Pervasive Computing and Space

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Abstract: Changes between Accessibility space and Physical space is a major factor in the “pervasive computing scenario”. An example of this type of change, drawn from the maritime domain, is presented. The case is used to suggest concepts and notations for understanding the change. Finally, I argue that skills developed for adapting traditional stationary signs to their physical surroundings can be exploited in the mobile ones as well.

Key words: Pervasive computing, Tangible objects, Accessibility space, Physical space, Conceptual space, Maritime automation.

1. INTRODUCTION

This paper addresses the technological scenario that is normally described by terms such as pervasive computing or embedded systems (May et al. 2001, Andersen & Nowack, to appear, Bergman 2000).

The scenario predicts that the following will become true in the future:

Our daily environment will contain a network of more or less specialized computational devices that interact among themselves and with us. These devices will be distributed in the physical space around us, they will have a higher degree of autonomy than we are used to, and they will increasingly serve as a medium for cooperation and communication among humans. Some of these devices will be moveable and travel together with humans while others will be stationary. Since the devices will be located in many places and some of them will be able to move, they must be sensitive to their context of existence—their *habitats*. These habitats will typically be a combination of three spaces: the *physical*, the *informational* and the *conceptual* space. For example, May et al. (2001) envision that an intelligent

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book will behave differently when it is in the bookstore, in the library, or in the home.

The main point is that our relation to computers will no longer be distinct and separate from other activities: rather we will be “embedded in a sea of computation”.

In this paper I shall give an semiotic analysis of the three involved spaces and I shall show that forerunners of the scenario has been in existence for a long time. My empirical examples will be drawn from a project on maritime instrumentation I am currently conducting at the Danish Center for Human Machine Interaction (CHMI; reports can be found in <http://www.cs.auc.dk/~pba/ReportList>). Ship instrumentation is not a typical example of pervasive computing, although one can consider maritime systems as embedded and moveable systems. However, the maritime domain has the advantage that the interaction between the three spaces can be studied empirically, which, for very good reasons, is not the case with our hypothetical scenario.

2. SPACES

It follows from the nature of pervasive computing that physical space acquires a new significance, compared to traditional systems. Whereas a bank system may be located anywhere and needs not move if the bank moves, a car's cruise control system must move with the car, and the PDA must move with its owner if it is to be any good. However, like all other computer systems, pervasive systems still live in an informational space that is defined by the logical connections the system can make to other systems. Pervasive systems thus live in two kinds of spaces, and the main point of the paper is that the interaction between these two spaces will change, and, as a consequence, will change a third space, the conceptual space.

The reader may by now have qualms about the notion of “space” employed. Is informational and conceptual space not just loose metaphors? In this section I shall try to precisely define what is meant by the notion of space, and how the three kinds of spaces differ. The main point is that the notions of *dimension* and *distance* can be defined in all three cases, and this is what motivates the common concept of space. However, the physical distance concept is metric, and thereby differs from the corresponding informational concept that is not metric.

I define a space as a collection of points with geometry-like properties. On such property is the notion of *distance*. If the distance between two points are given by a definition or constrained by a set of axioms, the distance between two collections of points P and Q , $d(P,Q)$, can be defined

as the smallest of all the distances between pairs of points in P and points in Q.

Spaces come in many types. A *metric* space is a space where the distance property obeys the following three equalities:

$$d(P,Q) = 0 \text{ iff } P = Q \quad (1)$$

$$d(P,Q) = d(Q,P) \text{ (symmetry)} \quad (2)$$

$$d(P,Q) + d(Q,R) \geq d(P,R) \quad (3)$$

The normal physical Euclidean space is metric since distance here is defined as:

$$d(P,Q) = \sqrt{(x-a)^2 + (y-b)^2 + (z-c)^2}$$

Thus a physical space is a continuous three-dimensional metric space.

