GEOGRAPHY AND DEMOGRAPHY

Cartography

Handling and Mapping Geographic Information

Coordinated by
Claire Cunty
Hélène Mathian

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SCIENCES

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Contents

Foreword

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Within the framework of the ISTE SCIENCES encyclopedia and, more specifically, of the "geography and demography" field, four works are devoted to cartography. Cartography is a scientific and artistic discipline (Robinson 1952, 1953), and it is indispensable to any person, organization or institution that needs to process and represent geographic data to bring out its spatial characteristics. With current technological changes, the continuous increase in the use of Web 2.0 and the appearance of social networks, cartography is undergoing profound changes.

This discipline has, in fact, undergone many more or less fundamental changes over time, both conceptually and technically, the two being intimately linked, as de Rosnay (2008) writes: "Scientific progress and technological progress feed each other". If its junction with statistics, as early as the end of the 19th century, had introduced new processes to translate localized phenomenon, the advent of the computer, and subsequently the birth of computerized cartography, could be considered a revolution. The latter was coined in an article by Tobler in 1959, simultaneously announcing the steps for the construction of an automated map and the basic principles of what would become geographic information systems (GIS).

Between this date and the beginning of the 1980s, this "new" cartography was developed in two directions: on the one hand, computer cartography, which reproduced what had previously been done manually, and, on the other hand, computer-assisted cartography, which opened up new avenues for creating

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innovative representations or introducing methods of surface analysis[1]. In the early 1980s, microcomputers appeared, whose immense capacities are now available to a large number of people with minimum knowledge. “Making” maps seems to be easier, updates become simpler, and software, of varying quality, is multiplying. The availability of the Internet, and especially the Web in 1994, further simplified the diffusion of graphic documents, which multiplied.

In addition to these new features, a fundamental change involved the communication paradigm, which is essential in the field. Despite automation, the arrival of the Internet and the Web, the logic of moving from an author/producer (the one who conceives, who represents) to a reader/user, sometimes with feedback, remains predominant; the reader, the one who consults, who looks at the map and uses it, remains passive, even if, thanks to animation and especially interactivity, they can move their document around, zoom over it, fly over it, etc.; but they cannot modify it. However, with the arrival of Web 2.0, the Semantic Web and the advent of the Geoweb from 2005 to 2010, and especially 2015, a new turning point is taking place: the reader/user, whoever they may be, becomes active. They can modify the maps on the Web and can even create them. This is the beginning of a new period for cartography, which will be further developed in the works for the ISTE encyclopedia, in order to present an updated state of this science, with its transformations for the period 2010–2022.

The chosen date of 2010 as the threshold is explained by the fact that many works on cartography, both in French (Béguin and Pumain 1994) and English (Cauvin et al. 2010a, 2010b, 2010c; Slocum et al. 2009), were published in the previous years, exposing the characteristics of the field just before the “real” start of the Semantic Web, highlighting the steps necessary to produce a map, as well as the successive choices that must necessarily be made. Indeed, the construction of a map requires at least three main steps, each of which has a very specific role. The first step is to create a localized database from the geographic information provided. The second stage ensures the processing and transformation of the data in the database, insisting either on the locations or on the thematic data, or on both simultaneously, with or without taking time into account; it leads to the determination of the representation mode adopted. As for the third stage, that of communication and diffusion, it is not only based on technical solutions, on semiotic choices, on the adoption of particular actions, etc., but also on the knowledge of elements of visual perception and cognition.

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1 This approach largely corresponds to the analytical cartography introduced by Tobler (1976, 2000).

These three stages[2] are interrelated and are linked to both the challenges and the relationship between the recipient/user of the map. These three stages guided the selection of the four works chosen for the ISTE encyclopedia, because they start from the state of cartographic science at a period just before important changes. It will therefore be easier to highlight, describe and characterize the specific and original features of the years 2010–2022. One volume is devoted to each of the stages, and a fourth shows cartography from a historical aspect, thus facilitating a better understanding of the changes over time. Each volume can be read independently of the others and in an order that the reader wishes, according to his or her desires and expectations. The same is true for each chapter.

