A collage metaphor to support inter-modal wayfinding

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Abstract. This paper presents a hierarchical model for inter-modal wayfinding that is structured by the metaphor collage. Inter-modal wayfinding is understood as wayfinding using several modes of transportation: walking, riding bus or train, driving, etc. The paper analyzes an example for intermodal wayfinding in Hamburg city. The resulting model of the wayfinding process is structured according to four levels of activity that support multiple levels of user needs. The metaphor collage is appropriate for the process of wayfinding where many different information types are connected in a very specific time- and space-dependent fashion. A cognitive collage has been identified as one type of spatial mental model that is used by humans. We expect that a traveler will use a system more easily which underlying model conforms to her mental model of wayfinding. The model supports multiple levels of user needs. It can be used for on-demand path information at information kiosks or over mobile devices. At the same time it is a fitting model for information integration as needed for example by information brokers on the web. This work is part of the effort of naïve geography, which promotes the development of models conforming to humans' mental models.

Keywords: wayfinding models, metaphors, process modeling, multiple levels, task hierarchy, activity theory

Statement: I hereby state that neither the paper nor a simile has been submitted elsewhere for publication.

1. Motivation

In this paper we present a model for wayfinding that uses the structure of a collage. Humans collect information about routes and represent this spatial and non-spatial information mentally. Tversky has suggested that a collage is a fitting metaphor for the mental representation of wayfinding information (Tversky 1993). Our work uses

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the structure of a collage to represent assorted wayfinding information about a specific route for a specific user at a specific time. This work is part of the effort of naïve geography which aims at incorporating human mental models into formal models about space and spatial behavior (Egenhofer and Mark 1995).

Cities need to be navigated by humans in order to be apprehended. They are large spaces, views are obstructed, it is only possible to walk along certain paths, other paths are underground or within buildings with no visibility of the surrounding area for orientation. When navigating space, humans can be active, i.e., drive a car, walk, or ride a bicycle. But they can also be passive, e.g., ride the bus, the underground, or take the train. Within the public transportation system the possibility for action is restricted. The system can only be accessed and left at certain points along a path. Rules, like ticketing or signaling a stop, apply.

We understand inter-modal wayfinding as wayfinding with several modes of transportation, i.e., a combination of different means to get from one place to another. This can usually be found in a large city where changing from walking to riding the bus to taking the subway is the normal way of using the transportation system. Inter-modal wayfinding uses diverse and even contradictory information. A collage presents a good model for this diverse information.

We propose to use the metaphor cognitive collage as a structuring metaphor for the model of inter-modal wayfinding in a city. The goal of this paper is to analyze and describe the process of inter-modal navigation in a European city and to provide a formal model of the structure of inter-modal navigation with the help of the metaphor cognitive collage. We are especially interested in the connections between parts of the cognitive collage as they correspond to parts of the path that form a unit.

Existing computer models of wayfinding are primarily interested in modeling spatial learning and human problem solving. See, for example, the TOUR model (Kuipers 1978), TRAVELLER (Leiser and Silbershatz 1989), SPAM (McDermott and Davis 1984), and NAVIGATOR (Gopal et al. 1989). Notable exceptions are the models of Timpf et al. (1992), Raubal (1997, 1999), and Claramunt (1996). Timpf et al. proposed a hierarchical model of wayfinding in interstate networks based on hierarchical graphs. Raubal describes a model based on affordances and image schemata for wayfinding in an airport, i.e. a building. Claramunt uses the metaphor spatial collage to create a wayfinding map using several scales for a traveler by car. Our definition of collage is different from the definition of Claramunt, who restricted a collage to be the connection between two different spatial views. We understand by wayfinding collage the model of a navigation process from start to end plus related information.

The model we present in this paper is of interest to mobile users. We image mobile devices or electronic paper maps that can be ‘loaded’ with a specific route at information kiosks or via the internet. With the help of visualization techniques like magic lens (Stone 1994) and fisheye views (Furnas) only that part of the route is enlarged that is needed, whereas in the background the collage as a whole is visible. In addition, the map can be updated with newer information (like traffic information or times for the next train or bus). Representing the information as a map is not the

only possibility. Hand-held devices can talk or show with arrows where to go, similar to car navigation systems. Even for those applications it is important that the underlying model be similar to humans' mental models.

