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# Explore maps as you read a comic book

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**Abstract.**

While maps have been evolving towards more interactivity and pan-scalar display, their design did not change this much, lacking progressiveness between the numerous maps at different zoom levels. Drawing inspiration from the well-established theories of comics and cinema, this article explores the essential mechanics of these mediums, particularly focusing on the common challenge of progressiveness in their panoptic design. Progressiveness, defined using terms from comics, cinema, and music, becomes a pivotal concept in pan-scalar map design, emphasizing consistency, comfort in reading, and the absence of breaks. The goal is to elucidate the elements within the cartographer's control during the pan-scalar design process, akin to film editors manipulating semantic, syntactic, and rhythmic functions. This article not only conceptualizes progressiveness but also proposes initial measures to enhance it in pan-scalar maps, thereby expanding the understanding of the design space and the diverse choices available to cartographers.

**Keywords.** cartography, multi-scale, progressiveness, comics, music, cinema

## 1 Introduction

Of the two great forms of storytelling with images, both cinema and comics have mastered their successive arrangement of images to the narrative ends. However, despite the apparent irreducibility of the image and the story, there are sometimes exceptions – "mute" comics, and plotless movies – that argue the true definition of the medium, reducing it to its form. Deprived of the narrative apparatus, the enlargement of the definition to "juxtaposed sequential static images" (McCloud, 1993) raised other questions, as it can either designate comics, movies (being very slow comics before being projected) or pan-scalar maps. Referred to as "interactive zoomable applications composed by numerous maps at different zoom levels where each representation at an individual scale is incomplete to facilitate pan-scalar navigation" (Gruget et al., 2023), pan-scalar maps still lack theory in the best way to compose its pan-scalar design. This results in many pan-scalar maps mainly adhering to quality criteria defined for the classical static maps. However, we consider that the primary consideration of a pan-scalar design should be the articulation of its frames, before assessing the quality of each map, to avoid disorientation as defined in (Touya et al., 2023).

By approaching comics, cinema, and music, in their essential form, we dive into well-theorized and fully matured mediums that provide a better understanding of their mechanical construction, including articulations. In this article, we will therefore define progressiveness using concepts coming from comics, cinema and even music to theorize what progressiveness means in the context of a pan-scalar map while demonstrating its fundamental role in the design process. By conceptualizing progressiveness, the goal of this article is to better understand what a cartographer can manipulate in the pan-scalar design process. As it is, we are uncertain about which variables we can employ to enhance progressiveness. By exposing the design space, we therefore want to show the diversity of possible choices to improve progressiveness through analogies. Much as film editors, employing the three functions of editing - semantic, syntactic and rhythmic - to make a movie (Aumont, 2015), cartographers must also consider these three aspects in their work. The first part of the article is dedicated to the conceptualization of progressiveness, borrowing the three notions from the French writer on film theory Jacques Aumont, and the second part is dedicated to our first propositions for assessing progressiveness in pan-scalar maps.

## 2 Progressiveness in other media

The following subsections dive into the medium's construction, between sequences and breaks, before detailing the three foundations conceptualized by Jacques Aumont, i.e. the meaning, rhythm and consistency, while taking examples in other media such as comic books, music and cinema, to better define progressiveness.

## 2.1 Sequences and breaks

Before diving into the different levers of the designer to improve progressiveness, it is important to better define its medium: the pan-scalar map. Pan-scalar maps exhibit multiple representations of the same geographic objects as scale changes (Mustière and van Smaalen, 2007), and can be derived from a multi-representation source database or from a single database with map generalisation and filters to show the good representation at the good scale. Each representation corresponds to what we call a *map level*, displayed at some range of zoom levels. Even though zoom levels are now continuous in current pan-scalar maps, a same map level is usually displayed at one zoom level $n$, which means from level $n$ included to level $n+1$ excluded. Sometimes, the range of a map level is bigger than one zoom level, which means that this map level is shown at several zoom levels and the map reader only sees an enlarged or reduced version of the map level while zooming in and out. But with the current tools for web mapping such as OpenLayers or Leaflet, we could imagine a pan-scalar map where the map level changes every 0.5 zoom level.

