THE SIGNIFICANCE OF TRAVELLER'S ROUTE KNOWLEDGE FOR CHOICE OF COMMUTING MODE OF TRANSPORT

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Dissertation submitted in partial fulfilment of the requirements for the Degree of Master of Science in Geospatial Technologies

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February 2012

ACKNOWLEDGEMENTS

This thesis deals as much with geographic information as with psychological and cognitive approaches to such information. This is inspired by some of the classes about the nature of geographic information I have attended during the course of the MSc in Geospatial Technologies programme as well as my Mother's, Prof. Jolanta Kruk's, research into child learning processes.

ABSTRACT

Travelling in a city is an essential part of everyone's life, whether it is the routine daily commute or navigating to a previously unknown place, and can be accomplished with a variety of means of transport. This thesis explores how personal, first-hand route knowledge influences choice of mode of transport. This is motivated by the premise that human-oriented approach for computer systems design can be of significant benefit to the user. Public (bus, train, tram, metro) and private (bicycle, car, on foot) means of transport are considered and compared. Collected survey data analysed with a logistic regression method does not show any relationship between route knowledge and choice of mode of transport.

KEYWORDS

Route knowledge

Wayfinding

Transport mode choice

Mental map

Cognitive space

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1. INTRODUCTION

Travelling in our own city is an everyday activity each of us undertakes. A number of decisions are made and a lot of considerations have to be taken into account for every commute. Questions such as: where is the start and the end of the trip? what is the trip length and what means of transport are available between them? what would be the preferred mean of transport? what is the route itself like? are only some of those considerations and they describe the focus of this thesis. The interplay between these factors is the specific topic for data collection and analysis.

Some of the fundamental concepts employed in this paper are directly related to National Center for Geographic Information and Analysis' Research Initiative 21: Formal Models of the Common Sense Geographic Worlds (Mark, Egenhofer, & Hornsby, 1997) and the "Naive Geography" paper (Egenhofer & Mark, 1995). The latter is also an inspiration for the interest in the topic.

1.1. OVERVIEW AND MOTIVATION

Geographic Information Systems (GIS) are relatively new tools that are used to deal with spatial information. Their origins are dated back to 1960's, but the bodies of knowledge on which they build, such as geography and cartography, stem from ancient times. Some of psychological concepts are just as relevant today as when they were first published centuries ago. And yet, even now – or perhaps especially now – we still struggle with the very nature of the data and information we are dealing with. The human cognitive and spatial reasoning mechanisms are very sophisticated and have been a subject of extensive research throughout decades (Tolman, 1948)(Piaget, 1964)(Montello, 1993). GISs however lack similar capabilities. What geographers used to take for granted and what people effortlessly deal with on a daily basis using common sense – requires explicit formalisations before it is of any use in computer systems.

One of spatial tasks that come naturally and often unconsciously to people is wayfinding. Based on some knowledge of the environment – often fragmentary, incomplete, or even inconsistent and self-contradictory – one is often able to move between two locations in a fairly efficient manner (Egenhofer & Mark, 1995). This happens in situations when one knows exactly the relationship between their current location and the destination as well as the exact route they are going to follow, but also in situations when one is to go to an earlier unknown place or using a new route (Montello, 2009).

The practical differences between these two situations – when the route is known and when the route is unknown to the traveller – and the implications of each will be further explored in this thesis.

1.2. AIM AND APPROACH

The goal of this is study is to investigate how detailed, personal knowledge of the route along which a person would travel in a city could influence this travel's mode of transport. Such a route knowledge is a representation of a sequence of locations that constitute the route and is gained directly by following the route (Werner, Krieg-Brückner et al., 1997).

One might suppose that it is more convenient for the traveller to use public means of transport in an unfamiliar environment because they only need to worry about recognising that they have arrived at the destination (passive travel - Montello, 2009), rather than go through the process of how to arrive there. Conversely, walking, cycling or driving might be preferable in familiar environments where navigation is not a concern because the traveller knows the route (active travel).

The hypothesis to be tested then is this: the first-hand familiarity of the route to the traveller influences their choice of mode of transport for any given trip. "Trip" should be understood as a single journey or a commute between two locations within a city area. Should the hypothesis find support, a formal way of describing it will be proposed. For example, a model that would distinguish between familiar and unfamiliar environments could be a basis for a wayfinding application. Such an application could suggest a bicycle in an area that is familiar and a bus in an area that is unfamiliar to the traveller. Data has been collected via a questionnaire and analysed to find evidence supporting the hypothesis stated above. However, no such evidence has been found and the initially planned formalisation of the hypothesis is not feasible.

The initial idea for the practical part of this thesis to extend the existing Umwelt model (Ortmann & Michels, 2011) by including the distinction between "known" and "unknown" routes has been rendered pointless by the data analysis. The conclusions made based on the survey data do not justify modelling relationship between the traveller's route knowledge and travel distance. However, the data indicates a clear influence of travel distance over the mode of transport. This relationship can be also put other way around – that any particular mode of transport is only used for trips of certain length. A beginning of an attempt to formalise this idea is the last stage of this thesis.

2. BACKGROUND AND LITERATURE REVIEW

This research theme draws largely on body of psychological and cognitive sciences. Extensive literature is available and an attempt to summarise the key terms (each under its own section) is made in this chapter, starting with an overview of the field and proceeding to specific concepts.

Cognitive science is a field dealing, among other things, with how knowledge about one's surroundings is acquired, processed, stored and used. These are all key factors relevant for wayfinding tasks. Scale is a heavily used term with more than one common meaning and defining it is necessary for any discussion that follows. The term environment can also be used to denote a number of distinct concepts – all of them related with "surroundings" or "habitat" – and the precise way in which it is used needs definition. Cognitive spaces describe a human-oriented partitioning of environment into "larger" and "smaller" classes. Such a perspective is important for realising that a subjective human perception has great influence over spatial thinking. Mental map is a tool used by people to remember environment from personal experience and directly influences any spatial task within this environment.

At the end of the chapter examples of work that deal with similar problem using similar approach are briefly discussed.

2.1. COGNITIVE SCIENCE

Literature produced by GI specialists attempting to summarize the subject enumerates a number of perspectives on human cognition developed by philosophers, psychologists and knowledge theoreticians over the years (Montello & Freundschuh, 2005), here however we will only briefly discuss the most prevalent approaches. The central concept to any discourse on human cognition nowadays is *constructivism.* Generally attributed to Jean Piaget and traced back to the synthesis of empirical and rationalist approaches(Kant, 1781, pp. 160-167), it states that knowledge, rather than obtained directly from the surrounding world by an agent, is constructed within their mind based on sensory signals (Montello & Freundschuh, 2005). It is then stored as a *representation* which rather than being a direct image of the real-world phenomena is a metaphor of it. As a metaphor would, the representation is more accurate in some and less accurate in other aspects about the phenomena. It differs based on the conditions in which it was created as well as from individual to individual (Kavouras & Kokla, 2008).

Such a concept stems from two great traditional philosophical perspectives on cognition: rationalism, stating that knowledge is a result of reasoning and empiricism, which argues that our source of knowledge is an experience. Those two opposing ideas were successfully merged by Immanuel Kant who, in his *Critique of Pure Reason*, argued that both experience and reasoning contribute to expanding one's knowledge. Such an approach gives foundations to modern constructivism. Having such solid grounds and many practitioners(Hua Liu & Matthews, 2005), constructivism isn't a homogeneous theory, but rather one that has a number of branches. Two of the most prominent – and most clearly distinguished – ones are Piaget's genetic and Vygotsky's environmental (situated) constructivisms.

The genetic perspective means that knowledge acquired in the cognitive process has to fit pre-defined (genetic) mental structures. It is stored, organized and updated accordingly, and depends largely on individual . This means, that individual characteristics such as character or gender should be taken into the account when considering one's cognitive process (Kwan, 2002). This is distinguished from environmental perspective saying that human's environment shapes and determines the individual (Vygotski, 1978, pp. 88-90), which in turn influences their cognitive abilities. Such an approach gives great importance to cultural factors and differences between societies (Mark & Frank, 1990).

It is now recognized that geospatial knowledge constitutes a unique problem for cognition research (Mark, Egenhofer, & Hornsby, 1997): its continuous spatial and temporal dimensions provide a reference system for all the other phenomena (interestingly, this idea has also been described by Kant as early as 1781). This is a system that we are accustomed to think in naturally. It is not however the case with digital computers, whose structure for data storage and processing typically favours precision over fuzziness and hard logic over descriptive uncertainty. In other words, geographic space as understood by humans (or at least as it is thought to be understood) is difficult to represent accordingly in finite, binary computer systems for artificial intelligence use (Schuurman, 2006). It is therefore appropriate to find out if this limitation is either acceptable or possible to overcome (Goodchild, Egenhofer, Kemp, & Mark, 1999).

2.2. REPRESENTATIONS

Cognitive science generally concerns itself with studying *representations* of objects (*categories*). It has been suggested that such studies in themselves are inherently flawed (Mark, Egenhofer, & Hornsby, 1997). In order to have a sound grasp of the phenomenon we should never separate object's mental representation from the object itself (Kant, 1781, p. 183). This is the place where epistemology meets ontology. These two traditional branches of philosophy have been tackling general questions about the existence since ancient times and form an extremely broad body of knowledge to draw from.

Ontology has been widely accepted by the GIS community as a study of real-world phenomena and their relationships with one another. The word 'ontology' has even been accepted to denote – perhaps somewhat clumsily – a structured categorization of objects together with their descriptions in information sciences. However, as defined when it was first introduced (Gruber, 1995), this term refers to "specification of a conceptualization". Specifically, what "we need [is] conventions at three levels: representation language format, agent communication protocol, and specification of the content of shared knowledge". So rather than the studied object itself, ontology here describes its abstraction – or, a structure of those abstractions and their relationships to each other.

Epistemology (along with "epistemologies" (Schuurman, 2006)) on the other hand is just beginning to get in focus of the researchers in GIScience. It refers to study of mental representations – our concepts – of real objects. The objective here therefore rather than capture the essence of the *thing in itself* (Kant, 1781) is to define how is it represented. Traditionally, this would refer to a human mind but for contemporary applications it is just as important to tackle such representations in computer systems.

It is important to always keep in mind this general overview when considering the more specific concepts outlined below. Especially important is the relationship between the real world, its perception and its various representations, both human- and computer oriented.

2.3. SCALE

Scale is a fundamental concept in reasoning about GI, and yet there is a lack of clear and commonly agreed upon definition of scale, especially in context of computer systems. While having a critical importance, it is one of the basic concepts that is used to define many others, and yet in itself – presents a number of different interpretations.

