Looking at maps: reflecting on the role of Cognitive Cartography in the cartographic design process

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Abstract: This chapter explores the theoretical foundations and current developments in Cognitive Cartography, focusing on its implications for map design and user interaction. The first section analyses cognitive processes involved in map reading—particularly attention, perception, and cognitive load—highlighting how these are shaped by user-related factors (such as age, experience, or environmental conditions) and map-related factors (such as visual complexity and task demands). The second part addresses methods for evaluating optimal map use, combining subjective tools like user questionnaires with objective techniques such as eye-tracking. This dual approach allows for a deeper understanding of how users cognitively engage with maps, informing more effective and user-centred cartographic design. By bridging cognitive science and cartographic practice, this chapter contributes to the development of evidence-based strategies that enhance spatial understanding and communication.

Keywords:

- Cognitive Cartography
- Cognitive Load

- Map Design
- Perception
- Eye Tracking

1 Maps: more than just pretty pictures

Cartographic representation is Geography's natural language for explaining occurrences in the world, with maps serving as its preferred tool (Montello, 2002). Since the mid-20th century, it has been widely accepted that the primary function of maps is linked to communication, which directly depends on the explicit or implicit decisions made by the cartographer in designing and producing the map (Robinson, 1952).

There are **multiple perspectives** (Figure 1) **through which the process of understanding cartographic reading** can be framed (Mocnik, 2022), depending on the standpoint adopted: (1) the Representation Perspective, in which the map adheres to reality; (2) the Cognitive Perspective, which posits that individual perception of maps follows systematic patterns; (3) the Information Perspective, where maps are considered a means of communication; (4) the Pragmatic Perspective, wherein the map's appearance is determined by its intended use; (5) the Social Perspective, which acknowledges collaboration among cartographers to align their efforts; and (6) the Emergent Perspective, which accounts for the influence of external agents in rationalising design decisions in cartography. These perspectives, in any case, are not mutually exclusive but rather compatible with one another.

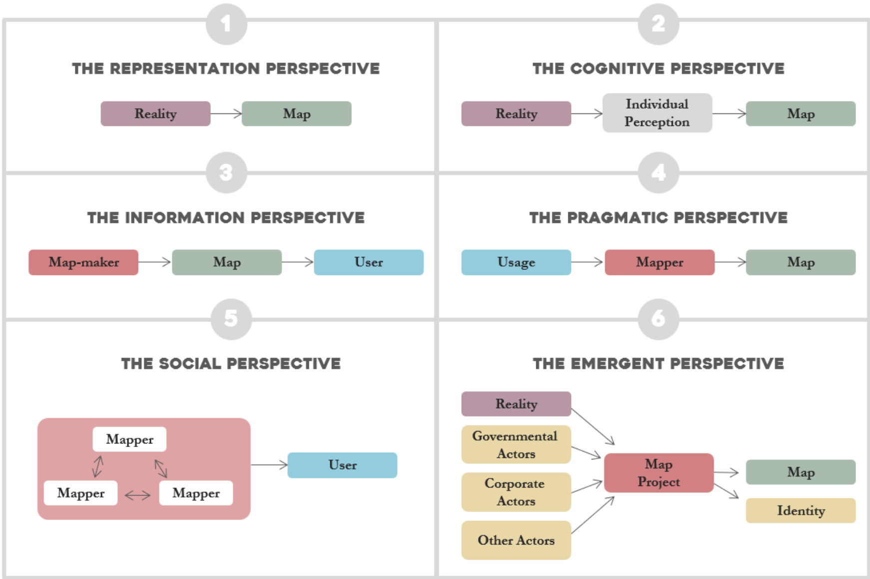

Figura 1: Global framework perspectives on understanding cartographic reading. (Mocnik, 2022).

Within the context of this chapter, the Informational Perspective is examined in depth to establish a connection between cognitive science and cartographic design.

2 From sender to symbol: the Cartographic Communication Chain

The Information Perspective aligns the phases of the cartographic process with the terminology of Communication Theory or SMCR model (Source–Message–Channel–Receiver) (Berlo, 1999) based on the premise that it effectively explains the encoding, transmission, and interpretation of geographic information in a simple, intuitive, and sufficiently comprehensive manner.

Building on SMCR, a workflow sequence is proposed (Figure 2), enabling a logical and coherent integration of the two traditional spheres of cartography—the production and use of maps—as established in classical models

(Koláčný, 1969). Additionally, a third sphere related to map design is incorporated (Zúñiga Antón, 2009). Organising all elements from various conceptual frameworks into a single scheme is not straightforward; however, it has been possible to delineate the position of each phase within the global framework. This working model specifically refers to the cartographic process associated with thematic maps, understood as those designed to analyse the spatial variations of one or more themes that can be geographically located.

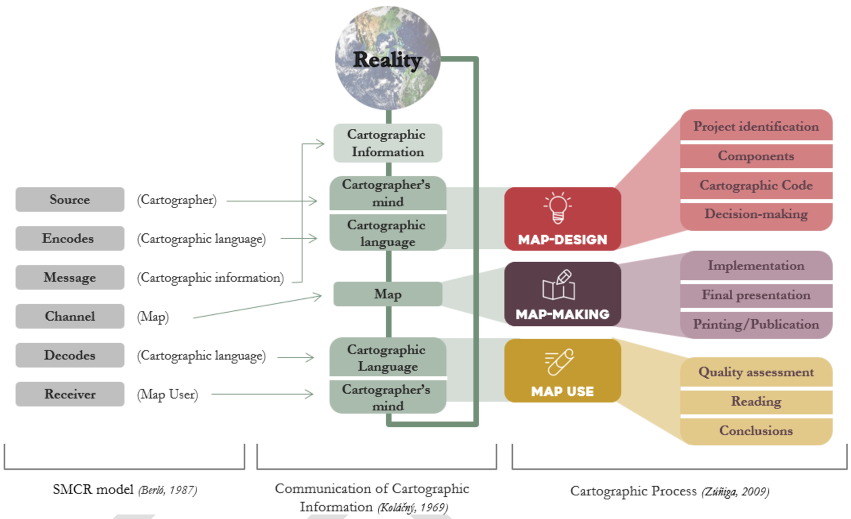

Figure 2: Correspondence between Communication Theory (SMCR), Communication of Cartographic Information and the Cartographic Process. Source: Own elaboration based in Berló, 1987; Koláčný, 1969 and Zúñiga, 2009.

