Title: REPRESENTATION OF LARGE-SCALE ENVIRONMENTS

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REPRESENTATION OF LARGE-SCALE ENVIRONMENTS

The purpose of this report is to, through a literature study, shed some light on peoples' representation of large-scale environments. This knowledge will make it possible to adapt the information from a navigation or route guidance system to the drivers' representation of the environment. In other words, if one knows how drivers are thinking about their environment, then it is possible to provide them with information that they understand and can use effectively during navigation.

Before considering the question of how people represent large-scale environments it seems necessary to briefly analyse the task of navigation. The reason is that the navigation task will, to some extent, determine what type of information a driver needs from the environment.

Navigation - a conceptual analysis.

From a psychological point of view, all types of navigation can be seen as a complex mental task. It can be seen as a form of problem solving, closely related to spatial reasoning. Psychologists have for a long time been interested in spatial reasoning. For instance, Helmholtz (1866) called spatial reasoning "unconscious inference". Spatial reasoning is also a base for many everyday activities, for instance, in the process of finding the way from home to other places. It is also used in different mental activities, for instance, the ancient Greeks used the loci method (a form of spatial trick) to remember long speeches.

Navigation in this context is defined as a goal directed process where someone has the intention to reach a different spatial position than the present.
It seems necessary to make a distinction between a navigation task where the navigator can see the new destination, and situations where the new destination must be inferred. When the destination can be directly seen, the task has a more perceptual character. When the target cannot be seen directly, the task has a more cognitive character, and the driver must infer direction, distance etc.

In this report, we will consider the case where someone is navigating in a large-scale environment. A large-scale environment is an environment where it is impossible to directly perceive every place, and consequently, the person who is navigating must use his cognitive resources to reach the target.

Another restriction is that we will assume that the task of navigation takes place in a fixed road net. In other words, we will not treat navigation in the air or at the sea here.

Necessary conditions for navigation.

The following prerequisites seem to be necessary for successful navigation in an environment.

1. A "mental model" or cognitive map of the environment. In this cognitive map different elements and their relations are represented. Even a driver in a totally new environment will have some kind of cognitive map (or anticipations) of what elements the environment will consist of, and probably also what relations that exist between different elements. From earlier encounters with, for instance cities, a driver will probably assume that there exist one main street, and that it is possible to go downtown by using that street.

2. Besides a cognitive map of the environment, a driver must also possess the ability to recognise the correspondence between elements in the cognitive map and in the ecology. A cognitive map is not an exact copy of the environment, rather a more or
less incomplete representation of certain aspects of the environment (Evans, et al., 1981; Gärling et al., 1982). Furthermore, the environment is constantly changing, more or less rapidly. Streets are changed, new houses are built, old houses are painted, but the driver must still be able to recognise the correspondence between elements in the cognitive map, and in the environment.

3. A driver must be able to use the cognitive map to draw conclusions about the environment, or go beyond the information given (Bruner, 1957). Otherwise the driver can never solve navigation problems, or find new routes to a destination, except by pure luck or chance. Stated differently, the driver must have some inference rules for using the cognitive map in a creative or new way.

4. The driver must also be able to transform already stored, as well as new information, about the environment into action plans for navigation.

5. In order to be maximally successful the driver must also be able to use the cognitive model in a consistent way.

What are the components of navigation?

We will here try to find components in the process of navigation, components reflecting what the driver sometimes must do. One problem here is that what the driver does can be analysed on many different levels, from eye movements to scripts, plans and more global strategies. Brunswik (1969) claimed that: "Lawfulness will not be found on the S-R level, but on the level involving goals and achievements".

Following Brunswik we will here concentrate on the level involving goals and achievements. The following points (A-K) can be seen as subgoals in a navigation situation.

A. The driver must locate his/her present position.
This can be done in many ways. The driver can look for features of the environment, and from them draw conclusions about the present position. The driver can also measure distance and direction from a known place, and thereby draw conclusions about the present position. The driver can also receive information about the present position from other people.

