The Abduction of Geographic Information Science: Transporting Spatial Reasoning to the Realm of Purpose and Design

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Abstract. People intuitively understand that function and purpose are critical parts of what human-configured entities are about, but these notions have proved difficult to capture formally. Even though most geographical landscapes bear traces of human purposes, visibly expressed in the spatial configurations meant to serve these purposes, the capability of GIS to represent means-ends relationships and to support associated reasoning and queries is currently quite limited. This is because spatial thinking as examined and codified in geographic information science is overwhelmingly of the descriptive, analytic kind that underlies traditional science, where notions of means and ends play a negligible role. This paper argues for the need to expand the reach of formalized spatial thinking to also encompass the normative, synthetic kinds of reasoning characterizing planning, engineering and the design sciences in general. Key elements in a more comprehensive approach to spatial thinking would be the inclusion of abductive modes of inference along with the deductive and inductive ones, and the development of an expanded geographic ontology that integrates analysis and synthesis, form and function, landscape and purpose, description and design.

1 Introduction

For those of us who have ever wondered how to build a good bird house, a book by Halsted [1] is enlightening. In Chapter XVII, which is entirely devoted to this important topic, we read: "It is a mistake to have bird houses too showy and too much exposed. Most birds naturally choose a retired place for their nests, and slip into them quietly, that no enemy may discover where they live. All that is required in a bird house is, a hiding place, with an opening just large enough for the bird, and a water-tight roof. There are so very many ways in which these may be provided, any boy can contrive to make all the bird houses that may be needed." (p. 203). An illustration depicting three different bird houses clarifies these principles (Figure 1). We see an old hat nailed on the side of a barn with a hole for an entrance; a three-level pyramid on top of a pole, made of six 'kegs' nailed to planks; and a house-like structure made of wood. Two of these designs actually reuse obsolete objects originally intended for very different purposes. We thus have three very different-looking spatial configurations realized with three very different kinds of materials. Yet 'any boy' can understand that a single functional and spatial logic is giving rise to these three contrasting forms.

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place for their nests, and slip into them quietly, that no enemy may discover where they live. All that is required in a bird house is, a hiding place, with an opening just

Fig. 211.—HAT HOUSE. Fig. 212.—KEG HOUSE. Fig. 213.—LARGE HOUSE.

large enough for the bird, and a water-tight roof. There are so very many ways in which these may be provided, any boy can contrive to make all the bird houses that may be needed. An old hat, with a hole for a door,

Fig. 1. Designing a birdhouse: three different spatial arrangements, three different kinds of materials, one set of functional requirements, one purpose. (Source: Halsted 1881, p. 203).

Let us now move on to something more familiar to geographic information science researchers. Figure 2a shows an ordinary urban streetscape. We see buildings, roads, cars, parking spaces, and benches. No natural process has created any of these objects, and no natural principles can explain either their individual shapes or the overall arrangement of the scene. Further, the location of a couple of natural objects visible on the picture – the trees – cannot be explained by any cause known to nature. Like in the case of the birdhouses, some intentional agent must have decided that the space in question needed to be configured in that particular way. And finally, exhibit number three (Figure 2b): Here is a natural landscape. Or is it?... A closer look reveals a number of straight lines crisscrossing the scene that have close to zero chance of having been generated by natural processes. The alert observer immediately realizes that these are the traces of earlier cultivation on a now abandoned landscape. This landscape and the streetscape of Figure 2a thus have something very important in common: even though no human presence is directly visible in either of them, they both reflect human *purposes*, the former through the outlines of old fences and retaining walls that used to support specific agricultural practices, the latter through the urban functions of shopping, resting and circulation served by its constituent parts and overall configuration.

So here is the point: Most landscapes that GIS deals with today are to a greater or lesser extent humanized landscapes, spatially organized so as to support specific functions, and changing over time as human purposes change. People intuitively understand why spaces are configured in particular ways, and they can anticipate what kinds of things *should* or *should not* be there based on explicit or implied purposes and the spatial functions that serve these purposes. In less obvious cases people will ask – but may lack the information to answer – questions such as:

- What is the purpose of this spatial object?
- What is the function of this place?
- What parts should compose this place?
- What else should be next to this place?
- How should this place be connected to other places?
- Is there a reason (*not* cause) for these changes on the map between time *a* and time *b*?