While data can be stored – and analysed – at a range of different "scales" by current GISs, functionality that results from that fact rarely goes beyond visualization at several "zoom" levels. A question of meaningful visualisation of GI at different scales is one that cartographers have been tackling long before computer systems were used for mapping (Mackaness & Chaudhry, 2009). The issue of data modelling and reasoning with it however goes deeper than cartographic representations, as it concerns the nature of the data itself rather than just its visualisation.

The term scale can be used to denote a number of distinct concepts.

If understood as the magnitude of a phenomenon (e.g. elevation above the sea level), scale might even be a defining criterion for this phenomenon's classification (e.g. as lowlands or as a mountain). Furthermore, such a usage of the word "scale" can be both absolute or relative: Wierzyca is a prominent landform in northern Poland exceeding 300m elevation above sea level and thus it is considered to be *góra* (a mountain) according to the most common (albeit not the only) Polish definition of the term. It does not however fulfil a similar criterion for common Spanish definition of *montaña* which requires at least 700m elevation. This can lead to significant ambiguity. Scale as the phenomenon magnitude is the meaning of the term that will be used further in this thesis.

Scale can also be used to describe the extent (spatial or non-spatial) of inquiry, for example, a "large-scale study" means one that encompasses a significant area or population. Another meaning of the term has been always associated with paper maps in the cartographic tradition. Bar and fraction scales are typical means of indicating the relation between the size of real world phenomena and their representation on the map (*representative fraction*). It should be also noted that the persistence of this meaning is so strong that it often finds its way into digital datasets' metadata where it becomes largely irrelevant because of GISs' ability to visualise data at different – to avoid using the term "scale" again – zoom levels.

The final meaning of the term scale may be understood as the level of detail (Montello & Golledge, 1999), (Goodchild, 2011). This is to indicate what is the finest (smallest) phenomenon that can be represented in the particular dataset.

Scale poses then a number of open research questions, as identified by several workshops and research initiatives (Mark, Egenhofer & Hornsby, 1997),(Montello &

Freundschuh, 2005) and its implications on GIS design have been mentioned numerous times (Egenhofer & Mark, 1995), (Mackaness & Chaudhry, 2009). Better understanding of what part does scale play in nature of geographic phenomena and human cognition of such phenomena might lead to improving both how GI data can be represented and reasoned about as well as simplify user experience when using geospatial applications (Egenhofer & Mark, 1995).

2.4. ENVIRONMENT

The concept of an environment may seem to be a straightforward one, but its importance for this thesis calls for a closer look. The common notion of the term means surroundings or conditions for a subject (agent). This is the meaning of the term when it is used without a prefix.

A detailed description and classification of various types of environments is provided by Bennet(2010). There are four distinct types identified: immediate, affective, local and global.

The immediate environment is one in physical contact with the subject. It directly affects the subject and can do so either over time (temporally extended immediate environment) or as a single event in a point in time (instantaneous immediate environment). It is not so much made up of objects, but rather of factors that influence the subject and only exists on the subject’s surface. Affective environment consists of features that are not in direct contact with the subject, but determine the immediate environment. For example, air in the room belongs to one’s affective environment, but the air’s properties (odourless, transparent) that directly influence the subject are the immediate environment. The local environment is one that is in proximity to the subject – for example within certain radius, or close enough to include elements of the affective environment. Global environment consists of all areas that share a defining criteria – for example a global city environment is a sum of all the city areas.

A different approach is however also possible. In case of a person travelling in a city their surroundings are the city features, most easily perceived by sight: buildings and squares, streets, bike lanes and sidewalks, greenery and advertisements, road signs and traffic lights. However not all of these are necessary always relevant. Depending on the task at hand, some of these may be essential for completing certain activity while others may be useless. For example, sidewalk is of little use to a car driver and advertisements are typically irrelevant for navigation. They serve their purposes in different situations, but their usefulness is always context-dependant.

It is possible to identify environment elements for each example of a city commute that are particularly relevant. For example, in cases of cycling these will be streets, bike lanes, traffic lights, and so on while in cases of a public transport trips they could include bus or metro stations and walkways that lead to them. Environment elements that have an essential function for a given task collectively make up a "functional environment" – or *Umwelt* (Smith & Varzi, 1999), (Ortmann & Michels, 2011) – for this particular task. So depending on the current need, different elements of the environment are selected by the agent as relevant.

2.5. COGNITIVE SPACES

If scale is a dimension encompassing the whole possible range, from the smallest to the largest, of the phenomena, then it is possible for us to partition it into subdivisions based on human cognitive process. That means that depending on how we perceive, conceptualise and reason about and within spaces of different scales, we can identify a number of its distinct types. Numerous such distinctions have been made.

A number of human-oriented classifications of seemingly continuous realm of scale have been proposed (Gaerling & Golledge, 1987), (Mark, Frank et al., 1989), (Mark, Egenhofer, & Hornsby, 1997) (Montello, 1993). An approach of defining *spaces* of different sizes has been proposed by Freundschuh and Egenhofer (1997) as a means of conceptualizing different ways humans deal with large- and small-sized environments. From simple small-and-large space contrast to more elaborate distinctions based on human abilities of cognition and interaction of environment, these classifications partition the continuous “space of spaces” into more-or-less vaguely defined classes.

The simplest one is binary, based on opposition of “small” and “large”, “near” and “far” (Downs & Stea, 1977)(Ittelson, 1973). The basis of distinguishing between the two is the need for movement necessary to appreciate the contents of the space: small-scale space is visible from a single viewpoint and no movement is necessary in order to experience – at least visually – the phenomena and objects within it. Or, to put it other way around – what can be seen from a single viewpoint constitutes a small-scale space. Conversely, large-scale spaces require movement in order to be experienced. This contrast is clearly very much context-dependent: The field of view one enjoys from the top of a hill is much different from one available indoors. Because of that, what according to this distinction, is a small-scale space in one case may in fact encompass a many times larger in metric terms area than a large scale space in another case.

The large-scale spaces then are, according to Ittelson, experienced directly thanks to movement through them. The act of locomotion allows for apprehending larger environment that it would be possible from a single location. During this process a representation of the environment is constructed. Such a representation has been termed as a mental map (Tolman, 1948).

Another, more complex partition of scale into cognitive spaces describes three types: small, medium and large (Mandler, 1983). Both medium and large-scale spaces in this classification require viewing from multiple points to be apprehended completely. In the medium-scale space one might not be able to see all the parts of the space, or all the sides of an object from a single point, but they can still observe the relationship between all the objects directly. In the large-scale space however the objects themselves are too spread out for the observer to see and relate all of them together – in order to do so a representation such as a mental map is needed.

Another classification (Gaerling & Golledge, 1987) makes an important relation between cognitive spaces explicit. While there are also three classes of spaces identified, a hierarchical structure of knowledge about them is noted.

4 classes of cognitive spaces: A, B, C, and D have been also delimited by David Zubin (Mark & Freundschuh, 1989). The A space is a space of type A objects, B space contains type B objects and so on. This model is meant to distinguish between objects of significantly different scales. The A space is a space of manipulable objects that can be easily picked up, rotated in one's hands and seen from all angles. These objects are no larger than human body. In contrast to that, type B objects are larger than human body are not manipulable easily or at all. They can be however seen from a single viewpoint and perspective. A house can be seen in such a way, provided one stands far away from it not to have to move their head or shift gaze to see it entirely. However, in this way, only one or two walls of the house can be seen, and since as an object a house cannot be manipulated, one has to walk around it to see it from all sides. A mental model of it has to therefore be constructed from multiple viewpoints as it is impossible to see the house from all sides directly at one moment. If such a model is constructed using multiple perspectives, then it is a type C object. Type C objects have been also termed as "scenes". They extend beyond a single view angle and thus require shifting one's gaze to be appreciated fully. Since they can't be seen in their entirety at any one time, their representations have to be constructed mentally. Finally, type D objects (termed also "territories") are too large to be seen directly as a whole and their representations can only be constructed piece by piece from multiple parts. They often serve as a mean of relating position of (grounding) other objects.

The crucial factor by which the objects and their spaces in Zubin's categorisation are distinguished is how they can be perceived. Can they be viewed from one or more angles? Can they be seen from one perspective, or do they require scanning or locomotion to fully appreciate. However, the classes A through D exhibit incremental changes in size, even if this change is often vague because certain objects can be classified differently depending on the context. Objects of "higher" (D being the highest) types can also be used to relate objects of "lower" types. Because of this fact it can be inferred that the spaces A through D have an ordinal relationship with one another, not unlike the hierarchical structure proposed by Gaerling and Golledge.

Daniel Montello's (Montello, 1993), (Montello & Golledge, 1999) distinction is even more elaborate. A spectrum of spaces is introduced: miniscule, figural, vista, environmental and gigantic. The miniscule space is one that contains objects and phenomena too small for humans to experience directly on their own. Either a technological aid such as a microscope or a representation such as a drawing is necessary for their apprehension. Those objects are therefore beyond our direct perception. Next, the figural space is the space of objects projectively smaller than human body. Those objects can be seen without help and manipulated by humans. Within the figural, a pictorial and a 3D objects spaces were identified by Montello. Pictorial space would contain drawings, maps and other flat representations – such as these used to show objects that fall into the miniscule space (see Figure 1). The 3D object space is the space of manipulable objects proper. A tabletop is a typical example of figural space and can easily contain objects both in pictorial and 3D object spaces. Because objects that are projectively, rather than absolutely, smaller than the human body, large, but far-away objects can also fall into the figural space. The vista cognitive space, as the name suggests, encompasses what is visible. This means that objects and phenomena that can be seen from a single standpoint make up the vista space. It is can be highly variable in absolute size: in one situation it will be limited by four walls of a room that the observer is in, in another situation it can span a vast horizon if seen from a top of a hill in the countryside. Objects in the figural space, those that can be manipulated, are necessarily contained also in the vista space and constitute a subset of it. The environmental space is much larger than human body and in order to be appreciated a travel within it is necessary. It may be too large to be seen from a single standpoint or parts of it may be obscured so that it is not entirely visible. In order to construct a mental representation of it, it is therefore necessary to experience it, over time, from different points of view by travel. Lastly, the geographic, or – as later renamed – gigantic, space is the one that is too large to be appreciated by direct perception – in this way it is similar to the miniscule space. As they are too large for us to experience them directly, knowledge of them is best structured using representations such as maps (again, examples of the pictorial space – see Figure 1).

