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Introduction.

The term space is defined and applied in different ways though out academic disciplines and fields of application. In the present context we use the term environmental space in the sense of the physical spaces in which we navigate and move[1].

When humans move in environmental spaces, we make choices. For that purpose we need knowledge about the options afforded by the environmental space, in a given situation. The space can serve several purposes. Here we focus on 1) destinations where our needs can be satisfied, and 2) space as a movement infrastructure itself. Accordingly preference analysis of this movement has to take these two aspects into account. As noted by [18] (p119) who - as a point of departure - conceptualizes '… the spatial choice process as the subjective selection of the most preferred alternative from a subset of alternative,…', eventually including an error component in this choice. The present paper also uses the random utility theory to [8] suggest a framework for analysing spatial movement as a choice process. The framework combines movement based on 1) perceived information on the immediate surroundings and 2) on mental maps on one hand vs. a) movement restricted by an infrastructure (e.g. a transport network) and b) non-restricted movement (e.g. on an urban square or an open meadow) on the other. The paper presents observations and results related to real world applications of the framework in relation to bicycle and recreation behaviour.

Perception, storage, cognition, adaption and application of spatial knowledge in relation to movement and navigation have been studied in a variety of scientific fields. Including psychology [10, 11, and 12], neuroscience /psychohysics [1, 9, and 13], behavioural geography [6 and 12], geoinformatics/GIS [2 and 17], and several fields of applied research including recreational behaviour [16], transport modelling [4] and econometrical choice modelling [19]. There is a tendency for the works within behavioural geography to acknowledge methods and theories from other scientific disciplines (mainly psychology and geoinformatics). One central consideration is the relation between the physical world and the subjective representation of perceived information from which spatial knowledge is gained and accordingly spatial decisions are made. Different people will apply the same information about their surroundings differently depending on for instance their personal characteristics (cultural, social, demographic etc.) and their motivation for moving. For a spatial context this cross-disciplinary paradigm is in particular addressed by the work carried out at University of California, Santa Barbara - spearheaded by the late Reginald Golledge (see e.g. [6]), but is also acknowledged in other fields, e.g. environmental economics [7]. The present work is regarded as part of the same strain of research.

As already indicated the concept of spatial movement decision-making and choices holds several connotations at different temporal and spatial scales. Spatial choices can be divided into choices of activity (e.g. to go the mall), mode (e.g. to walk), destination and route (see e.g. [3 and 5]). Emphasis of the paper will be put on individual human's navigation and path finding through different environments towards predestined destinations.

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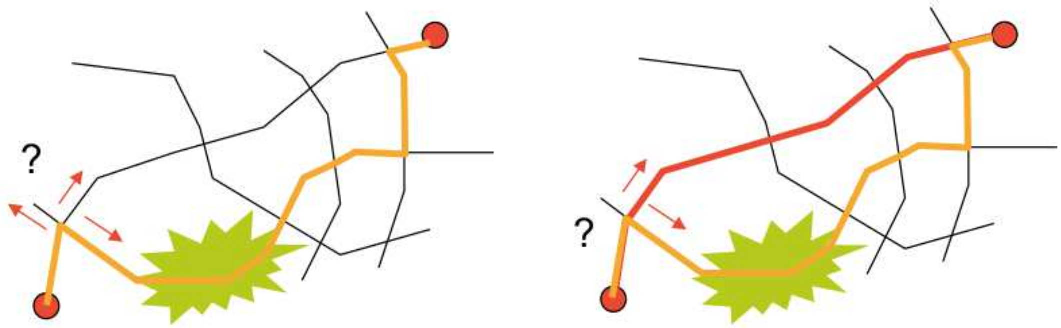
[1] We exclude notions of space aiming at metaphorical spaces (as in mathematics) and hyperspaces of the Internet [8]. Further – along with the distinction made by for instance [10 and 11] - we narrow down our scope to include only 'environmental' space and thereby exclude 'geographical' spaces (primarily representing the relative locations of regions and cities on Earth, 'figural' spaces (map representations) and 'vista' spaces (smaller location likes rooms town squares etc.).

We focus on what information can be elicited from revealed preference studies, where preferences are derived from subjects actual behavior. Consequently we can derive a preference for e.g. green space on a route from whether a respondent choose a route along a green environment more often than the alternatices

Montello [12] proposes that navigation takes place according to two spatial decision domains or scopes: Locomotion where navigation is based entirely on perception or our motor and vestibular systems. This is what you do when you are placed in an unknown territory with very little information about your surrounding except for what you get from your senses or corporal relocation. The other domain, Wayfinding is based on structured and comprehensive spatial knowledge in terms of a mental/cognitive map (which can be achieved from various sources including graphical maps, verbal descriptions, sensory stimuli (muscular or vestibular) combined by path integration [6]. The two approaches are illustrated in Figure 1.