The aim of the historical volume is "to outline the history of cartography as it is done, and as it continues to evolve, by proposing a synopsis of the reflections and their modifications over the last forty years, in order to advance a history of cartography that takes into account current reflections and research, and above all, that opens up new avenues to explore".

The volume on geographic information and cartography focuses on data, its characteristics and its use in cartography during a period where digital techniques are gradually, but fundamentally, recomposing contemporary societies. Data acquisition is no longer an activity reserved for specialists. The sources of geodata are diversifying, citizens are directly and often voluntarily providing geographic information (GPS readings, cell phones, connected mobile objects, X (formerly Twitter), etc.); networking is immediate. The search for information for the production of maps is therefore profoundly transformed and reveals major issues in terms of digital society.

The volume on the processing and mapping of geographic information has a double objective. The first is to present methods and techniques for processing and transforming information to produce maps that respond specifically to each problem. These procedures take into account the spatial, thematic and temporal components of this information, and focus on spatial and spatiotemporal processes using indicators and models. The second objective is to highlight the importance of the interdependence of the different stages of cartographic construction, in which the processing stage is central. On the one hand, the latter must take into account the data to be processed, selected at the previous stage. On the other hand, it specifies, for the next stage, the original cartographic representations that will result from the selected processing. These two objectives are systematically concretized with examples that provide a clear understanding of the methods and their contribution to the understanding of the phenomenon under study.

2 A similar pattern is found in the latest version of Robinson's reference book from 1995.

The volume on communication, however, deals with the transmission of the map, because the latter is not a document that we produce so that it can remain in our pocket. It must become visible, and eventually audible and sensible, by appealing to graphic variables or others types of variables, possible actions and presenting display device properties. This volume will certainly be the easiest for detecting the specificities of the current period, with the role of choices at all stages, the interweaving of these stages and the collaborative work.

With the same tools and the same means, specialists and non-specialists will produce maps by taking what is at their disposal but with distinct training, which induces risks. Indeed, the new cartographic processes that are constantly emerging have many positive aspects: ease of use, diversity and attractiveness. However, like all new developments, their advantages have a downside; each of these processes has specific properties that are important to know at least in order to apply them wisely and avoid mistakes. The four books presented here show that we are moving toward new logics, new ways of conceiving, translating, processing and cartographically transcribing geographic information, without necessarily having to reject what already exists. The world of maps does not escape the general evolution in which we are all participating, with our wealth and our worries. May these books help everyone to be aware of what they produce and to use all these tools with discernment.

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Introduction

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Mapping is perhaps the most formative and creative act of any design process, first disclosing and then staging the conditions for the emergence of new realities.

James Corner, 1999

I.1. Maps and mapping

The map is more than just a "simple" representation of space and must be seen as a succession of cartographic operations (Besse and Tiberghien 2017). It is both the graphic result and the set of cartographic operations that led to the resulting product.

> To operate is to transform a material by following a certain number of formal rules (rules that are not necessarily determined a priori, but which on the contrary can be invented or redefined in the course of the operation itself), in order to obtain a result, an object, a product. Every operation is a "formation" and a transformation [...] (Besse and Tiberghien 2017, pp. 14–16).

Formally, the transition from geographic information or geographic data to maps involves several stages of data "transformation", operating at different levels. Cauvin et al. (2010) define a categorization of these different "transformations": entity transformations, thematic and geometric attribute transformations,

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cartographic transformations, semiotic transformations and finally, display transformations (Figure I.1).

