The Visual Representations of Territorial Dynamics: Retrospective and Input from New Computing Environments

Paule-Annick Davoine[1], Hélène Mathian[2], Cécile Saint-Marc[1,5], Jean-Yves Blaise[3], Lahouari Kaddouri[4].

*LIG – STEAMER, Grenoble, France
**UMR 5600 Environnement Ville Société, Lyon, France
***UMR 3495 MAP – GAMSAU, Marseille, France
****University of Avignon, France
***** SNCF I&P, La Plaine Saint-Denis, France

Abstract. Nowadays, a diverse number of cartographical products are attempting to integrate the notion of time in their map views, through animated cartography and geovisualization platforms. These questions about representing time and timescales are not new. Many visual solutions have been proposed to carry out reasoning on both space and time in a very efficient and effective way. These representations of spatial dynamics constitute a heritage for modern visualizations. They can be classified in three families of practice: chronography (time oriented), cartography (space oriented) and statistics (theme oriented). This article deals with a review of past and current spatio-temporal visualizations. We first proposed a review of past approaches in spatio-temporal visualizations. We tried to determine how this whole heritage constitutes the foundations of modern cartographical exploration. Second, we analyzed a set of 42 dynamic cartographical visualizations on the Web on the basis of 13 criteria, which covered proposed functional features, semiological innovations and services rendered. This analysis revealed common associations of parameters and trends among current webmaps showing dynamics, but also a low diversity of certain dimensions of webmaps. We finally positioned them into MacEachren's "map-use cube" (1994), which is a frame of reference for geovisualizations analysis. Two new categories were intergrated in the cube, which superseded others in the webmaps case: maps for data contextualization and maps for data presentation.

Keywords: review, spatio-temporal visualizations, maps of territorial dynamics

1. Introduction

Nowadays, we are confronted with a wide range of available data that is often massive. For this data, visualization enables the identification of structures, dynamics and relations. Spatio-temporal data is not exempt from this trend. It is now well established that the visualization of spatial dynamics contributes to their analysis, by highlighting the transformation, modification and evolution of spatial organizations. These may correspond to diffusion processes, ranking processes, movements, that may be observed either over a long-term period (historical periods, centuries) or over a short-term period (day or month).

Exploring and carrying out analyses in order to identify and understand the multiple temporalities of a territory is based on the use of spatio-temporal data. Since Peuquet (1984), it has been common practice to deal with such data according to three dimensions: time (when), space (where) and theme (what). This is the case with the observation of the impact of Global Warming on the Earth over time (large scale), but also with the monitoring of traffic evolution on small roads in a small regions (small scale). Therefore, the problem of representing temporalities depends on the diversity of these questions and of these spatial and temporal scales. However, representations should be set aside from these different scales to focus on a common need: taking these three dimensions into consideration.

Nowadays, a diverse number of cartographical products are attempting to integrate the notion of time in their map views, through animated cartography and geovisualization platforms. These questions about representing time and timescales are not new. New abilities reside today in calculation capacities, real time visualizations, adaptable interfaces, etc. But beyond them, many visual solutions have been proposed to carry out reasoning on both space and time in a very efficient and effective way. This is the case, for example, with the cartographical representation of the '*Retraite de Russie'* map by C.J. Minard (1865) or The Train Schedule by E.J. Marey (1885). The project[1] into which this paper fits was the opportunity to look back on these legacies and to reinterpret them from a methodological point of view, in order to highlight their characteristics (Kaddouri et al. 2014).

This article deals with a review of past and current spatio-temporal visualizations. We first tried to determine how this whole heritage constitutes the foundations of cartographical exploration. Secondly, we proposed an analysis of a selection of websites that showed dynamic

[1] „Dynamical representations of territorial temporalities“, project of „Town, Construction and Land Planning“ Office (PUCA), French Ministry of Environment.

cartographical visualizations. This set of visualizations was analyzed according to criteria, which encompassed proposed functional features, semiological innovations and services rendered. We first compared these characteristics to the previous descriptions of what we called the cartographical heritage. We then suggested positioning them within the 'map-use cube' proposed by MacEachren (1994), which constitutes a conceptual reference for cartographical practices.