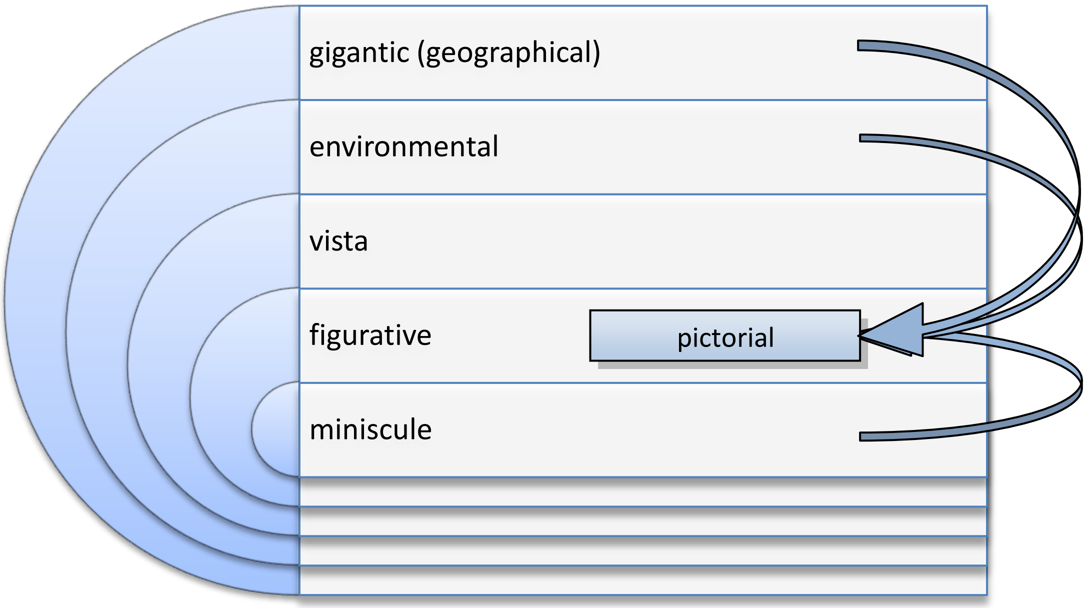

Figure 1 Cognitive spaces (adapted from: Montello 1993)

If such a partition functions in human perspective, a question arises if it could – and should – be also represented in GISs. And while this approach would be in contrast with continuous nature of geographical space as described by Tobler's First Law of Geography (Tobler, 1970), it has been proposed that it might be beneficial especially to users who aren't GI experts (Egenhofer & Mark, 1995), (Harris, 1996).

We typically think of certain phenomena using only some of the full range of cognitive spaces. To reach for one's glasses is an example of an action carried out in a figural space as it deals with physically manipulating a small object. A meteorological low travelling across the continent on the other hand is much too large to appreciate directly and is therefore an example of a geographical space phenomenon. It could be however seen on a meteorological chart where it becomes an example of a pictorial space object.

The above examples demonstrate that certain actions and phenomena can be typically conceptualised, experienced, and carried out in a particular cognitive space. No arbitrary quantitative metric distinctions between the spaces can be easily assigned because the distinctions are vague. This vagueness is a result of the conceptualisations being context-dependant.

Context-dependant variability of cognitive space delimitation means that a different cognitive space might be employed depending on a place where the agent is located. Consider a person in a room, when their field of view (their cognitive vista space) is limited by the four walls and doesn't extend beyond few meters and contrast it with the same person stepping outside of the building when the visible area abruptly increases. Similarly, a person in a densely built-up city centre will be not able to see as far as one in a high vantage point in a rolling hills countryside.

Certain objects, areas and phenomena may 'shift' between spaces depending on the situation and level of knowledge about them. A geographic space of a vast new city can gradually turn into environmental space as one gets to know the area better. Projectively small objects of the figural space become parts of vista space once one moves closer to them.

In most typical situations spatial navigation tasks – especially ones that are confined to the limits of a city area – take place in the environmental cognitive space. The notes above pertaining to it remain valid for the rest of this thesis.

2.6. MENTAL MAP

A mental map is a spatial representation with main purpose being allowing for knowing one's location and for movement through environment (Siegel & White, 1975).

Mental map was first described (with a healthy dose of humour) by Tolman (1948) based on a research on lab animals. It is a theory how do we learn about and subsequently mentally represent our immediately surrounding geographic space. The research was conducted by testing how rats behave in artificial mazes, how do various conditions influence their navigation performance and how do they adapt to changing situations. Tolman proposes that a mental map consists of paths and routes and includes “environmental relationships” between them. “Strip-like” or “narrow” and “comprehensive” varieties of mental maps are identified. Map of a narrow type can be thought of as a one-dimensional route between origin and destination. Its 1D character doesn’t mean that the route is a straight line, but rather that there are no branches or alternative routes included in the map – one can only move forward or backward along the route. In contrast, comprehensive maps include more full information about the environment such as a number of alternative, equivalent routes between the origin and the destination. In practice, most mental maps available to agents are somewhere between the two types: one typically has a better knowledge of the city they live in than just one route between his home and office, but also hardly ever does one have a complete knowledge of all the streets, buildings and other features. A mental map may be more comprehensive in areas which one visits frequently, such as the surroundings of one’s home, and more narrow in places only visited seldom. Tolman argues that results of his experiment point to conclusions that are just as relevant for humans as for his lab animals.

Studies of this concept were also famously conducted by Jean Piaget (Piaget, 1964), (Blades, 1991). His research focused on children learning about their environment. He investigated how children of various ages learn and reason about space by understanding how spatial thinking abilities are formed and acquired. Piaget identifies stages in child’s development in regard to spatial orientation. The first stage is characterised by lack of permanence. Little is memorised and recalled from memory. Things and places that are seen can be interacted with, those that are not seen – cannot. Places can be recognised upon encountering them, but they are just as quickly forgotten again. There is no concept of space where unseen things disappear to. Because of that, no spatial relationship model can exist between places and no mental map can be built. In the second stage a concept permanence of objects appears, however without ascribing conservation of properties to those objects. For example, an amount of liquid poured from a tall glass into a wide one is commonly thought in the second stage to change volume. It is still the same object, but with different properties. Mental representations are therefore possible and, as described by Piaget, used for navigation in two ways: a) for recognising known objects (landmarks) and places and relations between them in order to follow a route and b) for recalling and describing the route from memory. It is often however, that rather than the environment itself, it is the child's movement through the environment that is better remembered. The resulting knowledge is therefore not a fully-functional mental map yet. The third stage of development sees more attention drawn to objects as such. They can be seen as important landmarks and they can be positioned relative to one another. There is however lack of ability of abstract thinking meaning that direct experience influences heavily the mental representation. The resulting representation reflects the way knowledge about the objects has been acquired, for example important or often visited places are mentally placed closer than they are in reality. Only the last stage allows for abstract reasoning that provides solutions to this problem and allows constructing comprehensive mental maps of the environment.

Siegel and White (Siegel & White, 1975) have noted that a similar cognitive process to the one proposed by Piaget occurs also in adults when they familiarise themselves with new environments. There is a sequence of building a mental representation of space that gets progressively more complex and complete. However, in adults, this sequence cannot be explained by gradual development of cognitive capabilities as it can be in children. There has to be then another reason for this similarity. Their explanation is that familiarity with the environment arises gradually, through repeated direct experience – most importantly, locomotion through this environment.

The mental map then is essentially a representation of a naive geographic space. It is highly subjective and prone to many errors and misconceptions, and yet we use it as a reliable tool for orientation. It tends to be mentally (re)constructed on demand from memory to solve a specific problem at hand and can be each time different according to the intended goal.

Because of its selective use, human mental maps are typically full of inaccuracies and simplifications. Disjoint areas tend to be represented as completely independent, different mental ‘scales’ are used for travel inside and outside of the city, topological relationships are often preserved at the cost of absolute positioning (Egenhofer & Mark, 1995). Furthermore, we tend to think of the geographic space as flat, almost like a paper map. Vertical dimension is rarely significant for everyday activities and is easily omitted. Such simplifications account for mental map’s ease of use, without burdening the user with unnecessary details. For example, if a person follows the same route in two different directions they would see objects along the road from different perspectives. When asked for directions they might identify different landmarks depending on the direction in which the route is followed – even if objectively speaking some are clearly more prominent than others.

There are key elements that make up a mental map – landmarks and routes (Siegel & White, 1975). At least two interpretations of what a landmark is exist: standout features of the environment and “unique configurations of perceptual events”. While the first definition means that a somehow conspicuous element is prominent in the environment, the second one allows any unique point to be considered as a landmark. For its owner, his own house is a landmark, even if it is just one of a row of near-identical buildings for everyone else. A tall church tower on the other hand can be easily recognised by anyone. The more unique the landmark the easier it is recognised, especially by persons previously unfamiliar with it. How landmarks are represented in mental maps is then highly subjective. The origin and the destination of a journey can also be regarded as landmarks. It must be also noted that the landmark itself is not very useful for navigation purposes. It is the relation between the landmark and other elements of the environment (destination, other landmark) that allow it to be utilised. Routes are representations of the environment fitting the way in which one expects to move. Rather than representing features of environment itself, they are more concerned with one's locomotion in this environment. They also tend to be rather intuitive and conjured in mind automatically for the purpose of travel rather than require purposeful recalling from memory (although that is also possible of course). If a landmark is any unique configuration of perceptual events – so any unambiguously recognisable place – then a route can be considered as a sequence of such landmarks.

Siegel & White also note that mental maps often follow patterns described by gestalt principles. Environment features may be for example grouped together or arranged along straight lines, when in reality they are not.

One final note here is to remark on an interesting apparent similarity between construction of a mental map and 'shift' of a cognitive space described at the end of the previous section. As one learns particular environment better and better – constructs a more comprehensive mental map of it – they may also start to think about it differently. A map is no longer needed for navigation and the spatial representation is available from first-hand experience.

2.7. RELATED WORK

Two previous studies provide examples of how real-world phenomena and their human conceptualisations can be represented formally for use in computer systems.

The first one (Smith & Varzi, 1999) describes how the niche constitutes a crucial characteristic for a human or an animal – although the authors recognise that the concept can be applied to other domains than natural sciences as well. Its meaning is complex: the niche, in its biological sense, is the environment that surrounds its subject. It depends on physical, biological and chemical parameters that have to be within a range that is suitable for the subject. In this sense it is similar to the term habitat. The study however uses the term niche to denote a particular location in space-time currently occupied by the subject. It is its physical location in any given moment. It is also the point (or rather – surface) of contact between the subject and its environment through which all the interactions between the two must take place. Because of that last property, it is a suitable concept for modelling location of the subject and its capabilities in that location. To use our example of an urban dweller and traveller, the city, as it makes up traveller's environmental niche, allows for a range of activities through various elements that collectively make up the city itself. Those elements that are relevant for a particular task make up the functional environment described earlier.

