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Time, Space, Connection: Scaling Ambient Intelligence

Mirko Fetter and Tom Gross

Ambient intelligence aims to improve users' work and private life by analysing and adapting to the current situation with a special focus on the presence and activities of users. Technical progress provides increasingly improving mechanical and electronic support for precisely capturing and processing a vastly growing amount of data. At the same time adequately detecting the respective situation and related objective and subjective user needs remains a challenge. In this paper we discuss the design space for ambient intelligence by analysing three core dimensions of situations with users involved: time, space, and connections among users.

Keywords: Ambient Intelligence, Connection, Design Space, Space, Time, Ubiquitous Computing.

1 Introduction

Ambient intelligence (AmI) aims to improve users' work and private life by analysing and adapting to the current situation with a special focus on the presence and activities of users. AmI is often based on ubiquitous computing technology and goes beyond the traditional WIMP (*Window, Icon, Menu, Pointer*) paradigm of todays computers. In particular, it uses a broad range of opportunities for presenting information and functionality in the users' physical environment and, at the same time, offers users a broad range implicit input allowing users to naturally interact with the environment through their presence, movements, body expressions and language.

Vast progress in sensing technology provides increasingly improving mechanical and electronic support for precisely capturing information from the electronic and the real realm. For instance, software sensors can capture precisely what users are doing on their computer desktop and on the Internet as well as their presence and activities in the real world [1][2]. Also the capabilities for processing the captured data have been extended through progress in base technology such as faster and bigger disks for storing data, faster processors and networks for extracting and inferring on the data, and novel algorithms for identifying patterns in the data [3].

At the same time AmI is still facing challenges of context awareness. That is, detecting the respective situation and related objective and subjective user needs and providing adequate adaptation. According to Schilit et al. who did very early work on context awareness, a context-aware system "*adapts according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time*" [4, p. 85]. Counting and inferring on absolute numbers of positions of users and technology, and so forth is an important part of solving the context awareness challenge, but not sufficient for adequately adapting to users and their needs, because in both

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the work environment and the private environment the behaviour of individual users, and especially of users in groups, can become complex and difficult to interpret by computers [5].

In this paper we discuss the design space for AmI by analysing three core dimensions of situations with users involved: time, space, and connections among users. We first introduce a typical scenario of AmI. We then introduce the AmI design space based on the dimensions time, space, and connection. In particular, we provide definitions and concepts of the dimensions per se, and we then discuss permutations among the single dimensions with respect to typical patterns of time, space, and social connections from a users' perspective. We exemplify the design space in a short introduction of the IMInfer concept and prototype of AmI and instant messaging. We distil lessons learned concerning the application and use of the three dimensions.

2 Scenario

In this section we want to illustrate a situation of a typical knowledge worker. Imagine the knowledge worker Sue, who has finished work and has just travelled back home with a colleague in the train. Sue is sitting in the living room with her laptop to finish off a report for work that is due the next day—she wanted to work on it at home rather than staying in the office late. Her boy-friend Pete is sitting next to her and watches a soccer match on the television, while he is waiting for the lasagne that he is baking in the oven in the kitchen to become ready. Pete's phone is ringing—his work colleague Tony is calling to arrange the next squash match. So, Pete turns down the volume of the television and asks Sue to go to the kitchen to check the lasagne. Sue checks if they have some Parmesan cheese left, but cannot find any, and decides to switch off the oven and quickly get some cheese in the grocery store around the corner. After Pete has finished his conversation and prepared the table in the kitchen for dinner, Sue returns and they enjoy the lasagne together.

This scenario illustrates several aspects of typical everyday situations: users stay at various locations and spend a considerable amount of time to travelling between locations; users often have a mixture of planned schedule and spontaneous activities; users have various social relationships and social settings they are in; and users have fluent transitions between these locations, schedules, and social contacts. In the next section we want to discuss these aspects as well as the challenge to identify the core aspects and patterns of user behaviour depending on these core aspects.