(a) (b)

Fig. 2. (a) is an ordinary streetscape making no secret of its functions and purposes, including the purpose of the few 'natural' elements visible; whereas (b) is a natural-looking landscape that still bears physical traces from a time when it was used to meet specific agricultural needs. (Sources: (a) http://www.quinn-associates.com/projects/DecorVillage; (b) © J. Howarth.)

- Has the function of this place changed recently?
- How should this place change now that related activities or functions are changing?
- How should this place be configured in order to support the anticipated activities?

Yet the ability of GIS to support these kinds of queries is currently very limited. This is because *the thinking behind the understanding of function and purpose is not analytic but synthetic and normative,* whereas GIS is foremost an analytic tool. It may be argued that about one-half of natural spatial reasoning – the synthetic half – is not properly supported by GIS and is largely ignored in geographic information science. This paper presents a case for expanding the formal reach of the latter and the practical vocabulary of the former by introducing ideas and methods from the normative and synthetic sciences of planning, engineering, and design – more generally, from the disciplines known as the *design sciences*. Herbert Simon's seminal essay *The Sciences of the Artificial* [2] has contributed significantly to the recognition of the design disciplines as a distinct field of systematic intellectual endeavor, and to the understanding of the products of design – whether material or abstract – as belonging to an ontologically distinct class.

This paper focuses not on the activity of design itself but rather, on the question of how to introduce into GIS the concepts and modes of reasoning that will allow users to query and better understand human-configured – that is, designed – spatial entities. These include natural entities adapted for human use, from the vegetable garden in your yard to the Grand Canyon in its role as international tourist attraction, as well as those entities that are created entirely by humans to be university campuses, freeway or sewer networks, or cities. Even though the ultimate objective is practical, the problem of representing designed entities in a form that supports non-trivial automated reasoning and queries raises some very fundamental theoretical issues. Current approaches based on attribution facilitate the classification of such entities but as we will see below, this may not be sufficient. On the other hand, decades of research and software development in architectural and industrial design have yielded important insights into how designs are generated, but not on the inverse problem, more relevant to geographic information science, of how to decipher a 'designed' geographical entity. Still, there is much to be learned from these efforts to formalize the design process. Drawing on the theoretical design literature, the next section discusses the logic of design, which relies on synthetic, normative thinking and uses abductive inference extensively. Section 3, entitled 'The language of design', briefly explores the question of whether synthetic thinking in the geographic domain may require additional spatial concepts. It then introduces the concepts of functions, purposes, and plans that are central to synthetic thinking, and proposes a tentative solution to the problem of expanding the representation of function and purpose in human-configured geographic entities. Inevitably, the Conclusion that follows is brief and open-ended, more geared towards a research agenda than any concrete findings or recommendations.

2 The Logic of Design: Synthetic Thinking and Abduction

2.1 GIS and the Sciences of the Artificial

Spatial thinking as currently represented in geospatial models and software is overwhelmingly of the classic analytic kind that characterizes traditional science. Analytic thinking has been formalized, codified and successfully applied to scientific problems for centuries. However, it is not the only kind of systematic thinking of which humans are capable. Analytic thinking describes the world as it is (or may be), while humans are also very adept at reasoning about the function and purpose of things, easily switching between 'how does it *look*' to 'how does it *work*' to 'what is it *for*'. For example, an experienced engineer can look at a piece of machinery and (a) describe its structure, (b) based on that description, figure out how the machine works, and (c) from its function, infer the purpose for which the machine was built [3] Conversely – and more typically – the engineer will begin with a goal (purpose) to be met and will synthesize a product that functions in desired ways based on specific analytic properties of material and structure. Goal-oriented synthetic thinking of this kind is also known as *normative* because it is concerned with how things *should* or *ought* to be in order to fulfill their intended purpose. While 'normative' is usually contrasted with 'positive', normative reasoning also bears a symmetric relationship with causal reasoning which seeks to derive analytic explanations (Tables 1& 2). Synthetic, normative thinking characterizes not only the engineering sciences but more generally, the *design* disciplines which, in the geospatial domain, range from architecture, landscape architecture, and planning to decision science, spatial optimization, and various forms of spatial decision support. In actual fact, both the traditional sciences and the design disciplines use synthetic as well as analytic thinking, and normative as well as causal reasoning, though in different ways and with different emphases [4]. This paper argues for the need to expand the scientific reach of spatial thinking so as to formally integrate analysis and synthesis and thus also enable normative inferences that involve the functions and purposes of things.