The second study (Timpf, Volta et al., 1992) proposes a model of multi-level abstract human representations of the U.S. Interstate Highway Network. It recognises that a complete journey utilising the Network is conceptualised at three levels – planning, instructional and driver level – and that people switch between them naturally. Every element of the network, such as a highway or an interchange, is represented differently at each level, and each level requires different approach from the driver and calls for different actions – or at least different conceptualisations of actions. For example, at the driver level, the driver has to be concerned with fine-grained tasks such as lane change in order to take a highway exit, while at higher levels the task is generalised and does not involve so much detail. The model formalisation is presented as a possible basis for a Human Navigation System for Interstate Highway travel which is further develped in a follow-up work (Timpf & Kuhn, 2003). The whole idea of modeling human-oriented conceptualisations is aimed at „narrow[ing] the gap between the rigidity of computer processing and the flexibility of human reasoning." The premise that modelling human point of view should be of benefit to the system's user was also one of the inspirations for this thesis. We can manage to more closely match user's expectations by making a computer model follow their way of thinking.

3. METHODOLOGY: DATA COLLECTION AND ANALYSIS

Let us consider the matter of choice of means of transport by a commuter. With a wide range of situations and distances that a pertain to the concept of commuting we can attempt to find out what are the typical (most common) means of transport for commutes of certain distances and what additional factors do they depend on.

For the purpose of this thesis these additional factors had to be ignored. While there is obviously a great variety of situations, introducing any variables that are not essential would only obscure the most relevant data. Some of these factors are:

- Monetary cost – different modes of transport have different prices
- Effort cost – riding a bike uphill requires significantly more effort than driving
- Personal preference – while some prefer taking public transportation system others might appreciate flexibility of driving
- Local characteristics – in some places riding a bike is very popular while in others taking a taxi might be relatively cheap
- Particular scenario necessities – doing monthly shopping requires carrying large amount of cargo while things one needs everyday can easily fit in a backpack; in some cases one might be pressed for time while in others they can allow themselves to walk

This list is by no means complete, but it demonstrates how many various variables have to be kept in mind but – for the purpose of following analysis – discarded. With enough survey data however, it should be possible to identify what means of transport are typically used for commuting at what distances, irrespectively of the factors listed above.

One can expect a change of transportation method with distance: walking for short distances, public transportation service with high stop frequency such as a tram or a bus for slightly longer distances, lower stop frequency service like metro or suburban train for even longer distances and so on. This pattern should be visible in the collected data.

The key question in the survey is to indicate whether the commuter knew the route they were going to take before the journey and serves the purposes of answering the question if the commuter's route knowledge influences the decision regarding mode of transport for particular journey.

For the purposes of this research, the data collected and analysed is limited to the following:

- Route length (distance)
- Prior knowledge of the route (mental map)
- Mode of transport used

In the following analysis, the mode of transport is seen as dependant on the travel distance and route knowledge.

As a side note, it would be valuable to explore in detail the effects of factors listed on page 23, however it would only be possible with a large-scale study with much more survey data.

3.1. QUESTIONNAIRE

A questionnaire was presented to volunteers willing to participate in the study where they were asked which mode of transport had they chosen for a particular journey. The questionnaire has been built using Google Forms platform that allows creating a flexible online survey and collects the answers in a Google Spreadsheet.

The questionnaire was intended to be short and easy to fill out quickly multiple times. A single submission of the questionnaire takes less than 30 seconds and pertains to a single journey made by a participant. It was therefore desirable that each participant responds multiple times – a number of 10 to 20 responses has been suggested, although few participants have submitted so many responses. The questionnaire was purposefully presented to the participants with little introductory information. First reason for that was not to discourage them with a lengthy introduction. The second reason was not to introduce too many constraining assumptions and allow as natural responses as possible.

The questionnaire was designed to give insight on the following matters:

- What are the typical modes of transport for journeys of certain lengths?
- Do these modes change depending on having detailed route knowledge prior to the trip?

The questions and their explanatory notes were:

1. Origin
   Address (street, number, city!) or Google Maps coordinates or anything else that allows me to find the place unambiguously

2. Destination
   Street address (including city!) or Google Maps coordinates or anything else that allows me to find the place unambiguously

3. Was the route familiar to you from first-hand experience before you went?
   Did you have the complete trip "in your head"? Could you envision the whole way in your mind's eye?

4. How did you travel?

   on foot, bus, bike, car, part by metro and part on foot

Questions one, two and four were open questions and allowed free text input for answers. Question three allowed for a choice of “yes” or “no”.

A pilot test was run before the questionnaire was made available for wider audience. Three participants were asked for feedback if the questionnaire is clear to understand and easy and quick to complete. The major change made based on these comments was including the explanatory notes and auxiliary questions as seen above. These proved to be very helpful in clarifying the intentions of the questionnaire and ensure that results were as expected. Some responses were however unusable because the participant has not understood the questions and submitted not relevant data.

The questionnaire was also translated into Polish and Spanish to make it easier for native Polish and Spanish speakers to submit responses. The full questionnaire as it was presented to the participants and its translations are provided for reference in the Appendix on page 46.

PARTICIPANTS

The questionnaire was distributed mostly using personal contacts as well as mailing lists. Because of that, the participants of the questionnaire come from diverse backgrounds. Although no personal data was recorded in order to preserve anonymity of the participants it is estimated that four out of five participants are or previously have been studying on working in a geo-related discipline. People coming from and living in a number of cities across the world have responded, although only 4% of the answers refer to non-European cities.

ANSWERS

The results come from a number of different places. Participants were asked to describe whichever trips that they remember. Because of that the trips come from cities that differ in respect to available and popular transportation methods. In the city Lisbon, Portugal the Metro is a convenient and common way of travelling between the city centre and University facilities. In the Gdańsk agglomeration in Poland, which has a very elongated shape, the suburban train is the fastest public transportation method and often used by people commuting between various cities of the agglomeration. In the city of Münster, Germany bicycle is a very popular method of transportation as the city has excellent bike lane network. An effort was made to include as much data as possible from various places so that no single city is overrepresented and thus effects a bias on the whole dataset. Overall, 327 answers have been collected. The raw data is available in the attached spreadsheet.

3.2. DATA PRE-PROCESSING

Data obtained from the questionnaire required pre-processing and cleaning in order to be usable. The pre-processing tasks were:

- Removing entries that were not correctly spatially referenced
- Removing entries that were ambiguous, such as: “transport mode – sometimes by train, sometimes by car”
- Aggregating transportation modes such as “car” and “motorbike” were both interpreted as “driving”
- Selecting the main transport mode for a particular trip, such as: “transport mode - part on foot, part by bus” was interpreted as “bus” whenever walking simply meant arriving at the bus stop
- Removing answers that did not conform to the “within a city” requirement – those that pertained to inter-city travel over long distances. Journeys

between adjacent cities (such as between distinct cities of the Gdańsk Agglomeration or Ruhrgebiet) were preserved

All of these tasks were done manually, so that each entry was inspected to ensure data quality and consistency.

The next step was to calculate the distance between each entry's origin and destination points. This was done using the Google Maps website to make sure that the addresses were interpreted correctly – each trip was visualised on a map along with the route length. Whenever this was not the case (problem with address interpretation as in the example of "C/Maria Dolores Boera, num. 5, 5ºB, 12006 Castellon" that puzzles Google's gazetteer and requires removing the door number to be identified correctly) the data was further cleaned into a format more understandable by Google Maps. All the distances are network distances, meaning they specify actual distance travelled on the most likely route rather than straight-line distance. In case when there was no data available for public rail transportation routes such as trams and trains, a road route closest to it was selected to get an approximate result. The results were rounded to the nearest full 100 meters.

3.3. EXPLORATORY ANALYSIS

A total of 327 individual responses has been collected. After the pre-processing tasks outlined above a total of 262 individual responses were used in the analysis. The complete analysed dataset can be seen in the Appendix on page 48 and the raw data is provided in the attached spreadsheet file. Following analyses were done using Microsoft Excel with Data Analysis toolpack, WEKA data mining software and R statistical analysis software.

Summary statistics of the result answers for the travel distance are presented below (distance values in kilometres):

Count	262.00
Minimum	0.10
Maximum	21.00
Range	20.90
Mean	4.82
Median	3.40
Standard Deviation	4.26
Skewness	1.56

The answers range from 100m to 21km, with the majority of answers pertaining to shorter trips: the mean of the distance is 4.82 and the median is 3.40 which indicates positive skewness of the data. The skewness is 1.56 which confirms that the most answers refer to trips whose lengths fall in the shorter half of the range. This is made clear when the data is visualised. The histogram representing frequency with which travel distances were given in the responses to the questionnaire is presented in Figure 2. The bin width was selected as 0.5km as this value makes for the most meaningful visualisation. This value is not used in further analysis and is used only for exploratory analysis and data visualisation.

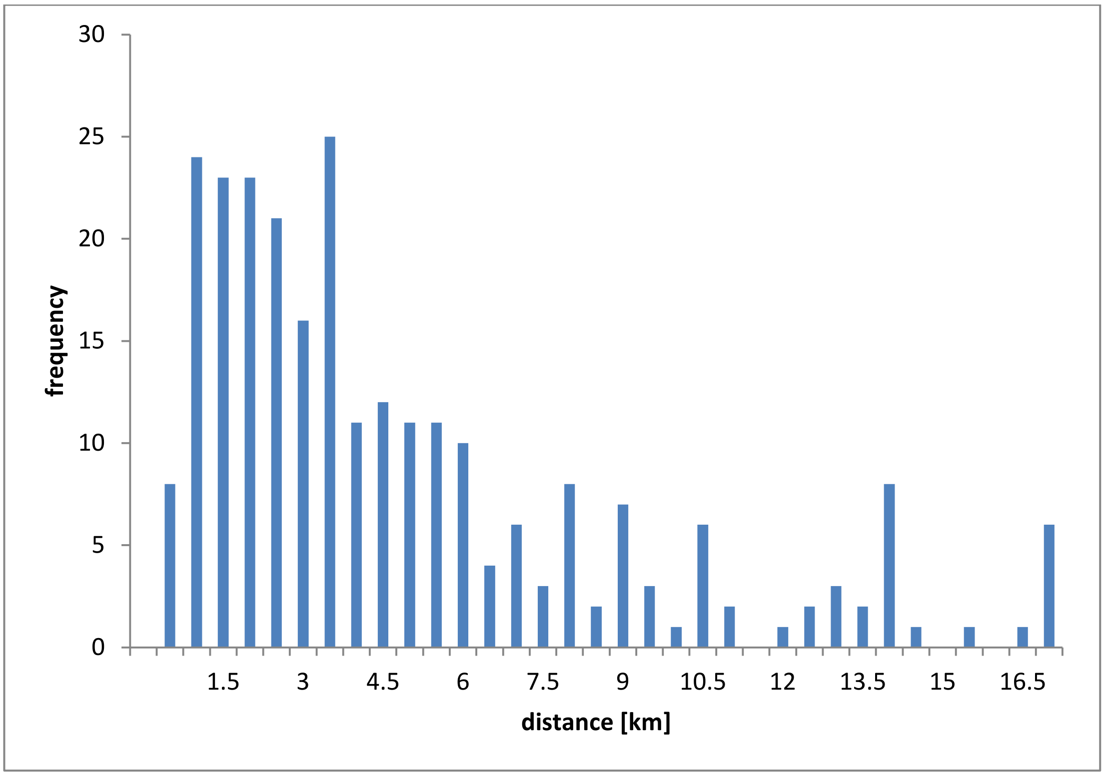

Figure 2 Travel distance histogram.

