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Supporting wellbeing through improving interactions and understanding in self-monitoring systems

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Abstract. We use computing devices at work, at home and on the go. We generate huge amount of data that is stored (either temporarily or permanent) on our machines or on remote servers. There is a lot of value in this information and some of it is already further exploited by many external parties. So, if others consider our information important why don't we take proper advantage of it? How can we use the information we generate to our own advantage? How can we use this information to improve our lives and support our wellbeing? And how can we create better environments that will be able to offer more personalized and engaging interfaces supporting such diversity of information? We offer here our answer to such questions by presenting the MyRoR system with its main goals of better supporting self understanding and offer more natural interfaces for information visualizations, based on personalized and interactive stories.

1. Introduction

Wellness and *wellbeing* are terms used more and more these days in various contexts but what do they actually mean? A quick Internet search will bring up various definitions, more or less vague. In most instances, wellness and wellbeing are associated with being healthy and happy, even though, as discussed in [1], in reality these states include subjective perceptions meaning that an ill person can have a sense of wellbeing while a seemingly healthy person might not have it. The limitations of these terms come mainly from the fact that most of the time *health* refers to physical aspects, even though definitions that are more complex have existed for a long time. Most prominently, the WHO (World Health Organization) Constitution, defines health as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*". However, with chronic diseases becoming a huge problem in our societies, more understanding is necessary for determining not only how to treat them but also how to prevent them. The necessity to understand what influences such chronic diseases broadens the concepts of wellbeing and wellness and they became more holistic. We give here just a few examples of the multiple aspects of wellness[2]: in [2], Corbin et al. define wellness as a "multidimensional state of being, describing the existence of positive health in an individual as exemplified by quality of

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[2] For further readings on wellness-related literature we recommend [4] and [5].

life and a sense of well-being". In [3], wellness is described as having 7 components: physical, social, emotional, intellectual, spiritual, occupational and environmental. Other dimensions mentioned in [6] are financial, mental and medical. As mentioned before, the increased focus on wellness and its multiple facets was necessary in order to create a more preventive focus of healthcare systems and individuals. While wellbeing is more of a *state* of feeling well (overall), wellness can be seen as a *life goal*, which includes self-responsibility and a daily process of making lifestyle decisions and dealing with various aspects covered by the components described above [1]. There is now much more understanding of the impact our daily lifestyle choices have on our wellbeing and healthcare systems do consider the aspect of making people more aware and informed as very important in the strategy of dealing with the problem of chronic diseases [7][8][9]. The advances in wearable technologies as well as the realization that self monitoring systems help people become more aware and even change their behaviors [38][10] have helped create many solutions that deal with various health aspects. However, most of the existing systems focus on physical health recording and monitoring and pay little attention to other dimensions, much as the views on health discussed above. We will present some of these existing solutions in Section 2.

In this article we argue that it is time to take advantage of the varied data available through our smart environments and move from focusing only on *what* happened towards *why* it happened. We believe that by using self-monitoring technologies that are able to create a more detailed and complex picture of our lives, we will be able to address the wellbeing at a holistic level and not only by looking at various separate aspects. Our aim is to create systems that support users in self understanding and self reflection. We discuss the challenges presented by dealing with different types of information, especially in terms of modelling and visualization and we introduce our approach for creating interactive, personalize and informative systems. As a case study, we introduce our system approach and we discuss its design and implementation together with a user experiment. We conclude with a discussion of our results so far, our ongoing work and future plans.

2. Background and motivation

Lifestyle choices affect our lives in multiple ways but most evident is their role in chronic diseases. Chronic diseases is a generic name for various health conditions that, once acquired cannot be cured but just managed. According to the World Health Organization (WHO), chronic diseases are the leading cause of illness and death in the world [7], posing a considerable financial and emotional burden on patients and their support networks. Some of the most common chronic diseases are coronary heart disease (CHD), cancer, renal disease, diabetes and mental health. In 2005 in UK there were more than 17.5 million people living with at least one chronic condition and it is estimated that by 2030 the incidence of chronic disease in the over 65s will more than double [8]. Many people are diagnosed with more than one chronic disease and sometimes one condition becomes a risk factor for another one. One important aspect is that chronic diseases are not only a problem of elderly, as people from various age groups are now affected, a situation mainly caused by changes in our lifestyles. Certain lifestyle-related factors, such as smoking, alcohol, physical inactivity, diet (irregular meals, salty or fatty foods) and psychosocial stress, have a proven impact on chronic diseases, which also means that they have become the main targets for preventive healthcare programs [7][9]. Prevention plays an important role both in avoiding acquiring a disease, as well as for avoiding worsening of an existing condition. Lifestyle management support can have a significant impact as most of the patients living with chronic diseases fall into the low risk category, which means that, with the right support, they can learn how to manage their disease [8].

Various programs for inducing and supporting preventive behaviours have been implemented using various channels, such as printed material, TV and radio campains or through healthcare providers offering advice to patients, e.g., on what to eat in order to avoid cholesterol or how to avoid living a sedentary life. The advances in wearable monitoring systems allow for an increased offering in solutions that can record, store (either locally or remotely), and analyze patient data. Using such systems for outpatient monitoring benefits both healthcare systems and patients, as patients can live normal lives and avoid hospitalization. The importance of empowering both patients and medical staff with more objective information obtained through outpatient self monitoring systems is emphasized in recent reports such as [10]. The same report also documents a continuous shift in attitudes both of patients and medical staff towards using such technologies, especially as they become more unobtrusive and as their benefits (both social and economical) are better understood. A large number of the 1000 people interviewed in [10] (in UK, ages from 16+) were already using various means for self diagnosis (60%) and a significant number of people (over 60%) were interested in monitoring their own health, particularly for various parameters such as cholesterol and blood pressure.

Using wearable systems for outpatient monitoring accrues multiple benefits, for all parties involved. We are including here some of the existing self monitoring systems[3].

2.1. Lifestyle management and self-monitoring technologies

The increased availability of wearable and unobtrusive sensing devices, either based on specialized systems or on widely available mobile devices such as smart phones, has made it possible to create more sophisticated self-monitoring systems both for clinical and lifestyle scenarios. In this section we intend to take a look at some commercially available self-monitoring systems, the types of users they aim to support and how they usually work. We separate the existing systems on two major health categories: physical and mental health.

2.1.1. Physical health

2.1.1.1. Movement (physical activity, fall detection, energy expenditure)

Systems that measure movement can have both medical and lifestyle applications. GPS and 3-axis accelerometers integrated into wristwatches, pedometers, pendants and smartphones are used both for measuring how much and how fast a person moves and for detecting falls. Some of the most popular fitness-related devices are produced by Garmin, Polar and they usually include a heart monitor that allows for keeping track of the effort level. Products such as WristCare (from Vivago) [11] and SenseWear BMS [12] allow for creating movement activity profiles for a certain user and then detecting and signalling abnormal patterns. The WristCare also integrates skin temperature and

[3] More information on studies using such systems (including benefits) can be found in [38], a report published by the Department of Health in UK in 2005-2006.

skin conductivity sensors and it uses a few initial days to learn what is “normal” for the user and send alarms when the values change.

For more assistive scenarios, fall detection systems such as Philips’ LifeLine [13] and Wellcore Emergency Response System [14] allow for monitoring as well as alerting in emergency situations. Usually, such solutions include various options to determine who and how to alert in emergencies. These systems mainly work only in home scenarios, as they connect through the main phone lines.

As phone applications become more and more popular and smartphones now include sensors such as GPS and accelerometer, various applications for fitness as well as assistance have started to appear (e.g., iFall for Android [15], Sports Tracker for Symbian [16], or Nike+iPod [17]).

