Chapter

Introductory Chapter: Geographic Information Systems and Science

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1. Introduction

Information science can be defined as the science that investigates the properties and behavior of information, the forces that govern its flow, and the means of processing it. The process includes the origin, dissemination, collection, organization, storage, retrieval, interpretation, and use of information. Although this view is not consensual, one can state that there are several information sciences and they can be separated into two groups. The first group (e.g., librarianship, journalism, and communication) mainly studies the transfer of information and the second group (e.g., philosophy, sociology, and cognitive sciences, in general) focuses preferably on certain aspects of information transfer.

Nonetheless, it is not easy to think of a science in which at least one of its study objects does not consider the geographic space. However, it is evident that some areas today have appropriated the geographical information more than others have. Assuming that data (geographic or not) is a construction of the knowledge within a certain political, economic, and spatiotemporal context, then the question is how it is possible to set apart the geographical, or in a more broad sense the spatial, context of these data?

Spatial knowledge has long been critically important both in the development of human activities and in the understanding of how humankind interacts with space. The possibility of knowing the geographical location of a phenomenon, to establish relationships with other elements of the territory, to identify spatial patterns, or to make decisions based on their geographical examples of how spatial information and knowledge have over the years a preponderant role in social, political, and economic development.

The geographic information of the world is in a period of exponential development, sustained by the availability of new sensors, imageries, open georeferenced data and social media, and moving devices, allowing to produce new knowledge about that world and empirical geographical phenomena [1, 2]. Almost all the phenomena we face daily assume a territorial expression. Represent, analyze, and know the spatial dimension associated with these phenomena is one of the main challenges faced by the Geographic Information Systems (GIS).

The continuous collection of geographic data of holistic nature and the analysis of its place in territory, i.e., location analytics, allows a more straightforward science [3] that can influence the creation and the use of geographic knowledge. This holistic point of view allows researchers to put questions that before were impossible [4]. Multidisciplinary approaches take along important knowledge about the adoption of system approach to information management.

Just as the information science can be understood as a group, geographical science is a set of sciences interested on physical and/or human geographic processes.

Although this definition is consistent with the broad definition of geography, the term should not only be circumscribed to the current school of Geography, but also involving areas such as meteorology, geology, environment, epidemiology, geomarketing, and many others that study the phenomenon's geographical dimensions. In fact, today, GIS brings together several areas of knowledge. These areas of science influence each other, creating conceptual and technical interfaces such as multidisciplinarity.

Michael Goodchild first coined the designation "Geographic Information Science" in 1992, defining it as the persistent research, consistent with methodical values, of the type and characteristics of the data [5]. This science operates through the techniques, methods, and approaches associated with GIS and seeks to redefine the geographic concepts and their use in the context of GIS. Thus, it becomes clear that the term Geographic Information Science (GIS) is also multidisciplinary.

2. Is GIS a science?

Is GIS a science? In 1992, Goodchild [5] was asked to write a paper defining what could be Geographic Information Science. At that time, GIS became more generalized in enterprises and in research, becoming also popular in training programs, so GIS community began to view it as more than just a tool or system as they started to research GIS itself.

Goodchild paper gave a major contribution in coining the term GIscience or GISc; however, the author did not propose a definition for this science. Instead, he addressed the uniqueness of geographical data in terms of its properties and the need of particular methodologies to deal with it [5], and he presented eight major contents that this new science should address, namely: information gathering and quantification; data acquisition; geo(spatial) statistics and other location analysis tools; spatiotemporal modeling and spatial concepts; spatial data infrastructures, algorithms and procedures; visualization; and decision-making, administrative and moral concerns.

Almost 30 years passed since Goodchild wrote this paper entitled Geographic Information Science and discussing the science in GIS. Even though 30 years have passed, it is curious to note that:

1) The contents are up-to-date. For instance, in data collection and measurement, we still discuss challenges regarding generalization and abstraction; data capture also possess challenges now much more related to the massive production of data partly due to the web and Internet of Things (IoT) developments, and the quality of that data in a time where almost everyone can produce geographic data. In addition, in display domain, we passed from problems related to 2.5 and 3D to 4D, 5D, virtual reality, and immersion. On the other hand, in relation to institutional, managerial, and ethical issues, the new improvements in the web raised more challenges related to free data software and interoperability, and to volunteer geographic information (VGI) and the production and use of data, or to geographic information (GI) access disparities and data privacy problems.

2) Whether GI is a science or it is there to support other sciences continues to be a long-standing debate. Why is it so? Because it lacks its own law, it applies (adapt) other science algorithms and theories, so it cannot exist independently from the other sciences, and it is extremely dynamic with new branches being added frequently and with it added are fuzzy boundaries with other sciences [6, 7].

