Habitats for the Digitally Pervasive World

Daniel Chien-Meng May and Bent Bruun Kristensen

The Maersk Institute, University of Southern Denmark
Campusvej 55, Odense M 5230, Denmark
{dmay, bbkristensen}@mip.sdu.dk

1 Introduction

The vision of ubiquitous (Weiser 1991) and pervasive (various 1999) computing that we are moving towards is one where computational capability will make its way into most of the physical objects and space around us. Beyond this, computers are also heading inside us and may be so prevalent as to be disposable (Arnold, Segall et al. 1999). We shall move from the perspective of computing in the corner (where computers and our relationship to them are distinct and separate) to our being submerged in computing (where it may be more accurate to suggest that we are embedded in a sea of computation, and it embeds itself within us).

Not only has this involved technological innovation, but necessitates a grappling with soft issues—amongst them, social, cultural and political issues. However, the history of pervasive computing demonstrates a bias that has been heavily skewed towards technological and engineering activities (Abowd and Mynatt 2000). Indeed, there is a persuasive argument that the primary challenges faced by pervasive computing are not technological but human (Thackara 2001). Yet the technology of pervasive computing has been a powerful catalyst for convergence: pushing together physical materials and information, but also raising questions about how these integrate with *what it is that we do* and the *purpose of our tasks.* Put another way, the question of human interaction in the digitally pervasive world has been raised precisely because the technology has pushed us to the point where we *can sensibly question* how computing should fit into our lives, rather than the other way around.

1.1 A Holistic Approach

An emphasis on technology to the exclusion of human concerns will cause us to fall short in developing pervasive computing systems, but neither can we emphasise the human element without recourse to real-world practicalities and technological possibilities. Thus, our approach to the challenge of pervasive computing is to adopt a holistic perspective. We call our approach *TangO* for *tangible objects* (May, Kristensen et al. 2001; May, Kristensen et al. 2001; Andersen and Nowack 2002; Hallenborg and Kristensen 2002) for we believe that the objects we create for the digitally pervasive world through this approach will become more real, richer and satisfying in our interaction with them—more tangible. The TangO view of the world is that it comprises three dimensions (**Fig. 1**): we need to consider them equally when we are modeling and designing artifacts in the digitally pervasive world.

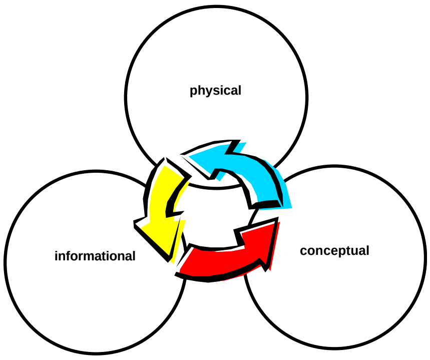

Fig. 1. A three-dimension view of the world

In the **physical dimension**, we interact with artifacts in their physical form: we can touch them, throw them around and move them around. In the **informational dimension**, we interact with artifacts in their informational form: we can store them, copy them and modify them. These artifacts not only store information, but may have computational ability and also act with autonomy. In the **conceptual dimension**, we interact with artifacts in their conceptual form: concepts shape the way we understand the world and how we will act towards the world. Most of them, when we are engaged in the design of artifacts, we subconsciously iterate through these different dimensions, as they represent the different aspects of the artifacts we are designing and the contexts in which they will be used.

These three dimensions enjoy interplay: they are not merely related to each other, but they intersect and depend on each other. To model an artifact in any one dimension without considering its connection to the other spaces is to model an artifact that does not take into account the needs of the pervasive world. When we design and create artifacts in any form—physical, informational, and conceptual—without combining and managing the interplay of these three dimensions, then we encounter a disconnectedness and incompleteness. Managing the forces between these dimensions is the key to modeling and creating artifacts that are useful and appropriate for the pervasive world.

This is the background to this chapter, which presents the concept of *habitats*. We are using habitats as an abstraction to model spaces and environments in the digitally pervasive world. As an abstraction, we want to be able to apply it in an orthogonal fashion across the different dimensions in our world. In doing so, it is a step towards a better approach to designing for the digitally pervasive world; an approach that is less fragmented than current design approaches, more coherent and integrative of different dimensions of our world.

2 Habitats

We've chosen to characterize spaces and environments in the digitally pervasive world as *habitats*. This is deliberate, as we believe that characterizing the spaces we move through as habitats confers certain useful properties. We conceive of habitats as:

(a) Specifying some kind of locality, an area that is delimited by some kind of boundary,
(b) Comprising inhabitants,
(c) Providing support to its inhabitants in the form of opportunities and services that allow its inhabitants to interact and achieve their various goals.

It is not coincidence that this conception draws directly from the biological notion of 'habitat', indicating the kind of geographical locality in which particular plants and animals naturally grow or live (Simpson and Weiner 1989). That a habitat and its inhabitants exist in a close relationship is a given: a habitat nurtures and supports its inhabitants who constantly adapt the habitat to their use, while inhabitants themselves can adapt to their habitat. The notion of *habitat form* is used to describe the form developed by a race or organism in response to its habitat.

