The Cognitive Approach to Modeling Environments (CAME'06)

Kai-Florian Richter, Urs-Jakob Rüetschi (Eds.)

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Contact Address:

Dr. Thomas Barkowsky
SFB/TR 8
Universität Bremen
P.O.Box 330 440
28334 Bremen, Germany

Tel +49-421-218-64233
Fax +49-421-218-9864233
barkowsky@sfbtr8.uni-bremen.de
www.sfbtr8.uni-bremen.de

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THE COGNITIVE APPROACH TO MODELING ENVIRONMENTS
(CAME'06)

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KTH School of Architecture

More park space in a denser city
- Measuring open space accessibility and smart growth

Alexander Ståhle
School of Architecture, Royal Institute of Technology
Address: S-100 44 Stockholm, Sweden
Email: alexander.stahle@arch.kth.se

This paper is a short version of a longer article submitted to a major scientific journal.

Abstract
This study suggests new tools for understanding and measuring how urban morphology affects green space accessibility, not only because urban structure distributes open space to people, it also creates users and stakeholders. A questionnaire from 2001 (TEMO) states that, citizens in some dense inner-city-districts experience higher green space accessibility than in some low-density "green" suburbs in Stockholm. This peculiar result was the starting point of testing old and new measures in ten different city districts, using a new GIS-application "The Place Syntax Tool" (PST). PST makes it possible to calculate the 'topological' open space accessibility from every place (address point) in an urban area, current or planned. A new measure, which take range, orientation (axial line distance), green space size and number of use values into account, correlated considerably better to the questionnaire (R^2=0,74 p<0,001), than any of the conventional measures. Correlation was also found when comparing another questionnaire asking "How often do you go to your favourite green area?" (USK 2002) and axial line accessibility to green areas (R^2=0,77, p=0,018). Consequently, better measures of accessibilty and attractivity could change the common opinion of open space and "green" from a static to a dynamic urban entity, to optimize urbanity.

Keywords: open space, green structure, urban parks, urban morphology, accessibility measure, place syntax, space syntax, urban planning, landscape planning, smart growth, Stockholm

Introduction: the dichotomy "dense" or "green"

The two prevailing urban planning schemes dominating the 21st century have been densification and sprawl. These strategies, which have obvious consequences for green and open space, have both frequently led to deadlocks in planning, especially concerning green space exploitation. This conflict describes the well known and long debated dichotomy within urban planning and design: 'dense' or "green'. If Nozzi (2003) thinks that transportation planning is the key to cope with sprawl I believe, with support from the findings presented in this paper, that open space planning can be just as powerful tool to manage urban growth, and for example a qualitative densification of sprawl.

Findings and correlations

The findings of this study are first of all of correlational character. Measures have been found that correlate with empirical data. And it has to pointed out here that there have not been any research yet (of my knowing) that has done these detailed axial line accessibility studies and at the same time correlated them with empirical data. No one has in this way integrated Space syntax (Hillier) and green space morphology before. Recent green structure studies are often based on vague assumptions and weak morphological descriptions.

Measured and experienced green space accessibility
The questionnaire from 2001 (TEMO) that asked "Do you experience a lack of parks and nature areas in the vicinity of your home?" was found to correlate, after extensive testing of many different open and green space accessibility measures, with the combined measure presented in the former chapter. This measure calculates, according to the theoretical presumptions, accessible green surface area multiplied with its number of use values, it weights green areas according to axial line distance (one axial step away means half the green space), but limits pedestrian range to 1000 meter. The correlation is to be considered as fairly high, $R^2=0.74$ ($p<0,001$). If two of the study areas are taken away, Årsta and Gamla Enskede, the correlation goes up to $R^2=0,98$ ($p<0,001$). The intriguing thing is that correlations for any other conventional measures (open space sqm/pers) or guidelines (Boverket or Stockholm parkprogram) was only $R^2=0,02$-$0,22$.

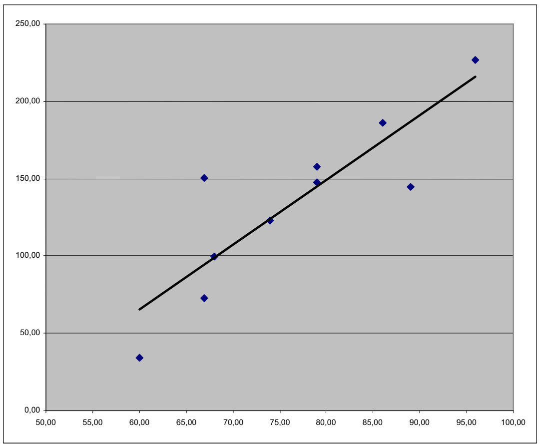


Fig. Correlation $R^2=0.74$ ($p<0,001$) between how many that, according to the TEM0 questionnaire, do not experience a lack of parks and nature areas, and the combined measure of green space accessibility for the ten study areas.

The principal finding from this correlation is that there seem to be four major factors that determine green space accessibility; *surface area*, *use values*, *orientation* and *range*. The result implies that if they all are systematically topologically measured in GIS it means a new powerful tool for urban structure analysis and design. Then, looking at the results it points out the intriguing fact that the dense inner city areas with relatively low green and open surface area experiences and measures not only similar but higher accessibility than two of the post war suburbs, which on the other hand have many times higher green and open surface area. Hence there exists in life world reality – 'more park space but denser city'. The explanation is of course foremost the differences in accessibility.

The results clearly imply that there are structural deficiencies in the post war areas. This can be described as an open space structure efficiency ratio, which means dividing the combined measure with open space accessibility 1000 meter bird's distance.

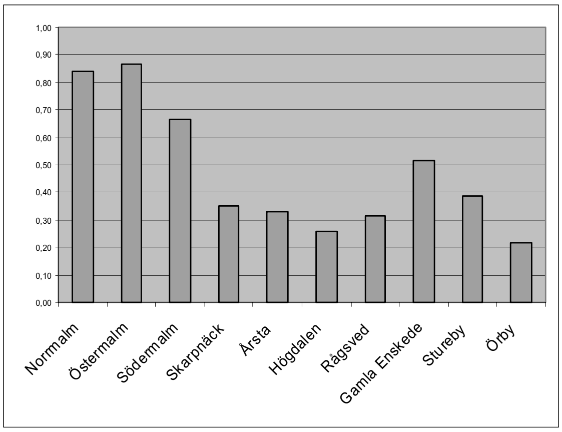


Fig. Open space structure efficiency for the ten study areas.

The figure above shows that the inner city grid more effectively distributes its green spaces to its inhabitants, than the interrupted grids in the suburbs. The best suburb, Gamla Enskede garden city area (from Unwin and Howard), is the only suburb which in some ways is like the inner city structure. If one looks at the best study area Östermalm, it is systematically planned accordingly to the Swedish late 19th century regularist Albert Lindhagen, who was of course inspired by Haussmann in Paris among others. Lindhagen claimed that "the parks should be in everyone's way…". The resulting and in my opinion very successful park planning scheme in Östermalm looks basically like this: A basic matrix of a continuous street grid in which a connected green structure is integrated. The green structure consists of urban parks, which are interconnected by 40 meter wide green esplanades (like boulevards but with trees and lawns in the middle of the street). These esplanades also lead out to the larger park and nature areas - "the green wedges". The consequence of this urban morphology is that when anyone is standing on any street that person sees a green area in the far end of the street, and you know that this green area is part of the larger continuous green structure.

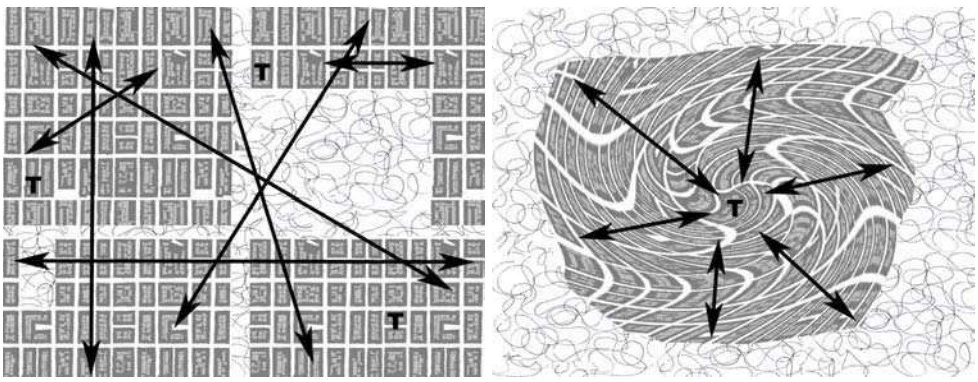
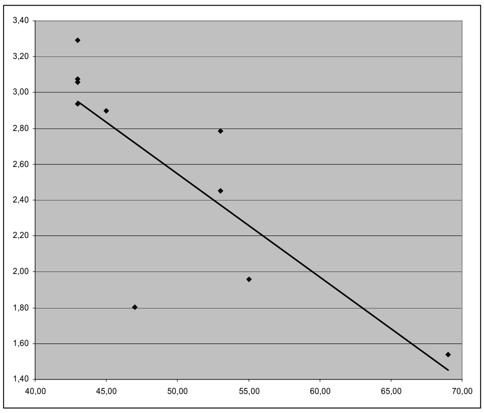


Fig. Principal schemes of the traffic integrated inner city grid with an integrated and continuous green structure (left) and of the post war suburb with a surrounding greenbelt and an interrupted street grid, with vehicular and pedestrian traffic separated (right). Arrows show principally daily movement patterns.

In the post-war suburbs the main green structure is basically segregated around the settlement as greenbelts separating different suburbs, all according to the park planning principles of the Stockholm general plan from 1952. These principles came from the municipal park officer Holger Blom (1938-71), who took much of these ideas from Frederick Law Olmsteds principle of having "an emerald necklace" around new towns. Firstly, this urban design concept seem not as effective, in terms of land use, as the Haussmann-Lindhagen concepts, when looking from a life world point of view. Secondly the modernist principles hav also created un-equitable distribution of open space and open space stakeholders.

Green space proximity and experienced visit frequency
Turning to the USK questionnaire, which stated “How often do you visit your favourite park/nature area?”, correlation was found by measuring axial line proximity to nearest green area, R^2=0,56 (p=0,018), but also by measuring public green space surface area within five axial lines, R^2=0,77 (p=0,018).

1) 

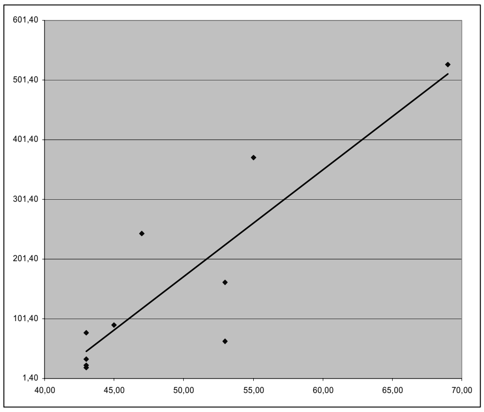
2) 

Fig. Correlation between how many who says that they visit their favourite park or nature area at least once a week and 1) axial line distance to the nearest public green area R^2=-0,56, p=0,018, and 2) public green space surface area within five axial lines, R^2=0,77 (p=0,018).

These correlations were however not done on study area level, but on city district level. Study areas were defined from homogeneous urban morphology, but city districts are administrative areas and much more heterogeneous structures, of different sizes and shapes. Therefore these correlations are not as strong as the earlier green space accessibility study. Still they are very clear on one thing. Axial line distance, i.e. orientation, seems to be the major explanation to why and how often people visit urban green areas. This conclusion is also confirmed by the Space syntax axial line integration analysis which shows that green areas in the inner city grid is much more spatially integrated than in the post war suburbs.

Green space attraction, occupation and structural integration
The on-site observations show that the selected inner city parks have more visitors then the selected 1950:ies parks. This is not so surprising compared to the area population densities. But, when the parks were divided into two groups; inner city parks and 1950:ies parks, correlations were found within the inner city parks between the number of use values and the number of staying visitors (not passers-through), R^2=0,83 (p=0,03). The same relation was not found to correlate at all in the 1950:ies parks, R^2=0,05 (p=0,686).

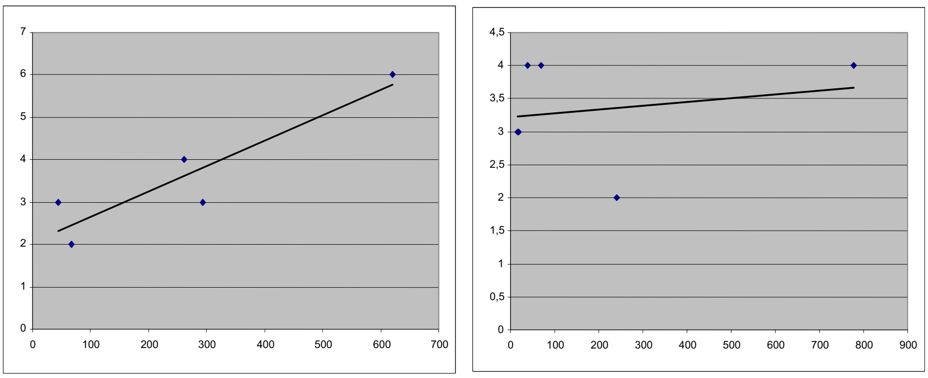


Fig. Correlation between the number of staying visitors and the number of use values in the inner ciy parks R^2=0.83, p=0.03 (left), and the 1950:ies parks R^2=0.05, p=0.686 (right).

My conclusion of these results is, very much similarly to the two earlier findings, that the high global spatial integration of the inner city parks means that they are appropriated more frequently. They are within the daily natural movement patterns, but they are also "marketing" themselves to the citizens because they are highly visible and legible. Hence, the post war parks are not appropriated accordingly to their attractivity because of low spatial integration and legibility.

Conclusions

The study has presented three major findings. The first is that a combined quantitative measure of green area size, number of use values, axial line distance and 1000 meter pedestrian range can measure green space distribution, when calculated as 'topological' (from all addresses in an urban area) accessibility. Calculations for ten study areas of different urban morphologies, 100 hectares each, correlated better than any conventional measure or guidelines, with a questionnaire asking "Do you experience a lack of parks and nature areas in your vicinity?" The second finding is that axial line distances to the nearest public green area correlated better than any metric measure with the questionnaire asking "How often do you visit your favourite park/nature area?" for ten city districts. The third finding is that the number of use values correlated with the number of staying visitors in five inner city parks, but not in six post war parks of the same size. This confirms the theory of natural movement and that spatially integrated parks are more effectively used and probably have relatively more stakeholders.

There are two major conclusions to be made here. The first concerns the morphological design outcome, and the second the planning process. Firstly, it seems that there are some urban designs that work better than others. The Swedish post war modernist suburbs, as they have been fulfilled in Stockholm according to the General plan of 1952, have consequently got lower integration values, lower open space accessibility and land use efficiency. These suburbs can in my opinion to be considered as sprawl, or more bluntly as 'un-smart growth'. In comparison the Stockholm inner city grid, that has its park structure from 19th century regularism based on "the Lindhagen plan" from 1860, which has more spatially integrated streets and open spaces. Consequently, the structural inefficiency of sprawl opens up for qualitative in-fill and restructuring which can mean denser city but higher green space accessibility. This has been indicated by Dolores Hayden, Peter Calthorpe, Nozzi, Xaveer De Geyter among others, and could be called *the new regularism* for the 21th century.