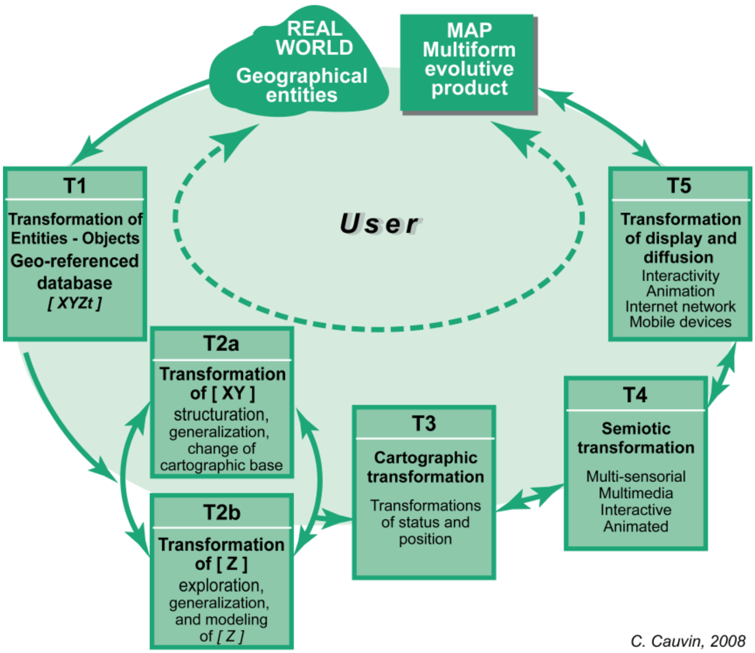

Figure I.1. *The map as a sequence of transformations (Cauvin et al. 2010)*

The aim of this volume is to present the various operations involved in the articulation between geographic information and the map, within the purview of *processing* (T2a, T2b, T3 in Figure I.1). We have chosen to present these within an operational framework. All the examples and developments presented in the chapters are strongly rooted in a *spatial analysis* approach, that is to say, with the objective of describing and modeling spatial structures. In all the chapters, the authors review the operations involved in handling geographical data, from a pragmatic point of view, in relation to a geographical question, focusing on a number of these contextualized choices. All of these operations are associated with choices and methods that "orient" the data in a certain direction (by giving it a meaning), shedding light on a geographical question by taking into account the constraints of the medium and the target audience. The questions and developments associated with these operations are being renewed within the technological context (widespread geo-referencing of data, Big Data, etc.) and methodological context (democratization of programming libraries, technological evolution of visualization environments, etc.), while necessarily retaining conceptual reflections.

Geographical data[1], processing and mapping are linked in different ways depending on the role of the map: it can be the result, an intermediate stage in an analysis, or an interface for data exploration. The categorization proposed by MacEachren (1994) is very useful and widely used to position cartographic productions according to their objectives (Figure I.2). He defines four uses of cartographic representations based on three dimensions: the level of knowledge of the phenomenon addressed, the level of interactivity with the map and the target audience. Most of the analysis approaches developed in the chapters of this volume fall into the exploration/confirmation phase.

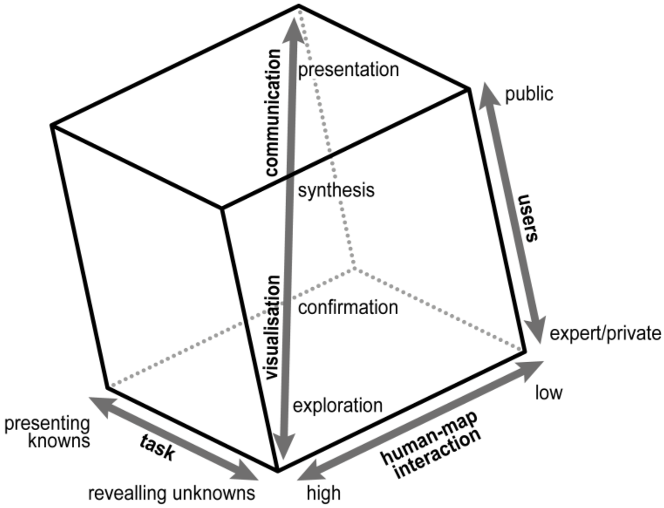

Figure I.2. *Different visualization objectives, according to MacEachren (1994)*

Some chapters develop a chain of processes responding to a specific geographical question and show how the map accompanies this process (Chapters 4, 5 and 8); others offer an updated or contextualized view of a specific methodological question (Chapters 1 and 3); still others present an inventory of solutions to a specific methodological question (Chapters 2, 6 and 7) (Figure I.3).

1 Throughout the volume, "geographic information" and "geographic data" will be inter-used with the same meaning. Thereafter, in the introduction, the term "data" will implicitly mean "geographic data".