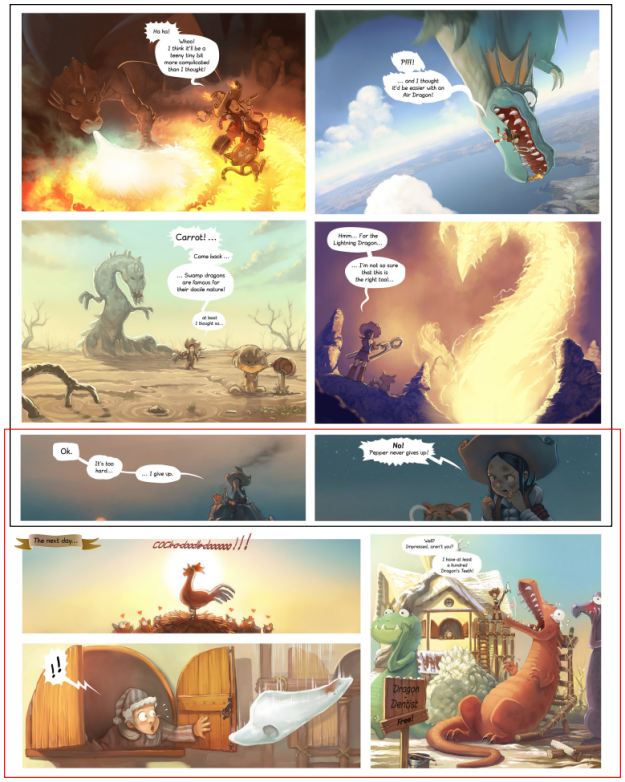


**Figure 1.** Two sequences in the comic Pepper and Carrot (©David Revoy) bound by a link of consistency of meaning.

In this article, we assimilate the cartographic designer with a director in cinema or a composer in music. Each representation and each articulation has to be carefully crafted by him. Much as comics, relying on sequences of vignettes, pan-scalar maps are produced by designers who define multiple map levels that follow one another, and designed as a consistent suite. In Figure 1, we draw a parallel between the consistency of map levels in cartography and panels in comics, which defines sequences. In this example, both sequences illustrate one narrative step in the story: the dragon hunt, then the new method. The consistency can either rely on the narration, or the construction of panels, with the first sequence displaying serial images of each dragon hunted. In cartography, sequences are not built on narration but on cartographic hierarchy: a spatial organization which determines what theme is in the foreground and the background of a map. Linked to the information one is seeking at a specific scale, these various representations of space correspond to different modes of reasoning applied to the geographical area (Ruas, 2004). There can be several types of hierarchies in pan-scalar topographic maps, from the city or cadastral maps (from 1:1k to 1:10k) to topographic maps (from 1:20k to 1:50k) or roads maps (from 1:100k to 1:250k), as illustrated in Plan IGN, a pan-scalar map produced by the French national mapping agency (Figure 2). Each hierarchy is displayed in sequences of three (for city areas) to five (for buildings) map levels.

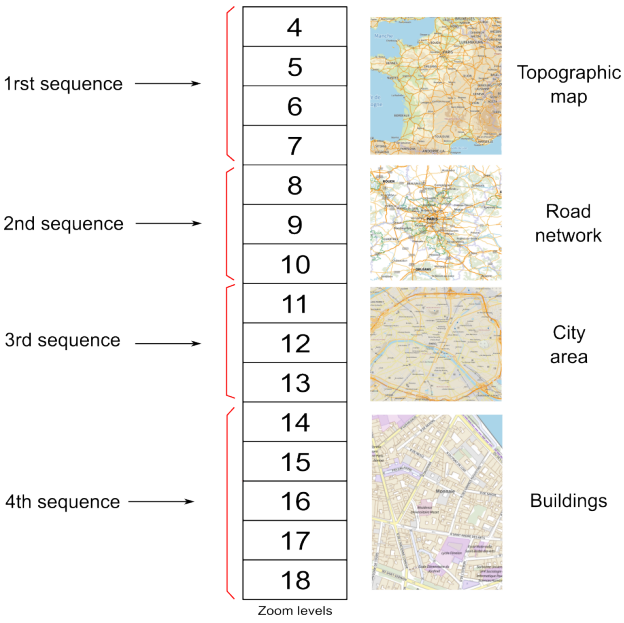


**Figure 2.** The sequential structure of Plan IGN, composed of four main sequences displaying the same map levels over several zoom levels.

Spatial organization is not the only one defining sequences, as we can see between the 3rd and the 4th sequence, where each sequence displays a different vertical spatial hierarchy of buildings. By vertical hierarchy, we mean a class of relations that links objects and groups among different map scales, resolutions, or levels of details, defined in (Steiniger and Weibel, 2007). For example, there is a vertical relation for cities from their representation as a set of building polygons to their representation as a built-up area (Figure 3). Now that sequences are defined, the challenge faced by cartographers lies in the transition

from one scale to another within a sequence and between sequences.

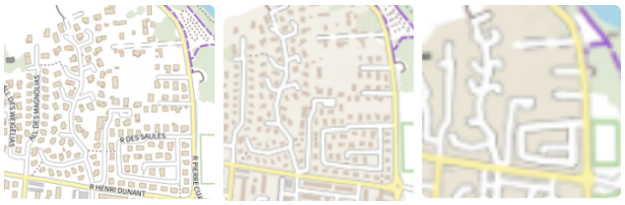

**Figure 3.** A closure by superimposing both buildings and urban areas in Plan IGN

We define a *closure* as a succession of transitional maps between two sequences, leading to a more significant leap in abstraction to highlight a change for the user, similar to how punctuation marks in language help in better understanding the text. Transitions between cartographic hierarchies especially need to be perceived by users to show a different spatial structure. In this aspect, we highlight how meaningful a closure can also be in comics, demonstrating its capacity to produce humorous effects, as illustrated in Figure 4 where the abstraction gap highlights the difference between seriousness and pathos. With this example, we want to show how designing pictures with bigger gaps of abstraction can serve meaning, both in comics and cartography. In cartography, a closure can be crafted by superimposing both abstractions, as illustrated in Figure 3.

However, closure can also be perceived as *breaks*, i.e. sudden and pronounced disruption of fluidity and harmony in visualization between scales, while zooming in and out. Occurring either between or within sequences, breaks can be caused by the designer's incorrect choices in sequencing or poorly managed gaps. When such situations arise, map levels lose their continuity of meaning, akin to the discontinuity sometimes found in comics. For example, Figure 5, analysed in (Nofuentes, 2010) shows a comic with breaks as it arbitrarily juxtaposed images. Yet, both the perception and the intensity of breaks rely on human attention. Therefore, users can be subject to change blindness, which refers to the inability to detect changes (and breaks) to an object or scene ((Simons and Levin, 1997)).

### 2.2 A continuity of meaning inspired by comic books

The study of a semiotic system must, first of all, pass through a decomposition into constitutive elementary units: the smallest commutable elements that have a proper meaning, to paraphrase Christian Metz (Metz, 1977). Two signifying elementary units emerge in the dissection of comics: the discrete units composed of isolated lines or groups of lines that form drawings, and larger units called "panels" (Groensteen, 1996). Similarly, pan-scalar maps are also composed the same way, the groups of lines corresponding to the topographical elements displayed on the map and panels being the map level displayed on the computer/smartphone screen.