Another application for this model is the integration of information in an information broker on the web. In a scenario where location based services are managed by information brokers the broker has to integrate information coming from different sources. The metaphor collage provides a good structure for (at least partial) integration or ordering of heterogeneous information based on the task of the broker. The information can be spatial (route), temporal (duration of trip), financial (ticketing), social (dangerous at night), etc. The integration has to be primarily spatio-temporal for wayfinding, but the other information may serve as constraints or additional decision criteria for alternative routes.

This paper is concerned with modeling wayfinding for mobile users. We will not study the process of finding the shortest path or descriptions thereof (Golledge 1995, 1999; Fontaine 1999) nor are we interested in network algorithms. The question whether to use verbal information rather than pictorial information as answer to a wayfinding query is part of future work. The design of databases to support wayfinding will not be treated. This paper is not about knowledge acquisition for wayfinding and subsequent representation in a human brain but about a computer model for wayfinding which structure is inspired by the metaphor cognitive collage.

The study is interesting for researchers in human cognition and wayfinding, researchers in human-computer interaction, designers of tourist information systems, and providers of wayfinding services in an urban environment.

The paper is structured as follows: chapter 2 inter-modal wayfinding, chapter 3 cognitive collage, chapter 4 wayfinding model, chapter 5 discussion and conclusions.

2. Inter-modal wayfinding

Inter-modal wayfinding is understood as wayfinding using several modes of transportation. This means, that a combination of different transportation means (feet, bus, train, etc.) is used to get from one place to another. This can usually be found in a large city where changing from walking to riding the bus to taking the subway is the normal way of using the transportation system. This space belongs to the class of large-scale spaces, i.e. geographic space (Montello 1993).

We assume that a human person supplied with appropriate information finds her way from origin to destination using several transportation modes. Additionally, we have included the restriction that the human person is novel to the city and has not used the transportation system or this particular route before. This is usually the case for people traveling to conferences or business meetings.

In route descriptions two perspectives exist: a route perspective describes the route as if the person was walking, i.e., following the personal reference frame and with changing views and from changing view-points. A survey perspective describes the

route from a single vantage point, e.g., from above or from an oblique angle as if standing on a building and pointing out the route. In our example we have chosen the route perspective, since we intend to give step by step instructions in the same reference frame as the traveler, if the need arises.

Wayfinding example

Fig. 1. Activity graph

Our wayfinding process takes place in Hamburg. A person needs to travel from the Informatikum (Department of computer science) to Hamburg main station (fig. 1). When inquiring for directions to the main station of Hamburg, the traveler gets the following information:

> First you take the bus 181 to Hagenbecks Tierpark. Then, you take the subway U2 to Hauptbahnhof Nord.

Fig. 2. Essential action graph

This description gives the traveler a general sense of where and how to go. Two modes of transportation are mentioned: riding bus, and taking subway. Two places are given: Hagenbecks Tierpark, and Hauptbahnhof Nord. One place is implied: bus station (fig. 2). However this descriptions leaves room for misconceptions. For example, bus station 181 Hagenbecks Tierpark and subway station U2 are two different locations. They are very close, but it is necessary to walk from one to the next – something to be mentioned especially to impaired people. The same observation is true for Hauptbahnhof Nord subway station and main train station with the added difficulty that the path is inside a building and three-dimensional.

The following description is more detailed and includes the connections between stations of the same name:

> First, you go from here to the bus station Informatikum and take the bus 181 to Hagenbecks Tierpark. There you walk to the platform of the subway station U2 Hagenbecks Tierpark and take the subway to Hauptbahnhof Nord. Finally, you have to take the stairs and walk to Hauptbahnhof Nord main entrance.