2.1.1.2. Heart rate/blood pressure monitoring

Given that heart-related conditions top the list of chronic diseases a large selection of systems exist for recording and monitoring of such data. Data usually recorded is blood pressure, heart rate, pulse, heart rate variability and ECG. The data recording can be done at certain times or continuously, by using heart monitoring devices, most of them provided through hospitals or primary healthcare providers.

Examples of heart monitoring systems are: t+ blood pressure (OBS Medical) [18], Medixine’s Chronic Disease Clinic [20], HealthBuddy (from Bosch Healthcare) [19], and CardioNet solutions. For most of the existing solutions data is stored on a remote server and analyzed by nurses, doctors, clinicians, etc. Patients might be able to add certain notes, symptoms, and so on, and receive certain feedback from medical staff.

Certain sensing devices such as the Alive Heart and Activity Monitor [22] also provide finer granularity data through ECG recording and it can be connected to other recording devices (e.g., mobile phones) through Bluetooth.

2.1.1.3. Food/calories intake/weight management

Solutions for recording food and calories intake can range from manual to fully automated. In the manual mode, the user has to record what she ate during the day and how many calories it contained.

There are now multiple applications for iPod/iPhones and Android phones that can help people keep track of what they eat (e.g., CalorieCounter for iPhones).

The HealthBuddy system [19] provides a middle solution where the user is prompted to use a compatible scale that can send information to the hub through Bluetooth. The device also includes an interactive and supportive questionnaire that helps users record more information about their eating patterns.

More automated solutions can be built based on reading RFID tags attached to food items or based on scanning barcodes and determining their caloric value using web services.

2.1.1.4. Diabetes support

In such systems patients usually record blood glucose measurements, timestamps as well as information related to administering insulin. In most of the systems, the patient manually performs the measurement, recording and insulin delivery. Some of these solutions are Medixine’s Chronic Disease Clinic [20], t+ diabetes from OBS

Medical [18] and HealthBuddy [19] that provide support in various ways and combine recording with visualizing and medical support.

However, new systems have recently appeared where certain or all steps of the process have been automated. For example, the MiniMed from Medtronic [23] can use under skin sensors for automated and continuous glucose monitoring and an automated insulin pump. Less invasively, the Calisto GlucoBand [24] wristwatch can use bio-electromagnetic resonance to measure and monitor blood glucose levels.

2.1.2. Asthma and COPD (Chronic Obstructive Pulmonary Disease)

While some symptoms might be similar, asthma is more common in patients under 35 years old while COPD is mainly induced by smoking and environmental pollutants and is more common in patients over 35. As both asthma and COPD involve problems with the air flow, the main parameter monitored by systems addressing them is the peak flow information. Other parameters monitored for COPD patients are the forced expiatory volume in one second (FEV) and the blood oxygenation levels (SpO2). Usually, these parameters can be manually recorded by the patients in an electronic diary, together with certain observed symptoms. Data is stored on a server where medical staff can examine it and give feedback to the patient (e.g., t+ asthma and t+ COPD solutions from OBS Medical [18]). An interesting system is Medixine’s Health Forecasting [25] focused mainly on preventing weather related crisis, by sending alerts based on weather forecast, as there are observed correlations between certain weather conditions and an increase of asthma and COPD-related hospital admissions.

2.2. Mental health

Even though mental health is extremely important and a large number of people will suffer from a diagnosable mental condition at some point in life [39], the area remains poorly addressed by self-monitoring technological systems. Systems such as HealthBuddy [19] provide a certain support for depression patients, by using an interactive questionnaire and prompting for a periodic recording of blood pressure. Most of the self-monitoring methods for depression focus on keeping manual mood diaries.

2.2.1. Memory support

Various systems exist for helping patients with memory problems keep track of their medication. Most of the systems allow patients or their carers to pre-program alarms for times when certain pills should be taken. Some of them also store pills and include sensors that record when the pillbox was opened, such as the Daily Alarmed PillBox from PivoTell [30]. Some systems can even communicate with a mobile phone if the pillbox has not been opened at the scheduled time, such as the SIMpill [31].

Various research projects have also used camera-based systems, such as SenseCam, for supporting patients with more advanced memory problems [42].

2.2.2. Relaxation systems

Stress is part of our lives and various methods exist to address it, most of them based on relaxation techniques. Biofeedback systems offer technological support for such processes. The systems we looked at employ various sensors and methods. The main sensors used are for measuring GSR (skin conductivity), heart rate, heart rate variability, and EEG (electrical brain activity).

Various visualizations and interaction methods are employed to allow for controlling the measured parameters. For example, certain systems use game-based interfaces allowing users to control functionalities in the games through controlling their physiological parameters (e.g., Journey to Wild Divine [32] and products from SmartBrain Technologies [33]). Other systems use sounds, lights or charts for allowing users to become aware of their stress levels as well as enable their control (e.g., GSR2 Biofeedback Relaxation System [34], StressEraser [35], Resperate [36], emWave PSR [37]).

2.3. Trends in lifestyle management

Many of the existing health monitoring system providers chose to create integrated health hub devices that allow for recording more than one parameter and even include small screens that can be used for various types of communicating with a patient. Most of the health hubs available combine two or more of the physiological parameters mentioned above. For example, the HealthBuddy [19] can integrate data received from various compatibles devices such as digital scales, blood pressure monitors, digital blood glucose level readers, etc., and it has a display used for asking questions, prompting for values or tasks, giving encouragements and advices.

Similar systems are provided by Viterion Telehealthcare (Viterion 100, Viterion 200) [26] and TeleMedCare, whose TMC Home [27] collects information from various devices as well as using questionnaires to gather more information from users. Its health hub also has video capabilities to facilitate communication between the patient and the monitoring medical staff. Tunstall Lifeline provides various solutions for telecare/telehealth addressing conditions such as COPD, CHF (Chronic Heart Failure), CDM (Chronic Disease Management), diabetes and coagulation issues, by allowing it to integrate multiple sensors with their hub [28].

Sensor vests are another type of integrated systems. Vivometrics and Xenetec were producing such systems but they seem to have disappeared, so it is not clear how popular such systems proved to be.

As seen, most of the available solutions focus on recording and monitoring physiological parameters. The market is extremely segmented and based on proprietary devices and formats. There is however a certain drive to create interoperable solutions, such as the Continua Health Alliance [41]. In most cases user data is sent to remote servers to be stored and analyzed by nurses or clinicians. These self-monitoring systems are mainly targeted at patients with existing health conditions and focus mainly on prevention of worsening conditions or detecting emergency situations. Systems are mainly provided by hospitals.

Mobile phones are some of the most pervasive computing devices and they can now be used for collecting, interpreting, visualizing as well as remotely sending and accessing information. More and more mobile-based applications appear everyday allowing people to keep track of various lifestyle-related aspects: heart rate, exercising, blood glucose levels, etc. It is now possible to also integrate various sensors with mobile phones, such as the Alive Heart and Activity Monitor [22] or the Nike+iPod. Companies such as MobiHealth [29] even provide whole solutions around mobile phones that can measure multi-lead ECG and EMG, plethysmogram, pulse rate, oxygen saturation, respiration and core/skin temperature through an Android phone.

Within the research community there have been multiple projects focused on developing wearable and integrated self monitoring systems or platforms for distributed wellness data collection , some of them being described in [61] [62][44].

However, looking at available lifestyle management systems, there seem to be very few systems that support users in understanding why something happened. Correlations between physiological data recorded and events that might have triggered certain changes are mostly based on recollections, subjective and prone to various memory errors. In most cases, patients can monitor certain physiological data but have no idea what context the data was collected in and what might have affected their wellbeing.

We believe that the number of self monitoring systems used and owned by individuals will continue to grow, driven by an increased availability of sensors and sensor-based applications as well as by the higher degree of acceptance towards digitally recording life experiences that can be observed in younger generations [40].