Secondly, concerning the planning process, there exists, as discussed in the introduction, a locked situation where urbanists stand against environmentalists, 'dense' is against 'green'. The GIS-tools and findings presented in this study could, if they are considered as credible knowledge, help both parties to see that urban design can be creatively used to understand land use efficiency and open space distribution equity. The tools and findings can in this way help overcome deadlocks and NIMBYISM in planning. In the end, much can be gained if the common opinion of open space and "green" change from a *static* to a *dynamic* urban entity.

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Investigating the effect of Visual Integration on Wayfinding performance using 3D VE

Itzhak Omer and Ran Goldblatt
Department of Geography and Human Environment, Tel Aviv University
Tel Aviv 69978, Israel
Tel.: +973(3)6406841. Fax:+972(3)6406243
omery@post.tau.ac.il; **ran@eslab.tau.ac.il**

Abstract

We investigated the effect of two properties of visual integration on wayfinding performance in a 3D virtual urban environment: overlapping between visual fields and the topological depth between these visual fields (length of visual chain). The results show that a high degree of visual fields` overlapping (more common visible elements) between an origin and a target element helps people to construct (ordinal) procedural spatial knowledge, especially when the overlapping is a direct one (similar common elements) or with a short topological depth. It was also found that visual overlapping contributes to the construction of topological configurational knowledge.

Introduction

The visual conditions of the urban environment can be defined as the number and structure of visual fields and their integration. These visual conditions have the potential to effect the quality of spatial knowledge acquired by human subjects and their ability to construct a cognitive spatial representation of it (Mark, 1993). Moreover, according to Cornell et al. (1994), wayfinding is based on ordered recognition of familiar vistas or views along a route. Previous studies have already found that cognitive spatial representation is influenced by the number of visual perspectives and the extension of their visual fields (Janzen et al., 2001), and by the integration between these visual fields. A similar idea was suggested by Kuipers and Levitt (1988) who argued that integrating vistas by the observer may also serve as building block for a construction of configurational knowledge of a large-scale space.

One of the main contributions to the understanding of how visual integration of spatial structure effects wayfinding performance is given by Space Syntax approach (Penn, 2003). The important property from the perspective of this approach is the intelligibility of an environment. The concept of intelligibility according to this approach is defined as ”the property of the space that allows a situated or immersed observer to understand it in such a way as to be able to find his or her way around in it…defining it as the predictability of the global structure of an environment from a reading of its local properties” (Bafna, 2003, p. 26-27), Technically, intelligibility, as a measure of this predictability is defined as the degree of correlation between the local integration of a spatial unit or its connectivity (the number of spatial units directly connected to a given spatial unit) and its global integration (the average topological depth of the spatial unit from all other spatial units within a given system) i.e. “It predicts that a small town whose street network is arranged such that streets that have a high degree of integration connect to more streets on an average, and those streets that are globally segregated connect to fewer streets directly, will be an intelligible” (Bafna, 2003, p. 26-27). Several researches have shown that a more intelligible environment helps people find their way more easily (Hillier et al., 1993; Conroy-Dalton, 2001; Bafna, 2003; Penn, 2003). Other researches have found that a high degree of global integration (short topological depth of a given unit from all other visual units) contributes to the imagability of urban objects or street segments (Shokouhi, 2003). In this respect it should be noted that a highly imageable or legible city could positively effect peoples ability to orientate themselves and find their way in the city (Lynch, 1960).

However, while the concept of visual integration has been examined with focus on the property of topological depth between spatial units, less attention has been paid to the property of the overlapping between visual fields. Since this visual property has the potential to enhance integration between visual fields and configurational knowledge, at least implicitly, it also has the potential to effect wayfinding performance and the ability of people to construct spatial representation of a given learned environment. Oman et al. (2000) also point out that “people occasionally need to reorient themselves when they view a familiar environment from an unfamiliar direction…. in such situations, the ability to imagine the spatial structure of an environment from a different direction is presumably important” (p.355-356).

Based on this research assumption, the specific aim of the study presented here is to examine how the overlapping between visual fields and the topological depth of this visual overlapping (length of visual chain) affects the ability of people to acquire procedural spatial knowledge through direct experience (primary learning).

For that purpose we had conducted experiments by using a 3D virtual environment (VE) constructed specifically for that aim. In the next section, we present the experiments and the criteria for designing the VE’ layout structure. The last section concludes the paper and points out possible future work.

Methodology

In the current research it was important to control the number and structure of the landmarks that could be seen from any reached viewpoint and to examine the behavior of the participants during various wayfinding tasks. We were specifically interested in the participant’s ability to choose the shortest path between any two given landmarks in a few wayfinding tasks, as an indication for a procedural spatial knowledge. For this aim, a 3D VE of an imaginary small scale urban area of approximately 0.25 Square Km was built using Skyline® 4.6 software (see Fig. 1). As illustrated in figure 2, seven urban landmark elements (buildings) with unique typical textures in addition to 375 buildings with a generic texture were used in the experiment. In this respect, it should be noted that while using such a VE model lacks a certain degree of validity regarding the differences between cognitive mapping of real and virtual environments (as well as the design constraints described above), it allows a control of the environments` layout and a detailed documentation of the participants behavior.

The VE was designed with respect to two visual properties: the overlapping between visible fields of landmarks (the number of common visible elements from any examined pairs of landmarks) and the length of the visual chain of those pairs (the topological depth).For that purpose, a different number of landmark elements were visible from each of these elements, e.g. the *city square* was identified by the largest number of visible elements (four elements: *clinic, restaurant, school* and a *tree*), while the *commercial center* allowed only one element to be visible from it (the *tree*).

Fig. 1: Snapshots of the 3D Virtual Environment (VE) of the imaginary small scale urban area.

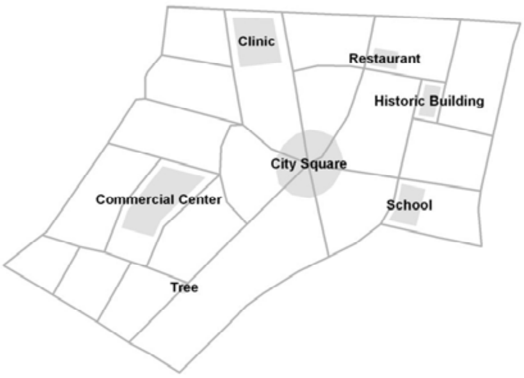

Fig. 2: The seven landmark elements used in the experiment

The experiment

14 participants (7 males and 7 females), at an average age of 29.8 (std. 4.5) took part in the experiment. The experiment includes two phases: a learning phase and a wayfinding task phase.

a. The learning phase:

The participants were introduced to the VE through three rounds of recorded tour around the imaginary city. While viewing the recorded tours, the participants were asked to carefully pay attention to the exact location of each landmark element, so that at the end they will know how to reach one element from another.

b. Wayfinding task phase:

Five wayfinding tasks were examined (see table 1). In each task the participants were given the following instruction: "you are currently facing landmark element X. please guide the researcher how to reach landmark Y using the shortest path". Each task can be characterized by two properties: the number of common visible elements and the length of the visual chain between each examined pair of the landmark elements.

In order to obtain the trajectory patterns of each individual's wayfinding task, the real-time-log data was recorded, then converted to GIS layers and at the end visualized as polylines using GIS environment.

Results

According to the hypothesis of the research, it was expected that the more there are common visible elements between an origin and a target element, or alternatively, the shorter the visual chain between them (i.e. the less number of steps in a visual chain) - the easier it will be to reach the target landmark element and thus, it will be easier for the participants to complete the task. We estimated ease of task completion using the length of the taken route during the wayfinding task relative to the shortest available path.

As expected, we found that both, the length of the visual chain and the overlapping between visible fields may affect wayfinding performance. These findings are described bellow:

I. The length of the visual chain

Results have shown that the shorter the visual chain between the origin and the target elements - the easier it is to complete the task and reach the target element along the shortest route. in the task which required 3 steps to be taken between the origin and the target elements, only 57% of the participants successfully completed the task (following the shortest route) in comparison to the task which required only 2 steps, in which 75% of the participants successfully completed the task .

II. Overlapping between visible fields

As hypothesized, tasks in which the origin and target elements shared a large number of common visible elements, resulted in the best wayfinding performance; That is, almost all of the participants were able to complete the task following the shortest available route between the elements. One of the tasks, which was characterized by a combination of a short visual chain length (only 1 step) and a fairly large number of common visible elements (3 elements), resulted in the best wayfinding performance; 13 participants completed this task following the shortest available route between the elements Based on the above results, we assume that this visual property of urban environment assists the construction of an ordinal procedural knowledge, in addition to visual topological depth which was already examined in previous studies.

The influence of visual conditions on the configurational knowledge, the higher level of spatial knowledge, was also evaluated through the experiment. In order to investigate this issue, we asked eight of the participants to mark after the learning phase on an A4 sheet of paper the exact location of the city's elements. Then, using GIS software, we calculated for each participant the mean distance error of the elements` location on the map in relation to its real location. It was found that the success rate of the task completion, as an indication of procedural knowledge, was correlated (R^2=0.82) with the accuracy of the landmark locations in the maps drawn by the participants at the beginning of the wayfinding task phase.

Conclusions

According to the hypothesis of the research, a high degree of overlapping between the visual fields (more common visible elements) of an origin and a target element was found to help people construct an (ordinal) procedural spatial knowledge. Moreover, when this overlapping is a direct one, namely, when there is only one visual chain step between two elements, the participants achieved the best performance in the wayfindig tasks. It was also found, that visual overlapping and a short topological depth between them contribute to the construction of topological configurational knowledge. The results of the research encourage the use of complementarily methods to the graph theory based methods such as space syntax, for analyzing the visual structure of urban environment which focuse on the overlapping between visual fields and the topological depth between them. A multidimensional topological analysis for a structural analysis of geographic systems is an example for such kind of method (Jiang and Omer, 2006).

This research is a preliminary study on the effect of visual overlapping on wayfinding performance. Concerning the limit empiric scope of the research, it certainly deserves further study. From a broader perspective, we also plan to explore the relevance of visual overlapping in the urban layout for a variety of wayfinding and spatial knowledge acquisition skills.

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Isovists, Occlusions and the Exosomatic Visual Architecture

Alasdair Turner*
a.turner@ucl.ac.uk

Bartlett School of Graduate Studies, UCL, Gower Street, London

Abstract. Recently, simulation agents (or animats) using an exosomatic visual architecture (EVA) have been shown to correlate well with observed pedestrian movement in both building and urban environments. An EVA uses a grid overlaid on a two-dimensional plan of a system to record the locations visible from the current grid square. The agents are allowed to roam freely in the environment, and lookup visual information from the EVA in order to guide them through the plan. This allows many agents to navigate concurrently using visibility relationships. However, while good correlation between observed physical and virtual systems has been shown, experiments to date have been based on agents which move stochastically to visible locations. This leads to them congregating in large open vistas, where there are more visible locations. In contrast, when people are observed, they tend to follow the edges of spaces to move or take direct routes across open spaces to the far side. Here we hypothesize that rather than using open space to guide them, people instead use the visual clue of an occluding edge to indicate where further movement potential may lie. We supplement the information in the EVA with details of the isovist at each location, to supply the locations of occluding edges from each grid square. We show that these new agents follow paths much more similar to observed pedestrians using an open space. We speculate that the invariance of the occlusion points within a plan may thus lead to an economic skeletal mapping of the environment, and possible basis for a cognitive map.

1 Introduction

An isovist is the visible polygon from a location in a plan of an urban or building environment, as shown in figure 1. Benedikt introduced the concept to architecture in order to try to quantify the perceptual experience of a place [1]. In particular, he recognised that the way people moved around a space might be influenced by the shape of the isovist, not simply by the objects within it. He supposed that people would be guided by isovist properties, following Gibson's suggestion that people may be guided by direct (or active) perception, that is, simply respond directly to the affordances offered by the environment rather than any higher cognitive function [2].

* With many thanks to Christian Beros of Universidad de Chile for his permission to use the South Bank data presented in this paper

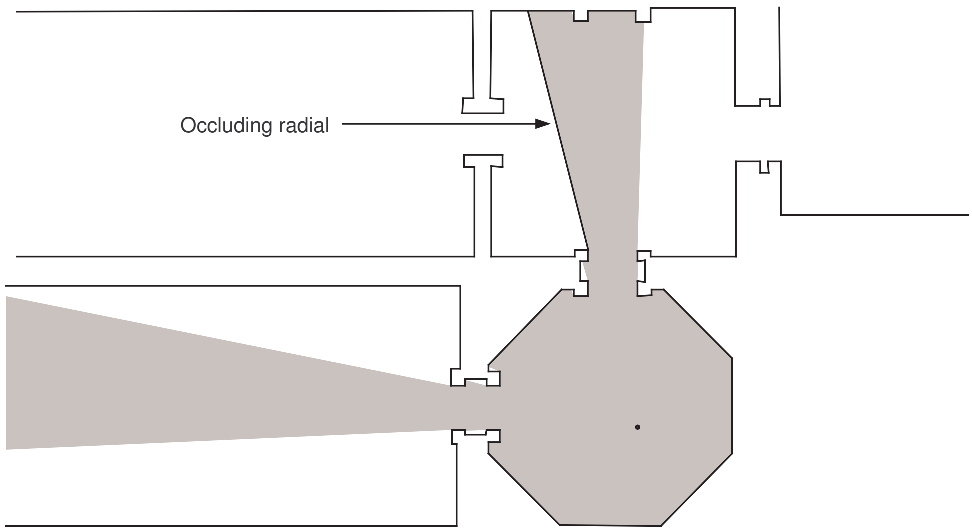


Fig. 1. An isovist from a location, with occluding radial marked.

Recently Turner and Penn introduced simulation agents guided by the simple isovist property of visible area in the direction of movement [3]. They constructed a dense grid visibility graph [4] of a floorplan and allowed agents to choose their next destination from a selection of grid points in the agents' field of view. They discovered that if the agents are given a field of view of 170° and allowed to progress three steps before reselecting a destination, then aggregate movement of agents in a gallery space correlates well with observed movement of people. However, application to larger scale spaces has proved less successful, perhaps due to a less controlled environment where entrance and exit are unconstrained, but also perhaps because the agents appear to congregate in larger spaces, as direct perception leads them towards open areas. This can lead to a stark contrast between agents and observation where there is park space. For example, in the area of the South Bank in London by the London Eye, paths recorded for people followed through the space differ strongly from the patterns of agent movement (compare figure 2(a) with figure 2(b)).

However, when Benedikt introduced isovists, he also proposed a measure of *occlusivity*. This measure indicates where isovists have long lengths of occluding radials, that is, a radial that marks a boundary between visible and occluded objects (see figure 1). For navigational purposes these occluding radials might also be important, as they mark areas of unexplored space that may be entered by continuing in the direction of the occluding radial. Therefore, in this paper we examine the effect of agents guided by occluding radials.

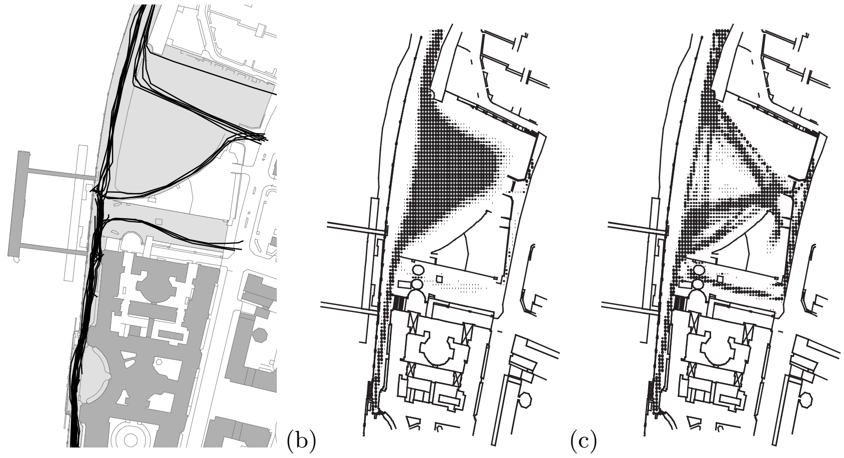
(a)  (b) (c)

Fig. 2. (a) Pedestrian movement through the South Bank, London. Observations and image by Christian Beros. (b) Standard direct-perception agents (c) Agents driven by occluding radials.