For our purposes, an inhabitant is a thing that is capable of acting with some level of autonomy and agency. Typically, living creatures such as humans and animals are considered inhabitants in habitats. If we consider that certain non-living entities are capable of autonomy and agency—such as computer programs, robots and tangible objects (Kristensen, May et al. this volume) —then these could also be considered as inhabitants within certain types of habitats. For the purpose of exploring the habitat concept, this chapter focuses on living creatures, primarily people, as inhabitants, and the analysis of tangible objects and other entities as inhabitants will form the basis for a subsequent discussion.

The concept of habitats connotes the organic and dialectic nature of interaction: by thinking of environments in terms of habitats, we avoid thinking of spaces as being clinical and implicitly ignoring the rich interaction therein. By thinking of habitats, we naturally consider the inhabitants, their needs, their goals and intentions and how they interact with the rest of the habitat. Thus, context, situatedness and heterogeneity are up-front considerations when thinking in terms of habitats, capturing the real world as it is, rather than over-abstracting away its inherent complexity.

The relevance of this approach to characterizing spaces is considered in relation to a multi-disciplinary trend in characterizing things from a more holistic and organic perspective. Such approaches are similarly being adopted across a variety of disciplines that include software (Lehman 1980; Gamma, Helm et al. 1994), architecture and building (Alexander 1979; Brand 1994), business and organizational theory (de Geus 1997). Such an approach appeals on a number of levels: they are plausible, describing things as they seem to be; there is no shortage of exemplars and we can identify with those; they represent an alternative to 'machine thinking'

(Taylor 1911) and an approach to creating longevity and robustness that is difficult to achieve.

2.1 Physical habitats

Physical habitats are probably closest to our intuitive understanding of what a habitat is. Habitats traditionally derive from the study of natural sciences such as biology, in describing the localities where organisms and life-forms grow and live. However, we might also consider that man-made physical environments could be characterized as habitats—and the scale can vary tremendously (eg. room section, room, collections of rooms, floors, building, group of buildings, communities, etc). Conceiving of such environments as being habitats, rather than mere ‘spaces’, is advantageous in that it introduces the notion of thinking about how inhabitants and habitats influence each other and *evolving* over time.

Fig. 2. Physical habitats evolve over time.

The pictures in **Fig. 2** (Brand 1994) illustrate that it is the nature of constructed physical environments to evolve over time. There is a strong argument that the most effective buildings—those that are shaped to contours of our needs—are *grown* rather than *constructed*. The latter view posits that we construct physical spaces and their structure is pre-determined at the outset; the former view argues that that space is in a constant state of evolution and shaping by its inhabitants. Brand (Brand 1994) argues that the credo “form follows function” is misleading; form is often designed to *freeze* function. In reality, our needs do not remain static, and we reshape our physical environments after that fact. Eventually, “function melts form.” Thus, we are challenging the natural flow of growth when we attempt to construct physical spaces that serve for all conceivable uses, and if we try to do this, then our physical spaces will not support our needs—it is better to grow physical spaces.

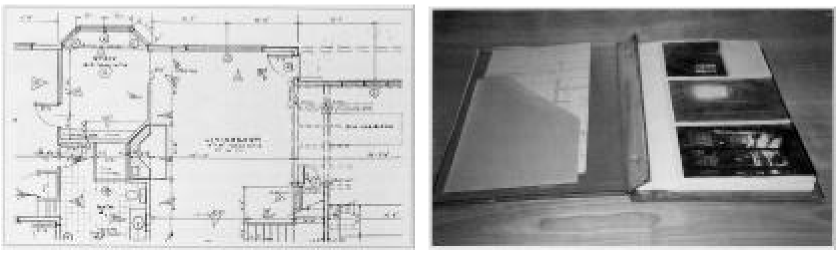

Fig. 3. Supporting evolution of physical habitats.

Brand (Brand 1994) describes how one architect prepares the houses he builds for evolution—during the construction process, he takes photographs of the frame of the house and the hidden structure (**Fig. 3**). These are keyed to blueprints. The photographs and blueprints form a 'book' that is passed to the owners; the book acts as a reference for the owners and future builders to use when the house is modified. The alternative is to knock down walls and discover what *really* exists in the structure. Traditional modification usually involves rediscovery of previously known facts about physical habitats.

2.2 Informational habitats

If physical habitats are spaces that are created and exist in the physical dimension of our reality, then informational habitats are those spaces that are created with and exist in information. Here, we are extending the concept of habitats from merely being physical. Typically, if we start discussing 'information' and 'spaces', then we tend to automatically veer towards virtual reality (Kelly, Heilbrun et al. 1989) or collaborative technologies studied by the computer-supported-collaborative-work (CSCW) research community. Technologies such as chat rooms, ICQ™, Groove™ and research projects like WORLDS (Fitzpatrick, Kaplan et al. 1996) present exemplars of 'information spaces'. This is a convenient metaphor because thinking of information spaces in this way characterizes them in a way that is similar to physical spaces—chat rooms mirror physical rooms where discourse and conversation take place, virtual collaborative spaces are the informational analogue of project conference rooms, virtual museum tours try to take us through the museum as if we were there.

