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RESEARCH ARTICLE

More is less – Adding zoom levels in multi-scale maps to reduce the need for zooming interactions

Marion Dumont[1], Guillaume Touya[2], and Cécile Duchêne[3]

[1]IGN, Saint-Mande, France
[2]Univ Gustave Eiffel, IGN-ENSG, Champs-sur-Marne, France
[3]Univ Gustave Eiffel, IGN-ENSG, LASTIG, Champs-sur-Marne, France

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Abstract: When you zoom in or out of current multi-scale cartographic applications, it is common to feel lost and disoriented for a few seconds because dimensions and map symbols have changed. To make the exploration of these multi-scale maps more fluid, one option is to design maps where the transformations due to scale change are more progressive. This paper proposes to use cartographic generalization techniques to design these multi-scale maps with additional intermediate scales to improve progressiveness. These more progressive maps are tested in a user study with a task requiring multiple zooms in and out. The users perform better with the progressive maps, and in particular, the total quantity of required zooming is reduced compared to maps without additional intermediate scales. However, the survey is not fully conclusive on task performance due to the complexity of such a survey with real maps. This difficulty in assessing how well progressive map generalisation reduces disorientation is discussed and guidelines are proposed to design further studies.

Keywords: cartography, multi-scale, zoom, user study, map generalization

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1 Introduction

When zooming in or out of a multi-scale cartographic application, the map content changes into a new one adapted to the new scale, but the user often feels lost, or disoriented for a moment in this new map. This phenomenon, sometimes called the "desert fog", is common in multi-scale interactive environments [38]. Just like a real desert fog, a zoom in a multi-scale map removes most of the visual cues of the previous map view, and of the location you were looking at in the previous map view. To soften this desert fog effect, more progressivity in the changes across scales should be helpful and is the idea behind past research on smooth zooming [8, 94, 96]. There are two main directions to achieve smoother zooming: (1) designing better multi-scale interactions [29], or (2) designing content for the map that is better adapted to a multi-scale exploration [15].

In this paper, we are interested in the latter idea. Map generalization seems to be a good way to derive this adapted map content [15]. Map generalization is the map design process that seeks to simplify the information displayed on the map to make it legible at smaller scales (Figure 1). Map generalization techniques can be used to derive more continuous [95] or progressive [14] transformations of the map content across scales. But generalization techniques, as well as other traditional cartography techniques, are rarely used when designing these multi-scale maps to be displayed into geoportals, as most of the time cartographers were not involved in their design [27].

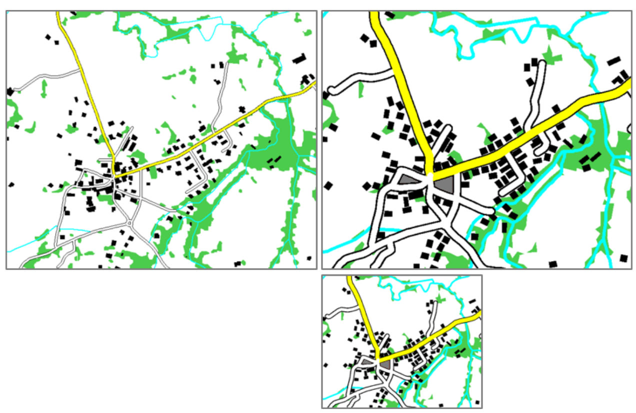

Figure 1: A topographic map at the 1:25,000 scale (left), the same area generalized for visualisation at the 1:50,000 scale; symbols are enlarged to be legible, buildings are enlarged, simplified, and displaced from roads to avoid overlaps (right). The same 1:50,000 scale map is resized to its exact size when printed on paper (bottom).

Traditionally, the evaluation of map generalization is based on design specifications defined by an expert in cartography, for example a symbol has to be large enough or a building has to be placed further than 0.1 mm from a road symbol [50]. But contrary to standard practices in information visualisation or human-computer interaction, user studies are extremely rare. So, even if the requirements of the experts are met for a given design, there is no guarantee that the user experience really improves with this design. Moreover, in a multi-scale map, such an approach only enables the assessment of the individual maps that compose it. It does not enable us to assess the multi-scale map as a whole and therefore assess whether it causes more or less desert fog. This is why this research addresses a double challenge: (1) designing additional scales that reduce the disorientation experienced by the user during the exploration of multi-scales maps, and (2) designing an evaluation process that measures user experience to check if progressive generalisation really reduces desert fog during a multi-scale map exploration.

To address these two challenges, there are two main contributions in this paper:

1. Four different techniques are proposed to generalize topographic maps in a progressive way, in a scale range between 1:25k and 1:100k. All these techniques seem to reduce the desert fog effect.
2. The paper describes the first controlled user survey to assess the (positive) impact of progressive map generalization on the use of multi-scale interactive maps, while map generalization evaluation is usually based on the expertise of some cartographers.

The following section describes past research related to fluid multi-scale map exploration. Section 3 presents different ways to enhance multi-scale maps with progressive intermediate new scales. Section 4 describes the user experiment we conducted and presents its results. Then, Section 5 discusses this experiment and what we call the user survey conundrum with map generalization evaluation. Finally, Section 6 draws some conclusions and proposes ideas for further research.

2 Fluid multi-scale map exploration

2.1 Disorientation and multi-scale map exploration

Based on broader definitions of geographic disorientation [19, 53, 55], we define cartographic disorientation as follows: disorientation occurs during the exploration of a panscalar map when people are consciously aware that they do not know where exactly the place depicted on a map is or where they need to go (horizontally or vertically) to get to the desired map view [86]. With this definition, the desert fog effect seems to be one expression of cartographic disorientation, but not the only one. Cartographic disorientation is modelled as a reconciliation problem between the landmarks and regions identified in the current map view and memorised from past views of the interactive exploration, and the mental representation of the user [86].

There are multiple causes for this failed reconciliation that causes disorientation, such as: the mental representation of the place depicted in the map is incomplete, a lack of landmarks in the map, the map is not at the scale the user is assuming it is, the user lacks expertise on the use of multi-scale maps, etc. [86]. We believe that all these causes could be mitigated by better map design, and this is what we tried in the study presented in this paper.

From a cognitive perspective, the way our vision and our brain work might also explain this disorientation and the desert fog effect. Change blindness [91] might be one cause of disorientation as vision focuses on specific parts of the map during a zoom [97], and the map reader might be blind to changes elsewhere in the map. Inattentional blindness is another significant cognitive effect that makes us blind to some details when we have to focus our vision on too many objects [66], which is the case when the map is changing too much during a zoom. Finally, working memory has physiological limitations that might prevent us from fully processing all the information change caused by a zoom [65, 86]. As the disorientation feeling can be very short, it could also be explained by a failed reconciliation during the pre-attention phase of vision [89], which forces the user to focus on the map to find landmarks while the reconciliation can sometimes be immediate.

2.2 Fluid exploration of data visualizations

Multi-scale maps can be considered as a specific type of complex interactive multi-scale visualization. As the desert fog and disorientation are not specific to maps but are also common for other multi-scale visualizations [38], it can be interesting to look at the past propositions to enable fluid interactions [17] while exploring similar multi-scale visualizations. To explore multi-scale visualisations, different types of techniques are possible and can be combined [9]: zooming, overview+detail (e.g., the overview map sometimes showed in the corner of mapping applications), focus+context (e.g. fisheye lenses), or cue-based techniques (i.e., artificial cues are added to the visualisation). We are mostly interested in zooming, as pan-and-zoom remains a predominant interaction available in current multi-scale maps.