2 Methodology and Analysis

We construct a set of isovists covering a dense grid[1], placed every 0.75m throughout the environment, as this gives an approximation to human step size. We break each isovist down into a series of 32 angular bins, and record the occluding radials in each bin. This provides a database of the visual connections within the system which is an external to any simulation agents in the system, i.e., exosomatic (outside the body). Thus, this visual system is called an exosomatic visual architecture [5]. We run agents system which use this architecture as a lookup table for their vision. Following [3], each agent has a field of view of 15 out of the 32 bins (about 170°, which approximates the human field of view). However, rather than selecting a point from the isovist to move towards, as in [3], our agents herein choose an occluding radial at random from those available in its field of view. We weight the choice of radial by the distance to the occluding point, on the grounds that near occlusions may simply be a distraction to the onward movement of the agents: our preliminary experiments showed that without this weighting, the agents were simply attracted to high densities of occluding edges, such as columns or trees. We also needed to account for the detail of our plans, where slight deviations in the border created short occluding radials. Hence, if the occluding radials were less than 1.5m, they were ignored. The resulting model is still far from ideal: clusters of radials attract the agents, and so the agents were told simply to pick the furthest occluding point from each

[1] The experiments in this paper were conducted using the Depthmap program written by the author. Depthmap is freely available for academic use, see http://www.vr.ucl.ac.uk/depthmap/ for details.

bin. For each model, a quantitative assessment was made against two test cases for which we have pedestrian data: a small model of an urban area (Barnsbury in North London) and the Tate Britain Gallery in Millbank. In both cases, little improvement was made over the original direct perception agents. However, in a qualitative analysis of the South Bank in London, the improvement of the new agents was demonstrable. Figure 2 shows observations made by Christian Beros, and the two sorts of agents. As we noted, the direct perception agents tend to aggregate in the open space, with little movement along the major axes. However, the occlusion driven agents, whilst not perfect, pick out much better the sorts of paths the pedestrians follow.

3 Conclusion

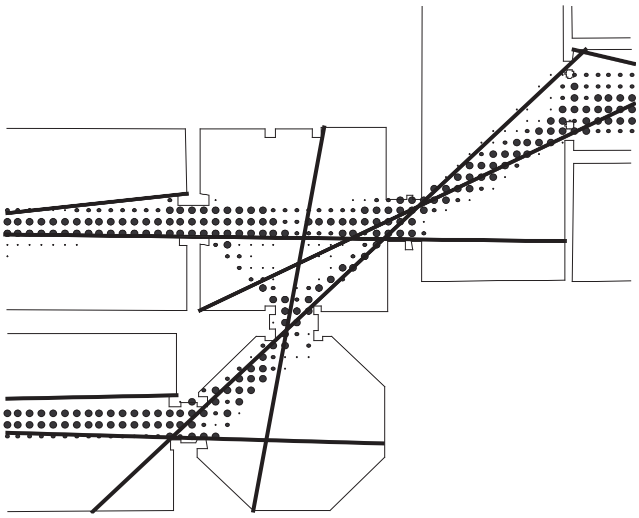


Fig. 3. Cummulative paths for occlusion-driven agents (dots) overlaid on an axial map (bold lines) in part of the Tate Britain Gallery.

This paper has sketched out how agents may be programmed to use occluding radials to guide their movement. We have shown that, in open areas, the paths generated by these agents correspond more closely to observed pedestrian movement than agents driven by direct perception.

One further observation is that the occluding points at the start of occluding radials are invariant as the agents move from location to location. These convex vertices in the plan might be considered as the basis for a line map, joining the edges traversed by the agents. Such a map is much like an axial map from the domain of space syntax [6]. Indeed, it is interesting to compare an automatically generated axial map [7], based on similar vertex joining rules, with the trails left by our agents. Figure 3 shows the comparison. It is worth noting that in the construction of the axial map, certain lines from the skeletal network have been removed. Some lines on the axial map do not quite match the underlying movement pattern, and vice versa, but the similarity implies that a map linking topological skeleton and movement patterns may well be possible. These lines of reinforced movement would seem to be an ideal basis for a skeletal cognitive map, such as proposed by Kuipers [8].

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Ground truthing space syntax

Drew Dara-Abrams[1]
Department of Psychology
University of California, Santa Barbara
dara-abrams @ psych . ucsb . edu

Workshop on the Cognitive Approach to
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I. Different environments, different models

How can we formally model a built environment and capture the fundamental properties relevant to its inhabitants? Space syntax provides a set of rigorously defined techniques for describing spatial configurations like building interiors and urban squares—it appears to be a natural approach to use.[2] Yet whether you chose to use an axial map, a visibility graph, a segment map, a trial run of agents, or any other such computational method in the space syntax toolkit, the question of ground truthing remains.

You must make a set of decisions about what environmental features to include in your model, to what level of detail you will describe them, how you will consider variable and changing features, and how you will address error and uncertainty. These questions are critical to the cognitive relevance—not to mention the empirical evaluation—of any resulting model, yet they have received less attention than the mechanics of space syntax. A variety of space syntax techniques are now well-defined in algorithmic terms; still, I can find no guidelines for exactly what environmental features to input into those algorithms. What essentials of the multitudinous world should we record and subsequently abstract into the language of space syntax?

Simply put, space syntax analysis begins by dividing open space from closed space. In Central London, the native habitat of space syntax, open space is pavement—that is, roadways, sidewalks, squares—and closed space is buildings. Axes or segments are laid through open space.[3] Isovists expand through open space.[4] Agents move through open space.[5] Consequently, the boundary between open and closed space is key. When modeling the overall structure of a city, particularly one that is dense and built-out, the question of where to draw that boundary isn't vexing. It may even be avoided, by directly creating an axial or segment map from readily-available road-center lines.[6] Building interiors are also straightforward. Not only are architectural plans usually available, but more importantly, walls and other elements of a building's mass naturally demarcate open space.

Smaller than the far-reaching scale of the city and larger than the enclosing scale of the building is the outdoor landscape. These environments are the surroundings that we move through, the vistas that guide and engage us. At this scale, detail is necessary. Buildings lend some definition to the surrounding space, as do planters, bushes and trees, staircases, ramps, benches, streetlamps, signage, and other pieces of street furniture. Certain landscapes may not be as articulated as others. Consider the differences between a parking lot off an exurban strip and a university campus of quadrangles, lawns, and walkways.

Different professions work at these three scales: architects craft buildings; urban designers and landscape architects shape the outdoor landscape of city squares, shopping centers, and campuses; and urban planners orchestrate cities and regions. Correspondingly, models will include and be defined by different features depending upon the scale they represent. Applying space syntax to building interiors and city structures seems relatively clear. My interest is in the intermediate scale, and my concern is how we draw the line between open space and closed space at that scale of the outdoor landscape.

II. Modeling outdoor landscapes

Two overarching approaches to modeling the world occur to me: visibility and accessibility.[7] Certainly our experience includes other characteristics, such as auditory, tactile, olfactory, semiotic, and social. The picture becomes even more complex if you also include other people. In the context of space syntax, what matters is the configuration of space—the dividing line between open space and closed space. Visibility and accessibility can each serve as criteria for placing this line. In the archetypal example of London, visibility and accessibility correspond. The buildings and other masses that define closed space block people's movement at the same time as they block people's sight.

My example is a university campus in the United States, where I have found the situation to be much less definite. Paved pathways are clearly accessible, but what about lawns? And with appropriate shoes, a sense of adventure, and a looming appointment, you could walk through a planter, too. A building obviously blocks your vision, but what about a decorative trellis? Depending upon their design, fences can block visibility and they definitely block accessibility. In other words, accessibility and visibility do not necessarily correspond, and details like these aren't necessarily included in maps or plans. Thus the title of this paper. To model an environment like a university campus, you have to take what plans you can find (ideally as CAD files) and then, by surveying on foot and making subjective decisions (ideally in keeping with some sort of systematic guidelines), you must verify and elaborate the details.

III. Visibility as the defining characteristic

Visual perception of our surroundings is certainly fundamental to spatial cognition and behavior. (Yet it is not necessary, as demonstrated by blind and vision-impaired people.) J. J. Gibson, in his ecological theory of perception, proposes that vision allows us to directly perceive our surroundings and their affordances. This emphasis on vision appears in space syntax techniques as well. Axes in an axial map are most easily explained as lines of sight. In that case, an overall axial map represents the topology of the key sightlines in an environment.

Vision is even more so the organizing principle behind the technique known as visibility graph analysis in the space syntax community and viewshed analysis to geographers and landscape architects.[8] Whichever name is used, the basic ingredient is the isovist, the area visible from a particular point.

If visibility is taken to be the defining characteristic of our interactions with the surrounding environment, then visibility ought to be the criteria we use to place the boundary line that divides open space and closed space. Open space includes spaces that are visible to each other, whereas closed space includes visual barriers. Table 1 lists some environmental features that you may want to record when surveying with visibility in mind. A model that only includes building footprints or road-center lines is too meager to capture all the salient details relevant to visibility in many outdoor landscapes.

Large shrubs and trees can block visibility about as completely as a wall of brick can. Unlike the wall, vegetation may change from season to season. The goals of your model will naturally determine how you address the issue of changing visibility. For instance, if you are using it to evaluate pedestrian flow rates, presumably the model ought to reflect the time of the data collection.[9]

Blocks movement and usually blocks sight	
Blocks movement and usually blocks sight: ▪ building walls (at ground level, which is not necessarily the same as the building footprint) ▪ retaining walls, freestanding walls ▪ fences, gates ▪ sculptures and other art installations ▪ vendor's carts ▪ tall vegetation (trees, shrubs) ▪ smaller vegetation ▪ street furniture (planters, streetlamps, signposts, benches, picnic tables, staircases, ramps, railings, newspaper racks, bike racks)	*Allows for "official" movement (and open to sight)*: ▪ walkways, sidewalks ▪ squares, plazas, courtyards *Allows for "tromp-everywhere" movement (and open to sight)*: ▪ lawns ▪ open ground *Allows for sight, but not movement*: ▪ lakes, streams, and other water features

Table 1. Some environmental features to consider including in a two-dimensional pedestrian-oriented model of an outdoor landscape's spatial configuration.

IV. Accessibility as the defining characteristic

With knowledge gleaned from vision and other senses, purposeful movement through an environment is possible. Open space allows for movement and activity. Different varieties of open space afford different amounts of movement. A level, paved walkway is accessible to most everyone, whether they are on foot or in a wheelchair. Stairs reduce accessibility, as does grass, which only some will think to or want to walk across. Again, the question is where to draw the line between open space and closed space.

When modeling an environment, I survey two different sets of accessibility features and create two separate versions. The first, an "official" accessibility model, limits open space to paved areas like walkways. The second, a "tromp-everywhere" accessibility model, expands open space to include other areas through which an able-bodied person might also move. Table 1 lists some relevant features to consider. Note that I am now speaking in terms of environmental features that correspond with open space, whereas I described visibility in terms of identifying closed space. This is a pragmatic decision, although it might reveal a theoretical difference between visibility and accessibility.

As the terms imply, the distinction between "official" and "tromp-everywhere" accessibility is the result of social, not just physical, factors. Many choose not to walk across grass in order to avoid scuffing their shoes, but at the same time they are guided by the implicit social conventions of sticking to the path. Public spaces, private spaces, and "spaces of fear" are just some of the many varieties of other socially defined spaces that human geographers are concerned with. Space syntax research has been guided by an assumption that these social factors arise in large part out of the physical configuration of an environment. Few would want to admit the surveyor's subjective decisions of what environmental features to include on the map also have an effect. That is another reason to follow consistent guidelines, which clearly separate the options of "official" and "tromp-everywhere" accessibility, when surveying.

As is the case with visibility, accessibility can change based on environmental conditions. My first space syntax model was of a college campus in snowy Minnesota. During the winter, the formerly accessible campus lawns might be underneath a layer of ice or snow. Not that the impediment stopped everyone—over time, intrepid travelers would scrape "cow paths" through the snow. If only pedestrian movement were always so well marked and preserved!

Snow is less of a concern in the environments I am now modeling in Southern California, where car is king. I mention cars because they are another source of variability in an environment.

Late at night, a road may be completely accessible to pedestrians, but come rush hour, no one would think to walk there. Or consider a parking lot that fills up during the day and empties at night.

Speaking of cars and other transportation methods, these guidelines are clearly oriented toward pedestrians. If you were surveying with vehicle accessibility in mind, you would certainly draw a different line between open space and closed space.

V. Assessing models based on human evidence

In this paper I have suggested three different ways to model an outdoor landscape: visibility, "official" accessibility, and "tromp-everywhere" accessibility. Each will produce a quite distinct characterization of the environment in question. Multiply those three approaches by the number of different space syntax techniques available to use with each, and you can be overwhelmed by options.[10] To create all of those models and run all of those analyses is more akin to a fishing trip than a systematic evaluation. Let's try the latter. First, we can trim the number of options based on theoretical grounds. Visibility graph analysis is naturally applied to a visibility model; we need not always run such an analysis on either of the accessibility models. If axial maps effectively represent sightlines (which some might say is an improper reduction), that type of analysis is also more appropriate for the visibility model. Segment maps better represent the paths that people can take and the choice points available in an environment, and so they seem more appropriately used with an accessibility model. Of course, we are still left with a number of different models of the environment in question and of analysis methods to use.

Experimental data from people is the criteria we can use to compare and evaluate these different models and analysis techniques. If our goal is to develop a cognitive approach to modeling environments, then the best models and the best analysis techniques will be the ones that most accurately predict human performance on controlled tasks of spatial cognition and human behavior in natural settings, at both the individual and the aggregate scale. The space syntax literature has focused primarily on one variety of human behavior at the aggregate scale: counts of pedestrians walking through particular "gate" points.[11] The spatial cognition literature is filled with many more relevant and useful experimental methods, although few have been tested against the quantitative models of environments that space syntax techniques provide.

Experimental methods in spatial cognition can reveal individuals' spatial judgment and memory for an environment, including the systematic distortions that characterize their knowledge of distances, directions, and shapes. And other experimental methods explain how people move through their immediate surroundings (locomotion) and plan their overall travels (wayfinding). All of this research in spatial cognition can help us precisely compare the merits of an "official" accessibility model analyzed as a segment map, a visibility model analyzed as a visibility graph, and so on.

In my current research, I am attempting to unite the careful experimental methodology of spatial memory and judgment with the formal description of environments offered by space syntax. I asked students on that Minnesota college campus (Carleton College) to create a map of the campus and to point from certain well-known locations on campus to other well-known locations (Dara-Abrams, submitted). An axial map analysis of the walking paths on campus—an "official" accessibility model—predicted how well participants performed on the tasks. They were significantly more accurate in their pointing when they were asked to imagine standing at a location with a high global integration value (one of the key space syntax measures used with axial maps), and they were significantly more accurate in placing the more highly integrated buildings in their map. More recently I have been comparing participants' performance on those types of tasks with all three of the models mentioned in this paper.