**Figure 4.** A closure displaying a meaningful gap of representation in comics (©Bérénice Le Mao)


**Figure 5.** Beginning of a comic built on breaks called "Mise au monde" (©Alvaro Nofuentes)

In the realm of micro-semiotics, topographical elements are handled by generalisation, which serves a crucial func-

tion as it facilitates the establishment of an identification link between data presented in different forms. In cartography as in comics, the significance of data is indeed intricately linked to its form, underscoring the inherent challenge in generalisation processes, whose goal is to change the form while keeping the meaning. Yet, this intricate process must not only preserve the meaning of an element consistently across all scales of its representations but also convey its relationship with elements in its vertical spatial hierarchy while maintaining its links with the environment. In Figure 6, the cartographic style plays a crucial role in the continuity of meaning, with consistent use of colour for each vertical hierarchy, facilitating easy identification despite the geometric changes between maps 3 and 4. The clear perception of the various vertical hierarchies, including highways, major roads, and simple roads, also allows the user to maintain orientation while exploring the pan-scalar map.

**Figure 6.** An example of a vertical hierarchy between roads structured by importance

To ensure a good continuity of meaning, designers must also consider the overall construction of each map level, akin to the role of panels in comics. In the previous section, we saw how structuring information can convey meaningful insights, through cartographic hierarchy. In general, each map level needs to rely on repetitions, to create meaningful transitions. Comics are built on the same technique, illustrated by Figure 7, where the repetition of characters is effectively conveyed between the first and second panels and between the third and fourth panels. When identification through shape suffers from great abstraction, identification is relayed by other means, like between panels two and three, where the character is identified by the repetition of colour. Groensteen calls this technique the “iconic redundancy”, often seen as a “price to pay” to ensure the continuity of meaning (Groensteen, 1996).

### 2.3 Rhythm requirements in maps: a glance in musicology

Unlike cinema, pan-scalar maps (and comics) showcase static images. However, to ignore speed — its images are immobile and no voice imprints a delivery on the dialogue — does not suggest any less of a cadenced reading, where each new panel hastens the story while, simultaneously, holding it back (Groensteen, 1996). Figure 8 illustrates this notion by presenting the same story with two different pacing approaches to highlight the varied time intervals between panels.

Pan-scalar maps, much like comics, can be considered a form of "subtractive and additive art" (McCloud, 1993),


**Figure 7.** Smooth panels transitions in the comic Pepper and Carrot (©David Revoy)


**Figure 8.** A story displayed in slow (left) and fast (right) cadencies, by Scott McCloud.

emphasizing the importance of refining their rhythm. We can divide rhythm into two categories: the tempo being user-defined map usage rhythm, involving the pace of the user zooming in, zooming out, and panning, just like a conductor reading scores; and the cadence as the rhythm of the map conceptualized by the cartographer-composer, determining the distance in zoom levels before observing a change in representation along with their degree of abstraction.

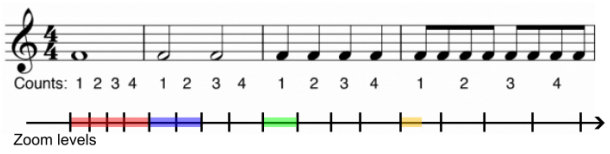


**Figure 9.** An analogical relationship between music and pan-scalar maps.

Employing musical terminology, each zoom level corresponds to a beat, while a map level represents a note (figure 9). A map changing at each zoom level (figure 9 in

green) is akin to a quarter note, hastening the pace, while a whole note corresponds to a map level sustained over four zoom levels, in a slower cadence. We refer to this initial cadence as a map cadence, as it indicates the number of zoom levels for which a map level is displayed.

Yet, there is another cadence pertaining exclusively to data within a map, as they undergo generalisation throughout the pan-scalar map: the cadence of abstraction. When data experiences a substantial abstraction gap (Figure 10 in red), the pace is expected to increase, posing a threat to the continuity of meaning. On the contrary, a slow generalisation process (Figure 10 in yellow) can contribute to the iconic redundancy described previously in the last section.

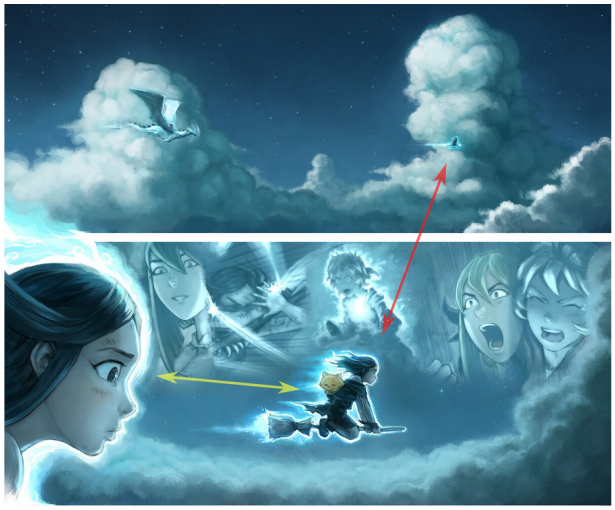

**Figure 10.** Two different cadences of abstraction (fast in red, slow in yellow) in the comic Pepper and Carrot (©David Revoy)

In summary, both cadences are crucial for composing a pan-scalar map rhythm. We have made the deliberate choice in this article to avoid delving into tempo, as its determination is largely contingent on individual user preferences.