2.1 Accessibility spaces

What, then, is an informational space? The objects in such spaces consist of bits and the actions in the space comprise the normal data processing operations. But are bits not physical entities? No, they are more abstract. We cannot equate a web-page with its physical existence on a computer, since it makes sense to say that the “same” page can appear on millions different computers, and that it is the same page, even if the web-clients display the page differently. We can say that the informational space describes the structure and processes that are taken as invariant over a set of physical realizations. Semiotically speaking, the informational space is a *form* concept. In particular, information space is identical to the *expression form* in the sense of Hjelmslev 1963, i.e. the invariants underlying the different physical manifestations of our means of expression.

In HTML the unit “heading 1” belongs to the informational space, but its exact shape (font size, font type, bold/italic/normal) on a particular machine does not. This is completely analogous to the fact that a particular phoneme, say /e/, can be manifested as ink on a paper or as a waveform of sound, and that each of these variants may have many subvariants, depending upon the sociolect and dialect of the speaker.

Another similarity between informational space and the Hjelmslevian notion of form is that in both cases the units are only defined by *differences*. The only important features of “heading 1” and “heading 2” in HTML is that they are represented by two different bit-patterns so that the browser can react differently to them. The exact bit-patterns are irrelevant.

In exactly the same way, the only important property of the language elements /e/ versus /i/ is that they are marked as different. It is irrelevant to a form description that this difference in spoken language is realized as a different formant structure, in written language as different strokes, and in Braille as different configurations of dots.

Summarizing, we can say that the informational space contains the invariants of the means of expression realized in physical space. The physical space is the expression *substance*, the informational space the expression *form*. Slightly differently worded: informational space contains the *syntactic* layer of the computer based sign (cf. the syntactic level of the semiotic ladder in Stamper 2001: 128) where the means of expression are structured, changed, and transported.

I shall focus on one particular aspect of informational space — the aspect that makes it relevant to talk about a space at all, namely the *accessibility* relation.

A syntactic description includes a description of contiguity relations: which parts belong together with which parts? Is part A to the right or left of part B?

However, instead of contiguity I shall use the broader term accessibility. A term B is accessible to term A, if properties of B can influence the behaviour of A. The reason for replacing contiguity by accessibility is that B will often influence A even if they are physically distant. For example, data on a server in Tokyo can influence the page on my computer in Denmark if it is accessible to my www-browser because its URL is available.

The relation “B is accessible to A” is reflexive and transitive but not symmetric.

The *path* from A to B, $path(A,B)$ and the *distance* from A to B, $d(A,B)$, can be defined as follows:

1. $Path(A,B)$ = a set of points $x_1...x_n$, such that $x_1 = A$, $x_n = B$, and $Accessible(x_i, x_{i+1})$, $1 \leq i < n$. Thus the path consists of a set of points where the next point is accessible to the previous one.
2. $d(A,B)$ = the number of points in the smallest path from A to B, not counting A. Thus, if B is directly accessible to A, the distance from A to B is 1.

Since the accessibility relation is not symmetric, accessibility spaces are not typically metric. In Fig. 1 the distance from A to B is 1, but from B to A it is 2. Furthermore, accessibility spaces are not *continuous* as physical space

but *discrete*. It does not make sense to use reals to measure distances in accessibility space: how can the distance between web-pages A and B be 4.67?

Figure 1. Non-metric accessibility space

To a large degree, the change envisioned consists in a changed relationship between accessibility space and physical space. However, before we become overawed by the dazzling new world which computer industry opens for us, we should realize that the existence of interlinked accessibility spaces and physical space is a very old invention!

The imposition of roads — a non-informational accessibility space — upon physical nature is probably the oldest example of the effect of superimposing accessibility spaces onto physical spaces. The many traffic networks of modern society — bus routes, railroad tracks, flight schedules — provide a huge number of additional examples.

We have in fact invented various types of signs for representing their interrelations. In geodetic maps with the road net superimposed, the physical space is superordinate, and the accessibility space must adapt. Route diagrams, on the other hand, are primarily representations of an accessibility space, defined by the accessibility of stations via trains. The physical space is adapted to the accessibility space to give a rough indication of physical distances, but they cannot be trusted.

