Using Contextual Information in Personal Informatics Systems to Reveal Factors that Affect Behavior

THESIS PROPOSAL

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Abstract

A class of systems called *personal informatics* is appearing that help people collect and reflect on their behavior for self-reflection and gaining self-knowledge. Today, there is a personal informatics device, application, or website for almost any behavior (*e.g.*, Mint for recording spending, Nike+ for tracking physical activity). These existing systems only show behavioral information: pedometers count number of steps, diabetes devices measure blood glucose level, and finance applications track purchases. Behavioral information is sufficient for some awareness needs, but sometimes information about the factors that affect behavior is needed: one may take more steps at work than at home; blood glucose level is affected by what one eats; and off-budget purchases may be due to unexpected events. When people are interested in the factors that affect their behavior, they have to use a mish-mash of websites and devices to collect data. They have to go through the tedium of organizing, formatting, and integrating their data together. Worse, they are left to remember, infer, or guess how the different factors affect their behavior.

One source of information that people can use to find the factors that affect their behavior is contextual information. Advances in sensor technologies, increased capacity of storage devices, and ubiquity of access to information from the Internet make it easier to collect various contextual data about daily activities of people. These pieces of information may represent factors that have direct effects on an individual's behavior. For example, events attended may have an effect on one's productivity or people spent time with may have an effect on one's moods. In this dissertation, I propose to prove this thesis:

> *A tool that allows users to associate contextual information with behavioral information can better reveal factors that affect behavior, compared to existing systems that only show behavioral information.*

The dissertation will have the following contributions:

1. Demonstrate the value of contextual information in personal informatics systems in revealing factors that affect behavior.
2. Identify and resolve the different issues within each stage of personal informatics systems that prevent users from finding factors that affect their behavior.
3. Develop a tool that helps people make associations between contextual information and their behavior.

To explore how personal informatics systems can reveal factors that affect behavior, I will focus on personal informatics systems for physical activity awareness. Like most personal informatics systems, physical activity awareness systems only focus on one type of information: levels of physical activity, *e.g.*, step counts, energy expenditure, and heart rate. However, physical activity levels are not the only information relevant to physical activity. Information about factors that affect physical activity, such as lack of time, choice of activities, the environment, and social influence, are also important. Because information about these factors are often not collected, and when they are collected, they are often separate from the physical activity data, understanding how these factors affect physical activity can be difficult.

The primary cause of this difficulty is that users must remember, infer, or guess what factors affect their physical activity. For example, a user wondering why she was inactive this week compared to last week have several difficulties: 1) she may not remember exactly how active she was; 2) she may infer spurious factors that have no effect on her physical activity; and 3) she may guess incorrectly at the factors that affect her physical activity. When users do collect other information that may be related to their physical activity levels, such as GPS location or weather information, users have to go through the tedium of organizing, formatting, and integrating their data together. Users eventually abandon data collection because of this tedium.

To demonstrate the use of contextual information to reveal factors that affect behavior, I propose to design and implement a new kind of physical activity awareness system called IMPACT (Integrated Monitoring of Physical Activity and ContexT), which has appropriate support for collecting both physical activity and contextual information and tools for users to reflect on both types of information together and to make associations between them.

So far, I have conducted three studies: a diary study and deployments of two prototypes. The studies have shown the following results: 1) users make associations between physical activity and contextual information that help them become aware of factors that affect their physical activity; 2) reflecting on physical activity and context can increase people's awareness of opportunities for physical activity; and 3) automated tracking of physical activity and contextual information benefits long-term reflection, but may have detrimental effects on immediate awareness. Given these encouraging results, I propose to develop a third version of IMPACT that will support more contextual information related to one's physical activity, better interaction with data during collection, and better visualization of information. The design of these features will be guided by results from previous and planned exploratory and field studies. To evaluate the effectiveness of the final prototype, I will compare it in a field study to steps-only systems and identify features that are critical to its effectiveness. At the end of the development and evaluation of the third prototype of IMPACT, I will take the lessons learned and describe how they may apply to personal informatics systems for other types of behavior.

1 Introduction

The importance of knowing oneself has been known since ancient times. Ancient Greeks who pilgrimaged to the Temple of Apollo at Delphi to find answers were greeted with the inscription "*Gnothi seauton" or "Know thyself*". To this day, people still strive to obtain self-knowledge. One way to obtain self-knowledge is to collect information about oneself—one's behaviors, habits, and thoughts—and reflect on them. Computers can facilitate this activity because of advances in sensor technologies, ubiquity of access to information brought by the Internet, and improvement in visualizations. A class of systems called personal informatics is appearing that help people collect and reflect on their behavior (*e.g.*, Mint for spending habits, Nike+ for physical activity). Today, there is a personal informatics system for almost any aspect of a person's life, such as moods felt, health symptoms experienced, exercises performed, computer applications used, steps taken, electricity consumed, and hours slept.

Most personal informatics systems only collect one type of data about one aspect of a person's behavior [29]. For example, pedometers count number of steps; diabetes devices measure blood glucose level; and financial applications track purchases. This may be for simplicity's sake, but some information is missed. People's behaviors are affected by factors in their lives; one may take more steps while at work than at home, blood glucose level is affected by what one eats, and off-budget purchases may be due to unexpected purchases. Knowing the factors that affect behavior can be useful for making better decisions, avoiding unproductive habits, and changing behavior [10, 27].

When users are interested in factors that affect their behavior, they have to use a mish-mash of websites and devices to collect data. The responsibility lies on them to put together the pieces of their personal data puzzle. They have to collect different types of data using different types of tools. They have to go through the tedium of organizing, formatting, and integrating their data together. Worse, they are left to remember, infer, or guess the different factors. With all the tasks that people have to accomplish everyday, finding the factors that affect their behavior may just become a burden abandoned on the wayside.

One source of information that users can use to find the factors that affect their behavior is contextual information. According to Dey [9], "Context is any information that can be used to characterize the situation of an entity." In this case, the entity is some behavior about an aspect of a person's life, while context are the factors that affect the behavior. Context characterizes the individual's behavior, some of which may be factors that have a direct effect on the behavior. In this dissertation, I will show the value of contextual information in personal informatics systems for revealing factors that affect behavior. I will prove the following thesis:

> *A tool that allows users to associate contextual information with behavioral information can better reveal factors within one's life that affect the behavior, compared to existing systems that only show behavioral information.*

The dissertation will have the following contributions:

1. Demonstrate the value of contextual information in personal informatics systems in revealing factors that affect behavior.
2. Identify and resolve the different issues within each stage of personal informatics systems that prevent users from finding factors that affect their behavior.
3. Develop a tool that helps people make associations between contextual information and their behavior.