### 2.4 A Cinematic Consistency Assessment

Beyond rhythm, "one of the key constraints influencing the production, interpretation, and general apprehension of films" (Renoue, 2007) relates to consistency and its construction around *isotopy*: "generic or specific features highlighted by their permanence or redundancy" (Renoue, 2007). 'Un Chien Andalou', a plotless movie directed by Buñuel and co-written with Salvador Dalí, exemplifies the notion of isotopy. Consistency is not found in the narration but in the recurrence of death figures (Figure 11.1) or the permanency of a mysterious box (Figure 11.2). Likewise, consistency assumes a parallel significance in pan-scalar maps. In this article, we categorize pan-scalar consistencies into four families, drawing inspiration from principles in cinema theory.

1. Semantic consistency, encompassing consistencies of space, shape and colour, is responsible for maintaining the continuity of meaning. By respecting the principle of non-contradiction, a pan-scalar map can ensure logical consistency and respect for the logical spatial relationships among geographical entities, preventing network disconnections among others. In cinema, an inconsistency of this type results in a mismatched cut, a technique used in Méliès movies that should be avoided in cartography.

2. Predictability also contributes to consistency, relying on "repetitions that enable the audience to grasp the structure through a memory process that recalls other motifs and attempts to assemble them" (André et al., 2018). This mnemonic consistency integrates both conventions (e.g. vertical hierarchy of roads represented in Figure 6) and pattern preservation, creating a causal effect. Users anticipating a gradual disappearance of elements across scales, while zooming out on a pan-scalar map illustrates this notion. While some films, such as those by Hitchcock, rely on deliberately crafted dead ends, a pan-scalar design must, on the contrary, steer clear of such inconsistencies.

3. Beyond repetitions, consistency is maintained through constancy, defining the essence of sequences. Across the pan-scalar map, this sequential consistency enables users to better grasp the boundaries of each sequence, through a rhythmic constancy. Figure 12 illustrates this concept with a movie crafted around sequences that adhere to the same back-and-forth arrangement pattern (Palma, 2021).

4. The last consistency is the one establishing homogeneity. This harmonic consistency is in charge of the organic unity of a pan-scalar map, in trying to minimize, as much as possible, the differences and partial autonomies of sequences. A map without harmonic consistency is like an inconceivable entity (ex: Penrose triangle) where we perceive something conceivable from mutually irreconcilable perspectives. Designing multi-scale legends (Gröbe and Burghardt, 2019) can be a way to achieve this homogeneity.

By the end of this section, we can therefore define progressiveness as *the minimization of breaks of meaning, rhythm and consistency.*

## 3 Assessing progressiveness in a pan-scalar map

In this section, we present several experimentations and their methodologies revolving around the assessment of pan-scalar progressiveness using the different concepts previously defined.


**Figure 11.** Un chien andalou, a movie directed by Buñuel and constructed around isotopies of death (1) and permanency of a box (2)

**Figure 12.** "Méditerrannée", a movie directed by Pollet constructed around a series of plans in a back-and-forth arrangement

### 3.1 The ScaleMaster: a tool to illustrate sequences and rhythm in pan-scalar maps

To best exemplify sequences and rhythm, we decided to use a ScaleMaster: a decision tool specifically crafted to "guide multi-scale map design" by emphasizing "changes to the map display, including symbol design or symbol modification" (Brewer and Buttenfield, 2007). Each line of the tabular document corresponds to specific data, detailed across scales with annotations explaining the generalisation processes that occurred. We believe that adopting a method akin to a conductor's score is indeed the most effective approach for examining the two previously defined cadences: the cadence of abstraction and the map cadence. We adapted the tool to improve our ability to visualize abstraction gaps, assigning them distinct colour degrees. Furthermore, map cadences are not analyzed by scale but rather by zoom levels, the new foundational unit of pan-scalar maps.

Figure 13 displays a partial section of a ScaleMaster, built by observing the hydrographic network from IGN Plan, following the instructions described in (Brewer and Buttenfield, 2007). The complete version[1] includes the ScaleMaster of Google Maps and OpenStreetMap. This figure is taken from the scale master on the IGN Plan, a pan-scalar map produced by IGN, the French national mapping agency, illustrating three elements: river lines, areas and water areas (i.e. lakes, ponds, etc.). The first noticeable aspect pertains to the rather long map cadences, with each abstraction map spanning across three zoom levels. This design choice might cause breaks, as the longer you wait before changing the representation, the greater the abstraction gap will be, as seen in Figure 13 and picture c of Figure 14. The number of zoom levels is indeed limited to approximately 20 levels, making it challenging to implement a generalisation process that accommodates both long map cadences and slow abstraction cadences (see pictures b and d in figure 14), while keeping the map uncluttered. To foster progressiveness, we therefore believe it is advantageous to engage in generalisation more frequently to minimize abstraction gaps.

Dumont demonstrates how effective adding intermediate representations is by generating five abstraction maps between zoom level 15 and 13 (Dumont, 2018). However, even if she notes a clear improvement in efficiency, she also laments the difficulty and time required to produce them. In this article, we show that generalising at each zoom level is enough to significantly improve progressiveness. Therefore, we believe the more progressive map in Figure 14 is the one in line (a), with enough generalisation at each zoom level.

