Mapping Interactions in a Pervasive Home Environment

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Abstract. This work focuses on the visualisation of interactions in a pervasive home environment. Home as a space and as an activity container is traditionally linked to the habitual acts of the inhabitants. However, the infiltration of wireless connectivity, throughout the home and external to it, suggests that, in contrast to the traditional notion of hominess, we as inhabitants do not have the means to perceive significant data connections that take place throughout our home. These connections may range from simple data transfer to sensing and decision making, all taking place around our home and unseen. To this end we have tried to find the means to represent these connections in a visual way, in order to provide a tool that will help to reveal the structure, form and perplexity of digital connections to the inhabitants of a pervasive home environment. The study concludes that in order to visualise all this data, maps have to be formed that include both the material and immaterial infrastructure of home, as well as the connection between them and the rest of the world. These maps are bound to have the characteristics of centralised, distributed and decentralised networks, rendering them as hybrid maps, depending on the type of information they deal with.

Keywords: pervasive home, cartography, visual representation, spatial concept.

1 From the Shrinking of Physical Space to the Digital Expansion of Home Space

We are witnessing a drastic change in the organization and the characteristics of domestic space. The international trend for less physical home space, that follows the need to minimise energy consumption, brings out lighter forms of housing [1]. Many current examples and initiatives such as *pocketliving* or *micro-homes* point to the same direction. During the last decade, architectural publications and design trends thrive with titles dedicated to small/minimum/tiny/portable/flexible homesetc., which shows that architects and designers have been incorporating and advocating the idea of shrinking living quarters, reflecting a wider social anxiety for a sustainable future. The situation is reminiscent of the conditions that led to the design ethics and construction of the modernist housing schemes in post-war Europe [2].

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Since recorded time, affluent societies considered that the inventory and collections of objects in the home played a central role in the definition and cultivation of the family's identity, however, 20th century consumerism culture has rendered it as a massive phenomenon. In The Meaning of Things [3], the authors explain how certain categories of household possessions were more valued for the symbolic and emotional meanings they embodied and that those possessions changed with age and gender. The excessive materialism of that period led to an increasing need for domestic space that could house collections of personally valued objects. Research has shown that while families in developed countries tend to be smaller, the average size of homes had been increasing up to the year 2000 [4]. In recent years, however, we are witnessing a reverse trend as research shows that in most developed countries the changes in family structure have led to a decrease in the size of the average household [5]. The physical contraction of the domestic envelope means that households can afford less material possessions, so in many cases possessions with limited function or functionality are left out.

Domestic space also becomes, less physically significant perhaps because daily life increasingly focuses around a series of digital habits and objects. Recent research shows that the new class of global nomads forms "situational attachments to objects, appreciate objects primarily for their instrumental use-value, and value immaterial or 'light' possessions as well as practices."[6] They clink to portable and replaceable possessions, especially portable electronics that enable them to stay connected to networks, as they tend to value accessibility more than the object's value per se. As consumerism shifts more to the purchase and storage of digital artefacts, and as we increasingly base our daily activities on digital media, our dependence towards the physical space of home and its objects possibly weakens. The condition of *existenzminimum* (minimum existence), apart from being a necessity and the product of planning strategies, appears as a desirable choice for contemporary city dwellers [7]. According to Aaron Betsky's view, contemporary home can be thought of "as a storage device containing all the domestic products by which we extend our body into the world". For him, we no longer inhabit homes, but they are primarily "places where such objects are collected"[8, p.43]. However, today the number of physical artefacts in a home decreases, as the number of digital artefacts increases,

In contrast to the physical shrinking of home and the diminishing of its possessions and material substance, we experience an infinite expansion of the its operational and sensorial reach, which is more than ever connected to the global thoroughfare. The digitisation of daily life signifies a huge expansion of the domestic realm, far beyond the physical territory defined by the enclosure of the building envelope. At the same time, the division of work and public life from home, and the concepts of free time and privacy, products themselves of the industrial revolution and modernity, are transforming into very thin permeable layers in our daily routine, as we return to a pre-industrial condition where home space becomes, under certain circumstances, inclusive and less private.

In a sense, the evolution of domestic space is analogous to the evolution of many technological products that moved from cumbersome and materially saturated objects with limited functionality to minimised ultra-thin devices with far infinitely complex

functionality and connectivity. However, home is not a gadget. This antithetical transformation (physical contraction and operational expansion) of contemporary domestic space augmented with communication and ambient technologies is at once destabilising and de-territorializing the nature of home. If the loss of stability, the augmentation of capacities, or the effort to internalise the effects of the acquisition of new skills is a cause of de-territorialisation of personal identity [9, p.50], then the same might apply to home, the "mirror of self" [10]. The aforementioned transformations have a profound impact on the way domestic space itself is ordered, rendering whatever order there seems to exist obscure and hermetic. Dwelling, unlike the Heideggerian definition of gathering and preserving the fourfold in a place– is being gradually replaced by a kind of multiple, fragmented and provisional inhabitation.