B. **The driver must possess (or be given) at least one destination.**

Also this can be done in more than one way. One way is to use the cognitive map, and in that identify the destination(s). Another way is to use some external representation of the environment, for instance a cartographic map. A third possibility is that the driver is given a destination from someone.

C. **The driver must find one, or more than one, way to get to the destination.**

This can be done by using the cognitive map, external maps, and by asking other people.

D. **If the driver can find more than one way to get to the destination, then the driver must choose one of the routes.**

E. **To be able to choose between different routes, the driver must get information about the routes.**

Exactly what kind of information depends upon the purpose with the trip.

F. **The driver needs decision rules to choose relevant information, give weight to different information sources, and to combine different sources into a judgement.**

G. **After choosing one route, the driver can start to drive toward the destination.**
This represents a step from a planning to a manoeuvring activity.

H. After travelling for some time, the driver might need to control the position.

This can be done by looking for external or internal cues, indicating the present position.

I. After travelling for some time, the driver might pick up information that makes it relevant to change route.

Traffic conditions, environmental conditions may have changed, and made it necessary to choose another route. Or another goal with the trip might have been introduced (a new destination for a taxi driver, a child in the car is getting hungry, etc). This may lead the driver to start from the beginning again (p. A).

J. When approaching the destination, the driver must be able to decide when s/he is close to, or at it.

This can be done by observing the environment in search for cues, or by some kind of mental process (dead reckoning).

K. After arriving to the destination, the driver might be confronted with a new problem of navigation.

The driver must find a free and suitable parking place.

From the analysis above we can conclude that the drivers' cognitive map of the environment plays an important role in navigation. It may serve as a collection of facts about the environment, and as a creative device for solving problems of spatial nature. It constitutes the base for learning. New knowledge is incorporated (assimilated) into the cognitive map, leading to changes in its structure (accomodations). In the next sections, the nature of the cognitive map will be discussed in closer detail.
What is a cognitive map?

The concept of "cognitive map" has a rather long history in psychology. Tolman (1948) used the concept to explain the problem solving behaviour of rats in a maze. The cognitive map was, by Tolman, seen as a problem solving device.

Today there is some controversy concerning the nature of the cognitive map. The term "cognitive map" can be interpreted as if man and animals had something like a cartographic map inside the head. On the other hand, it can be interpreted as a general ability to represent information about the environment.

Downs (1981) proposed a view similar to the one held by Tolman. Man and animals have a spatial competence, according to Downs. This competence is to be seen as a part of a general problem solving ability, and a cognitive map should, in this context, be seen as a creative device for solving particular problems (of spatial nature). The cognitive map should, according to Downs, be regarded more like action plans, rather than like an inventory of what is known. People don't have a "map in the head", but rather "mapping functions". The mapping functions exist as rules for transforming objects and relations into spatial models. For instance, when we learn to find our way in an environment, we usually don't see the environment from above. But, thanks to our mapping functions, we can draw a map over some district, from a birds eye view, even if we never have seen the district from above.

Gärling and Golledge (1989) argued that maps are, by definition, models of the environment. They also conclude that the nature of this cognitive map (or model of the environment) can possibly depend upon how knowledge about the environment is acquired. This knowledge may be acquired by direct experience, for instance by walking or driving in an environment, or by travelling around with train, subway, busses etc. It can also be
acquired more indirectly, for instance by studying cartographic maps of different kinds, and by receiving verbal information from other people.

Neisser (1976) regarded the cognitive map as a schema that embeds other schemata. The cognitive map directs the pick up of information from the environment, guides action, and is in that process also changed. Neisser stressed the point that the cognitive map should be regarded as an active information seeking structure, not a passive and unchanging collection of facts. This structure directs perceptual exploration, which in turn takes samples from the environment, which leads to modification of the structure, and so on.

Kuipers (1978) assumed that the cognitive map can have many shapes.