Together, they cover a wide range of processing operations that link data and maps, and allow us to discuss the various challenges involved.

In this introduction, we propose two methodological readings of the contents of this volume. At the end of the introduction, a "map" of the chapters is proposed, showing the specific features of each chapter in relation to the various issues raised above and in the course of the two readings that follow (Figure I.3).

I.2. Preliminary reading: through the prism of a few operations and methods

A preliminary reading of the chapters should be based on a few key concepts that underlie the differentiation of practices.

These entry points correspond to different operations. The sequence of these operations generally follows a pattern: (1) geographic information, (2) processing and (3) visualization (the orange outer circle in Figure I.3). However, this sequence is often not so linear, and there is frequent to-ing and fro-ing between operations, especially with the development of digital information visualization interfaces, which enable operations to be interactively linked. For example, an initial hypothesis on a question may lead to the mobilization of data, followed by a type of processing and visualization. The result sometimes leads to reconsideration of one or all of the operations.

Therefore, we propose an initial reading in light of this sequence of operations to clarify the processes discussed or used in the various chapters that concern entities and data, treatments and methods mobilized and re-presentation.

I.2.1. *Linking between data and entities*

Moving from a phenomenon to its measurement requires the conceptual clarification of the geographical entities being produced. For example, observing the spread of Covid (a phenomenon) requires us to make explicit the objects (mobile individuals, hospitals, towns, etc.) and operations that will be carried out to define the *geographical entities* that will enable us to approach the representation of the phenomenon. This conceptualization stage enables us to give meaning to the data being mobilized to illustrate a given phenomenon. This can be omitted when the aim is simply to *show data*, without any real reflection or link to a phenomenon or its analysis, as demonstrated by the success of dashboards (business intelligence tools) which automatically visualize data: the map is the data, and the processing is essentially used to manage technical issues of visualization within interactive environments.

Focusing on data processing in the sense of data analysis, the chapters in this volume all address the question examining the transition from *entity design* and associated issues to *information construction*, contextualizing it in relation to a variety of uses.

Certain chapters are based on a formalism, today considered as classic in the field of GIS, which consists of identifying, when describing entities, what belongs to the geographic dimension and what to the attribute dimension. A geographic object is defined in terms of a geographical dimension (XY), a thematic component (Z) and, where appropriate, a temporal dimension (T). Chapters 6 and 7 discuss specific transformations of these dimensions, and Chapter 8 outlines an extension for links between places.

Other chapters adopt an operational approach to data; the formalizations used focus on the issues associated with data interoperability, making it possible to give meaning to entities. This question is particularly relevant at a time of data "deluge", encountered with Big Data, or new data, from the Web, such as those mobilized in Chapters 2 and 8. Chapter 2 offers an epistemological perspective on this new paradigm and discusses methods for integrating it into geographic entities. This point is also addressed in Chapter 3 by formalizing the processing operations (and representations) that enable the integration of environmental "objects" of diverse origins. Chapter 5 presents another complexity of data construction, with the example of land management data (DVF: demande de valeurs foncières / land values request). Other related issues are discussed, such as the harmonization of international data to ensure comparability (Chapters 1 and 8), and statistical categories and their legitimacy (Chapter 4).

Hence, the variety of examples throughout the volume enables us to cover a wide range of data types and associated issues: administrative data, sampled or continuous data, big data, qualitative data, quantitative data, linkage data, etc. The examples also offer a wide range of levels of complexity. They also offer a wide range of levels of complexity: from simple location data with a single attribute (Chapter 2) to data requiring location reconstruction (Chapter 8) through disambiguation (natural language processing [NLP][2]) and whose form is a link between geographical entities. All the chapters make this entity-data link explicit, thus ensuring the articulation between the thematic question and its empirical and technical operationalization.

2 Also known as automatic language processing (ALP).

I.2.2. *From data to map*

I.2.2.1. *Creating indicators*

Perhaps the most recurrent operation is that of creating indicators and plotting them on the map. This involves operations on both the thematic and geometric components. These correspond to "traceable" operations, involving a simple calculation (a rate of change between two dates, a duration calculation, a discretization), a spatial calculation (accessibility) or the result of a statistical method involving assumptions, and a chain of more complex operations involving optimizations, for example (calculation of a principal component analysis [PCA] factor or regression residuals). These operations are dealt with in all the chapters, justifying them in relation to the issue addressed.