Table 1. Normative versus causal reasoning

Normative	**Causal**
what *x* in-order-for *y*	*y* because *x*
what *purpose* in-order-for *spatial-pattern*	*spatial pattern* is-caused-by *process*
what *spatial-pattern* in-order-for *purpose*	*process* causes *spatial-pattern*

This integration is critical because the majority of the earth's landscapes now bear the traces of purposeful human intervention as the land is continuously adapted to support specific functions and activities of everyday life. Landscapes adapted by people are not just abstract spaces but *places* rich in personal and cultural meanings. Yet we still lack the formal conceptual frameworks, methodologies, and tools to deal with notions that will help analyze, understand, and anticipate spaces configured for human use and the reasons why these are the way they are, and to understand places as well as spaces. While concern for function and purpose is common in both the social and the life sciences, that interest is not well supported – at least not in the geospatial domain – by an appropriate scientific infrastructure to help formalize and implement modes of thinking that connect the configuration of the land with its functions and purposes. We would like to be able to represent in geospatial databases, and better understand with their help, the human motivations that led to the emergence of particular geographic landscapes and the ways that changing motivations lead to changes in land use and land cover. Such understandings will be essential if we are to model the complex changes now occurring in the ways the earth's surface is used, and their implications for the sustainability of both human populations and biota.

A number of different areas of thought, many with a spatial emphasis, have developed around normative and synthetic thinking. As mentioned earlier, engineers design structures, machines, devices, algorithms, and new materials that function in particular ways to meet specific purposes. So do the planning disciplines, from architecture and urban design to landscape architecture and regional planning, which seek to configure geographic space so that it may better support particular human activities or ecological functions. Decades of efforts have gone into formalizing the design process, resulting in both increased theoretical understanding and the development of software for the support of architectural, industrial, and other design activities [5] [6] [7]. On the formal side, artificial intelligence has contributed considerably to our understanding of synthetic and normative reasoning through the work on plan generation, frames, expert systems and other topics characterized by inferential reasoning that is neither primarily deductive nor inductive [8]. More recently the international DEON[1] conference series, "…designed to promote interdisciplinary cooperation amongst scholars interested in linking the formal-logical study of normative concepts and normative systems with computer science, artificial intelligence, philosophy, organization theory and law", [9] has helped broaden the appeal of normative thinking well beyond its traditional strongholds.

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[1] 'Deon' is the Greek word for 'what needs to be' and gives rise to 'deontic logic', a notion closely related to the term 'normative' which is derived from the Latin.

Table 2. Contrasting the dominant analytic stance of GIS with the synthetic stance of the design sciences

GIS & traditional sciences	The Design sciences
Analysis	Synthesis
From instances to principles	From principles to instances
Causal	Goal-oriented
Descriptive	Prescriptive
Positive	Normative
IS	*OUGHT*