This perspective, which conceptualises **cartography as a communication process**, assumes that two active agents participate in the existence of a map: the mapmaker, responsible for designing and producing the map, and the map-user, who interprets it. Both agents hold equal importance and give meaning to the map itself (Caquard, 2015). The design of a map should be guided primarily by the correspondence between the characteristics of the represented data and the chosen symbology (Lambert & Zanin, 2023). At the same time, it is also essential to consider user experience to enhance the overall design (Montello, 2002).

The first assumption derives from *Sémiologie Graphique*, defined by Bertin in the late 1960s (Bertin, 1967). In Europe—particularly in France and

Spain—it became a sort of cartographic dogma that has shaped the practice of generations of cartographers since the 1970s (Palsky, 2017). It cannot be considered a conventional cartography manual, as it encompasses the broader field of graphic expression, analysing a set of graphical methods that Bertin regarded as a *monosemic system*, where each sign carries a single, predefined meaning. Until then, "good representation" was primarily expected to be complete and accurate. However, with Bertin, the priority shifted towards the effectiveness of communication, taking into account the importance of the mental cost of perception, as defined by Zipf.

This connects to the second assumption, which assigns an active role to the map user, particularly regarding how the human mind processes maps—activating specific cognitive processes. These processes include both low-level perception, which deals with basic sensory input, and high-level cognition, which involves attention, perception, learning, and memory (Montello, 2002). Perception is particularly relevant in this context, as it refers to the cognitive process of recognition, interpretation, and meaning-making, enabling individuals to form judgments based on sensory input from their physical and social environment. This process also involves learning, memory, and attention (Vargas, 1994).

Perception is considered subjective—it varies from person to person—selective, as individuals, sometimes unconsciously, choose to perceive certain elements while ignoring others, and temporary, as it processes information over a short period (Etece, 2023).

The **Perception Process** consists of three stages (Figure 3): sensory stimulation and selection, organisation, and interpretation. Although individuals are rarely aware of passing through these stages separately, they fundamentally shape how we construct mental images of the world around us.

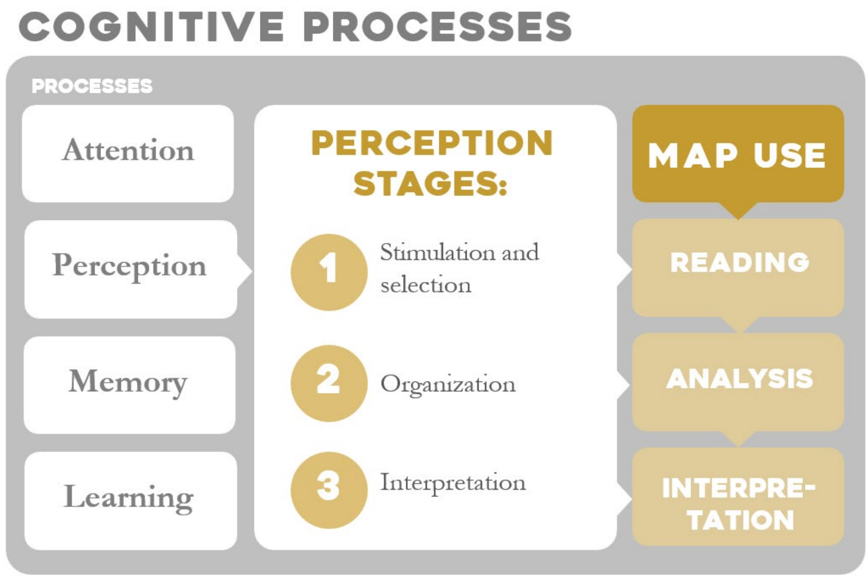

Figure 3: Correspondence between global cognitive processes and their application in cartographic use. Author’s own elaboration based on Vargas (1994) and Rock and Palmer (1990).

These processes, when applied to map use, function as follows: in **Sensory Stimulation and Selection stage** individuals perceive only a limited portion of the stimuli in front of them. The selection of which part of the stimulus to focus on is neither random nor entirely conscious. Three key factors influencing this selection process have been identified: needs, interests, and physiological limitations (Green et al., 2023). Individual characteristics also play a role in this selection. In cartographic design, this phase highlights the importance of visual hierarchy, which relies on size, colour, and the positioning of map elements. Ultimately, this process involves structuring and prioritising map content to enhance communication (Llasera, 2023). It corresponds to the most fundamental stage of map reading and decoding.

The **Organisation stage** involves processing stimuli and fitting them into a recognisable pattern. The way we understand this process is rooted in Gestalt Theory, which explains how external stimuli are translated into mental images, emphasising that perception is a complex interaction between external input and internal cognitive processes (Rock & Palmer, 1990). When applied to map reading, this phase consists of connecting visual elements with stored knowledge—engaging working memory to process what is seen while linking it to pre-existing schemas in long-term memory (such as spatial patterns, cartographic design strategies, and knowledge about the subject and location represented). In essence, this is the stage where the human mind attempts to understand how the map functions. It corresponds to the analytical phase, focusing on identifying spatial patterns and trends within the map.

Finally, the **Interpretation stage** is where meaning is assigned to the perceived content (Green et al., 2023). It represents the final step in which the previously selected and organised stimuli are given context. Individual experiences and personal values influence this process (Etece, 2023). In relation to cartography, this is the phase where the user fully comprehends the map's function and representation. At this point, the map can be read, evaluated, and used to describe spatial patterns and trends. Depending on the user's prior knowledge, conclusions can be drawn not only about the causes behind a spatial distribution but also about its potential consequences. This phase corresponds to interpretation, knowledge integration, and the deduction of conclusions regarding spatial distributions.