Home becomes a hybrid place. As it becomes increasingly open to other activities (work, education, leisure, healthcare, commerce, etc.), and connects to disparate places, times and cultures, these different cycles and routines get mixed. This multiplication of functions in the home delivers interior spaces supporting daily routines as obscurely and chaotic ordered as the urban sprawl of our cities. For example, the modernist purely functional classification, and ordering of rooms [11] according to their use (e.g. bed-room, bath-room, living-room, dining-room, etc.) seems irrelevant as spaces may support varied and multiple activities other than the basic daily ones.

In addition to its programmatic multiplication, home faces another challenge: the fragmentation of its place and the distribution of inhabitation to disparate places simultaneously or periodically. The destabilising of the traditional family structure, extremely mobile and flexible working patternsand other social phenomena lead more people to adopt nomadic lifestyles. Christos Papoulias' project "Dispersed House" proposed a house whose functions have been dispersed into the fabric of the metropolis, as a reflection on fragmented metropolitan living, and "a search for the end of the unified house" [12]. Actually, the fragmentation of the domestic space is nothing but a by-effect of the individualisation of society, where communities are fragile, short-lived, scattered and erratic, "desperately in need for networking", sharing intimacies as the "only remaining method of 'community building'"[13, p.37]. Ambient communication between disparate intimate spaces is the technological boon that ensures the maximum possible of remote togetherness/intimacy in an otherwise lonesome and fragmented living.

2 "Reading" The Home

Aaron Betsky suggested that architecture may tackle sprawl's elusive order by constructing icons, interfaces and narratives. Icons function as the gathering places or objects, the centres of activities that stand still in a continuously changing world, yet, they remain enigmatic. Interfaces are the structures of coherence that help us understand the interrelations of the objects we accrete for our use, while narratives bridge time and space creating dynamic and changing images of objects or places [8, §2.5]. As Pavlos Lefas points out interpreting Betsky, both the form-giving of physical objects (built environment) as well as the representation of these objects are equally important architectural tasks [14, p.162].

It becomes evident that what Betsky refers to as interfaces and narratives, are actually the artefacts, representations, mappings, communication systems, perceptual and sensorial augmentation, or any other means that enable the reading and linking of the various fragments of home. Moreover, these artefacts excrete their peripheral nature and become integral aspects of home, at least as important as its physical and immaterial form, creating an "archipelago" of discrete islands connected by complex dynamic network connections [15]. Objects communicate among themselves and with networks outside the physical boundaries of home in a fashion that is constantly changing and difficult to trace down all the time. They interact with each other and with points globally dispersed by imperceptible data transfer and background tasks. However, while their main job is not to demand attention, they create a veil of uncertainty that inhabitants might find confusing or discomforting, mainly because home as sanctuary is desecrated by “secret” communications and decisions not directly conferred by the inhabitants.

The fact that immaterial connections between householdobjects become equally important to physical space, presents the need to elaborate on meaningful representations of home that escape the confinements of the traditional plan drawing and become dynamic and multi-layered to reflect their daily use by the inhabitants. In order to understand what is happening inside our home, we have to be able to know - and ultimately see - what communications and decisions take place and when they are active. These personal geographic studies can help create the new home-places by constructing and retaining identity, relationships and memories. Most of us would directly consider an augmented building plan as the means to quickly visualise all this information. However, this cannot be the case, since home is growing into an entity whose range is disproportionately larger than its diminishing physical boundaries. We chose cartography as a means to visualize all this information taking place through contemporary home environments, which constitute unexplored territory in our fully documented world. The next section attempts to address this issue through assessing several network mapping practices and their principles, and reflecting on the visual forms of augmented-home maps.

3 Determining the Map Characteristics

The early representations of hybrid domestic spaces, which incorporated some sort of ubiquitous technology or intelligent monitoring and managing systems, were created by the scientists and researchers who created the first ubiquitous computing experimental homes (Figs. 1 & 2). These static or dynamic representations depict the spatial configuration of connected devices, their links, and their mode of operation. Usually, they are followed by list of the mapped devices. The location of each device is not precise but topologically related to its location within the actual space. Furthermore, some of these representations showed real-time information about the status and activity of each connected device. Although, those depictions of networked home environments were still based on the configuration of the plan of the physical space, one can find similarities with the representations and schematic diagrams for electronic circuits.