GIS continues to rely on a predominantly analytic mode of thinking, despite the fact that many of the entities it represents, from roads and cities to rice paddies and ski runs, are such as they appear because they are configured *in order to* support specific human activities and purposes (Table 2). While for years GIS has very successfully supported spatial decisions relating to the allocation and configuration of such entities [10], it cannot yet support queries as to why – say – there is a small structure at the bottom of the ski slope and whether another one should be expected to be at the top, or how that entire configuration of open spaces and installations may change if the ski resort closes for good. This is because GIS databases and operations can provide highly detailed descriptive information on what is out there but they don't normally place entities and relationships in the context of the human activities that require spaces to be configured in particular ways [11]. The difficulty of distinguishing between land cover and land use in GIS provides the archetypal example of what may be missing from analytic descriptions of the geographic world [12]. In traditional representations of land use, residential areas, roads, and buildings are coded no differently than lakes, streams and rock outcrops, with only an item key or map legend indicating that these are actually *artifacts* – artificial things that people made and placed there for a purpose. While the purpose itself is invisible, it is reflected in characteristic functional spatial relations robust enough to be sometimes recognizable not only by human intelligence but also by machines. Thus Ahlqvist and Wästfelt [13] were able to develop a neural net algorithm that could identify summer farms in Sweden from medium resolution satellite imagery. These farms consist of a collection of different land cover patches that stand in specific spatial relations to one another. Their complex spectral signatures defy automated detection at medium resolution, but giving the algorithm some hints about necessary functional relations (here, a couple of distances between patches that belong to different land cover classes) results in highly accurate identification of summer farms. What kind of spatial thinking does that experiment point to? What connects Swedish summer farms, streetscapes, abandoned fields, ski slopes, and birdhouses –geographically speaking? How could we harness the underlying logic so as to expand the range of queries that GIS could support? These are the questions that this paper sets out to address.

2.2 Abduction in Geographic Information Science and GIS

As Chaigneau et al. [14] note, "Function is central to our understanding of artifacts. Understanding what an artifact is used for, encompasses a significant part of what we know about it” (p. 123). The inability of GIS to properly support this kind of understanding is likely what prompted Bibby and Shepherd [15] to write: “the ‘objects’ represented in GIS are unquestionably assumed to have a prior, unproblematic existence in the external world….a crippingly restrictive conceptualization of objects”(p. 583). Artifacts, which in the general case include both artificial objects like roads and buildings and spatial adaptations like gardens and Swedish summer farms, are always the formal or informal, explicit or implicit products of *design*. Note that ‘design’ means both drawing and intention. It is the intentional dimension of artifacts that is the key to understanding their nature, and which makes a simple tin can, in Simon’s [2] example, an object of an ontologically more complex order than a tree. While humans will immediately recognize the tin can as an instance of an artificial container, no amount of analysis of geometry, topology and attributes can provide a satisfactory understanding of that object.

All complex reasoning, including spatial reasoning, involves three complementary modes of inference: deduction, induction and abduction. The relationship between these modes is shown in Table 3. All three involve, at different stages (a) *rule(s)*, by which we mean the general principle(s), premises or constraints that must hold; (b) *case(s)*, that is, exemplar(s) of phenomena to which the rules do or may apply; and (c) a *result*, or the specific state of affairs to which the rule(s) is or may be applicable. These three modes have different properties. Deduction, induction and abduction yield certain inference, probable inference and plausible inference, respectively. But also, the amount of entropy (information to be obtained) from the inference increases in that order, being minimal for deduction and maximal for abduction. All three modes are present in scientific reasoning, from the deductive power of mathematics to the value of fruitful generalization from a sample, to the inferential leap leading to new discoveries.

Table 3. Symmetries connecting the three basic modes of inference (after Peirce: see [16])

Deduction	Induction	Abduction
Rule	Case	Result
Case	Result	Rule
Result	Rule	Case

Deduction and induction have both been extensively formalized over centuries of mathematical and scientific development and deduction in particular is amply supported in software, including in GIS. Abduction on the other hand, even though it was sketched out (and named) by Aristotle, was only rediscovered in the late 1800s by Peirce [16] and still lacks the recognition and degree of formal support that deduction and induction have enjoyed since antiquity. As Worboys and Duckham [17] note, “In general, computers rely solely on deductive inference processes, although inductive and abductive reasoning are used in some artificial intelligence-based systems. As a consequence, processing in a computer is deductively valid, but this mode of reasoning prevents computers from generating new conclusions and hypotheses” (p.297). Indeed, abduction produces a plausible explanation or hypothesis (‘case’) for a given state of affairs (‘result’) such that the explanation satisfies a number of premises or constraints (‘rule’) that may be theoretical, methodological, empirical or pragmatic.