2. Methodological Heritage

Why should we be interested in legacies at a time when interactivity allows all kinds of combinations and is able to multiply potentialities? It seems to us that some of the solutions provided by these legacies are not so commonly used today. And while cartographical solutions are well known in the geovisualization field, time-oriented solutions are much less well-known, even if they are more common in the dataviz field[2]. We will present a brief outline of these perspectives. We will then revisit some emblematic spatio-temporal visualizations, in order to extract the main characteristics from a spatial and temporal point of view. This should help us consider « new maps and visualizations » and understand the contributions of other domains.

2.1. Chronological inventory

This historical overview was the opportunity to compare and contrast three families of practice: chronography (time oriented), cartography (space oriented) and statistics (theme oriented). The three approaches may be compared to the classic three-dimensional decomposition of a phenomena, i.e. space, time and theme (figure 1). This decomposition is similar to how our knowledge of phenomena is built through three subcognitive systems associated with the questions Where, When and What (Peuquet 1984).

---

[2] According to an inquiry at Modys summer school http://www.map.archi.fr/modys/viz/bubbleviz.svg

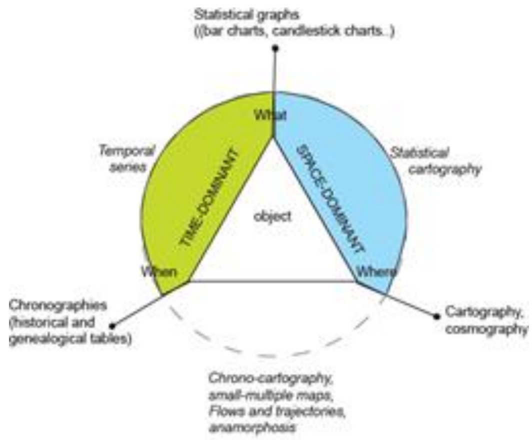


Figure 1. Representation groups based on a the triad decomposition

The corpus of visualizations for the period from 2000BC to 1950 was extracted from the works of M. Friendly (www.datavis.ca), E.R. Tufte, J. Lefort, G. Palsky, G. Schuller, R. Spence, J.P. Saint-Aubin, D. Rosenberg and A. Grafton. Based on this corpus, not only was some great progress made in cartography, but also in pioneering works in time and data visualization. An illustration of this confrontation may be found on the project's website (http://www.map.archi.fr/jyb/puca/). It led to the highlighting of some points:

- The continuous development of practices.
- The shift from a symbolic expression towards rationality and accuracy; measurements affected the representations.
- The coexistence of the individual principles of the two specialities (cartography vs. data and time visualization), and of the bridging principles between specialities, thus combining different types of representation. In the former, progress was made according to internal heritage and needs. In the latter, progress came from a combination of perspectives.
- The number of combined developments is quite limited, but reflects a great diversity of permutations.

A selection of these different legacies was gathered to illustrate how the dimensions could be combined, with a particular emphasis on spatial and temporal dimensions.

2.2. Intersecting views on time and space: two emblematic graphs

Whether it was space or time, the developments of the representations diverged somewhat in the middle of the period: the time representation switched from a symbolic abstraction, rooted or not in space, to a mathematical abstraction. The accuracy of space replaced the symbolic abstraction and with this, the ability to integrate different scales. Nowadays, it seems we are better equipped to represent space than time. And yet heritage from time oriented data visualization looks richer (Blaise, Dudek 2012, Blaise, Dudek 2011). Should the spatial representation be limited by the tyranny of accuracy and to the location, especially as time is more easily modelled as currently practiced: ordinal time, cyclic time, uncertain time…?

What seems important in these representations involving time and space is the way **change** is processed, that is to say, how the variation in comparison with time is represented. In the geovisualization field, it is common practice to differentiate movement and change. However "movement" may be seen as a series of location changes. Thus movement involves time and space, which are combined and are the support for the theme if necessary. If change concerns the theme (built up areas, population…) then space is the support for the change of theme.

2.2.1. Representation of the movement

In the case of movement representation, the effectiveness of the choices of legacies are very much a source of inspiration. This is particular to movement because of the specificity of this phenomena: on the one hand, movement can easily be associated with a trajectory, that is to say, a one dimensional representation; on the other hand, as time is contained in the movement, there is no need to dedicate one dimension to it. For a two-dimensional representation, there are potentialities left.

