Challenges raised by the implementation of topographic, anamorphic and shrivelled cartographic models as supports to human route selection tasks

1st Alain L'Hostis
Univ Gustave Eiffel, Ecole des Ponts
LVMT
F-77454 Marne-la-Vallée, France
alain.lhostis@univ-eiffel.fr ORCID:0000-0002-2334-4127

2nd Valérie Gyselinck
LaPEA
Université Paris Cité, Université Gustave Eiffel
Versailles, France
valerie.gyselinck@univ-eiffel.fr ORCID:0000-0001-9715-6148

3rd Simon Lhuillier
LaPEA
Université Paris Cité, Université Gustave Eiffel
Versailles, France
simon.lhuillier@univ-eiffel.fr ORCID:0000-0002-5002-1745

***Abstract*—In order to compare their readability for a route selection task to be performed by human participants, a visual material made of three different map models was created. This paper presents the constraints and choices to be made for the generation of a graphical material that can meet this aim. The same geographical theoretical space was considered. It was composed of six nodes representing significant places of the geographical area and two types of networks connecting them: a fast transport network at 100 kph, and a slower one at 50 kph. We produced a conventional topographic map, an anamorphic, plastic space cartography, and we generated a shrivelled, three-dimensional, geographical time-space representation. In particular, we examined the case of space inversion, i.e. situations where the duration optimised trip contains a section completed in the opposite direction to the destination. Expert analysis by the authors suggests that in this case, the shrivelled map outperforms the topographic or anamorphic map for the routing task.**

***Index Terms*—Cartography; Anamorphosis; Shriveled map; Route selection task**

I. Introduction

The geographical time space designates the geographical extent where movement occurs. Representing it graphically is a theoretical and technical challenge; another challenge is to ensure this graphical representation is legible and understandable for the non-expert user.

Geographical time-space possesses several key properties exposed in [1, 2], that culminate in the notion of *space inversion* (3, p. 106; 4, p. 162). When different speeds are allowed by the coexistence of a fast infrastructure over a space covered by regular, slow transport network, space inversion refers to the need to move in the opposite direction to the destination to reach the entry point of the fast transport infrastructure, such as an expressway entrance. In that respect, conventional and plastic space cartographic representations cannot take into account the space inversion [5], whereas shrivelled maps can make it intelligible to the reader. We expose here the challenges of generating a graphical material suitable to compare these three different cartographical modalities of representing the geographical time space.

II. Three cartographic models for the representation of geographical time-space

The first model refers to the usual, conventional, geographical map, and we name it the topographic model. In the topographic map model, we have a kilometre scale that allows to convert visual lengths into spatial distances. The models also allows representing transport networks and graphics semiology [6] permits to use visual variables to indicate a level of quality, in our case the speed, in the network. We chose to use colour as the visual variable, inspired by the colour code used in conventional road maps.[1]

The second model refers to the anamorphic cartography, where locations are moved on the plane of the map to account for travel times. The *plastic space* maps [7] were developed from early works by Tobler [8] during the 1980' [9, 10]. In order to apply the geometric transformation of the positions of places we used the software 'Darcy' [11], a Java port of Tobler's code, named in reference to seminal works by Thompson [12]. In 'Darcy', we used the unipolar algorithm, and deformed the external boundary following the displacement of places. This algorithm simply moves places according to time-distance from a given centre.

The third map model refers to the three-dimensional shriveling model imagined by Mathis [13], implemented by L'Hostis [14, 15], and improved by L'Hostis and Abdou [1]. This model

[1]We use red for main roads and expressways, and yellow for secondary roads, as in ViaMichelin maps. Another mainstream routing service, Google maps, recently modified its graphics semiology from colours to variable width to hierarchise the network; we may test this solution in the future.