Formalizations of the abduction problem can be found in the design and artificial intelligence literatures, e.g. [5],[18]. For example, according to [18], "the abduction problem is a tuple $\langle D_{\text{all}}, H_{\text{all}}, e, pl \rangle$ where D_{all} is a finite set of all the data to be explained; H_{all} is a finite set of all the individual hypotheses; e is a map from subsets of H_{all} to subsets of D_{all} (H explains ($e(H)$); pl is a map from subsets of to a partially ordered set (H has plausibility pl (H)). H is complete if $e(H) = D_{\text{all}}$**;** H is a best explanation if there is no H' such that $pl(H') > pl(H)$." (p. 28). The range of pl (H) may be a Baysian probability or other measure with a partially ordered range and is estimated in the context of the 'rules' (prior knowledge) applicable to the case.

Abduction is often discussed as the logic of medical diagnosis or detective work although its application is much broader, since it underlies constraint satisfaction problems and hypothesis generation of any kind. Abduction has also been recognized as the hallmark of synthetic thinking in general and of design in particular, in the sense that every design problem is a constraint satisfaction problem, and every design solution is a hypothesis in that the design in question is a plausible answer given the facts of the matter. For example, the design of a house must satisfy a number of environmental, legal, social, and resource constraints, along with spatial constraints of minimum area and height, of adjacency, connectivity, occlusion, etc. that derive directly from the domestic functions (cooking, entertaining, sleeping,…) to be supported. While many routine tasks in the geographic information domain involve abductive thinking (e.g., the interpretation of imagery or more generally, of patterns in the data, or the development of models of spatial processes in the absence of general laws), certain equally important tasks relating to artificial entities in particular are not currently supported by GIS and related tools. Examples include: identifying the function and/or purpose of an untypical spatial configuration; reconstructing the plan of a partially preserved archaeological site; identifying the location of spatial parts functionally related to a particular artificial entity; predicting changes in land use and land cover given knowledge of changes in human activities; deciding whether an apparent change on a map relative to an earlier map is real or the result of a mapping error; and designing any land use, watershed, or landscape plan to serve specific human or ecological purposes within existing geographical and resource constraints [19].

The next section argues that the tools to support such tasks are not well developed because the necessary concepts and modes of reasoning, and their relationships to more familiar spatial concepts and analytic modes of reasoning, have not been sufficiently investigated in geographic information science. These are however well established in the synthetic, design sciences, from which we may have much to learn.

3 The Language of Design

3.1 The Vocabulary of Design

What may be the ontological implications of expanding the language of GIS so as to include synthetic thinking and the purpose-orientation of design? A useful place to begin is the investigation of the spatial concepts involved in design and in analytic geospatial science, respectively. Are they the same concepts? If so, what distinguishes the two perspectives? Are there two overlapping but not identical sets of concepts? If so, what are the differences? At least one project exploring these questions is already underway, currently developing a catalog of spatial terms extracted from the literature of both analytic geography and design [20]. For the purposes of the present paper a top-down approach building on the discussion in the previous sections appears more suitable.

As mentioned earlier, both analytic and synthetic reasoning are based on the three complementary inference modes of deduction, induction and abduction, though these are used differently in the two perspectives and to different ends: for describing a present, past, or future state of the world in the analytic case, and for bringing about a different state of the world in the synthetic case. This difference is akin to the distinction made in the philosophy of mind between the two ways, or 'directions of fit', in which intentional mental states can relate to the world[2]. Thus the mind-to-world direction of fit, which includes beliefs, perceptions and hypotheses, concerns actual states of the world (*facta*), whereas the world-to-mind direction, which includes intentions, commands, desires and plans, concerns states of the world that do not yet exist but that one wants to make happen (*facienda*) [21]. It is easily seen that analytic thinking is about *facta* whereas synthetic thinking is about *facienda* – this is precisely the IS-OUGHT distinction highlighted at the bottom of Table 1.