Another domain to learn from when designing the pervasive technology is the skills developed for designing and placing stationary signs. Although these signs do not move, their designers have taken great care to adapt them to their social and physical surroundings. A good example is the signposts of railway stations and airports. In such locations, the designers can make a good guess at the tasks and information needs customers will have when located on specific time-space coordinates.

2.2 Signs, time and space

When skilled architects design signposts, they make the signs sensitive to their habitat in two ways:

- They provide the information needed by people located in that specific time-space habitat.

- They use the habitat as part of the meaning of the sign. The sign borrows part of its meaning from its context.

In Fig. 2, the sign “Århus H” has a size and placement so that it can be seen by passengers in arriving trains, because some of these passengers want to get off at this station and therefore need to know its name.

Furthermore, the representation is interpreted as a proposition, “*This* place is called Århus”, but the object referred to is determined by the physical location of the sign. If placed in Aarhus central station, the proposition is true, but if the sign is moved to Hamburg Hauptbahnhof, the proposition expressed by the self-same sign is false.

Figure 2. Attaching signs to space. This place is called “Århus”

Fig. 3 is controlled by a computer system and is placed at the entrance to two platforms. The information presented on the screens is related to the place — trains leaving or arriving at this platform — and the time — trains arriving or leaving within a time window of a few minutes. Before the passenger got so far, he passed a similar screen in the hall that gives information about *all* trains leaving or departing from *this* station around *this* time. And when he gets down to the platform, he will notice Fig. 4 telling him that *this* train is going to Struer *now*.

Figure 3. Attaching signs to time. At this time trains are leaving for Struer at these platforms

Figure 4. Promising. This train is going to Struer

The same attachment between space-time and information would be useful in a future situation where the sign moves with the passenger. Suppose for example that passengers were given a PDA as an electronic ticket at the check-in at an airport. This PDA has the advantage of knowing the flight number of the passenger, so it can both give traditional context-sensitive information about the placement of the lounge and the way to the correct gate, adapted to the passenger's current location, but in addition it can inform about the process of boarding (*gate open, boarding, gate closed*, and possible delays) and it can replace the loud-speaker calls, which are difficult to hear and may easily be missed, by a personal message to the passenger concerned.

The point is thus that there is a lot to be learned from well designed stationary signs when designing the mobile ones.

2.3 Conceptual space

The existence of two spaces, the accessibility space and the physical space, thus turned out to be an old story with well-established conventions. We now turn to the last space, *conceptual* space.

	Male	Female
Child	boy	girl
Adult	man	woman

Figure 5. Semantic field of person designations

In which sense can we talk about a conceptual space? There is in fact a long tradition in semantics for doing so. A popular representation of word meanings is the *semantic field*. A semantic field consists of one or more dimensions. A dimension represent a property and the points on the

dimension the values of the property. Fig. 5 shows a popular textbook example.

There are two discrete dimensions, *age* and *gender*. Each dimension has two values, *adult/child* and *male/female* respectively. The purpose of semantic analysis is to find dimensions and values that recur in many different words (for example *calf/ bull/cow*). The values of the dimensions used to distinguish word meanings are called *semantic features* or *semes*.

It is not difficult to define measures of *distance* between concepts. One method is to count the number of operations of adding and deleting features that are necessary for going from one lexical meaning to another. Thus, the distance from *human* to *man* is two since we need to add *adult* and *male* to get from *human* to *man*. The distance from *animal* to *man* is 4 since we must remove *non-human* and add *human*, in addition to adding *adult* and *male*. Finally, the distance between *man* and *woman* is 2 (remove *male* and add *female*) whereas it is 4 between *man* and *girl* (remove *male* and add *female*, remove *adult* and add *child*).

Some authors have taken the spatial idea very seriously and begun investigating the possibility of different geometries for different domains. Gärdenfors 1992: 58 offers Fig. 6 as a representation of the property space for colour adjectives. The dimensions are *hue*, *saturation* and *lightness*.