Just as each space syntax analysis technique appears to be best used with particular models, particular combinations of model and analysis could conceivably lend themselves better to predicting certain varieties of spatial cognition and behavior than others. For instance, an "official" accessibility model analyzed as a segment map may be best at predicting people's cognitive maps of a familiar environment—over time they have learned the overall organization of the environment and the possible paths they can take through it—while a visibility model analyzed as a visibility graph may better account for the movements of a tourist wandering in a new environment. Such speculation may make logical sense, but the support of empirical investigation is also needed. I intend my research to help, if only in a small way, toward that end.

VI. Conclusion

Ultimately we would like to understand the interplay between people and their surroundings, an issue central to the theoretical concerns of spatial cognition and the practical concerns of architecture, urban design, landscape architecture, and urban planning. The development of space syntax techniques has shown that a cognitive approach to modeling environments need not recreate the entire world and all its complexity. Focusing only on the spatial configuration of environments—effectively the line between open space and closed space—will produce a useful model. In outdoor settings, this line can be placed according to a variety of options. Here I have discussed visibility as well as an "official" and a "tromp-everywhere" notion of accessibility. To compare the merits of these different models, as well as the space syntax techniques that can be used to analyze them, I suggest that we turn to experimental evidence from spatial cognition. Only together can spatial cognition and space syntax develop a cognitive approach to modeling environments.

Notes

[1] The National Science Foundation supported the preparation of this paper through the Interactive Digital Multimedia IGERT, grant number DGE-0221713. Thanks go to Helen Couclelis, Daniel Montello, and Mary Hegarty for helpful feedback. As I hope this work will be relevant to a multidisciplinary audience, I include a good number of references in these notes.

[2] Bafna (2003) provides a concise introduction to space syntax, although his examples are primarily of clearly-defined indoor settings.

[3] Turner, Penn, and Hillier (2005) give an algorithmic definition of an axial map. Segment maps are demonstrated by Turner (2005) and Iida and Hillier (2005).

[4] Although not the first to use the term, Benedikt (1979) is the oft-cited paper on isovists.

[5] See Turner and Penn (2002) for more on agent simulations with space syntax techniques.

[6] Two uses of road-center lines in the space syntax literature are Dalton, Peponis, and Conroy-Dalton (2003) and Turner (2005).

[7] Stamps (2005) draws a similar distinction between visibility and accessibility. His experiments demonstrate that people's "impressions of enclosure were more influenced by visual permeability than by locomotive permeability, but the reverse was found for impressions of safety, which were more strongly influenced by locomotive than by visual permeability" (p. 587).

[8] Turner et al. (2001) introduces visibility graph analysis. See Bishop (2003) as well as Ervin and Steinitz (2003) for brief overviews of viewshed analysis.

[9] Not only does the visibility of fixed elements in an environment change—the conditions of that environment change too. Here in Santa Barbara, the fog can envelop the coastline and greatly reduce visibility. But these changes do not affect the spatial configuration of an environment; rather, it is the viewing properties of the observer or agent that change. Ervin and Steinitz (2003) discuss the problems posed by atmospheric interference and variable lighting conditions. One solution they consider is using probabilistic analysis to account for the uncertainty and complexity inherent in visibility computations.

[10] Rather than try to evaluate the different models individually, we could combine all of the models into one, attaching some sort of weight to each element. "Official" accessibility

barriers, like the edge of a paved walkway, could be given less weight than a more solid barrier, like a building wall, say. But modifying the particulars of space syntax —in effect blurring the line between open and closed space—is beyond the scope of this paper, not to mention my expertise.

[11] The space syntax community has slowly begun to empirically test its models against data from individual human participants. Haq and Zimring (2003) demonstrated such measures to be strong predictors of wayfinding behavior (where people walked) and abilities (how well they performed on assessments of their knowledge) inside large buildings, such as hospitals. And Kim and Penn (2004) found that the integration values, a key space syntax measure, of street maps sketched by people correlate with actual integration values of the streets.

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Conceptual Spaces for Data Descriptions

Carsten Keßler
Institute for Geoinformatics, University of Münster
carsten.kessler@uni-muenster.de

Abstract

Cognitively adequate information representations have a great potential to improve interactions between systems and users. They are able to account for a specific user's personal understanding, knowledge and preferences. To utilize this capacity for the personalization of services, we need to represent information on a level that corresponds to human cognition. In this paper, we show how to generate such a description in the form of a conceptual space from an existing landmarks database. We then analyze this process for future automation and generalization.

Introduction

People's interaction with their environment has been an important research topic for a long time. It has been worked on from different perspectives such as activities and behaviour in space, or navigation on different scales and in different modes (e.g. [5], [12], [2]). Cognitively adequate information enables improvements for systems which assist users in performing spatio-temporal tasks in their environment. The representation of information on a level which corresponds to human cognition bears great potential for the personalization of services, and for the integration of semantic descriptions.

The aim to assure a common understanding of the semantics during information exchange has often resulted in fixed interpretations of terms, regardless of the fact that the parties involved might have a different understanding of them. As a result, services such as navigation assistants or location based services provide all users with the same output, irrespective of whether these are useful for a specific user or not.

The approach of cognitive semantics accounts for the fact that the understanding of a term is dependent on an agent's knowledge and context. In contrast to the *realist* approach, where "the meaning of a word or expression is something out there in the world" and "similarity is something that exists objectively [...], independent of any perceptual and other cognitive processes" (pages 151 and 110 in [3]), the *cognitive* view is capable of explaining phenomena such as learning or the change of concepts over time. From a system engineer's point of view, cognitive semantics can be useful in the design of geospatial services, which can adapt to a specific user. To utilize this potential, cognitive descriptions are required both for the users and the system. *Conceptual spaces* provide spatial representations of concepts from the cognitive perspective. They arrange concepts as points in a vector space. This space is spanned by *quality dimensions* which correspond to the properties of the concepts.

The prospect of this paper is to demonstrate how to derive a conceptual space from a given data source. As a case study, a landmark selection scenario in the city of Vienna is used. A database with 58 buildings in Vienna's first district is analyzed and converted into a cognitively adequate representation, namely a conceptual space as formally defined in [1]. Although this research focuses on the first steps towards user-adapting services based on cognitive adequate data representations, it also provides insight on the differences between human perception of space and the according data representations. Both the use case and the data presented have been developed and collected in [8] to investigate the selection of landmarks for navigation.

In the following, we will first present conceptual spaces. We will then show how to define a conceptual space, and go through the process of creating a conceptual space for a database containing landmarks. This will be followed by an analysis of the extraction process, focussing on automation. We will conclude with an outlook on future work.

Conceptual Spaces

Conceptual spaces have been introduced as a framework for representing information on the conceptual level [3]. Gärdenfors identifies three different levels for representing information in cognitive science: According to the *symbolic* approach cognition is symbol manipulation. Methodologies currently used for the semantic web are based on this approach [4]. The *associationist* approach puts the stress on the associations between symbols, as in artificial neural networks, for example. The third one is the *conceptual* approach, which will be elucidated in the following.

A conceptual space represents the properties forming a concept as quality dimensions with a geometrical or topological structure. Hence, they span a vector space with concept instances being points (i.e., vectors) in that space which take a value for every quality dimension. The calculation of similarity values is based on the inverse distances between the vector representations of the concepts. Depending on the kind of dimension, different metrics apply for the distance calculations. Gärdenfors distinguishes *integral* and *separable* dimensions. A group of integral dimensions is characterized by the fact that one needs to assign a value to every one of them to completely describe the concept (e.g. hue, saturation and value of a color). For integral dimensions, Euclidian metric is usually applied. Separable dimensions, in contrast, can stand alone, such as the height or the age of a building, and apply city block metric[1]. The distinction into these two groups of dimensions stems from the way humans perceive their environment: Integral dimensions are processed holistically, whereas separable dimensions are processed analytically [7]. A set of integral dimensions that is separable from all other dimensions is called a *domain*. To reflect the saliency of particular dimensions, individual weights can be assigned to all dimensions [9] — e.g. in the concept "landmark", the height and color of a building are more important than the number of people living in it. These weights can be task-dependent.

Aisbett and Gibbon (2001) present a general formulation of conceptual spaces [1]. The authors formalize conceptual spaces as a meso level representation embedded between the higher-level symbolic representations (the realist approach) and the lower-level network representations (the associationist approach). This formalization is especially useful for the given task because it explicitly links these three levels of representation to each other. Hence, it provides useful hints on how to infer the conceptual space for the given landmark database, and the results can be checked for coherence with the model.

Criticism on conceptual spaces, as on other geometric models for concept representation such as multidimensional scaling, is based on violations of the basic metric axioms — i.e. minimality, triangle inequality, and especially symmetry [13]. Since this paper develops a conceptual space for a given data set, minimality cannot be violated. Two landmarks can only be identified as identical (similarity = 1, distance = 0 respectively) by the system if a landmark is compared to itself[2]. Based

[1]It has been shown that other kinds of Minkowski metrics may provide improved descriptions of the perceived similarity [6].

[2]However, it must be borne in mind that the user might confuse two landmarks with a high similarity value. For the given scenario, this can be handled by a spatial buffer to make sure that for a given landmark, there is no confusable other landmark within the area of sight.

on the same assumption, i.e. that a computer cannot confuse similar things, the triangle inequality necessarily holds. Even if there are two identical buildings, they are still distinguishable from each other by their location, given by the street name and number in the scenario. The violation of symmetry can easily be shown in subject tests with directed tasks, for example Mexico is usually rated to be more similar to the USA than vice versa. Different similarity values for the two directions of a comparing task stem from the fact that one concept is more prominent than the other one. Hence, extensions have been developed for conceptual spaces that introduce bias values to reflect the prominence of a concept; for an overview, see [6], chapter five. For simplicity, symmetry will be taken for granted below, following the assumption that the user working with the system does not know any of the landmarks in his environment and is therefore not biased concerning prominence.

The System Space

Though conceptual spaces were initially developed to represent the human understanding of terms, they can also be utilized to describe the data and services a machine offers [9]. Representing a data source as a concept improves techniques for service and data source discovery. Current query techniques only find information which exactly matches given criteria, usually provided as keywords. This is due to the fact that current descriptions are mainly based on metadata and ontologies, which reduce relations among concepts to *is-a* relationships (such as “a cathedral is a church is a building”). With these descriptions, similarity measurement is only indirectly possible, through calculations on the ontological tree structure — if at all. Conceptual spaces allow for the discovery of *sufficiently similar* sources of information by calculating similarity values based on the properties of an object. For example, when a tourist searches for a museum for medieval art at his destination, but there is no such museum, the search engine could provide him with historic buildings from the same era. Those alternative results were then based on a high similarity between the query concept and the results, e.g. on the dimensions for age and attractiveness for tourists. Although they do not match the query exactly, they provide valuable information. Beyond that, conceptual spaces, once defined for a service and a user, could improve the personalization of the service. A service which is aware of a specific user’s conceptual space knows which information is valuable for that user, and which is useless. Imagine a traveling architect, for example, with his personal device that is aware of his interests and the special knowledge he has due to his profession: His device can select landmarks for navigation based on architectural features that do not stand out for lay-persons, and notify him of architecturally interesting sights on his way. This personalization can even be fine-tuned to special eras or styles, reflecting the detailed preferences by weights on the according dimensions. The high level of individual adaptation is possible because the device acts on a level of information representation that corresponds to the user’s understanding.

Conceptual spaces are supposed to be especially useful in a spatial context because we perceive space directly. We see the world when we are walking outside or driving a car, and we look at a representation of the real world when we use a map. It is this perception that distinguishes conceptual spaces from other semantic descriptions such as ontologies: while ontologies show how symbols are related to each other, without being anchored in the real world, conceptual spaces are based on people’s perceptions as the fundamental quality dimensions. Other, more complex quality dimensions may build upon them, but human perception is what ties conceptual spaces to the real world.

According to the formal definition provided in [1], a conceptual space includes the following elements (summarized; see the original paper for the exact, extensive definition):

1. A base conceptual space with a distance metric and a betweenness relation

2. A concept space and a symbol space

3. A set of dimensions, composed of subsets of integrate dimensions (domains) and separable dimensions

Beyond that, the definition includes an attention buffer and copies of the base conceptual space, specifying levels. The attention buffer formalizes the process of highlighting a region in a conceptual space because of its importance for a given task. Striving for a conceptual space representing the given landmark database independent of a specific task, this aspect will be ignored in the following. The copies of the base conceptual space provide a representational solution for the *binding problem*: In a complex concept, these levels specify which property refers to which sub-concept. As the case study does not include complex concepts, this part will also be omitted[3]. The process that will be analyzed can be summarized as shown in figure 1.

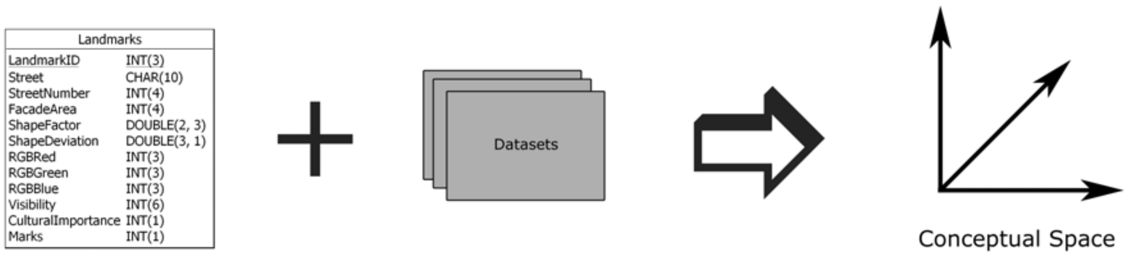

Figure 1: The database schema and the set of 58 landmarks are used to define the conceptual space.

Specifying the Database's Conceptual Space

So far, we have pointed out the potential usages of conceptual spaces, focusing on applications with a spatial context. However, hardly any of the above techniques have been implemented or tested so far. To come to working results, we will next go through the process summarized in figure 1. The results will be described informally; for a general formalization of the derivation process, which is in line with the formal definition of conceptual spaces in [1], further research is required.

The starting point for the definition of the conceptual space for the landmark database is the symbol space given by the database schema. Every field in the database stands for a property (i.e. the property's name), and every dataset assigns specific values to the properties, describing the landmarks on the symbolic level (see table 1 for an extract). In the first step, we generate dimensions according to the fields of the database. We use the data type defined by the database schema and the measurement scale [11] of every field to assign the appropriate metrics and betweenness relation to every dimension. Note that the measurement scales are not defined by the schema; additional knowledge about the semantics of the fields is required to infer them. Table 2 shows an overview of all database fields with data types, descriptions and measurement scales. For instance, the values in the field *Visibility* are on the ratio scale, whereas the entries for *ID* are on the nominal

[3]Moreover, the formation of complex concepts requires a detailed understanding of the underlying basic concepts. Since these are still a research topic with many open questions, they should be addressed first before investigating complex concepts in the future.

scale, although both of them are stored as integers. To come to this conclusion, we must know that *Visibility* refers to the size of the area from which the landmark is visible, and that an area is on the ratio scale because it allows for the determination of the equality of ratios. The values for *ID*, however, are arbitrarily assigned identification numbers, which are not ordered and thus only allow for determination of equality. Accordingly, *Cultural Importance* is on the ordinal scale, because a landmark with value 2 is more important than another one with value 1, but it does not make sense to calculate differences. The measurement scales for the remaining fields are derived correspondingly[4].