What makes GI a science? Reitsma [6] presented an interesting argument on this issue. He supports that GI is a science because it has a distinctive object of study and the (geographic) representation of the world, as Goodchild, in 1992, once referred to when he argued about the uniqueness of spatial (geographic) data. Therefore, how to transform spatial data into geographic thinking or knowledge is the major core of this science [5].

Is there a definition for GISc? All said, we might well think that there is no definition for GISc. In fact, defining GISc is not consensual, just as GIS for long time. Nevertheless, there are some attempts. Rapper's definition is perhaps the most well known as he defines GISc as "a perfect multidiscipline with a core of theory, data, and software engineering work and a periphery of engagement with related disciplines"[8]. While Reitsma [6] suggests that it is the study of how geographic information is formed, collected, managed, analyzed, and visualized to represent the world. Others added that GISc is also responsible to analyze the impacts of GIS in society and vice versa [8, 9].

3. GIScience

Geographic Information Science (GIS) operates through the techniques, methods, and approaches associated with GIS and seeks to redefine the geographic concepts and their use in the context of GIS. Thus, it becomes clear that the term GISc is also multidisciplinary.

Here, we begin to propose some concepts more comprehensive about geography, which treats "Geo" not only as a discipline, but also as a means to an end. For this, first, we first go to the conceptualization of science as a body of systematized knowledge acquired through observation, identification, research, and explanation of certain categories of phenomena and facts and formulated methodically and rationally.

Going a little further, we came to this definition of Geographic Information Science, by Mike Goodchild, a researcher at the University of Santa Barbara who advised former President of the United States of America, Al Gore, on the movie "Inconvenient Truth." "Information Science can be defined as the systematic study, according to scientific principles, of the nature and properties of information. Geographic Information Science is the subset of information science that is about geographic information" [5].

That is, does it make sense to talk about Geographic Information Science? Or is it ok using a shorter term Geoscience? Indeed, the concept of Digital Earth was introduced by former United States of America vice president Al Gore in 1998 [10]. Gore compared it to a digital world that mirrors the reality [11]. This concept becomes a reality thanks in large part to virtual globes (like Google Earth) that ease the massification of both the search and the sharing of information [12].

It is projected that Digital Earth should be a space for sharing of global information for development between regions and generations [13], and it is considered that the integration of this parallel world in the daily life of humanity will already be put in place in 2020 [12]. This context is perceived as an added value for geography. In addition to reinforcing its importance as a science of innovation, it still benefits from a new dimension of space, which leads to virtual geography, supporting the development of a geography with new contours, supported by the proliferation of new digital technologies [14]. The contents that are part of the GISc are:

- Data collection—all forms, from total stations, Global Navigation Satellite System (GNSS) receivers, satellites and drones, smartphones, devices of IoT and to the users themselves, who are also "walking sensors."

- Storage platforms and data management—here, we talk about anything that can store some kind of data or information, which can be in local servers, in the cloud, or in any other place.

- Data modeling, algorithms, and processes—the different data formats—vector, raster, point clouds, tables, and so on—how are they modeled, converted, and used.

- Data visualization—a few decades ago printed maps were the visualization standard but the emergence of computation led cartography to the screens. Today the geographic information is in the palm of our hand (e.g., smartphones), but also in new platforms such as virtual and augmented reality glasses, 3D printers, etc.

- Data analytics tools—not long ago, the power of layering or mapping the best route between multiple points was restricted to "semigods who inhabited the geoisland," but today anyone has the power of GIS in two clicks away (neogeography [15]).

- Institutional aspects—this is the item that makes it clear that GISc is much more than geotechnology because institutional issues involve politics, conflict of interests, cultural differences, disputes over ownership of data, and many others.

- Data sharing—finally, the ways of sharing information have changed a lot and will advance even more rapidly in the near future. Nowadays, novelties cross the world in a few seconds through social networks. This leads us towards a set of paradigm shifts about who owns the data, what is the reach of the information, what will be the impact of it, and about who will be the end users.

GISc must focus in the essential concerns that come from GI. Further expressions have more or less a similar connotation, e.g., spatial information science, geomatics, geoinformatics, and geocomputation. They all will advocate a scientific attitude regarding the core subjects upstretched by GIS applications and associated technologies. They all also have diverse backgrounds and highlight unalike means of facing geographic problems.