While this is not an inappropriate point of perspective, we limit ourselves if our concept of 'informational habitat' is ascribed by a view of information space that draws from physical space as a metaphor. If we consider our definition of 'habitat', then an informational habitat is some kind of locality with inhabitants, who draw upon the support of the locality and both adapt accordingly … similar to our notion of physical habitat, except that the medium through which interplay occurs is information.

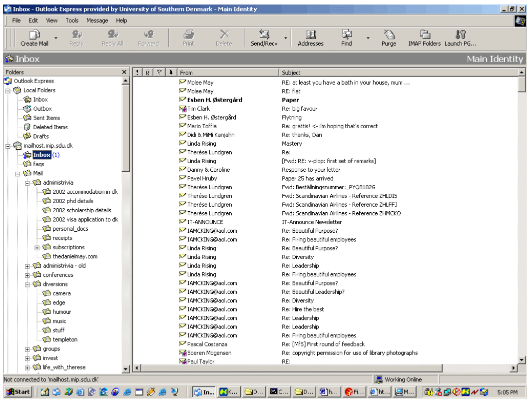

Fig. 4. Email as habitat.

Our everyday information environments can be seen as habitats. Email has been characterized as an informational habitat (Ducheneaut and Bellotti 2001). There is a topology and structure inherent in our mail folders and mail client software that causes us—the users of the program—to ‘inhabit’ our email, rather than to merely ‘use’ it. We customize the client software, structure and re-structure our mail folders, and organize our email in different ways over time. Email is an interesting case in point, as it actually comprises two habitats: mail folders and mail client software. I can use different mail client software to access the same set of mail folders and each time I do so, I feel as if I were operating within different habitats, even though I am interacting with the same set of mail folders. For instance, I can use my preferred mail client software when I’m with my notebook computer but when I’m without my personal computer, I use a web mail client from any computer running a web browser. Both mail clients are different habitats, offering different experiences and supporting me in different ways. Mail client habitats can become more complex: a number of them are extensible through programming languages and plug-ins. Thus, over time, my particular mail client can evolve over time in this way.

Fig. 5. Classification system as habitat.

Classification systems and information architectures can be thought of as habitats. Many libraries worldwide use the Dewey Decimal Classification (DDC) system, first published in 1876, to classify books. The system employs a notational hierarchy (e.g. **6**00 Technology (Applied Sciences) ? **63**0 Agriculture and related technologies ? **636** Animal husbandry) that has evolved over time to keep pace with the development of general knowledge. We can think of classification systems like DDC as informational habitats: users of books at many schools or public libraries will 'inhabit' DDC, navigating through the space to find particular books or just to explore within a subject area.

The proliferation of web sites with large amounts of information, structured in complex ways, can be considered as informational habitats. Interestingly, the collection of methods and techniques for describing the organization of such sites is called 'information architecture' (Wurman 1997; Rosenfeld and Morville 1998), suggestive of a space-related view of information and drawing an analogy between physical and informational material. Even more pointed towards a habitat view is that of 'information ecologies' (Nardi and O'Day 2000) which posits an organic characterization of information and its interaction with people.

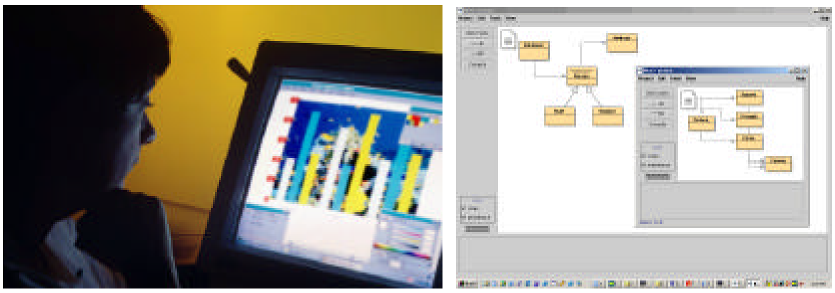

Fig. 6. Application server as habitat.

Environments for programs can be thought of as habitats. Application servers such as iPlanet™ are designed to host and deploy applications over the Internet. Programs are written to exploit the environment provided by the application server (e.g. e-commerce tools, database connectivity, directory services). We can consider the application server as a habitat: programs are inhabitants that draw upon the services and support provided by the application server. Programs evolve over time through programmer intervention or machine generation, all the while being supported by the application server. The application server habitat evolves through customization and addition of plug-ins; this evolution is mediated through system administrator intervention. Human intervention plays a part in this evolution; we can imagine more autonomous evolution on the part of inhabitants and habitats for systems more similar to multi-agent systems (Bradshaw 1997).

The example above introduces the additional concept of a program as inhabitant within an informational habitat. We introduce the possibility of programs being considered as inhabitants, as they may act with some degree of autonomy and agency. Coupled with the richness of informational habitats, thinking of programs as inhabitants of such habitats may be a useful way of understanding and designing informational environments. We choose not to expand on this discussion here, but this is an important point for later work. It is especially pertinent when thinking about programs that will engage in more evolutionary behavior and have the capacity to perform reasoning.