Fig. 1. plan and depiction of devices in the "Adaptive House" Colorado, source: `http://www.cs.colorado.edu/~mozer/Research/Projects/Adaptive%20house/java%20interface/ji.html`

Fig. 2. list of devices in the "Adaptive House" Colorado, source: `http://www.cs.colorado.edu/~mozer/Research/Projects/Adaptive%20house/java%20interface/ji.html`

In such representational examples the accuracy of location information is compromised in order to render the patterns of connectivity more comprehensible. An example of a similar process, employed at a much larger scale, is the evolution of the London tube map. Starting as a geographically precise cartographic representation (Fig. 3), it gradually evolved through schematic abstraction to a kind of topological diagram improving on the legibility of lines, stations and connections (Fig. 4). Comparing, the present familiar version of the tube map, with a contemporary

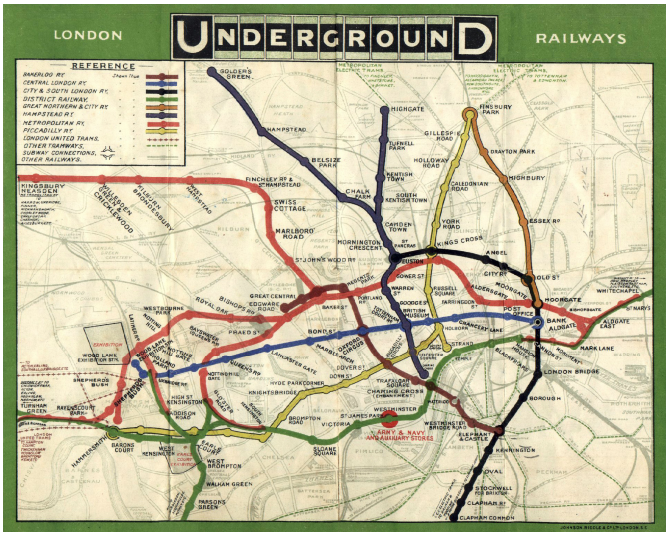

Fig. 3. Early cartographic representation of the London Tube

Fig. 4. Current London Tube Map. Notice the abstraction on detail and the precision in node (station) representation.

geographically precise depiction of the same underground network (Fig. 5), one can easily notice the large discrepancies of the former concerning accuracy of distances and shapes, especially in the periphery.

This resembles today's popular visualizations of smart-home networks, which employ a similar semi-decentralized diagram model. In this model connection nodes are grouped into several areas (entertainment, security, energy), then connected to the home controller. The segmentation of networks into areas creates a tree network diagram, where most connections of the same type have a bus structure, thus creating a hybrid map.However, contemporary home devices have the ability to create individual networks where other devices can connect to. In this way a connection diagram could include multiple networks that exchange information through a rhizomatic, or lattice structure, or a distributed network pattern, which is also the main type for visually representing highly complex networks such as ARPANET (1977) (Fig.6), or its later descendent the World-Wide-Web (Fig 7).

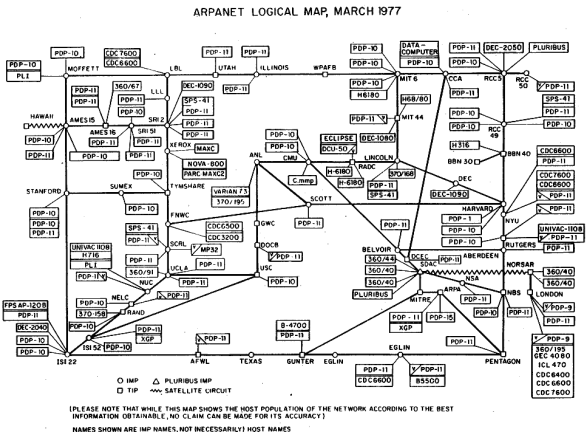

Fig. 6. ARPANET Logical Map, 1977, (`http://commons.wikimedia.org/wiki/File:Arpanet_logical_map,_march_1977.png`)

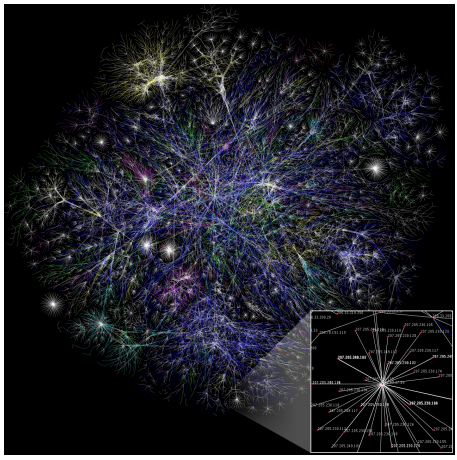

Fig. 7. Partial map (30%) of the Internet based on the January 15, 2005 data found on opte.org. Nodes are IP addresses. Length of lines indicate delay. Lines are colour-coded according to their corresponding RFC 1918 allocation. (`http://en.wikipedia.org/wiki/File:Internet_map_1024.jpg`).