Finally, we arrive at the pyramid (**Figure 1**) that clearly shows the three dimensions of Geographic Information Science [16], each one of equal importance. One should note that of its three vertices, only one is related to technology, which is the dimension related to computing (although originally it was written computer, we can substitute here for any device with capacity to collect, store, analyze, and share geographic information). The other two pillars of the GISc relate to people and society in general. These are the vertices of a triangle, and GISc places itself in the

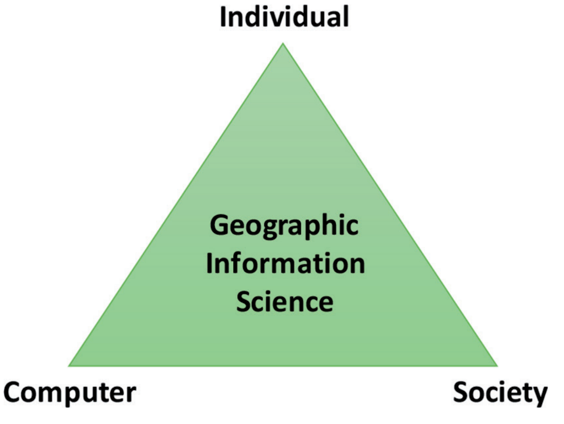

Figure 1.
Dimensions of geographic information science [16].

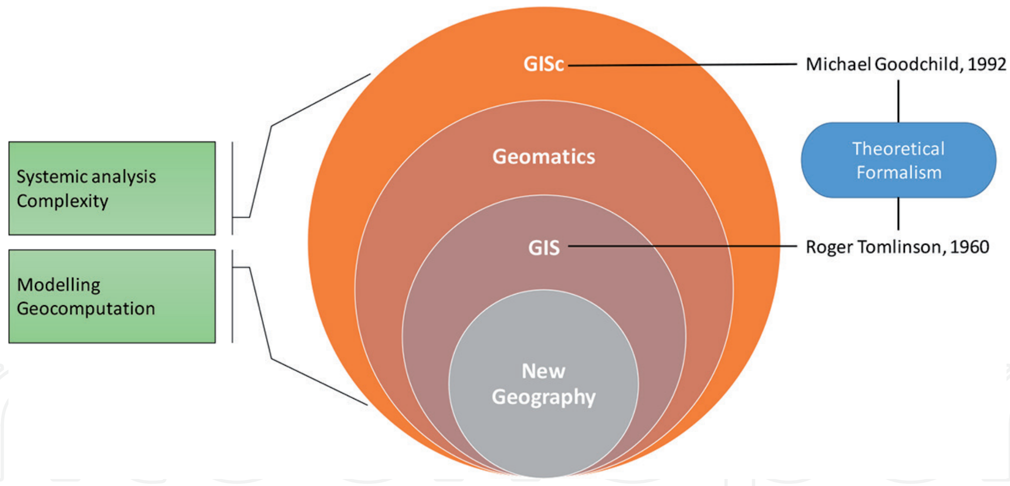

Figure 2.
From geography to GIS.

center. The several expressions used to refer to GISc may serve to fill this triangle: That is, terms like geotechnology, geomatics, and geoprocessing are valid for some approaches, but GISc is much more than that.

The field of GISc has only been recently evidenced as a scientific domain with autonomy, and not simply as an instrument or just an occasional merge of knowledge from other areas. In its fundamental component, it includes matters of cartography, positioning, information systems, computer graphics, and more. The exploitation of information can also make use of knowledge in the field of statistics, operational research, expert systems, and decision theory. The incorporation of concepts and the specific problems of the numerous fields of application brought together all these general problems of geographic modeling, adding to them theories and techniques in fields as diverse as physics, geography, planning, health, demography, and among many others.

One of the major challenges of GISc is the development of techniques and abstractions that are capable of adequately representing dynamic phenomena. Indeed, the GISc corresponds to a set of scientific knowledge and methods fundamental to the development and validation of spatial theories, but they do not advocate GIS as an isolated entity, i.e., a science per se (**Figure 2**). This approach agrees with the definition of GIS as a tool but considers it reductive, since it excludes concepts; fundamentals; methodologies; rules; and methods of analysis, measurement, evaluation, and decision support of spatial models.

Thus, there are significant issues where GISc is all about using a GIS environment to remake, restructure, and solve preexisting research problems, many of them much older than GIS itself. Indeed, it is much easier to label GISc than to define it [17]. Therefore, scientists usually adopt a defensive position when it comes to positioning GISc in relation to other sciences [6, 18].

