Agent-Oriented Context Collection and Customised Service Delivery

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Abstract

A key issue in pervasive computing is the trade-off between personalised services (e.g. according to context) and volunteering information (i.e. the context itself) in order to secure those services. In this paper, we propose a novel agent-based architecture to facilitate collection of contextual information and the delivery of personalised services, where both collection and delivery processes are sensitive to the business model underpinning the application domain. We explicate this architecture through a 'virtual clipboard' scenario, in which relevant content is provided for the highlights of a museum visit. The content is delivered according to contextual information, which includes an estimation of each visitor's emotive state. This is computed from physiological sensor readings obtained during human-computer interactions. The architecture thus provides a platform to investigate the extent to which a user is prepared to reveal information and to forgo certain aspects of privacy in order to leverage the benefits of added-value services.

1 Introduction

The term *context* has been defined as information characterising the situation of a person, place, or object instrumental to interaction between a user and an application [5]. This definition applies to users, applications, devices and environments associated with specific interactions. *Context-aware systems* are applications, computers or devices having sensor-based access to context that enables them to adapt their behaviour accordingly [3,13]. While issues have been raised about operational aspects of such systems [6], potential advantages and usage have also been identified alongside the challenges [3, 5, 13]. In particular, collected context can be used to construct user-models for analytical and operational purposes. Factors affecting the *context collection* process include the amount, type and frequency of generated data. In addition, the physical properties of the system — such as sensor accuracy, processing power and underlying communications model — are significant. All these factors collectively determine the quality of an ongoing context collection process.

The process of *context analysis* begins once sufficient context is gathered. Identifying an ongoing user-system interaction as a *session*, we note that analysis can occur both *during* (dynamically) and *after* (off-line) a session. In the former case, the analysis can be used to refine the adaptive behaviour of the system [10] within a current session. In both off-line and dynamic cases, the quality of the context analysis process determines the accuracy of the inferences concerning the user.

The role of context analysis in the above processes can be equated to that of an *agent* — a semi-autonomous software entity acting on behalf of a user. The utilisation of context to positively adapt system responses can also be viewed as pro-active agent behaviour. In addition, adopting a business-oriented perspective permits the identification of promising agent-mediated e-commerce applications.

In this paper, we describe an agent-based, business-oriented approach to context-collection and dynamic analysis within a pervasive computing environment. We apply this approach to the collection of *affective* context in particular — context reflecting the emotional state of the user. We use these elements as the basis of an intelligent business infrastructure enabling a user who is prepared to reveal information and to forgo certain aspects of privacy and security to leverage the benefits of added-value services.

The rest of this paper is organised as follows. In Section 2, we present the *Virtual Clipboard*; a scenario identifying key motivations and requirements of our system architecture and its operation. In Section 3, we identify the main activities within the context collection process. In Section 4 we describe the *Affectiveware* framework behind the collection of affective user context. We look at one of these activities — *decision-making* — in more detail in Section 5. We describe the underlying business framework in Section 6. We comment upon related work in Section 7 and conclude with a summary and description of future work in Section 8.

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2 The Virtual Clipboard

Advanced multimedia services can be very useful in cultural settings like museums, festivals, historical monuments, archaeological sites, guided town visits or zoos. Visitors enjoy seeing the exhibited objects, but they are also keen on learning more about them and advanced multimedia services can provide just that. Visitors of a museum for instance can — when equipped with a mobile device — gain access to additional information that is stored digitally. Adaptive and context-aware services can improve the consumption experience significantly. The setting of a museum therefore provides a good business use case for the dynamic context collection and utilisation technologies we subsequently describe.

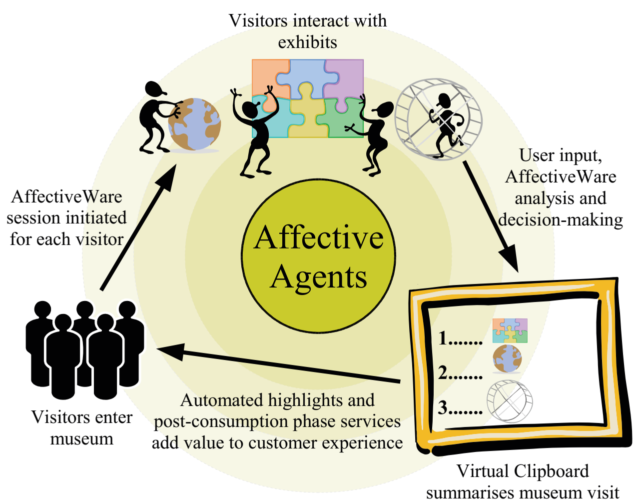

Figure 1. Virtual Clipboard scenario interactions

Our scenario (see Figure 1) connects the technological tools we present with the logic of the underlying business framework. Relevant content for the summary of a museum visit is automatically provided by the AffectiveWare-based (see Section 4) *passive virtual clipboard*. It uses collected context to present the customer's favourite interactions during the visit. It therefore provides added value during the visit and an integrated customer experience as it enables services during the post-consumption phase.