Two examples are of great interest in this confrontation: the first is space-oriented; it concerns Minard's well-known map (1869); the second, time-oriented, is Marey's Time table (1885). These two visualizations are well known in the field of visual analytics (Tufte, 2001) and are remarkably effective. For both we just highlighted the way time, space and theme were abstracted, represented, and combined to illustrate the change.

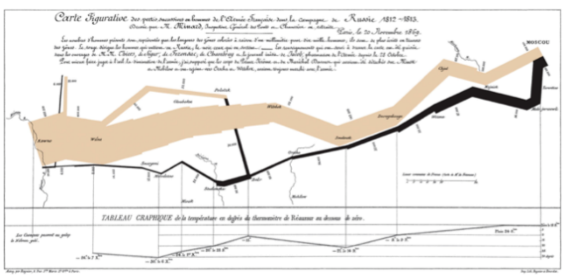
In Minard's map[3] (figure 2a), the choices and qualities of the representation may be summarized as follows:

---

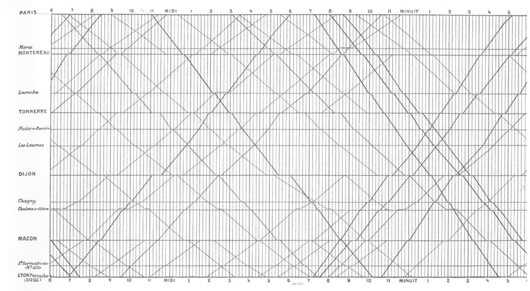
[3] It is to be noted that this emblematic map is an inspiration for many developments. http://www.itc.nl/personal/kraak/1812/3dnap.swf; Aaron Walburg, Stephen Hartzog, 1996, http://www.math.yorku.ca/SCS/Gallery/minard/march-animated.gif.

- space and time are very simplified (stop points and dates) and rivers are the only elements of spatial contextualization,
- change of location : trajectory,
- change of population : difference of size trajectory,
- thematic contextualisation: correlation over time with explanatory factors (temperature).

In Marey's table (figure 2b), space is seen as it is on the rail network, that is, in a linear fashion. Cities are localized on an axis (ordinate axis) according to their spacing between Paris and Lyon. Two abscissa axis represent time, i.e. a day in number of hours. The top axis corresponds to the departure time, the bottom one to the arrival time. A journey is represented by a line that joins the two points (from the city of origin, departure time to the destination, arrival time). This illustration answers Tufte's rule "1+1=3". The strength of the graph is that, as well as the two dimensions of time (t) and space (x), the speed (dx/dt) is also demonstrated by the slope of the line.



(a)



(b)

Figure 2: Two emblematic representation - the basis for a methodological reflexion on time representation: (a) Minard's map (b) Marey time table

2.2.2. Representation of change

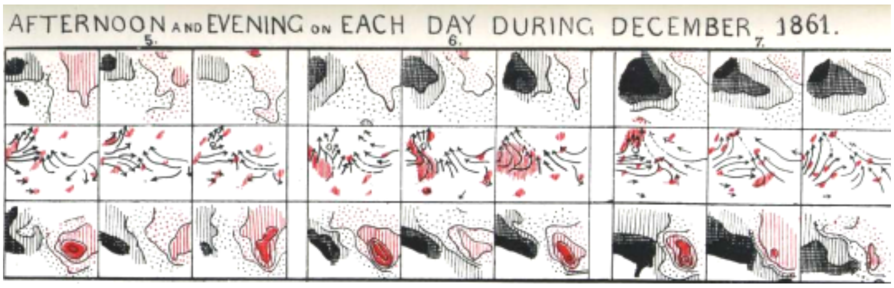
Considering the case where only the delineation of objects changes (urban sprawl) or when space alone is the support for a thematic change (the evolution of a communal population or the evolution of the land use of a plot), legacies are also very rich.

The fact is that many examples represent a change on maps if this change may be modelled as a movement. This is the case for instance, of urban sprawl, in which the evolution of the delineation evolves from center to periphery. This is also the case for the phenomena of diffusion (for instance, epidemics), in which change goes from zone to zone. These two cases may be seen as trajectories. It is possible to identify the variation in space relative to time.