3 The Design Space of Space, Time, and Connection

In this section we reflect on typical situations that can occur in ubiquitous computing environments such as the one in the scenario, and discuss core dimensions that should be considered when developing concepts and systems for AmI. In many approaches of location-based or context-based systems the location (i.e., space), and the timing of the interaction (i.e., time) of the interaction between the user and the system have been identified as core dimension (e.g., Jones et al. 2004 [6] give a great classification and overview of context-aware systems). The social setting of the user with other users who can be present or remote (i.e., connection) is equally important, but has been less emphasised. For instance, Markopoulos et al. [7] writes that *"a less-explored design problem is how such technologies can be designed to fit the social processes in which they are embedded and to blend socially in the activities of their users"*. Still, as the example scenario shows: space, time, and connection are core dimensions that need to be captured and inferred in order to properly understand the situation [8]. We describe the dimensions *per se* and introduce permutations among them.

3.1 The Dimensions *per se*

The dimensions space, time, and connection mostly appear in combination with each other. However, in order to better understand each dimension per se, we start here by discussing each dimension in isolation: we provide a definition for each dimension, characterise the dimension, and then describe how the dimensions can be combined, the measuring units, and the patterns that can be identified for each measure.

3.1.1 Space

The concept of space has been treated in many fields from philosophy over physics to mathematics and viewed under a variety of perspectives from the early Aristotelian notion of space up to modern string theory. For our approach the concept of space derived from classical mechanics based on Isaac Newton [9] fits best, as it precisely reflects on space per se and mostly leaves out the other two dimensions. This leads us to the definition of absolute, physical, Euclidean space and its manifestation as relative space by taking the earth into account as the frame of reference (as done in the field of geodesy). This is fully sufficient for our purpose of covering relevant spatial localisations for AmI and what its hardware sensors are able to measure.

Le Système international d'unités (SI) [10], which is worldwide the most common system of units, defines the metre as the base unit for the measurement of length and so provides an appropriate tool to subdivide and map the space of the three-dimensional world we live in. On this basis we can scale the space from nanometre to kilometre and beyond; and it allows us to convert with other systems (e.g., WGS 84 [11] as used in many modern devices such as the Global Positioning System (GPS)).

3.1.2 Time

Time (even more than space) has inspired many European philosophers as prominent as Immanuel Kant or Gottfried Leibniz and has often been treated in combination with space as fourth dimension. Physicians and mathematicians in fields like quantum mechanics currently discuss time in dependence with other influencing factors on an atomic and subatomic level. These concepts of time often take into account other dimensions and are as such difficult to apply in AmI scenarios. In this paper we therefore adopt the idea of Newton: "*absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration*" [9], which becomes apparent in its relative form as a measure for duration.

As the unit for this relative occurrence of time the SI defines the second which "*is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom at a temperature of 0 Kelvin*" [10] and its decimal multiples and submultiples. These conventions together with the accepted Non-SI units, minute, hour and day allow us to measure and describe the order and duration of the occurrence of events to various levels of granularity.

3.1.3 Connection

As the third fundamental dimension enabling interaction in AmI we identified connection as the level of social connectedness between individuals and each other person. The human connections among people are analysed in various disciplines, mainly sociology and psychology. For instance, in social network analysis social structures consisting of individuals and their connections are analysed and measured [12]. Also, in sociometrics the connections of humans in groups are analysed [13]. From an AmI perspective trust and privacy are important aspects of human connections, and therefore, friendship and affect. They can have strong influence on the users' wishes for configuration and interaction with the ubiquitous computing environment [14].

Analogue to our above reflection on the distance between two points in space per se or two points in time per se, we would need to define a measure for the closeness of a relationship between each two people in terms of friendship, trust and privacy. It is hardly possible to find an appropriate measure for connection per se—this is, independent of the space and time. We, therefore, just want to introduce indifference as the absence of giving weight to another person as the point of reference, with varying levels of dislike on the one side and varying levels of empathy on the other [15].