2.3 Conceptual habitats

In the same way that habitats can be constructed from physical material and information, we can have habitats that are defined in terms of *concepts and ideas*. What do we mean by this? In the same way that we as inhabitants can move through physical habitats and interact in informational habitats, we can exist and interact in conceptual spaces. Although much less tangible than physical material or information, concepts and ideas can form habitats that create particular support for us as we think and act in relation to the world around us. Here, the space is being created from 'conceptual' material rather than being delimited in terms of physical or information dimensions. Consider one example:

> *Cyberspace is the 'place' where a telephone conversation appears to occur. Not inside your actual phone, the plastic device on your desk. Not inside the other person's phone, in some other city.* ***The place between*** *the phones. The indefinite place* ***out there****, where the two of you, human beings, actually meet and communicate.*(Sterling 1993)

Cyberspace, as a type of conceptual space, is formed by the perceptions of our minds. We believe that we are communing in this space, the place between the phones, as a consequence of conceiving of the interaction in this way. More recent cyberspatial notions of communities, groups and social worlds are also conceptual habitats. Of course, cyberspace is enabled through informational habitats such as servers, connections, storage spaces, accounts, and at the ends of the physical telephone circuit we exist in our physical habitats. There are also many other kinds of conceptual habitats.

Fig. 7. Culture as habitat.

We can think of a culture as a habitat. Skansen is an open-air museum (**Fig. 7**) on the island of Djurgården, near Stockholm. It was founded for the purpose of showing how people had lived and worked in different parts of Sweden in the past. As such, it tries to encapsulate aspects of the Swedish culture. Culture is a conceptual habitat, ascribed by beliefs, customs and practices. While a culture expresses itself in concrete artifacts (May 2001), a culture itself is made of up concepts or 'thought stuff'. Perhaps to underscore the point further, we can consider a key feature of a culture as what it *excludes* rather than includes. There is a mutual interplay between culture and its inhabitants: the culture supports, sustains and influences its inhabitants, while the inhabitants can also reshape the culture in turn. Those people who do not want to be part of a culture anymore effectively leave this habitat, and it will no longer support or sustain them.

Fig. 8. Group as habitat.

Culture is not the only form of conceptual habitat. Arbitrary designations and rules can create particular groupings of people (Fig 8)—the space is not defined by set of beliefs and customs, but by convention and prescription. You may be assigned to a team to complete a certain project, designated by management: management has laid the boundaries for your thinking about your participation in the project; you think about it in terms of your team, your role in the team, cooperating with the other team members, etc. It is a conceptual space within which you operate. You may elect to join a soccer team: your concept of this team, your place in it, and its practices and activities, is largely determined by the rules of soccer. However, as you start to interact as a team, you start to establish a culture within the team—with customs, beliefs and practices—so you create another conceptual habitat within the original habitat ascribed by the rules. Inhabitants in cultural habitat that do not fit, for example, players who don't join in the customs and practices of the team, may find themselves on the outer but still nominally part of the team.

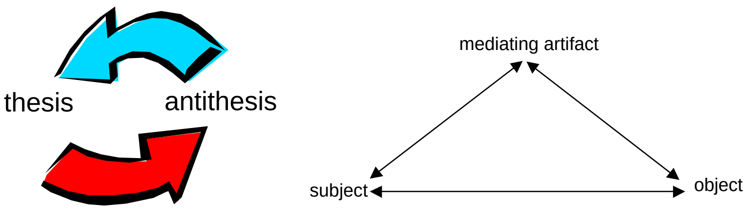

Fig. 9. Conceptual frameworks as habitats.

We can also see conceptual frameworks such as philosophies and systems of ideas as forming habitats. For example, a philosophy such as Marxism assumes certain boundaries and assumptions; the notion of a material dialectical process fits within this conceptual space, but not that of spiritual idealism (one which fits into Hegelian space). A conceptual framework such as activity theory (Engeström, Miettinen et al. 1999) assumes that subjects (humans) use mediating artifacts (tools) to interact with the object of an activity (the problem space). Within the space of this conceptual framework is the assumption of an asymmetric relationship between humans and tools. Thus, concepts that consider software and hardware as equivalent to humans would not be compatible in this conceptual space.

Again, evolution is an inherent part of conceptual habitats. Ideas change and alter over time; they also cross-pollinate with other ideas from other conceptual frameworks, giving rise to new habitats. For instance, if we look at the history of philosophy, we see the evolution of multiple conceptual habitats, building on pre-existing habitats and splitting off to form new habitats. The same can be said of cultures and sub-cultures.

3 Habitats in the Digitally Pervasive World

Our central thesis in designing for the digitally pervasive world is that it requires a holistic approach to modeling: we need to be able to frame problems and their solutions in a lexicon that can give force to the complexity of the world and bridge traditionally disparate views of the world. Integrating these perspectives is a central challenge of designing and implementing a pervasive system. The digitally pervasive world also challenges us to ask what comprises *the system*. Traditionally, computing has assumed that *the system* is a combination of software and hardware. Pervasive and ubiquitous computing pushes us towards thinking about *the system* as a human activity system that is inherently socio-technical, a combination of people, hardware, software and processes that relate them.

