Continuous cartography: generalisation for mixed-scale and mixed-space map views

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Abstract: Given that modern (often mobile) devices used for consuming geospatial information afford an explicit understanding of the user's goals and context, we argue that generalisation logic may benefit from better linkage to the context-dependent needs of the map user. A journey can be conceptualised as a sequence of navigation tasks. While a traveler experiences a journey as a continuous phenomenon, our methods of cartographic representation typically result in the traveler interacting with a set of discrete map views. Continuous cartography refers to the representation of a single integrated map view. While continuous generalisation has been explored in a number of research threads, in this paper we present initial work to more explicitly link a continuous approach to cartographic representation with the sequence of navigation tasks a traveler undertakes. The implication being the need for map views that integrate spatial information from multiple forms of spatial representation. This work strongly links with issues of automation and the effectiveness of maps delivered through the limited screen real estate of mobile devices.

Keywords: multi-scale generalisation, continuous generalisation, automated cartography, spatial cognition, navigation

1. From discrete to continuous cartographic representation

'Discrete' cartographic representation refers to the representation of geographic entities and relations in map views that conform to a uniform scale and uniform mode of representation (typified by the topographic map). A user may interact with a discrete map view (zooming to see more detail for example), but this operation is applied to the whole extent, and so the user effectively transitions to a 'new' view. Over the course of a complex journey, using a mobile device as a navigation aid, a map user will often transition through a number of views – changing scale in the topographic view, or switching to a highly schematised view of the public transport network, for example. In contrast to the cartographic design paradigm we have just described, 'continuous cartography' supports the representation of geographic entities and relationships in such a way as to be able to integrate scales and levels of schematisation in the same map view, and to smoothly transition between these varying forms of representation. While this work links with the research into continuous generalisation (e.g. van Oosterom and Meijers, 2011), continuous cartography moves beyond smooth transitions between scales to deal more explicitly with supporting digital map users as they progress through sequences of navigation tasks.

The central motivation behind the research discussed in this paper is to investigate whether a continuous approach to cartographic representation may be able to support a reduction in extraneous cognitive load (Sweller, 1988 Bunch and Lloyd, 2006), relative to the traditional 'discrete' approach, as discussed. Intrinsic cognitive load is the cognitive effort of comprehension resulting from the inherent complexity of phenomena (the geographic environment), whereas extraneous cognitive load is the cognitive effort that is attributable to the way in which information communicates the character of the underlying phenomena. A journey is a continuous experience, so would the gap between intrinsic and extraneous cognitive load be reduced if cartographic representation was also continuous? The implication of this line of investigation is that we must be able to automatically infer the user's preferred form of representation for each phase of the journey, and pre-select this heterogeneous set of information so that visualisation methods may resolve these elements into a single view. In this paper, we propose that the logic by which this set of information is selected is based on our understanding of navigation tasks, and the sequence of decisions a traveler is likely to undertake given some particular start point, a destination and set of transport modes.

2. A task-based perspective

We define a navigation task as a decision-action pair that can be inferred based on knowledge of location, destination and travel mode/ modes. So, a journey is taken in order to complete a goal, and a sequence of sub-tasks are required to complete that journey. We argue that spatial decision-making should be analysed in the context of the macrocognitive functions such as planning and adaptation that are employed in our day-to-day activities (Crandall et al., 2006), with sequences of tasks constituting our overall acts of goal completion.

We envisage navigation tasks as impacting the form of the map (such as integrating topographic and schematic representations), and the actual generalisation process itself; there being a number of opportunities to re-think our approaches to processing geometries such that we can present highly effective map views to the user that increase the ease with which complex environments may be navigated. Before continuing the explanation, we briefly review literature that provides some insight into the historic approaches that are of relevance.

3. Existing approaches to task-based map generalisation

We briefly review research that has sought to bridge the divide between the user's context and our exocentric model of geography, observing that much of it relates to location-based services, either delivered via a smart phone or via in-car systems.