1) 2)

Figure 1: Choice in a network: 1) navigation based on locomotion (perceived information) – choices are made between out-going edges at every node of the network. 2) navigation based on wayfinding (based on mental or screen/printed maps) – choices are made with regards to entire, alternative routes.

Analytical framework.

RP analysis assesses the relation between observed behaviour and a identification of a set of alternatives (that were not applied by the subject). Accordingly, a main – and far from trivial – challenge is generation of such feasible alternatives. Feasible in the sense that they could actually serve as an alternative for the individual subject and also in that it is not possible to analyse an extremely large (depending on definition even infinite) amount of alternatives and consequently a decision has to be made on how to define possible networks. .

Apart from the navigational domains (locomotion vs wayfinding), also the date model of the infrastructural domain has to be considered. Most research within transport choice modelling is based on motorized movement, and consequently movement is restricted by available roads. This may come short when less restricted transportation (e.g. pedestrians or animals) is considered. Here a continuous data field approach, based on cells, may be more appropriate. This is illustrated in Table 1.

Table 1: A framework of analytical objects for assessments of spatial choices and decision-making.

		Infrastructure	
		a) Restricted	b) Free/open
Navigation domain	1) Locomotion	Outgoing edges from a node of a network	Cells representing next step in a raster
	2) Wayfinding	Routes (a series of edges) in a network	Routes (a series of cells) in a raster

The typical way of analysing choices in the random utility framework is by logistic regression, where the chosen route as well as the alternative(s) are described. Explaining variables might include spatial characteristics of the choice such as length, curvature, elevation profile, number of turns, land cover profile, but also socio-economic characteristics of the subject if available. Based on these choices the marginal rate of substitution between two characteristics can be calculated (resulting in willingness to travel or willingness to pay (or accept) estimates; elasticities can be calculated to predict behavioural changes and of course also the direct probability of a given choice over the alternatives can be calculated. . Such probabilities can be applied to e.g., agent-based simulation models to guide agents' spatial behaviour. In the following we describe in more details how this analysis can be carried out for the four possible situations described by infrastructure and navigation domain (cf Table 1), and in particular how the relevant choice set can be defined.

1a: Analysing outgoing edges from network nodes (locomotion/restricted)

In this mode movement is modelled by choices made between edges spanning out from the choice location (i.e. the present node). In that case generation of alternatives to the selected edge is unproblematic. In addition to the attributes of the edges, a number of topological characteristics were assessed, - including the edges' relation to the destination and to the previous edge. Figure 2 shows an example of generation of such a choice set generated for bicyclists in Copenhagen [14]. The study included approximately 1800 trips taken by 179 bicyclists in Copenhagen. The results indicate significant effect of a number of the analysed variables, including both negative effects (for instance deviation from the bearing towards the destination and deviation from a direction 'straight on' regarding the previous edge) and positive effects (presence of bicycle facilities (tracks or lanes) and designated bicycle tracks). The approach is useful for identifying characteristics immediately observable from a point, but not for giving characteristics describing the entire route. Furthermore, interlinkages between nodes will have to be handled by e.g. lag-models.

nodeid	edgeid	selected	dist	angle	angletodest	envtype	cyktype	groenm	gr
23706	35218	f	0,0680689	90,7171	118,496	5	0	0	
23706	19393	f	0,0680689	-90,6798	-62,9007	8	4	0	
23706	38738	t	0,0680689	9,86938	37,6485	3	0	8,55881	
23902	62795	t	0,0874397	77,4672	115,947	5	0	6,48953	
23902	1062	f	0,0874397	-104,399	-65,9196	3	0	15,6367	
23981	23140	f	0,106775	7,98253	126,802	5	0	0	
23981	1264	f	0,106775	98,0552	-143,125	5	0	0	
23981	60730	t	0,106775	-84,8396	33,9801	3	0	0	
24018	21972	t	0,145716	10,7535	44,9166	8	4	23,4775	
24018	1510	f	0,145716	96,436	130,599	3	0	18,5805	
24018	11543	f	0,145716	-87,0796	-52,9164	3	0	37,3328	
24093	22833	f	0,149579	83,2144	128,667	8	4	209,469	
24093	20682	f	0,149579	-97,3655	-51,9134	8	4	200,887	
24093	10609	t	0,149579	-4,38384	41,0682	8	4	87,6988	