While zooming remains the premium interaction to interact with multi-scale visualizations, several improvements of the basic zooming interactions [4] were proposed in recent years. The progressive loading and rendering that is now used in most cartographic applications improves fluidity and was adapted to other types of information visualizations [23]. GravNav proposes a gravity-inspired model to assist the navigation across scales and performs better than pan and zoom to explore very large images [36].

Past research also highlights the importance of the feedback given to the users when zooming [21]. In human-computer interaction, the feedback corresponds to a clear indication of the consequences of the interaction. The current zooming interactions with maps give very little feedback to the users, which can explain the prevalence of the desert fog. Visual cues, such as grids superimposed on the visualized data, also appear to be good solutions to guide zooming and reduce the desert fog [42]. Such visual cues are rarely used in mainstream mapping applications.

There are also research projects that focused on the comparisons of techniques for fluid exploration of data [47, 56, 72]. These papers provide additional context for designing a user survey to compare different techniques.

2.3 Fluid interactions with multi-scale maps

Besides the propositions for a fluid exploration of complex data visualizations, there were propositions of interactions specific to the exploration of multi-scale maps.

Even with a simple zoom in a cartographic scale-space diagram [20] as proposed by the current mapping applications, there are still several possibilities to design the interaction, centering for instance on the center of the previous view or on the position of the mouse cursor [98]. Similarly to GravNav, BigNav is a new interaction mode to navigate across scales that maximises the mutual information between the user and the machine [45]. Applied to multi-scale maps, users complete searching tasks faster with BigNav than with classical pan and zoom.

We have seen in the previous sub-section that visual cues could ease the navigation of users and this principle has quickly been applied to maps with Halo [3], a technique that shows visual cues on the off-screen map objects (Figure 2a). More recently, two other techniques based on visual cues were proposed and are particularly interesting because they also provide some feedback during navigation. The first one, TrailMap [101], leaves bookmarks on the map as trails of the past navigation with pan and zoom, and these bookmarks can be visualized with DragMag windows (Figure 3). The second technique, called Personalized Compass [51] shows a compass in the center of the map, showing the direction of

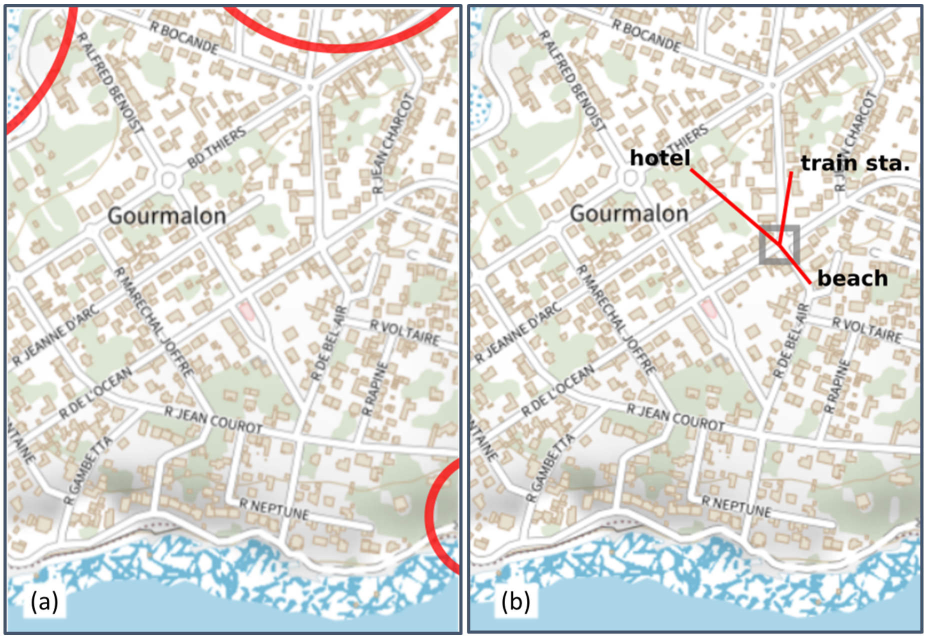

Figure 2: Two human-computer interaction techniques to reduce the desert fog effect by adding visual cues in the map view: (a) Halo shows where the important landmarks are with arcs of a circle (the largest the radius of the circle, the further the landmark) [3]; (b) Compass that shows the location of the same landmarks with a compass cue placed at the actual location of the user [51].

landmarks that are important for a user (Figure 2b); as the compass changes dynamically when zooming, the user gets direct feedback of the effect of the zoom.

TopoGroups [99] and TopoText [100] are techniques that do not rely on zoom to explore different scales. They both follow the principle of OVERVIEW+DETAIL and propose the visualisation of three scales at a time using visual variables such as color to get a graphical view of the multi-scale hierarchies. But in this case, the hierarchies are not cartographical but in additional text information (*e.g.* tweets) rendered on top of a map. PolyZoom [37] is another example of an OVERVIEW+DETAIL technique applied the exploration of multi-scale maps.

Besides OVERVIEW+DETAIL, FOCUS+CONTEXT techniques also enable the exploration of multiple scales, and some of the recent magnifiers proposed in the literature were applied to multi-scale maps [1, 43, 63, 64, 78, 102]. However, these techniques cannot replace fluid zooming; they are complementary and are even more effective when associated with fluid zooming.

As mentioned in the introduction, designing better interactions is only a part of the solution to reduce disorientation, and we believe that it cannot be the only solution because the disorientation is caused by the differences in the maps at different scales. To find a good solution to the desert fog effect, it is necessary to change the design of the map, which is discussed in the following section.

Figure 3: illustration of the Trail Map technique [101]: the past zooms are bookmarked below the map view, with a visual cue showing where the bookmarks are in the map, using a color variable.

2.4 Continuous map generalization

Continuous map generalization has reached the stage of practical applications in recent years, and it can be a different way to reduce the desert fog while zooming. With continuous transformations that can be smoothly shown during the zoom, a so-called smooth zooming can be achieved [94]. As generalization usually involves geometry transformation and simplification, morphing techniques were adapted from computational geometry to add continuity between a detailed and a simplified geometry [44, 57]. There were also propositions of data structures to store continuous transformations of geometries, and then retrieve the best geometries for a given scale value [95]. In addition, there were also propositions of continuous generalization for multi-scale magnifiers [93], rather than for smooth zooming.

But often, abstraction changes in a map are complex to model as a continuous transformation: for instance, the buildings are represented as individual polygons at large scales but are represented as solely built-up areas at smaller scales, and the continuous transformation between a set of polygons into their global footprint is not always understandable [60]. As a consequence, continuous generalization can also cause discrepancies in the abstraction changes and cannot completely solve the desert fog effects when zooming. This is why we propose an alternative to continuous generalization that we call *progressive generalization*, where a small number of additional intermediate scales are added,and the level of abstraction changes more progressively in these intermediate scales. This alternative is presented in Section 3, but first, in the following section, we review some methods to evaluate the usability or the effectiveness of an interactive multi-scale map with a user study.

2.5 Evaluating the usability of an interactive multi-scale map

Usually, maps processed automatically or semi-automatically with map generalization are evaluated either by experts with a visual inspection or by quality measures computed on the map [50, 77]. When the user is introduced in the evaluation loop, it is only to rate the map as good or bad [76]. But now that map generalization is used to populate multi-scale interactive maps, user studies become mandatory to evaluate their usability [29]. However, in other domains of cartography, it is quite usual to assess the usability of a map design with a user survey [54, 68], and there are plenty of examples to inspire from.