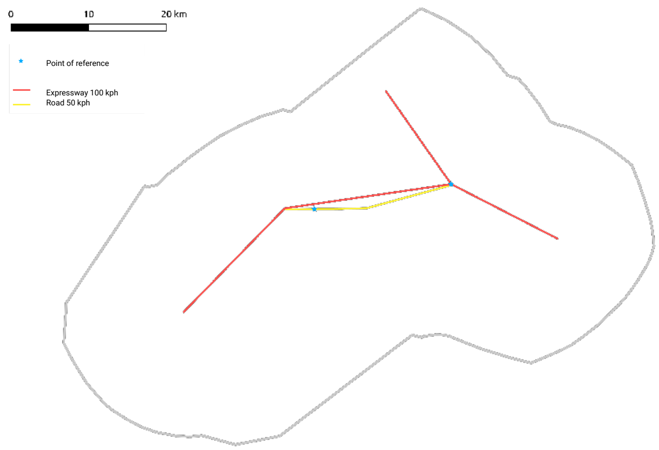

Fig. 1. Topographic map for a *route selection task*, scale in kilometres

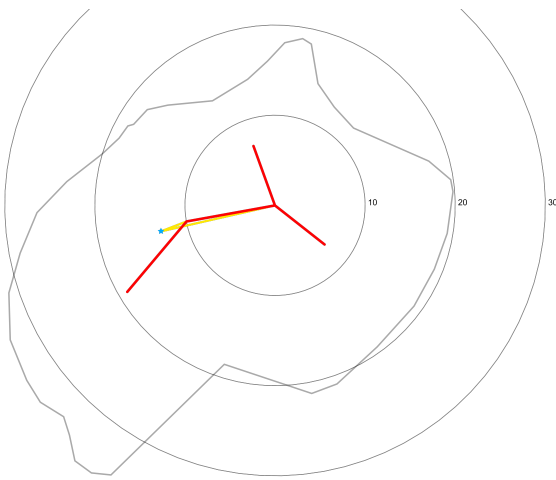

Fig. 2. Unipolar anamorphic cartography for the same *route seclection task*, scale in minutes indicated along iso-time circles

can be connected to previous time-geography representations with slower, longer edges depicted in two dimensions as more or less compressed springs [16, 17]. By design the model does not need a three dimensional deformation of the geographial surface, but this helps the readability of the representation. This implementation has a transport surface made of an assemblage of cones. Each cone has for summit a node of the transport network, or a geographically significant place such as a human settlement. Additional points of interest may be displayed on the cones surface. Fast transport links appear as straight lines joining cones summits, while we drew slower roads as yellow segments on the surface of cones. The three-dimensional nature of the representation brings in issues of visibility that must be adressed by adjusting the angles of view.

This model requires at least two different transport speeds. In the case of a third, intermediate speed, links of that transport system can be drawn without touching the geographical surface as in L'Hostis and Abdou [1].

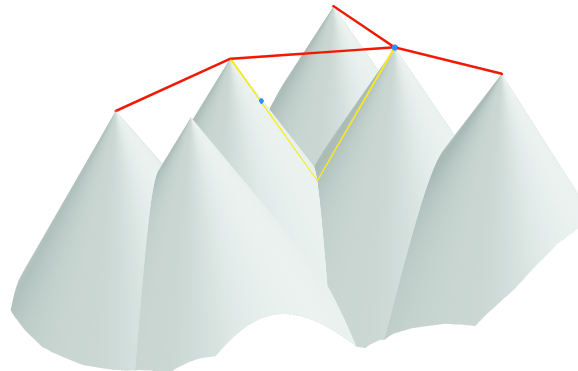

Fig. 3. Shrivelled three-dimensional geographical time-space map for the same *route seclection task*, all lengths are proportional to the travel time

III. The space of implementation

We aimed at replicating a typical situation of route selection in geographical space with a car using a combination of regular and fast road infrastructure. In order to be able to compare the cartographic models we chose a unique geographical space that will be represented under the three models. To make sure the readers can not infer previous knowledge about the area, we considered a theoretical space, without real geographical existence.