As the previous section illustrates, we find the habitat an appealing abstraction for thinking about spaces because it has properties we can reason about that are *orthogonal* across the different dimensions we move through (**Fig. 1**). The following example explores how habitats can be useful in characterizing a human activity system. It is based on an actual subject conducted by a Scandinavian university.

Example: Collaborative Group Project. A university department conducts a subject that is project-based. Students are formed into teams, responsible for individual projects (construction of a hardware device involving software control). The team members are not just drawn from the same local class but include students from a class conducted overseas; students must be able to collaborate in virtual teams. Students carry wireless devices and there is wireless access available in some lecture theatres and meeting rooms. We can explore this example in various ways, but right now we'll focus on how we can use the concept of habitats to help us analyse, design and structure the system to support students' collaboration and completion of their projects. The following sections consider possible habitats (listed in bold type) that exist in the collaborative group project.

3.1 Physical Habitats

Although students will spend much time in their teams collaborating on their projects, the subject also comprises lectures where they learn about how to collaborate, manage projects and discuss technical issues relating to their projects. These take place in the **lecture theatre**. The university department also provides **meeting rooms** where teams can physically meet together and work on their projects. Students will also collaborate on their projects from **external locations** such as home, another part of the university or another person's home; we could also think of the students overseas as being located in these other places.

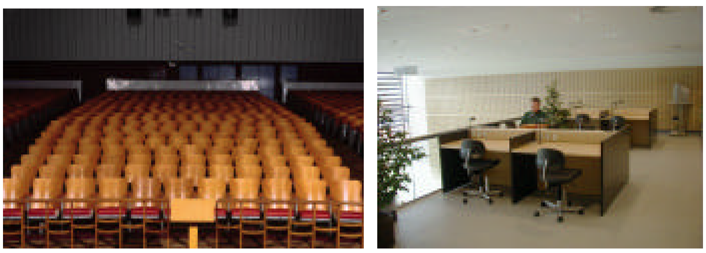

Fig. 10. Lecture theatre and meeting rooms as physical habitats.

In analysing the lecture theatre as habitat, we might consider how well it supports the discussion and demonstration of hardware devices that are the students' projects. If the class is large, are there sufficient projection facilities? Should students want to check on their work or communicate using their wireless devices, does the habitat support this effectively or is the signal strength too weak? The meeting rooms are habitats: they should support the teams when they meet to work on their projects. Are the meeting rooms shared with students from other subjects? (This may cause conflict as different subjects have different demands and goals.) Are there computers in the meeting rooms? (Because teams comprise members that are located overseas, team members who meet physically will also want to meet virtually with overseas team members.) Is it possible to partition the meeting rooms into smaller areas so that teams can work with some degree of privacy? (Now we can consider these team areas as habitats themselves.)

3.2 Informational Habitats

The main information repository for the subject is a **web site**; the site is an environment where students can seek out information, interact with each other by message board, and download resources for their project. Team members will collaborate with each other, using some kind of **shared collaboration space**, and they may do so synchronously or asynchronously. Such a collaboration space could be any combination of tools such as web site, ftp site, shared directories, basic talk and messaging tools, Lotus Notes™, CVS, ICQ™, Groove™, NetMeeting™. Products from their work-in-progress are stored in this space. Assessment is performed periodically by the subject coordinator, in order to ensure that teams are on-track with their projects. Because team members are distributed around the world, project teams meet with the subject coordinator using a chat/conference tool over the Internet, where he can perform a **team assessment**. Throughout the subject, students will have **work spaces**; these represent information environments where a student is engaged in getting some work done. A work space can be a student's email, but also a collection of documents that he or she is currently working on. Work spaces need not be digital—it could be a memo board, shared project journal—and they may involve ad-hoc collaboration with other people and their work spaces.

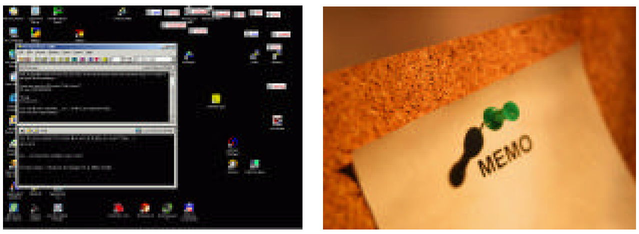

Fig. 11. ICQ collaboration space and work spaces as informational habitats.

How should we support these? Students may access virtual collaboration spaces from university computer laboratories, so there needs to be consideration of how the physical space supports such collaboration. Support for work spaces include physical areas where documents and other information may be stored, as well as virtual work spaces where electronic documents can be stored. Policies regarding this ought to be considered: are these work spaces shared, or are they considered public areas? Should informational habitats be strictly regulated so as to encourage students to have physical interaction? Should shared collaboration spaces be allowed to be accessed during lectures? We can see that the regulation and management of informational habitats derives in a significant way from policies and principles regarding the way the subject is run. These are conceptual issues, which include philosophical and cultural principles.