This brief foray into the philosophy of mind reinforces the notion that the critical difference between analytic and synthetic thinking is on the side of the observer-actor's intentional stance rather than the world. It also suggests, though it does not prove, that any differences in vocabulary between analysis and design should also be on the side of intentional rather than spatial terms. One may surmise that there will be differences in emphasis (i.e., some spatial terms will be more prominent in analysis or in design because they relate to concepts that are more important in one or the other tradition), and that there will be qualifiers to spatial concepts commensurate with the objectives of each of the two perspectives. As an example of differences in emphasis, take the concept of 'pattern'. It is central to both analytic geospatial science and design, but many more synonyms of the term are commonly used in the latter: shape, structure, configuration, arrangement, composition, design, motif, form, etc. [22]. This is because 'pattern' and related notions are very critical to design, being in many cases the end result of the design activity itself. Spatial analysis, on the other hand, places considerable emphasis on uncertainty-related spatial concepts such as fuzzy regions, epsilon bands and error ellipses, because its objective is not to change the world but to accurately represent it. (Clearly, these concepts are also very important in some areas of engineering design, though as constraints rather than as objectives). Because of the emphasis on correct representation, accuracy, precision, fuzziness, and so on are also important qualifiers in analytic spatial thinking, whereas the synthetic stance is much more invested in concepts that qualify the fitness-for-use (aesthetic as

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[2] This distinction is also familiar from the philosophy of language, where the focus is on speech acts rather than intentional mental states. See [27].

well as practical) of the products of design, such as ‘efficient’, ‘functional’, ‘harmonious’, ‘pleasant’, ‘symmetric’, ‘human-scale’, or simply ‘good’.

Having found no significant differences in the vocabulary, i.e., in the spatial terms used in analysis and in design, the next question should be about the syntax: How are spatial elements put together to yield arrangements that support specific human purposes? What is it about the resulting forms of artificial entities and spatial configurations that allows them to serve such purposes? How can we understand what these configurations and entities are *for*, and how they relate to human activities? The first question concerns design as a process and is beyond the scope of this paper. The other two, which are about making sense of what humans have designed and built, are explored in the following.

3.2 Purposes, Functions, Activities, and Plans

Purpose is what makes the human world tick and yet there is no place for it in traditional analytic science, whether natural or social. Traditional science is the realm of causes and effects. Purpose, on the other hand, is what the design sciences are about. In the spatial realm, purpose is the interface between the human world of intentions and the world of intentional spatial configurations – the adapted spaces that we call farms, airports, transport networks, or cities. Purpose itself is invisible and immaterial, but it is expressed spatially through *activities* and *functions*. Thus farmers engage in a host of different activities that may include feeding, breeding and moving livestock, growing, harvesting, storing and transporting crops, running a horseback-riding barn or bed-and-breakfast, and so on. Similarly, airports are the places where airplanes take off and land, where aircraft and service vehicles circulate and park, and that people enter and navigate to specific departure gates; and so on. Mirroring the activities, which are temporally bounded occurrences, are the corresponding functions, which are associated with the corresponding artificial entities in a more enduring (though not necessarily permanent) fashion. The barn is still the barn after the animals have left; the airport is still the airport, and the departure gates are still the departure gates during the night hours when there are no rushing passengers or departing flights. Functions reflect the abstract relational structures characterizing human-configured spatial entities of a particular class: Every farm is unique, but all store the hay as close as possible to both a delivery road and to where the cows are kept. Further, the functions themselves are reflected in the *adapted spaces*, the concrete, appropriately configured entities made up of specialized sub-spaces with the required geometrical and other attributes, standing in specific spatial relationships to one another. Finally, these four elements – purpose, activity, function and adapted space come together in (spatial) *plans* (Figure 3). These plans may be implicit or explicit; they may be formal or informal; they may be individual or collective; they may be laid down on clay tablets or on paper, or they may reside in peoples’ minds; and they may be finite and immutable or they may be always in flux. No matter in what form, plans always express a desire to adapt geographic space to specific purposes and to the functions and activities these purposes entail.