To explore how personal informatics systems can reveal factors that affect behavior, I will focus on personal informatics systems for physical activity awareness. The domain of physical activity awareness is a good lens to explore the thesis because physical activity is affected by many factors [51] and research has shown that awareness of these factors is critical to circumventing barriers to becoming active [43]. This focused exploration will result in several studies and prototypes of a physical activity awareness tool that supports collection of contextual information and reflection on the information. I will also present an argument that the lessons learned from the exploration of physical activity can be generalized to other types of behavioral information. In the next section, I will present in more detail the argument for supporting physical activity and the plan for exploring how contextual information can reveal factors that affect behavior.

1.1 Personal Informatics and Physical Activity

Lack of physical activity is a common problem that increases the risk of otherwise preventable diseases, such as obesity, chronic heart disease, diabetes, and high blood pressure [41]. A recent study by the Center for Disease Control found that more than half the adult U.S. population did not participate in regular physical activity [45]. Lack of awareness of physical activity is one of the reasons people lead sedentary lifestyles [55]. Many personal informatics systems for physical activity awareness help users become more aware of their physical activity levels, such as step counts, energy expenditure, and heart rate [2,22,31]. Pedometers, an example of such technology, have been shown to also help increase physical activity [2, 55].

Most physical activity awareness systems focus on one type of behavioral information, *e.g.*, step counts, energy expenditure, and heart rate. However, physical activity levels are not the only information relevant to physical activity. Physical activity is affected by many factors, such as lack of time, choice of activities, the environment, and social influence [51]. Awareness of these factors is critical to circumventing barriers to becoming active [43] and may help with finding active lifestyle activities (*e.g.*, walking *vs.* driving short distances or taking stairs *vs.* elevators) that have been shown to be easier to incorporate into daily life [28,41]. People need information in addition to physical activity levels to help them understand how different aspects of their lives, such as events, places, and people, affect their physical activity. In this dissertation, I will show the value of contextual information in personal informatics systems for physical activity.

So far, I have developed and deployed prototypes that support physical activity with contextual information with varying success in helping users become aware of factors that affect their behavior and help them better manage their physical activity behavior. My proposed work will build on the current findings from three studies. Major findings from each study were (in order):

1) users make associations between physical activity and contextual information that help them become aware of factors that affect their physical activity; 2) reflecting on physical activity and context can increase people's awareness of opportunities for physical activity; and 3) automated tracking of physical activity and contextual information benefits long-term reflection, but may have detrimental effects on immediate awareness.

Using the stage-based model of personal informatics systems [29], I analyzed aspects of each of the prototypes from the studies. In summary, the following are opportunities for development (refer to Table 1 for a comparison with the other studies and prototypes):

- Support for flexibility in choice of contextual information.
- Improve data collection through mixed use of automated and manual collection without sacrificing immediate awareness.
- Better visualization of associations between contextual information and physical activity to improve awareness of factors that affect physical activity.
- Demonstrate that showing contextual information with physical activity makes a difference compared with showing physical activity on the following measures:
    - Interest in the visualization (number of views, self-reported measure of interest)
    - Number of newly discovered factors that affect physical activity
    - Locus of control
    - Self-efficacy
    - Reports of how users have used their newfound knowledge to change their activity

I will develop the above features in a third version of IMPACT. The design of these features will be guided by results from previous and planned exploratory and field studies. To evaluate the effectiveness of the final prototype, I will compare it in a field study to steps-only systems and identify features that are critical to its effectiveness. I will also run the field study with sedentary

Study	Preparation	Collection	Integration	Reflection	Action
1 Diary Study	assigned activity, location, people	manual	manual	manual	finding factors that affect physical activity
2 IMPACT V1	assigned	manual automatic	manual	automatic	awareness of opportunities for physical activity
3 IMPACT V2	assigned	automatic manual	automatic	automatic	long-term reflection benefits, but detrimental to immediate awareness
4 Proposed Work	flexible	automatic manual	automatic	automatic	automated collection without immediate awareness loss; various measures, but not focused on physical activity change

Table 1.Summary of aspects of previous studies and proposed work.

and physically active users to explore the different information needs of people who have different levels of physical activity.

This work has several technical, theoretical, and human-computer interaction contributions:

- Evidence that people seeking to be active need to become aware of factors that affect their behavior.
- Evidence that contextual information associated with behavior is one way to help users become aware of *factors within their lives* that affect their behavior.
- Evidence that contextual information can increase user's awareness of opportunities for physical activity.
- Support for automatic and manual collection of several types of personal information.
- Interaction techniques for maintaining manual data collection over a long period of time.
- Interactive visualizations of contextual information associated with physical activity specifically designed for non-experts that reveal factors that affect one's physical activity.
- Description of the different information needs of people with different physical activity levels.
- Demonstrate a personal informatics system that is designed holistically. The IMPACT prototype is developed with consideration for all the different stages of personal informatics.
- User studies that demonstrate that an IMPACT prototype increases users' internal locus of control, and self-efficacy.

In the next chapter, I review related work on self-knowledge and awareness of behavior, personal informatics systems in general, and personal informatics systems for physical activity awareness. In Chapter 3, I discuss a study I conducted to understand personal informatics systems and problems that people encounter using them. In Chapter 4, I present a series of studies that I have conducted (a diary study and field studies of two prototypes), which add several insights into how a physical activity system could reveal factors that affect physical activity using contextual information. In Chapter 5, I present the stage-based model of physical activity and use it to analyze the previous prototypes on how to improve them. In Chapter 6, I propose a third version of the IMPACT prototype, which addresses the problems of the previous prototypes. In the remaining chapters, I present my evaluation plans, the contributions of my thesis, and my proposed schedule.

2 Related Work

I have organized the related work into three sections. First, I will discuss current research in self-knowledge and awareness of behavior. Second, I will discuss personal informatics systems and current research on tools for collecting and reflecting on personal information. Lastly, I will discuss personal informatics systems for physical activity awareness.

2.1 The Self and Awareness of Behavior

To illustrate the *self* I refer to in this work, I will use the example made by Brown [5]. In the statement "I see me," the self is involved twice. The *I* self is the subject, the self that is doing the action of seeing. The *ME* self is the object; the person is seeing herself. This is the *reflexive property of the self* that personal informatics systems aim to help.