When it was not possible to schematize change as a movement, another solution was developed, namely, a series of observations, that Tufte much later called the "small multiple". This format led to the practice of "data mining" which is today at the heart of *Infovis* and more generally *Visual analytics*. It involves placing successive stages so that change may be read side by side (differences between two contiguous stages) or over the whole set of stages (reading of the tendencies, contrasts...).

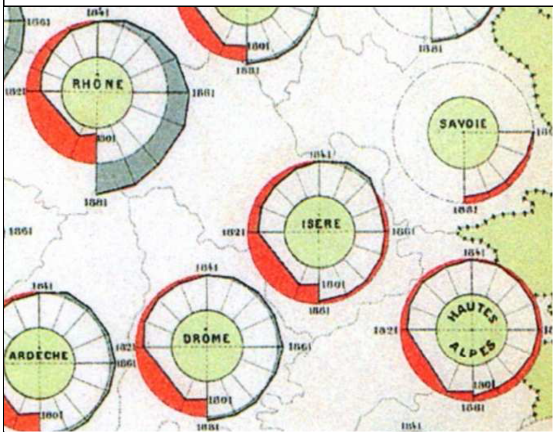
Of course, the system is greedy for space and an effort to reduce the problem has to be made. F. Galton improved the approach when analysing the European meteorological patterns in his *Meteorologica*. He observed a limited set of parameters three times a day (figure3a): barometric pressure, temperature, wind direction, rain. His analyses were graphically translated as a discrete, multi-resolution temporal serie. They were the result of one month's observation. Galton used the visual format *small multiples* (or map collection) to evaluate the correlation between the different parameters and to highlight the ratio between pressure and wind directions (CCW for low pressure phases, CW for high pressure phases).

An alternative to small multiples, may be a summing up of the evolutions, and that is possible when focusing only on one measurement. This leads to a cartography of evolution profiles. It is what has been done in figure 3b (French Ministry of Public Works, 1884). As opposed to the small multiples where time is out of the mapping, in this case, time is inside the cartography, it is even in the symbology: symbols are temporal graphics. Thus it is possible to read a posteriori, either globally or locally, the spatial components of the change. Nonetheless, it seems to be difficult to add some contextualization effects when representing the evolution of any explanation.



(a)

F. Galton's three graphic units, representing three days of observation.
Each graphic unit is represented vertically (observations in the morning, at midday and in the evening) and horizontally (pressure, wind and rain, temperature).



(b)

Five-yearly movement of the population per department 1801 - 1881. (Zoom on eastern departments) From Album de Statistique Graphique, 1884, 25; [In] G.Palsky 1996

Figure 3. Representing change: from instants successions to a summary

In the whole set of examples presented here, the aim was to facilitate the reading and the understanding of maps and graphs, by revealing associations of similarity or dissimilarity, of order, of proportionality in time and space (Bertin, 1967). With these examples we wanted to illustrate and highlight the relationships between pure cartography, often preferred when analysing spatial evolution- and the field of data visualization, for which the formalization of temporal dimensions and the use of abstraction bring a useful alternative.

3. Analysis of contemporary applications: corpus and methods

What effect the introduction of modern technologies has had on the visual representations of time and changes? The analysis described in this part was a first step towards answering this relatively difficult question. An analysis was carried out on the different characteristics of current interactive and animated cartographic visualizations on the web. These digital maps were grouped under a larger term: geovisualizations. The main studied characteristics were the visual representation of space and time and the contextual elements of the products.

3.1. Studied Corpus

The studied corpus was composed of 47 web geovisualization applications[4]. Nowadays, the Web is the primary platform for the diffusion of cartographical products, whether they were specifically developed for this platform or just broadcast through video. The collection of applications was carried out over a six-month period from February to July 2013. The only selection criterion was 'every visualization of phenomena occurring in space and time', without considering the targeted audience, the nature of the phenomena, or the software technologies. A first validation of this corpus was done by locating these visualizations in MacEachren's map-use cube (1994) according to its three dimensions: interactivity, types of links with the information and types of audience. An analysis grid was then developed to explore the diversity among these web geovisualizations.

3.2. Analysis Grid

The analysis of our corpus was processed on a three-level grid: a conceptual level, an applicative level and a factual level.

