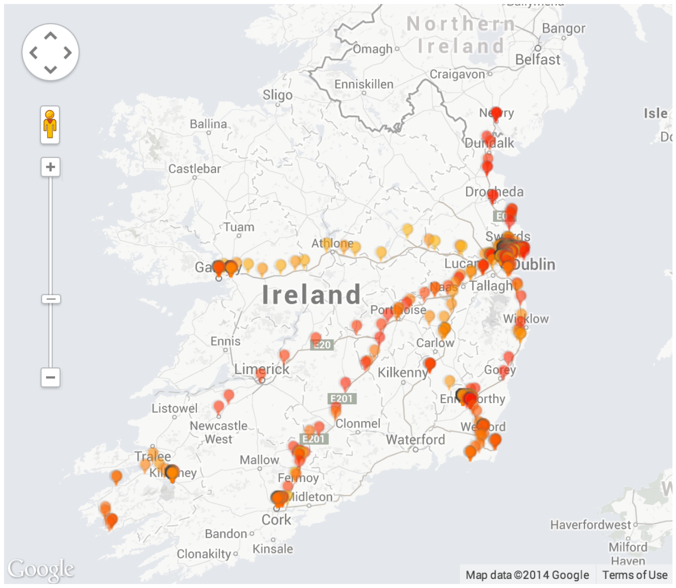

Figure 1.2: A Location Lifelog of one of the authors over a period of approximately one month in early 2014. This log was gathered automatically by the Openpaths app and uploaded to a web service, where the data can be shared with research projects.

ging techniques to record activities which are subsequently presented to the wearer as a memory from the recent past to remind him/her to manually log any missed activities.

There is also recent progress in the area of location logging, whereby apps on a smartphone make use of the inbuilt sensors to log the movements of an individual. This may be for social purposes (e.g. Foursquare checkins), for fitness purposes (any exercise mapping app), or just for lifelogging purposes (e.g. the OpenPaths app). An example of the location log for one of the authors over a one month period is shown in Figure 1.2.

However, we do note a recent movement of technology away from the focused quantified self analytics towards the idea of the totality of life experience. The Moves and SAGA smartphone apps capture in a non-visual manner all life activities (locations, activities) of the individual and present them in a basic version of a lifelog.

Recently introduced hardware devices such as the OMG Autographer and the Narrative Clip (to be discussed later) bring the idea of the capture of the totality of life experiences one step closer. Such cameras capture thousands of images per day from the wearer's viewpoint and will enable a new suite of true lifelogging technologies. One such example is triggering recall of recent memories; an application of lifelogging where the detailed lifelog acts as a memory prosthesis, thereby providing support for people with Alzheimer's or other forms of dementia. It is well-known in memory science that experiences from the past can be spontaneously re-lived based on a trigger such as an image, smell, sound or a physical object, as presented in Hamilakis and Labanyi (2008). Examples might be the smell of a pine tree which can remind a person of Christmas or a even specific Christmas from their childhood. Similarly, re-living recent experiences from a lifelog, such as the ordinary things that happened during a given day, can induce spontaneous recall, known as Proustian recall, which is discussed in Stix (2011). There have been several studies reported using visual lifelogging devices, which log and then re-play a given day for a person with memory impairment, triggering short-term recall of everyday happenings and in this way opening up cognitive pathways. Berry et al. (2009) describe studies at Addenbrooks hospital in Cambridge, UK that show measurable effects of replaying a day's activities for memory rehabilitation.

Yet while we can record a given day in very fine detail, using lifelogs for the detection of longer-term cognitive decline or gradual behaviour change, for example, is far more difficult because of the variations in our daily activities; put simply, there is no such thing as a normal day in our lives, as described in Doherty et al. (2011a).

There is also potential for lifelogging technologies to be used by organisations as a means of recording/logging the activities of employees, for various reasons, such as logging employee activities for legal/historical reasons, replacing manual record taking, logging information access activities as in Kumpulainen et al. (2009), or potentially as a new technology to support aspects of what Stein (1995) refer to as organisational memory. The idea here is to automatically capture procedures and processes for everyday activities in the workplace. While this tends to have more success for office environments where we log digital activities (web usage, emails, document accesses) rather than physical ones, there are examples of recent work with healthcare workers in clinical practice who have to log their work and record their clinical notes at the end of a shift, Kumpulainen et al. (2009), as well as lifelogging for other job-specific tasks, Fleck and Fitzpatrick (2006). Lifelogging has also been used in market research, targeting novel qualitative analysis based on analysis of subjects' lifelogs and the amount of exposure they have to advertisements, Hughes et al. (2012).

Therefore, we can see that there are a huge number of application areas for lifelogging, though many of them have been driven by throwing technology at problems rather than having the technology developed specifically to address the problem. In Chapter 5 we discuss applications of lifelogging in more detail.

For the remainder of this review, we will focus on the actual implementations of lifelogging that have heretofore been employed by researchers; therefore the focus of the review will be on visual lifelogging using wearable sensors, that aim to record the totality of an individuals experiences. We will leave aside descriptions of quantified self analytics tools and other limited forms of lifelogging.