James divided the self into three subcategories [25]: 1) *the material self*, tangible objects, people, or places that people can call *my* or *mine*; 2) *the social self*, how other people see us or our social identities, and 3) *the spiritual self*, our *inner self* or *psychological self*, which include our perceived abilities, attitudes, emotions, interests, opinions, traits, and wishes. This work is interested in these subcategories as they remain static or change over time. This self may be remembered (*e.g.*, "I remember last year that I exercised three times a week.") or recorded (*e.g.*, "My bank statement shows that I spent $30 more this month than last month.").

Self-knowledge in this work is one's knowledge of one's own behavior. Knowing one's behavior has many benefits, such as fostering self-insight [17], increasing self-control [39], improving learning [46], and promoting positive behaviors, such as energy conservation [53]. For example, Benjamin Franklin tracked the days in which he accomplished one of his 13 virtues for 60 years [11].

Gaining self-knowledge is not easy. People do not have complete knowledge about themselves or about things that affect their lives [58]. This is because people have limited memory, cannot directly observe some behaviors (*e.g.*, sleep apnea), and may not have the time to constantly and consistently observe some behaviors (*e.g.*, manually counting steps throughout the day). Another problem with people's memory is that people tend to remember negative things [12]. Remembering only the negative aspects of an activity (*e.g.*, remembering how many times one lost in racquetball, instead of the sport's health benefits) can be discouraging. People also have biases that prevent proper explanation of events that happen to them. When people are asked why they do something, they use common theories to explain their behavior instead of the actual causes of their behavior [37]. For example, diabetes patients have limited knowledge of the connection between their behavior and the fluctuations in their blood sugar [14,32].

Tools can help. People can manually record their behavior and reflect on the log. Many time-management books [56] advocate observing one's activities for a week, recording it in a time log, and reflecting on what activities are not productive. D*I*Y Planner (http://diyplanner.com) has many forms that people can use to record various types of behavior, such as sleep, exercise, health, and finance.

With advances in sensor technologies, ubiquity of access to information brought by the Internet, and improvement in visualizations, more people are using computers to track their behavior. The next section describes computer technologies for this purpose. For now, I will discuss some reasons why computing technologies may be helpful. First, it is estimated that one's whole life (in text and audio formats) can be stored in just one terabyte of storage [15]. With the increasing capacity of computing storage and its decreasing price, more information about a person can be recorded in the future. Second, there are plenty of sensors that can sense things that a human cannot observe. In addition, computing technology can infer information from observation quickly, thus reducing the cognitive load of the user. Lastly, the sensing of activities is not subject to the person's moods or varying perceptions of what is happening, thus the information about one's activities can be presented more objectively.

This research posits that awareness of behavior is not limited to information about the behavior alone. Contextual information may be important in revealing factors that affect behavior. According to Dey [9], "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves." Using context for self-knowledge in personal informatics systems, context *characterizes* the information collected about an individual's behavior. Context may be information about where a set of steps taken in a particular amount of time. It may be information about types of food eaten related to a person's blood sugar level. It may be information about the hours of sleep in the past week or amount of caffeine intake that may characterize a person's insomnia. In other words, contextual information answers the *five Ws (and one H)*: *who*, *what*, *where*, *when*, *why* and *how* of a person's primary data.

2.2 Personal Informatics Systems

In this section, I briefly discuss prior work on personal informatics systems. This section is divided into three subsections: tools for collecting personal information, tools for reflecting on personal information, and personal informatics systems, which combine collection and reflection of personal information.

2.2.1 Tools for Collecting Personal Information

Many research areas focus on collecting personal information. Lifelogging research explores the use of sensors to collect various types of information about people's daily lives. MyLifeBits [15] envisions a future when daily activities of people, such as computing, web-browsing activity, electronic communication, and media usage, are recorded and archived. SenseCam, a wearable digital camera, takes photographs throughout the day while worn by the user [18]. The device also contains other sensors, such as light sensors, an infrared detector, and an accelerometer. GPS and microphones can be added to collect additional information.

The experience sampling method or ESM is used in studies to collect personal information *in situ* (in the actual situation) over a long period of time. Researchers have developed many techniques to motivate people to participate in these time-intensive studies, such as improved questions and mobile devices that facilitate data input [52]. Context-aware devices alleviate interruptions by alerting the participant at more opportune times [23]. However, reflection on the data collected by ESM is for the researchers conducting a study and not the study participants. Recently, some experience sampling projects have been developed that allow participants to reflect on their collected information: Track Your Happiness (http://trackyourhappiness.org) and ES+feedback, a project I worked on with Hsieh and others [20].

Personal Information Management (PIM) focuses on how people manage their information so they can perform their tasks more efficiently [26]. PIM also explores how people can retrieve their information, but the focus is less on self-reflection and more on staying organized.

2.2.2 Tools for Reflecting on Personal Information

On the reflection side, Casual Information Visualization [44] and Slow Technology [16] help people reflect on everyday patterns. Casual Information Visualization aims to expand the definition of Information Visualization beyond work-related and analytical tasks to include non-experts. Slow Technology is a design agenda aimed at encouraging the development of systems that foster users to slow down to reflect, rather than speeding up performance. Static abstract art displays have also been used to give information about an environment [19,35,47].

These areas of research focus primarily on reflection and less on collection of personal information. While these systems discuss personal reflection, it is not their primary focus.

2.2.3 Personal Informatics Systems

Personal informatics is a class of systems that *help people collect personally relevant information for the purpose of self-knowledge* [29]. While the research areas mentioned in the previous sections examined collection and reflection separately, personal informatics takes collection and reflection as a whole process. That is, the user is involved in both collection and reflection because the data is *about* and *for* the person,. Effective personal informatics systems help users collect the *necessary* personal information for *insightful* reflection. Personal informatics goes by other names, such as “living by numbers”, “quantified self”, “self-surveillance”, “self-tracking”, and “personal analytics” [59,60]. Personal informatics systems provide an advantage over simply trying to remember information about the self, because pure self-reflection is often flawed. These systems help people by facilitating collection and storage of personal information, and by providing a means of exploring and reflecting on the information.

There have been a number of research personal informatics systems that have combined collection and reflection on personal information. There are research personal informatics systems for computer-mediated communication. Viegas and colleagues [57] developed Themail, a visualization that shows users how their relationships with others changes over time as reflected in their email correspondences. Perer and Smith [42] developed visualizations that allow users to reflect on hierarchical, correlational, and temporal patterns stored in their email repositories. There are also research personal informatics systems for sustainability. PEIR (Personal Environmental Impact Report) is a mobile phone and web site system that tracks GPS location to inform users of four environmental impact and exposure scores: carbon emissions, impact on sensitive sites, fast food exposure, and particulate exposure [36]. StepGreen is a web site where people can report their sustainable actions and see visualizations of their progress [33]. UbiGreen is a mobile phone system that tracks and visualizes green transportation habits [13]. Mycrocosm is a visual micro-blogging site that allows users to collect and reflect on various types of personal information [2].