3.1 Representations of relative geography: bridging exocentric and egocentric models

Terms such as 'on-demand', user-centric, and adaptive generalisation are used to describe the process of creating maps more tailored to the individual – i.e. maps that take account of location and mobility, screen real estate, and task. Key to expressing information specific to a task is the notion of a map view that reflects aspects of the geography that are relative to the context of the map user, as opposed to simply reflecting a generic view of the absolute position of entities and their spatial configuration. Perhaps the clearest example of this is the representation of distances as a function of the time needed to traverse a route segment, as opposed to displaying a representation of the absolute Euclidean distance. For example Kaiser et al. (2010) illustrate how Cartesian space can be distorted in order to create spatio-temporal hybrid maps. They also demonstrate how space-time maps can be 'travel-centric' in which space-time is a measure with respect to a straight line path (A-B). A related approach is characterised by the LineDrive project in which Agrawala and Stotle (2001) gave visual precedence to journey segments with a higher frequency of decision-making, therefore distorting the Euclidean representation of the route to make better use of the limited screen estate of an in-car interface. Dogru et al. (2008) also explored in-car navigation, with the use of linear buffer zones along shortest path routes in the selection and reclassification of land use, thus enabling the selection of points of interest and landmarks. With respect to task more specifically, Dogru et al. (2008) briefly mention elements of decision making (planning, route following etc.) for in car navigation, but these are not used as a basis to select different algorithms. It would perhaps be more appropriate to say this is an example of a thematic-based approach to map generalisation as opposed to task-based, given the user is rather weakly modelled. Timf et al. (1992) do however consider tasks more directly for in-car navigation, with the authors demonstrating how sub-tasks (planning, instructional and driver levels) may be used to govern both the selection of entities relevant to the goal, as well as their level of detail. The use of algebraic specifications facilitates this process of linking task to appropriate levels of generalisation. The requirement to link task to specification requires us to model the meaning of the entity and its associations with other entities;

hence the energies devoted to ontological modelling (e.g. Touya et al. 2012).

Particular mention should also be made of work by Harrie et al. (2002) around variable-scale approaches specifically for small screen displays. This work was born of a very similar motivation to the present research and pointed toward the need for further development of innovative approaches to cartographic representation, given the emerging mobile interaction paradigm.

3.2 Contextual data: linking user needs with geographic environment

A fundamental consideration is the method by which we define how the geography relates to the user. Various research seeks to understand the saliency of the geography and to comprehend the driving logic through which entities and relations should be ultimately rendered. Again, much of the work in this area has been through the LBS community, with a particular focus on mobile services and the possibilities afforded by smart phone technology. Sarjakoski and Sarjakoski (2005) for example showed the need for highly individualised information requirements that in turn require the delivery of personalised maps to the end user. The vision of this research was that a highly-integrated model was required to facilitate the combination of multiple datasets (Balley et al., 2014), thus supporting a wide spectrum of smartphone applications.

In their 2009 paper Raubal and Panov link context, user model and task model to produce an adaptive LBS that could be used as a basis for implementing context aware services – the ambition being the delivery of relevant navigational information in a range of contexts and ambient conditions. This user-centric approach sought to reduce user interaction and cognitive load; the adaptation through the use map generalisation was identified as a future goal.

In summary, there is extensive literature on the science of wayfinding, including experiments in the effectiveness of various design approaches. This is complimented by research in map distortion – either as a means of locally disambiguating map entities, or in visualising time-space representations (Kaiser et al. 2010). We argue however that there appears to be a distinct opportunity to explicitly formalise our knowledge of a user's goal such that we can automate the provision of task-focused map views that take advantage of a capacity to mix levels of details, and mix forms of visualization (for example integrating schematic and topographic maps).

4. Toward a functional approach to generalisation

Tasks are about goals, decisions, actions and behavior. While map generalisation is ultimately about supporting decision-making, its methods are clearly centred around the display of geometric objects for the purpose of communicated aspects of the character of a geography. We propose that the high-level conceptual device that links these two domains is that of the functional view of geography. As illustrated by researchers such as Klippel and Richter (2004), and Tomko and Winter (2013), we can think of geographic representation as being broadly split between structural and functional properties. The structural view is synonymous with the exocentric approach which emphasises the absolute position of geographic entities (Klatzky, 1998) and, in turn, underpins spatial information that supports a 'survey' orientation strategy. The functional view emphasises aspects of the structure that help to 'specify action' (Klippel and Richter, 2004), and so are synonymous with user task and, more broadly, with a 'route' orientation strategy (a clear sequence of actions).