Complex visualizations of knowledge and networks, specifically, gradually evolved together with our more intricate understanding of our world, from attempting to depict "problems of simplicity", with a centralized model (A), to portraying "problems of disorganized complexity" with decentralized diagram models (B), and finally today to explain "problems of organized complexity" employing distributed models (C) [16, p.45] (Fig.8).

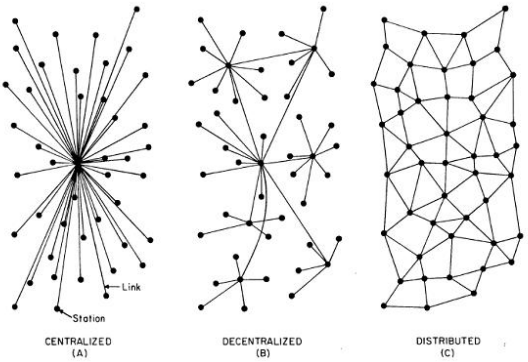

Fig. 8. Paul Baran, (A) Centralized-(B) Decentralized-And-(C) Distributed System, 1964. In those diagrams, the nodes are exactly the same, and only their connectivity pattern changes.

However, it seems that when referring specifically to the structure of home-network, which is closely related to physical places, as well as the identities of people, different types of network models may operate at different scales, or according to where the emphasis is at a certain time. We also anticipate that patterns of connectivity (from centralized to distributed) may differ according to time and occasion resulting in a hybrid network form. According to Lima [16, pp.80-81] the key functions of network visualizations are: a) to document, b) to clarify, c) to reveal, d) to expand, and e) to abstract. Projecting these functions to the environment of home and the visualizations of its networks, one can establish the following:

1. Documenting the trivialities of everyday or personal life is not a new thing. Art and the social sciences have attempted in the past to provide detailed accounts of everyday life of individuals, families and small social groups. However, the more widespread use of embedded or mobile sensing devices with the ability to be located, combined with personal data from social networks results in the accumulation of a vast amount of detailed information (big data), that some of them have never been recorded before. The documentation of this data, which refers to domestic behaviour is an almost uncharted territory. Currently available technologies do not support an accurate (<50cm) tracking of the location of a person or object in interior spaces. This should be improved in order to have accurately situated data of home-life.
2. Documentation of domestic-based big data, through visualizations of home-networks and other interrelations are an indispensable instrumental aid in order to make the complex structure of home intelligible and transparent to everyday people, whose lives are being depicted. Making the complexity of contemporary home visible is one step further to making home once again a core of order.
3. Home-network visualizations will eventually help us identify latent or subconsciously felt patterns concerning the developing of our identities and behaviours, as well as comparing them to similar patterns of other individuals, broader social groups, or globally. They can give us new insights on our everyday interactions,

making it possible for us to take informed decisions and adaptations to our lifestyles, social relationships and living goals.

4. The more the complex picture of our home-life is brought to light and new intricate details and patterns emerge, the more we would be encouraged to delve into further exploration. At the same time, the ability of network visualizations to provide abstracted representations of casual life, help promote a reflective mode, and are a vehicle for imaginary exploration.

Lima further identifies fifteen different types of network representations, although new types might emerge[1]. Among those, the ones that appear to afford a more refined topological structure, therefore possibly more appropriate for home-networks visualizations, may be the Area Grouping, The Centralized Burst and Ring, Circular Ties, Organic Rhizome, Ramifications, Scaling Circles.

Independently from the graphic typology of the network representation, it is important to note that, depending on the scale and size of the representation, the depicted information should adjust, and the representation, itself, affords different methods of analysis. Therefore it is important to consider three fundamental views in line with a specific method of analysis: *macro view, relationship view* and *micro view* [16]. Macro view, offers an overview, where one can discern general patterns. Relationships view, offers a representation in an intermediate scale, where one can elaborate on the connectivity patterns and interrelations between individual nodes. Micro view, finally, offers a detailed view of specific entities.

