

Maps through the lens of scientific representation theories

Abstract

This article examines how contemporary theories of scientific representation can shed light on the status of maps. Traditionally defined as models of geographic reality, maps are increasingly viewed not as mere reflections of the world but as complex representational constructs embedded in theoretical, technological, and communicative contexts. Drawing on key philosophical frameworks – including similarity, structural isomorphism, inferential accounts, and the DEKI model – the paper examines how maps function as tools of cognitive surrogacy rather than direct imitations of space. This approach clarifies the representational mechanisms underlying cartographic practice, including symbolisation, abstraction, and intentionality. The discussion also addresses how recent developments in geoinformation technologies and digital cartography challenge conventional definitions of maps. Ultimately, the paper argues that maps should be seen as epistemic devices that mediate knowledge about the world through interpretive models rather than as neutral depictions of spatial reality.

Keywords

Cartographic modelling • cartographic representation • map as model • structural similarity • theories of representation

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Introduction

In geographical science and cartography, a map is commonly treated as a model, representing a portion of reality – such as the environment, landscape, or spatial phenomena (Czerny 1994; Andrews 1996; Krukowski 2021). This understanding has substantive ontological (what kind of entity a map is), semantic (how its elements refer to the world), and epistemological (how it licenses and constrains inference) consequences.

The advent of geoinformation technologies has revolutionised the concept of maps and their functions in cartography and GIScience. These developments are redefining the map and its functions, with a focus on technical change alongside epistemic and practical aims. This transformative impact of technology is a key aspect of the evolving field of cartography (Makowski 2001; Baranowski, Gotlib & Olszewski 2016; Kraak & Fabrikant 2017; Lapaine et al. 2021; Gotlib, Olszewski & Gartner 2021; Krukowski 2021; Polous 2023).

Against this background, three guiding questions orient the analysis. What does it mean to claim that a map represents reality? How does a map relate to the world it depicts? In what sense does a map serve as a vehicle for knowledge? These questions defy simple answers, but general theories of scientific representation in the philosophy of science provide a framework for thinking them through. These theoretical accounts examine how a model refers to its target and supports knowledge. Three linked dimensions are at stake: the ontology of the model and its relation to reality, the semantics of how elements represent aspects of the world, and the epistemology of how models license, test, and sometimes falsify claims.

Within this framework, several prominent accounts exist. Structural and similarity views regard models as reflecting the

relevant structure of their targets (van Fraassen 1980). Inferential accounts emphasise the rules that permit warranted conclusions (Suárez 2004). Conventional-intentional views focus on agents, aims, and shared practices (Hughes 1997; Giere 2004). The DEKI model, a systemic approach, plays a crucial role in integrating these diverse strands (Frigg & Nguyen 2016). In his historical analysis, Winther (2024) demonstrates how Carnap, Goodman, Toulmin, and Kuhn each used the map metaphor to develop core intuitions about scientific models, lending additional warrant to the analytical programme pursued here.

Core cartographic operations, including projection, data selection, graphic generalisation, and editorial design, indicate that maps do not simply mirror the world. They construct an image under specific cognitive, semiotic, and technological assumptions. This observation raises issues about whether maps merely reflect or also co-create reality, how users decode embedded knowledge, and which cognitive, cultural, and technical limits constrain their effectiveness.

This article outlines selected theories of scientific representation and applies them to the theory of the map and cartographic modelling. The aim is to clarify the ontological and epistemological status of the map as a scientific model and to indicate in what sense maps function as tools for knowledge, exploration, and communication in the spatial sciences. More specifically, the article proposes eight operational criteria for analysing maps as epistemic representations. These criteria – covering denotation, selection and idealisation, structural fit, interpretive key, surrogative inference, functional adequacy, intentional – conventional grounding, and sources of error – provide the basis for the analytical section presented before the conclusion.