First, the cognitive map is like a map in the head, or rather like many, loosely related, maps. They all represent spatial knowledge.

Second, the cognitive map is like a network, made up of streets and intersections.

Third, the cognitive map is like a catalogue of routes, where each route is a procedure for getting from one place to another.

Learning is assimilation of new information in the cognitive map, and problem solving is extracting answers from the map.

To summarise the different views, there seems to be agreement on some topics. First, the cognitive map can be seen as some kind of representation, or model, of the environment. Second, it has something to do with the actions of spatial nature that someone is performing. According to Downs, the cognitive map is more like actionplans than like a collection of facts about the environment. According to Gärling, Böök and Lindberg (1984,1986) cognitive maps are acquired in connection with the formation and execution of travel plans. According to Kuipers, the cognitive
map is like many maps, a network and action plans.

Since there is agreement concerning the role of the cognitive map as a representation or model of the environment, an important question is: how is information in this model or representation stored? Is it stored in a picturelike (analog) fashion, or in some other way?

**Representation of environmental information - general.**

Anderson (1983) assumed three codes of knowledge representation. The first code is called a **temporal string**. This representation encodes the order of some events or items. It is assumed that it records ordinal information about the events or items, and not interval information. For instance, when travelling a certain route the temporal string encodes the order (or the temporal sequence) in which different places is located on the route. It does not encode the exact distances between the places.

The second code is called a **spatial image**. This representation encodes the configural information of events or items, but not absolute size. For instance, a building located in connection of a route can be recognised equally fast on different distances, as long as the configural information is the same.

The third code is called an **abstract proposition**. As indicated by the name, this representation is more abstract than the other two representations. This code is independent of the order of information, and it may also ignore some physical details. The focus of this representation is on the meaning of something. For instance, the proposition "the big red house is located near the road" ignores exact physical details of the house, as well as on which side of the road the house is located. Instead it carries the meaning that a something is located in connection with a road.

It seems reasonable to assume that all these types of representations can be used for the learning of large-scale
environments. The temporal string to encode the order of places along a route, the spatial image to encode the configural information of buildings in connection with the route, and the abstract proposition to encode meaning, and use as a communication device.

In the next section we will review some of the research concerning how people are representing environmental information.

**Representation in cognitive maps.**

Research conducted by Kosslyn (1980) on visual imagery has indicated that information may be internally represented in both image form, and propositional form.

Levine, Jankovic, and Palij (1982) found support for the idea that cognitive maps are analog, maplike structures.

Gärling et al., (1982, 1983) argued that the cognitive map has both propositional and analog (image like) aspects.

Gärling and Golledge (1989) noted that the nature of the cognitive map possibly can depend upon how it was acquired. Somewhat simplified, a cognitive map can be acquired through direct experience with some environment, or by studying some kind of model (i.e. a map, a scale model etc.) of the environment.

A conclusion seems to be that there is some agreement concerning the representation of environmental information in cognitive maps. Both analog or imagelike, and propositional representation have been found in different studies. It seems likely to assume that perceptually available items can be, or are, coded in an analog or imagelike way, while other (not directly perceptually available) items are coded in a propositional representation. Items following a route could be coded by the temporal string, sometimes combined with propositional and image coding.
The content of the cognitive map.

The next question of interest is what aspects of a large-scale environment that people are encoding into their cognitive map. A large-scale environment contains an enormous amount of potential information, and people learning the environment must take a sample of some, relevant, aspects. The question here is, what samples of the environment are people learning?

A classical work in this area was carried out by Lynch (1960). He interviewed residents in Boston, Jersey City, and Los Angeles. The subjects were asked what came to their mind when they thought of their city, what they would encounter when travelling from place A to B, etc. They were also asked to produce sketch-maps of the cities. From this material Lynch concluded that peoples cognitive maps of cities typically include some elements.

Landmarks, are objects that easily can be seen from a distance. Examples of landmarks are towers, unusual buildings, monuments, etc.