How should we interpret such models? One possibility is to use the same idea as we did in the case of the physical space and accessibility spaces: superimposition.

Thus, semantic fields describe the way linguistic distinctions are projected onto the physical and social world we live in, in the same way as the accessibility space of railways can be projected onto a Euclidean plane.

Semantic fields embody the same form/substance distinction we met previously in the domain of the means of expression. The semantic substance is the domain of discourse, for example trees, forests and woods. This substance is defined by choosing the dimensions of the field. The lines drawn in the fields represent the semantic form (Hjelmselv: content form): they symbolize how a particular language divides and articulates the substance. For example, English makes a distinction between large and non-large collections of trees (*forest/wood*) which Danish does not have. Both languages distinguish between *units* and *material* but in a different way: *wood* in English can be used both of a *collection* of trees and the material, whereas the term for the *individual*, *træ*, is the one used about the material in Danish.

The distinction between the content and expression planes of a sign is a functional one: there is nothing inherent in sounds that categorizes them as a means of expression. In fact, we can easily make sounds our topic of discourse ("Dropping the h's is vulgar"), or, conversely, use pieces of wood

as our means of expression (“the hiding place is marked by two crossed branches”).

Many interesting problems have been addressed in relation to conceptual spaces. One long-lasting discussion concerns the nature of the boundaries. Are boundaries like lines or planes that divide the space into clear-cut sections, or are the spaces organized according to other principles? For example, colour terms do not seem to have sharp boundaries but seem to be defined by their focus, i.e. a colour area that is seen as typical of the term.

[...] some, at least, of human categorization is not in terms of sharp boundaries, but rather in terms of well-defined foci with hazy (fuzzy) boundaries[...] *Comrie 1995: 38*

Figure 6. The colour space

3. PHYSICAL SPACE, ACCESSIBILITY SPACE, AND CONCEPTUAL SPACE IN THE MARITIME DOMAIN

In this section we shall give a real example of the interplay between physical space, accessibility space, and conceptual space. It is taken from the maritime domain.

One of the most important processes in modern ship design involves physical space and accessibility space. The main tendency is that the accessibility space has grown because remote control and remote sensors were introduced.

Fifty years ago, the accessibility space of the individual officer was rather small, so being in one physical position prevented the officer from many tasks. For example, when the captain was placed at the wheel on the bridge, he could neither control the engine, nor fix the ship's position in open water, or judge the distance from pier to ship during berthing.

These tasks had to be cooperative, since they require people to be at two different positions, which is (not yet) humanly possible.

Consider for example the cooperation between engine room and bridge. In older ships, the controls of the engine were placed in one location, and the rudder, machine telegraph, and windows were located in a different place. If one man was to control the ship, he would have to be at two different places at the same time: at the bridge and in the engine room. Since this is impossible, a division of labour was established between the engine and the bridge.

Figure 7. Old-fashioned Machine telegraph. The orders to the chief are communicated by pressing buttons

In order to make this cooperation efficient, a new artefact was introduced, the machine telegraph (Fig. 7):

a bell system relayed bridge commands to the engine room, where the engines were manually adjusted to meet bridge orders. Now, direct control from the bridge allows the deck department to implement engine speed changes directly. In addition, displays on the bridge convey data that were once only available to the engineering department. *Lee & Sanquist 1996: 367*

Thus the importance of captain-chief cooperation was greatly diminished when the remote-control telegraph appeared, allowing the captain to by-pass the chief and himself control the engine (Fig. 8).

Figure 8. New remote-control machine telegraph controlling two propellers

A similar development happened with many other tasks.

Take position fixing. In Hutchins 1996, the Watch Standing Procedures on an American naval ship require the cooperation of four people: two pelorus operators placed outside, one in each side of the ship, a recorder recording the position in the log, and a plotter marking the position in a map. Positions were taken each 3rd minute.

