

# Stratified, Destratified, and Hybrid GIS: Organizing a Cross-Disciplinary Territory for Design

By

Moa Karolina Carlsson

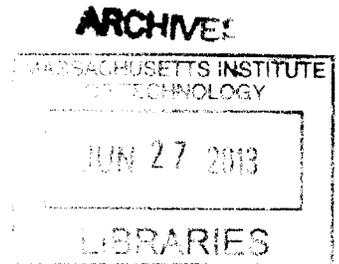
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## ABSTRACT

Although the term Geographic Information System (GIS) is most commonly associated with computer software, the principles of GIS existed long before it was implemented on a computer. This thesis hypothesizes that the computerization of the formerly analogue GIS in the 1960s, which emerged with *CGIS* and initiatives at the *Harvard Laboratory for Computer Graphics and Spatial Analysis*, can be read as the establishment of a pre-existing analytical conception of the environment over its synthetic and holistic counterpart. It is often claimed that the analytical nature of computerized GIS was determined by the capabilities and limitations of the digital computer. While this techno-centered trajectory of GIS is fairly well documented, the present thesis aims to open up a new perspective on GIS, by highlighting an alternative history of modeling both natural and artificial geographical information through the *Ecological Method* of Ian L. McHarg, the late Emeritus Professor of Landscape Architecture and Planning at the University of Pennsylvania.

In the thesis, these two parallel trajectories of analytical and synthetic/holistic methods are examined through two general schemes by which cross-disciplinary geographical information is organized, from the perspective of a general user. The two models, henceforth characterized as “stratified” and “destratified” models, both deal with the linking of cross-disciplinary and geographically referenced information, differ in logic and user interaction, but are argued to be equally computational.

The motivation behind the present research is the realization that, to date, the technological aids available for design in cross-disciplinary and dynamic environments do not suffice. Whispers of a new design-oriented platform, which one might characterize as “Landscape Information Modeling” or “LIM,” are starting to be heard, and the main purpose of this thesis is to contribute to such discussion.

Thesis Advisor: George Stiny

Title: Professor of Design and Computation



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Stratified,  
Destratified,  
and Hybrid GIS:  
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# 01. Introduction



## 1.1 Hypothesis

The core principles of a Geographic Information System (GIS) concern the organization, processing, representation and interpretation of geographically referenced data. Although the term Geographic Information System (GIS) is most commonly associated with computer software, the principles of GIS existed long before it was implemented on a computer. The shift from analogue to digital GIS occurred in the 1960's and 70's when the discipline of cartography, i.e., the making and study of maps, was merged with sub-disciplines of computer science and mathematics. Digital GIS was invented during the spring of the environmental movement,<sup>1</sup> at a time when the political environment, primarily in North America and Britain, sought answers to big and often planning-oriented questions, involving many parties, fast. The computer seemed suitable for this task, due to its capacity to provide at least two of these three traits, i.e., speed and memory. It is often claimed that the functionality of digital GIS was determined by the capabilities and limitations of the digital computers available at the time,<sup>2</sup> and hence turned into a primarily analytical device.<sup>3</sup> While this techno-centered trajectory of GIS history is fairly well documented, this thesis aims to open up a new perspective on GIS, by highlighting a co-existing approach to cross-disciplinary information modeling. This new perspective provides insights into three different models which differ in logic and user interaction, but are argued to be equally computational.

The hypothesis of this thesis is that the shift from analogue to digital GIS occurred not along a technological continuum, but involves two historical trajectories, with foundations in either synthetic and holistic, or analytical conceptions. The two trajectories are exemplified through the study of two general schemes by which information is organized, from the perspective of a general user. The two models, henceforth characterized as "stratified" and "destratified" GIS, both deal with the linking of cross-disciplinary and geographically referenced information but invite the user to engage with the data in distinctly different ways.

At the heart of the study is the field of landscape design. Landscape is a field concerned with humanity's shaping of its environment, a definition which requires an inherent capacity to mediate a plethora of artistic and scientific fields. At present, landscape, as a design discipline, is on the verge of entering what appears to be a new digital realm, monopolized by computer optimism. This shift not only entails new technologies to adopt but more importantly, new perspectives of seeing, thinking, and designing

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<sup>1</sup> One of the key publications of this era was Rachel Carson's *Silent Spring*, from 1962.

<sup>2</sup> Nick Chrisman, *Charting the unknown: How computer mapping at Harvard became GIS* (Redlands, CA: ESRI Press, 2006), 23.

<sup>3</sup> *Ibid.*, 28.

landscapes. Finding itself in a liminal state, characterized by ambiguity, openness, and indeterminacy, it has become apparent in landscape design that, to date, very limited theoretical or practical foundation exists to guide the transition in a way to expose new possibilities for design. For lack of alternatives, or lack of time to develop them, one current tendency is to extend the functionality of GIS, as currently implemented, to landscape design,<sup>4</sup> or to incorporate landscape practice into the modular and combinatorial enterprise of Building Information Modeling (BIM).<sup>5</sup> The incorporation of landscape practice into the BIM workflow, as we know it today, is occurring through the expansion of current component families to include site-based components for landscaping, planting, and topography.<sup>6</sup> The purpose of this thesis is to provide historical context which helps illustrate why the transition of landscape practice to these established computer systems, although possible, is but one option- and speculate about possible alternative approaches. New tools for design in cross-disciplinary and dynamic territories are required.

## 1.2 Method

This thesis comprises a comparative study of three approaches to the organization, processing, representation, and interpretation of geographically referenced information, i.e., the implementation of the principles of GIS. The first, and perhaps least-known approach, is founded on a holistic world view and aims to consider the whole environment at once, which requires a process of de-stratification of information layers. This approach is exemplified by Ian McHarg's "Ecological Method,"<sup>7</sup> in which transparent map overlays of natural and artificial landscape characteristics are fused to provide a holistic and homogenized setting for design.

The second approach is well documented and reflects a discrete world view implemented through methods of analysis and information stratification. This approach is exemplified by SYMAP and the

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<sup>4</sup> Hanna C. Karen, *GIS for Landscape Architects* (Redlands, CA: ESRI Press, 1999) and Carl Steinitz, *A Framework for Geodesign: Changing Geography by Design* (Redlands, CA: ESRI Press, 2012).

<sup>5</sup> James L. Sipes, "Integrating BIM Technology into Landscape Architecture," *Landscape Architectural Technical Information Series*, 1, (2008).

<sup>6</sup> Ahmad Mohammad Ahmad and Abdullahi Adamu Aliyu, "The Need for Landscape Information Modelling (LIM) in Landscape Architecture," in proceedings of: *13th Digital Landscape Architecture Conference*, 2012, Bernburg, Germany.

<sup>7</sup> Ian L. McHarg, "the Ecological Method (1969)," *Theory in Landscape Architecture: A Reader*, ed. Simon Swaffield (Philadelphia, PA: University of Pennsylvania Press, 2002), 38-43.