ID	Street	No	Façade Area	Shape Factor	Shape Deviation	RGB Red	RGB Green	RGB Blue	Visibility	Cultural Importance	Marks
24	Stephansplatz	1	1266	0,752	33	91	96	109	4738	3	0
25	Stephansplatz	4	679	0,94	0	154	164	184	2190	1	2
26	Stephansplatz	5	1702	0,755	0	173	184	205	4578	1	1
27	Stephansplatz	6	2279	0,735	0	154	167	194	2803	1	1
28	Stephansplatz	1	3309	1,27	57,7	52	55	64	11051	3	0
29	Stephansplatz	4	763	0,798	0	130	139	162	4398	1	1
30	Churhausgasse	1	819	0,712	0	105	107	122	1853	1	1
31	Churhausgasse	2	1035	0,824	0	113	115	133	1058	2	1
32	Stephansplatz	3	2296	0,693	0	123	129	151	3832	2	0

Table 1: Extract from the landmarks database.

To derive the appropriate metrics for a dimension, we also need to know whether it is a separable dimension, or if it is integrate with other dimensions, forming a domain. The three dimensions for the façade color domain in RGB mode combine using city block metrics, because all three dimensions are required to completely describe the color. Thus, the dimensions are integrate. The remaining dimensions are separable from each other and should consequentially be assigned Euclidian metrics; however, this is not always possible. Looking at the measurement scales, we see that the dimensions for the database fields with a nominal scale cannot be used to calculate any distances. Instead, we have to fall back on a Boolean metrics, which only allows us to specify whether two landmarks are identical on the according dimensions, e.g. whether they are in the same street. Similarity values other than 0 and 1 are not possible. Note that it is only possible to use Euclidian metrics on the dimensions for the fields with an ordinal scale because they are already expressed in numbers from 0 to 3. If they were identified by keywords (such as "no marks", "used commercially", "commercially used by a well-marked venue" etc. for the field *Marks*), it would be necessary to assign numbers to them, which reflect the order of the original values [10].

The betweenness relation for every dimension required for the complete definition of the conceptual space is strongly related to the metrics. For the dimensions combining with Euclidian or city block metrics, betweenness is implied in the metrics. For the dimensions applying Boolean metrics, which stem from the database fields on the nominal scale, this is not possible. The first condition for the betweenness relation *B(a,b,c)* requires the variables a, b and c to take different values ([1], p. 199), which is not possible with Boolean metrics, providing only two distinct values. Hence, the betweenness relation on these dimensions is empty. However, it is still possible to determine whether a concept representation is between two others, using only those dimensions which allow for the computation of betweenness.

[4]There is no field with interval scale in this database; *year of construction* would be an example.

Field Name	SQL Data Type	Description	Measurement Scale
ID	INT	Unique ID	Nominal
Street	CHAR	Street name	Nominal
No	INT	Street number	Nominal
Façade Area	INT	Façade area in m^2	Ratio
Shape Factor	DOUBLE	Proportion of height to width of façade	Ratio
Shape Deviation	DOUBLE	Deviation from rectangular shape	Ratio
RGB Red	INT	RGB value for red	Ratio
RGB Green	INT	RGB value for green	Ratio
RGB Blue	INT	RGB value for blue	Ratio
Visibility	INT	Size of the area from which the façade is visible in m^2	Ratio
Cultural Importance	INT	Four ordered classes with increasing importance	Ordinal
Marks	INT	Four ordered classes with increasing recognizability	Ordinal

Table 2: Field names from database schema with according data types and measurement scales.

Automating the Process

To utilize data descriptions based on conceptual spaces, automating the process described in the previous section is desirable. Particularly, this would allow for the generation of cognitively adequate representation for existing data without going through a cumbersome manual process. However, as the analysis of the process to describe a given landmarks database has shown, it is not possible to completely automate this process. Manual intervention is required at several stages to integrate additional knowledge, which cannot be retrieved from the database schema or the datasets.

In the first step, we created the dimensions of the conceptual space according to the fields of the database. We used information on the measurement scales and on integrate and separable quality dimensions to define the appropriate metrics for these dimensions; neither of them can be computed from the database schema or the datasets without additional knowledge. Without knowing about the semantics of the fields, it is not possible to determine the measurement scale. The same applies for the specification of separable and integrate quality dimensions. Looking at the three fields defining the RGB color value for the landmarks' façades, there is no hint in the database schema on their semantic relationship. Since the three values are numerically independent, statistical correlation analysis cannot reveal their semantic dependence either. Consequently, this part of the process is heavily relying on external input.

Once the measurement scales and the integrate and separable quality dimensions have been specified, the appropriate metrics can be assigned automatically. Separable dimensions apply Euclidian metrics, whereas integrate dimensions apply city block metrics. If this is not possible due to the fact that the according database field's values are on the nominal scale, Boolean metrics must be applied instead. The betweenness relation is then implied in the metrics, or empty in the case of Boolean metrics.

Conclusions and Future Work

We have outlined some initial ideas on the use of conceptual spaces for data and service descriptions. Beyond small examples of how to utilize them in the geospatial domain, we have used the case of a small database with landmarks in the city of Vienna to show what is necessary to derive a conceptual space representation from such a model. It was demonstrated that some information can be extracted, while other parts are merely derivable without interpretation and addition of external information. This leads to the basic conclusion that generating conceptual spaces from descriptions that are settled on the symbol level, comparable to a database, cannot be completely automated. It must also be noted that the fields in the database example are very closely related to properties humans can perceive directly. It can be assumed that the process gets more complicated with increased abstractness and complexity of the data model.

Future work should focus on developing best practices in how to generate conceptual spaces for existing data sources and services. The results of this paper should be used to specify a process for the derivation of a conceptual space from an existing database. This process should be formally in line with the definition of a conceptual space in [1]. Beyond that, it should especially focus on automating the derivation as far as possible and assisting the user when adding external information. In this context, it needs to be investigated whether external data sources are useful for the further automating. We should then strive for the generalization of the process to be applicable on other kinds of symbolic information representations, and finally evaluate the results in a case study with human subjects tests.

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Getting From Cognition to Collection: Data provision for usable models

Clare Davies, Ordnance Survey[1]
Research & Innovation, C530, Ordnance Survey, Romsey Road, Southampton SO16 4GU, UK
clare.davies@ordnancesurvey.co.uk

Abstract
This position paper argues that for cognitive science, GI science and environment modelling to work effectively together, priority needs to be given to research into *universal subtasks* – cognitive processes which are employed across a range of real-world tasks and contexts. For the work to be useful, more attention needs to be drawn to the implications not only for system design but also for data provision. An example is given from current collaborative work involving Ordnance Survey, and further example topics are suggested.

It is, of course, a truism that we should be able to build better models of real-world environments if we understand what users of those models know, and understand, and care about, concerning those environments and their uses. This is perhaps worth examining, however: perhaps it is not always as true as we assume. For instance, a current belief in this field is that what were once called 'cognitive maps' are closer to being 'cognitive collages' – a jumble of images, map fragments, routes, landmarks and other information (Tversky, 1993). Yet, to take a *reductio ad absurdum*, this does not make most of us want to simulate a similar multimedia 'collage' in our GIS or 3D virtual model for every user and every application. Indeed, the beauty of a single, simplified, virtual environment model is often that it unifies and removes clutter from the space, to make its structure and geometry easier to appreciate. The information that is given or withheld in any model should always depend on the task and context.

This task dependence, both in cognition and in user-centred design, makes life potentially difficult for generic geospatial data providers such as national mapping agencies, whose central database (but not all of the products derived from it) must be 'all things to all people'. In other words, even highly specific studies of human geospatial cognition may have implications for the content of that database. If the content is not there, or is stored in forms that cannot be converted to those necessary for a given type of model, then any number of research studies and prototype models will fail to result in real-world application, save for small case-study scenarios where data can be manually collected.

As a cognitive scientist working within a national mapping agency, part of my role is to try to bridge this gap - to produce, identify, sponsor and encourage research that centres around the human user but has clear potential to impact on, and alter the decisions made about, national and international geospatial data. The first implication of this concerns the lessons we can learn from empirical human-subjects studies, and from cognitive science theory and models. Ideally an outcome must be universal across tasks and user types, if we are to absorb its message into a national dataset.

Even then, we have to find a way of doing so that actually helps, rather than hinders, real-world tasks. Thus, for example, the knowledge that features such as mountains and neighbourhoods are generally fuzzy (Fisher et al, 2004; Agarwal, 2005) has to be interpreted and used carefully; many real-world GIS applications may depend on the convention of drawing crisp boundaries, despite their counter-intuitiveness. One data product may need to continue to provide these, while another may be developed to allow fuzzy algorithms to perform more subtle analyses on the data, and visualisation tools to show gently shading colours. Different task contexts will then determine the choice between them: just as we know that someone can't be a little bit pregnant (Pinker, 1998), so we are also prepared to accept crisp boundaries if a task or analysis demands it.

3D: up or down?

Speaking of "modelling environments" generally implies that the third dimension will be included, and this is where a disparity exists between two research traditions. 3D GIS research has often focused on models of a city, or a local area of it, at what Montello (Montello, 1993) might have called an 'environmental' or even a 'geographical' scale: e.g. a proposed planning development is set into the context of other surrounding buildings. The skyline, and views from points some distance away, are considered, and may sometimes be deemed more relevant than the ground-based view of someone standing just beside the proposed building or highway (Blaschke, 2004). Meanwhile the virtual environments domain has usually assumed that most of the time, the user is standing squarely on the ground and is 'walking' through streets or corridors (e.g. May et al, 1995; Rossano et al, 1999), seeing buildings and other objects more at the immediate 'vista' scale. The difference this makes to a user's experience of a model can be seen in Figure 1.

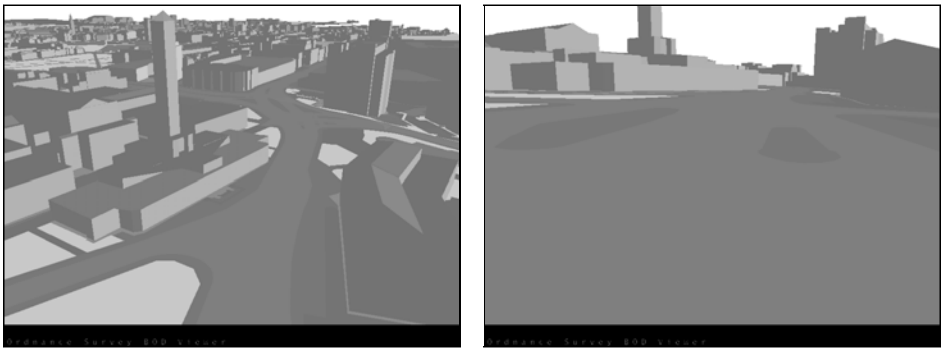

Figure 1: The difference for a user between a bird's eye and ground-level view, with a simplified city model.

Of course a typical 3D virtual environment can be viewed from any perspective, but the emphasis of a given project on one or another viewpoint will affect the developers' concerns with accuracy, structural detail and visual realism in the model, as well as surface visualisation issues such as illumination, texture and depth cues. In turn this can (or at least, ideally should) impact on a data provider's decisions about data collection methods - methods based on remote sensing will have better accuracy at roof level than from the ground, whereas ground-based survey will give the reverse. So, which matters more? Which types of structural, visual and functional information make a difference to users' cognition of a scene when the model is viewed from a given perspective, and which of these perspectives are likely to matter the most in real-world applications such as planning decisions? Hence, how should a data collector and provider prioritise the many aspects and details of a 3D real-world feature? Such questions are not easily answered; it is hard even to find clues in many published papers about typical modelling-plus-evaluation studies.

Beneath the task level: universal cognitive subtasks

Saying that modelling requirements are bound to users' tasks could make us feel discouraged: what then is universal? Fortunately, there are only so many things you can do with a space.

The focus on wayfinding in the GI Science area has been overwhelming and perhaps disproportionate, relative to the consideration of other less universal (but socially important) tasks such as physical asset management or civic government. Yet when we use task analysis or even just a moment's thought, we can often identify common processes that users have to perform in a wide range of task contexts. Perhaps supporting those processes might increase efficiency and effectiveness of GI use across many domains - a 'big win' for research.

One such process, which we are currently investigating at Ordnance Survey alongside external collaborators at the University of Huddersfield and University College London, is orientation. More specifically, we mean by this the situation where a person matches a scene to a map, to identify the direction s/he is facing[2]. This task has to be performed in wayfinding, of course, but also by surveyors, maintenance teams, emergency response officers, security personnel viewing CCTV footage, local historians examining old photographs and maps, and probably many others. Thus while navigation decisions are only taken while navigating, orientation is a more universal subtask. If we can understand people's cognitive strategies in doing it, and find which factors in the environment and/or map make the task harder in some places than in others, we have the potential to help map users by providing appropriate information (such as landmarks) in the 'harder' locations. In turn, this tells Ordnance Survey, as a data provider, how a future data product could select and deliver specifically task-appropriate information without overly cluttering a map or model.

Results to date suggest that the factors affecting orientation performance may indeed be predictable: scenes certainly differ in terms of the ease of matching them to a map location and direction. Investigations are continuing into the potential for measuring and predicting the factors in question just from the map itself, which could allow for semi-automated prediction of user needs. The same approach could be applied to the design of more 'legible' 3D models. Again, people need to be able to orientate effectively when 'in' the model, either in order to relate it to the real world it represents, or just to match it effectively to a 2D map of the same area.

Similar subprocesses and related research topics are identifiable with a little thought, although no overarching list appears to exist at present. It is suggested that some candidates could include:

- *Distinguishing separate properties and/or buildings*. Research could identify the minimum cues necessary for this, both in a simplified 3D environment and in generalised maps (necessary for any user who needs to identify specific addresses or building objects). Roof shape can be a clue, as well as lines drawn on a wall (which may not exist in reality), but which cues do people actually use? Can existing theories of perception and cognition predict what is needed to help a user 'parse' a visual scene as efficiently as possible?
- *Examining lines of sight*. With semi-obstructing structures or details, where and when do they need to be accurate, and how much so? To what extent is this task-dependent?
- *Matching items between real-world scenes, virtual models and maps*. We currently believe that an important part of the orientation task involves extracting the 2D 'ground' geometry of road layouts and buildings, to match these to the map. This in itself is a 'universal subtask' not only within orientation, but also when identifying one object among a number of similar ones (e.g. when deciding which building or terrain feature is shown in a photograph, relative to the set depicted on a map, without necessarily caring about its exact orientation). If the outlines on the map (or in a model) have been generalised (simplified), what details must remain to ensure accurate identification?

[2] For the initial work on this, we have separated this from the process of *locating* oneself in the space, although in reality people often have to achieve both simultaneously.

- *Aesthetics and affect*. We could try to apply knowledge from environmental psychology of people's aesthetic and affective preferences in environments. This could enable only emotionally salient visual details to be included in a simplified 3D model aimed at evoking the 'experience' of an environment (which may be for purposes as diverse as public planning participation, therapy for agoraphobia, and simulating people's wayfinding decisions when feeling vulnerable or motivated to explore - as in a videogame, or when researching the causes of crime or traffic 'hotspots'). Can we even separate such features and factors and include them in models (and hence, potentially, in the data supplied for such models to be built), or does it always feel false? Can a virtual environment actually feel 'nice' or 'threatening' enough to alter people's cognitive strategies and decisions?

Conclusion

Any work that attempts to bridge cognitive science and GI science needs to keep firmly in mind the relevance of the topic to real world applications, and specifically to the cognitive details of the tasks that people perform. Cognitive task analysis methods may help to identify these (e.g. Schraagen, 2000). To repeat, it is not only GIS and model tool vendors that should be impacted by good, solidly-grounded research in this area, but also data providers - for without the data, the models can't exist.