3. Towards an integrated lifestyle management system

3.1. Our approach

We believe that a lifestyle management system should be able to create a holistic, if not comprehensive picture, of a user's daily experiences. As we showed in the previous section there are currently multiple systems that address various aspects of users' health. However, what we believe is missing, is a system that helps users better understand what the relation is between the monitored parameters and what is going on in their lives.

Through our work we seek to go beyond just recording certain physiological parameters and create lifestyle management systems that better support people in understanding of *what* happened and *why* it happened. For creating such a system we build on existing sensing solutions and focus on collecting data that we generate through our everyday use of computing devices. Data we produce while using computers at home, at work or on the go is important because it creates a picture about what we like, what we do, who we interact with and where we go. In our work we focus on all aspects of creating such system, from information gathering to information visualization. One of the most important aspects of our work is to design fun and interactive interfaces that allow users to become part of the process of collecting, creating, and interpreting information so that reflective processes can be properly supported, much aligned with Shneiderman's view [56]. We also build on existing studies that show relations between what we do during the day and our wellbeing, such as [9], studies showing that people *do* like to think back and reflect on what happened and why they feel a certain way, such as [57][53] and studies showing that future generations of adults will probably be more open to monitor and record their lives [40]. We aim for creating a piece of *calm technology* [52], where *periphery*-based recordings of user context can be brought together into a supportive and engaging *center*-based interface.

Though the current trend seems to be that more and more "cloud" services collect user-related information either for adapting functionalities or delivering customized information, our aim is to design and build systems that can make use of our information but also allow us to control what, where and why such information is stored, as well be aware of what it is used for.

Even though we consider collecting more user information, we are not making the case for a Big Brother type of society. Our approach is more about empowering end users rather than giving the power to collect and correlate our data to “cloud” entities. Our goal is to support individuals in understanding the influence daily activities have over their health. For this, we set out to collect, interpret, correlate and visualize information that can make people aware of their health, where health is seen as a complex picture that includes physical, mental, emotional and social aspects.

3.2. Main scenario

To better exemplify what types of systems and interactions we envision we present here a user scenario.

Mary is 53 and she has developed a heart problem. She can still live her life normally but her doctor advised her to take it slow and pay more attention to her lifestyle. To make it easier, Mary is using the MyRoR system, which can record various activity data from her personal devices and correlate all information into a daily story view, so that she can see how certain activities performed during the day impact her physiological state, especially her heart condition. The system helps her remember what happened during the day and allows her to record her own thoughts regarding the events as well as her reactions. For example, the other evening Mary tried to figure out why she felt unusually tired. By using the MyRoR system, she could see that she had lots of meetings and skipped lunch. One meeting was especially demanding, as her colleague George kept interrupting her presentation, as usual, which annoyed her. The system not only helps her to better understand her own behavior, but also allows her to access some of the information when she talks to her doctor so together they could identify potential risk factors.

3.3. System requirements

Though we include discussions on choices regarding our system design and implementation throughout the article, we summarize here the main requirements guiding our overall system work:

1. Minimize the amount of sensors a user has to wear;
2. Tap into available information that can be used to describe multiple relevant aspects of user’s daily activities;
3. Build upon existing monitoring systems by integrating and correlating their data: There are now multiple systems available addressing various aspects. It is unrealistic to think that they will go away so a better approach is to make it possible to incorporate their data. This might not always be possible, as one way to differentiate is to create proprietary formats, but it seems to be that most of these systems can export data in certain widely used formats, such as XML. Certain ongoing efforts towards interoperability between medical devices such as Continua Health Alliance [41], give us some hope that in the future integrating various monitoring devices might get easier;
4. Work based on realistic scenarios, where monitoring systems cannot provide a comprehensive picture of users’ lives. It would be impossible and probably also very intrusive to try to record all our daily activities, so it is better to assume that self –monitoring systems will have to function based on incomplete information;

5. Reasoning engines should not replace users and medical professionals. Even though self-diagnosis through Internet search seems to become more and more popular [10], it is not something that we aim for at least not to the extent that it replaces human interactions. We should allow people to become part of the information gathering and interpretation. Such system should support users in understanding not present them with ready-made conclusions;
6. Create better interfaces and interaction paradigms. This is one of the biggest challenges, as the more and diverse information we add to the system the harder it becomes to visualize it in a comprehensive way. Current systems do not posses appropriate visualization means, as they mainly focus on time-based charts or map-based representations. So, how do we make these systems more comprehensive, interactive and engaging?

3.4. MyRoR system design

We will further discuss certain aspects of such system along three main information lifecycle: gathering, processing and visualization. Figure 1 presents a multi-agent view of our system along such components.

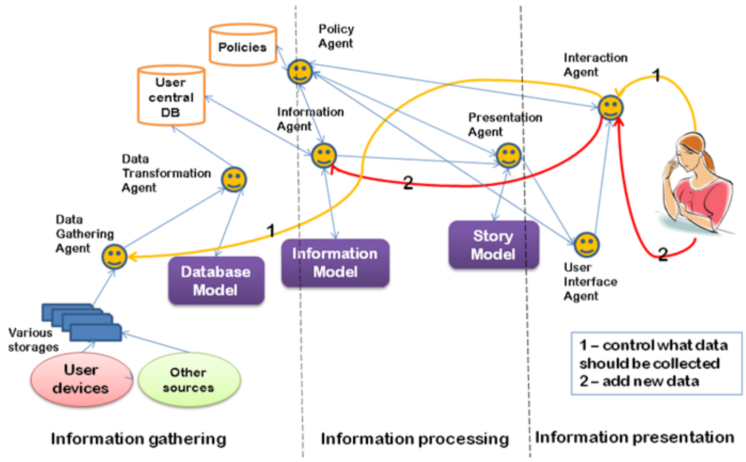

Figure 1 Multi agent system view

The *Data Gathering Agent* is responsible for collecting data from various input sources. Such sources can include various devices used by the user during the day (e.g., work machine, home machine, mobile phone, etc.) as well as external content servers providing user-related data, such as emails and calendar events. The data collection can be done both asynchronously and in real time, according to the intended scenario. We have so far mainly focused on the asynchronous mode, as we are more interested in providing support for user reflective behaviors. Throughout this chapter we will consider this type of information gathering.

The *Data Transformation Agent* performs various operations on input data available in differing formats and in multiple local storages, such as: data conversion (e.g., from bytes to values), data clustering, filtering, storing into a user database, including its optimization (for time and space), and Database Model management. The *Database Model* contains information about the database structure and governs the storage operations. Unlike many existing lifestyle management systems described above that collect and send data to remote servers, we focus on creating a user-controlled information storage that better addresses privacy concerns as well as fit the single user centric view of the current system. Ongoing work in the PAL project[4] looks into implementing various levels of access to such storage, depending on the situation and scope.

Data collected into the central database it is processed by the *Information Agent* through various specialized modules. Various types of information processing take place, such as *filtering* in order to discard useless or faulty information, and *interpretation* of existing information, *aggregation* of two or more types of data in order to create higher-level concepts, as well as *correlation* of two or more types of data according to certain interesting features derived through data analysis. The initial data, the newly created information and the rules for information transformation are contained in the *Information Model*.

As discussed before, capturing such a diverse and large amount of information allows for creating a better picture of what has happened and why but also brings in big challenges in term of presenting such information to the user. For various reasons discussed later, we have decided to use a combination of story-based and advanced chart-based visualizations for conveying recorded information to the user. The *Presentation Agent* has the role of assembling information into a story format, according to the *Story Model*.

The *User Interface Agent* is responsible for creating various information visualizations. Since the system is envisioned as being highly interactive, the *User Interface Agent* and *Interaction Agent* need to work together in order to: (1) allow the user to see and manage what is being collected; (2) allow the user to query for specific information; (3) allow the user to add new information as either annotations to existing data or new data altogether; (4) allow the user to customize the user interface to better reflect their personality; (5) take into account certain device capabilities, especially for scenarios that involve remote access to the system.