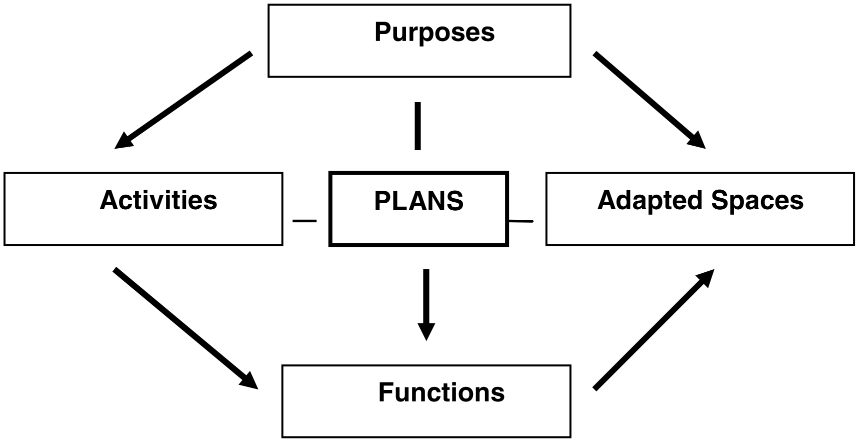

Fig. 3. How purposes, functions, activities, and adapted spaces may come together in plans

The tightly knit nexus of concepts represented in Figure 3, where some of the relations are as important as the entities, presents challenges for current, mostly object-oriented geographic information ontologies. The concept of function is particularly problematic because it cannot be properly specified except in the context of activity on the behavioral side, and of adapted-space on the spatial: functions mirror the former and are expressed in the later. Functions change when activities change and this also (frequently) causes changes in adapted spaces. Functions are thus relational concepts, somewhat like roles, which get their meaning from being associated with both a role-player and a context and which for that reason are not attributes, though both roles and functions are sometimes treated as such [23] [24]. It is indeed often sufficient to assume that naming an artifact is enough to specify its function (a knife is for cutting, a bridge is for crossing), but this ignores the fact that functions are largely in the eye (interests) of the beholder: a knife is also for spreading butter and for prying open lids, and so on. Thus a road bridge IS-A bridge and will normally be classified along with railroad and covered bridges. But if one is interested in the function of allowing vehicles to get to the other side of the river, the road bridge will more likely be classified along with fords and ferries, while from the perspective of the ecologist concerned with wildlife corridors, the function of a road bridge may be to provide a safe underpass for animals This fluidity of function, the endless affordances provided by natural as well as artificial entities that help support human activities and meet goals, is not well supported by current geographic information ontologies. This is also why functional classification is usually considered too problematic to undertake, even though it would often make more sense from the user's viewpoint [25].

Elsewhere I proposed an ontological framework for geographic information that includes the concepts of purposes, functions, and adapted spaces [26] but leaves out activities and plans. Not coincidentally, activities and plans are the only two synthetic concepts in this group. Activities are complexes of individual actions, at different levels of granularity, woven together so as to help realize specific purpose(s); plans are the quintessential examples of synthetic, design-oriented thinking. Purposes, on the other hand are antecedents, adapted spaces are outcomes, and functions are abstract expressions of the properties that make adapted spaces and activities correspond with each other. In this scheme, (user) purposes are at the very top of the hierarchy, thus drastically narrowing and refining the scope of relevant functions to be considered. Along similar lines, Howarth [19] has proposed and implemented a model for mapping activities at different levels of granularity into correspondingly nested adapted spaces by means of plans, and demonstrated the practical utility of that work with case studies from a historic California island ranch. For example, the function of an unlabeled rectangular space represented on an old map could be abductively inferred from a knowledge of the activities constituting a day of rounding up sheep by the ranch cowboys: based on qualitative information on the spatio-temporal pattern of these activities, and map information on distances and site characteristics, it was correctly concluded that the rectangle in question was used as a horse corral for the cowboys' mid-day break.