Researchers interested in interactions with multi-scale maps or other multi-scale visualizations propose many protocols to assess the usability of these interactions [9]. As these studies focus on the evaluation of the interactions and not the map, they often tend to use an abstract visualization to remove the additional challenges introduced by using a complex map [63]. We see also many cases where the study uses existing maps as a background (e.g. [37]), which is not adapted to the evaluation of different custom map designs.

One of the most complex challenges for user studies with maps is the choice of the user task [71], because a map can serve very different purposes [67]. In our case, we are interested in tasks that involve a deep or long exploration of the map, in order to cause a desert fog effect. There are interesting examples in the literature, such as memorizing tasks [5,11,98]. Studies assessing the usability of multi-scale interactions are also interesting for the choice of the task because they also seek to a multi-scale exploration of the map during the task [35,48,52,74]. Regarding task performance, completion time and error rate, frequently used in human-computer interaction studies, can also be used as a proxy to map usability [40].

Finally, eye-tracking techniques are now frequently used to evaluate a map, as complementary information to other evaluation procedures [7, 22, 59].

3 Intermediate scales to enhance map exploration

3.1 Intermediate progressive scales to enhance interactive multi-scale maps

The comparison of a large number of existing multi-scale maps [15] shows that they mainly follow two of the basic zoom mechanisms defined for multi-scale exploration [4]:

- a fixed number of zoom levels (between 10 and 21), following the WMTS standard [1] defined by the Open Geospatial Consortium;
- a continuous zoom between these zoom levels but a fixed number of maps that change when the user reaches a new zoom level. Between two scales, the map view is a simple enlargement of the map from the smallest of the two zoom levels (Figure 4).

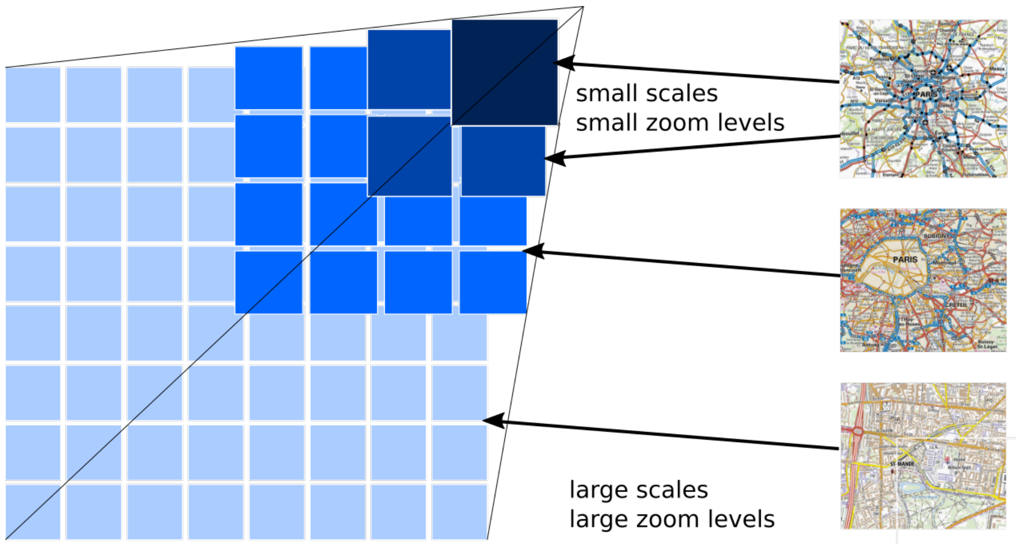

Figure 4: Basic principles of the architecture of multi-scale maps: a quad-tree is defined with zoom levels between 0 and 20, and maps are visualised at one or several of these zoom levels.

The comparison of these existing multi-scale maps also shows that the transformations across the scales are not progressive [15]. There are either too few maps, with the same map repeated at multiple zoom levels (this is the case with National Mapping Agencies that recycle paper maps online); or there is a lack of progressiveness in the level of detail of the maps despite a large number of different maps at the different zoom levels. This is the case, for instance, with Google Maps or with OpenStreetMap where the individual building polygons suddenly disappear at one scale to be replaced by built-up area polygons.

In the following sub-section, we propose several techniques to design more progressive multi-scale maps, but we need a default multi-scale map to compare the new techniques to. This default map, which we call INITIAL derives from one of the multi-scale maps made available by IGN, the French National Mapping Agency, on its geoportal[2]. We used a simplified version of this map, i.e. with less content, to better control differences between INITIAL and the other techniques (Figure 5):

- first, we limit ourselves to the scale interval between 1:25k and 1:100k scales;
- as we are not interested yet in the influence of text in the map, the text is reduced to a minimum, with only the main towns labelled;

[1] https://www.ogc.org/standards/wmts
[2] https://www.geoportail.gouv.fr

- only the main topographic themes are kept (buildings, roads, hydrography, vegetation, railways); these are the themes on which we will introduce more progressive transformations.

The INITIAL map contains only three maps between 1:25k and 1:100k scales, corresponding to the interval 13-16 for zoom levels. The other techniques presented in the next section contain additional intermediate maps, with 5 maps between the same scales, i.e. two additional maps compared to the INITIAL map, which is even more than the number of zoom levels in the scale interval.

3.2 Four strategies to enhance multi-scale maps

We designed four alternative maps using different automated map generalization techniques, adapted to achieve progressive multiple scales while the algorithms were initially designed for a single scale generalization (Figure 5).

All the maps at zoom levels 1, 2, and 3 were generalised using the CartAGen open source platform [88]. The transformations caused by the four techniques and their differences are described in the following sub-sections.

3.2.1 Common progressive generalisations

The four techniques compared in this project only differ from each other in the way buildings are represented across scales, but the other themes rendered in the map are also progressively generalised, but in the same way in each technique. First, roads are generalised by selecting the important roads and removing the ones that are not significant and do not alter the connectivity of the network. A selection algorithm [80], designed for the generalization of roads at one scale, was adapted to select consistent and progressive networks at several multiple scales (a road removed at level 1 cannot be on the map at level 2). The automated result was manually edited to correct some remaining errors after generalisation (Figure 6).

Rivers are also represented in the map as a linear network, so the generalization process is similar with the rivers of lesser importance being removed progressively at levels 1, 2 and 3 [79]. The importance of rivers is computed using the Horton order defined in hydrology [34], which depends on the order of the tributary streams of the river.

Regarding vegetation, we want to progressively delete the small and thin patches of vegetation polygons, so we use an algorithm based on erosion and dilation operations [84]. The railway network does not require any generalization in this scale range because it is only composed of two independent and important lines that should appear at each scale. Symbol overlaps between the network lines were manually processed by displacing the roads and rivers where the symbology overlapped.

3.2.2 AGENT-based progressive generalisation

The first technique to progressively generalise buildings, AGENTS, can be seen as the gold standard of automated urban generalisation. It is currently used in several national mapping agencies to automate the production of topographic paper maps [12]. The AGENTS technique is based on the AGENT model, i.e. a multi-agent system where the buildings are agents that seek to generalise themselves by applying simplification algorithms [2,70].