Representation by Similarity

One of the earliest and most intuitive accounts of representation is the similarity theory. According to this view, a model represents its target object by being similar to it in certain relevant respects. This notion has a long intellectual tradition, dating back to Plato, and appears well-suited to various domains. Paintings, sculptures, and drawings represent their subjects through visual resemblance, while scientific models are thought to analogously reflect the structure of the world (Frigg & Nguyen 2021). Ronald Giere (2004) proposed that scientific modelling ought to begin with maps: “How does a road map represent a city? Through spatial similarity to certain aspects of the city.” A map indeed exhibits certain similarities to the terrain – it reproduces the shapes of land masses or the layout of roads at a reduced scale, such that analogous spatial relations hold on the map as they do in the real world. This resemblance enables the transfer of insights from model to target. If two towns are close on the map, they should be close in reality – an instance of analogical reasoning. Advocates of similarity theory emphasise that such correspondences allow for the transmission of information: a property found in the model should also occur in the represented object, provided both share the relevant attribute. Maps, as models, clearly meet this condition – for example, if an area on the map is marked in blue to indicate water, one assumes the presence of a water body in the corresponding real-world location.

Despite its intuitive appeal, the similarity theory faces significant challenges. First, the logical structure of similarity relations is at odds with the asymmetrical nature of representation: similarity is a symmetric relation, while representation is not. Furthermore, almost any two objects can be deemed similar in some respect, unless criteria are explicitly imposed, raising the risk of trivialising the concept of representation (in the extreme case, anything could represent anything else in some aspect). To address this, the notion of similarity has been refined to encompass specific respects and degrees, thereby specifying which properties of the model and the target must correspond to each other. In the case of maps, this typically entails agreement on geometric attributes – such as shape and distance – within a given tolerance. The map faithfully reproduces the spatial layout while omitting other features, such as the architectural appearance of buildings.

Another difficulty concerns intentionality: resemblance alone does not suffice to make an object a representation. A random inkblot that coincidentally resembles the outline of Poland is not, in itself, a genuine map – it becomes one only if someone deliberately uses or recognises it as a representation of Poland. For this reason, more recent accounts incorporate intentional factors. Building on his earlier proposal, Giere (2004) argues that a model represents a target not merely by similarity but rather when an agent uses the model to represent reality in certain respects for a specific purpose – embedding similarity within an intentional framework. This perspective allows for representational inaccuracies: a hypothesis may be false, yet the model still qualifies as a representation, albeit an imprecise one. Maps often contain minor inaccuracies or distortions (e.g. simplified coastlines), albeit with error they still represent the area in question. A strict similarity theory, which demands complete feature correspondence, would struggle to account for this.

In sum, geometric similarity constitutes an important aspect of cartographic representation (e.g. a physical map portrays terrain through shaded relief) but it does not exhaust the essence of representation. Intentional use and agreed-upon symbolic meanings are equally indispensable components of this process.

The Structural Approach

The structuralist view refines the concept of similarity by emphasising the preservation of structure rather than loose resemblance. In the semantic view of theories, models are structures that represent their targets when a mapping exists between them, such as an isomorphism, homomorphism, or partial variant (Suppe 1989; da Costa & French 2003; Frigg & Hartmann 2020; Frigg & Nguyen 2021). Elements and relations in the model correspond to elements and relations in the world, so relational patterns in the model reflect those among relevant entities. This structural conception clarifies how inference works. A structural mapping allows established truths in the model to transfer to claims about the target. Maps exemplify this. Points correspond to locations and relations, such as adjacency, sequence, and connectivity, which track real geography. Scale defines a function from page distance to ground distance – for example, 1 cm equals 5 km. Topographic maps preserve adjacency and direction, roughly as a near-homomorphism between configurations in the map and the terrain.

Exact isomorphism is rarely attainable. It is symmetric and too demanding for realistic models, which simplify and omit. Projections distort area and distance. A spherical surface becomes a plane image. Hence, philosophers speak of partial isomorphism or homomorphism that preserves only selected relations (Frigg & Hartmann 2020; Frigg & Nguyen 2021). A map typically represents a subset of relations, such as network topology or the order of towns along a river, while omitting others – full three-dimensional morphology, for example (Czerny 1987). Such distortions can be functional – for instance, road maps that downplay relief to foreground connectivity. As later accounts will make explicit, structural selectivity of this kind requires a further mechanism that specifies which relational aspects are intentionally targeted.