Before or during the creation of indicators, the question of geographical level arises (e.g. At what level should real estate transaction prices be analyzed? Which geographical level best reflects ethnic segregation?). These questions lead to aggregation operations (from neighborhood to municipality, for example) or simplification of geometric information (do we calculate accessibility at the centroid of the zone or at the edge of the polygon associated with the zone?)

More often than not, the question of the indicator and that of the geographical level are inseparable and refer back to the previous discussion on the definition of the entities observed. Chapter 4 discusses this issue in particular, and the fact that the indicators created may be "sensitive" to the size and/or shape of grids, a problem known as MAUP (modifiable areal unit problem). The question arises differently depending on whether the grids are neutral "containers" with no diversity of shape or size (which can be assimilated to homogeneous grids), and the interest is solely in content, or whether they are administrative (or power) grids that involve a certain complexity, as they are neutral neither thematically nor geometrically (shape and size).

I.2.2.2. *Analysis methods*

In the field of spatial analysis, the creation of indicators mobilizes formal, quantitative, statistical and mathematical methods. These are essentially statistical methods used to identify, describe and explain the spatial organization of a phenomenon. These processes can be used at different stages or for different purposes. For example, spatial interpolation can be a method for "constructing information" (sample data, Chapter 2), for reconstructing spatial organization (Chapters 3 and 4) or for simplifying information (point density, Chapter 2). Methods and maps are interrelated. Depending on the case, the methods inform the map, or the map as a data arrangement is integrated with the method. It seems important here to introduce a distinction between the types of methods that are mobilized throughout the chapters, and which can, depending on the context, attribute different meanings to the map:

– classical statistics versus spatial statistics: when the methods employed are derived from classical statistics, the spatial dimension is not integrated into the processing a priori; visualization (transferring thematic information onto geographical space) can then sometimes reveal spatial effects a posteriori. Chapters 1, 3, 4 and 8 are typical examples. When methods are derived from spatial statistics, the spatial dimension (location, spacing, neighborhood, etc.) is formalized directly within the method. Chapters 4 and 5 are emblematic in this respect, with methods incorporating distances, neighborhoods and accessibility. Chapters 2, 6 and 7 provide further light on this type of approach;

– descriptive versus explanatory statistics: the properties of spatial data challenge the use of inferential statistical methods: dependent data (spatial autocorrelation), existing at several geographical levels (MAUP) and which may be considered as unique cases. Several chapters revisit these issues and propose different approaches (Chapters 4 and 5);

– exploratory versus confirmatory analysis: finally, the book presents several cases where the map is integrated into the analysis process, either as part of an iterative process (Chapters 5, 7, 8) or within an interactive environment (Chapters 1 and 2). In this case, the map is both a representation and a data selection operator, positioning the analyst in a research approach based on exploration rather than confirmation of statistical hypotheses.

I.2.3. *Several visualizations*

Maps play different roles depending on when they are used in information processing (Figure I.2), but the forms they take are equally diverse. These forms are linked to semiotic and semiological choices. All chapters take for granted the sign system defined by Bertin (1967) in graphical semiology, which associates certain signs with the level of measurement they convey (quantitative, ordered, different). Interested readers can refer to fundamental works in cartography (Cauvin et al. 2010; Béguin and Pumain 2017). The volume as a whole presents a wide variety of cartographic forms. As the object of the volume is the cartographic production process, their esthetics or perception is not discussed, except in Chapters 6 and 7.