Paths, are routes that people travel. Streets are an example of such paths.

Nodes, are points where several paths meet. Intersections, roundabouts are examples of nodes.

Districts, are regions of a city, regions that are similar in one or many aspect(s). Cultural, geographical, and perceptual similarities may be of importance here.

Edges, are visibly defined boundaries of districts or other areas. Rivers, walls, and expressways are examples of edges.

Several other studies have replicated the findings by Lynch
(e.g. Aragone’s & Arredondo, 1985; Evans, 1980), and they now appear to be well established.

It might be of some interest to speculate how these different categories may be encoded in a subject's memory system. Landmarks seem extremely suitable for an imagelike representation. They are, by definition, perceptually available. Nodes might also be possible to store in an imagelike form, and partly also edges. Paths, depending upon their length, may be partially stored in an imagelike form. Partially also in a propositional form. Different aspects of districts (e.g. based on perceptual similarities) may be stored in an imagelike form. Other aspects (geographic position, cultural aspects) may be more abstract and more suitable for a propositional representation.

In addition, Golledge et al., and Doherty and Pellegrino (1985) demonstrated the importance of navigational decisions for memory of places along a route. Places at choice points were found to be more easily recognised compared to places at nonchoice points.

Factors making these places distinctive, such as uniqueness in form, colour, size, may also enhance acquisition (e.g. Appleyard, 1976; Chalmers and Knight, 1985; Evans et al., 1984).

Gärling, Bök, and Lindberg (1986) noted that the taxonomy developed by Lynch is well established, but raises the question whether the taxonomy is psychologically meaningful.

Instead, they proposed another taxonomy where places, the spatial relation between places, and travelplans are represented in the cognitive map.

A place is to be seen as the basic unit, and can be represented by streets, parts of streets, buildings, landmarks, and districts. In the cognitive map, places are assumed to be represented as information about some properties, including name, perceptual characteristics, function, spatial scale (size), and attractiveness.
Spatial relations are, of course, a property of pair of places. Gärling et al., made a distinction between four different kinds of spatial relations. Spatial inclusion relations means that something (i.e., a shop) may be stored as included in the building where it is located. Metric spatial relations, is defined as the direction and distance from one place to another. Proximity relations, can hold for points that are not reference points, but may be related to reference points by means of proximity. Ordinal spatial relations, means that the rank order of distances may be able to recall, but not the exact metric relations (see Anderson, 1983).

An important question is systems of reference for spatial orientation. It is here possible to use different references. The body axes may serve as an egocentric reference system. Streets in a district may also be used as a local reference system, or the compass direction may be used as a global reference system. Kuipers (1978, 1982) argues that, in general, systems of reference in a cognitive map are local. This means that knowing the location of places relative to the compass direction is not very useful.

A travel plan, is basically something that specifies how to get from one place to a number of other places. The minimal set of properties needed for that is an ordered subset of places.

Gärling et al., (1986), made the assumption (similar to Kuipers, 1978) that information about the environment is acquired in connection with the formation and execution of travel plans. This assumption does not totally exclude other possibilities. They also noted that people have many different plans in an environment and therefore learn more than just how to get from one place to another.
The development of the cognitive map.

Evans, Marrero, and Butler (1981) examined changes in adults’ cognitive maps of novel environments as a function of increased environmental experience. According to Lynch (1960) paths and regions will be used early in the learning process of a city. After getting more experience of the city, people were presumed to rely more heavily on specific landmarks for navigation. Appleyard (1970, 1976) made some studies which replicated Lynch's results.

Hart and Moore (1973) and Siegel and White (1975) proposed a different point of view. According to them adult learning parallels ontogenetic spatial development. At first the child or adult is supposed to structure the environment in terms of egocentric location. After that a stable landmark based cognitive representation is achieved, where path structures are elaborated. The landmarks are supposed to serve as anchors for the elaboration of the path structure.