ODYSSEY package, two models of digital GIS developed at the Harvard Laboratory for Computer Graphics and Spatial Analysis in the 1960's and 1970's.

Both the destratified and the stratified approach to GIS propose a computational structure for the handling of cross-disciplinary and geographically referenced data, which invites a series of intriguing questions, such as the following:

- How is information organized, from the perspective of a typical user, in order to create a cross-disciplinary territory for query and/or design? What were the motivations for choosing these organization principles?
- In what format is data entered into each model?
- What is/are the format(s) of the output(s) from each model in relation to process and representation?
- What is the agency of the human designer as a user of the two methods?
- What are the differences in methodologies for cross-disciplinary evaluation of data, i.e., how are decisions based on observed phenomena arrived at, in the two models?

These questions allow for assessment of the underlying assumptions and intentions of the two general schemes of organization. By analyzing the reasoning that guided the implementation of stratified and destratified GIS, a new perspective on the system, as currently implemented, is opened. In addition, by highlighting the underlying logics of the two models, one can begin to speculate about new possibilities, hybrids in-between them.

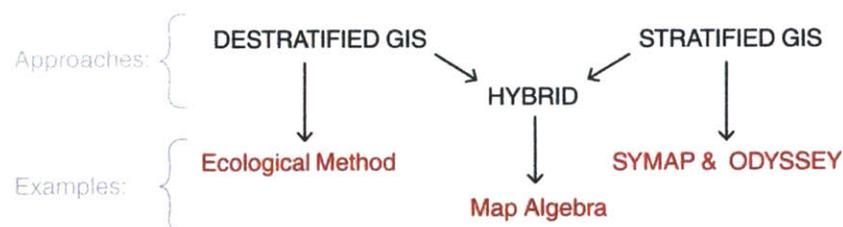


Fig. 1 Illustration of Thesis Content

### 1.3 Steps

This thesis project is developed in six steps: Problem Statement, Method, Definitions, History, Descriptions, Analysis and Reflections. Chapter 2, *Problem Statement* introduces the historical and cultural context of GIS as a set of principles which existed long before it was implemented on a digital computer. The discussion begins with the introduction to two world views, continuous or discrete, and identifies two models of GIS that correspond to the two approaches. Further the section illustrates why the developments in the history of GIS should not be viewed as one technological continuum, by pointing to the co-existence of three different models, exhibiting different logics, during the period centered around 1963. At the end of the section a shortcoming is identified in the current set of software available for design in dynamic and cross-disciplinary contexts. A platform which might be called Landscape Information Modeling (LIM) is introduced and it is speculated around how the findings in the present study can inform the discussions around such a system.

Chapter 3, *Method*, discusses the way the question has been addressed in this thesis. First the method of creating a historical reconstruction of the system, in the form of a timeline of a related history of ideas, is discussed. Secondly, a set of few key questions investigated in this thesis are highlighted which help specify the criterion by which the different models of GIS can be compared and evaluated. In addition, this chapter illustrates why McHarg's Ecological Method has been chosen to exemplify the de-stratified approach to GIS as well as why Dana Tomlin's Map Algebra has been identified as a possible hybrid approach.

Chapter 4, *Definition*, aims to provide a better understanding of the scope of this thesis by discussing the distinction between the fields of geography and landscape, as well as how these two fields relate to design. These definitions lead to a description of the common conception of GIS as a digital platform for storage, retrieval, manipulation, analysis and display of geographic data. The section continues by highlighting four phases, as identified by Coppock and Rhind<sup>8</sup>, of the development of the system, from digitalization to the present.

Chapter 5, *History*, presents two narratives of a history of ideas which this author sees as influential for the implementation of the two world views, based on analysis or synthesis, in GIS. The first history of idea pertains to the lineage of holism and is argued to have influenced the development of de-stratified

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<sup>8</sup> Terry J. Coppock and David W. Rhind, "The History of GIS," in Maguire D.J., Goodchild M.F., and Rhind D.W., eds. *Geographical Information Systems : Principles and Applications*, vol. 1, (1991): 21-43.

GIS, in which the whole enterprise is assessed in its totality. The second history of ideas, concern a lineage of analysis in a discrete world view, which is argued to have influenced the development of stratified GIS.

Chapter 6 *Description*, describes the details of the three studied models; destratified, stratified and hybrid GIS. The description is initiated by an introduction to each of the three models, where after the functionality, organization of data, and typical user methods are described, respectively. The descriptions of the models are arranged in chronological order, starting with Ian McHarg's Ecological method which exemplifies destratified GIS. The description continues with the description of two platforms of digital and stratified GIS, including SYMAP and ODYSSEY, and finishes with the description of Dana Tomlin's Map Algebra, which exemplify an approach to hybrid GIS.

In Chapter 7 *Analysis*, the three models of GIS are evaluated and contrasted, and their general schemes for organization of data in the different phases of operation, seen from the perspective of a typical user, are compared. The underlying assumptions and intentions of each model are exposed to evaluate differences in their underlying logic. It is argued why the models, despite their differences in logic and user engagement, should be considered as equally computational constructs, but that a hybrid model seem particularly well-suited for landscape design, which invites for further computational investigations.

Chapter 8, *Reflections*, aims to position the findings of this thesis within the context from which it was initiated. The significance of the study in a current context of techno-optimism is underlined by providing a new lens with which to view the current GIS technology. For the curious landscape designer a new set of insights to an established technology are provided which can help guide the development of alternative systems, better capable of holistically handling interrelated and dynamic information.

#### 1.4 Intended Contributions

History writing has a remarkable capacity to portray events as having continuity. In the case of GIS, the techno-centered historical trajectory most often described well suits the analytical nature of the system as currently implemented, but is a misleading description of the nature and importance of the earlier initiatives, based largely on holistic engagement with the environment. By extracting an alternative historical trajectory, it is argued that the shift from analogue techniques to digital process, in the 1960's

and 1970's,<sup>9</sup> occurred not in continuity but brought about a distinct shift of logic in GIS. By analyzing a timeline of related events, this thesis aims to identify how and why the discontinuity occurred.

Furthermore, this thesis involves a close examination of three cross-disciplinary models, with aims to abstract three general schemes by which cross-disciplinary information is organized (or appears to be organized) from the perspective of a typical user. These models include a destratified model, based on an ecological viewpoint, i.e., an anti-reductive view in the sense that the whole enterprise is considered at once;<sup>10</sup> and the stratified model, i.e., a layered information model which provides for specialized and analytical assessment; and finally, a hybrid model that exhibits characteristics of both of the other models. At the center of the investigation is the agency of the human designer as well as the interaction between the designer and the analogue or digital tool in each case.

This thesis aims to engage uncritical techno-optimists, and also those who are skeptical about the use of computational methodologies in design, but more importantly, the curious landscape designer. It is my hope that this thesis can help form a better understanding of the intentions and assumptions linked to the conception and evolution of GIS, which in turn may inform the formation of the hopefully forthcoming Landscape Information Modeling (LIM) platform.