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Cognitive structure, urban symbolic order and landmark detection

Ana Paula Neto de Faria[1], Romulo Krafta[2]

[1] Faculty of Architecture and Urbanism, Federal University of Pelotas

anapajuli@yahoo.com.br

[2] Faculty of Architecture, Federal University of Rio Grande do Sul

krafta@ufrgs.br

1. Introduction

The urban environment is cognitively structured by human mind in meaningful frames of information that bind together knowledge about objects/areas and their layout or spatial relations. The resulting structure is in fact an achievable order resulting from external and internal aspects of environmental cognition (Portugali, 1996). External aspects are referent to the physical characteristics of urban environment and also to the kind and intensity of activities and social practices present in urban space. Internal aspects refer to the perceptual and cognitive processing of available information during environmental cognition, which includes simplification, abstraction, categorization and inference.

Structuring environmental information can be seen as a cognitive mechanism that reduces uncertainty, turns feasible comprehension of extensive urban areas that are not actually known and guides actions and interactions in urban space. Agents base their actions with reference on this cognitively structured representation of urban space and not on the objective environment. Hence the representation of urban morphology based on cognitive criteria is an important issue in urban studies. In this paper we bring the hypotheses that this can be done with a spatial interaction model and present its implementation on landmark detection.

2. Cognitive Structure and Symbolic Order

When references are established between discrete portions of urban space and specific meanings, they become information units in people's cognitive structure of urban environment. As pointed by Lynch (1960), a portion of the understandings about the urban environment is widely shared by the social groups that interact with the environment. Commonality's are said to be due to the proper structure of the physical environment - that induces or stimulates certain apprehensions, to physiological similarities amongst individuals (Gibson, 1979), and to the social and cultural bases of environmental knowledge (Vygostsky, 1984). In this common cognitive structure the urban identity – that we call symbolic order – is expressed. Symbolic order synthesizes the convergence between syntactic structure, built form and social agency of urban space and can be understood as meanings attached to the components of urban form – social use, activities, and cultural, social and economic values. We believe that it's this symbolic order that is essential to be captured in the representation of urban space.

We have been working on a model able to capture symbolic order in urban form. Symbolic order is represented as a set of spatial relationships among physical attributes of elements present in urban morphology, mirroring human environmental cognition. The model is conceived as an iterative and hierarchical system of comparisons of spatial units. Urban space is recorded as spatial units, or cells, standing for individual land plots and buildings, as well as open public spaces. Open spaces are public squares and street sections defined as segments between street intersections. The hierarchical structure of the model is composed of three to five different levels that have correspondence with the interaction space or neighbourhood area of each cell and go from small-scale spaces until large environmental wholes. The number of levels depends on the overall size of the environment being represented. The hierarchical structure guarantees spatial coherence in the comparisons of spatial units. Hierarchical levels are correlated by bottom-up processing and supplementary top-down calibration. In each level cells are processed by a set of interaction rules that define the cells state value for that hierarchical level and the behaviour in the next level. Interaction rules determine the aggregation or segregation of spatial units based on cooperation or competition between units. Cooperation occurs in situations where comparisons detect high similarity or equivalence between spatial units, distinguishing continuities in the environment that may incorporate even the lower valued cells that lay in-between. Cells that cooperate are aggregated and act as a unique spatial unit in the next level. Competition happens when significant differentiation is detected between one spatial unit and all others in its neighbourhood area. In this situation the cell competes and tries to survive as a segregated spatial unit, which is only possible if it has really high distinctiveness from the environment. Top-down calibration stresses comparisons for segregation based on the influences received from higher level information units. The interaction rules perform the same functional proceedings in each level.

3. LANDMARKS IN SYMBOLIC ORDER

Landmarks are an important element in symbolic order. They are related to metonymical, symbolic and functional structuring of environmental information. Landmarks are metonymic when they stand for the activities that happen inside them or in the adjacent urban spaces, and also when they stand for an entire urban area. Symbolic structuring of information is responsible for the presence of landmarks that are due to correspondence between historic events or social and cultural values with the built form. Functional landmarks are related to navigation and orientation necessities and are visually noticeable in the environment owing to their visual saliency or strategic location. It is important to note that many local landmarks, important for urban navigation, do not appear in symbolic order.

An experimental module of the proposed computational model was created to test the power of the model in detecting buildings with high probability of becoming landmarks in urban symbolic order. For this purpose, the experimental module was restricted to the proceedings specific for variable calculus and competition processing with lot cells.

3.1 SPATIAL REPRESENTATION AND DATABASE

The computational model was applied to the urban core of a middle size city with great diversity of building types and functional uses. The study area has 2 public squares and 82 blocks divided in 1899 lots. The selected area has a relatively regular grid and a flat topography, ensuring minimum influence of external factors on lot cells.

Lots and urban spaces were defined using a digital urban cadastral map. The connection network, that makes explicit the relational structure between cells, was determined. Neighbourhood areas were also determined, defining the located regions in the connection network that represent the spheres of influence received by each cell in each hierarchical level. Due to the size of the defined study area the hierarchical levels of the model were restricted to three. In the first level the neighbourhood area consists of all lot cells connected to the same urban space cell of access. In the second level it comprises all lot cells in the limit distance of one step from the cell of access, and in the third level neighbourhood is extended to all cells in the system. These levels represent specific changes in perceptual and cognitive processing and are also representative of different aggregation levels of environmental information that appear in symbolic order.

No database was available so a local survey was done to register each cells attributes.

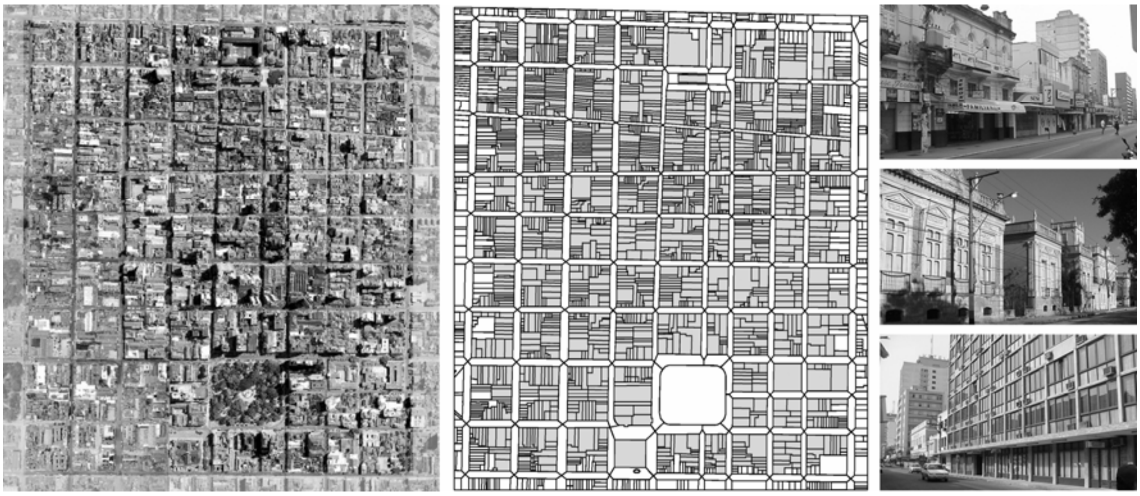

Figure 1: Aerial photograph and cell representation of the test area. Street photographs showing diversity of the built environment.

3.2 ATTRIBUTES AND DESCRIPTION STRUCTURE

Symbolic order is basically composed by what Downs & Stea (1977) and Passini (1992) call "descriptive component": information that turns possible the identification of places and objects and also states what things are. In the same direction Appleyard (1969) asserts that physical form, function or use, visibility and significance are responsible for the elements present in mental representations. Social-economic identities are also sited as being relevant in the apprehension of buildings and urban environments. Sorrows & Hirtle (1999), Raubal & Winter (2002) and Elias (2003) all indicate visual character, semantic distinction or meanings and location as important indicators of landmark selection. Based on these and other evidences from environmental perception and cognition the selected attributes are of three general categories:

- physical proprieties – describes the physical and perceptual features of the cell. Height, volume shape, form and distribution of opening, general colour, covering materials, setbacks, and presence of signs are attributes of this kind used in the experimental module;
- social and culturally shared information – defines to which functional and formal categories the cell can be assigned. Existence of socially shared linguistic labels used to refer to the buildings are also defined;
- relational proprieties – refers to the relative position that the cell occupies in urban space. Position in the block and building location related to urban space cell of access are described.

Attributes are either nominal (categories with no ranking like colour or volume shape) or ordinal (categories that admit a logical order like height or setback size) and are modelled as category data in the database.

Attributes, as presented here, are raw data. They don't represent what is apprehended from the information present in urban environments. Buildings are not landmarks in reason of their own attributes – it's a conditional property that depends on the features of the surrounding environment too. For more adequate representation of environmental information these attributes must be structured into descriptive variables that take in account the influences of the surrounding environment and the results of human cognition.

3.3 PRE-PROCESSING AND CELL DESCRIPTIVE VARIABLES

Cell attributes are processed using IF – THEN – ELSE type of sentences in different combinations to generate the cognitive information patterns that are relevant for landmark detection. Variables reflect simultaneously the physical characteristics and their apprehension conditions. Descriptive variables used for lot cells are:

- prominence – defines the distinction level of physical appearance in the context of first level neighbourhood by the comparison of its physical attributes with attributes of the other cells:

  IF [attribute *x*] ≠ from all other cells THEN [1] ELSE [0]

  Assigned scores are summed and increase in the number of not shared attributes cause exponential growth in prominence value;
- visibility and localization – determines the spatial and visual prominence of a cell, and hence its potential utility as a reference point in the environment. Cells receive a positive score for localisation in distinct or large open spaces, access by more than one urban space cell, significant height, and receive a negative score for big front setbacks:

  IF [positive attribute] present THEN [1] ELSE [0]

  IF [negative attribute] present THEN [-1] ELSE [0]

  All assigned scores are summed;
- level of typicality to category – how easily the cell can be apprehended as belonging to a given functional category. First the attributes to be compared are determined:

  IF [functional category attribute] = *z* THEN [compare attributes *x*, *y*, *w*] ELSE [try next functional category]

  Then the cell scores for each attribute equal to the predefined attributes of the typical category member[1]:

  IF [attribute *x*] = attribute typical member THEN [1] ELSE [0]

  Calculus is given by the summation of the score received from each attribute;
- unique membership of the category – describes the formal or functional distinction of a cell in its neighbourhood. Cells that belong to formal or functional categories that are not present in the other cells will score:

  IF [category attribute] ≠ from all other cells THEN [1] ELSE [0]

  Calculus results from the summation of all assigned values;
- special meanings – referent to socially shared information. Cultural values, historic importance or functional references are evaluated. These types of meanings normally have an associated name or linguistic label, and some also have related physical attributes. Cells are tested for the presence of each kind of special meaning. The cell scores if it presents all related attributes that match the expected combination for each kind of special meaning:

  IF [attribute *x*, *y*, *w*] = expected attributes of meaning *z* THEN [1] ELSE [0]

  Calculus is made by the summation of scores of each special meaning.

More details of calculus for each variable can be seen in Faria & Krafta (2003). The pre-processing of cells original database transforms the initial category data (attributes) into numeric data (descriptive variables). The resulting values are stored in the database attached to cells.

3.4 Landmark Detection and Information Processing

Landmarks are expected to have differentiated or more intense information patterns than the surrounding environment. The descriptive values numerically represent the intensity and differentiation of several overlaid information patterns of buildings that are simultaneously read in the environment. The combination of the descriptive variables can give us a numerical estimation of the buildings' general distinctiveness or saliency. The general distinctiveness (GD) of a cell is given by:

[1] The typical category member for each functional category was determined by statistical analysis of correlations between functional categories and attributes.

$$GD = \prod_{x=1}^{n} P_k \cdot V_k$$

where:

P_k = weight value for the descriptive variables

V_k = descriptive variables

The computational detection of landmarks is achieved by the successive competition between cells in the hierarchical levels of the model. Criteria for comparison between cells changes along hierarchical levels, with perceptual processes having primacy in lower levels, and cognitive processes becoming more important in the higher levels.

In the first level the weighted value is stressed on prominence and unique membership of a category. This insures primacy of visually apprehended distinction at local level. With the first GD values, cells compete with each other in the first level neighbourhood areas, and those that have the highest GD values and values until 20% smaller that the highest are understood as being more easily used as landmarks and receive state value "detachment". In the second hierarchical level only the cells with state value "detachment" remain as valid cells for processing's with competition rules and second level neighbourhood areas. GD is recalculated for all cells with reinforced weights on special meanings and visibility and localization, reflecting the importance of information utility and cognitive features in this level. Criteria for assigning state value "detachment" remain the same. The third interaction maintains the same GD calculus and state value criteria of the second level and compares all remaining cells. After the application of interaction rules in the third neighbourhood area, all cells that still have state value "detachment" are defined as potential landmarks in symbolic order of urban space.

The obtained results with the experimental module were compared to results obtained by traditional survey methods[2]. Correlations with the detected landmarks in traditional survey were very encouraging.

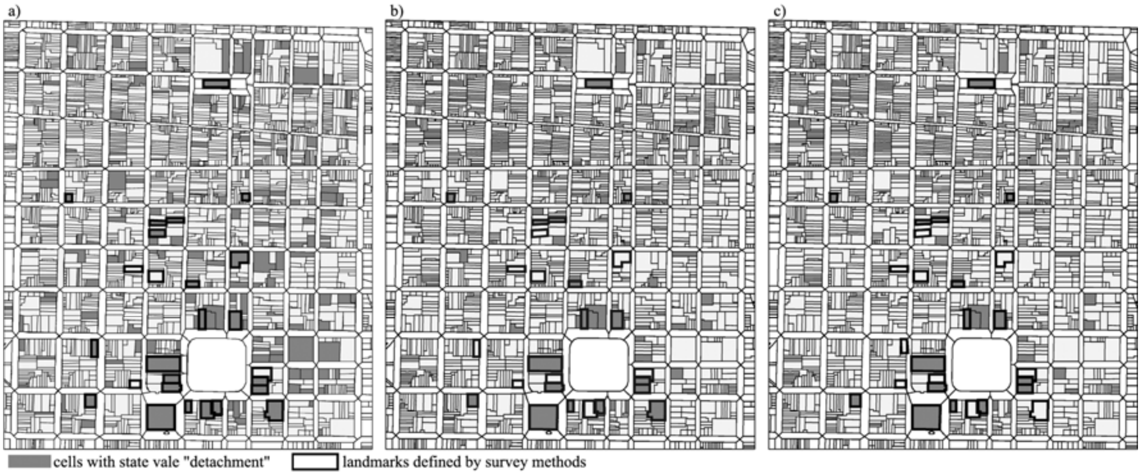

Figure 2: Cells with state value "detachment" in the three hierarchical levels and compared results with traditional survey methods.

Results from the first and second hierarchical level detected buildings that can be seen as potential location or rout landmarks in the sense that they represent those buildings that are more differentiated in the immediate neighbourhood, and for these landmarks only the relative uniqueness in neighbourhood is required. However it seems that other issues are also important for landmarks present in symbolic order.