3.3 Conceptual habitats

Conceptually, the **subject** tries to cover a set of competencies—namely, learning about project management, team dynamics, virtual collaboration, hardware and software implementation. We can consider that there are two main **disciplines**, namely, project management and computing. Topics that are not central or complementary to these competencies have been excluded from the course schedule. There is a different **class** each time the subject is run and from each class, different **teams** are formed.

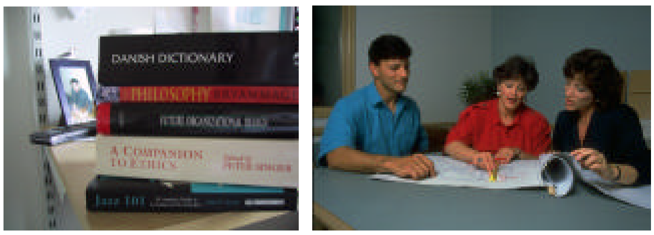

Fig. 12. Areas of competency/theory and groups as conceptual habitats.

The notion of *subject* and *discipline* describe groupings of knowledge that will define such practices as what will be taught, how students will think about their work, and how they differentiate themselves from other students taking other subjects and students in other departments. Within subjects and disciplines, there may be social culture that is passed on by lecturers and researchers (e.g. the culture of a humanities department is different to that of an engineering department). Physical habitats can be structured in a way to support the culture of a discipline or subject. For instance, some work places have corridors that support people running into each other, with whiteboards that allow people to stop, discuss and work on problems. There are alcoves where people can sit and talk.

The notion of *classes* and *teams* describe organizational groupings. It could be possible to create social habitats (a type of conceptual habitat, perhaps) where class and team members interact and bond together as a group. These organizational groups can be structured and reinforced through physical habitats (dedicated class-rooms and work areas for classes) and informational habitats (collaboration spaces for the class, separate collaboration spaces for the groups, noticeboard for the class).

3.4 It's The Big Picture

The discussion of the preceding examples illustrates the element of mutuality between the three dimensions. As each type of habitat is considered, it becomes natural to consider the relations between it and the other types of habitat. One cannot design a conceptual habitat without considering how and where it will manifest in physical and informational dimensions. Nor can you think of physical habitats without recourse to its conceptualization and attached information. That we consider the informational dimension of our world is comparatively recent activity in our history. While information has always been an aspect of our history, since sign systems were conceived, we have not focused on it as explicitly as we have in recent history. The consideration of conceptual and physical dimensions of artifacts has proceeded in a more conscious fashion than has our consideration of the informational aspects of artifacts.

With the advent of the information revolution, it is the informational dimension that is now the dominant factor under consideration in the creation of many artifacts and spaces that we inhabit, perhaps too much so. Yet it is also the informational dimension that is pushing us towards an understanding of the world as the convergence of these three dimensions, a more integrative view of the world around us. And it is in the interaction of habitats—both types and instances—and their inhabitants that we find the focus of the systems that we are contemplating and creating, rather than the static relationships and structures. "The play's the thing" (Shakespeare) is perhaps quite close to the reality of the situation.

3.5 Properties of Habitats

When reasoning about habitats, we can think of them as having particular types of properties. (The properties that habitats possess can be characterized in different ways (Andersen and Nowack this volume; Andersen and Nowack this volume).)

Intention. The insides of habitats are not context-free. Because of the relationship between a habitat and its inhabitants, the habitat must act in relation to the inhabitants, supporting their needs and their intentions. So although a habitat may not act with the same level of agency as an inhabitant nor could be thought of as having its own 'intention', it must be aware of and support the goals and telos of the inhabitants. In doing so, this will affect the purpose and behaviour of the habitat itself, how it relates to its inhabitants and to other habitats. It is an open question whether it is useful to consider habitats themselves as possessing intentions and goals.

Context. Because habitats are supporting the activities and life of their inhabitants, they must be aware of context within their boundaries. Beyond their boundaries, habitats are not islands unto themselves. Habitats are always placed in context to other habitats. In fact, habitats are not wholly self-sufficient, often relying on connectivity to a surrounding environment for support and also to make sense. This could just be seen as habitats being capable of being enclosed within another habitat—in this way, habitats can be treated as *objects*, not just as surrounding space.

Ontology. One of the fundamental facts of a habitat is that it ascribes a locality: separating *what is* and *what is not* the habitat (and therefore delineating what is within or without the habitat). As illustrated by the various examples in this chapter, the delineation of this boundary can vary for all kinds of reasons, but what is within the boundary exists within its own ontological space. The same rules do not apply outside the boundary of the habitat. Thus, habitats and their inhabitants share a certain expectation of how each other behaves, in terms of ontology. This distinguishes inhabitants from entities that enter habitats but are not capable of fitting into the ontology of the habitat.