The choice of cartographic representation is linked to the type of spatial structure under analysis:

– first of all, spatial structures can emerge because of the transfer of the thematic dimension onto the geographical space. However, the spatial distribution of weights/stocks (proportional figure maps) will not be graphically translated in the same way as that of relative data (choropleth maps). The analyses derived from these representations are different and complementary (Chapter 4). Anamorphosis (Chapter 7) illustrates one way out of the "simple" transfer process, enabling both dimensions to be visualized simultaneously. Generally speaking, transfer operations allow spatial structures to emerge, even when several thematic dimensions are taken into account simultaneously (Chapters 1, 3, 4 and 5);

– when the relationships between locations are at the heart of the analysis, these are represented cartographically by lines joining the connected locations. This is proposed in Chapter 8 (see also Mericskay (2023), Chapter 4). Chapter 4 depicts another form of relationship, emphasizing differentiation between neighboring units with "discontinuity" maps;

– finally, the analysis of processes and dynamics leads us to integrate the temporal dimension into the representation. To this end, a variety of graphical methods, including animation, are used to integrate time into cartographic visualization (Chapter 6).

These initial cartographic forms, which most often serve to reveal structures, may be succeeded by maps in which the cartographic choices seek, through graphic metaphor, to highlight the spatial and sometimes spatiotemporal structure of the phenomenon (partitioning the world in Chapter 1, delineating borders in Chapter 3, discontinuity in Chapter 4, spreading epidemics in Chapter 6, accessibility in Chapter 7). These maps feature greater graphic creativity and have the objective of conveying a message.

The development of visualization platforms enables the "raw" visualization of databases, with the aim of exploring the data itself (Chapter 2). This automation is based on cartographic know-how and associated processing. But this systematization, with no underlying question and no semiological adaptation to the question, goes hand in hand with a certain cartographic standardization that must be examined.

I.3. Secondary reading: relationships between the chapters

As in Figure I.1, the chapters can be organized in a loop, as they have been designed with a progression in mind. They have been designed in pairs to highlight certain stages, and the result shows that a number of other dimensions come into resonance with other pairs of chapter (Figure I.3).

– Chapters 1 and 8: One opens and the other closes this volume. These address the question of *relationships*: Chapter 1 looks at statistical relationships and Chapter 8 looks at the spatial relationships between entities. Both deal with a specific cartographic scale, that of the world, which raises cartographic questions that will be illuminated in two different ways. These two chapters introduce the discussion on *data exploration*, wherein the map is a tool that enables us to question the complexity of relationships, to go a step further in the thinking and in the expression of hypotheses, while also being the medium for understanding their organization.

– Chapters 2 and 3: The focus of these two chapters is on the first stages of transformation, namely, *data*: its design, acquisition and integration. The chapters discuss these issues in an original way, approaching the link between *cartographic objects and data* from a radically opposed point of view. Chapter 2 situates itself in the new paradigm of geographic information, referred to here as *new Web data*. It raises the following question: how can these data, which are produced in contexts often far from a protocol precisely adapted to an analysis, or in a participatory context, be integrated so as to serve analysis? Chapter 3 revisits the *construction of cartographic objects issues* for the observation of continuous phenomena, mainly in the context of the environmental field.

– Chapters 4 and 5: Each of these two chapters offers an extremely pedagogical approach, mobilizing *statistical modeling* to reveal forms of organization, that of racial segregation in Chapter 4 and that of a form of social segregation in Chapter 5. The methodological approach is slightly different, with Chapter 4 being more *descriptive* and Chapter 5 being more *inferential*. Both chapters discuss information construction, spatial zonings identification, MAUP and spatial autocorrelation. They clearly illustrate the range of choices that can be made during a data processing workflow, and how the map is at once data, a graphic representation and the result. The two chapters revisit this practice at each stage.

– Chapters 6 and 7: Each of these chapters offers a *panorama* of transformations associated with a specific dimension – that of *time* for Chapter 6 and that of *space* for Chapter 7. Chapter 6 proposes a *formalization of the data* used as an input to this review of cartographic solutions for integrating time. Each visualization is discussed in relation to the choices made on the data and the desired effects. Chapter 7 puts forward a series of *methodological formalizations* underpinning cartographic transformations and discusses the effects of these transformations on the basis of a single example. Both chapters deal with the question of *change*, of state in Chapter 6 and of form in Chapter 7. The two chapters converge on questions of *movement*.