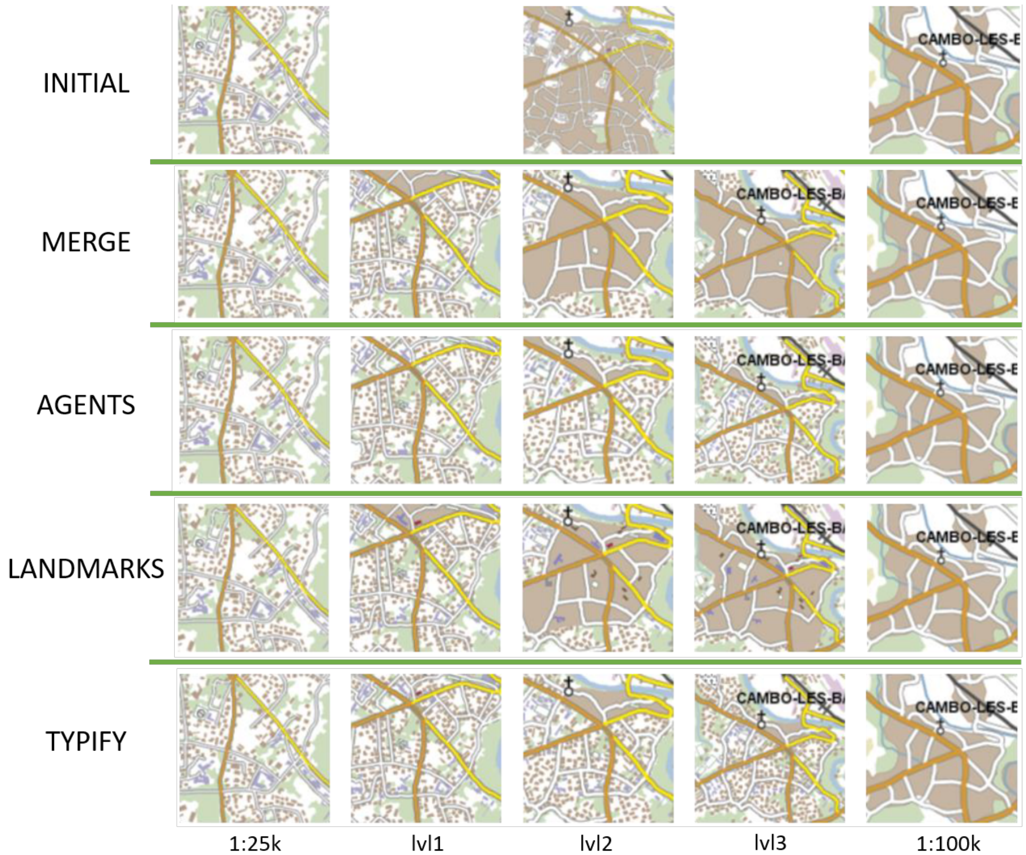

Figure 5: Different strategies to add intermediate scales with map generalization. INITIAL is the default map with only one representation between 1:25k and 1:100k scales. MERGE is a minimalist strategy where buildings are merged into a built-up area as soon as possible [85]. AGENTS makes a progressive use of classical agent-based techniques [70, 83]. LANDMARKS is an improved version of MERGE that preserves important landmark buildings. TYPIFY simplifies buildings while preserving important structures such as alignments [6].

The agents satisfaction is controlled by constraints on their size, their granularity, or on the density of buildings in a block [69]. In urban areas, hierarchical agents are used with city agents composed of block agents, composed of building agents. In rural areas, the AGENTS technique uses the CartACom model [13] where agents discuss with their neighbours to find the best displacement operation. Compared to past uses of the agent-based generalization techniques, we tweaked the parameters to derive progressive intermediate scales. Additionally, it was never used at scales as small as level 3 where the buildings are greatly enlarged, so we adjusted the algorithms used by the model to eliminate some more buildings in dense areas. Some results are presented in Figure 7.

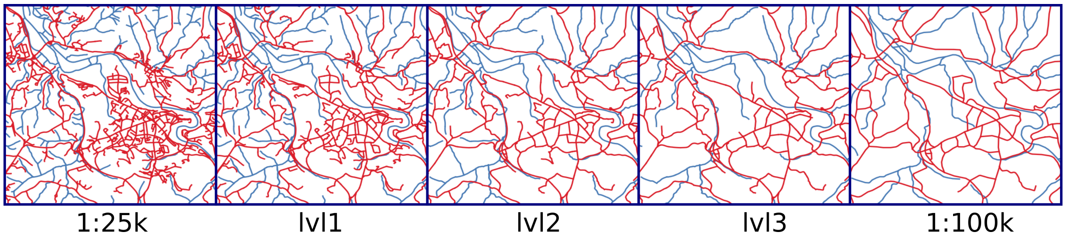

Figure 6: Progressive generalisation of road (in red) and river (in blue) networks.

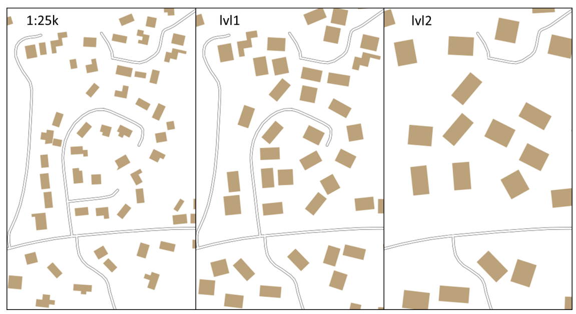

Figure 7: Progressive generalisation of buildings using the AGENTS technique at levels 1 and 2.

3.2.3 Progressive typification of buildings

The AGENTS technique gives a good simplified view of the map but was not designed for progressive transformations in a multi-scale map, and the building patterns might be altered at some scales when buildings are eliminated and displaced. As we believe that these building patterns might help the map user during a zoom, we tested a different technique for building generalisation, namely TYPIFY. This technique is adapted from the mesh simplification algorithm [6], with complementary ideas taken from another building typification [73]. Figure 8 shows the basic principle of this technique: a Delaunay triangulation is computed between the centers of the building polygons. Then, iteratively, two nodes of the triangulation are replaced by a single one if the edge connecting these two nodes is the smallest in the triangulation. The length of the edges is weighted by the similarity and the size of the buildings because building patterns are usually made of small buildings with similar regular shapes.

Then, the remaining buildings are enlarged and simplified in a similar way as the AGENTS technique. To obtain progressive scales, we change progressively how many nodes of the triangulation are eliminated. Figure 9 shows some results obtained with TYPIFY at the $lvl1$ scale. This technique does preserve building patterns (grids, alignments) more than AGENTS while still providing legible generalised views of cities and suburban areas. If these patterns are visually salient for the map reader, it can be important to preserve them in the intermediate scales.

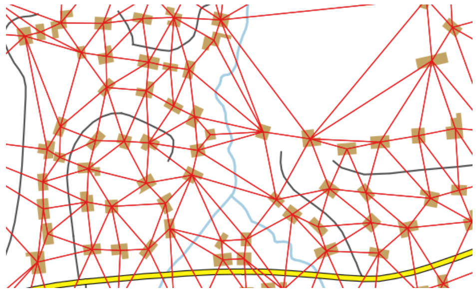

Figure 8: Principles of the TYPIFY technique: a Delaunay triangulation of the centers of the buildings is computed (the edges are displayed in red on the map), and then an iterative pruning of the graph is achieved by replacing two nodes connected by a small edge, by a single node.

Figure 9: Output of the TYPIFY technique at the $lvl1$ scale. The green ellipses show building alignments where one or two original buildings (image on the left) are removed while preserving the general pattern.