- Conceptual level: the aim was to identify objectives, expectations and services that were fulfilled by a dynamic visualization. It described the types of dynamics, the types of tasks targeted by the tool and the targeted audience. The possible types of dynamics included: location of events (e.g. natural disasters, points of interest…), thematic changes of space (e.g. change of land cover), changes in shape (e.g. expansion of a city), movements of individuals (e.g. migration trajectories of animals) and flows (e.g. origin-destination flows).

[4] The list of 47 visualizations is accessible on : http://www.map.archi.fr/jyb/puca/

- Applicative level: the aim was to describe methods used to represent processes in space and time, and the level of interactivity of each component. Representations of space and time included a representation scale (small, intermediate, large, very large) and the manner of representation: the representation of time through the temporalities of an animation, through the space of a timeline or through a thematic attribute; the representation of space through a map, a graph or a thematic attribute.
- Factual level: three detailed grids were drawn up for this level, in order to systematically compare applications: a grid dedicated to time, a grid dedicated to space and a grid dedicated to interactivity.

The analysis of the three levels allowed the identification of 13 generic criteria that are listed in *Table 1*. The criteria attributes that were numbered could exist together in the same tool, whereas the attributes that were separated by a slash (/) could not. These criteria were used to analyze the variability among the applications of the corpus, to identify existing relations between them and to identify trends among existing geovisualizations of dynamics.

Criteria	**Attributes**
Interactive environment	yes/no
Animated environment	yes/no
Dynamic link with the database	yes/no
Spatial dynamics	1) Locations of events, 2) Thematic change in space, 3) Change in shape, 4) Movements of individuals, 5) Flows
Rendered services	1) Data presentation, 2) Storytelling, 3) Exploration, 4) Prediction, prospects
Targeted audience	1) General public, 2) Professionals and experts
Representation of time	1) By time, 2) By space, 3) By semiotics
Representation of space	1) By a map, 2) By a graph, 3) By a cartogram
Graphical views	1) Presence of temporal graphs, 2) Presence of non-temporal graphs, 3) No graphs
Represented temporal granularities	simple/multiple
Represented spatial granularities	simple/multiple

Criteria	Attributes
Represented time scale	1) Immediate, 2) Short (days to months), 3) Intermediate (several years), 4) Historical (centuries and more)
Represented space scale	1) Local (city), 2) Intermediate (region), 3) Large (country, continent), 4) Global

Table 1. 13 criteria were considered to further analyze the diversity of applications

4. Analysis of the Diversity of Geovisualization Tools

4.1. Types of Visualizations of Dynamics

The first step of this study consisted in a univariate analysis to catch the diversity of the production among each descriptor and bivariate analysis to highlight patterns. A *dataviz*-like interface was developed in this project. It allowed the exploration of all these descriptors (http://www.map.archi.fr/jyb/puca/viz/bicriteres.htm).

Then, the significance of the relationship between the different characteristics of the applications was tested. A relationship between the attributes of two criteria meant that these attributes were often associated with each other by the producers of geovisualizations. The aim of this analysis was to identify systematic associations of characteristics and a potential lack of diversity for certain criteria.

This analysis allowed the identification of seven significant relationships between the descriptive criteria. The results are presented in *Table 2*.

Relation	Intensity (R2 ANOVA)	Explanation
Presence of animation – Rendered service	54%	- Applications which render a service of inventory are *rarely animated* ; - Applications which render a service of storytelling are *often animated*.
Presence of animation – Represented time-scale	55%	– Applications which deal with historical time are *more animated than the average*; – Applications which deal with an immediate time are *less animated than the average*.

Presence of animation – Represented space-scale	45% (quite low)	- Applications which show an intermediate space are *never animated*; - Applications which show a large or global space are *more animated than the average*.
Presence of animation – Spatial granularity	30% (low)	• Applications which present multiple spatial granularities are *often animated* ; • Applications which present a simple spatial granularity are *often not animated*.
Presence of animation – Time representation	88% (very strong)	– Animated applications often represent time *both with time (animation) and space* (timeline) ; – Non-animated applications often represent time *solely with space*.
Spatial dynamics – Represented time scale	59%	– Applications which present thematic changes in space often deal with *intermediate time* ; – Applications which present movements often deal with *intermediate* or *short time* ; – Applications which present changes in shape often deal with *historical time* ; – Applications which present locations of events AND movements at the same time often deal with *immediate time* ; – Applications which present movements AND flows at the same time often deal with *short time*.
Rendered service – Type of audience	54%	– Applications which render a service of exploration are often dedicated to *specialists* and rarely to the general public ; – Applications which render a service of storytelling are often dedicated to the *general public* ; – Applications which render a service of storytelling AND exploration at the same time are often dedicated to both audiences: *general public AND specialists*.