4.1 Elevating user decisions in the underlying conceptual hierarchy

At present, the map extent is defined by a journey's start and end, and the user's current location, which is assumed by default as the journey start, and is used as the variable to define the current map view and scale factor. We propose that with the aim of better reflecting the functional characteristics of the geography given the user's task, the journey is disambiguated from the overall environment based on the information required to support a prototypical sequence of decisions. This approach may be seen within the context of the anchor-point hypothesis (Couclelis et al., 1987) and related work, but with the focus very much on decision-making as opposed to a priori familiarity. To illustrate this proposal we use the case of a multi-modal journey that includes street-level navigation on foot in concert with the use of the public transport network. This example includes a clear sequence of sub-tasks that require a mixture of information types. The decisions that are needed to achieve the goal of reaching the destination are likely to be supported by a number of forms of spatial information, for example information from multiple-scales (e.g. higher levels of detail around complex route sections that are to be completed on foot), and more highly schematised views when traveling on public transport – the schematic views perhaps at smaller scale but retaining some visual cues but with the emphasis on the topological.

4.1.1 The end-to-end journey: multi-modal travel example

A route may be characterised by a sequence of key decisions that serve to frame the format of spatial information that should be presented to the user. Rather than a using a single uniform map scale, using a task-based model of the journey allows for the non-uniform application of generalisation processes, leading to a more organic, heterogeneous view, formed around user needs. By 'heterogeneous' we mean that the map view that is ultimately surfaced to the user is particular to the combination of start, destination and travel modes, and is therefore essentially unique and indeed cannot be supported by a generic base map. This is an inference based approach, with the journey start, destination and acceptable modes of travel serving as the parameters, and the feature geometry serving as the input.

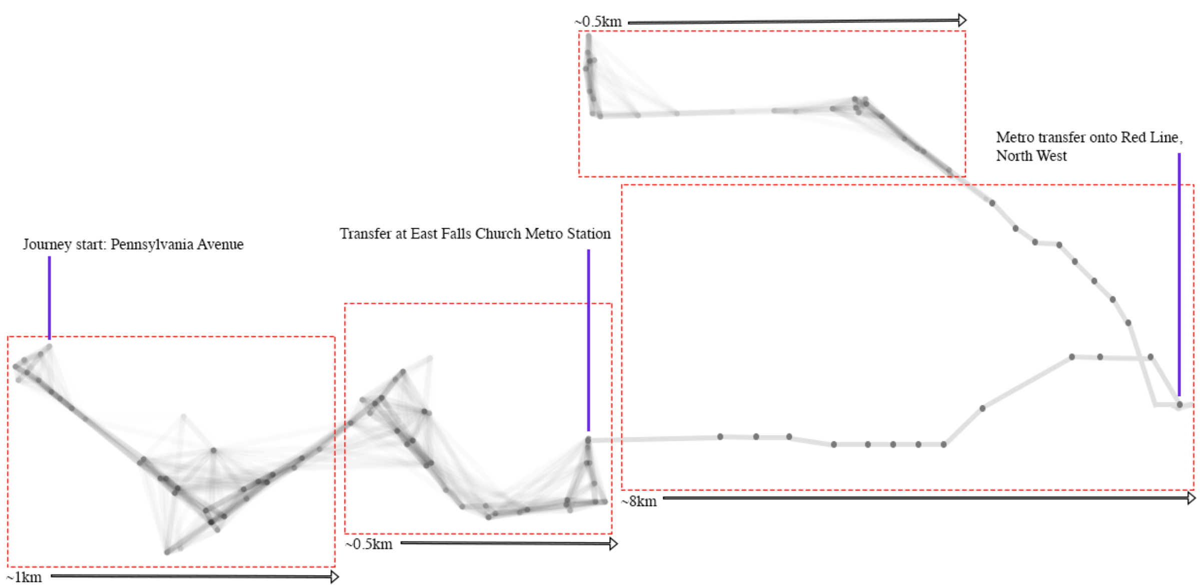

Fig. 1. Mixed-scale/ mixed-space view: journey across Washington DC from East Falls Church to Bethesda. The journey requires the user to navigate on foot to the East Falls Church metro station, to take the Silver Line to the Metro Centre, change onto the Red Line, then navigate on foot from the Bethesda station in the north of the city to the destination on Stratford Road.

In Figure 1 we see four dashed-line boxes demarcating distinct route phases in which a change of scale is required in order to support a specific level of detail. Here we see nodes representing geographic entities from varying conceptual scales ('mixed-scale') and varying forms of schematisation ('mixed-space'), representing key aspects of the geography relative to the current task. For example the highly detailed topographic information around key turning points during phases on foot, and the topological nature of the metro phases, which in fact cover by far the largest distance but can afford to be compressed given the simplicity of this phase of the route (valuable in the context of limited screen estate).