Much as time signatures in music, which indicate the number of beats in each measure and the type of note that receives one beat, a sequence is fundamentally defined by rhythmic unity. Figure 15 illustrates a ScaleMaster of water areas, employing the musical tool MuseScore. This visualization serves the dual purpose of indicating the number of map levels within each sequence and depicting rhythmic variety between sequences. However, is

[1]The full ScaleMaster of Plan IGN, Google Maps and OpenStreetMap is available here: https://zenodo.org/records/10406173

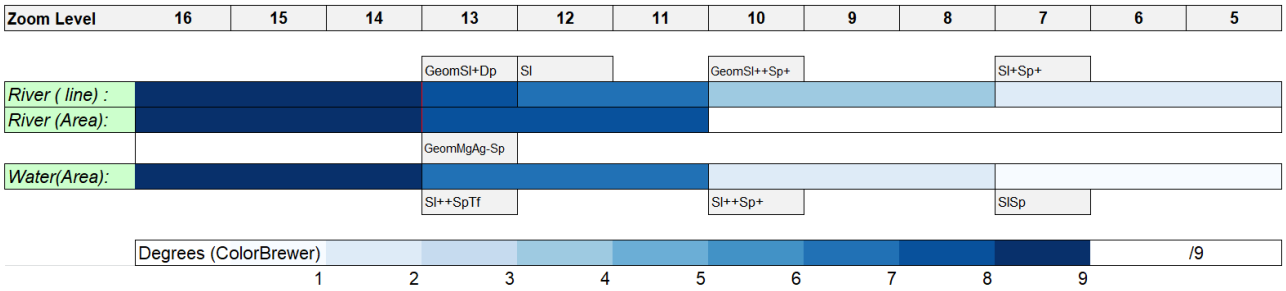


**Figure 13.** An illustration of the ScaleMaster of Plan IGN, a pan-scalar map created by IGN, the French national mapping agency.

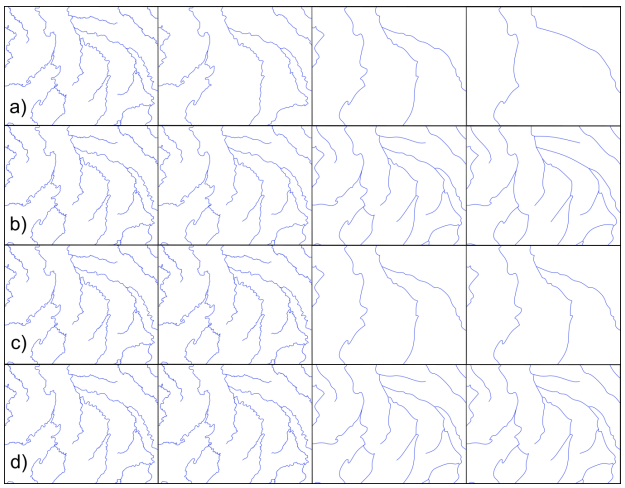


**Figure 14.** Four examples of river generalizations, using different combinations of map cadences and abstraction cadences: a) A generalisation with fast map cadence and fast abstraction cadence, b) A generalisation with fast map cadence and slow abstraction cadence, c) A generalisation with slow map cadence and fast abstraction cadence, d) A generalisation with slow map cadence and slow abstraction cadence.

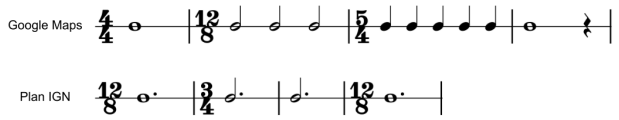


**Figure 15.** Two map cadences of water areas from Google Maps and Plan IGN.

rhythm determining the sequence structure or is it the opposite? We believe that the connection is significantly more intricate and nuanced than it may initially seem. In this article, we believe that map cadences should take into account data and its right decomposition throughout the generalised map levels. However, adapting the rhythm within each sequence to achieve consistency across the entire pan-scalar map can also contribute to progressiveness, much as Google Maps and Plan IGN. Observing figure 15, it is therefore notable that Google Maps exhibits a predominantly binary sequencing, unlike Plan IGN whose rhythm is primarily ternary, throughout the pan-scalar map. Therefore, we advocate for a continuous rhythm within a single sequence as it facilitates a more effective detection of closure while maintaining consistency throughout the pan-scalar map to establish a logical framework for map cadences.

In the broader perspective of the pan-scalar map, rhythm should not be designed individually for each theme or layer of the map but rather in harmony with the rhythm of other data. Cartographers can either promote a simultaneous rhythm across all themes (Figure 16 in green) or successive rhythms (Figure 16 in pink). This ability to handle polyrhythm is also one of the strengths of a ScaleMaster, as it mirrors the structure of a conductor's score. In this regard, Georges Méliès offers an interesting point of view regarding the entrance of the actors in his films, asserting that "phases should unfold successively, not simultaneously", to avoid a "chaotic scenario of individuals in motion" which could disturb the audience, leaving them unsure of where to direct their attention (Méliès, 1907). Similarly, we posit that a simultaneous rhythm across data like Plan IGN (Figure 16) is more likely to create breaks.

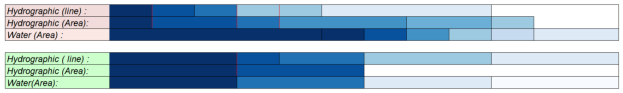


**Figure 16.** Two different polyrhythms, with OpenStreetMap (pink) encouraging a successive display of its data, contrary to Plan IGN (green) that favours simultaneity.

### 3.2 Detecting pan-scalar breaks

In this article, we believe that progressiveness should be defined as the minimization of breaks of rhythm, consistency and meaning across all scales and themes. Therefore, this section aims to present a corpus of breaks, analysed in various pan-scalar maps of different countries, and which can be thoroughly examined through this link[2]. Given the numerous ways in which progressiveness can be compromised when using a pan-scalar map, our goal is to better formalize breaks to help designers avoid them in the future.