Table 2. Relations between the different characteristics of visualizations

The second step of our study aimed to identify trends among existing dynamic visualizations. An Ascending Hierarchical Classification (AHC) was carried out on the thirteen selected criteria. It revealed nine groups which comprised between 3 and 10 applications. Table 3 summarizes the distinctive features for each group.

	Distinctive features	% in the sample
G1	Static view for presentation purposes, showing locations or movement, on a local scale	21%
G2	Static view, at an intermediate scale, for specialists	21%
G3	Animated view of movement or flows, on a local scale	13%
G4	Animated historical narrative, on a global scale, for the general public	6,5%
G5	Animated view for exploration purposes, on a large scale	8,5%
G6	View for presentation or exploration purposes, on a local scale, with multiple temporal granularities	6,5%
G7	View of thematic changes for exploration purposes, on a local scale, with multiple temporal granularities	8,5%
G8	Animated narrative showing thematic changes, for the general public	8,5%
G9	Animated view for exploration purposes, showing thematic changes on a global scale, for the general public	6,5%

Table 3. Features that dissociate groups of visualizations

4.2. Dynamics in geovisualization and cartography on the web

We attempted to place the studied visualizations in the frame of reference proposed by MacEachren: the map-use cube (1994) (*Figure 4*) according to their level of interactivity, the targeted audience and the previous knowledge of the information to be visualized.

First, a translation of the cube along the ‘interactivity‘ axis was observed (*Figure 4a*). Indeed, almost all the current applications allow the user to interact with the data, either to zoom and pan or to explore more precisely the data sets.

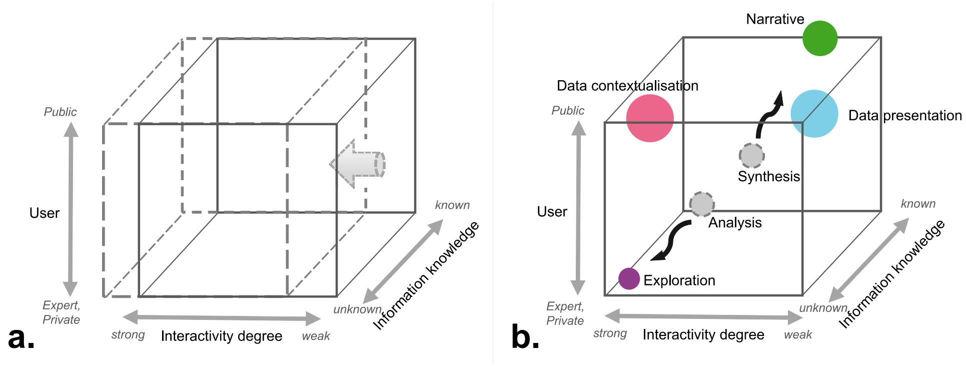


Figure 4. Analysis of visualizations of dynamics according to MacEachren's framework (1994). (a) Current translation in the cube with an increasing use of interactivity (b) Sizes of circles stand for the number of visualizations in this category in our corpus.

Whereas MacEachren's map-use cube presented four types of uses - exploration, analysis, synthesis and presentation - two new types of geovisualizations appeared (*Figure 4b*): data contextualization and data presentation. It seemed that the transfer towards interactivity went in parallel with data-oriented developments, at the expense of the analysis and the synthesis types. These opposite evolutions might be either independent (decline of the two types and rise of the two others), or be caused by a transformation in the conception of visualization environments. Whatever the explanation, this change seemed to mean that the analysis functions were replaced by a context-awareness or by an original data visualization. It is important to note that data could have been processed and analyzed before their presentation to users. In parallel, the service of 'storytelling' was more and more used: the synthesis became an animated narrative, in which the storyteller (specialist) was not needed any more because of dynamic semiotics and user controls that enabled users to replay narratives as often as they wanted.