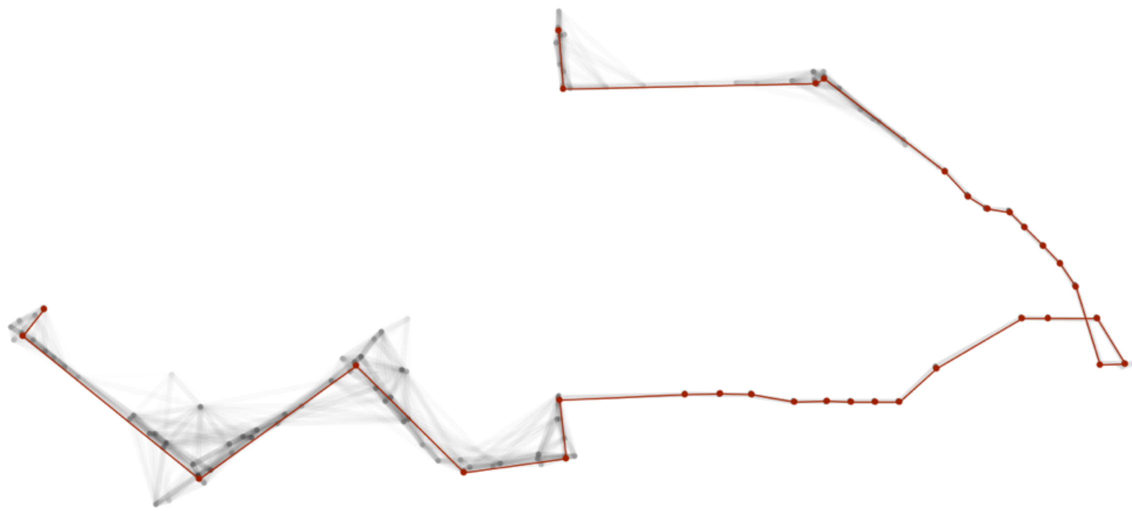

Fig. 2. Multimodal route across Washington DC. Tri-partite view across four key phases of travel – a walking phase, two metro trains, and a final walking phase to the destination.

In Figure 2 we see the disambiguated route across all phases of the journey. A potential application of task-based continuous map views is that we can reflect prototypical decision-making patterns such as the 'tri-partite' view within our generalisation logic. The tri-partite pattern reflects a journey object characterised by higher frequency of decision-making at the start and end, with longer sections of travel in the 'middle' that represent simpler sub-tasks (low intrinsic cognitive load), and therefore have a reduced information requirement.

5. Toward task-based generalisation for continuous cartography

While there are clearly many implications of 'breaking' the standard metric formalisation of geometric representation, we highlight three key areas for investigation.

5.1 Crossing conceptual cusps

As we know from both natural language route descriptions and from sketch maps (being two windows onto people's natural internal representations of saliency and spatial relations), the conceptualisation of a journey is likely to include a mix of entities from varying conceptual scales, with sudden jumps across 'conceptual cusps'. For generalisation to better support map views that reflect this 'cognitive collage' (Tversky, 1993), we require techniques for dealing with scale transitions and the mixing of entities from different scales in a way that still supports clarity and the conveyance of metric-like properties such as Euclidean distance. To give an example, as illustrated in Figure 3, if we transition from the Washington DC metro network at Bethesda, we transition from a situation that has required an emphasis on network structure (of the metro network) with a small scale and low level of detail, to the street network, where high levels of detail are required. How can we 'smooth' this transition if we are to integrate these varying forms of representation in the same map view? While a 'jump' from a non-metric, 'schematic' view to the metric topological view is perhaps the most extreme example, if we are to integrate multiple scales then we encounter a similar issue even for purely topological representations. An open question then is how to apply generalisation approaches to achieve smooth transitions across conceptual cusps, while maintaining recognition of key characteristics of the geography?