Linking these stages of perception to cartographic reading, it is crucial to consider both initial visual attention, which plays a significant role in the Sensory Stimulation and Selection phase, and Cognitive Load, which is particularly relevant in the Organisation and Interpretation phases.

3 Inside the Map-Reader's mind: exploring Cognitive Cartography

The use of the concepts outlined in the previous section has led to the development of the conceptual framework known as **Cognitive Cartography**. This is understood as a subdiscipline that encompasses both the application of cognitive theories and methods to the understanding of maps, and the use of maps to understand cognitive processes (Kiik et al., 2017).

Cognitive Cartography is structured around three **main lines of research** (Montello, 2002): (1) Map-Design Research, which focuses on understanding how maps are read in order to improve their design, making them more efficient, effective, and visually appealing; (2) Map-Psychology Research, which investigates human cognition using maps as stimuli—though not necessarily with the goal of improving map design and (3) Map-Education

Research, which aims to enhance teaching and learning processes through the use of maps.

Ultimately, the objective is to identify the **cognitive load** required by a map—that is, the mental effort necessary to extract and utilise the information encoded within it (Kiik et al., 2017). This concept is framed within the **Cognitive Load Theory** (CLT), which posits that when users read a map, they engage their Working Memory (WM)—which is limited in capacity—while attempting to connect it with their Long-Term Memory (LTM), which is theoretically unlimited (Baddeley, 1986).Cognitive Load, in turn, is influenced by both factors related to the map user and those inherent to the cartographic document itself (Figure 4). Building upon earlier classifications (Bunch & Lloyd, 2006) the following categorisation has been developed.

Among the **user-related factors** are the **user profile**, which includes individual characteristics such as sex, age, and prior experience in map reading or familiarity with the specific region or theme depicted, as well as the **reading environment**, referring to the conditions under which the map is used and how these affect each individual.

Map-related factors include the complexity of the map, since each map has a specific level of complexity depending on the design decisions made during its creation, and the difficulty of the task, understood as the level of cognitive demand required by the nature of the specific task the user is expected to perform.

In addition, cognitive load consists of three **key components:** intrinsic, extraneous, and germane cognitive load (Paas et al., 2003). **Intrinsic cognitive load** refers to the demand placed on working memory (WM) due to the interaction between the stimuli generated by the specific map being read and the long-term memory (LTM), particularly in terms of whether existing mental schemas can be utilised. **Extraneous cognitive load** relates to the cognitive resources required to understand the instructions associated with a specific map-reading task. Finally, **Germane cognitive load** concerns the WM resources needed to acquire, practise, and automate reading strategies and schemas, which are later consolidated in LTM.

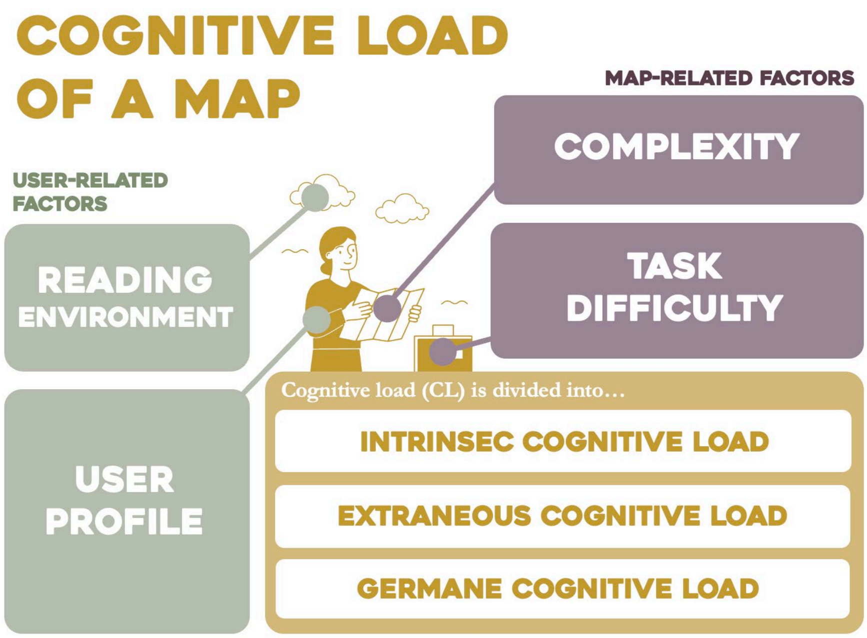

Figure 4: Cognitive Load: Summarize of Factors and Components. Author's own elaboration based on Paas et al. (2003) and Bunch and Lloyd (2006).

4 Making maps work: gauging cognitive load and optimal use

One of the key tasks of the Cognitive Cartography approach to map use is to identify what constitutes optimal use and an appropriate level of cognitive load. In this regard, it is essential to deepen our understanding of the cognitive process in order to improve map design. Achieving this requires exposing users to different cartographic models to assess both their efficiency (the speed at which maps can be read) and their effectiveness (the accuracy with which tasks are completed) (Kiik et al., 2017). It is also important to consider the user's reaction, understood as their level of satisfaction with the map, and retention, or their ability to recall the information they have read (Song et al., 2022).

There are three main methodologies used to collect information on how users complete assigned tasks (Kiik et al., 2017; Ooms et al., 2015). The first involves directly surveying or interviewing participants. The second is the

"*Thinking Aloud Method*", where users are asked to verbally express the steps they are taking as they interpret the map. The third involves eye tracking, which monitors the movement of participants' eyes as they read the map. It will be explored in greater depth as this technique has regained considerable attention over the last decade.

4.1. Following the gaze: eye tracking as a cartographic ally

The concept of eye tracking refers to a set of technologies that allow for the monitoring and recording of how a person visually explores a given scene or image—in particular, which areas draw their attention, for how long, and in what sequence (Hassan Montero & Herrero Solana, 2007).
The use of this technology dates back to the late 19th century (Płużyczka, 2018). Since then, there have been significant advances in sophistication, precision, and user comfort. Early devices were invasive for participants, requiring contact with the eye via specialised lenses. Later, true *eye trackers* emerged, operating through electrooculography, photooculography, or videooculography—the latter, particularly infrared videooculography, being the most widely used today (Kiefer et al., 2017; Krassanakis & Cybulski, 2019).