Many commercial personal informatics systems have leveraged the ubiquity of access to information afforded by the Internet and mobile devices to help people in various domains such as finance, health, physical activity, and productivity (*e.g.*, Mint: http://mint.com, CureTogether: http://curetogether.com, DailyBurn: http://dailyburn.com, and Slife: http://slifelabs.com, respectively). There are also systems that allow collection of various types of personal information (*e.g.*, Daytum: http://daytum.com, Grafitter: http://grafitter.com, and your.flowingdata: http://your.flowingdata.com).I have created a web site where people can find commercial personal informatics systems (http://personalinformatics.org/tools).

2.3 Personal Informatics for Physical Activity Awareness

Many devices exist that measure physical activity. Heart rate monitors measure heart rate to gauge the intensity of physical activity. The BodyMediaSenseWear armband (http://bodymedia.com) monitors acceleration, galvanic skin response, skin and ambient temperature to calculate calories burned. Pedometers or step counters are the most affordable and easiest to use [4,55]. Recently, mobile phones equipped with accelerometers have included step-counting software, *e.g.*, Nokia 5500 SportsTracker and Samsung SPH-S4000. Table 2 provides an overview of several commercial products and research activities in the domain of physical activity awareness.

The awareness of physical activity can offer provides several benefits. First, awareness can help users make better decisions. Awareness of one's environment has been shown to be critical in decision-making [10]. Begole and colleagues [3] used patterns of activity to help office workers plan work activities and communication. Many physical activity awareness systems leverage this. Second, feedback about exercise can help users prevent problematic behaviors. Discontinuing one's exercise regimen is a common occurrence among people. Martin and colleagues [34] showed that feedback is one of the several behavioral and cognitive procedures that can enhance adherence to an exercise program. Annesi [1] found that members of a fitness center who received exercise feedback attended the fitness center more and were less likely to drop out. Lastly, information about one's self can be used as a motivational tool. Paschali and colleagues [40] used simple accelerometers to track activity among adults with Type 2 diabetes and showed that feedback promoted exercise. Body and environment sensors are here today and more are being created. They just need to be applied to the problem of exercise adherence and their information offered as motivational tools to users.

Research has also been conducted on the use of novel visualizations for displaying physical activity levels. UbiFit Garden [8] displays physical activity levels using a garden metaphor in a glanceable display on the phone. The Shakra system used GSM signal strength to detect minutes of physical activity (*e.g.*, sitting, walking, and driving) and displayed cartoon visualizations of activity on a mobile phone [31]. Fish n' Steps explored motivating physical activity by using

Name	Monitoring Device	Information monitored	Feedback	Social
Pedometer	Pedometer	Aggregate step counts	Device	No
Nokia 5500 SportsTracker	Mobile phone	Aggregate step counts	Device	No
Shakra[31]	Mobile phone	Duration of different activities	Device	No
UbiFit Garden [2]	Mobile phone & Intel MSP	Duration of different activities	Device	No
Fish'n'Steps[30]	Pedometer	Aggregate step counts	Device & public display	Public display
BodyMediaSenseWear	SenseWear armband	Time-stamped activity level	Desktop application	No
Nike+iPod	iPod and in-shoe device	Distance walked/ran	Device & web site	Share in web site
First IMPACT prototype	Pedometer & journal	Step counts & context (manual)	Device & web site	No
Second IMPACT prototype	Mobile phone and GPS	Time-stamped step counts& context	Device & web site	No

Table 2.Overview of commercial products and research activities in physical activity monitoring.

visualizations of fish in a tank [30]. The BodyMedia SenseWear armband comes with software that creates visualizations of users' step counts and energy expenditure. Walking Spree (http://walkingspree.com) uses a pedometer that can upload data online for visualizations. The Nike+iPod system (http://nikeplus.com) monitors step counts using a device embedded in Nike shoes. Like WalkingSpree, users can upload and share data. Guidelines for designing physical activity awareness devices have been discussed by several projects [7,24] and I leverage these principles in the design of the prototypes. While these systems allow users to reflect on their physical activity using visualizations, they do not go beyond physical activity levels. My work builds on these systems by integrating contextual information.

Finding opportunities to be physically active remains a challenge for people [28]. Awareness of opportunities for behavior change is critical to circumventing them and making lasting behavior changes [43,51]. Focusing only on the amount of physical activity may be insufficient to help find opportunities for behavior change because there is a gap in understanding between the facts about such a physical state and what causes that state [14]. For example, knowing the number of steps in a given day does not answer where those steps were taken: Did I take the most steps at home or at work? Did walking outside for lunch contribute enough steps to my overall count?

Other research projects have stated the importance of helping people make connections between their behavior and factors that affect the behavior. For example, diabetes patients are taught to be aware of their blood sugar level, but blood sugar levels alone do not show the behaviors that contribute to those levels [14,32]. By showing people images and video, they can form conclusions, not just facts [54]. For example, asthma patients videotaping their daily routines realized they are in the presence of harmful allergens more often than they realized [48].

3 Stage-Based Model of Personal Informatics

To better understand personal informatics systems and problems that people encounter using them, I conducted a survey of people who use personal informatics systems. In this chapter, I will briefly introduce the results of the study: a stage-based model of personal informatics systems (Figure 1) and the barriers people encountered in each of the stages. Details about the study and the results are in this paper [29].