Searle's theory of Intentionality [27] may help provide a framework for completing the integration of the five elements of Figure 3. As discussed earlier, desires and purposes underlie the 'world-to-mind' direction of fit – changing the world so as to fit what's in the mind – and this notion of 'direction of fit' is closely connected in philosophy to that of 'conditions of satisfaction' What kinds of conditions can satisfy the purpose of making a living on a farm, or of running an efficient airport that is attractive to travelers and safe for everybody? Not all of the answers are of course spatial, but many are, and formalized spatial thinking ought to be able to grasp them. According to Searle the conditions of satisfaction for the world-to-mind direction of fit require world-changing physical *actions* by intentional agents. Two related kinds of intentions are distinguished: *prior intentions*, which are mental, and *intentions in action*, which are involved in carrying out the intended physical act and thus realize the conditions of satisfaction of the original desire or purpose. We are here interested in intentional actions that enfold in, and change the geographic-scale world. Figure 3 suggests two different kinds of such actions: those making up the complex activities that directly realize in whole or in part the conditions of satisfaction of the original desire or purpose (e.g., the daily activities involved in running a horseback-riding barn), and those needed to adapt a space so that it may adequately support these activities (e.g., developing the barns, corrals, riding rings, storage areas, office spaces, access routes, parking areas, etc. in the required sizes, configurations and spatial relations to one another). In addition to these two kinds of activities (one on-going, the other temporally delimited) which reflect two different intentions-in-action, there is a single prior intention expressed in the plan.

An important point in Searle's [27] theory of intentionality is the symmetry between the world-to-mind direction of fit that characterizes world-changing actions by intentional actors, and the more passive mind-to-world direction of fit that results in understanding and interpreting the world and its changes. With this last observation we may now have enough conceptual ammunition to tackle the central question of this paper: How could we expand current formalizations of spatial reasoning so that they may also support the interpretation and understanding of spatial entities purposefully developed or changed by humans. In other words, the challenge is how to get at the hidden underlying plan that ties together the functions and purposes of a human-configured feature in the landscape, its spatial organization, and any activities relating to it that we may be able to observe.

This appears to be a task tailored for abductive treatment. As discussed above (see Table 3), the basic form of abductive inference may be written as: *result* x *rule* → *case*. Here the 'result' may be the spatial configuration on the ground that must be interpreted; the 'rule' would then be the set of known functional organizations that may correspond to the spatial configuration at hand; and the 'case' would be the tentative identification of the artificial spatial entity in question as being very likely - a summer farm, a winery, a sacrificial place, a spa, a secret military installation. As Howarth [19] has shown, abduction may be used in this way for obtaining plausible answers to many different kinds of queries, under both static conditions and in cases where some changes from previous states have been observed, depending on what may be known and what may need to be inferred from among the elements illustrated in Figure 3. It thus appears possible that we may eventually be able to approach the outcomes of normative, synthetic human thinking in geographic space as rigorously and systematically as we do the products of natural processes.

4 Conclusion

Spatial configurations in humanized landscapes realize implicit or explicit spatial plans, which are schemas for promoting specific human purposes related to the land. Purposes are reflected in functions; functions support activities; activities enfold in adapted spaces; and plans connect these elements into normative configurations or designs. I argued that geographic information science should embrace this fundamental insight stemming from the design disciplines – not because it is itself a design discipline, or needs to be, but so as to be able to properly represent and analyze the human-configured landscapes around us. So far, with the exception of activities, the concepts surrounding the notion of (spatial) plan have received scant attention in mainstream geographic information science. It seems that the reasons for this apparent neglect have less to do with a lack of interest in these issues, and more to do with the ways spatial reasoning has been formalized and codified to date.

The paper identified two areas, quite possibly connected, where current approaches to spatial reasoning could be augmented. The first is the facilitation of abductive inference so as to complement the inductive and deductive forms already routinely supported in available models and software. The second is the expansion of current geographic information ontologies so as to encompass and implement the interconnected concepts of purpose, function, activities, adapted spaces, and plans. This will by far be the harder task of the two, requiring us to grapple with culturally contingent issues of means and ends, of needs, wants and choices, as well as with some controversial chapters in the philosophy of mind and social reality. Yet human purpose and its traces on the land, and conversely, the land's role in shaping human purpose, have been for decades the central themes in certain qualitative areas of geography from within the humanistic, cultural, and regional perspectives. We may have something to learn from these old-fashioned approaches also. As geographic information science matures with the passing years, I am reminded of a quote by a now anonymous (to me) researcher from the RAND Corporation: "In our youth we looked more scientific". I would not be the least offended if geographic information science were also to have *looked* more scientific in its youth.

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