It is important to note that Figure 1 includes a larger scope than currently addressed in our implementation, as it also reflects work on policy based information transactions currently done in the PAL project [43]. The *Policy Agent* is responsible for managing policies related to information usage, as well as various user preferences, and will become increasingly important once other information usages involving external parties are added to the system.

3.5. System implementation

In this section we describe the current implementation of our MyRoR system along the main information areas mentioned before.

3.5.1. Information gathering

The decisions we made regarding the information collected and sources used were governed by the requirements described in Section 3.3. Some of the most important criteria were that: (1) collected information can provide useful support for self-

[4] PAL (http://www.palproject.org.uk) is a research project funded by UK's TSB and EPSRC under the project number TP/AN072C.

understanding and reflective behaviours; (2) system can deal with both static and mobile scenarios spanning various spaces and situations; (3) system should include commonly used user devices such as PCs, laptops and mobile phones; (4) system should include commercially available sensing devices; (5) number of sensors should be limited both because of the amount of processing they require as well as to prevent creating systems that are too obtrusive or require too much time and effort to attach.

Figure 2 shows what input sources we have now and what information we are able to collect. The system can collect information from both physical (raw data) and logical sensors (interpreted data).

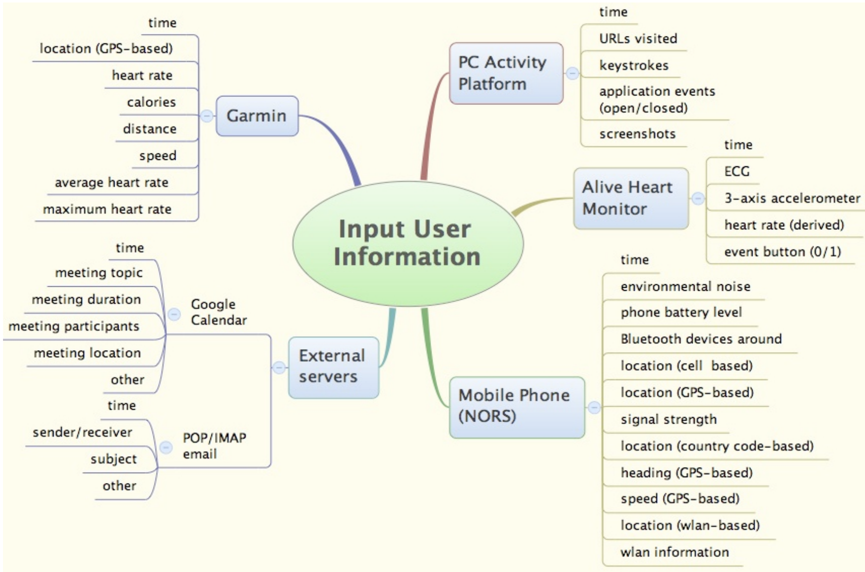

Figure 2 Input sources and data collected

Here are more details about the main sources we are using:

- Garmin ForeRunner 305 is a popular wristwatch-like device used for fitness-related monitoring. The device is capable of providing heart rate and GPS-related information, raw as well as interpreted (e.g., distance, speed, etc.). A chest belt monitor provides heart rate information. Data is collected and stored on the device in Garmin's own file format, TCX, an XML-based format using a specific Garmin XML Schema. The files are currently stored onto the user's machine over a USB interface. More recent versions of such devices are able to synchronize data with a computer automatically;
- Mobile phone (Symbian-based mainly such as Nokia N97 or Samsung Omnia HD) running NORS platform [44], a mobile Java-based sensing platform that implements various sensor handlers allowing data collection of phone data as well as from attached BT-enabled sensors. The NORS platform collects data in its own file format. The file can be stored on a PC either through Bluetooth or over GPRS;
- The Alive Heart and Activity Monitor is a small wearable sensing device developed by Alive Technologies [22]. The device can measure ECG through 2

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skin electrodes, and 3 axis accelerometer data. It also provides an event button that can be used by a user for various purposes, such as annotating certain interesting moments, making it easier for the system to find meaningful events. The data is recorded on an internal SD card. It can also be collected via Bluetooth through the NORS platform on the mobile phone and also directly recorded on a desktop through BT (e.g., for stationary scenarios when the user is at the computer);

- A PC activity platform that provides various types of information related to user’s activity context. Currently, the platform is Windows-based mainly for the sake of experimenting, but this is not to be considered a limitation of the system. We tested multiple existing activity platforms and decided to use the ActualSpy (http://www.actualspy.com/) platform, because it can record data on the local machine in open formats, and it allows for user awareness. The platform provides URLs visited (useful to determine web as well as search activity), applications used and associated events (i.e., application started, run, and closed), user name (helpful to differentiate between multiple users), keystrokes (can be used to search for certain keywords in order to determine interest as well as counted for activity intensity), as well as screenshots (timer-based images that can be used to create a comprehensive picture of currently used applications);
- External servers are used to provide more social activity information, such as emails sent and received and calendar information. We currently have modules that collect emails from POP3 and IMAP servers as well as obtain information from a user’s Google Calendar (assuming the person uses such calendar, of course). These modules can obtain information on-demand and such information is not necessarily stored in the database but used in understanding a user’s social context as well as activities and interest. Information obtained from such servers can be filtered based on time ranges and keywords. Currently, by using an Android phone, we are also able to add call and sms activity information to the Google calendar.

Figure 3 shows a platform view of the information collection process. *The Data Collection Platform* component comprises of various modules gathering data from multiple distributed sources, over various technologies (e.g., Bluetooth-BT, USB, IP) and storing it into distributed data storages.

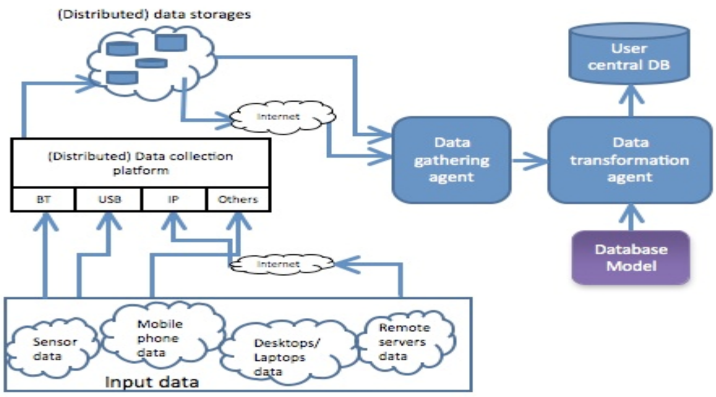


Figure 3 Data collection platform

The input data can be stored onto sensing devices, sensing gateways (such as phones), personal computers or remote servers. The Data Gathering Agent needs to know where the input data resides, collect it and pass it to the Data Transformation Agent for processing and storing into the central user database. We discuss some of the issues we have encountered in building this platform in Section 4.

3.5.2. Information processing

The Information Model captures both raw and processed information as well as relationships between them (i.e., how processed information has been obtained). A representation of the main objects included in the model is shown in Figure 4.