3.2.4 Progressive merging of buildings

As cartographers influenced by the history of topographic maps, we tend to display individual buildings at the level 1, 2, and 3 scales with the AGENTS and TYPIFY techniques. But the affordance of multi-scale maps is completely different than the affordance of a paper map at a single scale, so we wanted to try a technique that makes simpler maps, with built-up area polygons instead of individual buildings where building density is high. The MERGE uses a multi-criteria decision technique [81] to decide which blocks should be converted into built-up areas, according to building density, the proximity to town center, or the shape of the buildings in the blocks. The buildings that are not inside a merged block are generalised with the AGENTS technique. The visual complexity [85] of the maps produced by MERGE is much smaller than for AGENTS and TYPIFY, but you can still zoom in to see the individual buildings in the dense areas.

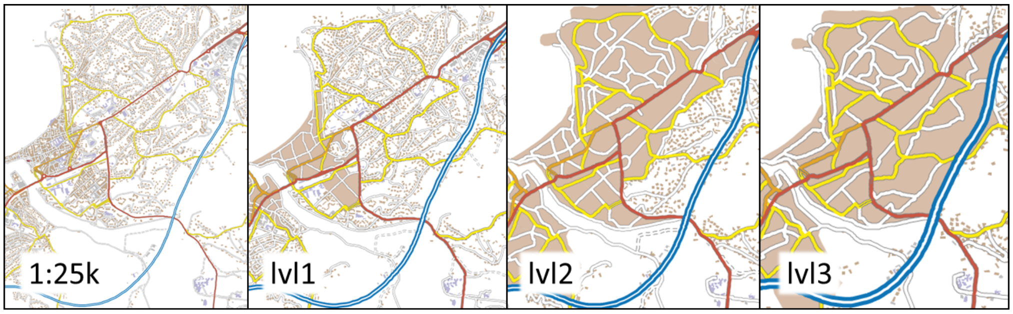

Figure 10: The three levels of the maps generalised with MERGE.

3.2.5 Merging buildings with landmark enhancement

The last technique, LANDMARKS, is a variation of the MERGE technique (Figure 11). It is based on the hypothesis that buildings in the map can be used as landmarks [75] during the multi-scale exploration of the map. Landmark buildings are selected automatically with a machine learning classifier [16, 85], and then manually refined because the automatic process tends to classify too many buildings as landmarks. Landmark buildings are displayed on top of the built-up areas. A different color is used for the building symbol depending on the nature of the building. Though more visually complex than MERGE, LANDMARKS remains less complex than AGENTS and TYPIFY.

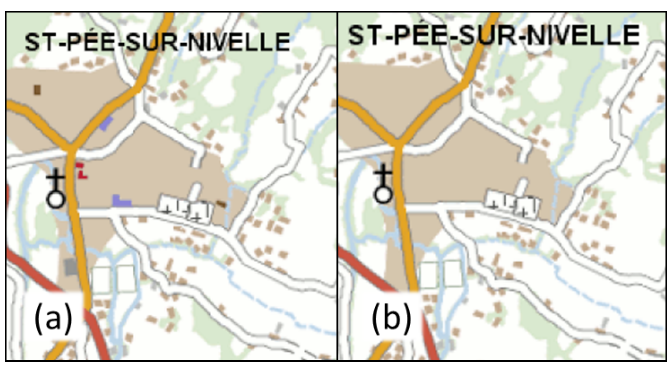

Figure 11: (a) Extract of the map generalised with LANDMARKS. (b) Same extract, generalised with MERGE.

4 User experiment

The goal of the user study presented in this section is to verify the validity of the hypotheses discussed in the previous section about the abilities of progressive map generalisation techniques to reduce the desert fog effect during the exploration of a multi-scale map.

4.1 Hypotheses

Our first and main hypothesis (*H1*) is that adding progressive maps improves zooming fluidity and reduces disorientation periods. So the four alternative techniques contain five maps instead of three for INITIAL. The other novelty of these techniques compared to the common generalization techniques used in practice [12], is the progressiveness of the scales. Generalization is achieved knowing that there are five levels to attenuate the transformations and seeking for continuity and consistency for two consecutive scales.

Another hypothesis is related to the use in existing maps of much simpler generalisation techniques such as MERGE and LANDMARKS. We make the hypothesis that this over-simplification is penalizing for some multi-scale tasks compared to classical generalisation approaches (TYPIFY and AGENTS) (*H2*).

Then, a third hypothesis (*H3*) emerged from analogies with other problems in spatial cognition, such as wayfinding: salient landmarks can help the user link maps and the location of their current view in the map. We think that the LANDMARKS technique will better perform than the MERGE technique (*H3*), because it introduces anchors [10, 87] for the map user without adding much visual complexity in the map.

A final hypothesis (*H4*) comes from the comparison of existing multi-scale maps: the preservation of specific building structures, such as alignments can improve how space is remembered by the users. The TYPIFY technique tests this hypothesis by generalizing buildings with a typification algorithm that better preserves than AGENTS the building alignments [6].

4.2 Participants and apparatus

The disorientation caused by the desert fog is not just a problem of orientation and map reading skills, even trained professional experts can be disorientated when they zoom in and out such maps [46, 61]. This is why we decided to select a convenience sampling of users with 16 postgraduate students in geographical information science. In fact, such students can be considered as a purposeful sampling of users [26], i.e. a convenience sampling that is qualified, in order to extract characteristics (e.g., map literacy or sense of direction), that correspond to the most skilled users. To assess if our convenience users are purposeful users, a questionnaire was proposed, derived from the Santa Barbara Sense of Direction test (SBSOD) [32]. The questionnaire contains 15 assumptions such as *I am very good at giving directions*, or *I very easily get lost in a new city*, and participants are asked if they agree or disagree with these assumptions on a 7-level Likert scale.

The results of the SBSOD for our users are compared to a benchmark sample from [31], which has a similar distribution of ages (between 17 and 22). The results of this comparison, presented in Table 1, show that our experiment sample has a higher sense of direction, which correlates with good map reading capacities [31].

The experiment was designed and carried out with ZVTM. ZVTM is a zoomable user interface toolkit implemented in Java, designed to visualise complex graphs or maps at multiple scales [62]. Contrary to classical multi-scale map APIs such as OpenLayers[3] or Leaflet[4] that were limited to the zoom levels of the WMTS standard[5] at the time of the

[3]https://openlayers.org/
[4]https://leafletjs.com/
[5]https://www.ogc.org/standards/wmts

Statistics	Experiment sample	Benchmark sample
Mean	4.5	3.9
Standard deviation	0.85	1.0
Minimum	3.5	1.6
Maximum	6.3	6.0

Table 1: Comparison of the scores of SBSOD between our experiment sample and a benchmark sample from [31].

experiment, ZVTM allows the visualisation of different maps between zoom levels, so it is possible to display all the intermediate scales of our alternative multi-scale maps (MERGE, AGENTS, LANDMARKS, and TYPIFY).

4.3 Procedure

Among the five objective primitives of map interactions identified by Roth [67], *associate* and *delineate* are considered as the most cognitively complex. *Associate* describes tasks where a user tries to characterise the relationship between several map features. *Delineate* describes the tasks where the user organizes map features in a logical structure. At the same time, they often involve the use of multiple scales, and they are tasks where loss of orientation significantly impacts task completion. This is why we chose a task that requires associations and delineations. The task designed in the survey is to follow a route by clicking on the road intersections of the route (Figure 12), and is inspired by [35,74]. To force multiple zooming interactions, the route is made visible at the small scales (around 1:100k), but the task can only be performed by clicking on the intersections at the largest scale (1:25k), as proposed in the route memorizing task by You et al. [98]. The intermediate scales are supposed to be used to get broader views of the memorized route. The user has to click on the first intersection highlighted by a symbol that the route encounters and this part of the route is drawn on the map. When the user clicks on the last intersection of the route, the task is complete. Each time the user clicks on an intersection that is not the next one on the route, an error is reported to the user, and the number of committed errors increments. Detailed written instructions explained both the goal of such a task and how it should be properly performed. Then, the instructor demonstrated the task on one trial.