The first applications of eye tracking in cartography drew on research from other fields such as art, photography, and advertising, which had developed recording techniques and task types applicable to map design and interpretation (Steinke, 1987). A key milestone was the 1970 "Map's User" conference held at Queen's University in Kingston, Ontario, which marked the beginning of a research period in cartography using eye tracking techniques. The work of Jenks (Jenks, 1973, 1975a, 1975b) during this period proved influential. As an example (Figure 5), one can observe the earliest instances of eye tracking on maps (White, 2018). Research gradually became more complex, both in terms of experimental design (task construction) and data processing (eye tracking metrics).

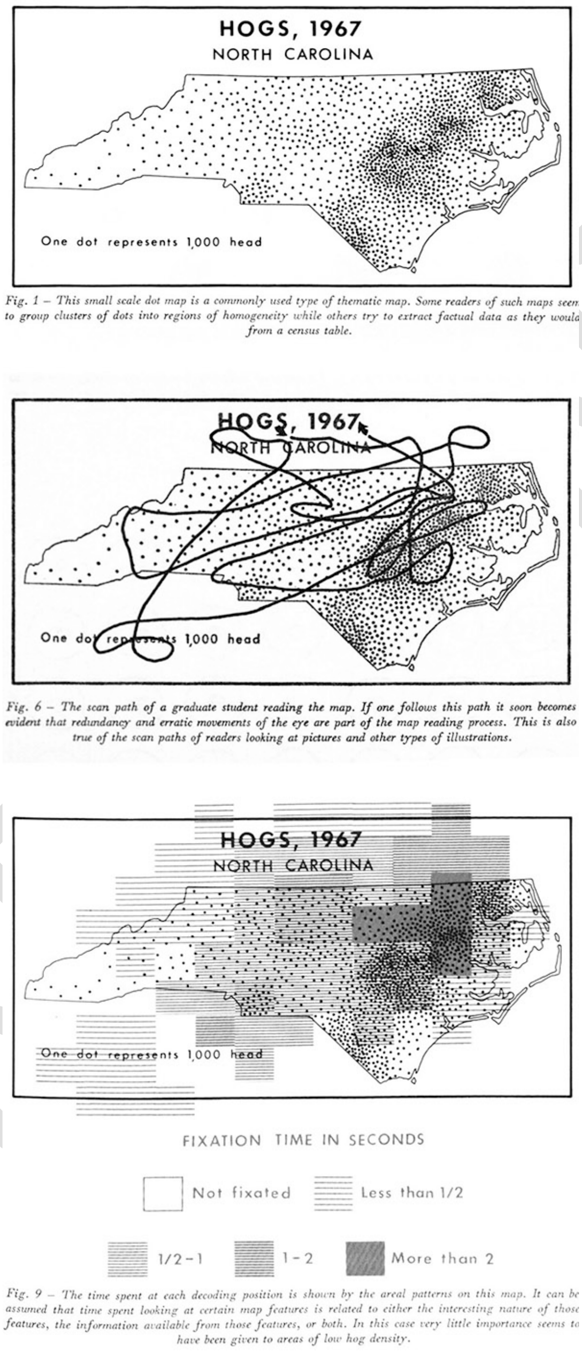

Figure 5: Example of eye tracking in map reading conducted by Jenks in 1973. Source: White, 2018.

However, from the 1980s onwards, research on map design lost prominence. This shift was partly due to the growing focus on Geographic Information Systems (GIS) and also because eye tracking experiments were expensive and time-consuming, often producing limited results in return (Montello, 2002).

In recent years, though, the concepts of Cognitive Cartography have regained relevance, echoing the interest they received during the 1970s (Caquard, 2015). This renewed attention stems from both empirical and critical branches of Geography, which have recognised the importance of placing cognitive processes at the centre of the cartographic experience. The rapid evolution of geo-technologies and their integration into digital environments has produced a paradigm shift. The widespread adoption of online cartography (Webmapping) and the democratisation of location technologies through tools such as Google Maps and OpenStreetMap (OSM) has led to a high dependence on navigation systems for everyday tasks.

This shift raises concerns about the potential weakening of spatial mental schemas—those lasting spatial memories stored in long-term memory—since location information is now often processed through digital applications rather than through direct interaction with space (Caquard, 2015). This change challenges the traditional, *indexical* nature of spatial understanding—based on personal, grounded experience—by replacing it with a *non-indexical* approach that offers a generic worldview to all users. This concern reinforces the idea of cartography as a process and provides fertile ground for the revival of Cognitive Cartography, especially through the integration of post-representational perspectives (Roberts, 2012).

Further indicators of this renewed interest include the growing importance of map design and eye tracking techniques. A meta-analysis by Alexander Kent, published in *The Cartographic Journal* in May 2017 (Kent, 2017), highlights this trend. By analysing the keywords used by authors in the journal between 2005 and 2017 (Wu et al., 2012), a clear evolution of the discipline can be observed (Figure 6). Key topics identified include eye tracking, VGI (Volunteered Geographic Information), OpenStreetMap, and cybercartography, along with more established themes such as map design and the history of cartography.

The prominence of terms such as *eye tracking*, *usability*, *evaluation*, and *surveying*—with the first rivaling the frequency of *map design*—indicates a growing interest in evaluating the usability of cartographic documents and ensuring their effectiveness from the user's perspective. At the same time, concepts such as VGI, OpenStreetMap, citizen science, PGIS, and town plans reflect the ongoing democratisation of cartography and its incorporation into processes of participation and governmental transparency at the local level.