[2] Mental maps and open questionnaires were applied to 250 city residents with different interaction levels with the study area

As expected a strong dependency on feedback processes from higher level aggregated spatial units was detected. Human selected landmarks were many times highly correlated with the special meanings of the urban spaces in which they were located. How ever it was not expected that these correlations could make void general distinction. Buildings that were highly correlated with the general meaning or character of urban space were preferentially selected even in the presence of better rated buildings in the majority of the descriptive variables and also in general distinctiveness. Hence prominent commerce buildings were preferentially selected when located in important commercial streets and historic buildings were more heavily cited in historical areas. For symbolic order, in some situations, the intensity or how well the building expressed the urban character seems more important than its differentiation from the environment.

Other insights to the cognitive structuring processes of environmental information were also possible with the computational model. Apparently the most important variables for defining landmarks are in decreasing order: special meanings, unique membership of a category, visibility and localization and prominence. The variable level of typicality to category is only important in some circumstances, needing additional tests for better definitions.

4. Concluding Remarks

The initial results with the experimental module indicate that representing the cognitive structure of urban space maybe turned possible in theoretical and practical terms. Many problems still have to be solved. One of them is the disaggregation level of data, representing large urban areas is quite a problem in the actual model formulation. A more feasible data structure is required for practical use. Top-down processing must be fully implemented to permit adequate detection of metamorphic landmarks. The complete development of the proposed computational model opens new possibilities in the modes that fundamental morphological elements can be represented in urban simulation models.

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On modeling of large-scale environments for solving spatio-temporal planning problems

Inessa Seifert

SFB TR 8/ Spatial Cognition,
University of Bremen, Germany

seifert@sfbtr8.uni-bremen.de

Abstract: the paper introduces a cognitively motivated approach for structuring and representing of unfamiliar large-scale environments. The proposed region-based representation facilitates collaborative spatio-temporal planning, where problem solving process is shared between a user and an assistance system. The problem domain is structured hierarchically into regions resembling human decision space. The region-based structure makes it possible to specify spatial constraints as well as to generate alternative solutions at different levels of granularity.

Motivation

Finding a path from A to B in a network consisting of nodes and edges is one of the classical problems in the history of computer science. One of the most famous shortest-path algorithms has been introduced by Dijkstra in 1959 (Dijkstra, 1959). Yet, several decades of interdisciplinary research in spatial cognition has been needed to develop the cognitively motivated principles for communication of route instructions, which help people to find a way from location A to location B in common street networks (e.g., Denis, 1997; Tversky & Lee, 1999; Dale et. al., 2002).

Psychological investigations on how humans perceive, learn and structure their knowledge about familiar or unfamiliar environments, and correspondingly how they perform spatial problem solving tasks, provide theoretical background for development of cognitively motivated models for representing and communicating knowledge about spatial environments (e.g., Rüetschi & Timpf, 2005). Spatial assistance systems (e.g., Rehrl et. al., 2005), which operate on such models contribute to user-friendly assistance with navigation tasks as well as a seamless transition from indoor to outdoor environments.

Availably of additional meta-information about geographic regions and locations makes it possible to associate specific properties, such as points of interest (e.g., national parks, museums or sightseeing attractions) with the topological data, i.e., how locations are connected with each other. Such information provides a basis for assistance with further spatial problems like spatio-temporal planning. A typical example of such task is planning of an individual journey or a city tour.

When planning a journey through an unfamiliar environment, travelers have to make a decision on *what* they are going to do, i.e., specify a set of activities. Along with the question *what*, they have to decide *where* the activities take place. Since the most of the interesting places and attractions are distributed around a country or a city, the corresponding locations have to be grouped together, to reduce the time for traveling from one place to another. Furthermore, journeys are usually constrained in time, so that journey planners have to fix the durations of their activities and put them into a feasible temporal order. Yet, especially in the early planning stage the information on *what*, *when* and *where* is known only partially and is available at different levels of granularity.

The next section outlines the characteristics of the problem domain from the human problem solving and knowledge representation point of view. The subsequent section identifies the gap between the existing approaches: task-orientated map production and personalized tour generation. To fill the gap, a *collaborative assistance* approach with spatio-temporal planning is introduced. Since collaborative assistance requires user's active participation in the problem solving task, human cognitive capacity and mental processing of geographic information has to be taken into consideration. The paper describes a cognitively motivated approach for structuring of the spatio-temporal problem domain, which allows for an adequate dialogue between a human and an artificial assistance system during collaborative spatio-temporal planning tasks.

Characteristics of spatio-temporal planning

Spatio-temporal planning encompasses putting a set of activities into a feasible order under consideration of spatial and temporal constraints. The corresponding constraints can be formalized as a set of activities with the following attributes. Each activity has an activity type (*what* to do), duration (*how long*), temporal order (*when*), and a spatial assignment (*where*).

Psychological findings describe mental knowledge representations as hierarchically organized and consisting of loosely coupled, contradictory and nested knowledge fragments (e.g., Tversky, 1993). Consequently, even if a journey planner has a rough idea of the activity types he/she prefers, the initial spatial assignments are known at different levels of granularity, e.g., a particular country, a part of a country, a city, etc. Various information artifacts like maps, traveling guides and the Internet provide users with information about different locations, which may sound interesting, but travelers have no idea of activities they can pursue there, i.e., type of activities that can be performed in a particular location or a region.

Although journeys and activities are constrained in time, optimization criteria regarding an overall goal of a journey have to satisfy such important criteria, like personal preferences, moods or even emotions, which are in turn hard to acquire and to formalize. Furthermore, journey plans are specified only to a certain degree, in order to be updated or changed in the course of traveling. Since the initial problem solving state encompasses only rough spatial assignments and optimization function together with a particular goal state are not well-defined, planning an individual journey through a foreign country is an ill-structured problem (Simon, 1973).

Existing approaches for assistance with similar types of problems

The existing approaches for assistance with the similar spatial problems found in the literature can be divided into two categories: task-oriented map production and personalized tour generation.

Task-orientated maps

Task-oriented map production (Zipf & von Hunolstein, 2003) aims at representing the relevant aspects of the environment, which are required for solving a particular spatial problem, providing users with answers to the questions, e.g., “where I am?” - you are here maps (Richter & Klippel, 2002), “what can I do next?” - adaptive mobile maps (Reichenbacher, 2005), “how can I get from A to B?”, - route directions (e.g., Richter & Klippel, 2005). Such representations single out particular aspects of the problem domain, i.e., objects and specific properties and relations between them which are relevant for the problem solving task and make it possible to solve the problem efficiently (Freksa & Barkowsky, 1996).

Yet, the exemplified problem solving tasks, which can be assisted using task-oriented map production, either encompass relatively small areas situated in user’s vicinity, or are well-defined, like, e.g., route instructions from A to B. And finally, the reasoning part about the combination of spatial and temporal constraints has to be performed mentally.

Tour generation

Another approach to assist in problems like journey planning is a personalized tour generation. In order to reduce the number of possible destinations, which come into consideration, such systems utilize user modeling and personalization techniques. For example, the profiling data including user’s preferences allows for reducing the number of the proposed items delivered by search engines (Schmidt-Belz, et. al., 2003).

A similar approach introduced in (McGinty & Smith, 2002) utilizes user modeling and profiling data in order to generate personalized routes between predefined starting and goal destinations.

The main disadvantage of the tour generation approach is the exclusion of user’s active participation in a process of planning. In doing so, the generated tours are difficult or even impossible to change. Personalization takes into consideration preferences of a single user. However, traveling is a social venture and no one likes to travel alone. Consequently, the profiling data has to be shared among the people, who travel together. However, it is not conform to the term “*personalization*”.

From that follows, that the spatio-temporal planning cannot be totally outsourced to a computational constraint solver or a search engine, but requires collaborative search for a solution.

Collaborative assistance systems

Collaborative assistance systems accompany problem solving process rather than providing users with a single solution (Schlieder & Hagen, 2000). A collaborative assistance system generates a set of alternative solutions which fulfill specified formalized hard constraints, for example, duration of the whole journey and durations of each activity, together with partially specified activity types and spatial assignments. The generated solutions have to be observed by a user, who decides, whether the generated solution space is "good enough" for a current situation, or should be refined due to personal preferences. In the second case, a user can specify further constraints, or on the other hand change or relax existing constraints in order to obtain improved solutions. In doing so, the constraint satisfaction processes is shared between an assistance system and a person. However, to establish an adequate dialogue between a user and an assistance system, the structure of the spatio-temporal problem domain has to resemble the human decision space.

In our recent works (Seifert, et. al., to appear) we introduced a concept of a cognitively motivated representation structure, which allows for specification of constraints as well as generation of alternative solutions at different levels of granularity. In the following, the paper provides a refined overview about the proposed region-based representation structure.

Region-based representation

The region-based representation is based on psychological findings considering human processing of geographic information, i.e., cognitive maps (Hirtle & Heidorn, 1993), cognitive atlases (Hirtle, 1998) and cognitive collages (Tversky, 1993). To facilitate the human co-processing of geographic information during the collaborative problem solving the system utilizes the cognitive phenomena *regionalization* (Montello, 2003) and *region connectivity* (Wiener, 2004).

Regionalization

"*Regionalization has its definite analytic and communicative utility. It simplifies complexity and avoids unnecessary precision, both in thought and speech*" (Montello, 2003). Therefore, the proposed region-based representation structure consists of hierarchically organized regions.

The geographic information provided by maps and geographic information systems (GIS) is extremely rich. Modern GI-Systems are capable of representing and manipulating of spatial and topological information about administrative, topographic, as well as thematic regions. However, to reduce the representational complexity and to convey the structure of an unfamiliar large-scale geographic environments popular traveler guides like the "Traveling Guide of California" (Vis a Vis, 2004), combine the administrative regions into *super-ordinate* parts of a large-scale environment (see Figure 1).

Figure 1: Example partitioning of California, USA[1]

Such global parts divide a large-scale geographic area into a relatively small number of regions. If such parts cannot be mapped to administrative regions, they are usually labeled by geographical or climatic specifics of the environment in combination with cardinal directions, like North Coast, Central Cost, South Coast, etc. (cf., Lyi Y. et al., 2005).

The proposed assistance system operates on a spatial hierarchy, which spans three conceptual layers: *locations*, activity type specific regions, denoted as *activity regions* and *super-ordinate* regions. *Activity regions* represent sets of *locations* which share some particular property or facility, (e.g., possibility for hiking, water sports, etc.). The size of *activity regions* depends on the scale of the environment in which a journey is planned, and of course on the duration of the whole journey and the durations and the corresponding activities. For example, an *activity region* which encompasses a visit to several museums in Rome during a weekend is smaller than an *activity region* of skiing in the Alps for a week. *Locations* bound into *activity regions* are situated at the lowest level of the spatial region-based hierarchy.

Region connectivity

Series of psychological experiments conducted in a virtual reality lab have shown that regionalization facilitates spatial problem solving tasks like navigation in partially familiar large-scale environments (Wiener, 2004). Mental representations formed in regionalized environments contain super-ordinate connectivity relations, i.e., *region connectivity*, which allow for performing spatial problem solving tasks like route planning more efficiently.

The proposed region-based spatial representation structure consists of **locations**, **regions**, **nodes**, and **paths**.

Locations are points of interest, where *activities* with specific *activity types* can take place. To communicate a *location* to a user, each *location* must have a name. The name has to be unique within an *activity region* that contains the *location*. A *location* can also serve as an abstraction of a region.

Activity regions contain one or more *locations* and a *node*. Such *node* is related to a *location* which connects a set of *locations* sharing the same activity type, e.g. visiting a set of museums, within an *activity region*. Such *node* has a connectivity cost, which results from an approximation, e.g., an average distance cost to the corresponding *locations* (see Figure 2). For the purpose of communication, an *activity region* has a unique name within a *super-ordinate region*. If no direct mapping to an administrative region is possible, such name is constructed from the corresponding super ordinate region and cardinal directions, i.e., (in the North, South of, etc).

[1] The example partitioning is produced from the test data acquired from different information resources.

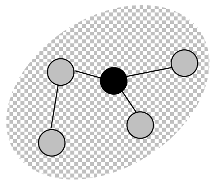

Figure 2: Locations within an activity region connected by a node.

Super-ordinate regions of an unfamiliar large-scale environment contain *activity regions*. The containment relation between the regions is represented as a *part of* relation. Such region-based partonomies allow for representing and reasoning about qualitative topological relations between regions with rough boundaries (Bittner & Stell, 2002). Furthermore, the proposed representation structure includes *neighborhood relations* holding between super-ordinate regions.

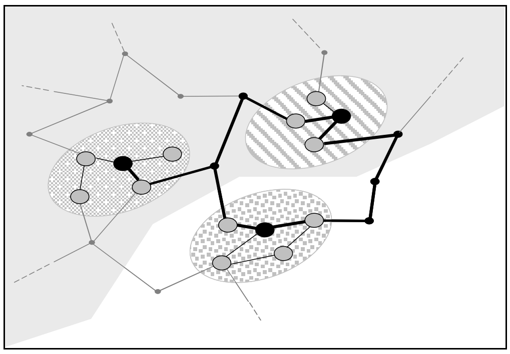

Figure 3: Connectivity of activity regions

A **node** with a connectivity cost is related a *location*, which binds the *locations* within an *activity region*, and is connected with other *activity regions* via *paths* (see Figure 2). The Figure 2 illustrates three *activity regions* situated in two different *super-ordinate regions*.

Paths connect different *activity regions* via *nodes* and have *distance costs*. Each intersection of path segments is also modeled as a *node*, which is related to some *location* but carries no additional connectivity costs.

Solving spatio-temporal problems interactively

Using regions and the relations between them, the initial problem solving state can be specified as a list of activities, in the form of the following data structure (see Figure 4).

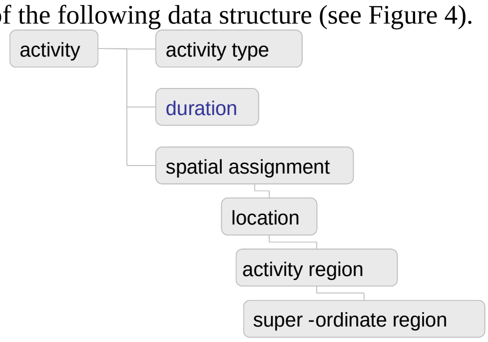

Figure 4: Activity structure.

The definition of duration of each activity is mandatory, whereas activity type and spatial assignment are optional. Using the region-based representation structure the spatial assignments can be specified at different levels of the spatial hierarchy, e.g., as a location, specific activity region, or a super-ordinate region. The temporal constraints can be expressed as valid temporal order of activities, i.e., following one after another.

Allowing user to specify particular activity regions, or a particular order in which the super-ordinate regions are going to be visited interactively, prunes significant parts of the problem space.

Using the cognitive phenomena of regionalization and region connectivity, the proposed representation structure facilitates the generation of alternative solutions and allows for an adequate dialog between a human and an assistance system.

Outlook and future work

The proposed representation structure is based on the assumption that humans operate on mental representations of spatial environments consisting from regions. Series of psychological experiments provide evidence, that such regions are hierarchically organized (e.g., Tversky, 1993; Hirtle & Heidorn, 1993; Hirtle, 1998) and connected with each other (Wiener, 2004). The described representation structure consists of *locations*, *activity regions*, *super-ordinate regions*, *nodes* and *paths*. The size of *locations, activity regions* as well as *super-ordinate regions* depends on the spatio-temporal context of the journey: durations of each activity, duration of the whole journey, and on the velocity of user's locomotion. The paper exemplifies three layers of a spatial hierarchy: *locations*, *activity regions* and *super-ordinate regions*. However, conceptual hierarchy of the corresponding *activity types* (e.g., swimming is a sub activity type of water sports), allows for introducing further levels of granularity to the spatial region-based hierarchy.