Zones and objects the customer liked most during the museum visit are determined based on the mood-analysis performed by the AffectiveWare platform spaces. They are collected in the virtual clipboard where the visitor has easy access to the highlights of the visit. In this way, a summary of the visit is provided and post-consumption services like personalized merchandise are facilitated. The virtual clipboard can also be used in an active mode. The tool then lets customers store content they see at one point so that they can access it later to get further background information on it, to make personalised merchandise with it or just to have it as a summary of the visit. Some customers will appreciate the active function of a virtual clipboard in order to make their visit more organized. They might have a professional background and are glad about the helpful tool. However, many customers do not have the time or do not bother to select their highlights themselves. They would, nevertheless, appreciate a summary of their visit afterwards. Either way, the gathered data in the virtual clipboard can be used to tailor meaningful content for the customer in the post-consumption phase. The virtual clipboard increases the utility of customers and also paves the way for specific post-consumption services that target topics or content that customers particularly liked or had interest in.

The collected data about what visitors enjoyed most can be used to offer personalised merchandise, such as a multimedia postcard that features favourite scenes of the respective customer. Moreover, the information obtained about the visitor's preferences can be used to guide customers to a post-consumption phase platform that offers additional services and also initiates recurrent consumption patterns.

Further information about topics that visitors enjoyed can be offered on the museum web site in online (e-learning) communities. These communities can be supervised and guided by experienced museum staff. Similarly, online communities can be maintained to let customers share their experiences during the visit with each other. New services can be introduced to them, as data collected through context-awareness can be used to offer customised community topics and customised new offers. Visitors can also be informed about upcoming events in the museum if these match with the interests of visitors. The online community on the web site can also be seen as a platform to collect purchases that were generated during the actual visit — for instance, the multimedia postcard that is picked up on the web site using a collection number. This way, customers are guided to the online community where the museum experience is potentially extended. Again, the online community areas can be visited actively/directly, but they can also be suggested based on context awareness data analysis.

We identify the enabling technology within the above scenario as *affective agents* (see Figure 1). Each participating visitor has an associated agent, running on a hand-held device such as a personal digital assistant (PDA) or tablet PC. The agent is responsible for primary context collection: both user-input and context are conveyed to the rest of the platform, typically through wireless communication. This data undergoes further processing, culminating in the delivery of context-aware services. An overview of the sequence of events surrounding context collection and adaptive service delivery is given in Figure 2.