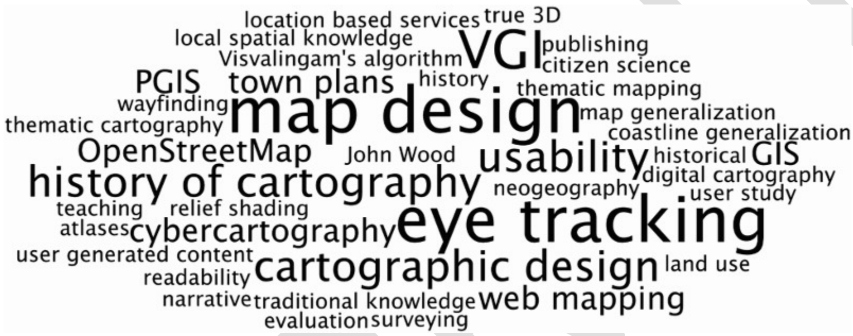

Figure 6: Keyword Cloud (Excluding Generic Terms), The Cartographic Journal 2005–2016. Source: Kent, 2017

A notable increase in the volume of publications related to *eye tracking* has been observed since 2010. While various aspects of cartographic design—such as encoding, labelling, and layout—continue to be constant subjects of study, the current trend leans towards renewed cognitive aspects linked to the processes of map production and use. These include the employment of dynamic and interactive cartography across different geovisualisation platforms and the use of navigation tools on a range of (Kiefer et al., 2017; Krassanakis & Cybulski, 2019; Punde et al., 2017)

As a final argument in support of the rising importance of Cognitive Cartography, it is worth noting the collaborative process led by the International Cartographic Association (ICA) to define a new research agenda, (Griffin et al., 2017). Ten themes were identified through ten keywords, one of which refers to Usability, encompassing concepts such as: user centred map design, usability test, visual perception of map and Spatial thinking, understanding and cognition (ICA, 2025).

Additionally, geospatial databases are now more accessible than ever, owing to technological advances in data storage, processing, and distribution, resulting in an exponential increase in cartographic output (Ooms et al., 2014). Moreover, digital cartography, particularly online mapping, has become the primary means through which maps are consumed today.

This situation necessitates the use of emerging technologies to incorporate greater levels of user interaction and to embrace new conceptualisations that support more effective communication—potentially reframing cartographic design as a form of visual narrative, adopting the Anglo-American term Visual Storytelling (Song et al., 2022). In this context, Visual Storytelling provides an entry point for hybridisation in cartography, bridging technology and practice, product and process, and design and critique, while also opening up new and valuable avenues for transdisciplinary research and design (Roth, 2021).

4.2. Design meets data: a dual approach to measuring map use

As previously mentioned, it is essential to be able to identify what constitutes optimal use and an appropriate level of cognitive load in the process of map reading. This requires exposing users to different cartographic models to evaluate both aspects (Kiik et al., 2017; Song et al., 2022). In order to establish whether a map facilitates such optimal use and maintains a manageable cognitive load, it becomes necessary to assess how users perform when interacting with the map. To assess the outcomes of map use, the following elements are proposed for evaluation: (1) Effectiveness: the accuracy with which a task associated with the map is completed; (2) Efficiency: the speed at which a specific map can be read; (3) User reaction: the level of satisfaction expressed by the user regarding the map and (4) Retention: the user's ability to recall the information previously read.

To gather information on map reading and cognitive load, two complementary techniques are proposed: (1) a **subjective approach**, based on participant questionnaires, and (2) an **objective approach**, based on eye tracking data that records participants' eye movements while reading the map. Ultimately, both approaches must necessarily converge in order to obtain a comprehensive understanding of the user's cognitive experience during map interaction.

4.2.1 Methodological proposal for a subjective approach based on questionnaires

Subjective data can be collected using questionnaires that include Open-ended questions of varying length, which require participants to write responses freely, without predefined answer choices and Closed-ended questions, which solicit brief, specific, and limited responses. In some cases, Likert-scale items will be used—psychometric tools where respondents indicate their level of agreement or disagreement with a statement, using an ordered, unidimensional scale (Matas, 2018).

To assess cognitive processes and user interaction during and after map reading, a structured questionnaire is proposed. The instrument is designed to capture both performance and subjective experience, and is composed of several sections, to be administered at two key moments: (1) while the participant is reading the map and immediately afterwards; and (2) in a follow-up session to evaluate long-term retention.

Initial Questionnaire

The initial questionnaire comprises the following four sections:

- **Section A: Participant Profile**
  This section collects basic demographic and experiential data, including sex, age, prior experience in map reading, and familiarity with the specific region or theme represented in the map.
- **Section B: Task-based Multiple-Choice Questions**
  This section contains approximately ten closed-ended questions designed to be answered while observing the map. The questions focus on map-reading tasks such as identifying, comparing, ordering, or extracting information.
  Example: For a thematic map of the city of Zaragoza showing the distribution of ageing rates by city block, a typical question might be:
  "The elderly population in the Las Delicias neighbourhood is: a) Between 0 and 12%; b) From 12 to 14%; c) From 14 to 18%; d) Over 18%."
- **Section C: Questions on Map Content (Post-reading, without map)**

Administered immediately after the map is no longer visible, this section includes both open-ended and closed-ended questions aimed at evaluating the participant's understanding and recall.
Examples:
Open-ended: *"Explain the map in your own words."*
Closed-ended: *"The Historic Centre and the University area have the same percentage of elderly population: a) Agree; b) Neither agree nor disagree; c) Disagree."*

- **Section D: User Evaluation of the Map**
  This section assesses the participant's subjective evaluation of the map through closed-ended items rated on a five-point Likert scale.
  Examples:
  1. "Would you say you understood the map?"
  2. "Would you say you liked the map?"
  3. "Is the design of this map complex?"
  4. "Is it difficult to read this map?"
  5. "Is it difficult to answer the specific questions?"

Follow-up Questionnaire (Retention Assessment)

To evaluate long-term retention, participants may be invited to complete a simplified follow-up questionnaire approximately two months after the initial map reading. This version retains the core structure of the initial questionnaire but focuses specifically on memory and perceived understanding.