This indicates that since more data is present in the shortest distances a special focus should be given to this part of the data range. Further analysis takes that fact into account and a subset of data is selected for a closer examination. A closer look at the data distribution (Figure 3) between the “known” and “unknown” categories reveals that the “unknown” has a slightly larger range. This is most easily explained by the fact that the best-known routes are the ones that travellers use frequently, on a daily basis. Longer commutes are typically not as common as shorter ones. Another reason for this lack of symmetry may be however the questionnaire’s participants’ backgrounds. This is addressed in more detail on page 37 and onwards. Figure 3 also indicates however, that the median distance for both classes is almost identical, the first two quartiles of answers in both “known” and “unknown” categories have very similar distribution. This means that for the trips shorter than the median distance (3.4km) there appears to be little or no bias towards one or the other category.

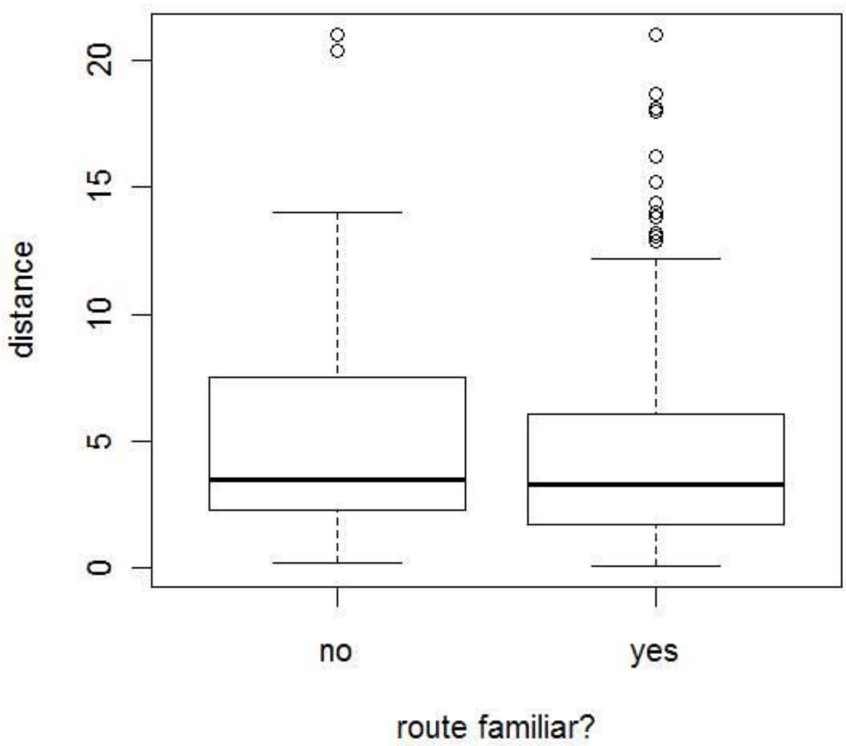

Figure 3 Distance against route familiarity box plot

Table 1 presents the summary of questionnaire responses used for initial exploratory data analysis. The table presents how many answers were given for journeys by each mean of transport and if the route was previously known to the traveller. The distance was arbitrarily divided into classes with bin width of one kilometre. This value is not used in further analysis and is used only for exploratory analysis and data visualisation.

	foot		bike		tram		bus		metro		driving		train	
	known	unknown	known	unknown	known	unknown	known	unknown	known	unknown	known	unknown	known	unknown
1km	19	7	3	2									1	
2km	12	5	16	2	3		3	1		1	1	1		
3km	5	1	9	4	3	2	7	3			2	1	1	
4km	4	3	8	8	1		4	2	3		1		2	
5km	2	1	3	3	3		5	2		1	1	1		1
6km	1	1	1	2		2	2	1	5	2	1		2	1
7km			2				2		2		4			
8km			2		1			2		2	3	2		
9km							2	2	2	1		1	1	
10km									1		2			
11km							2	1		1	1		3	
12km														1
13km				1				1					2	1
14km			1				1					1	4	3
15km													1	
more							2				2		2	2

Table 1 Questionnaire results summary

Table 1 demonstrates how certain modes of transport are preferred according to travel distance. Predictably, walking is most common for short trips under one kilometre and few people are willing to use public transportation for journeys shorter than two kilometres. This is clearly visualised in Figure 4 with box plots of each individual mean of transport. This figure also shows a clear differentiation between the modes of transport as far as travel distance is concerned.

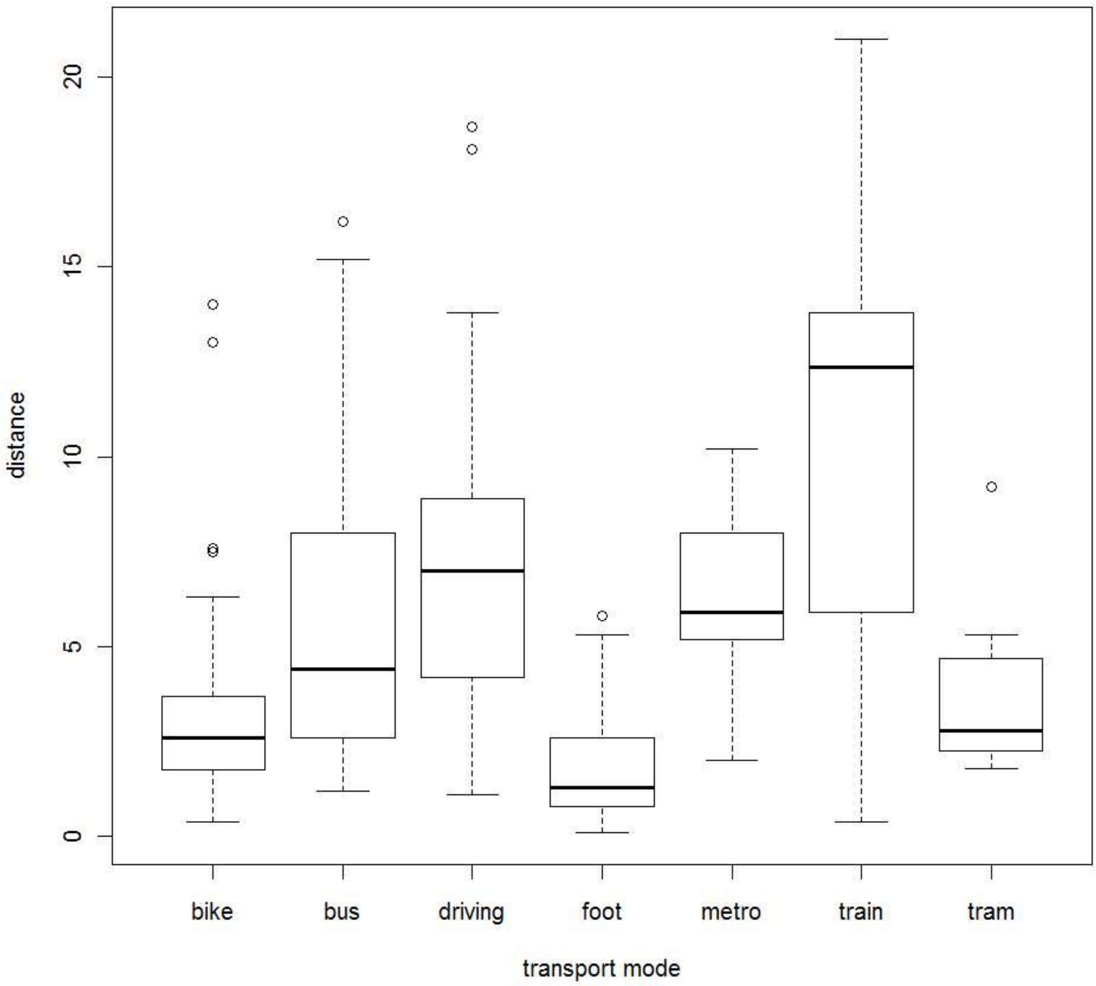

Figure 4 Transport mode dependence on distance box plot.

The proportional usage of all the modes of transport according to distance is visualised in Figure 5. It makes clear what percentage of trips at a given distance are made using which mean of transport. For example, “foot” and “bike” are clearly seen as having a large share in the first bins while “train” dominates the last ones.

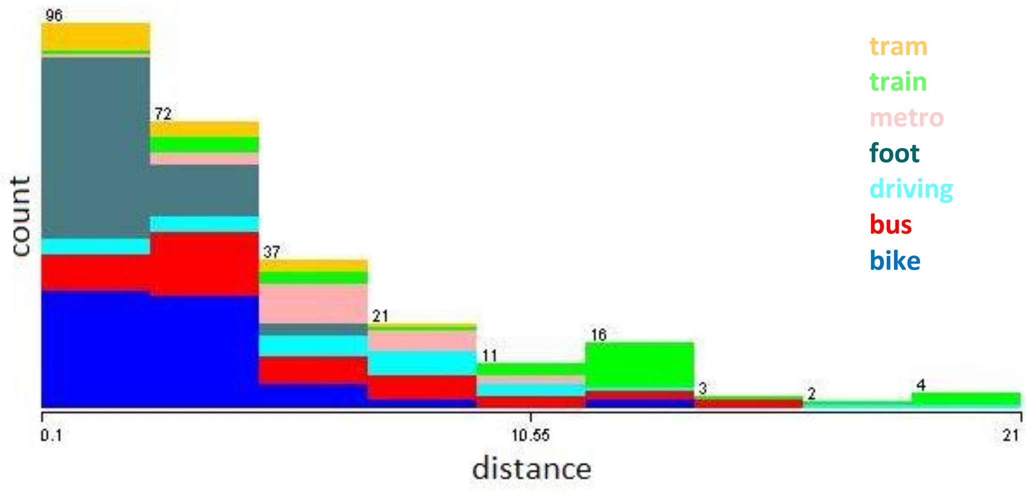

Figure 5 Breakdown of transport modes according to distance

However, there is no immediately visible difference between journeys made with prior knowledge of the route versus those where no such knowledge existed. Overall, out of 262 responses analysed, 179 of them refer to trips where the route was known beforehand (68%) and 83 refer to trip where the route was not known (32%). More detailed breakdown is presented in Figure 6. This indicates that most of the questionnaire participants preferred describing familiar trips – or that it was easier for them to recall more examples of such trips.