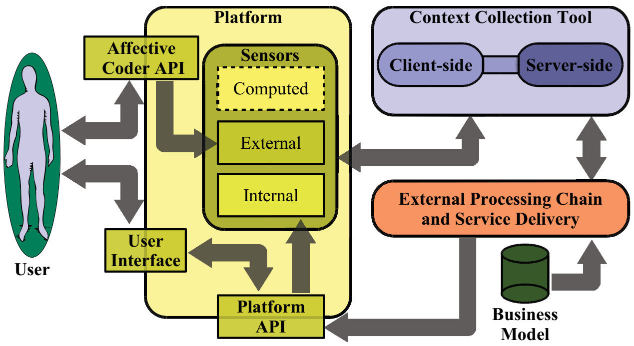

Figure 2. Context collection and processing chain

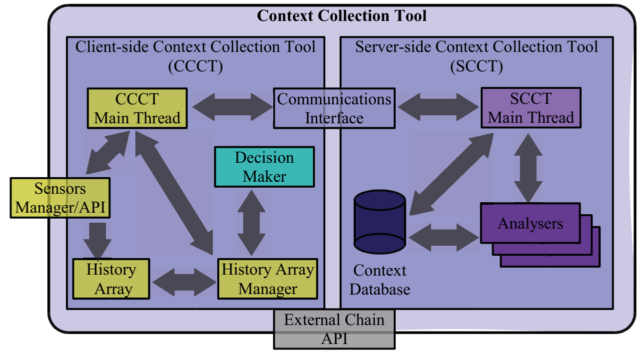

Figure 3. Context Collection Tool Overview

The context in the virtual clipboard scenario falls into three categories: aspects of the user's *affective* state and environment, the *operational* state of the mobile platform and *computed* state inferred through combination and analysis of the other two context categories. This context is forwarded to the *Context Collection Tool* agent (CCT). Part of the CCT resides on the mobile platform while another part resides on a remote server. The CCT records the context, regulates the sensors in the mobile platform and performs the analysis that produces computed state. The processed context is ultimately forwarded to an external processing module, which combines the context and a particular *business model* to modify delivery accordingly. In the following sections, we examine each aspect of the chain in turn.

3 Context Collection

Context collection is performed by two system components; one *client-side* and the other *server-side*, both being connected through a network. The client-side component is situated within the mobile platform. It is responsible for initial receipt and processing of reported sensory input. In this capacity, the *client-side context collection tool* (CCCT) also coordinates the following activities:

- sensor initialisation and status-monitoring;
- the rate at which the sensors are polled (if applicable);
- sensor contribution to the current composite context;
- supplying its server-side counterpart with context;
- forwarding processed context to the external chain

The activities listed above are largely self-explanatory. The concept of *sensor contribution* refers to whether the input reported by a specific sensor is included in the context processed by the CCCT and the rest of the platform.

We identify three types of sensor associated with the CCCT. The *external* type covers physical devices that sense stimuli originating outside the platform. These include *AffectiveWare* metrics such as skin conductance, relative humidity and temperature. The readings for these sensors are retrieved through an associated device API: in the case of the *AffectiveWare*, for example, a software API enables the CCCT to interpret the signals from the *AffectiveCoder*.

The *internal* sensor type covers attributes of the client-side platform in which the CCCT operates. These include metrics like CPU load, battery-life and screen resolution. The readings are retrieved by querying the platform API.

The *computed* sensor type covers derived stimuli. These are generated through analysis and composition of context from external and internal sensors. The resources of the mobile platform are typically insufficient to support analysis *in situ*. The CCCT therefore supplies its *Server-side Context Collection Tool* (SCCT) with the context instead.

As a server-based process, the SCCT is able to exploit more powerful or specialised computational resources in order to assess the incoming context. The SCCT first records the context in a database, which in turn is accessed by a series of concurrently-executing processes called *analysers*. Each analyser examines a portion of the historical context, combining individual sensor readings and identifying patterns in the data based on heuristics and statistical methods specified by the analyser programmer. The analyser records it computations in the database alongside the incoming context, creating *computed context*; a form of indirectly-sensed stimulus. This new context is then forwarded to the CCCT for display alongside the other sensors. In practice, multiple CCCT *instances* can connect to a single SCCT. The SCCT can handle this situation by running corresponding instances of the relevant analysers concurrently. The context supplied by a specific CCCT is identified by an associated user or device ID; in this way, the SCCT can return the appropriate computed context to each CCCT.

Working together with the SCCT, the CCCT forwards refined context to an external processing chain, which in turn performs further analysis in order to adapt the media delivery service accordingly. The refinement of context is handled by a central CCCT component, the *Decision Maker*, that is described in Section 5. In the following section, we review the framework that allows us to collect and utilise affective context in scenarios such as the Virtual Clipboard.

4 Affective Sensing

The overall aim in the design of the AffectiveWare platform is to facilitate the recording and analysis of physiological and ambient data to provide a real-time estimation of the users current mood. It is intended that ultimately the platform will evaluate the current status of the user's mood and transmit the information to a client application in a real-time feedback loop, known as the *AffectiveLoop* (Figure 4). This would enable any client application utilising the platform to respond to a user's emotional state, thus providing a satisfactory emotionally intelligent HCI. The use of such a client application would also benefit the customer by offering an additional flow of data, and thus greater control for the user in terms of their ability to manipulate the HCI according to their mood.