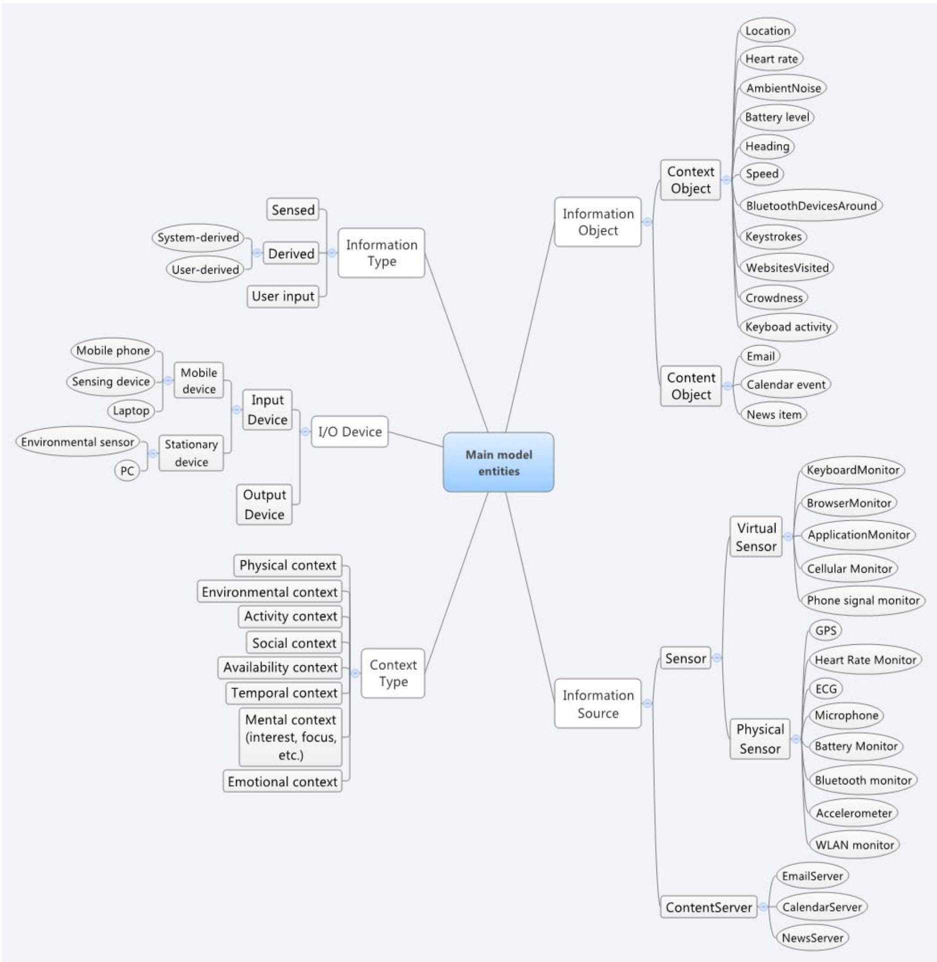


Figure 4 Main entities in the Information Model

The mind map model presented in Figure 4 is used to create the semantic model and the relationships between the entities.

An important phase in the modeling process is to identify which features should be extracted from the available information. Figure 5 shows what information can be derived based on available initial data and how initial and derived information are combined to create the various types of user context [55].

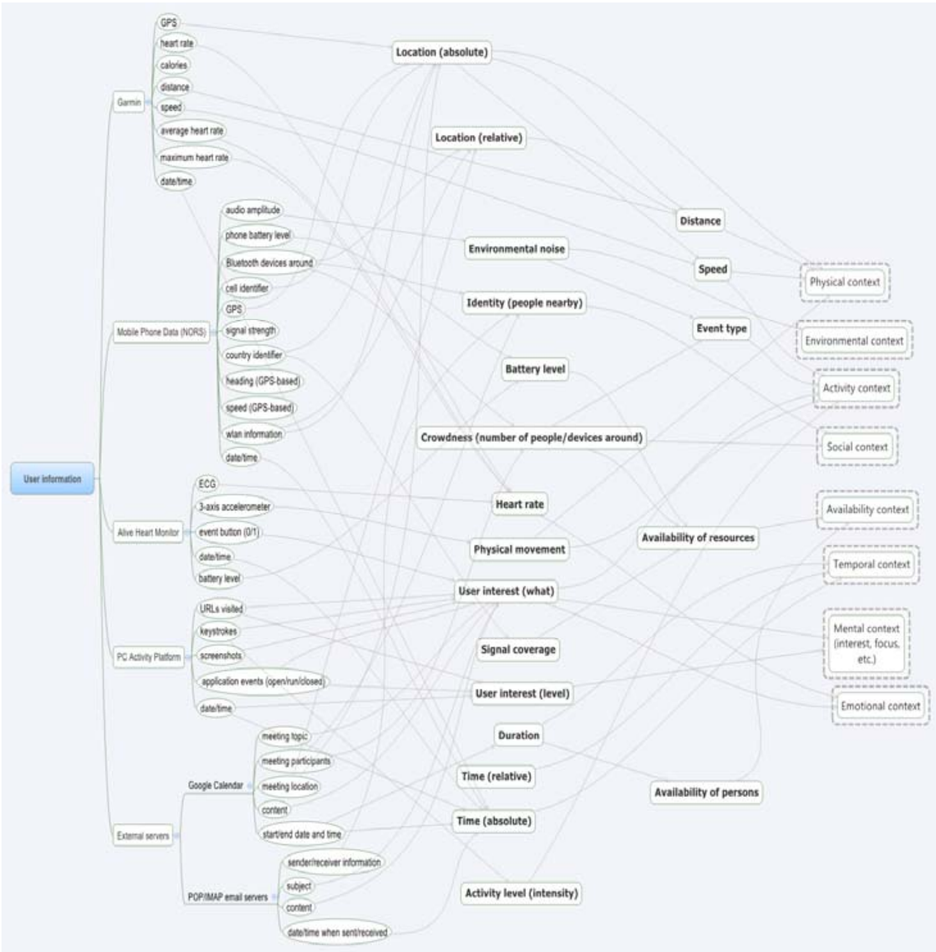


Figure 5 Information processing

The contexts we consider are:

- *Physical context*: location information (absolute, relative and at various granularity levels) obtained from various types of sensors – e.g., GPS, cell information, country code, wifi, meeting location, BT vicinity, as well as derived information such as distance, speed or heading.
- *Social context:* information about user's social, both based on physical and virtual sense, obtained from sensors (e.g., BT devices) or social communication tools such as emails, calendar, and chat programs.
- *Emotional context*: information about user's emotional state obtained from physiological sensors, such as ECG and heart rate, and through virtual sensors, such as keyword-based filtering of registered keystrokes, email content, etc.

- *Mental context*: information about user's interest both as topic and as intensity level, derived through web activity, applications used, keyword-based filtering of keystrokes, emails and screenshots.
- *Activity context:* information about what was the user doing derived from physical sensors, such as accelerometer data and GPS, as well as from applications used, web activity, screenshots and calendar information.
- *Availability context* : information regarding availability of people or devices
    - the availability of devices is determined through Bluetooth vicinity, battery level, signal coverage (if device is a mobile phone);
    - the availability of people can be determined through identifying people around, through checking calendar information. Furthermore, other types of context information (e.g., mental, activity) can be used for determining if a person should be interrupted or not.
- *Environmental context*: information about environment parameters that can have affect users, such as noise, temperature or lighting.

An appropriate balance has to be found between having too much abstraction and allowing transparency. Allowing end user access to certain unprocessed or lightly processed data can also generate abstractions that a system designer might not have considered or could not even consider due to incomplete information. For example, in our initial scenario, the system can realize that Mary's heart rate increased, her voice pitch raised and deduct that she was getting angry. However, Mary's status could also be a reaction to an increase in room temperature or to being in a crowded environment rather than anger. Her emotional state might also be influenced by other hidden parameters, current or historical, such as previous experiences related to people present, etc. In such situations it is better to show the user through the interface that something unusual happened at a certain moment during the day (e.g., based on her heart rate and voice pitch changes) and let her deduct what exactly happened and why, by allowing access to other collected information (e.g., who else was there, what else happened around the same time, etc.). With all the advances in emotion recognition, it is still hard to determine with certitude what the user feels, especially when considering real world settings (as opposed to controlled research laboratory experiments), as described by Picard et al. in [45].