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<sup>9</sup> Roger Tomlinson, "The impact of the transition from analogue to digital cartographic representation," *The American Cartographer*, 15, no. 3, (1988), 249-261.

<sup>10</sup> Ian L. McHarg, *Design with Nature* (Philadelphia, PA: The Falcon Press, 1969).

## 02. Problem Statement:

Design in Cross-Disciplinary  
Environments



## 2.1 Problem

This thesis concerns two modes of viewing the world, as continuous or discrete. These opposing world views relate, on the most fundamental level, to how we interact with the world through design.

A proven method for comparing and contrasting different approaches to something is to study the models through which they have been implemented. Accordingly, the present thesis involves a comparative study of two practical models of organization of geographically referenced and cross-disciplinary information in GIS. The two models, stratified and destratified GIS, co-existed during the shift from analogue to digital GIS in the 1960's. The aim of the thesis is threefold: first, to investigate the general schemes by which cross-disciplinary information is organized in the three models, seen from the perspective of a typical user; second, to investigate how a typical user interacts with each of the three models, in order to arrive at decisions based on observed phenomena; and third, to challenge the dichotomy of the destratified and stratified models by specifying criteria that can help in identifying or constructing hybrid approaches, i.e., ones that exhibit characteristics of both models.

The motivation behind the research presented is the realization that, to date, the technological aids available for design in cross-disciplinary and dynamic environments do not suffice. Although it seems there are an abundance of tools for specialist use, there seem to be few available that operate according to a more generalist model able to handle the plethora of information and disciplines involved in landscape design. Whispers of a new possible design-oriented platform, which might be called "Landscape Information Modeling (LIM) ," are starting to be heard,<sup>11</sup> and the main purpose of this thesis is to contribute to such discussions. A return to the analogue and digital roots of GIS, to critically evaluate their underlying logics, can lead to a critical understanding of attempts to create such a system, which, according to Ian McHarg, the late Emeritus Professor of Landscape Architecture at the University of Pennsylvania and key subject for the analogue section of this thesis, is still only in its infancy and has yet to reveal its full potential.<sup>12</sup> In order to better understand what the possibilities for the future might entail, a thorough survey of past events involving approaches to landscape and information technology is required.

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<sup>11</sup> Ahmad and Aliyu, "The Need for Landscape Information Modelling (LIM) in Landscape Architecture," 2012, and presentations, *BIM for Landscape Seminar*, the Association BuildingSMART-Norway, As, Norway, April 3<sup>rd</sup>, 2013.

<sup>12</sup> GIS World, interview. "In Memoriam: Ian McHarg Reflects on the Past, Present and Future of GIS," *GEO World*, October (1995): 46-49.

## 2.2 Problem Context

The history writing of GIS is as motley as it is abundant. Although written by many authors, the most common historical trajectory focuses on the development of digital GIS, and its immediate pre-cursors. This typical historical account describes digital GIS as having originated with Roger Tomlinson's Canada Geographic Information System (CGIS) in 1964<sup>13</sup> and having been further developed, initially by Howard Fisher, at the Harvard Laboratory for Computer Graphics before entering the commercial market in the 1980's in the form of desktop software, primarily after the establishment of the *Environmental Systems Research Institute* (ESRI) in 1969 by Jack Dangermond. In the vast amount of literature on the topic, three key texts which provide detailed documentation of these digital developments include Timothy W. Foresman's publication titled *the History of Geographic Information Systems: Perspectives from the Pioneers*<sup>14</sup>, Nick Chrisman's *Charting the Unknown: how computer mapping at Harvard became GIS*, and the special 1988 issue of *the American Cartographer*, edited by Roger Tomlinson, titled *Reflections of a Revolution: the transition from analogue to digital representations of space*. In addition to these historical accounts, publications highlighting the technical details of how the digital system has been developed since its implementation, through both raster-based and vector-based GIS initiatives, are abundant.

In the majority of these publications, the work of Ian L. McHarg, Angus G. Hills, Philip H. Lewis, Jaqueline Tyrwhitt, and Warren Manning, is often noted as representing an analogue precursor to digital GIS. While acknowledging their contributions to the field before GIS was digitized, their efforts are often evaluated from the current perspective of the computer, i.e., according to how their methods did or did not suit digitalization. As Nick Chrisman notes, "Both McHarg and Lewis put substantial faith in the integrative role of the designer in looking at the whole and seeing patterns, a role that still [in 2006] defies direct translation to computer software."<sup>15</sup> Other commentary on these efforts has claimed, often and misleadingly, that the analogue method of "[h]and-rendered cartography, other than specialized art, is becoming outdated."<sup>16</sup> Having identified this gap of documentation, this thesis aims to contribute

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<sup>13</sup> Roger Tomlinson, "The Impact of the Transition from Analogue to Digital Cartographic Representation," *The American Cartographer*, 15, no. 3, (1988), 249-261.

<sup>14</sup> Timothy Foresman, *The history of geographic information systems: perspectives from the pioneers* (Upper Saddle River, NJ: Prentice Hall PTR, 1998), 21.

<sup>15</sup> Nick Chrisman, *Charting the unknown*, 43.

<sup>16</sup> Bruce E. Davis, *GIS: A Visual Approach*, 2<sup>nd</sup> ed. (New York, NY: Cengage Learning, 2001), 23.

towards a more inclusive description of the history of GIS, by highlighting an alternative approach to its formation. This additional historical perspective on the developments in GIS holds potential to not only enrich the evaluation of the current system, but also to contribute to speculations about future developments.

### 2.3 Timeline: Deducing Pasts – Projecting Futures

The research methodology of this thesis has involved gathering relevant data primarily from published documents, and from existing video interviews with key subjects who were active during the period studied. In order to analyze the material and arrive at a more complete understanding and historical reconstruction of the period, a timeline of the relevant history of ideas has been compiled. In this context, two parallel trajectories of analytical or synthetic and holistic methods in GIS have been examined. The full timeline is included in the appendix of this thesis.



## 03. Background



### 3.1 Geography, Landscape, and Design

Mapping as a way of knowing and seeing, is a practice of both landscape and geography. In order to better understand the scope of this thesis, this section provides a brief summary of how geography and landscape are distinguished and how they relate to design. On the most fundamental level, one may attempt to differentiate between the fields by saying that while geography is used to describe the surface of the earth, landscape, on the other hand, is what we do to it, and as such denotes the external world mediated through subjective human experience. This statement, when examined in detail, immediately brings up questions concerning geographic subjectivity. Robyn Longhurst writes, "All geographical knowledge, whether it is spatial science, behavioral geography, Marxist geography, feminist geography or cultural geography, presupposes some theory of subjectivity. Different theories of subjectivity prompt different geographical knowledges."<sup>17</sup>

Charlie Fitzpatrick from Esri, attempts to define geography as a field primarily concerned with three questions: What is where? Why is it there? and So what? In this attempt, geography is viewed as a descriptive enterprise that aims to explain, analyze, manage, and predict the features and conditions of the earth.