Consequently, we have two different views on the development of cognitive maps. According to one view (Lynch, Appleyard) paths are learned first, and landmarks later. The other view (Hart and Moore; Siegel and White) assumes that landmarks are learned first, and paths later.

The results of the Evans et al., (1981) study supported the idea that landmarks are used as initial anchor points in the environment, and that path structures are elaborated within the initial landmark network. They also found that the learning of landmarks seemed to be a rather quick process.

It is assumed that people initially learn the relative position of landmarks in space. Exact landmark location emerges as a function of increasing path interconnection among the initial anchor points. When more routes are filled in between these points, the exact locus of each point is fine tuned, since fewer alternatives are possible.
Sadalla, Burroughs, and Staplin (1980) explored the function of landmarks as spatial reference points. Reference points are places in a region whose location is relatively better known, and that serve to define the location of other places. Instead of storing the relationship between every known location, the relationship between reference points may be stored. Other points can thereafter be computed from that knowledge.

The results of the study suggest that cognitive representation of large scale environments contains elements that can be termed reference points. This points serve as organising loci for other points in space. This view is similar to the one proposed by Evans et al., (1981).

In the Evans et al., study an attempt was also made to find out what determines the status as a reference point. For landmarks it has been suggested that factors such as recognisability (Lynch, 1960), use (Appleyard, 1969), and cultural meaning (Moore, 1979) have an important role.

It was found that familiarity, visibility from a distance, domination of nearby places, and cultural importance played the dominant role in determining a place role as a referential point.

To conclude this section, it seems to be some agreement that learning of large scale environments starts with learning of landmarks, or reference points. Paths between these reference points are thereafter elaborated.

Factors like familiarity, visibility, cultural importance, domination of nearby places seem to be factors which determines if a place will be a landmark or reference point.

The accuracy of the cognitive map.

An important aspect of the cognitive map is its accuracy, or correspondence to the ecology. People are using their cognitive
map to find their way to different destinations, and sometimes
they get lost in that process. If we know what shortcomings of
the cognitive map that is, at least partly, responsible for
that, then we also know something about the type of aid a driver
would need.

Earlier in this report (p. 2) we suggested some necessary
conditions for navigation. From that analysis it is possible to
list possible reasons for suboptimal navigational behaviour.

1. It was suggested that the driver needs a cognitive model of
the environment. One possible reason for suboptimal behaviour is
that the cognitive model is incomplete, or incorrect. Elements
and the relation between elements may be missing (e.g. due to a
lack of experience), or incorrect (e.g. due to memory lapses).

2. The driver must have the ability to recognise the correspon-
dence between elements in the cognitive map and in the ecology.
If the driver cannot do this, then the navigation process will
suffer. There exist several possible reasons for this lack of
ability. The environment may have changed since the driver
visited it the last time, or it may have properties that makes
discrimination between items extremely difficult, or it may be
extremely complex. Or the driver may have small possibilities to
observe the environment when driving, or may have information
about for instance landmarks coded in an abstract verbal code,
when the most efficient code would be to have it coded in an
image form, the driver may retrieve erroneous information, have
memory lapses etc.

3. A driver must be able to use the cognitive map to draw
conclusions about the environment. If the driver by some reason
cannot do this, then s/he will only be able to go to already
known places. The reason for this may be a high stress level,
sickness, fatigue, a lack of inference rules to apply on the
cognitive map, etc.

4. The driver must be capable of transforming knowledge of the
environment into actionplans for navigation. If the driver
because of some reason is unable to go from cognition to action, then the process of navigation will be less successful.

5. The driver must also be able to use his cognitive model in a consistent way. This is the same as saying that besides having correct knowledge about the environment, the driver must also be able to apply it correctly.

Of these five possible reasons for suboptimal behaviour in a navigation task, the first has received some attention.

Baird, Noma, and Wagner (1982) concluded that people's ability to make correct judgements of distances is not perfect. Both directly perceived and memorised distances were incorrectly related to real-world distances. This is in accordance with Andersons (1983) assumption that we primarily store ordinal and not interval information, using the temporal string.