Modern ships do not use alidades to get bearings. Instead the ARPA is used. An ARPA is a computer enhanced radar that can track the dots on the screen, and combine information from the ship's gyro and GPS to produce bearings and distances: if the radar spot can be identified with a landmark on the paper map, the ship's position can be plotted on the map relative to the landmark. This operation can be done by one person, but it is still not possible to steer the vessel and fix positions in trafficked areas. The reason is that the large paper map is located on a table that cannot be accessed from the steering console.

In some ships paper maps are still in use, but in others position fixing has been centralized to the central computer consoles which makes it a one man job to steer and fix position.

A radical development of these tendencies can be seen in some fast-ferries. Lookouts during berthing has been made superfluous by remotely controlled cameras, the whole engine staff has been moved from the engine room to the bridge (Fig. 9), all displays of the engine state are available on the bridge (Fig. 10), and information is centralized in front of the two officers whose surroundings look more like an airplane than a normal bridge.

Several countries are working to develop fully integrated bridges that combine elements of all these automated systems to produce an integrated suite of navigation and ship control aids. These changes may

make it possible for a single person to act as the helmsman, lookout, and watch officer. *Lee & Sanquist 1996: 366*

Figure 9. Combined engine room and bridge

Figure 10. Trend diagrams from engine department

This is a major change of accessibility space, and it has had very tangible effects on the physical and the conceptual spaces. Firstly, it has changed the knowledge requirements of the officers: in Denmark, for example, the maritime curriculum has recently been changed, so that the students are both trained as engineers and officers, cf. also Lee & Sandquist:

These changes may introduce new knowledge requirements regarding interpretation of engine room data similar to those found in the process control domain. [...] The captain of this particular ship said that having an unattended engine room during voyages greatly increases his stress level.

Lee & Sanquist 1996: 367-366

In addition, it obviously changes the cooperative patterns of the ship: what was before accomplished by a group of cooperative persons can now

be done by one individual. However, cooperation does not disappear, it just changes:

The design of automated systems is really the design of a team and requires provisions for the coordination between machine agents and human practitioners. *Woods 1996: 5*

As for changes of conceptual space: merging the engine room and the bridge is a major re-conceptualisation of maritime organization. For a long time, ships had two kings, the captain and the chief engineer. Although formally the captain was in charge, in reality the chief reigns supreme in the engine. His job is to produce the power, and the captain's job is to spend it. In my experience, there is not much communication between the two kingdoms, except politeness information from the captain about changes in the demands on the engine.

The maritime domain thus gives an existing and very clear example of the interaction between our three worlds: the main purpose is to reduce crew size which means circumventing the cooperative arrangements necessitated by the physical space of the ship. This is accomplished by increasing the accessibility space, which again causes changes in the demands for qualifications and in the organizational units of the ship.

4. REPRESENTING THE SPACES

In this section we shall suggest a method for representing the interplay between the three spaces described in Section 3 by means of the concepts defined in Section 2.

Physical space. This space contains the location and movement of persons and objects plus the physical cables connecting them. Furthermore it specifies mobility properties: which objects are attached to which objects.

Why not keep using the good old-fashioned map to represent physical space? Fig. 11 and 12 show a typical change in the maritime domain. In Fig. 11 only the rudder is remotely controlled: engine and lookout must be taken care of by other persons who must cooperate with the captain. In Fig. 12, engine plus lookout locations have been connected to the bridge.

Figure 11. Before

Figure 12. After

- *Accessibility space*. This space contains human and non-human actors and the paths mediating between them. We distinguish between the following categories:
- *Actor*: human or non-humans that can initiate actions . Persons or automatic systems.
- *Medium*: a *symbolic* mediator that mediates between an actor and its object of work or interlocutor . Controls, displays, natural language, protocols.
- *Machine*: a *physical* mediator that can exert force when started (controllable force) . Main engine, rudder engine, thrusters.
- *Environment*: physical factor that can exert force but cannot be controlled . Wind, waves, coastlines, grounds.

The distinction between controllable and uncontrollable forces is special to the maritime domain: manoeuvring is the art of pitting the controllable forces against the uncontrollable ones to achieve one's purpose (DMI 1995: 1).