Abstraction. We can apply principles of conceptual abstraction and modeling to habitats (Kristensen, May et al. this volume). In other words, we can apply principles of classification, generalization and aggregation. In this way, we can describe habitats at different levels of granularity, different levels of abstraction, as we need. We can also compose more complex structures of habitats containing other habitats, and other habitats in relation to each other. This makes habitats useful for describing aspects of the world and constructing artifacts in the world.

4 Habitats and Tangible Objects

As the previous section discusses, thinking of spaces as habitats confers certain advantages: we think of environments as evolving rather than being static, and we consider the design of human activity systems from the perspective of both environment and inhabitants (rather than emphasising one to the exclusion of the other). Such an approach is conducive to thinking about the digitally pervasive world, which is supposed to comprise technology and environments that are highly responsive to all manner of tasks in all kinds of contexts.

We consider habitats from the perspective of tangible objects: the digitally pervasive artifacts that we can create. An example of a digitally pervasive artifact is a smart badge that reveals its location or a PDA. We also envisage tangible objects such as those discussed at length in (Kristensen, May et al. this volume). We expect that tangible objects to have properties that complement those that are present in a habitat. Both are based on principles of growth and evolution, rather than specification and completeness, and as such, complement each other. There are a couple of key points in relation to pervasive computing from the perspective of tangible objects and habitats.

Firstly, tangible objects and habitats are about a ‘big picture’ perspective. Tangible objects actively engage with each other but also the habitat; the habitat supports tangible objects in their activity and also actively engages with them, evolving over time as a consequence of this interaction. Such interaction between inhabitants and habitats are a consequence of the TangO philosophy of seeking to capture the totality of the system's aspects. The implication for us is that systems begin to be considered less as highly structured, fixed and pre-determined structures and more as constantly interacting, dynamic and organic entities. In this way, they are closer to the original notion of system as conceived by systems theorists (Bertalanffy 1968). This idea of system focuses on the totality of interaction and the rich behaviour between all the elements—habitats, inhabitants, tangible objects. Again, it draws us to a view of system as ecology rather than machine.

Secondly, if we consider that tangible objects and habitats are really systems engaging in complex behaviour, then we expect to encounter emergent phenomena. Assuming we have tangible objects that possess adaptive and some level of autonomous behaviour and that these objects are situated in habitats that evolve and support activity between tangible objects, then we lay ourselves open to generative behaviour with the possibility of emergent properties. Domains such as art, generativity and emergence (McCormack and Dorin 2001) can be highly desirable outcomes, as the purpose is to surprise and create novel experiences for the observer. However, in the digitally pervasive world, art is only one such domain and there are many domains that pervasive computing will not be limited from. Domains such as business, manufacturing and medicine seek artifacts that display a greater measure of adaptability and intelligence than is typically experienced today, and yet often do not tolerate less than mission- or safety-critical performance (which may be difficult or impossible to guarantee in a system where emergence is a side-effect *or even a feature*). It seems an interesting and open question as to whether we are able to have our cake and eat it.

5 Concluding remarks

There are significant questions that arise if one takes habitat-based view of the world around us. What consequences do we reap if we take an organic approach to designing and growing environments? Evolution and growth takes time. Biological systems—which have long practised organic models of growth—are robust, but factor this in over many generations. This seems to challenge notions of creating physical and informational systems that are rapidly prototyped, highly tailored, developed in a short amount of time. There seems to be a clash of priorities and values. Habitats may also exhibit some kind of generative and emergent behaviour; this may be undesirable in the context of industrial and mission-/safety-critical systems. People and artifacts may need to perform to precise specification, else undesired consequences may arise. Perhaps habitats may need to be more rigorously defined in some contexts than others.

The interaction between inhabitants and habitats is a crucial point. We may be in the process of constructing a variety of complex habitats, intersecting each other and between the different dimensions. Such a lattice of habitats must be considered in relation to the trajectory of inhabitants through these habitats, for—unlike biological habitats—the inhabitants of man-made habitats leave and enter habitats as a matter of course. Inhabitants of biological habitats make the habitat their ‘neighbourhood’, where leaving it is leaving a locality that provides life-sustaining features. As we have tried to expand the notion of what a habitat is, we must also expand the notion of inhabitants and what they can do. For if we consider inhabitants in the everyday world—biological or artificial agents—then they can pass through and make use of many kinds of habitats.

The habitat is a useful abstraction for describing and understanding the different types of spaces we move through in our world. In designing systems for the digitally pervasive world, it is these spaces that we are trying to model and construct. In using orthogonal abstractions such as habitats to unify aspects of design, we are not merely catering for the designer but creating a common language that we can use to communicate with *all stakeholders* in the design process. Because the notion of system in the digitally pervasive world implies *an activity system*, users, agents and other stakeholders are vital—not just as people who will use the system but as inhabitants or actors in habitats that are part of the *system in evolution*. In the same vein, designers are also part of the evolving system.