Landscape, on the other hand, is an ambiguous term, used with great freedom. In common language the term is often used to denote the natural world or features of natural scenery, a connotation which, especially in the context of this thesis, is incorrect, or at least proves too narrow. The landscape geographer J.B. Jackson argues that we no longer bother with the literal meaning of the term and states that "We have coined a number of words similar to it: roadscape, townscape, cityscape, as if the syllable 'scape' meant a space, which it does not."<sup>18</sup> Also, Anne Spirn argues, in her book titled *the Language of Landscape*, that "landscape is not a mere visible surface, static composition, or passive backdrop to human theater."<sup>19</sup> Rather than being a physical feature of the environment, J.B. Jackson argues that landscape is a synthetic space, i.e., "a system of man-made spaces superimposed on the face of the land, functioning and evolving not according to natural laws but to serve a community."<sup>20</sup> Denis Cosgrove, the late Prof. of Geography at the University of California, Los Angeles, also emphasizes the human component in landscape by arguing for landscape as a cultural product. He states, "While

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<sup>17</sup> Longhurst, "Placing Subjectivities", in Kay Anderson, et al., *Handbook of Cultural Geography* (London: SAGE Publications, 2003), 283.

<sup>18</sup> J.B. Jackson, *Discovering the Vernacular Landscape* (New Haven, CO: Yale University Press, 1984), 4.

<sup>19</sup> Anne Spirn, *The Language of Landscape* (New Haven, CO: Yale University Press, 1998), 17.

<sup>20</sup> J.B. Jackson, *Discovering the Vernacular Landscape*, 8.

landscape obviously refers to the surface of the earth, or a part thereof, and thus to the chosen field of geographic enquiry, it incorporates far more than merely the visual and functional arrangement of natural and human phenomena which the discipline can identify, classify, map and analyze."<sup>21</sup>

The term "landscape" was first introduced in Britain around 500AD<sup>22</sup>. The etymological roots declare the term as concerned with the organization and demarcation of fields and other geographical spaces. The meaning of the first syllable, "land," is a space defined by boundaries,<sup>23</sup> which implies a space as defined by people, and as a result, a space which could be described in legal terms. The second syllable, "scape," can be traced to meaning "organization" or "system." The combined meaning of these two syllables makes "landscape" a term not with natural but social, cultural, and political connotations.

However, when the term "landscape" was reintroduced in Britain in the 1600's, its meaning had changed dramatically, and the term became used to describe works of art. At this time, a leisurely form of travel, known as the *Grand Tour*, was a common undertaking among the British upper class. While traveling on the *Grand Tour*, travelers would be exposed to the fine arts, natural scenery, and culture of continental Europe in the wake of the renaissance. To challenge the well-established focus on the epic and scenic beauty of Europe, William Gilpin sought to introduce exploration of rural Britain, as a counterpoint to the classical tours of Europe. In 1768, Gilpin introduced the aesthetic ideal of the picturesque as a new mode of seeing the world. In Gilpin's *Essay on Prints* he defines picturesque beauty as "that peculiar kind of beauty which is agreeable in a picture."<sup>24</sup> Gilpin's picturesque viewing of British landscapes entailed the imaginative structuring of landscape scenery into foreground, distance, and secondary distance, a compositional structure Gilpin appropriated from other landscape painters such as Claude Lorrain, Gaspar Dughet, and Salvatore Rosa.<sup>25</sup> During this period, local scenery was elevated "to the status of painted pictures"<sup>26</sup> and landscapes became viewed as synoptic compositions of natural beauty.

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<sup>21</sup> Denis Cosgrove, *Social Formation and Symbolic Landscape* (Madison, WI: The University of Wisconsin Press, 1984), 13.

<sup>22</sup> J.B. Jackson, *Discovering the Vernacular Landscape*, 5.

<sup>23</sup> *Ibid.*

<sup>24</sup> William Gilpin, *An essay on prints* (London: Printed for R. Blamire, 1768), 2.

<sup>25</sup> Bermingham, Ann. "System, Order, and Abstraction: The Politics of English Landscape Drawing around 1795," in *Landscape and Power*, edited by William J. T. Mitchell (Chicago, IL: University of Chicago Press, 1994, 2nd ed., 2002): 86.

<sup>26</sup> Elizabeth Meyer, "Situating Modern Landscapes", in *Theory in Landscape Architecture: A Reader*, ed. Simon Swaffield (Philadelphia, PA: University of Pennsylvania Press, 2002), 23.

Thus, with the etymological meaning of the term and the picturesque mode of viewing landscapes, it is apparent that no distinct boundary can be traced between what can be described geographically and what is perceived through the mode of landscape. A possible reason for the common misconception of landscape as simply natural scenery is that the work of the early naturalist landscape masters, such as Frederick Law Olmsted, is so well assimilated into the natural setting that for a layman it can be hard to distinguish between what is “original” versus “transformed.” To further highlight the blurred boundary between landscape as either synthetic or natural space, a closer look at the components of a designed landscape, as defined by the French landscape architect Jean Marie Morel de Kinde in the 18<sup>th</sup> Century, might prove useful. In his treatise *Theorie des Jardins* (1776),<sup>27</sup> Morel specifies four garden genres, classifiable by their varying degree of human involvement. The fundamental issue addressed by Morel, concerns how to effect the transition from a building, i.e., the domain of man, to the garden, i.e., the domain of nature. For Morel the most successful transitions between these two domains are those that are simple, seamless, and as natural as possible. The four genres are arranged in a sequence of descending size and naturalness. From the perspective of the building, the inner three genres, i.e., “le pays,” “le parc,” and “le jardin,” are all part of the same continuum and differ only in variety, size, scale, and degree of visible artistic intervention. The fourth genre, “le ferme,” i.e., the fields or productive land, is separate from the continuum due to its unique utilitarian character. Of the four genres, “le Jardin,” located closest to a building, has the most detailed and visible designed landscape whereas “le Pays,” located furthest from the building, is virtually indistinguishable from the surrounding natural scenery.

This range of human involvement, both through practical intervention and as visually detectable traces, proves a useful ground for defining landscape in relation to design and geography. In the context of this thesis, the term “landscape” denotes the world as shaped by subjective human experience, a definition which requires design. Interestingly, when adhering to this definition, it becomes apparent that landscape is inherently linked to time and to change, and constitutes a mesh of interlinked processes of varying amplitude, frequency, and speed.<sup>28</sup> But even viewed as a collection of artificial or natural conditions in flux, the human being as observer and participant in landscapes can never be omitted.

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<sup>27</sup> Jean Marie Morel de Kinde, *Theorie des Jardins* (Paris: Pissot, 1776).

<sup>28</sup> Richard Forman, *Land Mosaics: The Ecology of Landscapes and Regions* (Cambridge, MA: Cambridge University Press, 1995).