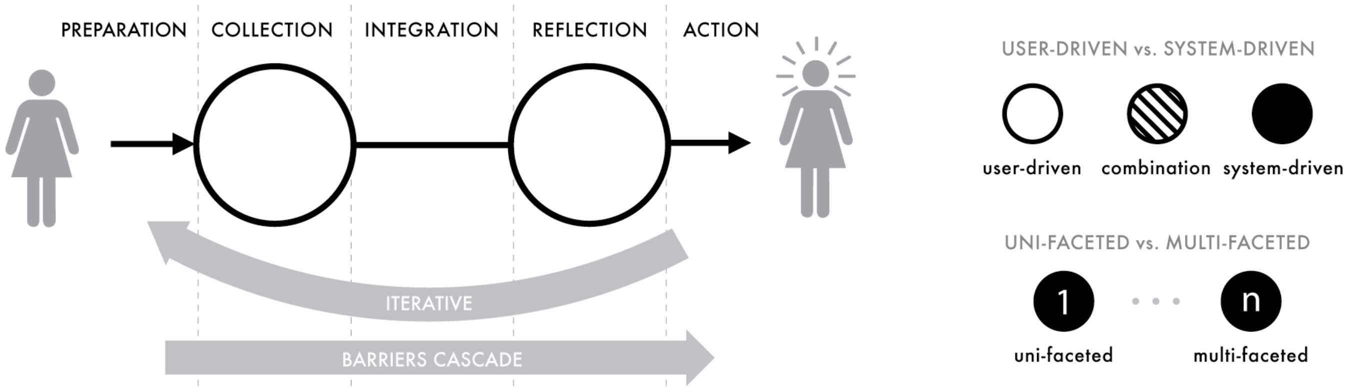


Figure 1. The Stage-Based Model of Personal Informatics Systems and its four properties: 1) barriers in a stage cascade to later stages; 2) stages are iterative; 3) stages are user- and/or system-driven, and 4) uni- or multi-faceted. The visuals for 3) and 4) can be used to show these properties for a particular system.

3.1 Stages

The *Preparation* stage occurs before people start collecting personal information. It concerns people's motivation for tracking, what information to track, and what tools to use for tracking. Problems can occur when the tool does not satisfy the user's information needs.

The *Collection* stage is the time when people collect information about themselves, such as their inner thoughts, behavior, social interactions, and their immediate environment. Many problems occur because of collection tools. Some problems occur because of the user's lack of time, lack of motivation, or forgetfulness. Other problems are data-related: some data are hard to estimate, lack of standard for subjective ratings, and difficulty finding information.

Integration is the stage where the information collected are prepared, combined, and transformed for the user to reflect on. Problems occurred when collected data comes from multiple inputs, when visualizations are scattered, and when the data collection format is different from what the visualization requires.

The *Reflection* stage is when the user reflects on their personal information. Users may reflect on the information immediately after recording (short-term) to be aware of their current status. Users may reflect after several days or weeks (long-term) to see trends and patterns. There may be problems during this stage because of lack of time, self-criticism, and problems with retrieving, exploring, and understanding information.

The *Action* stage is the stage when people choose what they are going to do with their newfound understanding of themselves. Some may tailor their behaviors to match their goals. Some systems alert users when particular thresholds are met. Some systems provide incentives to motivate users to take action.

3.2 Properties of the Stages

As a whole, the stages have four properties that have implications for the design and development of personal informatics systems.

The first property is that problems in earlier stages affect the later stages. For example, not selecting the right tool during the Preparation stage may lead to reflecting on incorrect data. Another example is that problems in the Collection stage may lead to sparse data, which may be insufficient for insightful reflection. This property suggests that the development of personal informatics systems should be approached holistically. Of course, we should take inspiration from different fields to resolve problems within each stage (e.g., visualization techniques from the infovis community), but development should not focus only on one stage, but consider the whole experience of the user throughout the different stages.

The second property is that the stages are iterative; users will incorporate new data, tools, and processes as they progress through the stages. For example, users may change the types of physical activity she performs. These changes require selecting a new tool, collecting new types of data, and reflecting on different visualizations. Often times, the user cannot bring their old data along with them. This causes problems because it makes comparing between different types of physical activity more difficult. This property suggests that systems should be flexible to support users' changing information needs. Some examples are support for import and export of data and rapid iteration so that users can hone in on the questions they want to answer.

The third property is that each stage can be classified as user-driven, system-driven, or a combination of both. In a user-driven stage, the user is responsible for the activity in the stage, while in a system-driven stage, the system is. For example, a user-driven Collection stage may require users to record information into a spreadsheet, while a system-driven stage may use sensors to track personal information. This property suggests that there are opportunities to alleviate the demands on the user using automation; however, developers should consider the tradeoffs (e.g., inaccuracy of automated tracking and loss of user control.)

The fourth property concerns facets of a person's life. Most systems are uni-faceted, collecting only one facet of a person's life (*e.g.*, Mint for financial matters, Nike+ for physical activity). Some systems are multi-faceted, collecting multiple facets of a person's life (*e.g.*, Daytum, your.flowingdata). However, such systems usually present multiple facets in separate visualizations. Many participants expressed their desire to see associations between different facets of their lives. However, there are several barriers experienced within the stages that we may expect in supporting multiple pieces of personal information. I describe them below. But I did not make these predictions before I conducted the IMPACT studies because the model was created after. These barriers are confirmed in the discussion of the prototypes and their deployments.

- *Preparation*. Users may have multiple hypotheses about what factors affect their behavior. Users or the system may not know beforehand, which data should be collected.
- *Collection*. Collecting multiple types of data requires more time and more things the user has to do. Users may also be required to use a multitude of tools.

- *Integration*. Users may experience problems organizing data from multiple places or having to view data from multiple applications, web sites, or visualizations.
- *Reflection*. Reflecting on multiple types of data requires spending more time exploring the data. There may also be barriers using the appropriate visualizations for insightful reflection and interpreting the data.
- *Action*. Among all the factors that affect behavior, users may have difficulty choosing which factors they can address more quickly or more easily.

4 Diary Study and Field Deployments of Prototypes

In this chapter, I discuss briefly the studies I have conducted in the domain of physical activity awareness to explore how contextual information can be used to reveal factors that affect physical activity.

4.1 Approach

I worked primarily with sedentary people because research suggests that they are less aware of how active they are and they need more information about how to become active compared to active individuals [43,51]. Consequently, I also focused on walking as a physical activity because sedentary individuals can more easily integrate walking into their daily lives than other forms of physical activity [38].

While there are many kinds of information that can be added to step counts, I focused on three different kinds of contextual information that have been explored extensively by the ubiquitous computing community: *activity*, *place*, and *people*. As technologies that monitor this information become more robust, they can be more readily integrated into physical activity awareness devices. My review of the literature suggests that integrating contextual information with physical activity has not been previously explored.