3.5.3. Information presentation and usage

Our exploration of interactive information systems and natural ways of presenting life experiences led us to *stories* as a means of relating information to humans. Stories offer a way of organizing information as collections of meaningful events brought together either by following a timeline or a certain topic or character, as described by Brooks in [47]. Related work in this space has mainly focused on computer assisted storytelling [58] or on creating stories based on image annotations [48]. An inspiration for our work on creating fun and interactive environments based on collected context data is the Affective Diary project [57], where the focus was on creating better visualizations for self-monitoring systems.

In our system, we explore this type of story-based information presentation from simple to more complex structures enabled by a modeling process that takes information from the *Information Model* and arranges it into a story-based representation, according to the *Story Model* (see Figure 6).

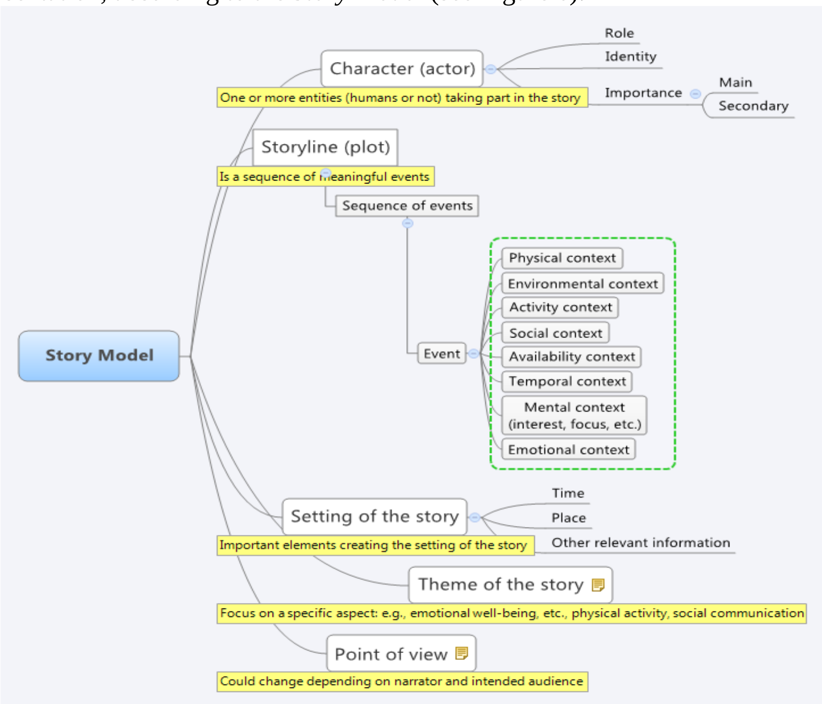


Figure 6 Story model

The main elements of a story, as described in Figure 6 are:

- Characters or actors: the entities that take part in the story, being them humans or other living beings. The characters have various roles and are connected by certain relationships.
- Storyline: this is the plot of the story and it is formed by a sequence of meaningful events. An event can be described in terms of the context types defined above and the "*meaningfulness*" of an event can be determined through observing certain changes in contexts.
- Setting of the story: includes important elements that create the setting of a story or of an event, such as time, place, weather, etc.
- Theme of the story: places a certain emphasis on one or more types of contexts. For example, it focuses the story more on physical movements or on emotional changes, etc.
- Point of view: it determines how the story should be told. For example, we are currently mainly considering the case when the system creates a story as a diary, where the main user (the one the data refers to) is also the

main consumer. However, in the future, we would also like to look at cases where the story can be customized by its main user to be shown to other people.

The story creation is done by the *Presentation Agent,* working together with the *Information Agent* in order to determine what events are *meaningful* as well as use recorded context information to fill in the other elements of the story. An example of a meaningful event is given in our scenario: Mary's meeting, her presentation and her increased heart rate. In this event, Mary is the main character with the other meeting participants being secondary characters. Through zoom-in functionalities, Mary has access to all information recorded during the meeting. She can also add her own annotations to the story (e.g., explain why she thinks she felt so stressed during the meeting). The annotations become part of the story and will be available to her when she reflects on the information in the future. This makes the story evolve in a subjective, human way, as feelings and explanations can change based on remembering things in a different way.

After considering multiple environments and libraries such as Alice, Scratch, Greenfoot [50], Prefuse, Piccolo and PHPGraphLib, we have decided to use Scratch [49] as well as Google Visualizations [51] to develop various ways of creating and representing stories.

Scratch is a Squeak-based environment (Figure 7) created as a way of making programming fun for kids. It has been developed by the Lifelong Kindergarten group at MIT Media Lab.

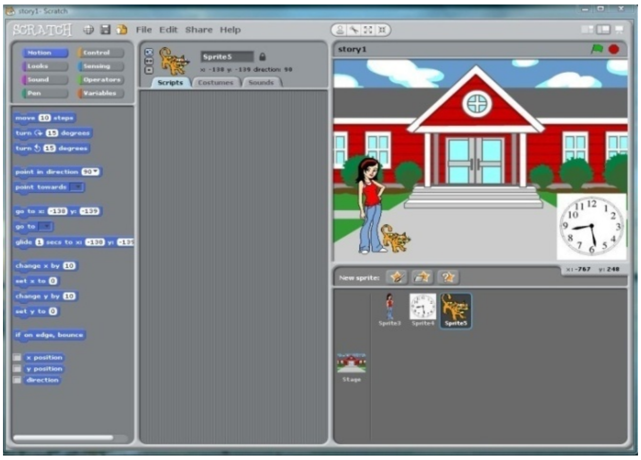


Figure 7. Scratch environment

The reason we have eventually decided to use Scratch is that it provides an easy way to create rich media stories, where images, colours, texts, sounds and animations can easily convey the multidimensional sense of change within a sequence of events.

The various types of context represented within an event (see Figure 6) can be visualized by using multiple types of media provided by such an environment (see Figure 8). Scratch allows users to add and customize images, record voice annotations, add audio, create movements, change appearance of characters (which can be used to convey a sense of mood and activity changing), and change backgrounds (can be used to show environmental and physical changes).

Time can also be conveyed in Scratch in various ways, such as using a sequence of clock images (see Figure 8) or by using an animated time line. Each character or object (called sprite) used in creating a Scratch story can be individually customized and controlled through parallel running scripts.

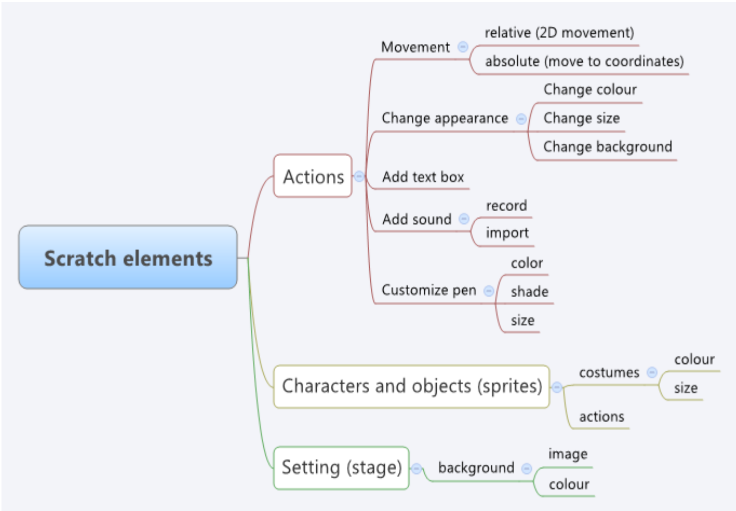


Figure 8. Main elements in Scratch

Our vision is to create a system that can offer both high-level, summarized view of information as well as allow access to more lower-level recorded data in order to increase user understanding. For this reason we have decided to use both stories and graphs. For creating more detailed visualizations are using Google Visualizations and correlated two or more types of data. The visualizations are embedded into a diary-like interface built within a WordPress environment one of the most commonly used blogging platforms [63]. The next section presents in more detail how collected data is interpreted and visualized as part of a user experiment.