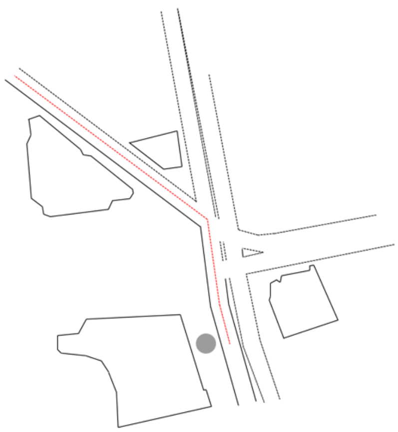

Fig. 3. Transition from DC metro to street – circular symbol denotes station, and therefore the 'entry point' from the metro network onto street network, with topographic detail required to support the correct turning action (left onto Old Georgetown Road), as well as overall orientation within the environment.

5.2 Representing a single journey object

We argue that a task-based approach to generalisation should accommodate the notion of a single journey object (Figure 4). That is to say that even for a complex journey across a relatively large area, the user's natural conceptualisation of a single continuous journey should be considered in our graphical approaches to representation. While there are examples of existing services that provide vector overlay on topographic base-maps to indicate phases of travel across an entire A-B route, the restriction of the base map leads to a limited ability to apply varying levels of detail and varying approaches to geometric treatment within the same map view.

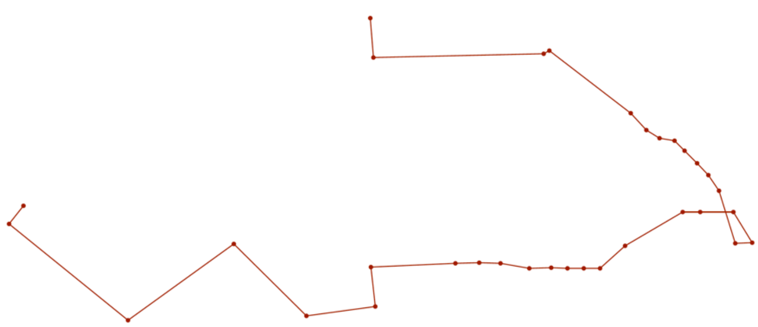

Fig. 4. Single journey object – nodes from varying conceptual scales and network types modelling a consistent flow within a mixed-space view (i.e. varying forms of generalisation for different journey segments).

5.3 Distinguishing the functional from the structural

We argue that a key challenge for this work is balancing the emphasis of the functional aspects of the geography with the representation of a broader geographical context – in other words supporting both route and survey orientation strategies, and supporting the user in developing survey knowledge, while still delivering on the aim to reduce cognitive load for complex journeys. This is partially a challenge in terms of the underlying data model, however it is ultimately a generalisation problem in terms of reconciling these aims within the final rendered map view. Figure 5 shows a simple functional representation; in the functional view, intersections are divided into three types – a basic intersection, an intersection with functional relevance to a decision (usually a turning decision), and intersections that are themselves decision-points (i.e. actually require a turning action). In this illustration, the first right is of functional relevance as it is 'the turning before' the required intersection, and the second is itself a decision-point. The modelling and inclusion of salient landmarks is key to the task – reflecting that functional emphasis.

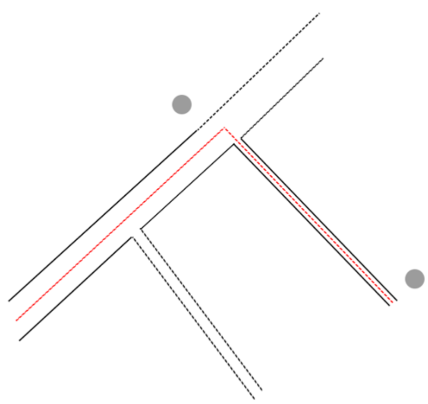

Fig. 5. Simple functional representation emphasizing aspects of the geography that help to 'specify action'(adapted from Klippel and Richter, 2004).

6. Concluding comments

In this paper we have discussed the argument for investigating continuous cartographic representation using a task-based approach, in which the task, and the decisions that must be taken to achieve the task, serve to form the primary logic of the ultimate form of representation. We have proposed that a functional approach to representation is the key to bridging this task-based view with the actual process of generalisation, and we have presented three key areas for further work to develop generalisation techniques that support this vision: crossing conceptual cusps, representing single journey objects, and distinguishing the functional character of the geography without losing the contextual information that supports survey knowledge. It is acknowledged that approaches to digital cartographic visualisation that move beyond the implementation of a base map create many practical and theoretical challenges. However, given the nature of our mobile devices and their status as the dominant platform for our interactions with spatial information, we argue, as have others, that an investigation into innovative approaches is warranted. This work is part of an on-going project to develop user-centric methods of automated cartography.

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