Nevertheless, they all agree that basic and applied science should have its reflection in society [19]. Hence, one may determine that GISc is extremely pertinent to society. This is more difficult to demonstrate them compared to the broader term of Geographic Information Technologies (GIT), which many times is shown to be capable of influencing the society and vice-versa [20, 21].

4. Geography and GIScience

At present, we are facing a paradoxical situation. On one hand, there is the emergence of neogeography and the proliferation of user-generated geographic content and more precisely volunteered geographic information (VGI). On the other hand, we are witnessing a new incursion of physics into social sciences, with a growing motivation for the use of physical models in the analysis of social systems, e.g., cities [22–25] and social networks [26].

We are turning our scope to the traditional latent tension between macrogeography, centered in general principles (law-seeking), and microgeography (description-seeking), which proliferated in most of the twentieth century. The former advocates a nomothetic geographic knowledge and the later an idiographic one [27]. This is not the first time, and surely not the last, we see this, and we have differential modeling to prove it [28]. GISc holds both, the first in algorithms and methods and the second in data. One can easily draw a connection between physics and GISc, passing through spatial analysis [29]. This is the first insight that we should retain, and this is particularly true for human geographers, in which spatial context does matter.

Despite all the efforts, human geography has denied the importance of physical principle-based models, which makes it clear that the interactions between low-level system components can produce new characteristics that proved to be unpredictable, even if we fully understand the central laws that rule the system, i.e., emergency. These characteristics are obvious human systems of (auto-)organized complexity and sophisticated feedback loops (positive and negative) driving to emergent behaviors and counterintuitive effects, e.g., cities [30]. Here, spatial context is fundamental, because it influences the local pattern of interactions between system components and consequently the system dynamics that emerge from individual behaviors [31] in a phenomenon where one could designate aggregate complexity.

The use of models in any branch of geography research has proven to be more efficient than the traditional techniques of data analysis. Stating so, one do not intend to appeal to the rejection of any other technique that has demonstrated its usefulness, neither do we expect that geographers change their research objectives. The use of models at all levels is presently a different question. Models are so effective and the functional explanation of a system is much more effective than a set of disconnected facts that the use of models will prove to be of the most importance in the long run.

To advocate the use of models is not necessarily to insist on the study of general geography, spatial distribution, or the purpose of formulating general laws. In the long term, the most significant result of developing geographic models will be the establishment of genuine principles, distinct from superficial generalizations. These models are supported by a stronger basis and are enhanced with values that emerge at higher levels. For instance, considering spatial interaction models, or one of its outmost representatives: gravity model, it was first drawn as an analogy to the third Newton's gravity Law, then strengthened through entropy maximization [32, 33], and finally turned spatially explicit. The outcome was a refined panoply of spatial interaction models, including the ones focused on origin-destination spatial context [34].

This is where geography is different from natural sciences. It is where the exceptions, the discrepancies, and the uniqueness cannot be ignored because of the fact that the Earth's surface is not an isotropic space. One should not end up studying the discrepancies between the normative model and the real case, instead one should insist in finishing the study of the particular cases, of the normative element, of the special element, and of all of them as one. Nowadays, we have the knowledge and necessary techniques to study what appear to be parts of a more general system. Geography will just achieve internal consistency by being able to abstract himself from reality.

The choice is not only between human and physical, regional and general geography, nor is it only between regional differentiation, landscape evolution, human ecology, and spatial distribution and the recognition of spatial patterns, but may also be between objective academic studies and practical spatial planning. It may be between pointing out objectives to build coherent theories to search for order in a complex world and trying to understand those parts. In both, models are inevitable, stimulating, and economic.

One may enquire whether we are looking for truth or utility: a pertinent question currently in geography. Many simulation models used for prediction and planning are black box models and may be useful in a short-term practical application even presenting a false assumption of the systems nature. We can name the abductive reasoning with this type of logical inference, which starts with data and finishes by drawing a hypothesis that best fits that data. This kind of tentative knowledge (might be true) is more fragile than induction (what is true) and deduction (what must be true) knowledge. Therefore, it should be validated and sustained by far-reaching theories [35].

One factor that has gained importance and helped to reinforce the role of quantitative geography (and to dispel fears) about model implementation is the growing mathematical component, sometimes leading to the designation of mathematical geography. At present, we recognize geomatics, i.e., mathematical geography, as a branch of geography. Thus, the concept establishes a parallelism between geography and algorithms. Hence, it can be said that quantitative geography, well seconded by the diffusion and rapid growth of the computational technology, has unfolded toward what would be the logical evolution, the appearance of the GIS. This branch has expanded too many other disciplines that use GIS and remote sensing (**Figure 3**) [36]. **Figure 3** expresses advances pushing geographic science beyond cartography into a far more multipurpose and dominant vision of "maps" that has its reflection on many sciences and/or technologies.