3.2 The Design Space

These three dimensions that come alive in their permutations, and the multiplicity of their occurrence and combinations at a different scaling in either dimension, define our design space for AmI. In the following we will expose how each single dimension influences each other and so spans the design space, for analysing the input and designing the output of seamless scalable cooperative ubiquitous systems.

3.2.1 Space and Time

Space in conjunction with time enables motion and so we are constantly leaving our trajectories in this permutation while following our daily routines. In AmI this motion can be sensed [16], inferred [17] and used to support the user [18] in multiple ways. But the influence time and space have on each other goes further. An example is the way we perceive space changes over time, as routes often travelled seem to be shorter than unfamiliar routes. Additionally, the perception of spatial distance is also dependent on the mode and speed of transportation and so the nearest supermarket is not the one with the shortest linear distance but the one that can be reached in the shortest time. These mechanisms of human spatial cognition should be taken into account when designing human-centred systems for AmI.

3.2.2 Space and Connection

The face of our world, its countries, cities, and buildings is the product of a variety of connections in the human society. The way we form our environment, plan our houses, arrange neighbourhoods and build our cities is a mirror of our social networks from families over colleagues up to the level of nations. In the inversion space also defines connections as it defines our spatial and social behaviour [19]. When we go to a stadium to see a soccer game we may feel more connected to the people there than those we encounter at a the train station or a shopping centre. Harrison [20] distinguishes “physical space” as a form of container from “place” as the understood reality, which comprise as set of implicitly negotiated cultural rules and an appropriate behaviour. The permutations of space and connection underlie a constant interdependency of one influencing the other and, in this way, is continuously reshaping the way we perceive it [21], utter it [22], or structure it [23].

3.2.3 Time and Connection

We base our social life and interaction rhythms on calendar units negotiated over millennia in different social groups like for example the Roman civilisation or the Islamic religion and over the boundaries over those groups. The seven-day week, the months or the Common Era are all cultural formations laid over the flow of time to come to a common sense in the calculation of time. Based on our social connections these units shape our life and the rhythmic patterns for working, relaxing, sleeping, eating and so forth. From working hours to semester turns is it us and our connections that shape time and vice versa time that shapes our connections and us. In time we learn to know our colleagues, miss our family, and maybe forget past acquaintances.

3.2.4 Space, Time, and Connection

The connections and permutations among all three dimensions can be multifarious. For this reason we only give some short examples here. One important issue is that connections and time give a meaning to space (e.g., "Home", "Work"). Tuan writes:

"*when space feels thoroughly familiar to us, it has become place*" [24, p. 73]. Also locations and time can reflect connections in terms of regular meetings with specific peo-

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ple (e.g., playing bridge on Wednesday evenings).

In general, on the one hand specific combinations of these permutations enable interaction among users, and on the other hand all inputs of all combinations cannot be inferred with one another. Therefore, it is useful to identify useful combinations in the form of patterns of ranges of parameters on each dimension.

In the next section we provide an example of a concept and system inferring on these three dimensions in order to identify useful patterns of parameters in distance in space, duration in time, and degree of connection.

4 Ambient Intelligence based on Social Settings

In this section we introduce the IMInfer concept for a cooperative ambient intelligence environment with presence and awareness support, which is based on the design space considerations from the previous section.

The aim is to improve human-connectedness while at the same time retaining an appropriate level of privacy for a diverse audience, in situations like in the scenario above. The approach is founded on the PRIMIFaces concept [25], enabling users to manage how others perceive them by selectively disclosing information sensors capture about them. We carried forward the thoughts of [26] by implementing Faces as specific fronts describing a particular level of confidence and trust including the type and amount of information and the designated receivers of this information. The kind of information exchanged between the parties varies from static contact information like the work email address over mouse-movements measured by software sensors to hardware sensors like a GPS mouse sensing the user's current position.