I.4. A map of the chapters

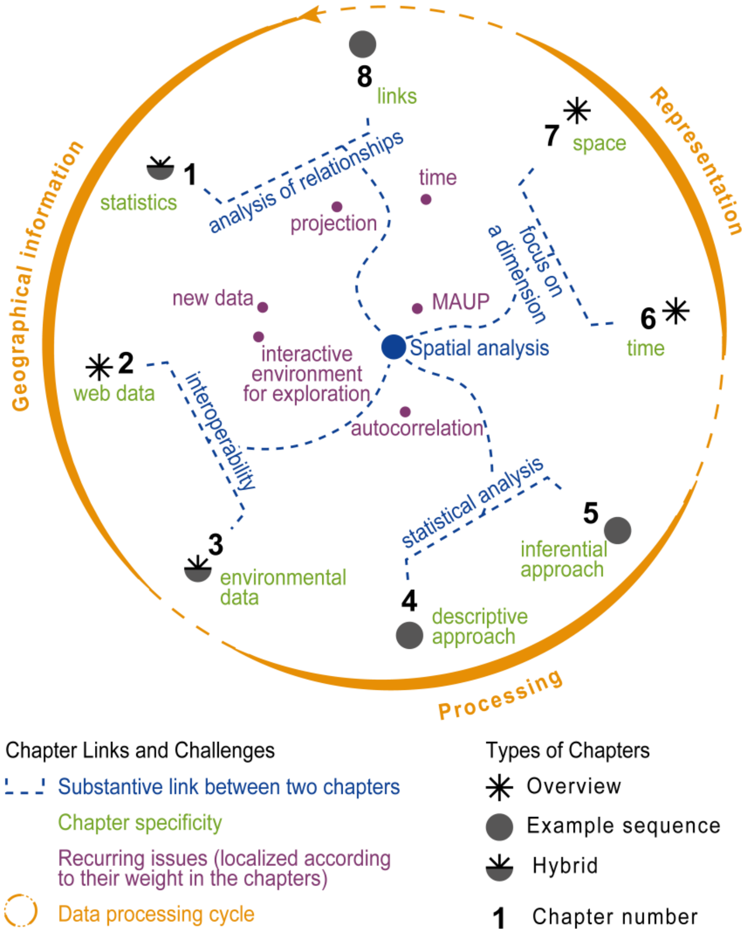

Figure I.3. *Chapter map: how they are linked, on which concept they rely*

Figure I.3 positions the chapters in relation to each other, and to the various points raised in this introduction.

– First, the chapters are positioned along a continuum identifying the key stages of a cycle that links the data to the map (orange circle). Of course, all the chapters cover all stages; even so, they have been positioned here to reflect as close as possible the key insights they elucidate.

– Signs remind us of the approach of the chapters: between overviews, unfolding examples and formal presentations.

– The chapters are linked by a dendrogram illustrating the proximities between chapters that the second reading has just described (blue). What unites them all is the fact that they mobilize *formal methods and models* for these transformations and are part of a *spatial analysis* approach whose aim is to reveal shapes and organizations.

– Concepts (green) highlight the specific features of each chapter, over and above the similarities mentioned above.

– A number of other concepts (purple) are covered in the chapters and are common to all. They are positioned according to their importance in the chapters.

Therefore, as this “map” illustrates, the chapters interconnect, and complement each other, refer to each other, sometimes repeat each other, and every so often respond to each other. Together, they cover a wide range of cartographic practices and productions, provide opportunities for reflection in many directions.

I.5. Acknowledgments

The content of all the chapters was the subject of exchanges between all the authors. Each chapter of the book was finalized through an iterative process of internal cross-assessment, including external experts (Marc Bourgeois, Julie Vallée, Sébastien Oliveau, Lena Sanders, Nicolas Lambert, Clarisse Didelon), the book’s two coordinators and the Cartography theme manager, Colette Cauvin-Reymond. Special thanks to the external reviewers for their willingness to be involved and their helpful suggestions, and to Colette Cauvin-Reymond for her invaluable advice and support. The whole process of writing the book gave rise to rich methodological exchanges. The assembled chapters reflect this richness and diversity of approaches to the map. We would like to thank the authors once again for their original contributions, which shed light on the different ways in which the map is used in our “in vivo” approaches.

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