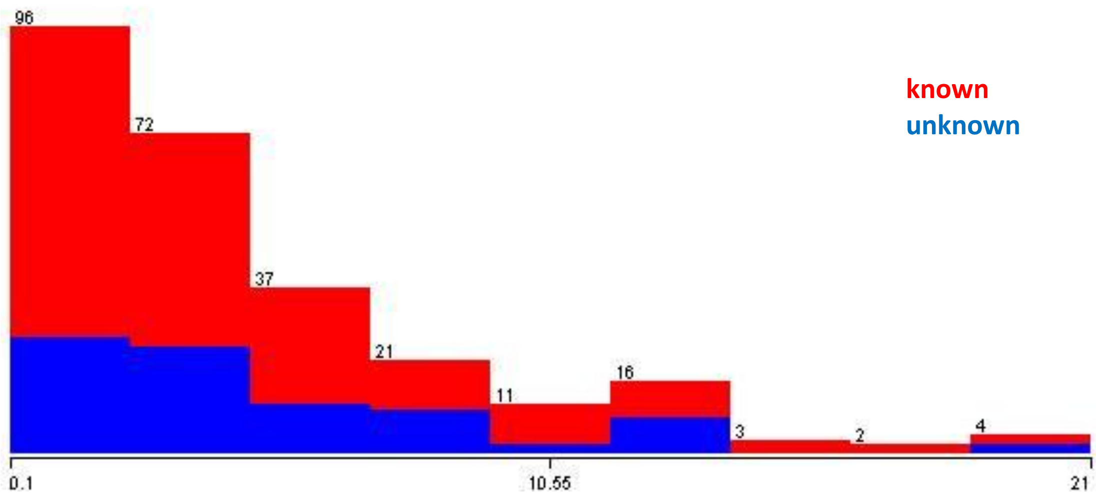

Figure 6 Route knowledge plotted against the route length.

Figure 7 visualises the difference in modes of transport between the trips taken with prior knowledge of the route versus those taken when no such knowledge existed and Table 2 presents the data in detail. Together, the figure and the table indicate that the difference between the trips with “known” and “unknown” routes – where present – is very small (less than or equal to three percentage points) when examined for the whole range of distance values. This means that any subsequent analysis should not be biased towards one or the other.

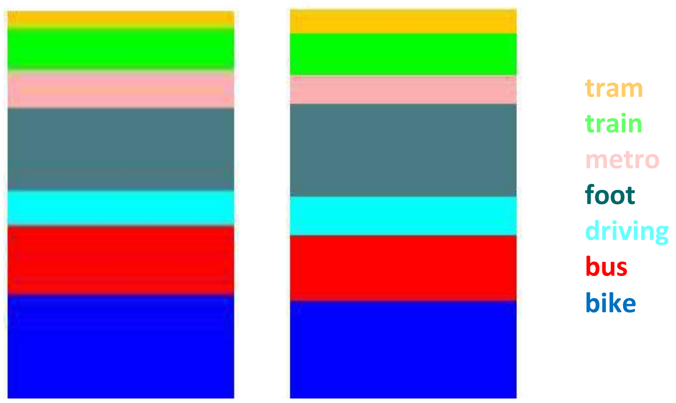

Figure 7 Unknown (left) and known (right) routes broken down into various modes of transport. Vertical axis normalised for comparison.

	bike	bus	driving	foot	metro	train	tram
unknown	27%	18%	8%	22%	10%	11%	5%
known	25%	17%	10%	24%	7%	11%	6%
overall	26%	17%	10%	23%	8%	11%	6%

Table 2 Unknown and known routes broken down into various modes of transport.

Answering the question if the prior knowledge of the route influences the transport mode choice *for a given distance* requires a more complex analysis method that would take into account the whole range of all the analysed variables.

3.4. STATISTICAL ANALYSIS

The aim of the statistical analysis was to find if prior knowledge of the route to be taken, which implies at least approximate knowledge of the route length (Montello, 2009), influences the choice of mode of transport. Using WEKA, a number of multilayer perceptron networks as well as logistic regression models have been built. Furthermore, an additional version of the dataset was created by removing the "familiar" variable in order to compare estimates and thus judge significance of this variable. Those models displayed a root relative square error in the range of 77-93%. To try to limit the amount of variables the algorithm should deal with, a separate models were also built for each of the individual modes of transport to look for a relationship only between the route familiarity and distance route length. These models however were characterised by root relative square error exceeding 100%. Such high error values discourage drawing any conclusions from these models so another method was used.