The habitat abstraction does not capture something completely novel about the world and its different dimensions. It is an abstraction that tries to distil a fundamental set of characteristics about the spaces through which we move. It can describe ideas and concepts, but also informational environments and physical spaces. In doing so, it yields a measure of comprehension that bridges perspectives borne of different disciplines, perspectives that are traditionally disparate. The habitat also encourages us to think in a certain way: of context, situatedness and connectedness. It encourages us to think of the spaces we create as changing, mutable, heterogeneous and complex. It encourages us to be careful of making the mistake, often by many technologists, of abstracting to pure forms. As such, the habitat tries to give force to our view of designing for the digitally pervasive world, that in order for us to design effectively—for people, by people—then we need to be speaking a same kind of language that can adequately express the world around us.

Acknowledgments

Photos and clipart were used with permission from Stewart Brand and the University of Southern Denmark Library. Clipart from the Microsoft Clip Gallery was also used.

References

Abowd, G. D. and E. D. Mynatt (2000). “Charting Past, Present, and Future Research in Ubiquitous Computing.” *ACM Transactions on Computer-Human Interaction* **7**(1): 29-58.

Alexander, C. (1979). *The Timeless Way of Building*, Oxford University Press.

Andersen, P. B. and P. Nowack (2002). Tangible Objects: Connecting Informational and Physical Space. *Virtual Space: The Spatiality of Virtual Inhabited 3D Worlds*. L. Qvotrup. London, Springer.

Andersen, P. B. and P. Nowack (this volume). Modeling Moving Machines.

Andersen, P. B. and P. Nowack (this volume). The Space is the Computer.

Arnold, D., B. Segall, et al. (1999). *Discourse with Disposable Computers: How and why you will talk to your tomatoes*. Usenix Workshop on Embedded Systems (ES99), Cambridge, Massachusetts.

Bertalanffy, L. v. (1968). *General system theory : Foundations, development, applications*. New York, George Braziller.

Bradshaw, J. (1997). *Software Agents*, AAAI Press/The MIT Press.

Brand, S. (1994). *How Buildings Learn: What Happens After They're Built*, Phoenix Illustrated.

de Geus, A. (1997). *The Living Company*, Harvard Business School Press.

Ducheneaut, N. and V. Bellotti (2001). "E-mail as Habitat." *interactions* **8**(5): 30-38.

Engeström, Y., R. Miettinen, et al., Eds. (1999). *Perspectives on Activity Theory*. Cambridge, Cambridge University Press.

Fitzpatrick, G., S. M. Kaplan, et al. (1996). *Physical spaces, virtual places and social worlds: A study of work in the virtual*. 1996 ACM Conference on Computer Supported Cooperative Work (CSCW'96), Boston MA.

Gamma, E., R. Helm, et al. (1994). *Design Patterns: Elements of Reusable Object-Oriented Software*, Addison-Wesley.

Hallenborg, K. and B. B. Kristensen (2002). *Pervasive Computing: Mapping TangO Model onto Jini Technology*. The 6th World Multiconference on Systemics, Cybernetics and Informatics, Orlando, Florida.

Kelly, K., A. Heilbrun, et al. (1989). Virtual reality: an interview with Jaron Lanier. *Whole Earth Review*: 108-119.

Kristensen, B. B., D. C.-M. May, et al. (this volume). Conceptual Abstraction in Modeling with Physical and Informational Material.

Lehman, M. M. (1980). "Programs, Life Cycles, and Laws of Software Evolution." *Proceedings of the IEEE* **68**(9): 1060-1076.

May, D. C. (2001). *Building the Cultural Artifacts of the Organization*. Proceedings of the European Conference on Pattern Languages of Programs, Irsee, Germany.

May, D. C., B. B. Kristensen, et al. (2001). Tangible Objects - Modeling in Style, Aalborg University.

May, D. C., B. B. Kristensen, et al. (2001). *TangO: Modeling in Style*. Proceedings of the Second International Conference on Generative Systems in the Electronic Arts (Second Iteration - Emergence), Melbourne, Australia.

McCormack, J. and A. Dorin (2001). *Art, Emergence, and the Computational Sublime*. Second Iteration: Proceedings of the Second International Conference on Generative Systems in the Electronic Arts, Melbourne.

Nardi, B. A. and V. L. O'Day (2000). *Information Ecologies: Using Technology with Heart*, MIT Press.

Rosenfeld, L. and P. Morville (1998). *Information Architecture for the World Wide Web*, O'Reilley & Associates.

Shakespeare, W. *Hamlet*. Act 2, Scene ii.

Simpson, J. A. and E. S. C. Weiner, Eds. (1989). *Oxford English Dictionary*. Oxford, Clarendon Press.

Sterling, B. (1993). *The Hacker Crackdown: Law and Disorder on the Electronic Frontier*, Bantam Books.

Taylor, F. W. (1911). *Principles of Scientific Management*. New York, Harper Bros.
Thackara, J. (2001). "The Design Challenge of Pervasive Computing." *interactions* **8**(3): 46-52.
various (1999). "Pervasive Computing." *IBM Systems Journal* **38**(4).
Weiser, M. (1991). "The Computer for the Twenty-First Century." *Scientific American* **265**(September 1991): 94-104.
Wurman, R. S. (1997). *Information Architects*, Watson-Guptill Publications.