If GIS traditionally has a singular connexion to geography, as it has to other sciences that deal with georeferenced data, e.g., engineering and landscape architecture, GISc,

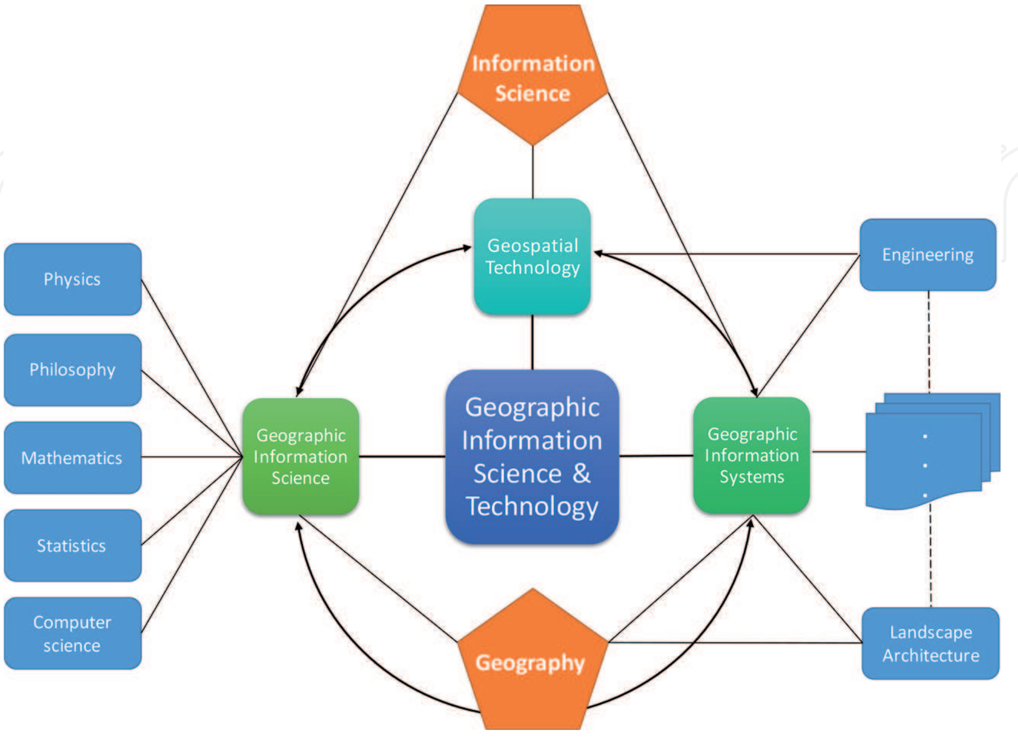

Figure 3.
From geography to GIS [36].

being an original set of concepts and expertise with an extensive applicability, has captured the attention of several traditional sciences, e.g., physics, philosophy, mathematics, etc. (**Figure 3**). As follows, GISc is many times labeled as interdisciplinary, multidisciplinary, transdisciplinary, and multiparadigmatic. Despite having different meanings, these definitions usually are used as synonymous. But, why this debate of science, subscience, or multidisciplinary field remembering the outdated—or perhaps not—discussion about if GIS and quantitative analysis are geography?

Some researchers still say that GISc is just a response to GIS technology and not a state-of-the-art science, giving the example of critical GIS, today fully integrated in GISc but initially the focus of pronounced disagreement [37]. This bifurcated propensity is clear in two polemic and completely distinct understandings [37]: one defending a mathematical and formal perspective of GISc, mainly focusing on quantitative and computational aspects [38], and other antiessentialist and anti-interpretative [39]. The latest one, being a deflationary method, allows joining a role of essential ideologies. However, taken to the extreme, it can lead to a totally amorphous field of research.

5. Insights into the future

According to Haklay [37], GISc relies upon an inductive approach (**Figure 4**). Contrarily to deductive approach that start with a theory that can either be corroborated or not, depending on the results of the validation tests, i.e., observations, carried out, inductive approach comes to theory based on observations, trying to detect patterns that can lead to the formulation of the former.

Remler and Van Ryzin [40] propose a clear division between observational studies, natural experiments, and weak/strong quasi-experiments (**Figure 5**). This distinction is made in function of the sorting method, if it has some degree of control (latter two) or if the researcher has no control over it (former two). Observation, i.e., evidence based approach, is supported by longitudinal and experimental procedures that reinforce the randomness prerogatives inherit from cross-sectional methods [41]. The new methods for data gathering and the availability of open big data enable this kind of approach for studying human-physical, or simply human, complex systems [42].