### 3.2 The Geographic Information System (GIS) - From Digitization to the Present

The most common conception of a Geographic Information System (GIS) is a digital platform for storage, retrieval, manipulation, analysis and display of geographic data. The term is most commonly associated with computer software, such as ArcGIS (Fig. 1), supplied by the *Environmental Systems Research Institute* (Esri). Jack Dangermond, founder and President of Esri, argues that while geography and design have existed for very long time, “in the last half of the twentieth century they began co-evolving with computational technology”<sup>29</sup>. He concludes, “GIS is making geography come alive. It condenses our data, information, and science into a language that we can easily understand: maps.”<sup>30</sup> It is easy to infer the motivation behind such a statement by the founder of Esri, today the world’s leading supplier of GIS software and database applications.<sup>31</sup> Concerning the success of the system, Dangermond notes that “GIS has certainly been successful – hundreds of thousands of organizations, big and small, have now embraced it and use it to guide their decision making.”<sup>32</sup> This view reflects the fulfillment of the key intentions for the digital system as implemented in the 60’s, i.e., the aim to develop a platform with capacity for analysis over large and often cross-disciplinary datasets. Over time these intentions have turned into what is sometimes called Geographic Information Science, which involves the study of the theory and concepts that lie behind GIS and other geographic information technologies.

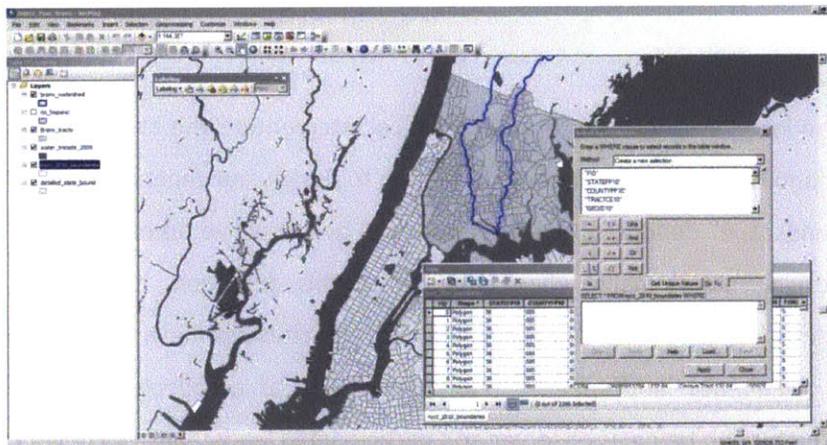


Fig. 2 Typical User Interface, ArcMap by ESRI.

<sup>29</sup> Carl Steinitz, *A Framework for GeoDesign: Changing Geography by Design*, (Redlands, CA: ESRI Press, 2012), vii.

<sup>30</sup> Jack Dangermond, “Geography: A Platform for Understanding,” *Essays on Geography and GIS*, vol. 5, (December, 2012): 6.

<sup>31</sup> Carl Steinitz, *A Framework for GeoDesign*, vii.

<sup>32</sup> *Ibid.*

GIS is currently widely used in landscape architecture and landscape design, but rather than being integral to the design process, GIS primarily serves as a technology for analysis purposes. Bill Miller, director of *GeoDesign Services* at Esri, notes: "GIS has grown to serve the data and analysis components of workflows quite well, but up until now it has played little role in serving the design component."<sup>33</sup> While Esri have acknowledged the short-coming of their GIS software in this respect, their solution, termed "GeoDesign,"<sup>34</sup> provides for an extension to the implemented framework, but without questioning or challenging the logic of the system, as currently implemented.

J. P. Coppock and J. W. Rhind,<sup>35</sup> argue that since the invention of digital GIS, the developments of the system can be classified roughly in four phases.<sup>36</sup> The first is the "pioneer or 'research frontier' period,"<sup>37</sup> with duration from the 1950's until approximately 1975. This period was associated with the formation of a new discipline, primarily in North America and Britain, through the undertakings of a few key individuals and often through idiosyncratic initiatives. A few of these initiatives include Roger Tomlinson's work, which in 1964 became known as the Canada GIS, early explorations of Edgar Horwood at Northwestern University,<sup>38</sup> and later Howard Fisher at the Harvard Laboratory for Computer Graphics and Spatial Analysis (LCG). An interesting initiative during this period was the experiments in interdisciplinary education carried out at the Harvard Graduate School of Design, Landscape Architecture Research Organization (LARO), which operated during the period 1966-1979. LARO was closely affiliated with both the Department for Landscape Architecture, at the Harvard Graduate School of Design, and with the LCG, and in some respects became the "testbed" for exploration by employing the new technologies in design settings.<sup>39</sup>

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<sup>33</sup> Bill Miller, *Changing Geography by Design: Selected Readings in GeoDesign* (Redlands, CA: ESRI Press, 2010), 3.

<sup>34</sup> Carl Steinitz, *A Framework for GeoDesign*.

<sup>35</sup> Coppock and Rhind, "The History of GIS", (1991).

<sup>36</sup> D W Rhind, D J Maguire and M F Goodchild, *Geographical Information System* (Hoboken, NJ: John Wiley & Sons, 1991), 39.

<sup>37</sup> Ibid.

<sup>38</sup> Chrisman, *Charting the Unknown*, 4.

<sup>39</sup> Descriptions of these initiatives can be found in Steinitz, Carl, and Peter Rogers, *A Systems Analysis Model of Urbanization and Change: An Experiment in Interdisciplinary Education*, MIT Report No.20, (Cambridge: MIT Press, 1970), and Steinitz, Carl, Timothy Murray, David Sinton, and Douglas Way, eds., *A Comparative Study of Resource Analysis Methods*, [Under Contract with the Department of the Army New England Division, Corps of Engineers, Waltham, Mass.] (Department of Landscape Architecture Research Office, Graduate School of Design Harvard University: Cambridge, MA, 1969).

According to Coppock and Rhind, the second phase of GIS development lasted from approximately 1973 until the early 1980's. During this phase, GIS software became adopted by many national agencies, such as local governments in both North America and the UK, which led to a focus on the development of shared conventions or so called "best practices." The 1980's can be characterized as the phase of development, a period which became associated with increased commercialization of GIS software database management applications, resulting in fierce competition among vendors.

Finally, Coppock and Rhind note that the fourth period, since the late 1980s, has become associated primarily with developments aiming to improve the usability of GIS technology by making software more user-oriented. This period also saw many technological breakthroughs, such as Dana Tomlin's Map Algebra which is further discussed in Chapter 9.

Because critique is a fundamental part of academic and social discourse, GIS has been under heavy scrutiny from many perspectives since its implementation on a digital computer. While the majority of critiques of digital GIS concern the underlying assumptions and intentions seen from a sociological or technological perspective, rarely are concerns raised questioning the opportunities and limitations for design that the system provides.