Connection in Space. By constantly tracking and storing the user's movement via GPS (using a mobile phone combined with a GPS mouse) we create a map of the user's trajectories through space. Specialised clustering algorithms analyse the GPS data and construct a model of the users' significant places, those visited for a specified minimum time. The users can mute Faces (that is, temporarily prevent information supply) at specific places to have location-specific privacy settings. In this way it is possible to co-relate connections to space and allow the support of specific occurrences and patterns of this permutation. The current implementation mainly focuses on users working on computers at different places and using traditional instant messaging, but the basic concept can be applied to other areas such as nomadic communication on mobile phones.

Connection in Time. When new contacts are added to the contact list, users can assign these contacts to the face(s) that best describes the current type of connections users have with that particular contact. Connections can evolve over time (e.g., a former colleague may become a private friend after some time). Consequently, we analyse all instant text messages users exchange with each of their contacts in each face over time utilising data mining techniques. By extracting linguistic features like individual jargon, the use of emoticons and abbreviations, etc. a classifier builds up classes for each face and its specific linguistic characteristics. So, the evolution of the degree of a connection between two users can be detected through changes in the exchanged instant text messages. And the system can recommend the users to adapt their Faces.

Connections in Space and Time. Fusing the outcomes of the connection in space and in time inferences, our approach builds a model of patterns reflecting diverse combinations of space, time, and connection. It co-relates what is said, where and when, between whom, and actively adapts the outgoing information to the specific situation. It classifies ongoing conversations to detect if the current, location-specific configuration suits the context, and matches Faces to conversation contents. For instance, it can recommend opening muted Faces. So, users can predefine configurations bound to specific locations, and the system can support additional adaptations. It might be a good predefined configuration to mute all work specific Faces when at home, as you want to fade out those entire job related issues in your spare time. But in some situations, for example, when a user works at home to finish a project, or discusses home related ssues with a colleague at the office, the connection dimension might outweigh the space dimension.

5 Lessons Learned

Analysing interaction along the identified dimensions can help to get a clear picture on the measures that need to be taken into account for adequately supporting users. Based on the theoretical investigation and the underlying literature research, as well as our practical experience from the IMInfer and other projects, we would like to condense the lessons to three messages that help to narrow down the number of all possible adjustments to come to an adequate adaptation of the environment to the context.

■ *Use clustering for scalability*. Scalability is important, and scalability requires clustering. Technology can capture changes at the finest level of granularity for example to track and record micro motions in milliseconds and millimetres. The first lesson is that the level of granularity has to match the intended purpose not the highest reachable accuracy of the sensing technology. In order to design scalable systems we need to find criteria that help us to identify clusters and to subsume phenomena at the right level of granularity. Figure 1 depicts clusters for all three dimensions based on the distances, durations, and connections of the above scenario; it shows different levels of granularity that can be nested or intersect each other. For instance, on the space dimension, in order to support Sue and Pete, it is vital to identify the places that are relevant to their interaction like the train or their kitchen and living room, rather than thinking about whether to use GPS, CellID, or Bluetooth positioning.

■ *Start from the big picture to get to the point*. For any inference at least two of the three dimensions need to be considered. The second lesson is to take a more holistic view in the scope of the three dimensions in order to come to a more precise statement, as one- dimensional observations