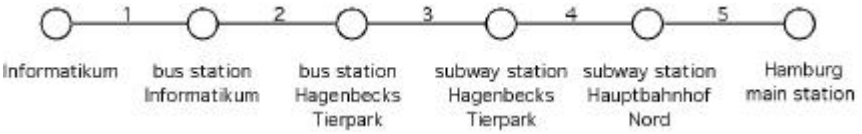

Fig. 3. Action graph

In this description walking as transportation means is needed three times and the traveler changes her transportation mode four times. Thus five steps or actions have to be performed during the wayfinding process (fig. 3). Each action uses a different transportation means than the ones before or after and they take the traveler from one connecting place to the next.

Each action is divided into more detailed steps called operations. These operations can be presented to the traveler depending on the wayfinding skills and the complexity of each wayfinding action. In our example the first action (go to bus station Informatikum) is not achievable for a person that is new to the area. Thus a more detailed description of this specific action is needed to ensure that the person indeed finds her way to the bus station. In addition, more detailed and redundant information for the rest of the wayfinding process can be given:

- Walk out of the campus area and turn left on Vogt-Koelln Strasse. Walk to next intersection and cross the street. The bus station is to your left.
- Get into bus 181, direction Hagenbecks Tierpark, buy ticket to Hauptbahnhof, ride 4 stations to station Hagenbecks Tierpark, get off bus.
- Identify way to U2 platforms, take stairs down to the platforms, walk on right platform with trains in direction Wandsbek-Gartenstadt or Barmbek.
- Get into subway, ride 9 stations or 20 min to subway station Hauptbahnhof Nord, get off subway.
- Take stairs at front of subway train, turn right at top, take next stairs to top, turn right and walk 10 meters, then you are at the front entrance of main station Hamburg.

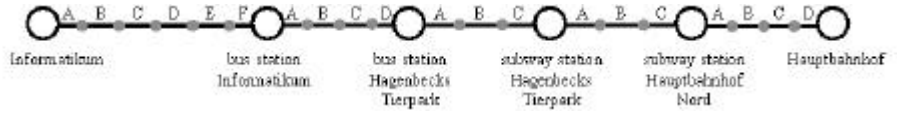

Fig. 4. Operation graph

This description is very detailed and describes all necessary operations. Additional and redundant information is given to give more security to the traveler and to ensure that the traveler does find the way as described (fig. 4). The description could be even more detailed and in some applications of wayfinding models like robot navigation even desired (see Kuipers 1993, 1999; Krieg-Brueckner 1999). In other special cases, e.g., a stranger not knowing the customs (like how a bus station looks like, how to pay for the trip etc.) more detailed but also more specific information must be provided.

Activity levels

Activity		**Wayfinding from Informatikum to Hamburg main station**				
Essential Action			Take bus 181 to Hagenbecks Tierpark		Take U2 to Hauptbahnhof	
Action		1	2	3	4	5
		Walk from Informatikum to bus stop 181	Take Bus 181 to station Hagenbecks Tierpark	Walk from bus stop to platform of subway	Take U2 from Hagenbecks Tierpark to Haupbahnhof	Walk from subway station U2 Hauptbahnhof Nord to Hauptbahnhof front entrance
Operation	A	Walk out of building	Get into bus 181	Walk towards U2 station	Get into subway	Take stairs at front of subway train
	B	Leave the campus	Buy ticket	Take stairs down to the platforms		Turn right at top
	C	Walk straight along Vogt-Koelln Strasse	Ride (4 stops) until bus stop Hagenbecks Tierpark	Walk on right platform with trains in direction Wandsbek-Gartenstadt or Barmbek	Ride (9 stations or 20 min) until subway station Hauptbahnhof Nord	Take next stairs to top
	D	Cross the next street	Get off bus		Get off subway	Turn right and walk 10 meters
	E	Turn left				
	F	Walk to bus stop				

Table 1. Activity levels in wayfinding case study

Table 1 shows the relation between activity, essential actions, actions, and operations for our wayfinding example. The distinction between different levels of detail for the wayfinding description provides us with a way to make distinctions between different user needs: the traveler that knows the area, has been to the city before, but does not know the route will be satisfied with essential actions or actions. The traveler new to the city but experienced in traveling will perhaps be content with action information. The inexperienced traveler new to the city will probably need information at the operations level. To identify possible obstacles and because redundant information might be the only possible one an impaired traveler will always need information at

the operations level, perhaps with additional information on elevators, where the doors will open at which stop (on the same or the opposite side), if the bus leaving now is a low-floor bus, etc.