A further issue is non-uniqueness. The same abstract structure can fit different phenomena. A single mathematical scheme might model planetary motion or electrical oscillation. Structure alone does not fix reference. Context and intention are needed. In cartography, the exact configuration of lines could match a different city plan or a fictional realm, depending on interpretation. Structural resemblance is, therefore, not enough. One must know which space the map is intended to represent. The pragmatic element is explicit in van Fraassen’s claim that representation exists only when something is used to represent something as thus-and-so (van Fraassen 2008). In practice, maps aim at isomorphism in selected respects, often geometry, yet their representational force depends on deliberate, rule-governed use by informed users.

Surrogate Reasoning

Despite debates about the model–target relation, most accounts converge on one point: scientific representations must enable reasoning on the model itself – surrogate reasoning (Suárez 2004; Frigg & Hartmann 2020). Using a model, hypotheses are framed and conclusions about reality are drawn from the model’s properties, rather than from the object itself. Any adequate theory must explain how manipulations of a representation yield knowledge of the target. Some philosophers even define representation by this inferential capacity (Swoyer 1991; Suárez 2003).

Suárez (2003) argues that scientific representation meets two conditions. It must exert directed representational force towards a target (intentionality), and it must allow competent agents to conclude that target. The second condition captures surrogate reasoning: a model should be built so that a prepared user can generate warranted claims by working on the model rather than the object (Suárez 2003). He also notes objective constraints.

Models cannot be arbitrary: some correspondence to the world is needed for reliable inference, not as a return to strict similarity but as a demand to preserve practice-relevant aspects of the target (Suárez 2003).

A complementary proposal from Contessa (2007) distinguishes mere denotation, epistemic representation, and faithful epistemic representation. An epistemic representation supports inference about the world. A metro logo only denotes the system and gives no grounds for reasoning about its structure. A schematic map of metro lines does this, since users can work out a route from A to B and, thus, the system's configuration. Faithfulness admits degrees. A current London Underground map is more faithful than one from a century ago. Both permit some inference, yet only the current one can be trusted to yield accurate and reliable conclusions – for example, whether a connection between stations exists.

The idea of surrogative reasoning marks a boundary between informational representations and purely conventional signs (Nersessian 1999). Mere intention or labelling is not enough for epistemic representation. Placing a saltshaker on a table and declaring “this represents Madagascar” adds no informative structure from which to infer anything about the island. There are no shared properties that would support meaningful conclusions. This familiar “representation out of a hat” vignette demonstrates that successful scientific representation requires agreed-upon meanings and informational or relational features that can convey knowledge (Callender & Cohen 2006; see also Suárez 2004; Frigg 2006). Historical critiques of colonial cartography make the risks concrete, since weak correspondence with spatial arrangements produced misleading political maps used for propaganda or administration (Harley 1989).

Maps provide a paradigmatic case of surrogacy. From a map, it is possible to identify towns along a river, estimate distances, plan routes, or anticipate mountain chains without direct observation of the territory. With cartographic conventions, users read landforms from contours, and densities from choropleths. Map-based inference can also surface facts that are hard to obtain otherwise. Analyses of historical maps, for example, may indicate former trade routes. Such findings are possible because maps encode essential spatial references, so questions about geographic space can be reframed as questions about the map and answered within its frame.

In effect, a map functions as a controlled thought experiment on a modelled object. Instead of traversing terrain, relations on the graphic plane are examined to judge reach, connectivity, and constraint. Cartographic models, therefore, act as cognitive surrogates that support predictions and explanations open to empirical tests.

The inferential perspective complements semantic accounts of the model–world relation and highlights practice. What matters is what can be done with a model to gain knowledge. On this view, the map is not merely an image of space; it is a cognitive tool for formulating, testing, and communicating geographical hypotheses.