We distinguish two types of accessibility relations:

- *Instrumental mediation*. Direct influence: the receiver of information A reacts mechanically and predictably to the information $\longrightarrow^A$
- *Semiotic mediation*. Indirect influence: the receiver of information A tries to understand the intention and decides his own reaction from this understanding. $\longrightarrow^A$

Machines normally implements instrumental mediation, humans semiotic mediation. However, in some cases, humans may react as machines.

See Fig. 13 – 16 for typical examples.

Figure 13. The user controls the machine and evaluates the displays. Using the machine-telegraph to control the main engine

Figure 14. The user reads a display provided by a sensor. Using the ARPA to view radar images of the environment

Figure 15. The user discusses with another user. Talking to the VTS

Figure 16. A medium can be the object of work for another medium. Controlling remote cameras

Fig. 17-18 present examples of accessibility changes. New connections are marked as bold. Originally, engine control involved a path of length two: captain signalling to chief and chief manipulating engine controls. Later the captain got direct access to engine controls and displays. The distance between captain and engine has decreased by one. The lookout case is similar: from communicating with a lookout with direct visual access, the captain gains a mediated access to bow and stern by means of cameras.

Conceptual space describes how actors view their work situation: the way the workplace is segmented, the patterns of behaviour, cooperative forms, individual qualifications, and information needs.

Figure 17. Engine control

Figure 18. Lookout

When the engineers moved up on the bridge in Fig. 9, the distinction between engine and bridge, which before involved both spatial and organisational position, is reduced to only organisational features. A similar example: some decades ago the social hierarchy on a ship was spatially marked at dinner time: officers had one messroom, the engineers another, and the plain sailors a third one. Nowadays all ranks tend to eat together.

Which forces cause the changes described above? We can divide the factors of work into two large groups (Lind 2000): The objective *opportunities* (the number and type of tools, machines, persons; physical space and accessibility space) and the subjective *capabilities* (skills, knowledge, and cooperative patterns).

When actors pursue a goal they will experience that the two set of factors match or mismatch. If they mismatch, one or more factor must be changed. Similarly, if one desires to change one factor and still pursues the same goal, other factors must be changed.

In the maritime domain, ship owners desired to decrease the number of employees while maintaining the safety goals and making production more efficient. Thus, there is a change of opportunities: fewer persons, and this creates a mismatch. A traditional ship cannot be manoeuvred by half the crew without jeopardizing safety, and therefore we got the big changes in accessibility space, enabling the individual to access more controls and displays than before. This again causes a change in the conceptual space: the engine and the bridge can no longer be conceived of as two separate departments. They are slowly merging, in education as well as in tasks and physical location: a change of capabilities.

The development will probably go much further: accessibility paths will be inserted between the ship and the harbour authorities, each party gaining access to the other party's information systems. Control relations will change so that harbour authorities gain more power over the ship inside the harbour's jurisdiction (as is the case in air traffic and railways). Furthermore, land-based specialists may gain access to the ship's data and assist in repairing faults and managing accidents from afar.

This again will cause changes in the self-image of the captain. The current role as "king of the ship" will change, and new cooperative patterns between captain, harbour authorities and land staff will emerge.

5. INTERACTION BETWEEN SPACES

Thus, the three spaces seem to form a circular pattern of mutual influence. Since we have described all three domains as spaces, it makes sense to look for functional dependencies between them. In the maritime case the following equation seems to hold:

- The number of persons physically aboard a ship is inversely proportional to the number of paths in the accessibility space.

Many well-known conjectures do in fact have this form. Some examples:

- Movement in physical space is inversely proportional to the number of paths in the accessibility space. Increased use of IT is expected to decrease the number of physical travels. Whether this is true or not is not known.
- The degree of centralization in physical space is inversely proportional to the number of paths in accessibility space. Increased use of IT is expected to enable employees to move into the country and work at home via telework. Whether this is true or not is not known.