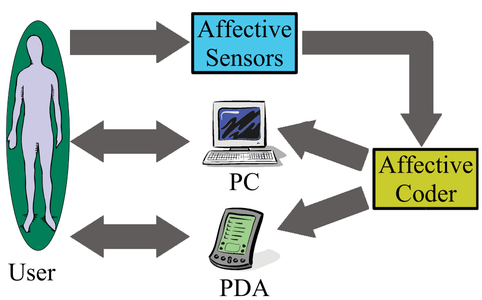

Figure 4. AffectiveLoop

Traditionally, the study of HCI has focused on the interaction between user and personal computer. Recent years, however, have seen increased usage of PDAs, such as electronic diaries and mobile phones. Interactions with a typical PC are relatively limited, with a mouse and keyboard the source of input and speakers and a video monitor as output. Interactions with PDAs can be even more limited. Typically, the user can only press a few keys or touch the screen in pre-defined areas. The aim of the AffectiveLoop (Figure 4) is to provide a different feedback mechanism within the HCI, by analysing an additional information flow from the human body and its environment and facilitating changes to the user experience based on this new flow. This information flow comes from physiological and ambient sensors placed on or near the body which are able to detect affective changes during the HCI. The primary intention is to gather information through the AffectiveCoder on the estimated mood of the user to inform the client application running on the PC or PDA. The aim is to make the HCI as natural as possible despite the addition of the sensors, so that the feedback is as genuine and accurate as possible. Thus it is of key importance that the sensors do not obstruct computer usage and are safe and easy to use. It is also clear that the AffectiveData has to be delivered in a format that can be used by the PC or PDA. The physiological and ambient data must therefore be coded into a digital format by the AffectiveCoder. The overall effect is one of a feedback loop, in which the mood of the user is input into the system and used to inform the emotionally responsive program, which in turn affects the mood of the user, hopefully resulting in a more satisfying HCI experience.

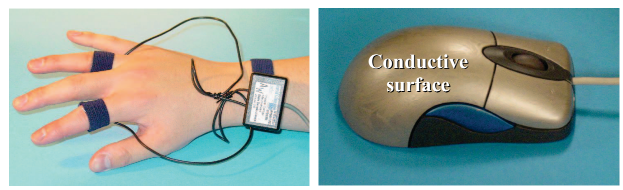

Figure 5. AffectiveRings (left) and AffectiveMouse

The AffectiveWare platform's key features are:

- *The interface between user and environment*. This allows physiological and/or ambient readings to be taken through specially designed sensors, in addition to the more traditional analysis of mouse and keyboard input;
- *The AffectiveAnalyser*. This executes algorithms based on fuzzy logic to abstract the estimated emotional status of the user from the interface data;
- *The platform's application interface*. It is intended that a client application use this interface to access the information gathered by the AffectiveAnalyser and change the client application behaviour accordingly.

The ultimate aim is to develop emotionally-responsive client applications based on the AffectiveWare platform. Doing so requires several key stages of development. The first is to identify and test appropriate sensors from which accurate digital physiological and ambient data can be obtained. Having selected sensors accordingly, software capable of estimating user emotions in real-time has to be designed and tested. The AffectiveWare platform depends on the accuracy and stability of these components. Similarly, the emotional estimation of the user by a computer has to have validity if the response of any program is going to be meaningful. By incorporating emotional feedback into the user interface of a client application, greater redundancy of action can be provided, thus enriching the user's overall experience of that application.

The design of non-intrusive sensors is paramount in the Affectiveware platform concept. The usability of the devices is a key consideration in terms of their intrusiveness and *quantity* of data produced in relation to its *accuracy*. We have built two different types of Sensors, each with particular characteristics. They are based on the same hardware solution, using the same schematics, but differ in terms of how they 'interface' with the user's body. The *AffectiveRings* (Figure 5, left) form a wearable device placed on two fingers and are designed for continuous contact with the body. This arrangement is advantageous in providing an uninterrupted flow of data through the AffectiveLoop, which in turn is likely to facilitate interpretation of that data. The *AffectiveMouse* (Figure 5, right) has been designed so that skin conductance readings can be read during normal computer mouse usage. This is a much less intrusive monitoring method than the AffectiveRings, but one more susceptible to data-flow interruption, as readings are only taken when the mouse is in use.

The software components comprise Software for the *AffectiveCoder* (the hardware that transforms the physiological readings into digital form and generates data packets which are transferred to the user's computer); the *AffectiveReader* (which monitors the incoming readings and transmits them for storage); the *AffectiveAnalyser* (which analyses the stored readings in the database and records the estimated mood); the *AffectiveWeb* (which displays the physiological readings and/or estimated mood in both textual and graphical format); the *AffectiveStore* (the database in which the physiological and ambient readings and the estimated mood are stored) and the *AffectiveAPI* (Affective Application Program Interface), which is used as the interface to external applications.