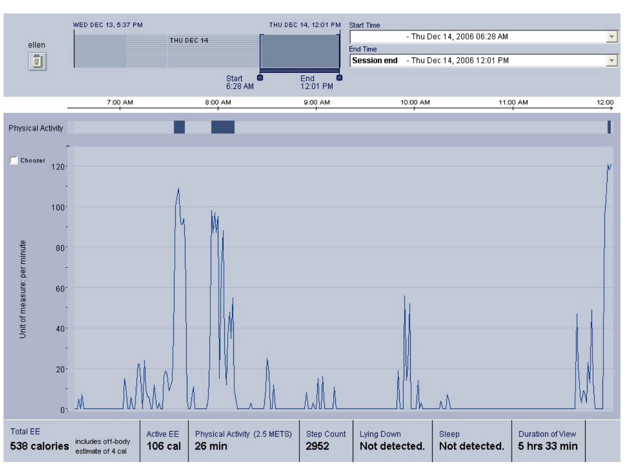
I also took a specific user-centered approach in conducting my studies. I started with the needs of the users and then created a series of prototypes to observe how users reflect on their information. There were three reasons for this. First, the primary goal of the studies was to understand how increasing awareness of context about physical activity affects the user and what the benefits are compared to existing systems *before* I invest time and money on developing more sophisticated technology. Second, I wanted to make sure that our deployed technologies were robust enough to be used for a long period of time. Finally, the current state of most systems to track activity and people require wide infrastructure changes or require more devices than most users were willing to wear. My approach is similar to technology probes [21], where low-fidelity prototypes are used to observe how people might use a new technology. As I progressed through the studies, I increased the fidelity of our prototypes addressing the lessons learned from the earlier trials.

I conducted studies that spanned a long period of time and were *in situ* for two reasons. First, if reflecting on information about oneself is going to be useful, users will need to have monitored their behavior for an extended amount of time and the data they view needs to be their own data (as opposed to synthetic data or someone else's data). Second, we wanted our studies to be ecologically valid. Consolvo and colleagues [6] further described the value of *in situ* deployments for ubiquitous computing technologies.

4.2 Diary Study

Before building prototypes, I conducted a diary study [49] to explore how people would reflect on contextual information about their physical activity. In the diary study, 4 participants (A1-A4) logged a detailed record of their activities (time, type of activity, location, and people), which they explored along with physical activity data from the BodyMedia SenseWear armband. The study had 3 phases: 1) participants did not see their physical activity data; 2) participants carried a pedometer to see their aggregated step counts in real time; and 3) participants saw detailed printouts of their physical activity (from the BodyMedia software) at the end of the day (Figure 2). The study revealed that *when given access to contextual information during reflection, people would associate them with their physical activity helping them become more aware of factors that affect their physical activity.* This activity of creating associations suggests some tangible benefit in helping people understand the relationship between physical activity and factors that affect it. This result manifested in three ways:

- Participants liked the daily reports of time-stamped data from the SenseWear armband. They *routinely matched segments on the graph* with activities they recorded in their journals to better understand how much physical activity they were performing while engaged in different activities.
- Participants *became more aware* of their physical activity and were often surprised when they discovered that a particular activity could be physically active. For example, A1 said, “I realized that walking up the hill on my way home burns a lot of calories, and that going shopping makes me walk a lot.”
- Participants also *found opportunities* for physical activity. A2 said that the device “caused [her] to incorporate mini-bursts of activity into my day.” A4 said “The feedback really makes me realize that walking makes a difference, even if it’s just errands.”



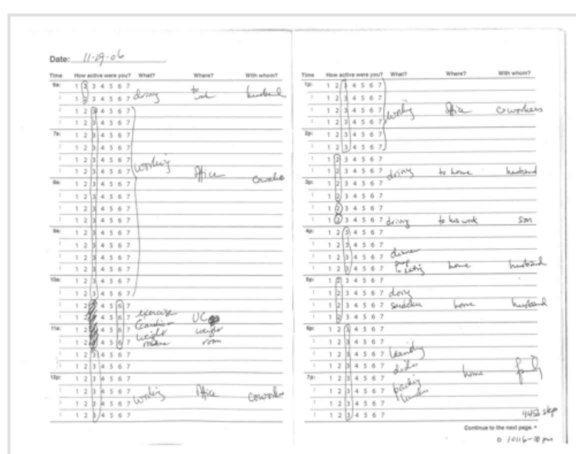


Figure 2. Screenshot of BodyMedia SenseWear graph and booklet entries by one of the participants in Phase 3 of the diary study.

4.3 IMPACT 1.0

With lessons from the diary study, I developed the first prototype of the IMPACT system. Similar to the last study, the system integrated physical activity monitoring with a journal for recording contextual information. The prototype used visualizations to help people to easily see the associations between their contextual information and physical activity. We conducted a 7-week field study of the prototype with 43 participants (B1-B43). We compared the prototype to a system that collected and visualized step counts only (Steps-Only). From interviews and surveys, participants revealed the value of contextual information compared to step counts only; they reported (on a 5-point Likert scale) *greater awareness of opportunities for physical activity* (3.93 vs. 3.57, $F[1,58]=5.32$, $p<.05$). Participants noted the usefulness of the IMPACT prototype. B12 said, "It helped me realize which activities were more important. For example, I didn't understand the importance of walking home versus taking the bus."

While participants considered the first IMPACT prototype the most useful, they also said it was the least easy to use. Participants reported that manually logging the extra contextual information was too tedious. Fortunately, the problem is addressable; 90% of the participants reported they would continue using the system if collection of context information were more automated.

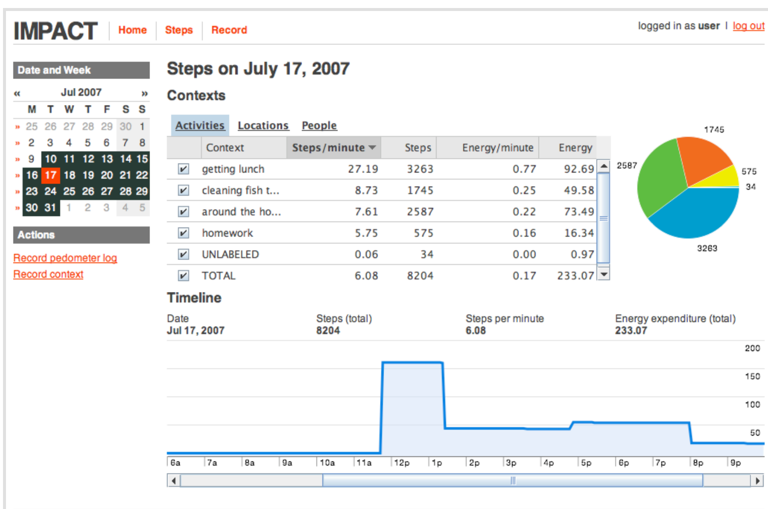


Figure 3. Screenshot of IMPACT 1.0

4.4 IMPACT 2.0

I created a second version of the IMPACT system that addressed the problems identified in the first prototype. The second prototype used a mobile phone and GPS to monitor step counts and the user's location. The mobile phone also has an easy-to-use interface to input what the user is doing and whom he/she is with. Instead of manually entering step counts and contextual information on the web site, a desktop application synchronized data between the phone and the new web site. If the user needs to add more contextual information after uploading, they can label periods of time on the visualizations