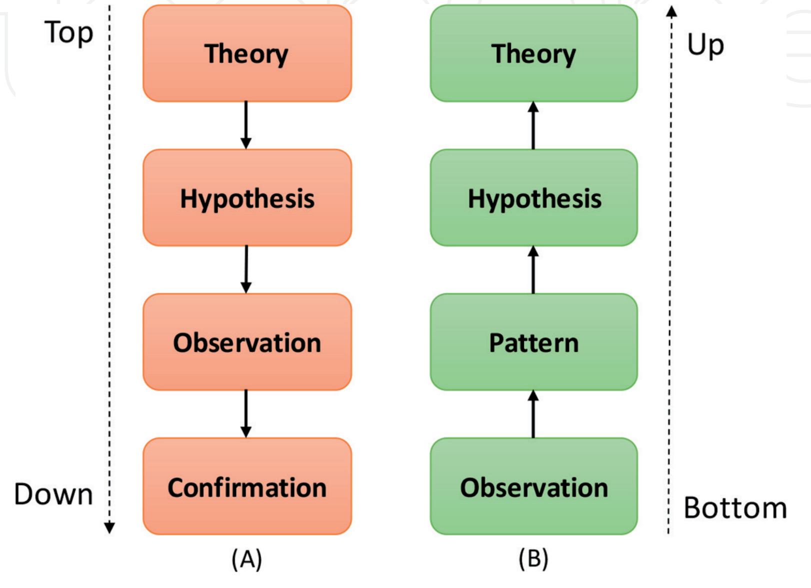

Figure 4.
Deductive (A) and inductive (B) workflows.

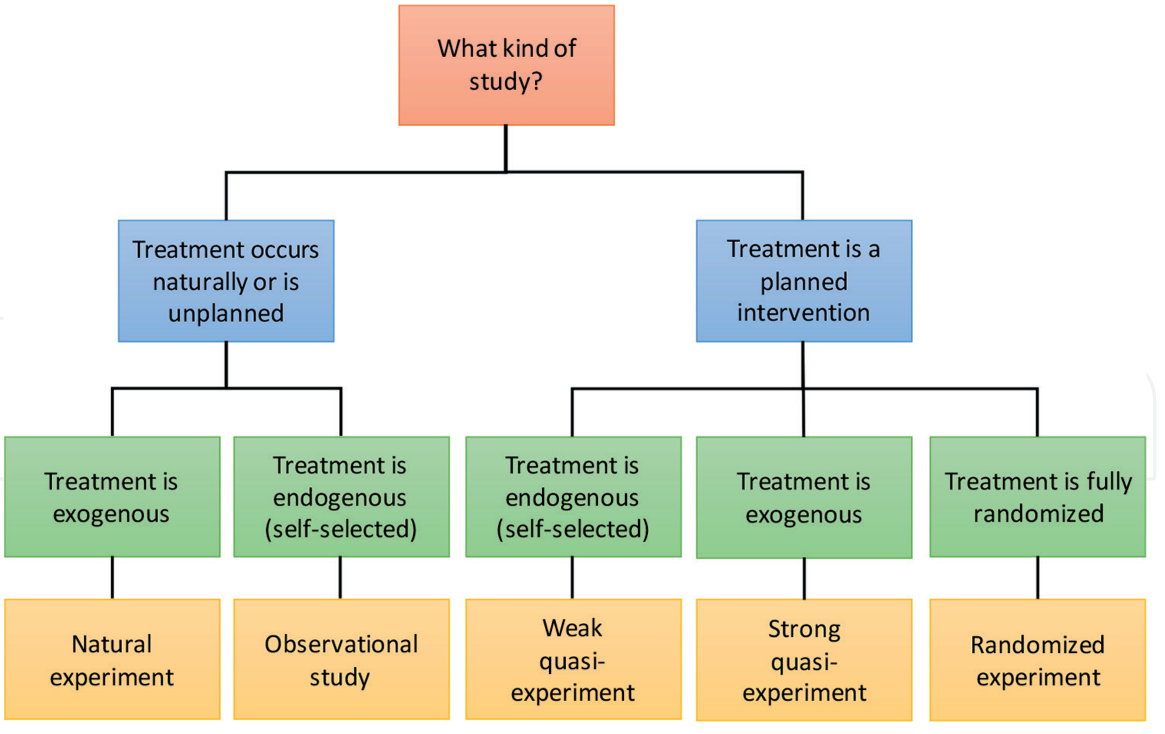

Figure 5.
Different approaches of experimental research [40].