We focused on a spatial configuration allowing to study performances for a route selection task in the context of space inversion, i.e. in the vicinity of the access point to an expressway. We considered a slow road space and an expressway linking selected access points, as nodes in a graph. For the sake of realism, we measured the speed on existing geographical spaces in Europe with regular road itineraries and expressway itineraries, using existing services[2]. Surprisingly, typical expressway and regular road measured speed converge around 100 kph and 50 kph respectively. These figures generate a very simple ratio of 2 between the two considered speeds. This ratio determines the slope of the cones in the shrivelled representation, on figure 3.

IV. Modalities of the shrivelled representation

We discovered through testing various light environments, and contrary to all previous representations [18, 15, 1], that a backlight was more efficient to underline the relief of cones in the three-dimensional scene, hence our choice in the lighting of the scene.

In order to generate a graphical material suitable to the routing task, we introduced another innovation in the cartographic design of the shrivelled map. We implemented the design of slow roads on the sides of the cones. Earlier versions of the model displayed slower edges, as in L'Hostis [15], but the geographical surface space was not represented as cones then, but rather as complex tesselation of triangles with out a unique slope. Never tried before, this novel implementation revealed another property of the model. Slope, being the key parameter

[2] OpenStreetMap and Google maps routing services.

of the representation, allows to convert space into time. But only edges following the slope of the cone, implying that they meet the cone's summit, are suitable; any other edge drawn on the cone but avoiding the summit will follow a complex slope and fail to respect the principle of the shrivelled mapping. The design of the shrivelled map corresponds to a deformation of the transport surface in such a way that the drawing of the graph will allow converting visual length into transport duration. Here we have to underline the graph nature of the representation [19]. This means that any geodesic curve drawn between two arbitrary points on the assemblage of cones will generally fail to meet the principles of the representation, because it will possess a slope or a combination of slopes differing from the slope computed by the ratio of speeds; only a geodesic curve between neighbouring cones summits, without intermediary obstruction by nearby cones, following the Voronoi tessellation principle, and hence passing through the saddle point between the two cones, will meet the criteria of the geographical time-space representation.

V. Expert analysis of the routing task on the three models

As a first investigation of the potential of the representation, we conducted an expert's analysis by the authors of the research themselves. The authors developed their analysis of the cartographic material in view of the routing task.

The graphical material on figures 1, 2 and 3 represents the same information on two possible routes, between two reference points, in a situation of space inversion. For human readers, the question resides in identifying the optimal route according to time distance. On the topographic map, the reader needs to mentally divide red routes by a factor 2 and adding yellow segments for comparison. On the anamorphic, plastic map, the reader is not provided with relevant information to choose between the two options, by regular road or by a combination of regular road and the expressway. Finally, on the shriveled map, where segment length all directly convert into time, the reader can immediately visualise that the shortest time path implies going back to the expressway entrance and avoid the longer, and hence more time-consuming, yellow, regular road itinerary.

Nevertheless, shriveling maps come with more visual complexity by comparison with the other types of maps. This trend will increase when considering larger, more complex graphs. In addition, shriveling maps need explanation and a familiarisation process for new users.

The expert's analysis clearly points towards the shriveled map performing best in solving the routing problem in this case of a space inversion. This hypothesis needs now to be confirmed through a user test, following a rigorous psychological experiment protocol; this will be realised in a future step of the research.

VI. Conclusion and perspectives

We have exposed the constraints we faced and choices we made to produce three cartographic modalities of the same geographical time-space. We implemented a topographic, an anamorphic, and a shrivelled map.

The expert analysis allows expressing the hypothesis that the shrivelled, three-dimensional cartography, is the best performing to solve the routing problem in a case of a space inversion. As nowadays, the task of route selection tends to be delegated to machines, it would be relevant to investigate the cases when routing problems are still tackled by humans, e.g. in contexts of service disruption, or of temporarily closed infrastructure.