5. Conclusion

We looked through some emblematic historical static representations and the way they allow the evaluation of change and the stimulation of questions about change factors. In these cases, abstractions were used to express a point of view on how time and space were experienced. Time-oriented representations of spatial data are less known in the GI Science community, even though they constitute a rich legacy. Have new technologies integrated these practices? Or are they only 'showing the data', using new potentialities without any points of view other than a sort of objectivity, which may be misleading? Through a sample of 42 geovisualizations of dynamics on the web, we saw that modern cartography was both characterized by a richness in the possible scales, granularities and functions of the maps, particularly with the use of interactivity and animation, and by a low diversity of cartographical products published on the web. For instance, the presentation of pre-processed data seems to be the rule, and the uses of temporal graphics inside cartography are rare. Nevertheless, interactivity is useful to contextualize and highlight associations. Our analysis identified nine types of web geovisualizations, going from static views of locations and movements (frequent), to visualizations for exploration purposes, showing multiple granularities (rarer). Among web cartographies, two new categories superseded others: maps for data contextualization and maps for data presentation. Web cartographies could benefit from using the whole set of the legacies, as a sort of grammar of solutions for spatio-temporal representations. The diversity and richness of maps could also gain from new associations between the geovisualization characteristics (dynamics, services, representation, scale and granularity).

6. References

Bertin J. (1967) Semiology of Graphics: Diagrams, Networks, Maps. University of Wisconsin Press, 1983 (first published in French in 1967, translated to English by Berg W.J. in 1983)

Blaise J.Y., Dudek I. (2012), Can Infovis tools support the analysis of spatio-temporal diffusion patterns in historic architecture? Archaeology in the Digital Era, G.Earl, et al. (Ed.), Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton 2012, Amsterdam University Press, Amsterdam 2013, pp. 367-378

Blaise J.Y., Dudek I.(2011),Visualizing alternative scenarios of evolution in Heritage Architecture, I-KNOW 2011 Proceedings, S. N. Lindstaedt, M. Granitzer (Ed.), ACM, New York, 2011, pp. 45

French Ministry of Public Works (1884) Album de statistique graphique de 1883. Imprimerie Nationale, Paris, France, 26 p.

Friendly M., Timelines and Visual Histories. Available online: www.datavis.ca/gallery/timelines.php (Accessed on March 18, 2013)

Galton A. (2004) Fields and objects in space, time, and space-time. *Spatial Cognition and Computation*, vol. 4, n° 1, p. 39-68, 2004.

Kaddouri L., Blaise J.-Y., Davoine P.-A., Mathian H., Saint-Marc C. (2014) *État des lieux des représentations dynamiques des temporalités des territoires*. Technical

Report, June 2014, 167 p. Available online: http://www.map.archi.fr/jyb/puca/pdf/Rapport_Annexes_PUCA_complet_final.pdf

Lefort J. (2004) *L'aventure* cartographique. Belin Pour la Science.

Marey E.J. (1885) *Train schedule from Paris to Lyon*.

MacEachren A. M. and Taylor D.R.F. (1994) Visualization in Modern Cartography. Oxford, UK: Pergamon.

Minard C.J. (1869) *Carte figurative des pertes successives en hommes de l'armée française dans la campagne de Russie, 1812-1813*. Lithography (624 x 207, 624 x 245), November 20th, 1869. ENPC: Fol 10975, 10974/C612.

Palsky G. (1996) Des chiffres et des cartes : la cartographie quantitative au XIXe siècle. CTHS.

Peuquet D.J. (1994) A conceptual framework for the representation of temporal, dynamics in geographic information systems. *Annals of the Association of American Geographers*, vol. 84, n° 3, 1994, p. 441-461.

Rosenberg D. and Grafton A. (2010) *Cartographies of Time*. Princeton Architectural Press.

Saint Aubin J.P. (1992) "Le relevé et la représentation de l'architecture", Service de l'Inventaire Général, Documents & Méthodes, Paris, France.

Schuller, G. (2008) Designing Universal Knowledge. Lars Muller Publisher, pp. 138–143.

Spence, R. (2001) Information visualization. Addison Wesley, ACM Press, Essex.

Tufte E.R. (2001) The Visual Display of Quantitative Information. Cheshire (Connecticut), Graphics Press, 2nd edition, 197 p. ISBN: 0-9613921-4-2