4. Case study

4.1. Experiment

To better exemplify the type of system we envision and the challenges we have encountered, we present here a user experiment that collected various types of user information over a few hours. In this scenario, the user is a PhD student having a board meeting and the experiment follows the user through the hours before the meeting, during the meeting and after the meeting. The table below shows what kind of data the system recorded during the experiment. During the experiment the user moved from home to university, around the campus, in the meeting room and then back home.

Input source	**Input data**
Alive monitor	ECG, 3 axis accelerometer, event button
Phone (with NORS)	Audio amplitude, Bluetooth devices around, GPS, cell ID, battery information
PC activity platform	Web activity, applications used, keystrokes

4.2. Visualizations

All the visualizations created based on the collected data are accessible via a Wordpress-based system, in order to create an environment that is familiar, portable and based on available and commonly used technologies. The Wordpress interface integrates with our MySQL user backend database and we have created various PHP and Javascript programs that access, interpret and visualize collected data.

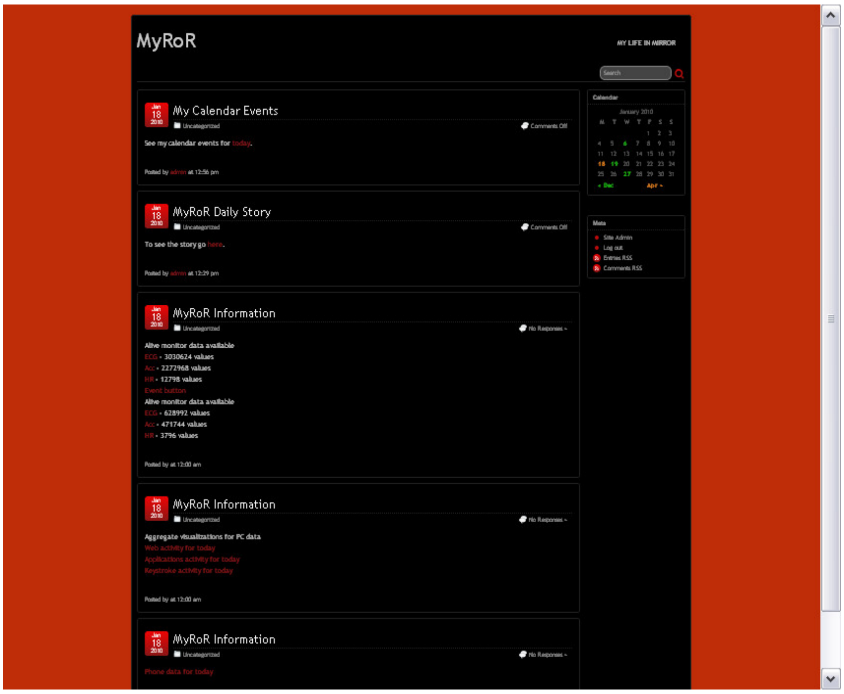


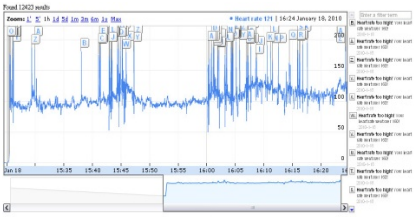
Figure 7 User interface to MyRoR system

A widget PHP script runs to check if new data is available in the database. If data is available for a certain day then the script creates posts that allow the user to access the data by using various visualizations of the data (raw and interpreted), including the story created based on the data.

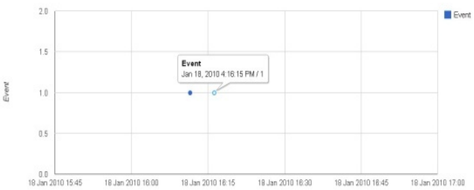
4.2.1. Detailed visualizations

In the current version of the system interface, individual posts are created for each source (see Figure 9), as we are currently using this version to organize and have access to collected data as well as test various visualizations and interpretations. Future versions might have a different interface.

In Figure 10 we have included various visualizations for data such as heart rate, noise levels, number and name of BT devices around, GPS coordinates, even button, keystrokes, application and web activity. In some of the visualizations, we were able to correlate certain data, such as GPS and time, number of BT devices, time and BT names, and heart rate and annotations based on certain conditions by using the AnnotatedTimeLine API and the MAP API offered by the Google Visualizations. More detailed information can be obtained by using the table representations (Figure 10.f), where full detail of captured data is available (i.e., time of collection, URL and window caption). Summarized visualizations, focused on giving an overall picture of words, are created by using word cloud API (h and g). Such summarized visualizations give a clear indication of what the user’s focus was during the recording period.

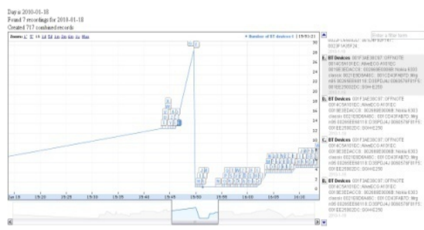


a) Heart rate with annotations

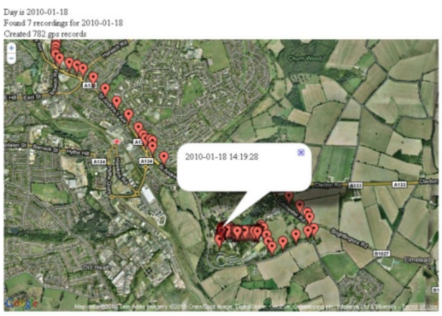


b) Event button with annotated time

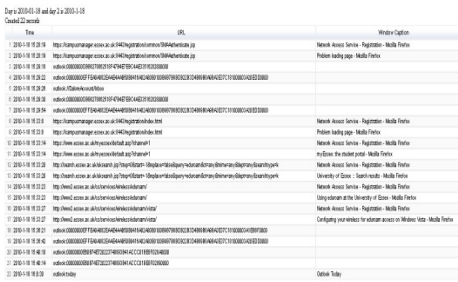
c) Audio amplitude – noise level



d) BT devices (number and names)



e) GPS with time annotation



f) Web activity - detailed

h) Applications used – word cloud

g) Keys and application context – word cloud

Figure 8. Various visualizations

While such visualizations can give a very good picture of various aspects of user's context at the time of the recording, it is very hard to combine them all into a summarized format based on graphs or maps. That is the main reason why we believe that stories are the appropriate format to create compressed and user-friendly interfaces.

4.2.2. Building the story

For creating the story, we have used BYOB (http://byob.berkeley.edu/), which implements certain extensions to Scratch while keeping the same main interface and concepts. The main reason we use this environment is that it allows lists of lists. Lists are collections of elements, much like arrays. You can see in Figure 11 how this feature is used.