Since there are only several means of transportation, which can be used for traveling today, the way people perceive, learn and structure large-scale environments supposed not to be continuous, but discrete. To identify the cognitively adequate granularity levels of activity regions together with suited activity types, more empirical research should be focused on task specific mental representations of large-scale environments.

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Use of Affordances in Cognitive Modeling for Wayfinding

Pierre-Emmanuel Michon[1], David Duguay[1], Geoffrey Edwards[1,2]

[1] Canada Research Chair in Cognitive Geomatics and Centre de Recherche en Géomatique (CRG), Université Laval, Québec, Canada.
[2] Centre Interdisciplinaire de Recherche en Réadaptation et Intégration Sociale (CIRRIS), Québec, Canada.

Abstract. The CADMUS system produces maps of perceived difficulties of displacements in complex buildings, for people without disability or for those suffering a physical or perceptive disability. Using a numerical model of the environment as a foundation and a descriptive model of the user, CADMUS generates models of the spaces that are perceived as accessible by the user. The quantification thus produced allows building administrators and therapists to evaluate the accessibility of buildings as a function of particular individual physical and cognitive disabilities.

Keywords: geographical information system, spatial perception, orientation, mental maps, affordances, wayfinding.

1. Introduction

Finding one's way in an unknown building is an everyday situation, but can become very challenging depending on the design of the building. Architects and designers tend to create spaces for the people who use them everyday. Furthermore, individual differences contribute to the variety of experiences [1]. When considering the whole of humanity with the full spectrum of physical and cognitive disabilities, the accessibility of a building becomes a problem for any society concerned with human equity.

The CADMUS project is one of the projects supported by the MIME (Movement In the Mind's Eye) research program, funded by the Canadian Institutes for Health Research and the Canada Research Chair in Cognitive Geomatics. The MIME program brings together an international research team from medicine, kinesiology, neurology, cognition, geomatics and engineering to study the interaction between the human body and its environment, in order to facilitate the development of new therapies for disabled individuals.

The goal of the CADMUS project is to develop a tool for evaluating the accessibility of both disabled and non disabled individuals with regard to public spaces such as hospitals, institutions, or universities. Evaluating accessibility is necessary for identifying the conformity of existing buildings to institutional norms, for planning the development of accessible future buildings, to support clinical workers in their rehabilitation work, and finally to help the general public to understand the everyday difficulties experienced by disabled people [2].

In order to evaluate the accessibility of a user to an environment, both the environment and the user must be modeled in the system, along with their interaction. In our application, most of the interaction between the environment and the individual results in action and cognition. We focus, therefore, on the functional structure of environments, as most public spaces of interest are man-made and intentionally situated. Concrete walls, doors, chairs, bathroom equipment and other objects can be encountered only because of the special function somebody planned to be served in that location.

In addition, we develop a cognitive architecture to simulate the perceptual and cognitive behavior of the user. This approach parallels that adopted in human-computer interface research, which seeks to emulate the user in interaction with a software system [3]. Researchers in this area have developed embodied cognitive architectures that simulate keyboard, mouse and gaze activities in response to computer software. In our model, we use a similar approach to simulate the movement and object manipulation tasks of users with respect to a spatial environment.

From a general point of view, the CADMUS system is designed (a) to import environmental models from Geographical Information Systems (GIS) or Computer Assisted Design software (CAD), (b) to edit these environmental models in order to identify objects and to describe their features, (c) to define a user's profile as a function of his or her disability, and finally (d) to provide the user with a map showing the set of accessible regions. This accessibility is rendered for each space in the environment. Spatial accessibility is represented on either a two-dimensional map or a three-dimensional visualization (see Figure 2), and is computed by taking into account the point of origin, and the three dimensional features of the environment. The environmental map is divided into iso-accessible sectors.

The system is composed of three sub-systems. The first system, the *user simulation* (or simply *user*), represents the agent navigating the world. The second sub-system is the *environment simulation* (or *environment*), which contains information about objects that constitute the world in which our "virtual user" will travel. The last sub-system, the *cognitive agent simulation*, is the link through which the *user* perceives, understands and acts within the *environment.*

2. The Environment Model

The lowest level of aggregation at which we choose to describe the environment is that of *objects* and their positions within the environment. Position is coded via Cartesian (x,y,z) coordinates [4], which an object may possess along with a set of visual, physical, associative and conceptual features (Figure 1). Visual and physical features are static features such as weight, volume, or color. Objects may also be aggregations of several smaller objects (*environment)* that are each designed to serve distinct functions. These functions may, however, be triggered serially or in parallel via what is called an *action script*. For example, doors are in fact composed of a doorknob and a panel, sometimes completed by a large wall button that can be considered as part of the door system. Actions such as [rotate] and [push] are to be applied to these objects in order to engage the script [open door]. In addition, some objects maintain certain special relations with respect to each other and these are captured in the *associative features*. Association can be either local, such as a handle on a window or a mural switch for a ceiling light, or they can be of an informative nature: linking an exit sign to the door to which it refers. There is no limit on the number of objects that can be linked together in our model. Finally, objects are linked to a *concept*, usually its object category label, which itself is linked to one or several *action scripts*. These scripts will be described in the *cognitive agent model* section. Objects composing the environment may also have a *state* feature. Static objects such as walls and floors are not defined in terms of state, but doors can be either open or closed, a door knob can either be pushed or released, and a lock can either be engaged or not.

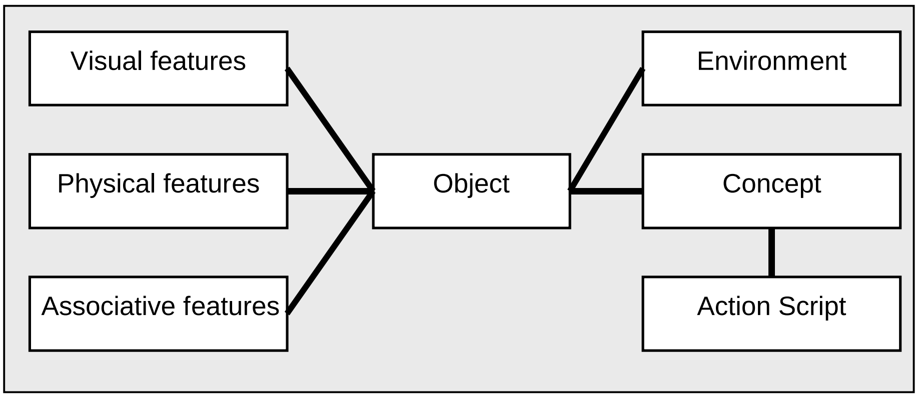

Figure 1. Structure of the object database, with links representing associative tables

Related with each object is an affordance or set of affordances, possibly a simple action suggested by its form [5]. For the regular wall switch, the form suggests that you can move it up or down. These affordances are not necessarily unique, as one can use a particular object in multiple ways and for multiple purposes. A stapler can be used without lifting it from the desk, or you can grab it and use it in your hands. In this case, the affordance for the stapler could be something like the combination of pull, grab, lift, press, etc. Manipulation of an object will, most of the time, change the state of the object itself or the state of another object linked to it. The result of a manipulation can be visible or not.

3. The User Model

For defining user disabilities, we analyzed in a reverse engineering way the *Guide Pratique d'Accessibilité Universelle* [6], elaborated by the Institut de Réadaptation des Déficiences Physiques de Québec (IRDPQ). This guide provides thematic entries presenting functional definitions of the environment's design elements, along with design rules and norms to make them accessible to most individuals. For example, the guide recommends straight stairs, 915 mm wide at minimum, with a step riser between 120 mm and 185 mm. The whole set of these design rules enabled us to extract eight categories for features critical to accessibility:

- General features: physical energy, perceptive and motor bracing;
- Cognitive features: attention, orientation, language comprehension, prior knowledge;
- Visual features: perceptive field, visual acuity, color perception, contrast perception, adaptation to changes in light intensity;
- Movement features: displacement volume, rotation capacity, speed, pace height;
- Support features: equilibrium, friction, adhesion, use of handrails;
- Manipulation features: distance of reach, height of reach, push-pull strength, rotation strength and angle:
- Auditory features: detection threshold, fatiguability;
- Tactile features: distance of tactile perception, expertise.

For each of these features, a base value is defined which corresponds to a non-disabled human of mean age and height. A user is then defined via a subset of features, the remaining features being defined as normal by default. The user features serve, therefore, as filters for the environmental features accessible via perception.

Cognitive features defined in the user model are a measure of the processing efficiency, which is independent from the content of cognition (*representations*), and can therefore be described with norms, such as attention span, sense of direction, language mastery, and strategy. Indeed, independently of any particular environment, individuals do not rely on the same strategy to explore a new environment or to find their way in a previously explored environment.

4. The Cognitive Agent Model

The first principle we followed is the modularity of the cognitive system. Following Fodor's point of view [7], processing modules are domain specific; they are encapsulated and can operate without referring to other modules (although loops can link several modules). We then distinguished six general functions for the cognitive system: Perception, Memory, Synthesis, Evaluation, Decision and Movement. These functional modules are linked in a non-linear manner, and some feedback occurs although information is more and more abstract as processing progresses through each module. Modules process information from the environment or from other modules in order to elaborate percepts, memories, situation models, states and desires, decisions, and finally actions. Modules and their sub-modules are specific enough to simulate specific peripheral and cortical inabilities resulting in cognitive impairments (e.g. retinopathy, visual agnosia, disorientation, Alzheimer-related short-term memory loss, etc.).

Perception is an analyzer of perceptual inputs in a perceptron-like design [8], composed of multiple-feature-specific detectors with regard to the input signal. The Perception Module is also the place where the percept is constructed from basic features (form, color, position, movement) and linked to a known concept (chair, handle, door). Perceived afforded actions access consciousness and enter working memory if they coincide with actions to be taken in the framework of a script that addresses an intention.

An important principle we wanted to include in the modeling is that some of the information about how objects are used, are invariant among humans and do not need to be learned. These invariants are called affordances, and allow some information about possible interactions people can have with objects to be associated directly with the object [9]. From the early stages of perception, objects afford actions that can be executed [10]. In our model, objects afford some actions to users who perceive them. These afforded actions are part of the percept, adding to the location of the object, and its identity [11].

Scripts are learned sequences of elementary actions that can be applied to objects. According to Passini, most of the information we have about an environment is coded in memory as an action plan [12] [13]. However, if actions are constituents of mental activity, not all representations are directly linked to these (think about electrons, black holes, or the liver, for example), and neither mental activity nor memory can be reduced to action plans alone.

Situation models are internal representations of a described or experienced situation in a real or imaginary world [14]. Humans have the capacity to divide their attention into at least two situation models, such as when talking about last Friday's meeting while driving to the restaurant, or thinking about an experimental design while jogging in the street. The focus of attention can very quickly switch from one model to the another if the situation requires this, but globally the long term model used to perform wayfinding (such as driving or jogging) is not flushed away when focusing on the anticipative or recall model. In a similar manner, imagining the consequences of taking an action does not systematically impair the current activity. Anticipatory and actual situation models are concurrent in working memory, but are commonly run in parallel [15].

Intention is a will for a particular state for objects [16]. Needs (imperious) and objectives (cognitive and optional to survival) are compared to a desired state, and intentions are created to get to that state at the desired level. Intentions are strategies to resolve a problem, for getting some parts of the environment into some state. Intentions are linked to action scripts that may be automatically activated when intentions are formed, and a search for those actions initiated by the script is engaged. Actions are not executed but are rather simulated in an anticipatory situational model that computes the results of the actions. If these results satisfy the intentions, actions are engaged through movement.

5. Implementation

Although the model has been worked out, full implementation has been achieved only for the affordance aspects of the system – not all the perceptual elements have been developed at this time [17]. We use three-dimensional data digitized and organized within AutoCAD™, however the data are structured according to a finer object granularity than that usually adopted [18]. This is necessary to support the various kinds of interactions that involve disabled users. For example, sections of corridor with different ceiling heights or floor tiling will have an influence on the ability of individuals with visual disabilities to navigate the space. Hence corridors must be digitized in separate sections for each such change in pertinent environmental factors.

We developed our own visualization module, based on the DirectX API, which we used to provide a data entry environment for semantically enriching the database with relevant object parameters. Combined with data entry forms for profiles of users (strength for twisting, pushing, pulling, etc.), these provide useful access to users and therapists interested in the software.

A functional software prototype that includes affordances and action scripts has been developed up to this point, along with the detailed specification for the cognitive agent. The software produces maps that are color-coded for accessibility.

Eventually, there may be interest in developing stronger linkages to virtual reality environments that simulate navigation. In our application, we use environmental information to assess the accessibility of public spaces to users with different physical and cognitive profiles. There is a small step from this approach, to one that interfaces with VR type environments.

An example of a visual output of the CADMUS prototype is shown in Figure 2.

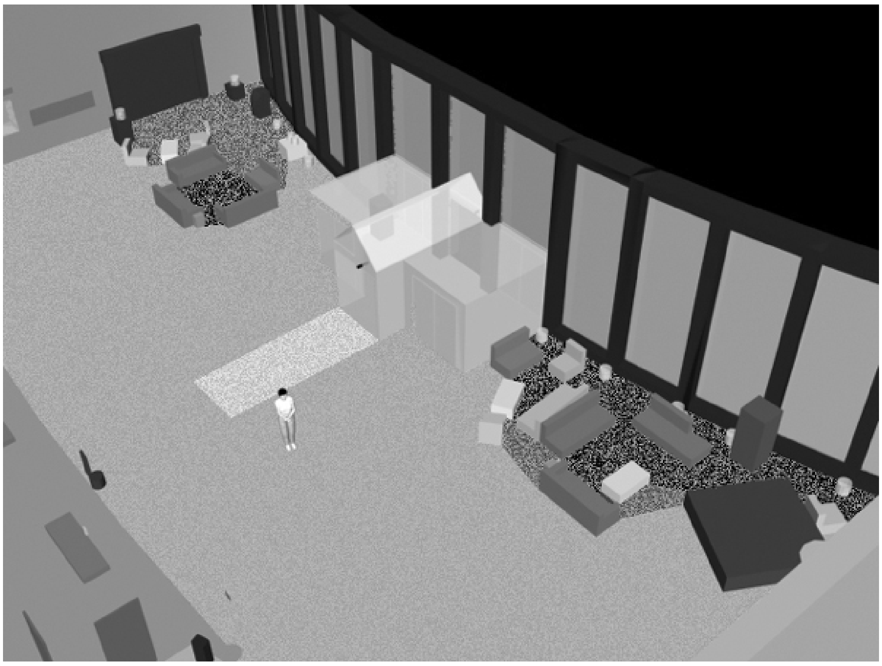

Figure 2: The screen shot shows the lobby area of the research hospital that constitutes our experimental site. The floor area is coded in different kinds of textured gray. Most of the floor area is accessible. The light rectangle in the middle is a carpeted area that may pose some problems to wheel chair users. The moderately dark textured area in the back corner represents an area with a number of obstacles that make it more difficult to access, while the dark textured region at the right (and in the square region near the back corner) is a region that is inaccessible.

6. Conclusion

The CADMUS system uses a method for characterizing environments according to the actions that can be taken within them, in order to evaluate global accessibility. Originality lies in taking into account both human perceptions and activities, motivated by our interest in the great diversity of human abilities and disabilities. Environments alone are not central in the CADMUS system, which differentiate it from any GIS system that captures only the spatial structure of buildings. There are both conceptual and technological challenges in linking GIS and cognitive systems. For the scientific community working on rehabilitation, this tool will allow a better understanding of the populations they are working for, mainly by quantifying their accessibility to public spaces.

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