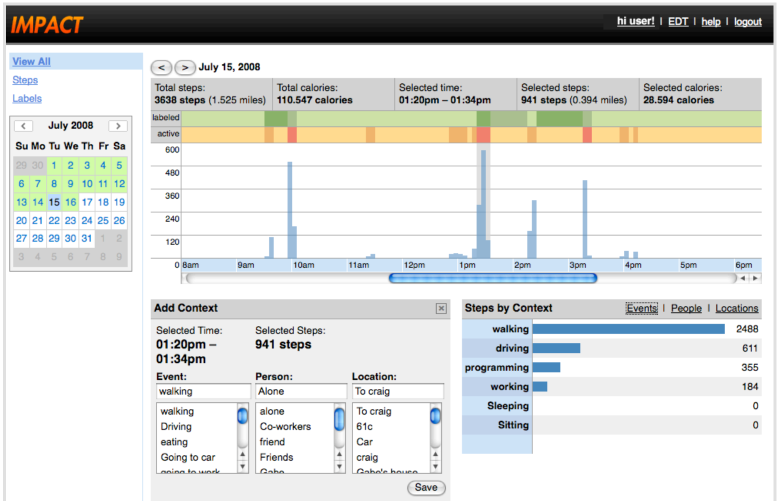


Figure 4. Screenshot of IMPACT 2.0

I deployed the second version of the IMPACT system to 49 participants (C1-C49) for 8 weeks comparing it to other versions of IMPACT without contextual information: *Steps-Only* and *Control*. This time around, having contextual information was not better at increasing awareness of opportunities for physical activity. Instead, awareness of opportunities increased for all users, regardless of the system that they used. One explanation why awareness increased with the first prototype but not the second is that users of the first version were more engaged; they had to physically write down their contextual information. While the second prototype eased the burden of data collection, the users were less engaged with their data.

A follow-up study six months later revealed the value of the extra contextual information. All users were curious about the peaks they saw in their graphs, they wanted to know what they were doing during those times of peak activity. However, only users who had collected contextual information were able to deduce what they were doing. Interestingly, some users pulled out their electronic calendars to see what they were doing on particular dates. These observations suggest that automatic labeling of contextual information is useful for reflection, especially, at a later time when users have likely forgotten their history. Another observation is that existing records, such as electronic calendars, may be leveraged to provide contextual information. These results suggest that easing the burden of data collection benefits long-term reflection, but may have detrimental effects on immediate awareness. This trade-off requires further exploration.

5 Prototype Analysis using the Model of Personal Informatics

Although the first prototype of IMPACT demonstrated an increase in people's awareness of opportunities for physical activity, it did not show actual behavior change and people found it difficult to use. The second prototype of IMPACT reduced the tedium of data collection by automatically collecting time-stamped physical activity data and location and automated integration with the web site. However, this prototype did not demonstrate an increase in people's awareness of opportunities for physical activity. I will use the stage-based model of personal informatics systems to identify the problems with the previous prototypes.

5.1 IMPACT 1.0 Analysis

User- vs. System-driven:

- *Preparation*. Users were instructed to record events, location, and people. They did not have a choice what type of contextual information to record.
- *Collection*. The pedometer recorded the users' aggregated step counts, but users had to write on their booklet time-stamped step counts and contextual information. Users collected step counts and contextual information in a paper booklet.
- *Integration*. Users transcribed their hand-written notes into a web site form.
- *Reflection*. The pedometer displayed aggregate step counts for short-term reflection. The web site has several visualizations for long-term reflection on physical activity and contextual information.
    - Timeline of step counts every 5 minutes (1 day) with context annotations
    - Pie chart of step counts per context (activities, location, people)
    - Histogram of step counts by hour of the day.
    - Histogram of step counts by period of the day (after midnight, morning, afternoon, evening.
- *Action*. The web site did not have explicit instructions on how to change behavior. The system *was not better* than pedometer-like systems at increasing physical activity. The system *was better* than pedometer-like systems at increasing awareness of opportunities for physical activity.

Barriers in earlier stages cascade to later stages. Several problems may have affected the quality of people's reflections. Collecting both step counts information and several contextual information over a long period of time was difficult. Worse, participants had to transcribe the data on the web site, which may have delayed users from long-term reflection on their data.

Stages are iterative. The study may have been too short for people to change their information to require a tool change. While they may have changed their hypotheses about what factors affected their physical activity, the system was inflexible about the types of information collected.

Uni- vs. Multi-faceted. The system is multi-faceted that it supported data collection of physical activity, events, location, and people.

5.2 IMPACT 2.0 Analysis

User- vs. System-driven:

- *Preparation*. Participants were instructed to record events, location, and people. They did not have a choice what type of contextual information to record.
- *Collection*. The mobile phone automatically recorded time-stamped step counts and GPS location. Participants were alerted when they are active and had the option to enter event and people information on the phone.
- *Integration*. The mobile phone automatically synchronizes with the web site using a desktop application that communicates using Bluetooth. The user has to initiate the transfer.

- *Reflection*. The pedometer displayed aggregate step counts for short-term reflection. The web site has several visualizations for long-term reflection on physical activity and contextual information.
    - Timeline of step counts every 5 minutes (1 day) with context annotations
    - Histogram of step counts per context (activities, location, people)
- *Action*. The web site did not have explicit instructions on how to change behavior. The system was not better than pedometer-like systems at increasing physical activity and at increasing awareness of opportunities for physical activity.

Barriers in earlier stages cascade to later stages. Several problems may have affected the quality of people's reflections. The automated collection of steps and GPS location may have caused users to interact with their data less compared to the first prototype.

Stages are iterative. The study may have been too short for people to change their information to require a tool change. While they may have changed their hypotheses about what factors affected their physical activity, the system was inflexible about the types of information collected.

Uni- vs. Multi-faceted. The system is multi-faceted that it supported data collection of physical activity, events, location, and people.

6 IMPACT 3.0

The analysis of the prototypes revealed opportunities for improving IMPACT. In the design of the third version of IMPACT, there are a number of issues that must be further investigated which I discuss in detail below:

- Support for flexibility in choice of contextual information.
- Improve data collection through mixed use of automated and manual collection without sacrificing immediate awareness.
- Better visualization of associations between contextual information and physical activity to improve awareness of factors that affect physical activity.