3. Wayfinding collage

Many models have been proposed for the representation of information of humans. The oldest and most known model is the *cognitive or mental map* (Downs and Stea 1977). This model has been claimed to be too rigid because it induces the modeler to assume map-like qualities of the representation.

The *cognitive atlas* (Hirtle 1998) has been proposed as a richer alternative to the cognitive map. This model takes into account that humans use information at several levels of detail and are able to switch easily between one and the other, switching at the same time the frame of reference and connotations. However, this model also induces the belief in a metrically correct representation of space.

Tversky (1993) has shown that some spatial information is not pictorial and thus cannot be represented in a cognitive map. She prefers to use the term *spatial mental model* to account for all types of spatial information representations, pictorial and non-pictorial. In the same work, she proposed the notion of a *cognitive collage* to account for the fact that spatial information collected and accumulated over the years is very diverse, has different formats, different levels of detail, shows different aspects or point of views and even allows for erroneous, contradictory, and incomplete information. She also stated the very personal nature of a cognitive collage that included recollections of places and memories, even overlapping (temporally or otherwise) information. In addition the metaphor is most appropriate for knowledge about environments that are not well known.

This metaphor has inspired work by Claramunt (1996) who built a model describing a cognitive map, which represents navigation knowledge. The model includes the notions of spatial view and of *spatial collage*. Each coherent description of the navigation process is termed a spatial view on a collection of database objects. A spatial collage is defined as a connection between spatial views. So, for example, the description of a navigation process would use three different spatial views and thus require two collages to connect them. This definition also restricts a collage to two spatial views and disregards the possibility of other means of information. This use of the term collage is fundamentally different from our usage. We use the term to denote the whole description of the navigation process not only the connections between views.

Cognitive collage

A cognitive collage for a wayfinding process is a collection of disparate pieces of knowledge about decision points along a route and the route itself: recollections of journeys through this decision point or along the route, memories of maps, recall of verbal (aural or written) instructions, facts about the decision point or the route,

different spatial (might also be historical) views of points along the route and more (olfactory information, associations (meeting with friends, seeing something strange)). The structure of the cognitive collage is unordered, the only combining effect for each of these pieces of information is that they belong to a route and can be 'triggered' through knowledge in the world.

Cognitive collages are used for environments that are not well known, where the information could not be integrated through lack of time or lack of survey knowledge. Typically only landmark and route knowledge are stored. Collages are often systematically distorted (only one source of information). Not all relevant information might be retrieved when needed, due to the inherent granularity of information and due to the fact that the information pieces are stored separately. When queried again, more information might turn up. Information often is partial and might even be contradictory.

A cognitive collage is highly personal and subjective. However there are pieces of information in a collage that could be termed objective: information on timetables, alternatives of routes, views of buildings, means of transportation, knowledge about decision points, etc. The structure of a collage can be used to associate many different pieces of 'objective' information to a given route. This is the goal of this paper.

A digital wayfinding collage

We are interested in providing a user with a collection of information pieces or fragments associated with a route the user has to travel. It is not necessary that the information be integrated with the route, as the user might not need it. In current car navigation systems the most detailed information is given to the user for fear that the user might miss some information. Our model is flexible enough to allow for users with different backgrounds and expertise in traveling and thus provides more or less information as needed. The information given by the collage provides a context for queries.

A wayfinding collage is the sum of all the pieces of information that an information system could retrieve at a certain point in time as they pertain to the route, including information on the route itself. Each piece of information is called an information fragment. Instead of trying to integrate all the information fragments and make them consistent, the system will only associate each fragment with the point of the route it corresponds to. These points may be places, locations or time points during an action or operation.

The collage metaphor provides a very good structure into which information fragments can be integrated and ordered such that they form a whole. The whole does not have to be coherent and can have redundant or incomplete information. This is part of the power of this metaphor.