The DEKI Theory

Recent developments in the philosophy of science aim to integrate similarity, structure, convention, and inference within a unified account of scientific representation. One influential proposal is the representation-as view by Frigg & Nguyen, known as DEKI (2016, 2021). The acronym names four operations that, together, make representation possible: denotation, exemplification, keying-up, and imputation. In DEKI, a model is an object paired with its interpretation in a domain. Representation occurs when it indicates a target, displays features that matter for that interpretation, supplies rules that

connect those features to properties of the target, and, on that basis, attributes properties to the target (Frigg & Nguyen 2016, 2021). Notably, DEKI allows representation without a real target. A map of a fictional land still represents that imagined geography in a representation-as mode (Frigg & Nguyen 2016).

Cartography provides a clear field of application. A national map denotes a specific portion of geographic space. It exemplifies lines, colours, symbols, and page distances which, under cartographic interpretation, acquire geographic meaning. The legend and scale key these features to facts in the world – for example, green indicates lowlands, shading represents elevation ranges, an icon identifies an airport, and one centimetre corresponds to approximately five kilometres on Earth. On this basis, the map imputes properties to its target. Seeing a labelled region, a user can infer the terrain, land cover, or the presence of transport infrastructure. Schematic cases also fit DEKI. Metro diagrams use a variety of colours to distinguish routes rather than the physical colour of the tracks, while road maps idealise curvature yet still support inferences about connectivity. The key formalises such conventions and turns exemplified features into usable information (Frigg & Nguyen 2016, 2021).

DEKI helps to align ontology, semantics, and epistemic efficacy. Treating the model as an object with interpretation provides an ontological anchor. Denotation and keying-up ground meaning, while exemplification and imputation explain how users draw warranted conclusions from a model. The framework also handles errors and absences. An erroneous treasure map still represents – only inaccurately – while a map of Atlantis represents an imagined target. Some questions remain open, including the exact ontology of models (mathematical structures versus physical artefacts) and how mathematical relations encoded in a key connect to physical properties. Even so, for cartography, DEKI offers a robust way to analyse iconic spatial analogy alongside conventional symbol systems and the interpretive procedures that link maps to the world.

DEKI formalises denotation, exemplification, keying-up, and imputation as explicit operations. These operations, however, presuppose a richer account of the intentional and conventional dimensions of mapping than the formal apparatus alone can supply. The following section addresses that dimension directly, examining how maps acquire their representational force through the deliberate acts of their makers and the shared practices of their users – aspects that extend beyond, and in part underpin, the DEKI framework.

Intentional and Conventional Relations

Scientific representation is not a purely objective relation of similarity or isomorphism; it is embedded in human intentions and conventions (van Fraassen 2008). In cartography, this is evident. Maps are created for purposes such as navigation or demographic display, and they rely on established conventions, including hypsometric colours, topographic symbols, and north-up orientation. Map-making is a deliberate act in which socially accepted signs are used to mark reality. Blue indicates rivers and dashed lines indicate borders. Correct interpretation presupposes user competence with those signs. Meaning arises within communal practices and standardised procedures.

Intentionality fixes purpose and scope. The same area appears differently on a road map and on a geological map because representation is guided by a description with selective emphasis and omission. The process is at once conventional and intentional. However, intention alone is insufficient. An arbitrary declaration that a dot is city X lacks a mechanism for epistemic engagement. Conventions must be anchored in the model's referential capacities (Frigg & Nguyen 2021). Symbols may be conventional. A city can be a black circle or a red square.

Spatial relations must still preserve salient aspects of reality – for example, the city's position relative to other features. Otherwise, representational intention is defeated. In practice, mapping fuses conventional choices with objective constraints, so that intentions remain within empirical bounds (Suárez 2004).

This balance aligns with Suárez's claim that representation depends not only on partial isomorphism but also on pragmatic factors tied to use (Suárez 2004). Applying a model is a communicative act. The author conveys information and expects the recipient to recover the intended content. This communicative, intention-based view is close to Grice's account of meaning as intention-based uptake (Grice 1957). Cartographic conventions, therefore, function as a language of signs and rules that let users interpret space in line with the maker's aims (Ostrowski 2013).