- **Section A: Recall of Map Content**
  This section includes both open-ended and closed-ended questions aimed at evaluating retained information.
  Examples:
  Open-ended: *"Explain the map in your own words."*
  Closed-ended: *"The Historic Centre and the University area have the same percentage of elderly population: a) Agree; b) Neither agree nor disagree; c) Disagree."*
- **Section B: Self-Assessment of Retention**
  This section gathers participants' subjective perceptions of their memory and understanding using Likert-scale items.
  Examples:
  1. "Would you say you understood the map?"

2. “Would you say you liked the map?”
3. “Would you say you remember the information shown on the map?”

This combined structure allows for the integration of immediate cognitive and affective responses with delayed assessments of retention, providing a more holistic understanding of the map-reading experience and its cognitive demands.

4.2.2 Methodological proposal for an objective approach based on eye tracking techniques

Objective information will be gathered through the registration of eye-tracking metrics. The function of eye trackers is to determine, based on ocular rotation, where the person directs their central vision—therefore, identifying the visual area being perceived most clearly at any given moment (Jacob, 1995). The rest of the visual field is processed through peripheral vision, which does not allow for precise identification of objects or elements, but does enable the detection of changes—such as motion—that guide or capture attention. In fact, the movement of the mouse pointer itself is often a source of visual distraction during eye tracking tests (Goldberg & Wichansky, 2002).

The fundamental assumption underlying eye tracking is that it provides a manifest measure of attention (Glenn Cummins, 2017). The continuous monitoring of the gaze point reveals attentional eye movements that cannot be directly measured by the researcher (Jacob, 1995). Eye movements occur in any visual processing activity as automatic responses that compensate for head or environmental movements, allowing the stabilisation of the retinal image on a fixed point.

Depending on their function, eye movements can be classified as follows: (1) Automatic compensatory movements that stabilise the retinal image by adjusting to head and environmental movements, allowing voluntary fixation on a specific point; (2) Voluntary movements that shift the point of fixation across the visual field (*saccades*, *fixations*), or that follow moving objects (*pursuit* and *vergence* movements) and (3) Micromovements associated with ocular fixation, including *tremors*, *microsaccades*, and *drifts*.
The two primary **types of eye movements** are saccades and fixations (Figure 7). When we visually scan a scene, the eyes do not move smoothly but

instead perform rapid jumps to redirect the visual axis to a new position (lasting 30–120 ms). These movements are known as **saccades** (Jacob, 1995). During a saccade, visual perception is effectively suppressed—even though we are not consciously aware of this lapse. Between saccades, the eyes pause briefly in a relatively stable position (lasting 100–300 ms), allowing the focused area to be seen clearly, this movements are **fixations**.

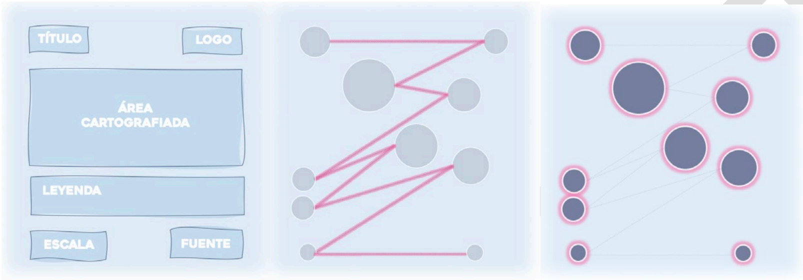

Figure 7: Eye tracking Structure: Areas of Interest (left) and Basic Eye Movements : Saccades (centre) and Fixations (right). Source: Carmen Bentué Martínez.

Eye tracking devices and software translate eye movements into what are known as eye tracking metrics. Most current software includes functionality to segment the visual stimulus into Areas of Interest (AOIs), enabling the extraction of specific metrics for each. These AOIs often correspond to the space occupied by individual map elements, although in some cases a grid-based segmentation is used, which tends to have less cartographic significance.

Eye trackers are typically categorised according to the type of hardware support into two main groups: mobile and remote devices (Punde et al., 2017). **Mobile eye trackers**, or head-mounted devices (usually in the form of glasses), record eye movements at short range (*Figure 8*). These allow participants to move freely and are therefore commonly used in studies requiring tasks to be performed in natural environments. **Remote or screen-based eye trackers** (*Figure 9*) record eye movements from a distance. These are the most widely used devices today. They are placed on or integrated into a screen that displays the visual stimuli with which participants interact. The system tracks the eyes within a designated area (*headbox*), while allowing sufficient freedom of movement for effective tracking.

With few exceptions, the operational principles of these systems are broadly similar. They generally consist of one or more cameras, infrared light sources, and computing capabilities. The device emits infrared light (via *pupil illuminators*) to illuminate the eye and produce visible reflections. High-resolution cameras embedded in the device capture images of the eye, identifying the reflections on the cornea and pupil. Using advanced image processing and machine learning tools, the angle between the corneal and pupillary reflections is calculated. Based on this vector, the gaze direction is determined and translated into gaze points—the data points representing where the participant is looking. Contemporary devices and software include mechanisms to perform a calibration process, which generates a 3D model of each participant's gaze, ensuring greater precision and accuracy in data collection.

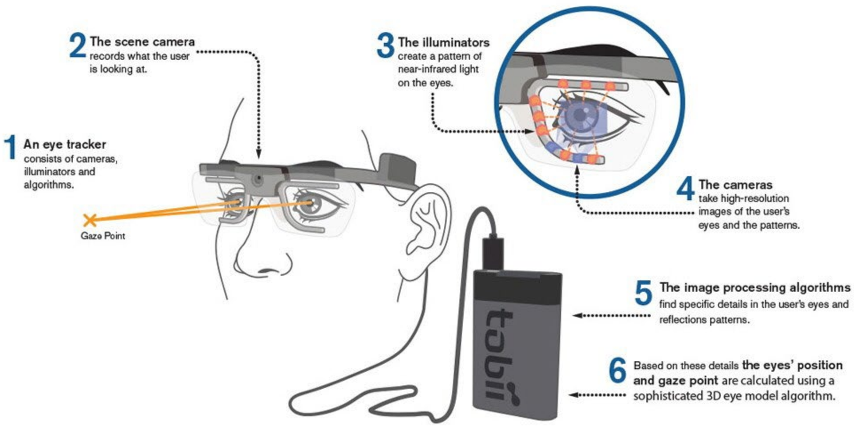

Figure 8: Components of a Mobile eye tracker (Tobii, 2023a)