Breaks involve sudden and pronounced disruptions of fluidity and harmony in visualization between scales. A break

[2] "https://zenodo.org/records/10406173"

of meaning is illustrated in Figure 17 where the road network is constructed by overlaying different layers of vertical spatial relations, which leads to disconnections when the overlaid layer disappears. To avoid this common break, we believe it is essential to ensure the overall consistency of a set of data, by avoiding decomposing a network according to attributive data. This statement aligns with Thomson and Richardson's roads network selection, focusing on strokes - sets of arcs that appear to be continuous to create linear elements - rather than on segments (Thomson and Richardson, 1999).


**Figure 17.** Disconnections in the road network in OpenStreetMap

Figure 18 exemplifies a consistency break, with a vertical spatial hierarchy of the road network represented by a range of colours that varies from one representation to another. Continuity here is solely achieved through shape, as colour consistency is entirely disregarded. This design choice may lead the user to mix hierarchies. Nevertheless, hierarchy is still present and discernible through the style, thereby mitigating the intensity of the break. In this article, we seek to emphasize the importance of refining style, as it can substantially improve both consistency and meaning by preserving hierarchies.


**Figure 18.** A colour inconsistency of the road network in the pan-scalar map of Luxembourg

The last type of break is illustrated in Figure 19, with a rhythmic break of roads, from a complex and detailed representation to a simple monochromatic linear depiction. Between the second and third map levels, the abstraction break is too pronounced, making it challenging for the user not to lose their landmarks, defined as "graphic anchors that are visible across multiple scales" (Touya et al., 2021). With this example, we want to show that rhythm has a direct impact on clutter, which is "an excessive amount of information in an image, and/or a disorganization of the information" (Rosenholtz et al., 2007). By skipping map levels due to a fast map cadence, designers run the risk of generating excessive clutter at some point, hindering the perception and understanding of data.


**Figure 19.** A rhythmic break in the pan-scalar map of Switzerland

Nevertheless, breaks are rarely of a single type and in most cases, a break of meaning is often combined with a break of rhythm or consistency, making it more difficult to ensure progressiveness. In Figure 20, we can observe a dual break in meaning and rhythm. The third map level displays well-visible main roads. However, in maps 1 and 2, distinguishing the main roads seen previously becomes challenging as all roads are perceived as equally important, resulting in a non-hierarchical network due to a big gap in rhythm. Contrary to Figure 19, where style could help remember the vertical spatial hierarchy of roads, the meaning is here compromised as the entire network is perceived in the same way. Hence, this break can be perceived with much more intensity, as progressiveness is only ensured by colour consistency.


**Figure 20.** A dual break in meaning and rhythm in Finland

Sometimes, breaks involve all three pillars of progressiveness, as illustrated in Figure 21 where the symbol of the hospital vanishes in the central map level, resulting in a loss of meaning exacerbated by the excessive abstraction between the maps, coupled with a lack of harmonic consistency. Therefore, to maintain a clear understanding of the hospital's location, it is crucial to rely on the building's shape before locating the hospital icon. This association is more effective when zooming out, but is hindered by a disruption in abstraction when zooming in. Excessive abstraction blurs the landmarks that rely on spatial relationships. Hence, it is essential to design progressiveness in a two-way process, to ensure the smoothness of both zoom in and out.

**Figure 21.** A non-progressive generalisation of a hospital in IGN Maps.

**Figure 22.** An example of a continuous generalisation disregarding closure in a pan-scalar map of Limburg, by Peng

In previous sections, we defined closure as an essential articulation between sequences. In this paragraph, we want to show that an absence of closure can be perceived as a break. Indeed, a pan-scalar map constructed around only one sequence disregards the different modes of reasoning applied to the geographical area (Ruas, 2004) and focuses on only on cartographic hierarchy. In Figure 22, we can observe a continuous pan-scalar map whose goal is to "help map users better keep track of their interested objects" to show that "it is visually smoother to merge simultaneously than to sequentially merge each pair of areas" (Peng et al., 2023). In this illustration, we choose to display 5 map levels of this map, but it is important to remember that there are many more map levels than zoom levels in this specific case. Focused on geometries, this pan-scalar map smoothly generalises data based on their respective shapes and semantics, which produces progressiveness issues. The road network gradually loses portions from the second map level onwards, eventually disappearing completely at the fourth level. Beyond the inconsistency in the selection, which causes the disappearance of a higher hierarchical level (in red) in the vertical relationship of roads before the intermediate level (in orange), we can note a gradual loss in meaning. From the fifth map level onward, the entire pan-scalar map only displays geometries of agricultural plots and cities, omitting both roads and rivers. This constitutes a major problem in terms of progressiveness. The sequence displayed is too long, which underscores the importance of segmenting a pan-scalar map into multiple sequences. This would have enabled the transformation of geometries according to the cartographic view readability, to ensure the persistence of its elements. For example, implementing closure would have converted the representations of the road and river networks, previously depicted as polygons, into lines. We believe that continuous generalisation is effective within sequences, to better identify the same data across consecutive map levels. However, closure is essential for a pan-scalar map.

### 3.3 A progressive map generalisation of rivers: a weaving between meaning, consistency and rhythm

We advocate for the essential role of generalisation, emphasizing the importance of avoiding breaks in meaning, rhythm and consistency to craft a progressive pan-scalar map. This section will therefore provide an illustrative exploration of how the preceding concepts can guide a pan-scalar generalisation process. We specifically focus on the hydrographic generalisation of the Adour-Garonne river basin, in France, from zoom levels 6 to 17. This example of generalisation demonstrates what it means to blend all these concepts to create a consistent rhythm, work in sequence, and reduce breaks.