The intentional-conventional view also clarifies ontology. A model can be a physical artefact with no inherent tie to a place. It becomes a map of Poland through designation and social acceptance that it corresponds to Polish territory. Models are often interpretation-dependent entities. If conventions are forgotten or altered, a wall map collapses into a pattern of colours. Representation is, therefore, partly conventional and grounded in agreement about what the model denotes and how to use it. It is not arbitrary because good conventions maximise accuracy and speed of comprehension. Standard road symbols illustrate this point. Conventionality also brings limits. Some phenomena are complex to render on a plane. Relief requires agreed techniques, such as shaded relief or contour lines. Every map is a compromise between fidelity and readability, shaped by the maker's aims and the user's needs (Krukowski 2021).

Operational Criteria for Analysing Maps as Representations

Having surveyed the principal accounts of scientific representation – from similarity and structure through surrogate reasoning and DEKI to the intentional – conventional dimensions of mapping – it is now possible to distil from these accounts a set of operational criteria. Rather than treating them as rivals, the criteria below translate their complementary insights into a framework for examining how any given map deals with representation, how it supports inference, and under what conditions it functions as a cognitive tool.

1. The denotational criterion concerns whether the map unambiguously indicates its target. Every cartographic representation is a representation of something: a particular territory, phenomenon, spatial relation system, or fictional space. Without a fixed target, there is no epistemic representation, only a collection of graphic signs. Within DEKI this corresponds to the condition of denotation – in cartographic terms, it involves identifying which portion of reality has been modelled and at what level of generality.
2. The criterion of selection and idealisation addresses which properties of reality are incorporated into the model and which are omitted or simplified. A map is always the result of selection, generalisation, and hierarchisation of content. Analysis must consider which aspects were deemed significant and whether the degree of idealisation adopted remains adequate to the map's purpose. This criterion distinguishes functional distortions – those serving legibility or usefulness – from distortions that diminish the map's cognitive value.
3. The criterion of structural correspondence asks which relations among model elements match relations in reality. This is not a matter of visual resemblance but of preserving relational properties relevant to the map type: adjacency, sequence, continuity, network connectivity, orientation, and – within limits – distance and area. Since full isomorphism is practically unattainable, homomorphism or selective

structural preservation is more appropriate (Czerny 1987). This criterion assesses whether the map retains the relations essential to its correct cognitive use.

4. The criterion of the semantic interpretive key covers the set of rules by which features visible on the map can be translated into claims about the world. The key may be explicit – as in a legend, scale bar, or projection description – or partly implicit, embedded in the standards and practices of map use. Without interpretive rules, a map remains merely an arrangement of lines and symbols: only the key makes it a representation suitable for epistemic use. In DEKI terms, this corresponds to the keying-up operation, which links properties exemplified by the model with properties imputed to its target.
5. The criterion of surrogate inference potential marks the boundary between a mere sign and an epistemic representation. A map fulfils a cognitive function when its structure and interpretive rules allow the user to draw warranted judgements about space – concerning connectivity, extent, accessibility, or the distribution of elements. The reasoning is surrogate in character because it operates on the model rather than directly on the territory. The broader and more controlled the range of such inferences, the higher the map's epistemic value.
6. The criterion of functional adequacy requires that a representation be evaluated in relation to the purpose for which it was produced and used. A road map, a geological map, a bathymetric chart, and a metro diagram do not represent reality in the same way because each privileges different properties and relations. The accuracy of a map is, therefore, not absolute: it is dependent on the cognitive, practical, or communicative task at hand. This criterion assesses whether the representational form chosen is appropriate to the function the map is intended to perform.
7. The criterion of intentional – conventional grounding indicates that a map represents through the combination of a deliberate act of reference and socially shared rules of reading. Structural correspondence alone is insufficient to determine what a map depicts, just as authorial intention alone cannot make an arbitrary sign into an epistemic representation. Both are required: the intention to refer to a specific portion of reality and a system of conventions that enables the recipient to recover the intended content. This criterion encompasses analysis of symbolisation, cartographic standards, user competence, and established interpretive practices.
8. The criterion of limitations and sources of error concerns the conditions under which a representation loses credibility or leads to erroneous conclusions: errors arising from the projection, scale, excessive generalisation, symbol ambiguity, missing metadata, or naïve interpretation. This criterion introduces a critical dimension into the analysis – particularly important for digital and interactive maps, in which some interpretive rules may be concealed within the interface, algorithm, or data-visualisation method.