1.4 Topics in lifelogging

The end-to-end processes of lifelogging and the applications which then use the lifelog, are complex and involve many challenges and multiple disciplines. Starting at the beginning and at the *hardware* level, are the sensors themselves which, in the case of wearable sensors, need to be robust and unobtrusive because the human body is a harsh environment for any kind of sophisticated technology. Robustness is needed because sensors can be impacted when we bump into things, they can be exposed to high levels of moisture and humidity when we get caught in the rain or even in bathrooms. They must be tolerant to drift in calibration and not require re-calibration too often if at all. Wearable sensors should also be small enough that they do not interfere with our everyday activities, and they need to have enough battery life to last at least a complete day without needing replacement batteries or re-charging. Energy scavenging is an important topic for wearable sensors and good progress is being made in this field, as shown in Kansal et al. (2007). If the wearable sensors log and record data on-board (i.e. no real-time upload) then they need enough storage capacity that data uploads are not required for several days ideally, and if they upload data wirelessly then they need to be able to take advantage of networks that come into range or to partake in ad-hoc networking. If the wearable sensors themselves support real-time upload of data, then this has a negative impact on battery life.

In terms of *software middleware*, the raw data captured from heterogeneous sensor sources has to be aligned temporally and possibly spatially as well. This requires more than just transfer from one format to another and usually needs data cleaning as well as alignment. Data quality is an important topic in areas as diverse as business informatics, Watson and Wixom (2007), and environmental sensing, Ganeriwal et al. (2008); O'Connor et al. (2009). In addition, topics such as how to dynamically compute and utilise the trust and provenance or the reliability associated with data streams which have all the issues mentioned above, come into play. In lifelogging there has been little work done in this area to date and there is much that can be learned about data quality, trust and reputation from other fields.

Once sensor data for lifelogs has been gathered, cleaned and aligned, *signal processing* is then required to analyse and structure this data. Heretofore, this as typically been structured into a data unit called an event, as shown in Figure 1.1. This automatic segmentation into events is similar to segmentation of video into shots and scenes and requires structuring personal data into discrete units. A subsequent phase of mining patterns and the deviations that those patterns can follow, would allow for the determination of their uniqueness or regularity within the lifelogger's lifestyle. It is worth noting at this point that an event is not necessarily the optimal data unit, but it is the one that has received most attention in research to date. The event segmentation models described later in this review are to be considered as early stage models. There is a lot of potential for more flexible retrieval units than events to be considered, but as of yet, this has not yet received much research attention.

This segmentation is then followed by *semantic processing* whereby we perform semantic analysis and annotation of data, including (since we focus on visual lifelogging) an analysis of visual data from wearable cameras. Ultimately this leads to a semantic enrichment of the lifelog data at the event level, or at the sub-event level, thereby helping to construct a rich lifelog.

Once a lifelog is created, we then turn our attention to how to use it and how to access it. The challenge here is learning what are the appropriate *retrieval models* for lifelogs and whether conventional information retrieval techniques, developed for accessing our equivalents of semantic memory, can find uses in information retrieval for episodic memory. Naturally such retrieval models would be based on identified use-cases, but many of the use-cases for lifelogs are as yet unknown. We do however have an early indication of use-case categorisations from the 5R's of memory access proposed by Sellen and Whittaker (2010), which are recollecting, reminiscing, retrieving information, reflecting, and remembering intentions. Each of these five R's address different access requirement for lifelogs. Once the use-cases have been defined, it then becomes important to consider the access methodologies and the HCI factors. Lifelogging is a topic which, like current and future web search, needs to support various access mechanisms to address not only the initial the 5Rs of memory access, but also to develop useful lifelogging tools for the first-generation of lifeloggers. A desktop interface to a lifelog may be useful to support detailed reflection, quantified-self style, whereas a mobile or wearable (e.g. Google Glass) interface would be needed to support real-time recollection or retrieval of information. Since the use-cases for lifelogging are not yet well defined, the access mechanisms are yet to be clearly identified, so at this early stage in lifelogging research, we do need to consider a range of commonly used access mechanisms.

Given this lightweight summary of just some of the major topics associated with lifelogging, we can see that it represents a complex set of challenges, not just the individual challenge areas taken in isolation, but the sum of the components into a whole. In the next section we present a summary of how we have structured the remainder of this overview of lifelogging.

1.5 Review outline

This review sets out to provide a comprehensive review of lifelogging, to cover the history of the field, the technologies that are currently available and the applications for which lifelogging can be used. In the next chapter we present a history of lifelogging, covering the major contributors and their impacts, as well as the advances in capture, storage and access to lifelog data. In Chapter 3, and in particular in §3.1 we give an overview of various lifelogging devices and technologies that have been employed in the field, for both capture and storage of lifelog data. Following that, Chapter 4 looks at the challenges in organising lifelog data with a focus on identifying and annotating or indexing events. Even though lifelogging generates an autobiographical record of our episodic memories and information retrieval is traditionally applied to some form of semantic memory, we believe it is important to look at how information retrieval techniques have a role in the implementation of access mechanisms to lifelogs. In Chapter 5 we present a wide range of applications of lifelogging and in the final chapter we reach some conclusions, we generate some pointers to future work and we discuss some of the most significant challenges facing this discipline.

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