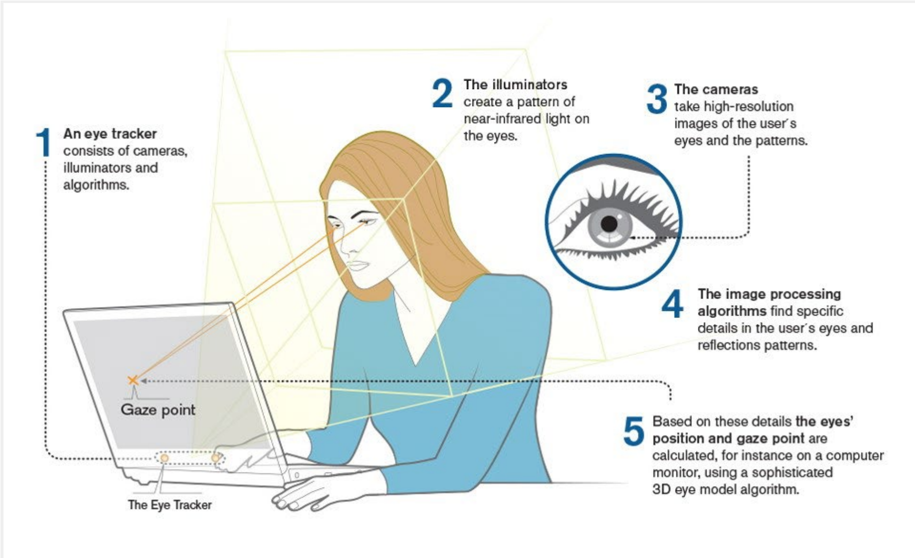

Figure 9: Components of a screen-based eye trackers (Tobii, 2023)

The most commonly used eye tracking metrics for analysing the graphical properties of a visual scene are outlined below, alongside examples of how these may be interpreted in cartographic evaluation experiments. It is important to emphasise that eye tracking, in essence, merely reveals where an individual looks; thus, the interpretation of the resulting data must be made within context (Glenn Cummins, 2017). In the case of cartography, this includes the experimental design and objectives, the map's properties, which result from the sequence of decisions made during the cartographic process, and the profile and characteristics of the user undertaking the observation.

Eye tracking metrics (Glenn Cummins, 2017; Kiik et al., 2017; Rayner, 1998)**:**

– **Dwell Time:** This refers to the total duration of time spent observing a map. In an experiment involving either free viewing or task resolution, it may be useful to measure the time taken to complete the task or the proportion of time spent on different AOIs.

- **Fixation Duration on an AOI**: This metric indicates how long a specific area was observed. The duration of a fixation is considered to be related to the depth of cognitive processing of the object (Rayner, 1998).
- In relation to saccades, the most widely used metric is **the Number of Fixations**, recorded as the count of fixations made during map reading. This can also be expressed as a percentage of total observation time. In a basic thematic map free-viewing experiment, a higher number of fixations might be expected on key elements such as the mapped area and the legend, followed by the title and other auxiliary components. However, an unexpectedly high number of fixations on a given area may suggest difficulty in comprehension. Other metrics, such as the spatial density of fixations or the Average Fixation Duration, may indicate visual search efficiency. A more concentrated pattern of fixations could suggest efficient search behaviour, while greater dispersion may point to a less efficient visual strategy. Another useful metric is the time to first fixation, based on the premise that the quicker a user fixates on an AOI, the more effectively its graphical properties capture visual attention.
- Saccade metrics can also be expressed as counts or percentages relative to total observation time, in addition to their characteristic measurement—**saccade length**, generally expressed in degrees. One may infer that a certain layout configuration is more efficient than another if it reduces the **total number or amplitude of saccades**. For example, in a cartographic composition featuring multiple maps, if each map's legend is located close to the corresponding map, the user might read the content more quickly than if all legends were grouped elsewhere.
- **Scanpath:** This refers to the sequence of eye movements (saccades and fixations) across a stimulus over a given time. It has both a beginning and an end, and therefore a measurable length. It may be of interest to analyse how this sequence varies according to different layout configurations, as well as based on user profiles. On one hand, one might expect a scanpath consistent with the visual hierarchy principles upon which the layout was based. On the other hand, users with a specific profile (e.g., more experience in map reading) might exhibit more regular and ordered sequences.

Finally, it is worth mentioning the **graphical representations** that some software tools can generate in order to summarise user behaviour visually (Hassan Montero & Herrero-Solana, 2007). The most widely recognised of these are heat maps (*Figure 10*), which aggregate gaze points and fixations to show a gradient between areas of higher and lower attention. It is also possible to obtain a graphical representation of fixations and saccades, where the larger the circle, the more time the eye spends on that point. (Figure 11). In these visualisations, the number inside each circle indicates the temporal sequence in which that point was visited, allowing researchers to reconstruct the order of visual exploration.

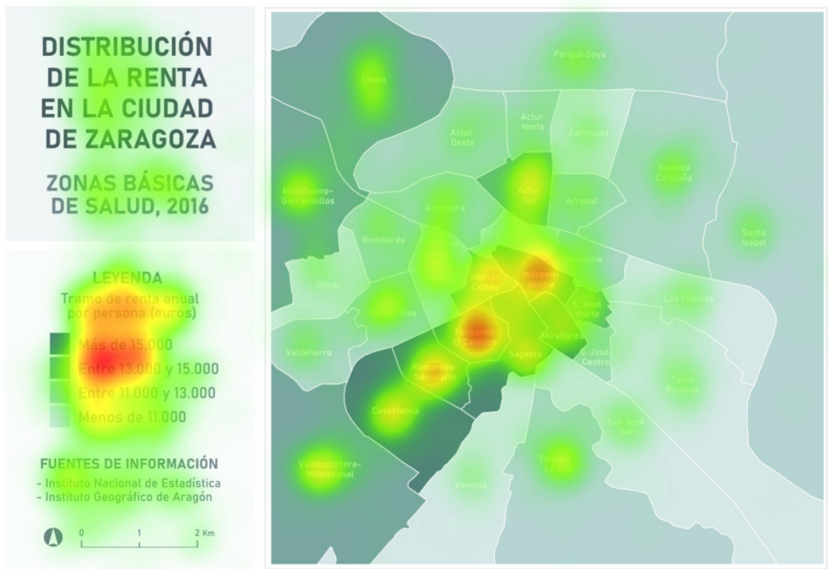

Figure 10: Example of a Heat Map generated from eye tracking data. Source: Carmen Bentué Martínez.