Using R, a logistical regression model has been built to identify the statistical significance of route familiarity. The summary of its findings is presented below.

```
glm(formula = transport ~ distance + as.factor(familiar), family =
binomial(link = "logit"),

    na.action = na.pass)

Deviance Residuals:

    Min       1Q   Median       3Q      Max
-2.3744  -1.3681   0.6643   0.8606   1.0508

Coefficients:
                        Estimate Std. Error z value Pr(>|z|)
(Intercept)              0.27226    0.32015   0.850 0.395103
distance                 0.16566    0.04935   3.357 0.000788 ***
as.factor(familiar)yes   0.16581    0.31212   0.531 0.595259
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

According to the model results route length is a significant factor for mode of transport choice. This was a conclusion to be expected, demonstrated by the raw data on figure Figure 4.

The model indicates however that there is no statistically significant effect of prior route knowledge on transport mode choice by the traveller. Since the hypothesis posed for this work is disproven, formalisation of this concept as an extension of the Umwelt model is not justified. However, the model can still be extended by the concept of functional distance as described on page 42.

3.5. PARTICULAR EXAMPLES AND GEOGRAPHIC VISUALISATION

As an additional way of exploratory data analysis two subsets of the data were selected for geographic visualisation. The Polish Tricity area and Münster are the most represented in the collected data.

The questionnaire data was geocoded for visualisation using the MapBox script for Google Docs that looks up WGS84 coordinates for the input search query and returns them in decimal degrees format using Yahoo!'s or MapQuest's geocoding service. The Yahoo!'s service proved to return more accurate answers. The result is that next to the existing data columns in the spreadsheet the latitude and longitude columns are created and populated with coordinates. The table was then exported to a file and read by ArcToolbox 'XY to line' tool that uses startpoint's and endpoint's X and Y coordinates to plot straight lines and save the result as a shapefile. Each line corresponds to one trip. Using an additional ID field and join command these lines were then annotated with the mode of transport and route familiarity knowledge. The results are shown on Figure 8 and Figure 9.

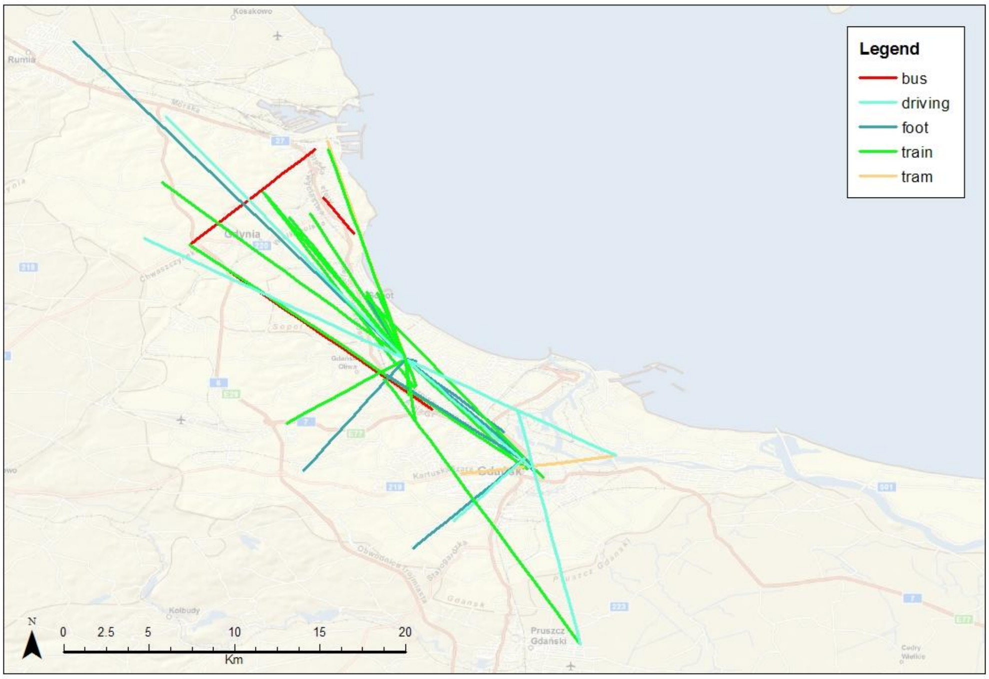

Figure 8 Trips in the Tricity, Poland area.

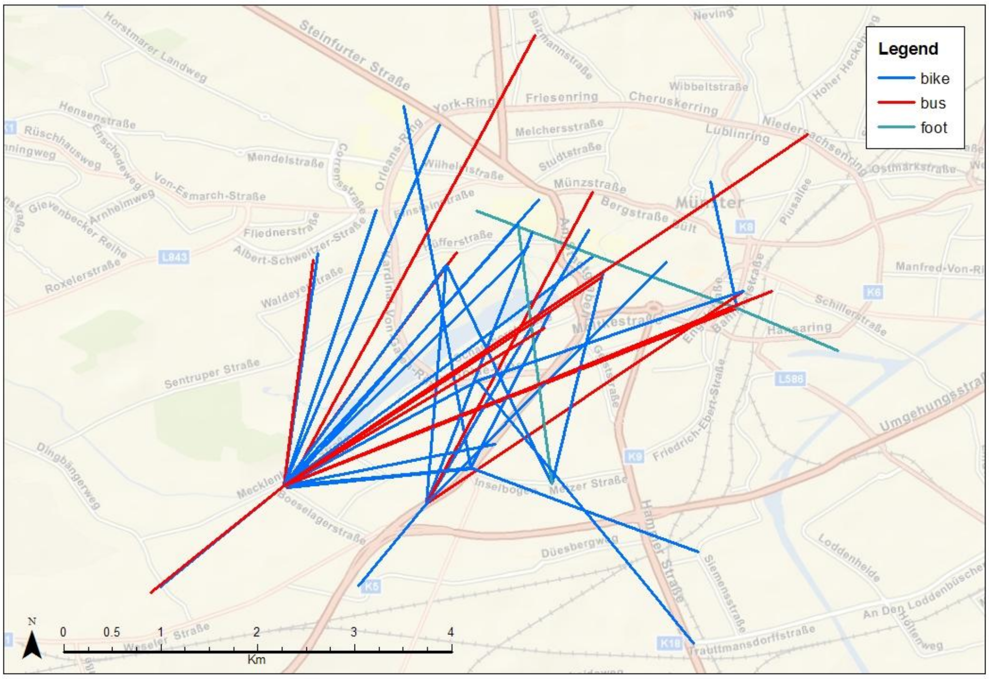

Figure 9 Trips in the Münster, Germany area.

In Figure 8 the following observations can be made. There are two main areas where most trips origin or destination lie. One of these is Gdańsk's central residential area and the other is the city centre. Most of the trips taken along the axis of the agglomeration were made by suburban train whose tracks go parallel to the coastline and provide the fastest public transportation method for longer trips. Perpendicular to this axis are Gdańsk's tram lines and Gdynia's bus lines that act as feeder connections to the train line for longer trips or simply as local connections.

In Figure 9 some points of interest can be clearly identified that correspond to places frequently visited by questionnaire participants: the University student residence at Boeselagerstraße 75 and Institute for Geoinformatics (ifgi) facilities at Weseler Straße 253 and Robert-Koch-Straße. Due to the popularity of bike as a method of transport in Münster there are many of such trips visible for all but the longest distances. Since both the student residence and ifgi are rather outside of the city centre there are no short (below 1km) trips reported.

Finally, the data relevant for the Münster area has been plotted (Figure 10) for another way of visualisation. The higher row in the plot represents unfamiliar routes and the lower row represents familiar routes. Jitter has been added to the plot to prevent data points from overlapping.

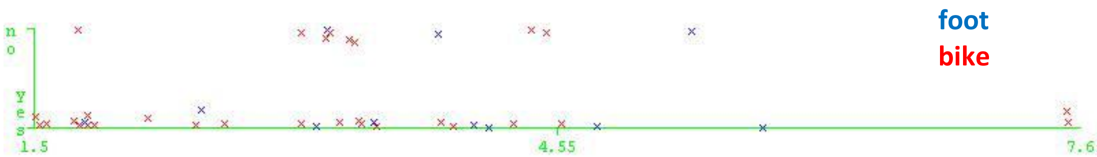

Figure 10 Münster walking and cycling trips. X axis represents distance, Y axis represents route familiarity.

The same data was also visualised on a map (Figure 11). Trips made on foot were removed for the sake of clarity. This allowed for creating a legible map where both means of transport and route familiarity could be represented.

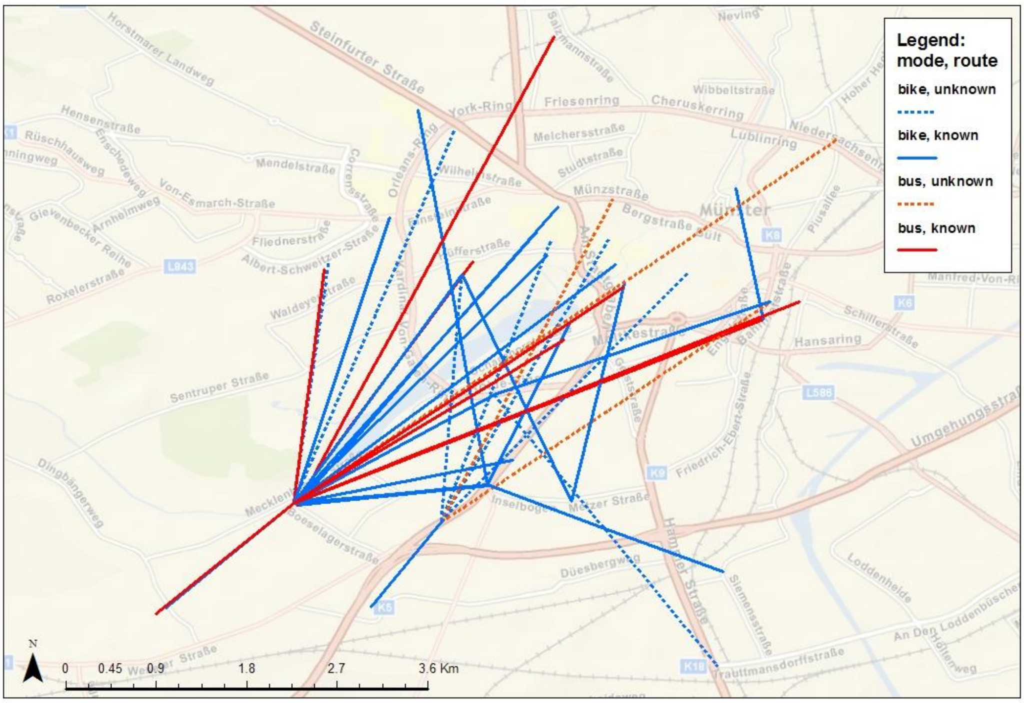

Figure 11 Cycling and bus trips in the Münster, Germany area.

Figure 10 and Figure 11 show that there is no pattern visible relating the route familiarity, mode of transport and route length which confirms the findings of the regression model. For the distances of three to five kilometres both bus and bike are suitable and likely transport choices which was initially visible in Figure 4.

3.6. PARTIAL CONCLUSIONS

Overall, the data collected does not support the hypothesis that possessing a knowledge of the route prior to the trip influences the choice of mode of transport. Data was analysed using statistical and geographical visualisation methods as well as a logistical regression model and a variety of data mining algorithms. None of these methods have yielded a result that supports the hypothesis.

The route length's effect on the choice of mode of transport is however clear and there is a visible, albeit vague, incremental order of means of transport used for trips of increasing lengths. If arranged according to increasing median value this order is: foot, bike, tram, bus, metro, driving, train.

Aside from that, other observations can be made based on the collected data. More of the participants' answers referred to "known" routes. This is especially conspicuous as many of the participants were people who move often and thus have to familiarise themselves with new cities. The questionnaire did not place a special focus on neither "known" or "unknown" types of trips and it was up to the participants to decide which type should they report. It seems that recalling well-known routes comes more easily to the questionnaire participants.

4. FORMALISATION

The last step of the work is to demonstrate how the discussed concepts and the analysis findings could be used in computer systems in a similar way to examples on page 20. The main hypothesis of the thesis did not find any support in the collected data so a similar relevant concept has been chosen for formalisation to model interactions between travel distance and mode of transport.

Functional environments (described in more detail on page 9) are sets of objects available to an agent in order to perform a certain action (Ortmann & Michels, 2011), (Smith & Varzi, 2002). They are purpose-specific, meaning that depending on the task at hand an agent identifies objects within his environment that are relevant to this task. An argument can be made that these environments are also scale-dependant, meaning that certain activities only “make sense” (or: are supported) in a certain scale. If scale is understood as a magnitude (size, extent) as defined earlier, this means that this scale can be expressed as a distance value.

Various modes of transport permit travel for various distances, e.g. walking as a mode of transport does not ‘make sense’ for very large distances for the purposes of navigating in a city. It might make sense for other specific purposes, such as tourism or hiking, but this is beyond the scope of this thesis.

The Umwelten model introduced on page 9 could be expanded to include the concept of functional distance – range, within which a given task makes sense. This would e.g. enable a computer wayfinding application to automatically suggest the most appropriate mode of transport based on the distance between the journey’s startpoint and the endpoint.

A successful extension of the existing model would consist of two steps: ontology extension and simulation extension. The ontology defines modelled concepts and the simulation is built on it to demonstrate how it operates. The first of these steps has been completed within the scope of this thesis.

4.1. ONTOLOGY EXTENSION

The Umwelt model has been built as an ontology using Web Service Modelling Language in its flight variant. It uses riding a bike as an activity example that is demonstrated in a simulation implemented in Java. The instructions how to install the required software and run the original simulation are available at http://trac.assembla.com/soray/wiki/SwoyABMDownloads. The following ontology extension uses the same WSML-flight language.

Existing ontology has been extended so that instead of driving only by bike, other means of transport can be modelled. Driving by car has been used as an example to demonstrate the approach while keeping the ontology simple. Any number of additional modes of transport however could be implemented in analogous manner.

The ontology as modelled originally (Ortmann & Michels, 2011) includes the Concept of DrivingToWorkByBike along with its DrivingToWorkByBikeEnvironment. DrivingToWorkByBike is an activity available to an Agent within its Environment.

A general Concept of DrivingToWork has been created along with subConcepts of DrivingToWorkByBike and DrivingToWorkByCar. Both subConcepts share the DrivingToWorkEnvironment as roads are modelled in a simple way without distinguishing between streets and bike lanes. This is however sufficient for modelling the functional distance. In case there was a future need to distinguish between different activity environments (e.g. if there was a need to model bike lanes that don’t permit car travel) this is a matter of including relevant elements in DrivingToWorkByBikeEnvironment and DrivingToWorkByCarEnvironment. The relevant code is presented below.

```
//domain ontology

   concept DrivingToWork subConceptOf Activity
      define ofType DrivingToWorkEnvironment
      hasParticipant ofType RepastCityAgent

   concept DrivingToWorkEnvironment subConceptOf AffectingEnvironment
      hasPart ofType {RepastCityRoad, RepastCityBuilding}
      isDefinedBy ofType DrivingToWork

   concept DrivingToWorkByBike subConceptOf DrivingToWork
      define ofType DrivingToWorkByBikeEnvironment
      hasParticipant ofType RepastCityAgent

   concept DrivingToWorkByBikeEnvironment subConceptOf DrivingToWorkEnvironment
      hasPart ofType {RepastCityRoad, RepastCityBuilding}
      isDefinedBy ofType DrivingToWorkByBike

   concept DrivingToWorkByCar subConceptOf DrivingToWork
      define ofType DrivingToWorkByCarEnvironment
      hasParticipant ofType RepastCityAgent

   concept DrivingToWorkByCarEnvironment subConceptOf DrivingToWorkEnvironment
      hasPart ofType {RepastCityRoad, RepastCityBuilding}
      isDefinedBy ofType DrivingToWorkByCar