5 Decision Making

The processing of context requires a significant amount of information interchange between the components described in the preceding sections. This is facilitated by a network layer incorporating wired and wireless clients as appropriate. Due to the soft real-time requirements of analysing the affective data (in order to dynamically adapt sessions), it is essential that the resulting data-flow remains manageable. There is therefore an identifiable need for a mechanism that constrains data-flow in such a way that auxiliary processing activities occur in a timely fashion. The same constraints must also allow sufficient data-flow for meaningful analysis to occur. In order to satisfy both these requirements, a process with control of the sensors (for regulating data-flow at the origin), understanding of the context (to establish its composition) and time-awareness (for a real-time response) is needed. In our system architecture, this role is performed by the *Decision Maker*.

The Decision Maker resides within the CCCT (see Figure 3). It is able to perform intelligent analysis of arriving context, employing a filtering mechanism that ensures significant changes in context trigger an appropriate response in system behaviour. These responses include stopping/starting individual sensors (if their input to the current context is considered superfluous/essential) and changing the rate at which data is reported from individual sensors (reflecting an individual sensor's weighting and variability in the current context). As data flows from sensors to the CCCT, it is stored in a *History Array*: a dynamically-resizeable cache containing the most recent sensor readings. The *History Array Manager* is responsible for maintaining this cache. The operational cycle of the History Array Manager is divided between two activities (see Figure 6). The first is the update of the History array in response to new context. The second consists of invoking the Decision Maker. Under real-time conditions, the time required for the update and for the Decision Maker to effect any decision must not collectively exceed the time at which the fastest active sensor is reporting data. If this is not the case, it may be necessary to adjust sampling rates or presence of the relevant sensor in the current context. Alternatively, the Decision Maker may have to constrain its analysis in order to keep pace with data arrival. In this respect, the Decision Maker should implement an *anytime algorithm* [8], where it is able to provide approximate but correct decisions if interrupted, with 'accuracy' or 'appropriateness' being directly proportional to the amount of time available for deliberation. Under soft real-time constraints, the requirement to produce a decision during each cycle can be relaxed.

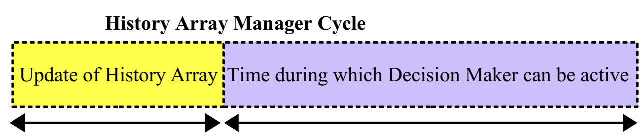

Figure 6. Soft real-time constraints on context processing

The Decision Maker's deliberations focus on two aspects of incoming data. The first is purely syntactic and involves analysing the incoming data as an arbitrary flow of data across a network, whereupon generic strategies for network traffic management can be employed. The second aspect requires an understanding of the data's meaning. To that end, the Decision Maker includes sub-components that specialise in analysis of particular data. This would, for example, allow the Decision Maker to differentiate between the inferred moods 'fear' and 'excitement'; two moods that might equally be reflected by similar physiological states.

This would require the Decision Maker to be able to assess the likelihood of such moods arising given the available historical data for the relevant user. The specific requirements of the user form an additional input to the decision-making process. By analysing and interpreting *user policies* specifying the long-term preferences of the user, the Decision Maker can influence context to achieve a more personalised and accurate delivery of service. Although our currently-implemented system does not incorporate user profiles, we have already devised plans for their inclusion and use in a subsequent version (see Section 8).

6 Business Models

The recent business model literature [7] stresses the importance of increasing the utility of customers by targeting their needs. Part of the subsequently-created value can then be obtained by the service providers and all stakeholders reap benefits. This customer economics framework stands in contrast to conventional approaches that focus on product or system economics. They either aim to reach cost leadership or to achieve *system lock-in*. While the potential profits from achieved system lock-in exceed the alternatives, this strategy is at odds with an open market and interoperable standards. Moreover, [7] collected empirical evidence in a study of Fortune 500 companies that customer economics-categorised firms demand a premium in the financial markets. *Customer lock-on* is achieved when customers voluntarily choose to stay with the service that addresses their needs and creates value. They stop looking for alternatives and thus competitors are kept out. This bonding experience between customers and service can eventually lead to positive word-of-mouth and more revenue from new customers. Context-awareness features increase the chances to deliver continuous personalised value. This makes the customer economics approach particularly attractive for advanced digital media services. Their potential interactivity features allow virtual feedback loops that create added value as it becomes possible to provide content more tailored to the customer's preferences.