6.1 Choice of Contextual Information

Instead of forcing users to only collect three types of contextual information (activities, location, and people), the new version will also support collecting other types of contextual information that may be related to physical activity (e.g., mood, weather, event information in user calendars). Participants from the previous studies have noted that they would like to see other types of information associated with their physical activity. When reviewing their information after a long period of time, some noted that they would like to check their calendar to see what they did on days when they were active. Others suggested that mood and weather information would also help. Essentially, supporting collection of other types of information allows users to check how other factors beyond activity, location, and people affect their physical activity.

6.2 Maintaining Immediate Awareness in Semi-Automated Collection

The first prototype suggested that some automation is needed to reduce the burden on the user during data collection. However, the second prototype suggested that some user interaction during the Collection stage is critical for people to maintain immediate awareness of their physical activity. To resolve this, I propose a data collection method whereby visualizations are shown to users when they manually collect a piece of data. This approach has been shown to encourage compliance in the context of experience sampling over a period of three weeks [20]. Specifically, when a piece of data is manually collected, other associated data that are automatically collected are revealed to the user. This method does two things: 1) it encourages manual collection and 2) it reveals automatically collected data that the user may not otherwise see.

6.3 Visualizations of Contextual Information and Physical Activity

These visualizations should reveal the factors that affect one's physical activity. Most physical activity visualizations are two-dimensional: physical activity level by day or physical activity on a finer-grained timeline (hourly or by minute). Some visualizations break the two dimensions by allowing users to attach annotations to specific instances of time. Previous versions of the IMPACT system used manually- and automatically-collected contextual information as annotations on the physical activity data. The final version will maintain this with improvements to make annotations easier to manage.

I will design different visualizations that will help users do the following:

- *Visualizations that help users make statements about instances of physical activity in time*. The visualization should help users answer who, what, where, and when questions about instances of their physical activity.
- *Visualizations that help users make comparisons between instances of physical activity*. The visualization should help users make statements such as "I am more active with this person / when I do this activity / when I am at this place / during this time."
- *Visualizations that help users make cause and effect associations between context information and physical activity*. For example, "these factors ____ affect my physical activity" and "When I am active, (my mood is improved / I feel less stressed)."

7 Evaluation

Before performing a field study of IMPACT 3.0, I will perform several iterations of usability testing of the collection devices and the web site to improve the design of the prototype. I will also develop a version of IMPACT 3.0 that does not support collection and annotation of contextual information. This version will be similar to pedometer systems with historical visualizations (e.g., Nike+).

When IMPACT 3.0 is robust enough for full deployment in the field, I will conduct a field study where the control group will use a version of IMPACT 3.0 with steps only and the experimental group will use a full version of IMPACT 3.0 with contextual information. The participants will use the systems for 8 weeks.

I will recruit participants from the general Pittsburgh population. Similar to the previous studies, I will recruit sedentary individuals. In addition, I will recruit physically active users. This is so that I can compare the two groups' experiences using the systems.

I will measure the following things during the field study:

- *Interest in the visualization*. This measurement will come from the number of web site views and self-reported measure of interest.
- *Number of newly discovered factors that affect physical activity*. The reflection interface will have a tool where users can annotate relevant activities/events on the timeline where they found new factors that affect their physical activity. The annotations will be labels and full-sentence free-form text.
- *Locus of control*. I will measure this using the Multidimensional Health Locus of Control (MHLC) Scales (http://www.vanderbilt.edu/nursing/kwallston/mhlcscales.htm).
- *Self-efficacy*. I will measure this using the Multidimensional Measure of Exercise Self-Efficacy (http://www.vanderbilt.edu/nursing/kwallston/mhlcscales.htm).
- *Immediate awareness*. I will measure this by experience sampling. Throughout the study, participants will be alerted to report how active they are and which factors have affected their physical activity.
- *Self-reports of change in behavior*. These will be self-reports by participants either by end-of-day or end-of-phase reports about how they used their newfound knowledge to change their activity.

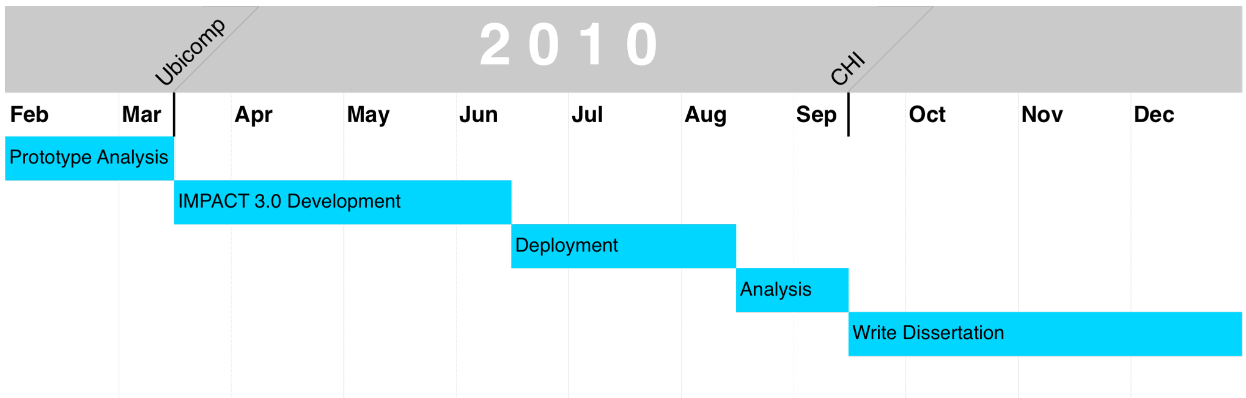
In the study, I will measure step counts, but I do not expect this to be the primary contribution. Finding a difference in step counts between the systems will require a much longer study. Additionally, finding the effect of IMPACT 3.0 on physical activity will require a true control where users are not using a device.

8 Scope

I could extend the proposed work in a number of directions that I may or may not pursue as part of my thesis work:

- Modifying the IMPACT web site to support other types of behavior (*e.g.*, blood sugar level, expenditure).
- Provide empirical evidence that design guidelines used in IMPACT for physical activity also applies to other types of behavior.
- Supporting sharing of data with others. Exploring the quality of discussions people have with others when discussing the factors that affect their physical activity.
- Conducting several studies to explore the details of how people reflect on their personal information, what conclusions they make from their data, and what processes they use to reach those conclusions.

9 Schedule



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