# 04. History: Two Trajectories



## Foreword to Chapter 4

Do we think of the world in terms of an uninterrupted succession of characteristics everywhere in space, or of an empty space littered with possibly overlapping objects? This philosophical question concerns two modes of viewing the world as either discrete or as a continuous construct, which invites engagement through either synthesis or analysis. In psychology, synthesis is defined as “the integration of traits, attitudes, and impulses to create a total personality,”<sup>40</sup> which can be viewed as an allegory for the composite representation of the environment created in Ian McHarg’s Ecological Method, as described in Chapter 6. Analysis, on the other hand is typically defined as “the separating of any material or abstract entity into its constituent elements,”<sup>41</sup> or in a narrower mathematical context, “the investigation based on the properties of numbers.” In the history of GIS, the distinction between the two approaches is not always clear, which opens up an interesting area of research.

Although authored by the contributions of many scholars and practitioners,<sup>42</sup> and often in autobiographical format, the history of GIS provides for a rich description of the dawning of a new digital system for data management and analysis, guided by scientific specifications. Timothy Foresman, author of *the History of Geographic information systems: Perspectives from the pioneers*,<sup>43</sup> argues that “No simple or single explanation can be expected for a reality based on confluent influences from many ancient roots.”<sup>44</sup> This, he argues, should not be a source of discouragement. He continues, “Lack of a single evolutionary path should not prevent us [...] from examining some of the major influences that helped to forge the current setting for GIS professionals, applications, and supporting industry.”<sup>45</sup> In accordance with Foresman’s statement, this thesis argues against taking the perspective that due to too many interlinked and parallel events, all events and influences in the history of GIS pertain to one, albeit broad, technological continuum. As a counterpoint, this thesis is an attempt to highlight two different approaches to GIS, and to describe the historical contexts that helped shape them. In this context one

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<sup>40</sup> “Synthesis,” in *Random House Webster’s Unabridged Dictionary*. 2nd ed. 1993. (New York: Random House Reference, 1993).

<sup>41</sup> *Ibid.*, “Analysis”.

<sup>42</sup> Foresman (1998), Tomlinson (1988), Chrisman 2006 and Steinitz (1970).

<sup>43</sup> Foresman, *the History of Geographic Information Systems: Perspectives from the Pioneers*, (1998).

<sup>44</sup> *Ibid.*, 3.

<sup>45</sup> *Ibid.*, 4.

can debate whether or not Waldo Tobler's first law of geography,<sup>46</sup> stating that "Everything is related to everything else, but near things are more related than distant things," really holds.

Despite multiple perspectives and accounts, it is generally agreed that GIS was designed with the aim to handle, process, and interpret geographically referenced data. As any GIS, analogue or digital, is umbilically connected to geographically referenced data, i.e., representations of natural or artificial phenomena related to specific locations on the surface of the earth, its model of implementation naturally depends on the worldview of its author. Without doubt, the arrival of the computer in the 1950's became a key breakthrough for the analytical approach, as the computer imposed a new rigorous and abstract logic. This new logic meant that much of the work for a typical user came to revolve primarily around specification, as the operations of the machine demanded explicit definitions and descriptions, both of the data itself and its organization, but also of the desired operations. In this sense, the computer became not only the main technology employed, but more importantly, would come to have a significant influence on the attitude towards the processing and interpretation of data, a change arguably reflected in the agency of the human designer.

It is often claimed that the development of digital GIS was motivated by three main goals; first, automation of the production of hardcopy maps; second, improved analysis of geographic data, including spatial-, statistical-, and network analysis;<sup>47</sup> and third, the formulation of conventions for a digital and universal Geographic Information System. The last goal was a project mainly concerned with overcoming the limitations of data handling and data analysis of hardcopy maps and related statistics.

#### 4.1 Trajectory 1: Engagement through Synthesis

No matter what aspect of landscape one chooses to engage in- e.g., the ecological, planning, social, political, ornamental, or gardening- landscape is a field tangled up in a plethora of scientific and artistic disciplines, including among many other, geography, meteorology, botany, ecology, horticulture, the engineering sciences, economy, architecture, design, and the fine arts. However, by turning that statement on its head, one might argue that it is all the same; it is all one. From this perceptual point of view, there are no separations or subcomponents, which mean that the sum is greater than the parts

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<sup>46</sup> Waldo Tobler, "A computer movie simulating urban growth in the Detroit region"., in *Economic Geography*, 46, no. 2, (1970): 234-240.

<sup>47</sup> Tomlinson, *The Impact of the Transition from Analogue to Digital Cartographic Representation*, 250-251.

because there are no parts. As seen by an observer and participant in landscapes, humanity's place is within and part of landscapes as opposed to separate and outside. In this perspective, the disciplinary sub-components, i.e., data related to specific scientific fields, are but artificial abstractions, used, in the very best case, as described by Herbert Simon, 'to show that wonder can be comprehended, but not to destroy wonder.'<sup>48</sup>

What grounds can one possibly have to back up such a statement, the generalists holistic view of landscapes as a fused whole? As pointed out by John Theodore Merz, *A History of European Thought in the Nineteenth Century*<sup>49</sup>, there are many who have advocated for a holistic view of nature, e.g., Leonardo da Vinci, Albrecht von Haller, Johann Wolfgang von Goethe, John Ruskin, Alexander von Humboldt, and Georges-Louis Leclerc Comte de Buffon.<sup>50</sup> Keith Wheeler's slim volume, titled *From Goethe to Geddes and the Search for Environmental Understanding*, provides an interesting historical lineage of holism, which without much effort can be extended to Ian McHarg via Lewis Mumford.

The lineage starts with Goethe, who is singled out due to his original holistic appreciation of both artistic and scientific aspects of nature. According to Goethe, "Nature is neither kernel nor shell; She is everything at once;<sup>51</sup>" a statement which is often claimed to place the work of Goethe "on the borderland of poetry and science."<sup>52</sup> Merz continues: "To this view every object of contemplation, be it large or small, physical or mental, is a whole, a totality, which, in the actual *Together* of its apparent parts, reveals to us something which is lost as soon as we start to dissect or analyse it."

To Goethe, sight, not thought, was the starting point in both poetry and science,<sup>53</sup> a view he shared with the great German geographer Alexander von Humboldt. Humboldt was a naturalist and explorer and a firm believer that the unity of nature was the seamless construct of the interrelation of all physical sciences. Humboldt writes, "Nature herself is sublimely eloquent. The stars as they sparkle in firmament fill us with delight and ecstasy, and yet they all move in orbit marked out with mathematical precision."<sup>54</sup>

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<sup>48</sup> Herbert Simon, *The Sciences of the Artificial*, 1-2.

<sup>49</sup> Theodore Merz, *A History of European Thought in the Nineteenth Century* (London: W. Blackwood and Sons, 1912).

<sup>50</sup> Merz, *A History of European Thought in the Nineteenth Century*, 612.

<sup>51</sup> *Ibid.*, 613.

<sup>52</sup> *Ibid.*

<sup>53</sup> *Ibid.*, 612.