Unlike the generalisation of buildings or road networks, where the focus is predominantly on establishing conventional consistency, hydrographic networks do not have any predefined vertical spatial relations, which explains why generalisation must instead prioritize the emphasis on its overall shape. To ensure semantic consistency, the first step involves the detection of hydrographic patterns, across the entire scale range of the map. In this example, we use a classification (Figure 23) of observable patterns within our basin, inspired by the categorization presented by (Howard, 1967).

For each pattern, we suggest an appropriate sequence of generalisation[3], that carefully considers meaning, consistency and rhythm aspects. Complex patterns, for example, typically require about 4 or 5 map levels (Figure 24.b) for proper generalisation, in contrast to simple patterns, which only need 3 (Figure 24.a). However, it is worth noting that each complex pattern is composed of multiple intertwined simple patterns. This observation is the reason why we propose multiple generalisation sequences for some patterns. In contrast to past river pattern generalisations (Shen et al., 2023), characterized by frequently accelerating rhythm, we propose a sequence (Figure 24.a) with a consistent rhythm and a selection that prioritizes read-

[3]Generalisations of each pattern are available here: https://zenodo.org/records/10406173

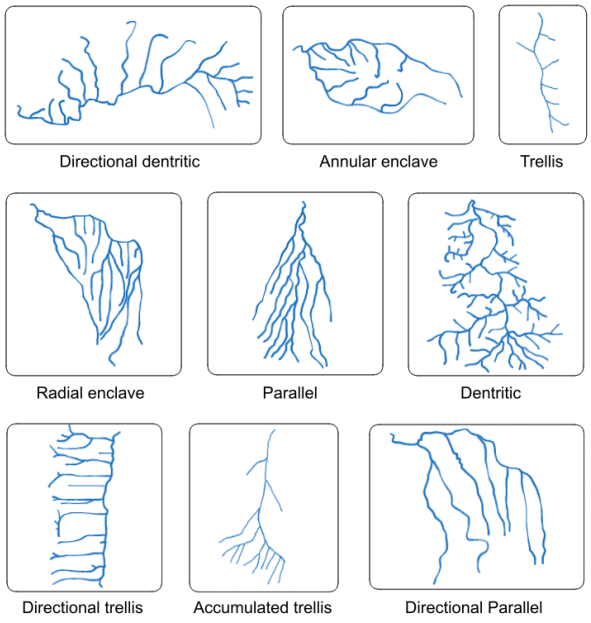


**Figure 23.** Classification of hydrographic patterns in the Adour-Garonne river basin

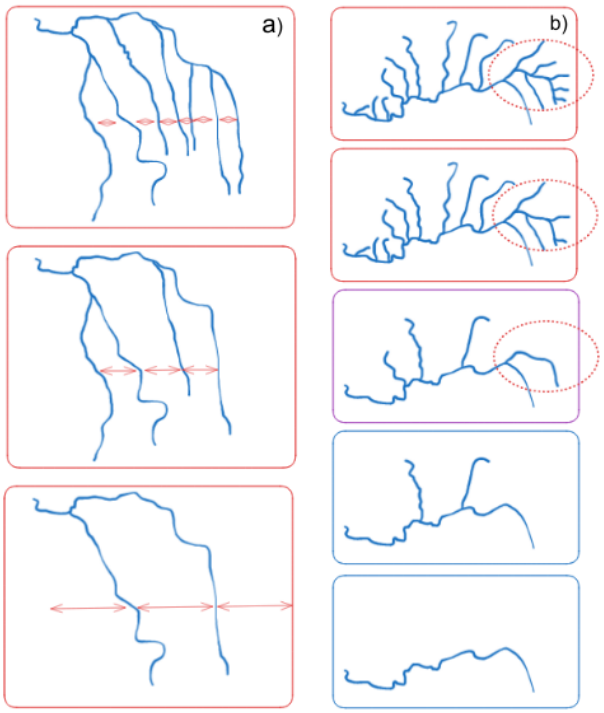


**Figure 24.** Two examples of hydrographic generalization with a) a sequence of a directional parallel pattern and b) an overlapping of two sequences of a directional dendritic pattern.

ability through an average spacing between rivers. Each sequence must revolve around the semantic consistency of the pattern, as depicted in Figure 24.a, where we understand, with each level of generalisation, that it represents a directional parallel pattern. By defining a finite decomposition for each pattern, the eye can efficiently train to recognize repetitions, thus generating mnemonic consistency reminiscent of musical motifs.

Previously, we observed recurring patterns within a single complex pattern. This interweaving of patterns is extremely crucial for understanding the entirety of the hydrographic network, constructed upon an interlocking of patterns associated with rivers of varying significance depending on the scale. In Figure 25, we can see a local pattern (accumulated trellis) associated with a secondary branch of a river. To effectively generalise all the patterns associated with secondary branches of the main river, it is necessary to understand how they are organized. In this example, the entire network represents another pattern (dendritic). This means that the designer has to finish generalizing all the small patterns corresponding to the secondary branches, before starting to generalise the dendritic pattern. However, these patterns do not have the same density (red: dense and green: not dense). Therefore, we emphasize the necessity to adapt the pace of generalisation according to density to effectively represent the next pattern. Indeed, generalizing at the same pace all patterns with different densities would have removed some secondary branches crucial for visualizing the dendritic pattern.

Upon analyzing the entire pan-scalar network, we observe the recurrence of patterns within specific scale ranges on the pan-scalar map. This leads us to categorize sequences into two types: micro-sequences, specialized in the appropriate generalisation of individual patterns (Figure 25), and meso-sequences at the pan-scalar map level, representing ranges of zoom levels in which specific patterns occur recurrently. Figure 26 therefore illustrates four levels of patterns, each representing a meso-sequence that integrates n sequences of listed patterns at this scale range.