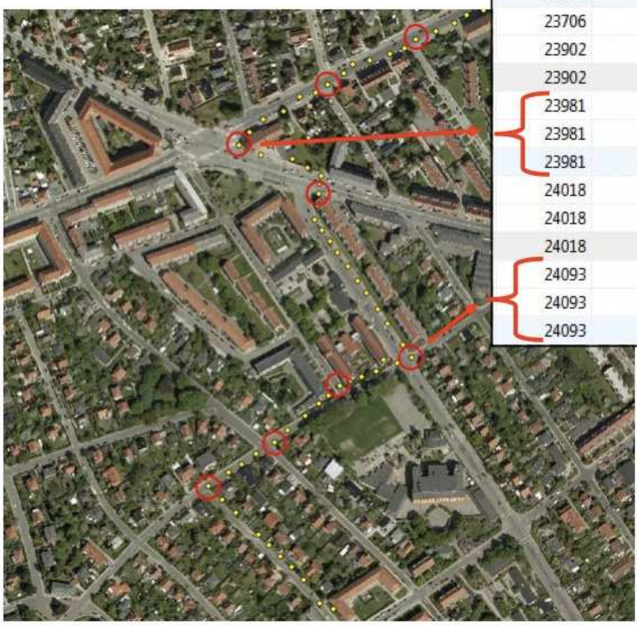
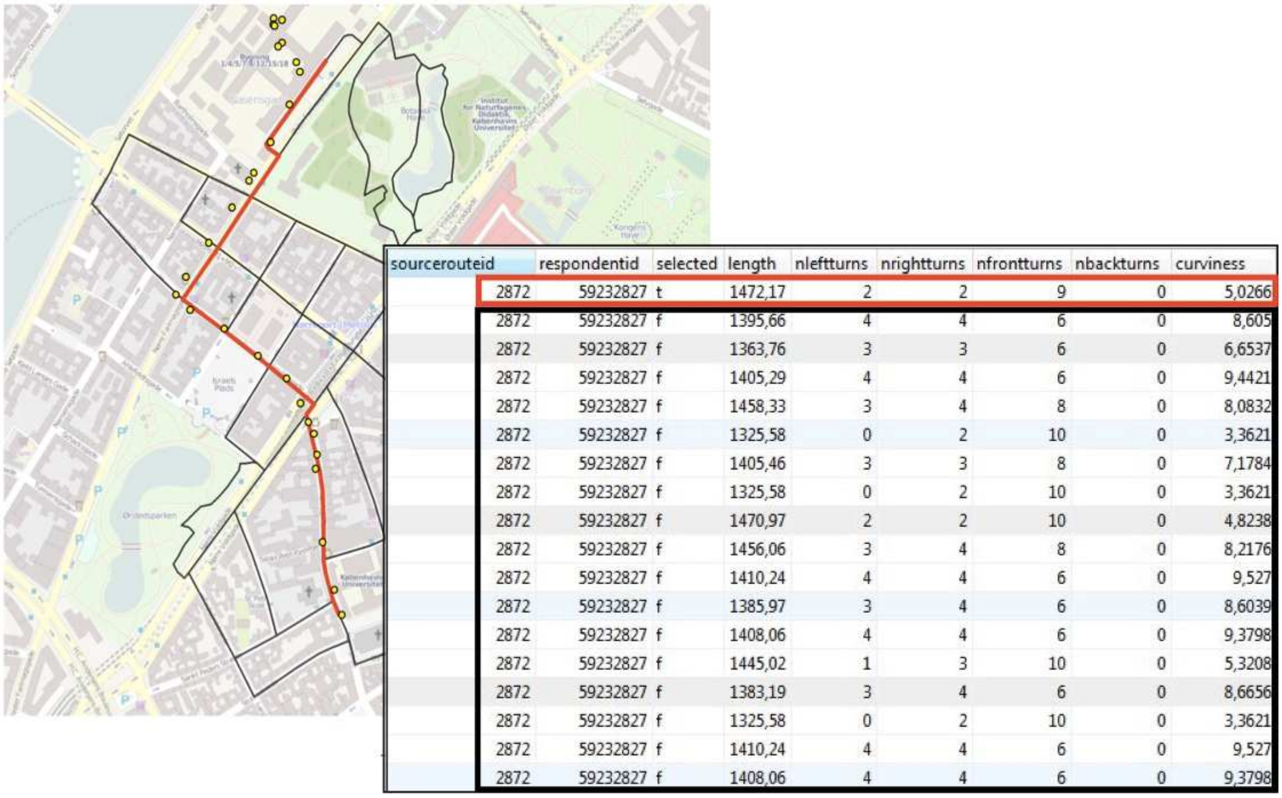


Figure 2: Example of a choice set representing bicyclists' choices based on locomotion. The Boolean attribute 'selected' (t/f) indicate if the option was chosen or not (i.e. for the first choice location indicated, edge 60730 was actually selected, whereas 23140 and 1264 where ignored. The U-turning edge was excluded from the choice set).