Also, Canter and Tagg (1975) found distortions in subjects' ability to estimate distances. They found a consistent overestimation of distances. Furthermore they proposed that the structure of a city affects people's ability to correctly estimate distances. A city with a confusing structure (Tokyo) may lead to an overestimation of distances. A more well structured city (Glasgow or Heidelberg) may lead to an underestimation of distances. Road and rail systems, general topography, and major geographical features may play a critical role, according to Canter and Tagg.

Gärling, Böök, Lindberg, and Nilsson (1981) found that directions are more accurately represented than distances.

Gärling and Golledge (1989) concluded that people have the competence to represent distances and directions in the same ways as they are represented in cartographic maps. In actual environments, however, many factors seem to cause performance to be suboptimal.

Levine, Jankovic, and Palij (1982) found that if a cognitive map
of an environment is acquired in a certain direction, then its use in another direction less effective. This phenomenon was called "orientation specificity".

A conclusion here is that peoples representation of distance and direction often is less than perfect. Sometimes the representation of routes seems to be suffering from "non reversibility", meaning that they sometimes only can be used in the direction they were acquired.

Conclusions

The purpose of this report was to review knowledge about how people represent large-scale environments. This is important if the information from a navigation or route guidance system shall be adapted to the users understanding of the environment.

A driver holds both general and specific knowledge about different types of environments. This general and specific knowledge is a part of the drivers cognitive map(s) of the environment.

There is some agreement among researchers that the cognitive map can be seen as some kind of representation or model of the environment. This representation or model is, among other things, used for navigational purposes, and also as a tool for spatial problem solving. Some researchers argue that the cognitive map incorporates actionplans and travelplans.

Information in the cognitive map is assumed to be represented in both analog (picture like) and propositional (abstract) representation systems.

There is also some agreement concerning what is represented in the cognitive map. Landmarks, paths, nodes, districts, and edges seem to be aspects of cities that are encoded in the cognitive map. It is also suggested that places at choice points are often recognised, and that factors making places distinctive (uniqueness in form, colour, and size) contributes to the
acquisition of information. Places, spatial relations and travelplans are also suggested as the content of the cognitive map.

The development of cognitive maps are believed to start with learning of different landmarks, or reference points. Paths between these landmarks or reference points are thereafter elaborated.

Concerning the exactness, or correspondence between reality and the cognitive map, it has been found that people often makes errors in estimating distances, and also (but to a lesser degree) directions. It has also been found that routes learned sometimes only can be used in the direction they were learned.

What are the implications for the construction of a navigation system?

From what is known so far, some tentative implications for the construction of a navigation system can be drawn. But it must be stressed that these implications should not be regarded as "facts", rather as hypotheses which must be tested empirically. After empirical studies it should be possible to evaluate the potential fruitfulness of the hypotheses.

1. If a navigation system is supposed to give the driver global information about a city (which should be regarded as an empirical question), then concepts like landmarks, paths, nodes, districts, and edges should be used.

2. Still, under the assumption made above, it seems suitable to give the driver information about landmarks in an analog or imagelike form, at least for drivers unfamiliar with a city. Information about paths and districts seems suitable to give in a propositional form (if they cannot be directly seen). For nodes and edges, no predictions can be made. More research is needed.
3. People need help to know in what direction to drive, and also help to estimate distance driven.

4. If people are given some kind of reference system during navigation, then it should be local. Instead of giving a travel direction in terms of compass directions (go north), direction to some local landmark or reference point should be given (go toward landmark X).

Implications for future research.

One very important question deals with the nature of a landmark, or reference point? The research so far gives only an abstract and sometimes confusing answer to this question, and what is needed is a more strict definition of what is and is not a landmark, or a reference point. Ideally we should possess a general theory about what makes something a landmark, or a reference point. With the help of such a theory, it should be possible to predict what drivers will use as landmarks or reference points in a new environment.
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