Beyond the expert analysis, this graphical material has been prepared in view of a psychological experiment with users asked to complete routing tasks, designed to compare the performance of the three modalities. In particular, we intend to measure the benefits for the routing task of the shrivelled, three-dimensional model, which has never been tested before.

References

[1] A. L'Hostis and F. Abdou, "What Is the Shape of Geographical Time-Space? A Three-Dimensional Model Made of Curves and Cones," *ISPRS International Journal of Geo-Information*, vol. 10, no. 5, p. 340, 2021.

[2] A. L'Hostis, "Misunderstanding geographical distances: Two errors and an issue in the interpretation of violations of the triangle inequality," *Cybergeo : European Journal of Geography*, no. 793, 2016.

[3] W. R. Tobler, "Map transformation of geographic space," Geography, University of Washington, Geography, Washington, 1961.

[4] W. Bunge, *Theoretical Geography*, seconde éd. augmentée 1966 ed. Lund: Gleerup, 1962.

[5] A. L'Hostis, "Theoretical Models of Time-Space: The Role of Transport Networks in the Shrinking and Shrivelling of Geographical Space," in *Methods for Multilevel Analysis and Visualisation of Geographical Networks*, ser. Methodos Series, C. Rozenblat and G. Melançon, Eds. Dordrecht: Springer Netherlands, 2013, pp. 55–66.

[6] J. Bertin, *Sémiologie Graphique*. Paris: Mouton Gauthier-Villars, 1973.

[7] P. Forer, "A Place for plastic space," *Progress in human geography*, vol. 2, no. 2, pp. 230–267., 1978.

[8] W. R. Tobler, "Geographic area and map projections," *Geographical Review*, vol. 53, pp. 59–78, 1963.

[9] A. C. Gatrell, *Distance and Space: A Geographical Perspective*. Clarendon Press Oxford, 1983. [Online]. Available: http://www.getcited.org/pub/102287206

[10] C. Cauvin, "Espaces cognitifs et transformations cartographiques," Lettres et Sciences Humaines, Strasbourg 1, Strasbourg, 1984.

[11] G. Vuidel and C. Cauvin, "Darcy," 2009. [Online]. Available: https://sourcesup.renater.fr/www/transcarto/darcy/

[12] D. W. Thompson, *On Growth and Form*. United Kingdom: Cambridge University Press, 1917.

[13] P. Mathis, "Espace et graphe, le p-graphe t-modal 1-planaire," in *Table ronde ASRDLF "Distance et analyse*

spatiale". Chamonix: ASRDLF, 1990, p. 10. [Online]. Available: https://hal.archives-ouvertes.fr/hal-02070946/

[14] A. L'Hostis, "Transports et Aménagement du territoire: Cartographie par images de synthèse d'une métrique réseau," *Mappemonde*, vol. 43, no. 3, pp. 37–43, 1996.

[15] ——, "The shrivelled USA: Representing time-space in the context of metropolitanization and the development of high-speed transport," *Journal of Transport Geography*, vol. 17, no. 6, pp. 433–439, 2009.

[16] F. Plassard and J.-L. Routhier, *Sémiologie Graphique et Évaluation*. Lyon: A.R.T.U.R., 1987.

[17] W. R. Tobler, "Visualizing the impact of transportation on spatial relations," in *Western Regional Science Association Meeting*. Hawaii: Western Regional Science Association, 1997, p. 7.

[18] A. L'Hostis, "Images de synthèse pour l'aménagement du territoire: La déformation de l'espace par les réseaux de transport rapide," Géographie et Aménagement, Tours, 1997. [Online]. Available: https://theses.hal.science/tel-00275807

[19] P. Mathis, *Graphs and Networks: Multilevel Modeling, Second Edition*. J. Wiley & Sons, 2010. [Online]. Available: https://doi.org/10.1002/9781118595473