A key component of customer economics is to provide an integrated customer experience. The customer-activity cycle (See [14] for more details) includes a pre- , during and post-consumption phase and can be used to ensure that value is offered at each critical step. Failure to do so creates value gaps as the flow of the cycle is interrupted. Innovations can fit into value gaps overlooked by conventional services and open access for competitors. They can also be used by incumbent services to fill value gaps in order to provide an integrated superior experience. Successful features of new multimedia technologies should thefore help to create valuable services in the post-consumption phase based on the collected context. Customers' willingness to pay is increased and a sustainable relationship between customers and services develops. This leads to recurrent consumption patterns or new customers following the recommendations of existing highly-satisfied customers.

7 Related Work

There are several cases of existing work combining agents and context-processing. In [10], for example, a context-aware multi-agent system is used for adaptive service recommendation. A user model is constructed by monitoring user service invocation, with a view to identifying usage patterns and associations. The agent system subsequently monitors context, recommending services to the user based on current time and location in addition to the preferences expressed by the model. Such systems may also support other types of information interchange: in [1], *personal information agents* each have access to an *agent model*, containing information about the preferences and requirements of a corresponding (human) user. This model is used to judge whether current context may be of interest to the user. The agents also interact amongst themselves in order to locate relevant information. It is argued that this behaviour, in conjunction with context-awareness, allows agents to operate more efficiently in resource-limited environments. Similarly, [15] identifies enhancements arising from combining mobile agents and context awareness in pervasive computing scenarios, wherein agents are positioned as specialists in analysis, interpretation and use of context. The changes in situation that typically arise within pervasive computing applications trigger corresponding changes in context. An agent's mobility allows it to migrate and assess new locations and environments, while its specialist knowledge enables it to suggest appropriate responses to detected changes

The dilemma of privacy versus personalised service in context-aware systems has also been acknowledged in previous work. [9], for instance, introduces *information spaces* to control both context flow and visibility. Information spaces are owned by both users and user agents. The latter protect the former by monitoring access to the information spaces and detecting potential conflicts of interest.

Ubiquitous computing systems and their applications have been discussed frequently in the literature. For example, a study of the role of PDAs in museums [12] highlights several features important for their effective use: *content*, *user interface*, *applications*, *form factor*, *positioning* and *integration*. To this list, we add the concept of context-awareness. A hand-held, location-aware museum guide has been described and analysed in [4]. An innovative aspect of our research is to extend an application's context awareness to a visitor's emotional states and integrate the collected data into an agent-based intelligent business infrastructure.

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8 Conclusions and Further Work

This paper has described an innovative agent architecture integrating four distinct, but complementary, developments:

- *context collection* which is fundamental in providing customised service delivery;
- *affective computing* via the AffectiveWare framework, which in turn forms a crucial element of the context;
- *decision-making* which gives the agent-based intelligence to act upon the collected context;
- a *business framework* which puts the developed tools to use within commercial applications.

The contribution of this work is therefore two-fold. Firstly, in purely application-related terms, we have developed a system which can model novel scenarios such as the Virtual Clipboard. Secondly — and more importantly — we have created a platform which can be used to explore a key issue in pervasive computing, namely the extent to which users are prepared to reveal detailed personal information about their emotive state in exchange for customised services that more effectively meet their requirements. A privacy model in [11] identifies three factors related to this issue: the *sensitivity* of the information being revealed, the *identity* of the information receiver and the *information usage* intentions of the receiver.

As one aspect of future work, we will address privacy-related factors through the introduction of a user-centred model enabling users to specify usage policies and access rights to their context. A policy will then form another means of representing aspects of user and their requirements. While this may at first appear to be a static approach (in contrast to making decisions on context), the decision-making process can turn this into a more dynamic procedure. The policy of a user will not only hold personal details such as name, address and age but also other important pieces of information such as the semantics or updates of the semantics of the data flowing through the system. This is required for the Decision Maker to interpret the data in a format it can understand and use for analytical purposes to detect changes. The policy is written in XML [2], and is parsed and updated by the Decision Maker, using XML reader/ writer classes respectively. The Decision Maker also has access to the schema of the XML policy for the validation purposes, as well as for checking for syntax correctness. This reduces the chances of receiving or building a corrupt policy. Policies are updated by the Decision Maker with current session data to aid future sessions by taking into account the preferred behaviour of the user-system interaction. The advantage of this feature is that it enhances the quality of personalised service delivery while simultaneously reducing direct user input.

Other research avenues include extending the agents architecture to the SCCT-level. This means collected mood data of visitors can be further analysed by collaborative filtering. Moreover, experiments are planned to enhance the AffectiveWare-based decision-making.

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