   concept RepastCityRoad subConceptOf Object
      hasName ofType _string
      partOf ofType DrivingToWorkEnvironment
      hasState ofType State
```

The extended ontology works correctly in the existing simulation.

4.2. FUTURE WORK – SIMULATION EXTENSION

The next step is to differentiate between bike and car travel by adding constraints on the maximum possible distance for each of them. This has to be done in the simulation stage and is beyond the scope of this thesis, however the overview of necessary work is presented below.

The Java simulation, once initialised, creates routes on the road network between randomly chosen startpoints and endpoints. In order to benefit from having a choice of different modes of transport, the route length has to be calculated and, based on the result, a decision which transport mode to use can be made. For example, let us assume that the distance permitted for bike travel is defined as six kilometres. If the distance exceeds that threshold, the only available option is driving. If the distance is below the threshold, both modes of transport are available.

5. CONCLUSIONS

The hypothesis that was to be tested at the outset of this work that "the first-hand familiarity of the route to the traveller influences their choice of mode of transport for any given trip" has not found any evidence in collected data and its analysis. There was no evidence, that unfamiliar environments discourage active travel and the necessity of navigation that such travel brings.

However, some other findings can be reported. The data indicates that there is an incremental sequence of modes of transport that are preferred for certain distances. This sequence, if arranged according to increasing median distance is: foot, bike, tram, bus, metro, driving, train. A similar incremental – or hierarchical – relation exists between cognitive spaces. Some of the distinctions proposed in reviewed literature make such relation explicit. These two incremental relations and their relationship might provide basis for future study.

Certain actions and phenomena can be typically conceptualised, experienced, and carried out in a particular cognitive space or spaces. This might provide an interesting future topic for agent-based modelling: a concept of cognitive space support for certain actions.

It was also noted that cognitive spaces delimitations are context-dependant and it would be extremely difficult, if not impossible, to arbitrarily ascribe metric measurements to those spaces.

A potentially interesting parallel between the 'shift' from geographic to environmental cognitive space and the process as building mental map of a new environment has been described.

6. APPENDIX 1 – QUESTIONNAIRE

6.1. ENGLISH

Please describe briefly your trip within a city.
Report each trip as a separate entry (i.e. use a new form).

The questionnaire is trivial. It's about a single trip within your city that you recently (or not-so-recently - it doesn't matter) made. Your daily trip from home to University, your weekly trip to the cinema, but also - and that's important - some trips that you don't do regularly. For example if you had to go to a shop in a part of town you don't visit often, or those that you made when you were learning a city you've just moved to.

1. Origin
Address (street, number, city!) or Google Maps coordinates or anything else that allows me to find the place unambiguously

2. Destination
Street address (including city!) or Google Maps coordinates or anything else that allows me to find the place unambiguously

3. Was the route familiar to you from first-hand experience before you went?
Did you have the complete trip "in your head"? Could you envision the whole way in your mind's eye?

4. How did you travel?
on foot, bus, bike, car, part by metro and part on foot

6.2. POLISH

Opisz krótką pojedynczą "podróż".
Każda osobna podróż powinna być zgłoszona osobno.

Kwestionariusz jest trywialny. Dotyczy pojedynczej podróży jaką niedawno - albo i dawno - odbyłeś/aś w mieście. Codzienna droga na uczelnie, wieczorny wypad do kina, ale też - to ważne - takie podróże, które zdarzyły sie pierwszy raz: na przykład wizyta w sklepie w części miasta gdzie nie bywasz często, albo przemieszczanie się po mieście gdzie niedawno sie wprowadziłeś/aś.

1. Początek

Adres (ulica, numer, miasto) ALBO współrzędne z Google Maps ALBO cokolwiek innego co pozwoli mi znaleźć miejsce na mapie

2. Cel
Adres (wraz z miastem!) ALBO współrzędne z Google Maps ALBO cokolwiek innego co pozwoli mi znaleźć miejsce na mapie

3. Czy przed odbyciem podróży jej trasa była Ci znana z doświadczenia?
Czy miałeś/aś kompletny obraz trasy w głowie?

4. Jakim środkiem transportu podróżowałeś/aś?
pieszo, autobusem, rowerem, samochodem, trochę metrem a trochę na piechotę...

6.3. SPANISH

Porfavor describe brevemente tu viaje dentro de la ciudad.
Informa de cada viaje como información independiente (es decir, utilizando un formulario independiente).

El cuestionario es trivial. Se trata de un solo viaje dentro de tu ciudad que hace poco (o no tan recientemente - no importa) hiciste. El viaje diario de casa a la universidad, el viaje semanal al cine, sino también - esto es importante - algunos viajes que no hagas con regularidad. Por ejemplo, si tenías que ir a una tienda en una parte de la ciudad que no visitas con frecuencia, o los que has hecho cuando estabas conociendo una ciudad en la que acababas de mudarte.

1. Origen
Dirección (calle, número, ciudad!) o Coordenadas en Google Maps, o cualquier otra cosa que me permita encontrar el lugar sin ambigüedades

2. Destino
Dirección (calle, número, ciudad!) o Coordenadas en Google Maps, o cualquier otra cosa que me permita encontrar el lugar sin ambigüedades

3. La ruta era una experiencia familiar de primera mano antes de que hubieras estado?
¿Has tenido el viaje entero realizado "en tu cabeza"? ¿Podrías imaginar todo el camino en el ojo imaginario de tu mente?

4. ¿Cómo viajabas?
A pie, en autobús, bicicleta, coche, parte en metro y parte a pie...

7. APPENDIX 2 – QUESTIONNAIRE RESULTS

distance	familiar?	transport
0.1	yes	foot
0.15	yes	foot
0.2	no	foot
0.25	yes	foot
0.3	no	foot
0.3	yes	foot
0.4	yes	bike
0.4	yes	train
0.6	no	foot
0.6	yes	foot
0.6	yes	foot
0.65	yes	foot
0.65	yes	foot
0.7	yes	bike
0.7	yes	foot
0.7	yes	foot
0.75	yes	foot
0.8	yes	foot
0.8	no	foot
0.8	yes	foot
0.85	yes	foot
0.9	yes	bike
0.9	yes	foot
0.9	no	foot
0.9	no	foot
1	yes	foot
1	no	bike
1	no	bike
1	no	foot
1	yes	foot
1	yes	foot
1	yes	foot
1.1	yes	bike
1.1	yes	driving
1.1	yes	foot
1.2	yes	bike
1.2	no	bus
1.2	yes	foot
1.2	yes	foot
1.2	yes	foot
1.3	yes	bike
1.3	no	foot
1.3	yes	foot
1.3	yes	foot
1.3	yes	bike
1.4	no	foot
1.4	no	driving
1.4	no	foot
1.4	yes	foot
1.4	yes	foot
1.5	yes	bus
1.5	yes	foot
1.5	yes	bike
1.5	yes	bike
1.5	yes	bike
1.6	yes	bike
1.7	no	bike
1.7	yes	foot
1.7	yes	bike
1.7	no	bike
1.7	yes	bike
1.8	yes	bus
1.8	yes	bike
1.8	yes	bike
1.8	no	foot
1.8	yes	tram
1.8	yes	foot
1.8	yes	bike
1.8	yes	bike
1.8	yes	bike
1.8	yes	bus
1.9	yes	bike
1.9	yes	foot
1.9	yes	tram
1.9	yes	tram
2	yes	bus
2	no	metro
2	no	foot
2.1	yes	bike
2.1	yes	bike
2.1	yes	foot
2.2	yes	foot
2.2	yes	bus
2.2	yes	tram
2.2	yes	bike
2.2	yes	driving
2.3	yes	bus
2.3	no	bike
2.3	no	bus
2.3	yes	bike
2.3	no	tram
2.4	no	bike
2.4	no	bus
2.4	yes	tram
2.4	no	tram
2.4	no	driving
2.5	no	bike
2.5	yes	bike
2.5	yes	bus
2.6	yes	bus
2.6	yes	bike
2.6	no	bike
2.6	yes	foot
2.6	yes	bike
2.6	no	foot
2.6	yes	bus
2.7	yes	bike
2.7	yes	bike
2.7	no	bus
2.7	yes	foot
2.7	yes	driving
2.8	yes	tram
2.8	yes	bus
2.9	yes	foot
3	yes	train
3.1	no	bike
3.1	yes	metro
3.1	yes	bike
3.2	no	bike
3.2	yes	bus
3.2	no	bus
3.2	no	bike
3.2	no	bike
3.3	no	bike
3.3	yes	bike
3.3	yes	metro
3.3	no	foot
3.4	no	bike
3.4	no	bike
3.4	yes	foot

3.4	yes	foot
3.4	no	foot
3.4	yes	bike
3.4	yes	bike
3.4	yes	foot
3.4	no	bike
3.4	yes	bike
3.5	yes	bike
3.5	no	foot
3.5	yes	bus
3.8	no	bus
3.8	yes	bus
3.9	yes	driving
3.9	yes	train
3.9	yes	bike
4	yes	bus
4	yes	foot
4	yes	bike
4	yes	train
4	yes	metro
4	yes	tram
4.1	yes	bus
4.1	yes	bus
4.2	yes	driving
4.2	yes	foot
4.2	yes	tram
4.3	yes	bike
4.4	no	bike
4.4	no	bike
4.4	yes	bus
4.5	no	bike
4.5	yes	bus
4.5	yes	tram
4.6	no	bus
4.6	no	train
4.6	yes	bike
4.7	no	foot
4.7	no	driving
4.8	yes	bus
4.9	yes	bike
4.9	yes	tram
4.9	yes	foot
4.9	no	bus
5	no	metro
5.2	yes	metro
5.3	no	foot
5.3	no	tram
5.3	yes	driving
5.3	no	tram
5.4	no	metro
5.4	no	bus
5.5	no	bike
5.5	yes	metro
5.5	yes	bus
5.5	yes	train
5.7	yes	bus
5.7	yes	metro
5.8	yes	metro
5.8	yes	train
5.8	yes	foot
5.9	no	bike
5.9	yes	metro
6	yes	bike
6	no	metro
6	no	train
6.1	yes	bike
6.3	yes	metro
6.3	yes	bike
6.5	yes	driving
6.7	yes	driving
6.8	yes	driving
7	yes	driving
7	yes	metro
7	yes	bus

7	yes	bus
7.4	no	driving
7.5	yes	bike
7.5	yes	driving
7.6	no	metro
7.6	yes	bike
7.6	yes	driving
7.9	no	driving
8	no	bus
8	no	metro
8	no	bus
8	yes	driving
8.1	no	metro
8.4	yes	metro
8.6	no	bus
8.8	yes	bus
8.9	no	driving
8.9	no	bus
9	yes	bus
9	yes	metro
9	yes	train
9.2	yes	tram
9.5	yes	driving
9.5	yes	metro
10	yes	driving
10.1	yes	driving
10.1	yes	bus
10.2	no	metro
10.4	no	bus
10.5	yes	train
10.5	yes	train
10.8	yes	bus
10.9	yes	train
12	no	train
12.2	yes	train
12.5	no	train
12.9	yes	train
13	no	bike
13	no	bus
13.1	yes	train
13.2	yes	train
13.6	no	train
13.7	no	train
13.8	yes	train
13.8	yes	train
13.8	no	driving
14	yes	bus
14	yes	bike
14	no	train
14.4	yes	train
15.2	yes	bus
16.2	yes	bus
18	yes	train
18.1	yes	driving
18.7	yes	driving
20.4	no	train
21	yes	train
21	no	train

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