<sup>54</sup> Alexander Humboldt, *Cosmos*, vol. 1 (London: Henry G. Bohn, 1864), 37-38.

Humboldt viewed nature holistically, and tried to explain natural phenomena without the appeal to religious dogma. He believed in the central importance of observation, and as a consequence had amassed a vast array of the most sophisticated scientific instruments then available. Each had its own velvet-lined box and was the most accurate and portable of its time; nothing quantifiable escaped measurement. According to Humboldt, everything should be measured with the finest and most modern instruments and sophisticated techniques available.<sup>55</sup> During his many extensive travels, Humboldt gathered an enormous amount of data which was later synthesized in his very extensive scientific and geo-poetic literary output.<sup>56</sup> In 1802 Humboldt set out on an expedition to climb Mount Chimborazo in Ecuador, which at the time was considered the tallest mountain in the world<sup>57</sup>. The expedition was later depicted by Goethe in his painting titled *Höhen der alten und neuen Welt bildlich verglichen* [Heights of the old and new world pictorially compared], (1807). From the data gathered on this expedition, Humboldt produced a large number of geo-poetic representations, all based on empirical observations made during the trip. As an example, the cross section of Mount Chimborazo (Fig. 3) displays Humboldt's conception of plant geography and reflects his effort to show the unity, diversity, and interconnectedness of nature. The transect shows Latin plant names at various altitudes, and in columns to the right and left of the drawing Humboldt presents relevant climatic conditions such as temperature, barometric pressures etc. It is the conjoining of these parameters which determined at which geographic locations plants grew, as depicted on the section. His techniques for linking scientific data via the means of artistic representation incorporated both the inorganic as well as the organic, i.e., both human and non-human phenomena in their totality<sup>58</sup>. Humboldt's emphasis on empirical observation and precise measurement methodology later was termed "Humboldtian science".

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<sup>55</sup> Otto Fränze, "Alexander von Humboldt's Holistic World View and Modern Inter- and Transdisciplinary Ecological Research," in *Northeastern Naturalist*, Vol. 8, no. 1 (2001): 57-90.

<sup>56</sup> Humboldt's great work, *Voyage aux Regions Equinoxiales*, spanning 35 volumes, was published in 1808.

<sup>57</sup> Caroline Schaumann, "Who Measures the World? Alexander von Humboldt's Chimborazo Climb in the Literary Imagination," in *The German Quarterly*, v. 82, iss. 4 (2009): 447-468.

<sup>58</sup> Keith Wheeler, "From Goethe to Geddes and the search for environmental understanding" (transcribed presentation, Fourth C. C. Fagg Memorial Lecture, Croydon, May 5<sup>th</sup>, 1972): 419.

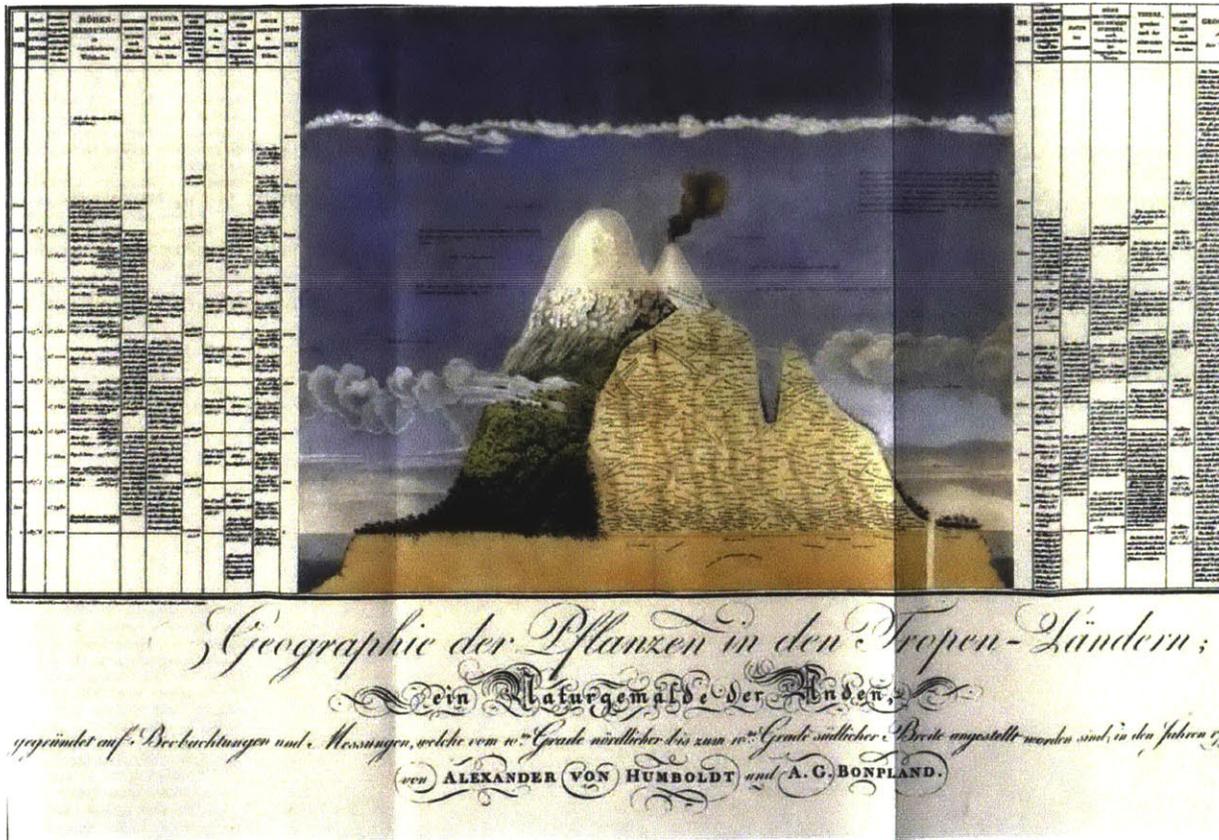


Fig. 3 Alexander von Humboldt. Cross-section of Mount Chimborazo. (*Geographie des Plantes Equinoxiales*, 1807)

Influenced by Humboldt's holistic ways of interpreting and describing nature, Élisée Reclus, a French geographer, writer, and anarchist, was a strong advocate for the harmony between human culture and the natural environment. As a geographer Reclus studied the unity of the earth, but was divided in his beliefs between inevitable progress in nature and man's capacity for destructive action against the environment.<sup>59</sup> As such, the main interest of Reclus, as stated in his obituary written by his close colleague, and fellow anarchist geographer, Prince Peter Kropotkin, was "The earth as the abode of man, and what man has done and is doing to his abode."<sup>60</sup> To Reclus, it was man's harmonious relation to nature and her capacity to manipulate and change the physical environment which was the focus. In commenting on and evaluating Reclus's great work, *Geographie Universelle : la terre et les hommes*,<sup>61</sup> Kropotkin wrote, "It is the comprehension of Nature of Goethe and of Shelley, in his softest, less

<sup>59</sup> Wheeler, *From Goethe to Geddes and the Search for Environmental Understanding*, 419.