We designed a Within-subject procedure, where each participant performs this task several times on each of the 5 different multi-scale maps (INITIAL, MERGE, AGENTS, LANDMARKS, and TYPIFY). 20 routes were designed in a 15*30 km area in the southwest of France, with as much as possible a similar length, and number of turns. 5 of the routes were used for a training step, and the 15 remaining routes were used in the 15 trials of each participant. Each of the five maps was tested three times by each participant, and a different route was used for each trial ($3 \times 5 = 15$). To counterbalance the inevitable learning effect and the variable complexity of the routes, we used a Latin Square to compute the order of the trials for each participant.

Task performance is assessed by measuring completion time and precision, i.e., the number of points not part of the route the participant clicked on. Time and precision are usual performance measures in geovisualization user surveys [40]. As disorientation might slow the user down after each zoom, disoriented users should take more time to perform the task. Disorientation is not only about being slowed down in a task, it is also an unpleas-

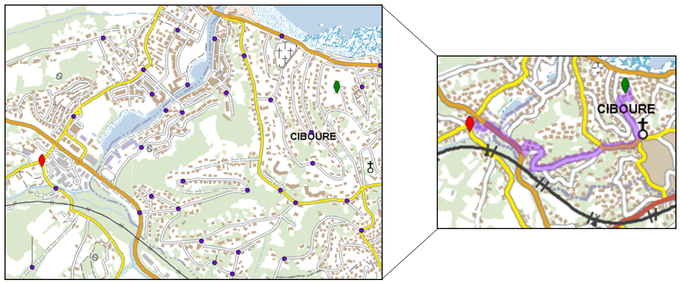

Figure 12: Principles of the task in the user experiment: the user has to click on the points that are crossed by a given route at large scale (1:25k, image on the left), in the correct order, but the route can only be made visible when the user has zoomed out between level3 and 1:100k scale (image on the right).

ant feeling that users may experience without being significantly slowed down. When a user is cartographically disoriented, they tend to zoom out to reconcile the map view with landmarks they recognise and/or remember. This is why the quantity of zoom, and the number of times the route has been watched were also recorded for each trial, as they may relate to a poor experience with the map or saturations of the working memory.

After the completion of the 15 tasks, each participant is given a questionnaire with 10 questions about their experience with the survey, with a Likert scale, and 2 additional qualitative questions with a text box to answer. For instance, we asked them if they often felt disoriented after a zoom interaction. Finally, to better understand how participants would solve the task, we used think-aloud with some participants [39]. However, as thinking aloud might affect the performance of the participants [58], we did not record their task results, we only collected their think-aloud feedback.

4.4 Results

The results of the survey are presented in Figures 13 to 14. The results are accessible on Zenodo[6]. The first hypothesis we wanted to verify (*H1*) was that introducing progressive intermediate scales would improve zooming fluidity. For our route-following task, this improved zooming fluidity should be translated by a quicker completion time and a reduced amount of zooming. The results do agree with (*H1*), with a completion time higher for the trials with INITIAL map. The mean completion time with INITIAL map is 85.5 seconds, while the mean completion times for the four other maps vary from 82.7 seconds to 84.8 seconds. The difference remains pretty thin, and we computed a two-way ANOVA test on a logarithmic transformation of the distribution, to obscure the extreme values, which are more due to one route being very complex, or to some participants getting frustrated with one trial. The test shows that this difference in completion time is not statistically significant ($\chi^2 = 1.80$, $p = 0.77$). Regarding the quantity of zooming interactions per trial, the results are similar with all four proposed progressive maps, with a mean of 5 zooming interactions per trial, but the mean is higher with INITIAL map (6 zooming interactions per trial), which also supports (*H1*). However, this difference does not appear as statistically

[6]https://doi.org/10.5281/zenodo.8385969

significant, as our two-way ANOVA test was inconclusive ($p = 0.09$). Finally, the number of times the participants watched the route per trial also supports (*H1*), with a median number of 9 for the INITIAL map, and a median value of 7 for the other four maps.

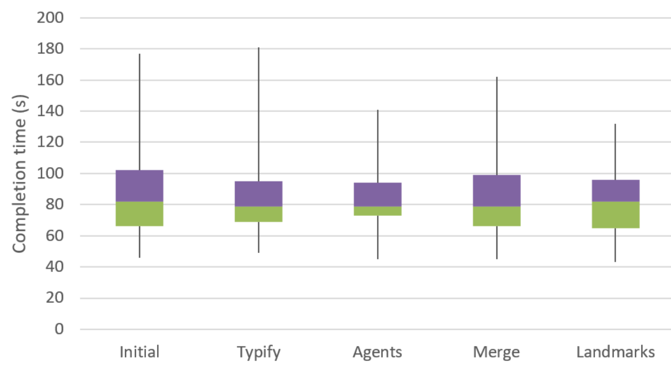

Figure 13: Box plot of the completion time results. The INITIAL multi-scale map has slightly longer completion times than the other maps (2 seconds for the median completion time).

Similarly to (*H1*), two-way ANOVA tests show no significant difference in time completion between AGENTS and the other proposed maps. There is also no significant difference in zoom quantity. As a consequence, so we cannot validate (*H2*), (*H3*), and (*H4*). However, some observations can be derived from the results for these three hypotheses.

First, there is evidence in favour of (*H2*) as time completion and zoom quantity are both better with AGENTS than with MERGE. So the details provided by AGENTS or TYPIFY at the intermediate scales seem to provide the progressive transition required for a fluid zoom. This tendency is confirmed when comparing AGENTS to LANDMARKS for completion time and zoom quantity.

Then, the comparison of results with MERGE and LANDMARKS provides evidence in favour to (*H3*). Users performed their task slightly quicker, and using fewer zooming interactions with the LANDMARKS multi-scale map, showing the importance of these landmarks to locate and remember the route across scales.

Finally, the evidence in favour to (*H4*) is very thin. The users perform the task with nearly the same completion time with AGENTS or TYPIFY, but they use a little more zooming interactions with AGENTS. Further experiments are clearly necessary to assess the importance of preserving spatial patterns such as building alignments when optimising zooming fluidity.

The results on the number of errors during a trial are presented in Figure 16. Unfortunately, this number of errors does not give any information on our four hypotheses, as there seems to be no relation between the multi-scale map used and the number of errors. The number of errors seems more related to the complexity of the route to follow with a significant increase for the urban complex routes (see the following section for more details). Moreover, the observation of the participants showed the importance of their behavior: some adopted a more careful behavior and made very few errors, verifying that each click of route intersection was correct, while others adopted a more risky behavior, making quicker runs of the trials, but also making many more errors.

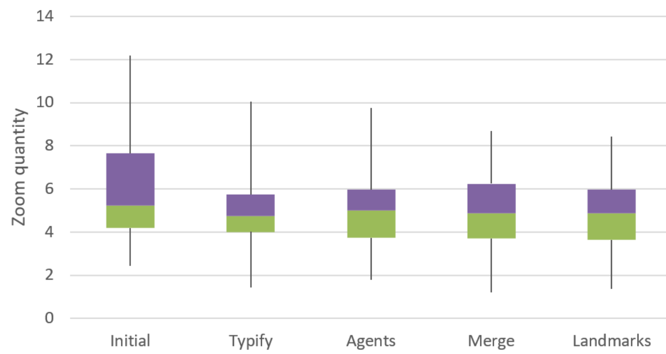

Figure 14: Box plot of the results for zoom quantity. The participants zoomed more with the INITIAL multi-scale map.