The colossal and distinct data dissemination through a multitude of worldwide connected databases lead to an increasing expansion of complex data availability, built from different sources, and to its interaction with the existing procedures and behaviors [43, 44].

The increasing growth of popularity in social media platforms, e.g., Facebook, Twitter, Instagram, or Flickr, etc., resulted in the availability of a large amount of VGI. Goodchild [45] defines VGI as geographic data produced by users usually with the backing of Web 2.0 capabilities [46]. Indeed, society changed from a web supported by documents to a web supported by databases, crowdsourced data and social networks [47], bent by social behavior [48] and giving access to both collaboration tools and environments, allowing analytical visualizations [49].

The Web 2.0 and the omnipresence of the data radically changed not only the technical support of GIS but also of GISc, extending the potentials of people participation in administration and planning processes [50]. This holistic point of view allowed researchers to study social phenomenon using the digital traces and social interactions that individuals leave online [51].

There are several examples of the VGI: potential to forest-fire mapping [52], crisis-maps [53, 54], geotagged (Flickr) photograph analysis for tourism management [55–57], or mapping the sense of place [58]. Twitter is also an important source of data [59] and Takhteyev, Gruzd, and Wellman [60] studied the social ties between its users.

Additionally, Crampton et al. [61] evaluated the possible influences of big data on critical geography using exploratory methods to overcome some of the limitations related to the usage of VGI, and Viana et al. [62] accessed the value of OpenStreetMap (OSM) data for land use land cover (LULC) cartography. One may state that neogeography is bringing cartographic and GIS expertise to the common citizens [19]. Nevertheless, VGI properties are very different from the ones of traditional data sources. This can turn possible a more complex and dynamic interpretation than the one that census data allowed [63], but implies further research in the field of GISc [46].

Constantly, wide-ranging-data assembly allows to reverse engineer the events that stimulate the emergence of unexpected outcomes [27]. The complexity of geographic systems points for knowledge experimental analysis throughout the observation of processes [64]. The changing potential of big data is not about the size but instead about its spatiotemporal resolution, thematic coverage and omnipresence, and crossing analysis levels, from the single to the all [27, 42]. Now, we can study global patterns within geographic information networks [1].

Elwood, Goodchild, and Sui [46] define VGI as a "paradigmatic shift in how geographic information is created and shared" and reinforce the idea that further research is needed to develop new methods of spatial data analysis. Intrinsically, the advances we are seeing in the fields of VGI and/or big data open new research fields for GISc, especially regarding analytical capabilities. Simultaneously, GISc looks for a procedural background for dealing with the specific restrictions related to the usage of VGI and/or big data. Such challenges comprise the data quality and understanding in order to achieve a statistical valid sample, privacy issues and methods, and techniques for dealing with geographic data.

6. Conclusions

GISc is strongly connected Geography, as they equally analyze the same features of reality [65] using comparable outlooks. Thus, GISc is the "science behind the system" [5] mainly focused in computational and representation topics, while Geography aims to model and predict geographical phenomenon.

The dissatisfaction with traditional social physics (and geography) is comprehensible. They both looked for universal laws, which now, looking back, seems a little bit naıve to say the least. At the time, due to limited data and weak computation processing capacity, researcher in general and specifically geographers presumed homogeneity within physical and social systems. Doing that, we turn an exciting and data-rich environment, i.e., reality, into sterilized, amorphous, lifeless models. At their beginning, spatial analysis and GISc followed this approach despite having much more appealing representations, i.e., maps.

The new Geography, social physics, spatial analysis, and GISc are substantially different, as they are data and computation driven. The computer is the essential feature rather than an auxiliary one. When becoming more and more sophisticated, GISc assumes that generalization is possible although context is extremely important.

Lastly, instead of flattening geographic space into an insipid uniformity, GISc promotes heterogeneity as a key feature to understand how processes evolve and how to get better outcomes through a science-based policy. In addition, this continuous research can focus on the complexity of policy results. Social and social-physical systems are complex by nature and have particular dynamics with several feedback (positive or negative) loops. Some of these feedbacks are expected, like the mechanism that all living systems have for maintaining orderly conditions (i.e., homeostasis), and others are not, leading to the appearance of new system features (i.e., emergence). For that reason, it can be demanding (or even impossible) to evaluate the success of a policy intervention. Big data, and its related constant data assemblage, enable this to happen naturally, without constraints [3].