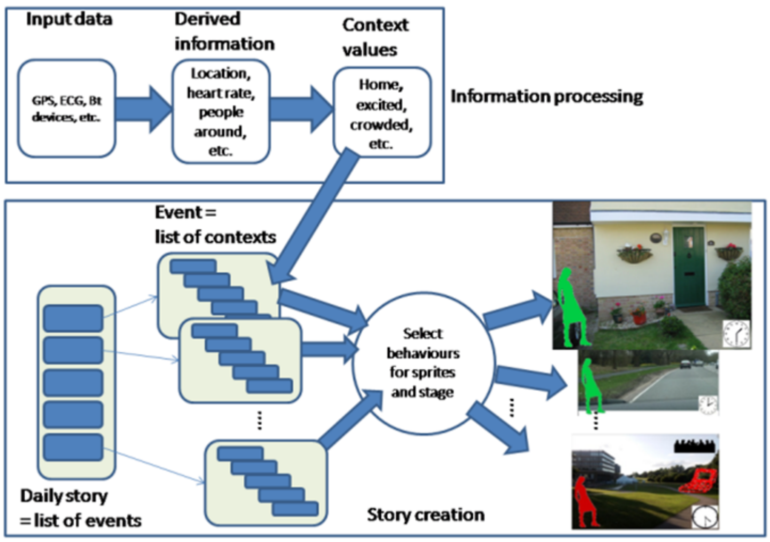


Figure 9Story creation process

The collected information is used to create derived information and create values for the contexts described above. The context values are then written in files that correspond to the list of lists structure described in Figure 11. The daily story we create is a list of events, where each event is defined by the various aspects of context and each context has one or more values. The values given to contexts are used to create the graphical representation of each event by using features offered by the Scratch environment.

The story is created through running various parallel scripts that test for keywords (i.e., context values) and then determine the behaviours of the various sprites selected to make up the story and the selection of the background.

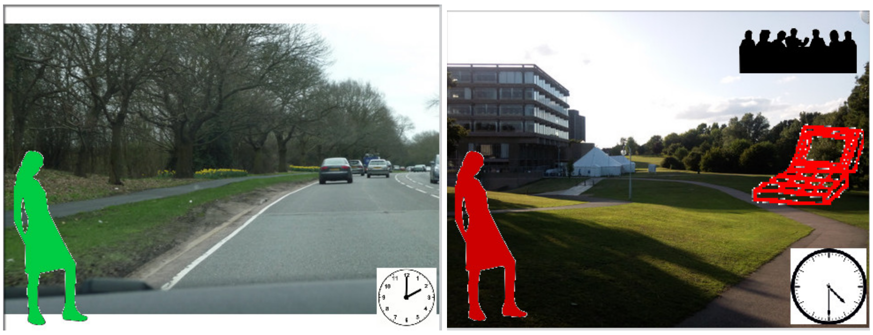


Figure 10 Two screenshots for two events: driving and having a meeting at the university.

The user has a lot of freedom to decide what colours, sprites, and backgrounds to choose. For example, in our story the Home location is shown as a background of user’s house (Figure 11) and the university location with a picture of the campus (Figure 12). Driving is shown by changing the background (Figure 12) though it can also be shown by using a car as a sprite. Current time is shown through various clocks. The meeting is shown through a sprite (Figure 12). The user has the option to select an own sprite as her avatar and she can customize its colour to reflect the emotional context: in this case the user decided to choose green for energetic (during driving and at home) and red for excited (during the PhD board). The appropriate sprite is then chosen based on the heart rate. Having such freedom to map emotional states to colours removes the ambiguity issues around personal interpretations of certain colours [57].

The blog interface allows us to group various types of visualizations and media together, so that the user has access both to higher-level representations, such as stories, and to more detailed one, such as graphs, tables, maps and word clouds. Another major advantage is that users can add their own notes and thoughts, which could be reflections based on visualizations as well as usual blog entries. Using the calendar as an entry point follows our thinking of creating daily stories and makes it easy to show which days have available data, as based on our experience, the data collection happens quite sparsely and it is usually motivated by the expectation that something a bit more unusual will happen during that day.

The blog can also be accessed from mobile devices (e.g., by using Wordpress apps on Android and iPod/iPhone), which makes it easy to access notes and visualizations as well as add new ones while on the go. More importantly, the whole environment can run within user’s own environment. We are currently using XAMPP which provides an Apache server and a MySQL database running on user’s machine and also allows external exposure for cases for remote access to the whole environment.

4.3. Lessons learned

In building our data collection platform we came across various issues, some of them quite expected and often encountered when building life loggers. We present here some of our preliminary results. Further experiments will be performed in the near future.

One of the main ones is related to *data size*. Some of the data collected, especially from ECG and accelerometer, generate a large amount of information, as they are sampled very often (300 samples/second for ECG and 75 samples/second for accelerometer). In order to avoid huge database sizes, we decided to create binary file repositories for ECG and accelerometer data and only store pointers to these files into the database. Hence, raw data is still preserved for further processing (e.g., heart rate determination based on ECG or activity context based on accelerometer data) but database size is substantially reduced. Writing to the database is a very time-consuming operation, especially for data sampled quite frequently. Hence, we use buffered writing operations in order to improve the data storing performance. Data size is also an issue for creating visualizations as the Google Visualization we used (Annotated Time Line) and other libraries seem to have problems representing such an amount of values so we had to vary the sampling steps depending on how many values were to be displayed.

Another important issue is the existence of various formats and synching methods used by our data sources, which requires a considerable effort when building the data gathering modules. Certain standardization efforts [41] should improve the situation but it still remains a major issue when building such a system.

In terms of battery life, the Alive monitor can record for a few days of intermittent operation but phones do not last more than a day, especially when GPS recording is involved.

Because of using multiple devices we found time correlation very challenging, as their clocks can differ from seconds or minutes (mainly due to imprecise clock operation) to hours (when time zone changes). Some devices can use time zones and others cannot. For example, the Alive Monitor cannot have any time zone set. Because of such issues, special care needs to be taken in correlating gathered data and certain assumptions need to be mad (e.g., the Alive monitor timezone is always GMT+0).

We have discussed before the challenges to visualize such diverse information by using currently available means. This is due to sampling differences (as data is not usually sampled at the same intervals) but also format issues, as number data fits in various ranges and string data is hard to represent.

In our data collection experiments, we have been focusing on a single user recording data in various situations such as at home, at work, or on the go. Our preliminary findings show that: (1) it is unrealistic to assume that people would wear or even remember to switch on devices all the time (e.g., Garmin requires an explicit Start/Stop action); (2) the incentive of using such system depends on how eventful the day is expected to be; (3) attaching wearable electronics such as a heart monitor belt is still not comfortable enough to allow for permanent data collection; (4) the accuracy of data highly depends on where and how the sensors are placed, a person's posture or movement.

5. Conclusions and future work

In this chapter we have focused on what we see as necessary improvements to existing lifestyle management self-monitoring systems in order to make them more informative and interactive. In the process, we have looked at various existing systems and we believe that what is missing in most such systems is a focus on supporting users reflect and understand *why* something has happened. For that, we need to not only focus on physiological and location data but also on other types of context data that can offer a better picture into what our activities and interests were at a certain point in time. In our system we have collected and correlated physiological and location data with various data we generate through our daily use of computing devices, data that creates a more complex picture of what our social, emotional, and mental activities were. The motivation behind this type of data collection comes from multiple studies showing links between what we do during the day, our lifestyles and our wellbeing and wellness.

We have also found that recording such varied data involves multiple challenges in terms of data collection, processing and visualization. Our exploration in more engaging and natural types of interfaces capable to correlate and summarize recorded user context brought us to story-based representations of data collected. For creating our vision of such stories we have made use of existing environments and technologies, allowing us to address important design criteria such as making use of various media, allowing the user to personalize stories the way they want, using familiar interfaces appropriate for a digital diary and allowing for both local and remote access of information stored within user's trusted environment.

When building our system we have considered various existing user studies and results with similar solutions and also tried to create something that *we* would use. Therefore, our initial user experiments were mainly designed to deal with the inherent issues introduced by building up the whole system, from data collection to data visualization. Future work includes further user experiments focused on various aspects, such as: (1) selection of further information that can better support self reflection and self understanding; (2) personalization of stories through various means: colours, audio, images, text; (3) using such system in specific health areas, such as bipolar disease; (4) introducing a persuasive dimension [54] into the stories.

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