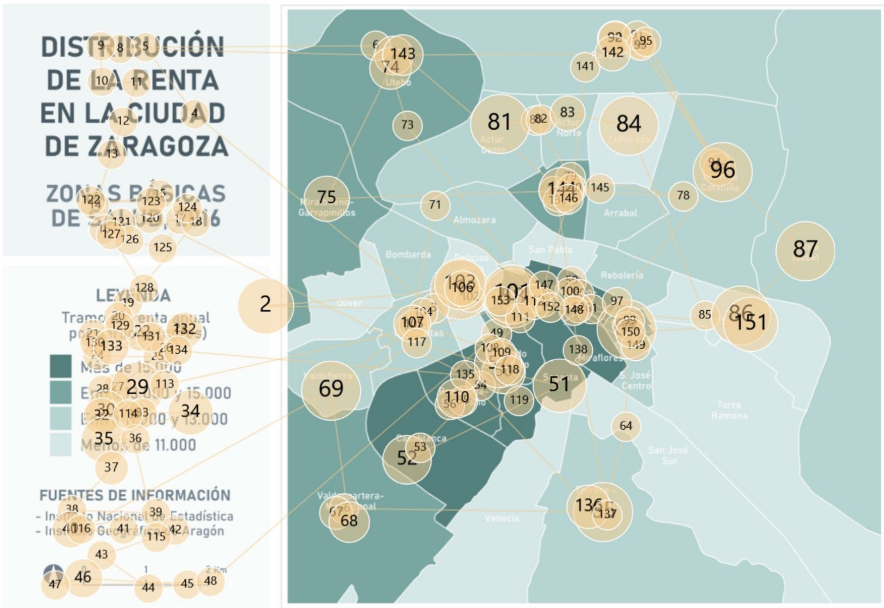

Figure 11: Example of a graphical representation of fixations and saccades on the map generated from eye tracking data. Source: Carmen Bentué Martínez.

4.2.3 Overall assessment of map reading

To fully understand how users engage with a map, it is necessary to move beyond isolated metrics and adopt an integrated evaluation framework. This section proposes a comprehensive approach that synthesises both subjective and objective data—combining questionnaire responses, eye-tracking metrics, and contextual variables related to map design and user profile. By bringing together these dimensions, the goal is to assess not only the cognitive effort required to read a map but also the outcomes of that effort in terms of effectiveness, efficiency, satisfaction and user reaction. This holistic perspective enables a more robust evaluation of cartographic products, guiding future improvements in design and usability.

To **calculate overall cognitive load**, three specific measures are selected: total reading time, number of fixations, and average fixation duration. In addition, it is possible to calculate variables associated with the factors that influence cognitive load. These can be categorised as map-related and user-related factors. Map-related factors include complexity, which is calculated based on the response to the question 3 in Section D – "Is the design of this map complex?" – as answered by both the user and the person who designed the map. Task difficulty is calculated as the average of the responses to questions 4 and 5 in the same section. User-related factors are also considered. The reading environment is evaluated using a 1-to-5 scale to reflect the conditions of tranquillity or distraction during the map-reading process. The user's profile is derived from the information collected in Section A, including age, gender, level of education, experience in reading maps, and familiarity with the region or topic represented.

The **outcomes of map use are measured** through responses to the questionnaire and through selected eye tracking metrics. Effectiveness is assessed by the scores obtained from the questions in Sections B and C, and is validated by the response to question 1 in Section D, which asks whether the participant felt they had understood the map. Efficiency is calculated using eye tracking data, taking into account the total time spent viewing the map freely, the average time taken to complete the tasks, and the sum of both measures. User reaction is gauged through question 2 of Section D, which asks whether the participant liked the map. Retention is assessed in two phases: short-term retention is based on the responses to Section B C of the questionnaire completed immediately after viewing the map, while long-term retention is measured by a simplified questionnaire administered two months later.

Once the cognitive load of a map has been calculated, along with the identification of its influencing factors and an analysis of map-reading outcomes, it becomes possible to assess whether the design of the map was appropriate. From this assessment, potential improvements can be identified, and directions for refinement can be proposed.

5. Unfinished maps: reflections, challenges and future routes

This chapter began with the idea that maps are Geography's natural language since they are powerful tools for communicating spatial phenomena. Rooted in the Information Perspective, we examined how Cognitive Cartography builds on this foundation by integrating knowledge from cognitive science, psychology, and perception theory into the cartographic design process.

By understanding maps as communication artefacts involving both a producer and a user, Cognitive Cartography offers a richer framework for map evaluation and improvement. The exploration of perception, attention, memory, and especially cognitive load, reveals how users interact with maps not merely as static visuals but as dynamic cognitive experiences.

We have proposed a dual methodological approach by combining subjective surveys and objective eye tracking techniques to assess map effectiveness, efficiency, user satisfaction, and user retention. These tools not only allow us to quantify cognitive effort but also open pathways for adaptive and inclusive design, tailored to diverse user profiles and contexts.

As cartography evolves in a digital and participatory age, it becomes ever more necessary to reconsider the role of the map user, not as a passive reader, but as a co-constructor of meaning. Future research in Cognitive Cartography should continue to bridge design and cognition, promoting evidence-based guidelines that respond to human mental processes while embracing new forms of visual storytelling.

Ultimately, by placing the user at the centre of the cartographic process, we not only refine our maps, we redefine what it means to truly read them.

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