2a: Routes (a series of edges) in networks (wayfinding/restricted)

This approach is frequently applied in transport modelling. The route taken can be identified in terms of origin and destination and a set of characteristics (length, number of turns etc.). The main challenge is to generate potential alternatives to the selected route. A baseline route for comparison frequently applied is to use the shortest path. A more advanced – and potentially more realistic - approach is to generate a series of alternatives. A number of potential methods have been proposed. Several authors point at 'labelling algorithms' where the network is searched forward until feasible routes are found (see e.g. [15]). Others suggest the inclusion of a measure of the overlap between an alternative compared to the remainder routes of the choice set in terms of a measure of 'Path Size' [4]. Measures of overlap can also be used as a constraint to the search to ensure that routes in a choice set are spatial dissimilar [14], thereby allowing better estimation possibilities. Results – again based on 1800 trips taken by bicyclists in Copenhagen – include measures of the bicyclists' willingness to cycle additional distance to obtain or avoid given characteristics of a route. For instance, in [14], we find that bicyclists are willing to bicycle 20% longer if a bicycle track is available all the way than if it is not, and bicyclists are willing to drive 80 m extra to avoid a left turn on the route [14]. Compared to 1a), the advantage is the possibility of describing proportions of the route, and distance is taken into account explicitly.



sourcerouteid	respondentid	selected	length	nleftturns	nrightturns	nfrontturns	nbackturns	curviness
2872	59232827	t	1472,17	2	2	9	0	5,0266
2872	59232827	f	1395,66	4	4	6	0	8,605
2872	59232827	f	1363,76	3	3	6	0	6,6537
2872	59232827	f	1405,29	4	4	6	0	9,4421
2872	59232827	f	1458,33	3	4	8	0	8,0832
2872	59232827	f	1325,58	0	2	10	0	3,3621
2872	59232827	f	1405,46	3	3	8	0	7,1784
2872	59232827	f	1325,58	0	2	10	0	3,3621
2872	59232827	f	1470,97	2	2	10	0	4,8238
2872	59232827	f	1456,06	3	4	8	0	8,2176
2872	59232827	f	1410,24	4	4	6	0	9,527
2872	59232827	f	1385,97	3	4	6	0	8,6039
2872	59232827	f	1408,06	4	4	6	0	9,3798
2872	59232827	f	1445,02	1	3	10	0	5,3208
2872	59232827	f	1383,19	3	4	6	0	8,6656
2872	59232827	f	1325,58	0	2	10	0	3,3621
2872	59232827	f	1410,24	4	4	6	0	9,527
2872	59232827	f	1408,06	4	4	6	0	9,3798

Figure 3: Example of a choice set representing bicyclists' choices, based on wayfinding. The Boolean attribute 'selected' indicated if the option was chosen or not. The route displayed in red is the actual (map-matched) route (attributes are shown in the red box of the attribute table). Alternative routes are shown in black (attributes in the back box of the attribute table).

1b: Cells representing next step in a raster domain (locomotion/free)

Examples of such behaviour are hikers in nature, animals browsing for food etc. In the locomotion domain (basing decisions on perceived information) the 'next' step has to be identified directly as a subsequent point on the recorded track. Alternative locations can be identified in relation to the present point according to for instance distance and angle between the present and the subsequent points. An example of this approach applied to analysis of recreational behaviour will be given at the conference. The advantage of this method lies in its ability to describe slow movements, and movements where the destination is less important than the travel. The challenge lies in data explosion, as it becomes very large when cell size decreases.

2b: Routes (a series of cells) in a raster domain (wayfinding/free)

In a continuous field with no infrastructure, having a mental or representative (e.g. graphical) map of the taken route can be described as above. An example of such a movement can be a ship travelling in the open ocean or a hiker making his/her way off-piste to a predefined point in nature. To our knowledge no attempts until now has been reported in the scientific literature to create alternative routes for such an analysis. One option would be to perform a weighted random walk - including a preference weight for the bearing towards the destination - between the routes origin and destination applied by means of an agent base model.

Concluding remarks

Movement tracks can be applied to assess spatial movement behaviour, including preferences and route choices. The results, parameter estimates regarding characteristics of recorded routes, can be applied to a range of scientific questions: Can route preferences be assessed by RP analysis of tracking data? How do different types of agents find their way and decide on routes? What is the relative importance of different characteristics?

Strategically the direct results (i.e. the parameter estimates) can be applied to more informed mechanisms behind route-finding software (impedance setting) and further be applied to simulation of spatial behaviour (e.g. in relation to agent based modelling). In relation to planning, the results can be applied to assessment of the potential effect changes made to the infrastructure. However, for both of these purposes, it is important to be aware of the movement possibilities in terms of infrastructure, and the cognitive choices in terms of decision strategies. Especially the latter calls for more research in terms of testing different approaches against each other, but also by including knowledge from the psychological and (economic) choice set formation literature.

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