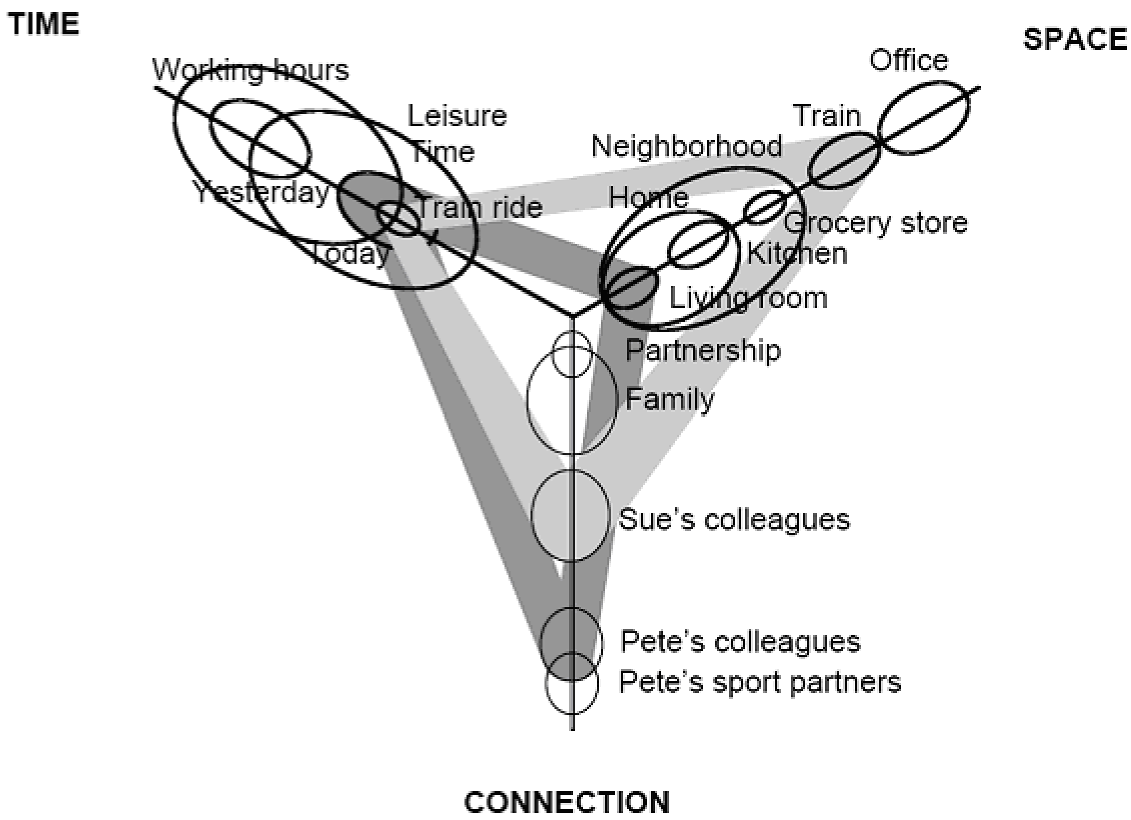

Figure 1: Applying Time, Space, and Connection to the Scenario.

lead to one-dimensional assumptions. Transferred to our scenario, by just analysing where Sue is or who she is with we probably would not get a precise understanding of her situation and her specific needs in order to assist her. While on the train together with the colleague, or working at home with Pete sitting next to her, taking into account more than one dimension will help to make better-informed decisions.

- *Provide distinct configurations in multifarious situations*. Although the situations are often hybrid and complex where more than one user in hybrid social connections are at each location and have fluid transitions over time, users still need distinct configurations of their environment. The ways we adapt the environment and configurations are distinct and often have to match a multiplicity of hybrid states. For instance, in the above scenario Sue is not just working and Pete is not just cooking, they have other things going on in the background.

6 Conclusions

What we perceive is a world where time and space are more and more influenced by technology. AmI allows us to tighten the bands to our loved-ones by establishing many new links that keep us connected. However, the vast amount of captured information challenges designers of ubiquitous computing environments, and AmI, to decide what to take into account for interpreting the context in order to better support the situated interaction, and what to consider as negligible. When ubiquitous systems become stable, leave the laboratories and get part of a bigger whole, it is essential for developers to understand where those systems should influence each other, where to exchange information and where not, in order to allow a seamless scaling from tangible interface via smart home to ambient city and beyond.

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