Although the above typologies and guidelines seem logical for any kind of network visualization, we need to consider whether they apply to the visual representation of home-networks, specifically due to their highly individual nature, and the extreme personal engagement with the depicted content. It is possible, for example, that the emotional significance of certain elements of home may dictate their detailed depiction even in macro view modes. In any case, we think that a certain degree of personal engagement and informality is necessary in order to domesticate network representations for home-use.

Cartography gives us some basic clues on how to organize and design the visualization of complex networks. The projection, orientation, scale and graphic language are basic parameters. The appropriate use of each one may result in an effective layout out of the intended information.

Projection describes the method of mapping three-dimensional measurements onto a two-dimensional medium, in relation to the viewing position of the cartographer, which is mainly from above. This is very effective for providing an overview, and appears to match with the cognitive maps of people for their surroundings, matching with the macro view described by Lima. Even in representations of homes and interiors, the plan view is the most common and effective projection for explaining topographical interrelations between objects, that occupy floor space.

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[1] These 15 types are: Arc Diagram, Area Grouping, Centralized Burst, Centralized Ring, Circled Globe, Circular Ties, Elliptical Implosion, Flow Chart, Organic Rhizome, Radian Convergence, Radial Implosion, Ramification, Scaling Circles, Segmented Radial Convergence, Sphere.

However, we found[2] that a commonly used projection for graphically providing an overview of simple home networks is the perspective or axonometric projection of the interior spaces, where the observer is still out of the depicted territory. Such, projections resolve problems of interrelating devices and nodes that are deployed three-dimensionally[3]. This type of representation does not solve all problems since overlapping and obscured parts, or densely packed three-dimensional information appearing as flattened could occur. Therefore, certain ways to convey "depth" in two or three-dimensional visual representations of home networks, would help the intuitive reading of complex and multi-layered spatial relationships. Such graphic tools might be decreasing focus, detail, and intensity.

Another issue concerning the projection of the map is **orientation**. Geographical maps are usually oriented towards magnetic north. In memory maps, the orientation is highly varied and seldom compass oriented. One hypothesis made by researchers studying home-range mapping by schoolchildren is that orientation tends, either in the direction of the most important element(s) in an individual's home range, or in the direction of the primary path leading away from home. It is also found that sketches of home plans usually place main entrance to the bottom or left of the page following the sequence of rooms from the entrance to the back of the house. From these two examples one can suggest that there is a certain natural directionality of home maps; the point of physical exit (from) or entry to the house is usually depicted closer to the map viewer's body or left hand. Instead, most network visualizations are indifferent to the observer's standpoint. Nevertheless, it is common practice to place the origin of graphs at the bottom-left corner. Other than that complex diagrams favor placing the origin point in a central position, and are usually unidirectional.

The **scale** of the map dictates largely the level of abstraction by which the territory or network structure and the information linked to it are represented. Smaller scale representations of places usually go hand in hand with greater abstraction of features and more general information, while larger representational scales allow greater detail and more information. Yet, in numerous cases, the scale and abstraction varies significantly in the same map, so as to give focus to a specific area. Usually this variation in scale and detail signifies a differentiation in perceived distance, familiarity and emotional significance. Thus, features and areas that are perceived or felt physically closer, or more familiar, or more significant to the author of the map, appear larger and with greater detail. In the opposite, large distances or features devoid of specific meaning are shortened, abstractly represented or omitted.

4 Conclusion

It is quite difficult to create a mental image of a pervasive home environment. Its complex structure, hidden data transfer and dynamic change over time makes it

[2] We arrived at this conclusion by examining many such representations, available online, which aim at being easily understood by a broad, non-expert audience (e.g.popular sites about home networks and smart homes, etc.).

[3] For instance, a surveillance camera at the ceiling would be falsely spatially related with a pressure sensor under the floor in a top view.

impossible for anyone to grasp all decisions and traffic throughout the home without a tool to visualize it. Contemporary network visualizations provide us with a set of possibilities for viewing specific parts and activities of the home, without the ability to integrate them into a single knowledge base. Nevertheless, experience from older and established mapping practices can give us valuable insights on how to deal with territorially related information, and cognitive mapping. This work has identified three parameters, referencing the level of detail that could be incorporated into mapping. These in conjunction with properties such as the projection, the orientation and the scaling of the map and its individual elements create a promising formula for identifying basic characteristics used to visualize a pervasive home environment. The hypothesis studied in this paper, needs to be supported by relevant field research and experimentation in the design and construction of such maps, engaging inhabitants and examining real scenarios. The scarce availability of domestic settings with a profound technological augmentation, such as the one envisioned by the ICT community for the near future, is a serious obstacle that needs to be considered, but should, push for imaginative methods to elicit useful findings making use of today's real situations.

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