The progressive generalisation of rivers proposed in this section is purely theoretical and cannot be obtained with an automated algorithm yet. This is our plan in the future to show that these guidelines for progressiveness can be followed by automatic algorithms, which is the condition to see more progressiveness in the pan-scalar maps we use every day.

## 4 Data and Software Availability

The data used in our experimental sections is open and available here: https://zenodo.org/records/10406173.

## 5 Conclusion

In approaching pan-scalar maps as a system, we wanted to show its organic totality, integrating a complex combination of sequences and articulations. In this article, we outline the three key pillars of a progressive pan-scalar design: meaning, consistency and rhythm. Thus, the exploration of these preceding concepts leads us to formu-

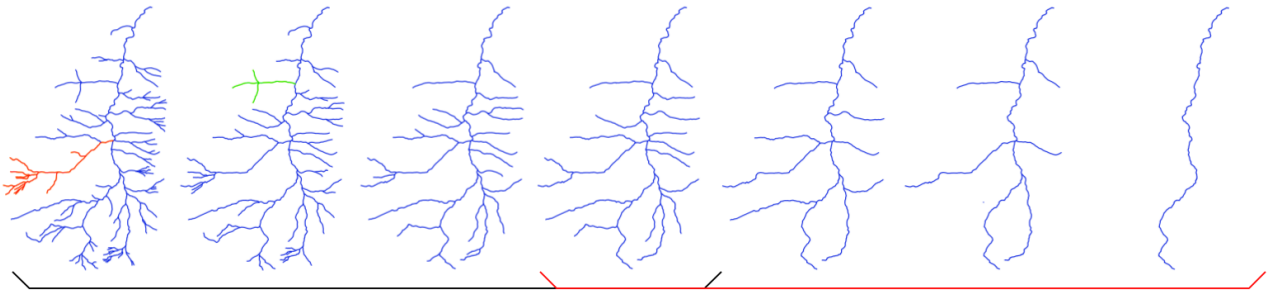

**Figure 25.** An illustration of two micro-sequences, with a first sequence illustrating the generalisation of patterns associated with secondary branches, and a second sequence dedicated to the generalisation of the dendritic pattern of the main river.

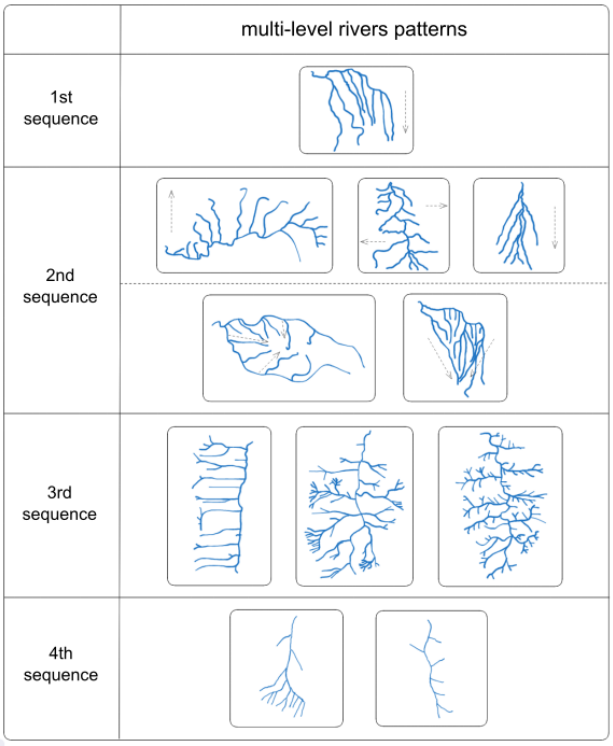


**Figure 26.** A multi-level classification of recurring hydrographic patterns in the Adour-Garonne river basin, structured by 4 four meso-sequences

late the definition of progressiveness as a minimization of breaks of the three kinds across all scales and themes. A map is not progressive if it introduces too much latency in the cognitive processing of cartographic information, either through a sequence of views with a too abrupt jump in abstraction, hindering the proper association of meanings, or through a disruption of constancy in rhythm or consistency. The various degrees of progressiveness arise from the diverse cartographic combinations of attention to meaning, rhythm, and consistency. The more a sequence of cartographic views utilizes cognitive devices of continuity, the more likely it is to be progressive. At the end of this article, we have successfully theorized variables related to progressiveness.

Now that we have identified them, we can proceed to experiment with these variables through user experiments. Moreover, our last exemplification of a progressive generalisation opens interesting perspectives, and techniques to automatically detect multi-level patterns should be considered in future studies. By providing a more precise definition of progressiveness, this article also paves the way for evaluation. There was a proposition to automatically evaluate progressiveness through generalisation constraints in (Le Mao and Touya, 2023), taking into account what appears to be in our model both rhythm and consistency. It would be interesting to follow this idea of constraints and propose progressiveness constraints monitoring rhythm, meaning and consistency breaks in different types of layers in the map. Furthermore, this study encourages us to broaden the scope of progressiveness to include interaction techniques. Is it possible and meaningful to engage directly with tempo, utilizing zooming techniques akin to the smooth scrolling experience employed by Google Maps, when a scroll of the mouse is now softened to a small 0.3 zoom level jump? Regardless, we believe that prioritizing progressiveness is crucial when developing new interaction techniques.

*Author contributions.* Bérénice Le Mao: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation. Guillaume Touya: Writing-Reviewing and Editing, Conceptualization, Methodology, Supervision, Funding acquisition, Project administration.

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