Figure 15: Box plot of the results for the number of times the route was watched in a trial. The participants watched the route more often with the INITIAL multi-scale map.

Finally, we analysed the answers of the participants to the qualitative questionnaire. First, there are very different perceptions of the complexity of the task: some participants found it very difficult, while others found it very easy. However, most of them admitted that some routes were more complex than others. This result aligns with observations on cartographic disorientation, as some users are more prone to disorientation than others [86]. Then, when asked about the strategy they used to solve the task, the majority of participants declared they changed it during the survey, but this answer is not really consistent with the data. Still regarding their strategy, 14 out of 15 participants used landmarks to perform the task, which confirms that a good multi-scale generalisation should preserve or even enhance the potential landmarks in the map. However, only one participant mentioned the buildings and built-up areas among the landmarks they used consciously during the task. The fifteen participants declared that they memorised portions of the route to perform the task, which confirms the importance of short-term and working memory in map-related tasks: as the task is demanding for memory, exploration should not overload it. Only one participant perceived a difference between the five techniques,

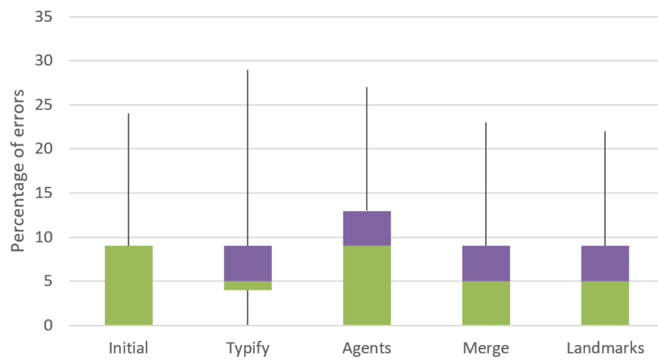

Figure 16: Box plot of the results for the percentage of errors. There is no clear relation between the type of multi-scale map and the percentage of errors.

which confirms a form of inattentional blindness when exploring multi-scale maps, and in this task, changing the building generalisation is a detail hidden by the focus of users on other themes of the map. Though they did not perceive the difference between techniques, almost half of the participants assumed that the map changed after each zoom, which is not true for small zooming interactions. Finally, many participants had no consciousness of the proximity of all routes, they thought all routes were located in different regions. This last result shows that the task did not require the creation of a small-scale mental representation of the region.

5 Discussion

In this section, we first discuss our results, trying to explain why they are not statistically conclusive. Then, we discuss lessons learned for future experiments on multi-scale map design.

5.1 What did go wrong?

Even if our results presented in the previous section give precious insights on our four hypotheses, we were expecting more pronounced differences between the five multi-scale maps, or at least between some of them. There are different reasons for this lack of conclusive evidence from the survey.

First, there was an obvious task complexity variability, with routes that were simple to follow, and others that appeared to be more complex to follow, despite our care to select similar routes. Figure 17 shows the completion times of all users for each route. A two-way ANOVA confirmed a strong correlation between completion time and the route chosen for the trial ($F(14, 195) = 9.25$, $p < 0.05$). A post-hoc Tukey test confirmed that routes 6, 7, 8, 10, 11, 12, 13, 18 influence completion time ($p < 0.05$), and so these routes are more complex than the others for the task. Figure 18 shows route 10 on top and route 5 at the bottom. If we consider the assumption by Golledge that routes are more complex when there are more turns, and more decisions to make to change directions [25], the simple route from Figure 18 appears to be a very rural one, with quite a few decisions to make at each crossroads. On the contrary, the complex route 10 is completely inside an urban area, with more possible turns, and the map is also more visually dense and complex. We measured the number of intersections crossed by each route, and the number of turns, and both indicators are significantly higher or lower for the 8 routes listed above. This difference in complexity between urban and rural routes was finally confirmed in the questionnaire filled out by the participants at the end of the survey, with only one participant stating that all routes had a similar complexity. It was also confirmed by the think-aloud participants. Given the difficulty of creating enough routes with similar complexity, we could have tested separately the trials with simple, medium, and complex routes, but we did not have enough trials with enough participants to run the test with different categories of routes. But whatever the presented route, it was a difficult task according to the qualitative questionnaire, and we observed a learning curve for all participants, as they were quicker in the late trials compared to the early trials.

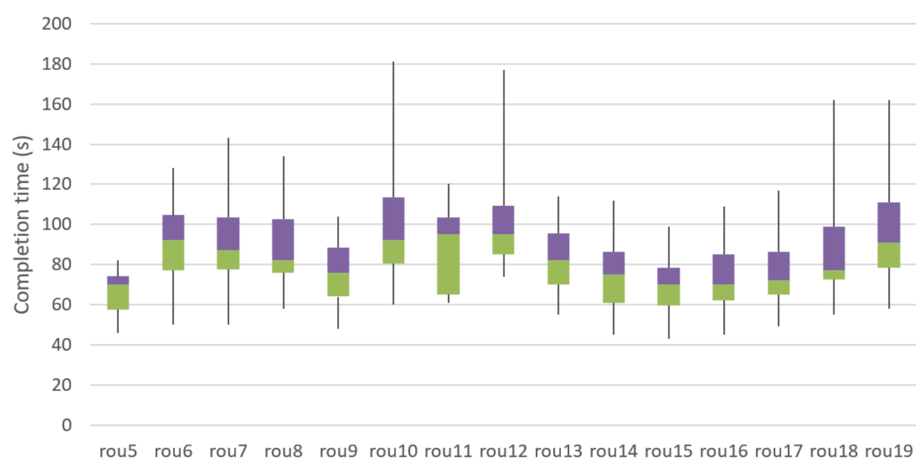

Figure 17: Completion times of all users for each route. The completion time distribution can be very different from one route to another.

Another reason why there were no statistically significant differences between the four proposed techniques, is that the task did not really require the use of buildings to memorize the route. Buildings are generally major landmarks in wayfinding [24, 49, 75], and our intuition was that they would play a similar main role in this route following task. In fact, interviews with some participants after the survey, as well as the think-aloud sessions, showed that buildings were rarely used to keep track of the route. The users mainly used the roads themselves, with their varying colors and symbol widths, as well as map themes such as rivers or forests. Only the representation of buildings changes in the proposed techniques, as AGENTS, TYPIFY, MERGE, and LANDMARKS have the exact same multi-scale representations of roads, rivers, and forests. As INITIAL is the only map with differences on these themes (they are transformed less progressively), it can explain why the only significant difference is measured on the INITIAL map compared to the other ones. Unfortunately, the pre-studies carried out did not highlight this issue because the participants of the pre-studies assured that they used the buildings as landmarks.