Taken together, these eight criteria constitute an analytical framework for moving from a description of theoretical positions to a comparative assessment of maps as representations. Their application allows different map types to be examined not only in terms of graphic form but also with respect to their ontological status, semantic mechanisms, and epistemic effectiveness. Each criterion draws on one or more of the theoretical accounts surveyed above, and none of the accounts, taken alone, satisfies all eight – a result that supports the complementarity thesis advanced in the conclusion.

Conclusion

The three questions posed at the outset can now be addressed. What does it mean to claim that a map represents reality? To represent is to denote a target, to exemplify selected properties through a system of conventional signs, and to key those properties to claims about the world in such a way that warranted inference becomes possible. How does a map relate to the world it depicts? This is achieved through a partial structural correspondence that preserves relational properties relevant to the map's purpose, anchored by the intentional act of its maker and the shared conventions of its interpretive community. In what sense does a map serve as a vehicle for knowledge? A map functions as a cognitive surrogate: a structured model on which users can operate to generate geographical judgements without direct observation of the territory.

Maps, viewed through general theories of scientific representation, stand between model and world. A map is a material or digital construct distinct from its target. It links to reality through structure and interpretation. It encodes information by marrying geometric resemblance with learned symbols and the author's intention. It supports surrogate reasoning and turns spatial form into knowledge.

The analysis developed here yields a complementarity thesis: the five accounts surveyed are not rival theories competing to explain the same phenomenon, but co-dependent analytical layers, each of which captures a dimension the others presuppose or leave underdetermined. Similarity grounds iconicity; structural correspondence explains how inference transfers; surrogate reasoning specifies the cognitive use a representation must support; intentional-conventional grounding fixes reference and shared meaning; and DEKI integrates these dimensions into a unified operational vocabulary. No single layer, taken alone, satisfies all eight criteria proposed above – each criterion draws selectively on more than one account; this is precisely why a multi-layered framework is needed.

No single principle explains mapping on its own. Pure similarity does not suffice. Isomorphism alone does not capture practice. A convention without structure loses its connection to place. Representation arises from the conjunction of structural mapping, intentional action, and a shared system of meanings. In the DEKI perspective, maps denote particular parts of the world; they exemplify selected properties in conventional form; they include a semantic key that instructs reading; they impute claims about geographic space to the user.

Different theories illuminate what it means to say that a map represents the environment. Structural relations ground iconicity and credibility. Similarity aids legibility – but its value depends on the purpose. Inference turns depiction into knowledge. Social conventions anchor interpretation and make the map a medium between maker and reader. Function ties representation to task, whether cognitive, navigational, or decisional. These dimensions are not alternatives but mutually constraining layers of the same representational phenomenon: each presupposes the others and none is intelligible in isolation.

Selective presentation and idealisation – themes of criteria 2 and 6 above – are limits, yet they are also the source of communicability. By selecting features, simplifying the form, and standardising symbols, maps become efficient vehicles for inference. They show enough truth to be useful, and enough form to be intelligible.

A good map integrates these strands. It is at once an image, an instrument, a language, and an act. Through this lens, cartography condenses the broader scientific problem: how to build a model of the world that remains faithful enough to guide judgement, and clear enough to invite understanding.

These findings carry concrete implications for GIScience. Viewing maps through the eight criteria developed above has direct consequences for practice. Denotation and structural correspondence inform how map layers and metadata standards should specify the target domain and the relational properties being modelled. The semantic key criterion suggests that GIS layer specifications should explicitly define which features are exemplified, which target properties are attributed, and the specific conditions under which inferences from the map to the world are warranted. Functional adequacy and the limitations criterion provide the basis for evaluating digital and interactive maps, where interpretive rules may be concealed in algorithms or interface design. Finally, intentional – conventional grounding provides a principled rationale for cartographic education: users must acquire interpretive competence, not merely technical skill, to read maps reliably. The philosophical analysis of representation is, thus, not merely a theoretical exercise; it has operational consequences for the design, documentation, and pedagogy of cartographic systems.

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