A policy intervention can result in numerous outcomes, positives or negatives, that will withstand for a while long [30]. The use of the actual time consuming deliberate experimental researches makes it problematic to explore all the amount of existing options [66]. Broader researchers' commitment to data-intensive analysis enables additional subtle, comprehensive, and profound approaches to complex

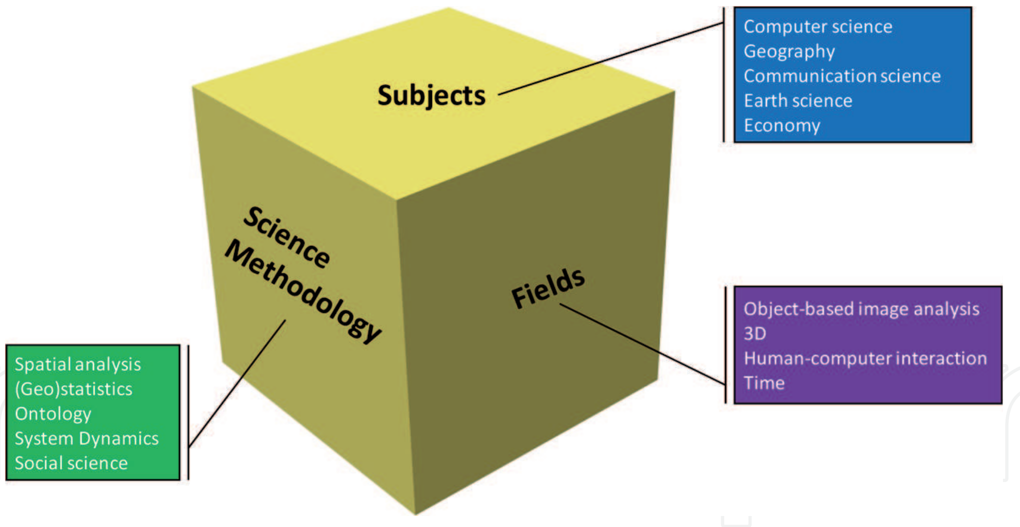

Figure 6.
Cubic representation of GISc research perspectives [73].

problems, refining the research and, at the same time, makes policies supported by science more understandable to the common people, e.g., climate change [67].

These progresses are still somewhat new [8], and GISc is just starting to methodically analyze whether these matters have (or not) the capability to leave a meaningful impact on society. Nonetheless, Big Data is probably the outmost important paradigm shift that, with more or less delay, will change GISc. The main question is the inherent and ever more spreading communicative status of geographic data [68, 69]. Web 2.0, VGI [70] and neogeography [15], and also the sensors that allow real time data capture prove that this a reality with no turning back [71].

Nevertheless, one should not be blind by data. Theory is critical to get enlightenments about what data reveal and for handling big data [42]. To avoid being trapped in a kind of data dependency, we need to understand the processes (including measurement methods and technologies) that generate it [72].

Blaschke and Merschdorf [7] recognized distinct trends in GISc. They systematized them into 10 items: (i) plenty of spatial data, (ii) thinking spatial, (iii) fuzzy analysis and turning into geographic nonspatial data, (iv) spatial computing, (v) ubiquitous computing, (vi) non-Cartesian measurements, (vii) spherical innovative spatial analysis, (viii) VGI, (ix) neogeography, and (x) geographic knowledge. From a citizen's and/or researcher's perspective, these 10 trends can be grouped into five main clusters: (i) big data and location analytics; (ii) the reborn of time geography with mobile users, mobile sensors, and trajectories; (iii) cognition, emotions, and other data unmeasurable in a straightforward manner; (iv) a more spatially aware society with geobrowers and/or virtual globes; and (v) the discovery of new geographic scales with, for instance indoor geospatial analysis.

The future will certainly continue to include various research fields (**Figure 6**), and yet, it is inspiring to enable harmony among processes and patterns. Looking to the possible interactions, one can isolate three groups, i.e., location analytics and mapping, spatiotemporal modeling, and social media and citizens. This last one clearly includes the user's perspectives, and it is heavily connected with the interdisciplinary that characterizes GISc.

Thinking and spatial reasoning constitute a form of thinking grounded in the concept of space, in the tools of representation and in the process of reasoning [74], and are stimulated through the manipulation of geotechnologies [75, 76]. Researches should act with extreme caution; as recently Facebook and Google shown to the world, there is not a crisp line, but rather a very fuzzy one, between naive and not-so naive social investigation [77]. The protection of citizens' privacy and the way it interlinks with the increasing need for data is a key point in the future of GISc [78].

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Conflict of interest

The authors declare no conflict of interest.

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