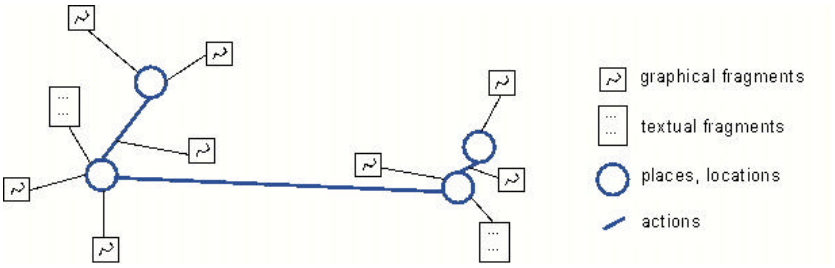

Fig. 5. A wayfinding collage

Figure 5 shows the components of a wayfinding collage: a route composed of places and actions, which are associated with graphical or textual fragments. For example: a place like the bus station Informatikum is associated with the timetable of the bus.

4. Model for inter-modal wayfinding

The model has two parts that are connected like a collage: the first part is the hierarchical model of the route at different granularity levels determined by the activity/actions/operations of wayfinding. The second part is the contextual information retrieved for the user's convenience. This information is there to answer likely queries of the user and at the same time provide each action or operation with the appropriate spatial and thematic context.

Hierarchical route graph

Our model uses a hierarchical graph to represent the route information at different levels of activity. A graph is a set of edges and nodes. Nodes are places (e.g., Informatikum, Hagenbecks Tierpark) and depending on the granularity level also locations (e.g., bus stop at Hagenbecks Tierpark, top of stairs). Edges connect nodes and thus carry information on the action or operation to be performed. Each edge corresponds to exactly one action or operation. In addition, temporal and spatial information can be added to the edges.

A hierarchical graph is a set of (in our case four) graphs that are connected to each other (see fig. 6). This graph encodes the knowledge about activity, actions, and operations at the same time as it stores knowledge about the routes at different levels. Each level shows the route at a different granularity, i.e. at a different activity level. It is interesting to note, that from the second to the third level the nodes are partitioned. However, from the top level to the next and from the third to the fourth level not the nodes but the edges are partitioned. Future investigation will show if this is a trait of the model.

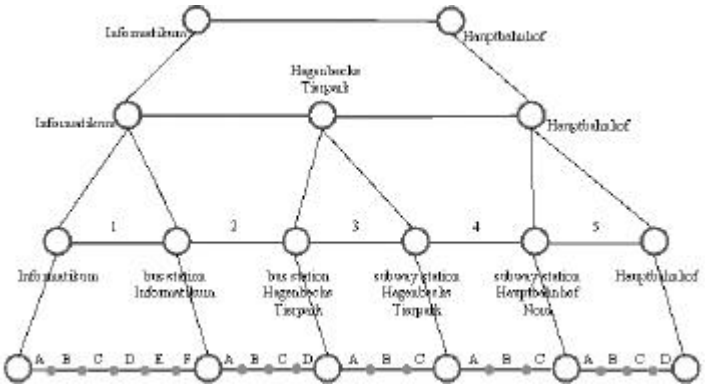

Fig. 6. Hierarchical route graph

Wayfinding Collage

The wayfinding collage is also represented by a graph. Nodes represent information fragments, edges connect the route fragment(s) with the information fragment(s). Information fragments can be linked to one or more route fragments and even to route fragments at different granularity levels. Each information fragment is the result of a query on a spatial or thematic database, a specific time-dependent view on data. A collage is a composition of views on data in a heterogeneous and distributed information system.