Other conjectures relate physical or accessibility space to conceptual space:

- The number of paths in accessibility space is expected to be inversely proportional to the fragmentation of conceptual space. Few contacts between subcultures are expected to give rise to differences in their semantic fields. That accessibility is related to linguistic diversity seems to be a well-established linguistic fact.

6. CONCLUSION

In this paper I have argued that changes between accessibility space and physical space is a major factor in the “pervasive computing scenario”. I have presented an existing case from the maritime domain and have used this case to suggest concepts and notations for understanding such changes. Finally I have argued that skills developed for adapting stationary signs to their physical surroundings can be exploited in the mobile ones as well.

In this conclusion I shall characterize the phenomenon of pervasive computing from two points of view, the Peircean and the Saussurean.

From a Peircean point of view one can simply say that pervasive and mobile computing tend towards producing *indexical* signs, cf. Section 2.2. This happens in two ways. Firstly, since the sign can be adapted to its physical context, parts of its meaning can be located in the surrounding space, as in Fig. 2-4. Computer based signs acquire *deictical* variants

referring to the device itself, as we already know it from pronouns such as *I*, *you*, *here* and *there* (Fig. 19).

Figure 19. Magellan 750M Mobile navigation system denoting its own position “I am here”

Secondly, causal connections between object, representamen, and physical space emerge. A mobile PDA can move in accessibility space by accessing different information services (and, as any mobile phone owner knows only too well, the accessibility space depends upon its location in physical space), but it can also move in physical space and adapt its representamen to particular locations: for example, in an airport it can use GPS information to determine the user's position, and display the correct gate to check in when the passenger is in the entrance hall but display a map guiding him to the correct gate when waiting in the departure hall. In addition, the object can influence the representamen by means of transponder signals: shops may broadcast advertisements to the by-passing PDAs, and, conversely, the representamen may influence its object as it has always been the case in process control: for example, the buttons on the House Automation System may turn off the lights, lower the temperature, and close the shutters. Fig. 20 shows these causal paths.

Figure 20. Causal paths in pervasive and mobile appliances

With Saussurean/Hjelmslevian spectacles, we can observe a closer connection between the expression form and substance. As already mentioned, the Hjelmslevian version of the sign is built upon an association between two set of distinctions, the *content form* that indicates how we articulate our social world (content substance) and the *expression form* that indicates how we use properties of objects and processes in our world (expression substance) to signify semantic distinctions. The *purport* is the world at large, conceived of as a continuum without inherent distinctions.

In the non-mobile world, the same computer would run a large number of different applications that — to a larger or smaller extent — can access each other's data, but only within informational space. The computational objects are *intangible* and their physical location does not matter.

In the future scenario, dedicated programs run on dedicated devices; there are many devices and they can sense each other. Thus, in a sense, the interaction between computational objects has become *embodied*, since the device itself can be read as a sign. This is not possible on traditional PC's that are characterized by their huge versatility. Anything can run on a PC, and the physical shape and location of the machine provides no clue as to its current function.

From a HCI point of view, this means that we can motivate the physical design better, e.g. the shape of the appliance and its physical buttons, by their intended meaning. This is seldom possible with general-purpose PC's.

The maritime situation represents an intermediary state. On the one hand, the ship is stuffed with devices: sensors, actuators, processors, controls and displays. But the strategy is still to implement accessibility as software properties that are inaccessible to the users. A major challenge to design is to design the tangible objects of the future in such a way that users can understand their interactions and can predict what will happen if one is added or taken away. This is not possible with the current intangible objects. "How can we see what is left when the GPS falls out", as an officer on a fast-ferry said. A good design of tangible objects might alleviate this problem. Exchanging intangible with tangible physical objects may even possibly enable officers to do small repairs themselves, since the repair would consist in replacing a physical device, and not in correcting code. This would be in line with the proud old maritime tradition of self-reliance. In principle, the crew ought to be able to find a way out of every calamity, since, at least in the good old days, there were no one else to do it. This tradition is currently threatened by the introduction of computers: if the computer breaks down, nobody is able to fix it.

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