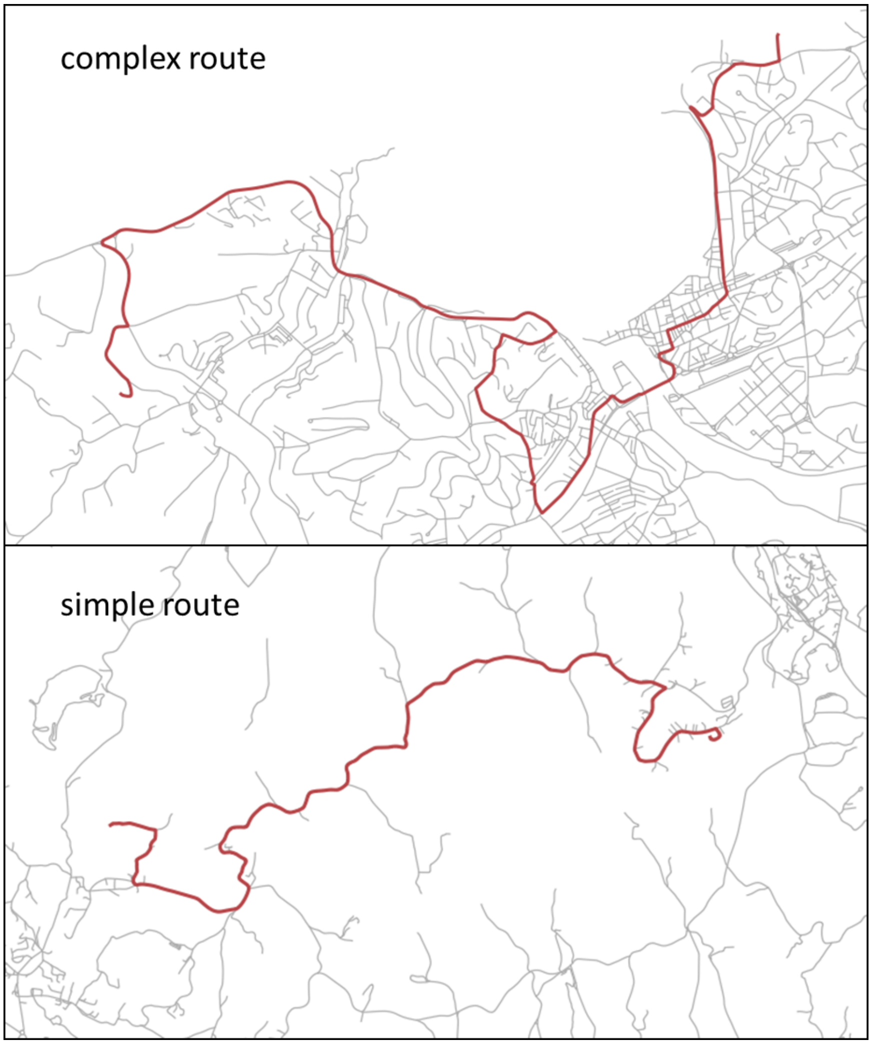

Figure 18: Two routes used as instances of the task with very different complexities: a complex one with many complex turns in a dense area on the top and a simpler, straighter route in a rural area at the bottom.

Furthermore, the analysis of the zoom quantity among our participants shows important differences, with users that zoomed many times whatever the maps, and others that zoomed only a few times. If the participants did not zoom so much, there was no reason to perform better with one of the proposed maps or the others. We identified two reasons to explain this difference between participants. First, the double objective of the task, i.e. following the route as quickly as possible and without any mistake, was interpreted differently by the participants despite our guidelines during the training phase: some were careful and tried to perform the task without any error, and so zoomed a lot to check that the route was correct; others focused more on time completion at the risk of making many mistakes. This problem was caught during the pre-studies, so stricter and clearer instructions were used during the study, but a few of the participants just did not follow the instructions. The second reason is that some users adopted a strategy based on memorizing for once the route, spending time visualizing the global route at the smallest scale, rather than frequently zooming out to visualize it once more. As a consequence, these users did not zoom a lot.

Finally, we make the hypothesis that larger changes in scale during the task would result in a greater variation in the completion time. A recent study shows that disorientation occurs more frequently when users make big zooms in [82]. In this study, we limited the scale gap due to the time cost of generalising the map at additional scales.

5.2 Lessons learned for future experiments

It is not new that user studies on interactive maps are very complex to design [68]. For instance, given the freedom of exploration given by multi-scale interactive maps, a strict purposeful sampling is necessary [68] while the sampling of participants we used appeared closer to a convenience sampling. Some of our participants appeared to be more motivated by the time performance and did not zoom enough to compare the proposed maps. Considering the sample of participants, the guidelines have to be extremely clear to make sure they interact with the map the way they should, and even so, the multi-scale map-reading strategy might be stronger than the instructions. We think that experimental research that studies these multi-scale map-reading strategies would be helpful for further research on the impact of map generalisation.

The same authors also claim that the high-level tasks on interactive maps are often ill-defined, and there is no clear relation between a high-level task such as 'map exploration', or 'associate' and 'delineate', and low-level tasks such as 'pan' and 'zoom' [68]. Our study supports their claim, as the participants did not always zoom in and out as much as intended when we designed the route following a high-level task. To avoid this gap between high-level tasks that are closer to the use of interactive maps, and the low-level tasks that we are interested in, it might be useful to define, and share some standard multi-scale exploration tasks, as recently claimed by researchers in geovisualization [71].

Furthermore, the comparison between multi-scale maps that do not contain the same amount of intermediate scales is complex because they are not *informationally equivalent* [41]. The problem is similar when comparing an interactive map with a static map [18]. In such cases, inference affordance [18] seems to be a better way to assess which interactive visualisation is the best, as it integrates the quality of the content and the quality of inferences made with this content. In other words, measuring task performance with quantitative measures such as completion time or errors is not enough to compare these different interactive visualizations, even though the difference seems pretty small. Eye-tracking techniques seem to be a good solution, coupled with a procedure similar to the one presented here, to better measure the inference affordance of the multi-scale maps [18, 59].

Finally, in this research, we only focused on improving map design, but we believe that the reduction of disorientation also requires better multi-scale interactions, or even better, a joint design of maps and interactions. Among the many tools to improve the interactions, we believe that animations [28, 92] could be used jointly with the additional intermediate scales to provide smoother transitions between distant scales.

6 Conclusion

In conclusion, the experiment presented in this paper tends to show that progressive map generalisation positively influences multi-scale map exploration. In particular, participants zoom in and out less often when they use a map with progressive generalisation at intermediate scales. However, this experiment also shows the complexity of multi-scale map exploration, and how difficult it is to control user surveys with real maps and realistic tasks.

The research presented in this paper is the starting point of new experimental research on the design of interactive multi-scale maps. Our first idea is to revisit the hypotheses presented in this paper with new experiments that take into account the flaws of the presented experiment, in particular the fact that our main variable in the techniques, i.e. the way buildings are generalised, did not really influence the route memorising task. We also need to design tasks where multiple zooms are really essential to complete the task. As mentioned in the discussion, another challenge is the difference of affordance from multi-scale maps with a different number of scales. It would be better to use some kind of inference affordance [18] rather than measuring completion time for instance. We also believe that this experiment shows that the desert fog effect occurring with multi-scale maps is not studied enough. We plan to design an experiment to measure the desert fog caused by zooming in on different kinds of multi-scale maps. We also want to focus more on the importance of landmarks in multi-scale map exploration. Research on spatial cognition shows that our mental representation of space is anchored by landmarks [10], and we aim at the design of a novel zooming technique, anchored by multi-scale landmarks [87].

Finally, disorientation also occurs when a user navigates into a 3D visualisation [30]. Zooming in 3D visualisations also causes a loss of visual cues, but adds further complications. There are propositions to improve the exploration of 3D geovisualisations [33, 90], and it would be interesting to assess the role of generalisation and abstraction changes in 3D navigation.

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