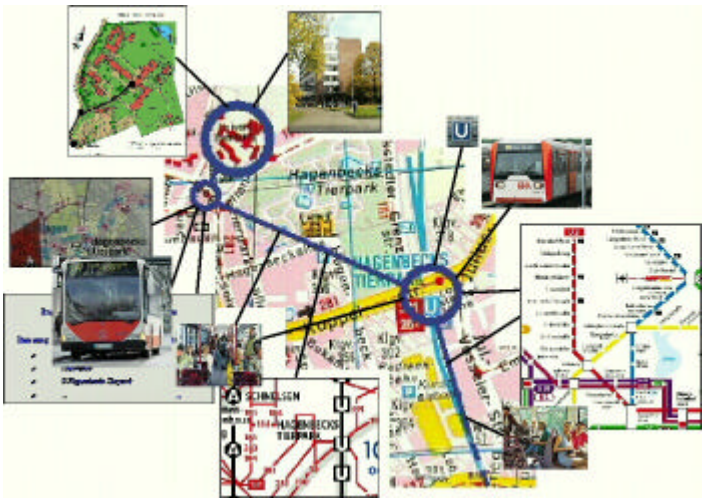

Fig. 7. Visualization of a wayfinding collage at the action level for our example

Fig. 7 shows the visualization of a wayfinding collage at the action level for the example presented above. The information fragments are taken from existing visualizations.

The wayfinding model can be communicated to the traveler in two different ways: pictorial or written/spoken. A user can retrieve a view on her collage by printing out the information, or letting it be displayed on her mobile device. The view is dependent on the point in time, the level of activity needed and other restrictions given by the user. Pictorial output of a collage is not very difficult, but requires a management of display space. Written output can be either a description in the same way as shown in chapter 2 or verbal information about the next step to be taken in the moment the traveler reaches a decision point. Each of these modes of output can give detailed or coarse information or anything in between depending on the needs of the traveler.

A motivation to use pictorial info for the wayfinding process is that humans like to know a bit more about their surroundings. Unspecific spatial information is best presented in pictorial form. The possibility to browse a map for other information while waiting for the transportation to arrive could be an advantage or an opportunity for advertising.

5. Discussion and conclusions

We provided a model for wayfinding that is very similar to humans' mental representation of wayfinding information. The model takes into account that route information can be given at several levels of granularity and that different levels might be necessary in the course of one trip due to missing knowledge in the world (Norman 1988). The wayfinding process is inherently spatial and requires two types of knowledge: knowledge in the head and knowledge in the world. Using our model, we have two specific types of knowledge in the world: knowledge in the world in general and knowledge on the wayfinding process as represented on the piece of paper or on the display. We can state that the more knowledge is in the world in general, the less knowledge is needed in the head or on the piece of paper/display. If we take into account our levels of activities, the more wayfinding knowledge is in the world (helpful signs, well designed architecture) the higher is the level of activities, i.e. the less detail the traveler needs to find her way.

In addition to the hierarchical model, we used the structure of a cognitive collage to encode contextual information about the route and the wayfinding process. Information fragments are views on data in distributed information systems, e.g., bus timetables or subway connection information. Within the wayfinding collage information fragments are associated with route fragments, i.e., places or actions. The wayfinding collage has many advantages: it uses the same structure and mental model as the human traveler. It can include uncertain and contradictory information without becoming unusable. Through the different levels of activity the model is more adaptable to user needs, can solve the contradiction by providing more detailed information and through the same way makes the information less uncertain. The model also includes redundant information, which provides the user with greater

security and flexibility. Redundant information might also solve the uncertainty of one fragment by providing a second one.

Future work

We have discussed the new model with the help of a single example. In the future we plan three wayfinding studies in different cities to corroborate the model presented here. In addition we would like to enlarge the model by incorporating the affordance model by Raubal (1997).

A formalization is underway, but we encountered problems with the nature of the links in the hierarchical model. Stell has presented a mathematical model for vague graphs (1999) that we intend to incorporate and that might solve our problem.

A topic that has come up in dicussions is how to 'trigger' the right information fragment when the user does not ask for it. A solution might lie in the work by Krieg-Brueckner (1999, p.24) that we intend to investigate.

While we were not interested in route production in this paper, we wondered if the hierarchical activity model could simplify the production of route instructions.

A hypothesis to investigate sometime in the future is that the difference of activeness in the actions has an influence on becoming or not becoming lost. While riding the bus or the subway, the traveler is passive. While walking between platforms or stops, the traveler has to be active. There might be a correlation between the lengths of time spent in either 'state'.

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