<sup>60</sup> Kropotkin, "Obituary of Elisee Reclus", *Geographical Journal*, v.25 (1905): 319.

<sup>61</sup> Elisee Reclus, *Geographie Universelle : la terre et les hommes* (Paris: Hachette, 1875).

tumultuous strophes.”<sup>62</sup> Kropotkin attempted to translate a passage from Reclus’s text, which he deemed provided insight to one of Reclus’s key motivations:

*Seen from above and from afar, the diversity of features intermingled on the surface of the globe – crests and valleys, meandering waters, shore-lines, heights and depths, superimposed rocks – presents an image which, so far from being chaotic, reveals to him who understands a marvelous picture of harmony and beauty. And if the world seems consistent and simple amid the endless complexity of its forms, shall the indwelling humanity, as is often said, be nought but a blind chaotic mass, heaving at hazard, aimless, without an attainable ideal, unconscious of its very destiny?*<sup>63</sup>

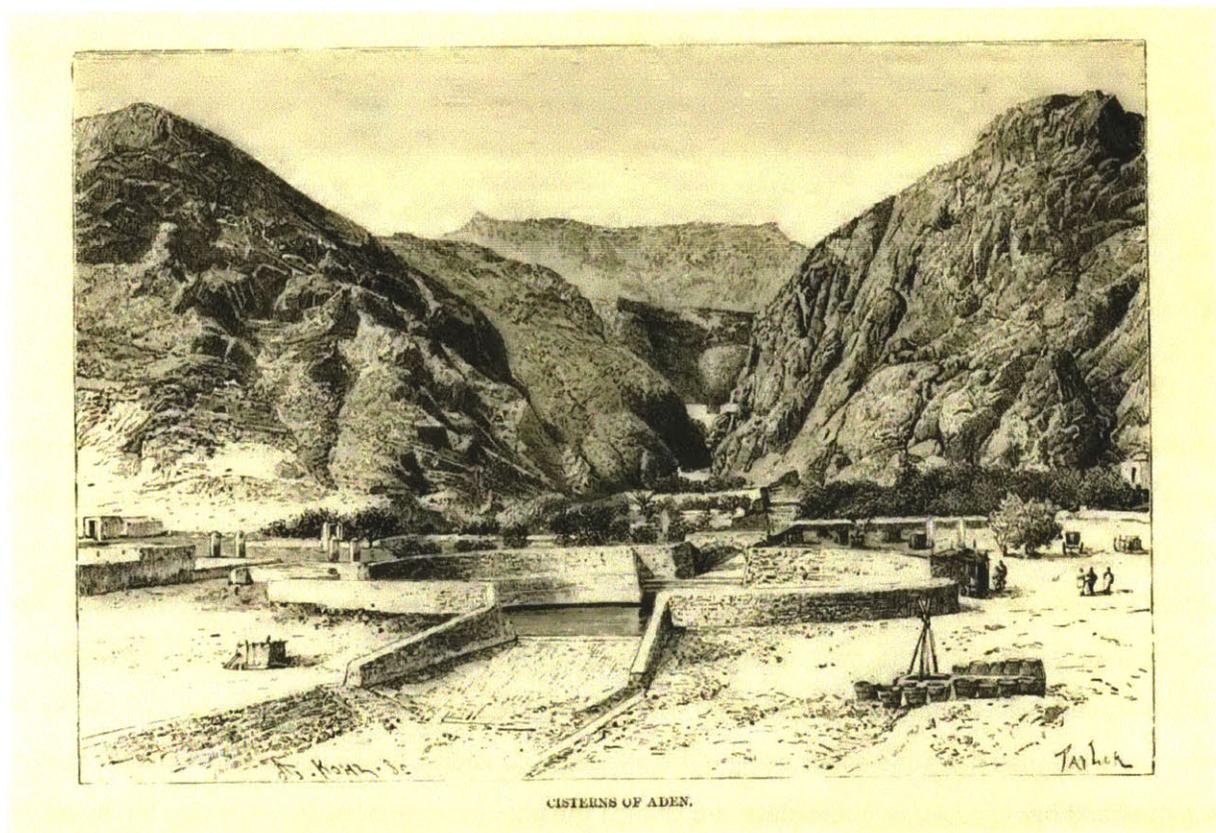


Fig.4 Élisée Reclus. Cisterns of Aden. (Plate from *Geographie Universelle*, 477.)

<sup>62</sup> Kropotkin, *Obituary of Élisée Reclus*, 341.

<sup>63</sup> *Ibid.*

Kropotkin, who was Russian, and Reclus had worked closely together in Switzerland between 1876 and 1881. In 1902, Kropotkin published *Mutual Aid: A Factor of Evolution*,<sup>64</sup> which provided an alternative view on animal and human survival, contrary to the, then popular, Darwinistic view of evolutionary progress through competition and survival of the fittest. In his book, Kropotkin used many examples from his scientific expeditions to illustrate his view of cooperation, i.e., “mutual-aid,” as the second, but most important factor in the evolution of the species and the ability to survive. Kropotkin was careful to distinguish between the more practical form of struggle, e.g., that among individuals for limited resources, which he deemed of a competitive nature, and the more metaphorical struggle between organisms and the environment, which he deemed more cooperative. He writes, “There is an immense amount of warfare and extermination going on amidst various species; there is, at the same time, as much, or perhaps even more, of mutual support, mutual aid, and mutual defense [...] Sociability is as much a law of nature as mutual struggle.”<sup>65</sup> As such Kropotkin did not deny that competition existed as an instinct and drive in humans, but argued that from an evolutionary perspective the importance of alignment and cooperation as key drivers had been gravely undervalued. The ideas of Kropotkin, and Reclus alike, concerned both natural and sociological aspects of the world.

Under the influence of the ideas of Kropotkin, Reclus, Humboldt, and Goethe, Ernst Haeckel would come to be the first to introduce the term “oecology,”<sup>66</sup> which he did in *The History of Creation* (1873). Haeckel (1834-1919), a German zoologist and evolutionist, was influenced by both Darwin and Goethe, and strongly agreed with their views on the interconnectedness in nature. Ecology, according to Haeckel was the holistic point-of-view rather than the analytic, and was by Haeckel’s definition, “the extremely varied [...] phenomena which show us the relations of organisms to the surrounding world, to the organic and anorganic conditions of existence: the so called ‘economy of nature’ the correlations between all organisms which live together in one and the same locality.”<sup>67</sup>

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<sup>64</sup> Peter Kropotkin, *Mutual Aid: A Factor of Evolution*, Chapter I (London: William Heinemann, 1902).

<sup>65</sup> *Ibid.*, 12.

<sup>66</sup> Wheeler, *From Goethe to Geddes and the Search for Environmental Understanding*, 423.

<sup>67</sup> *Ibid.*

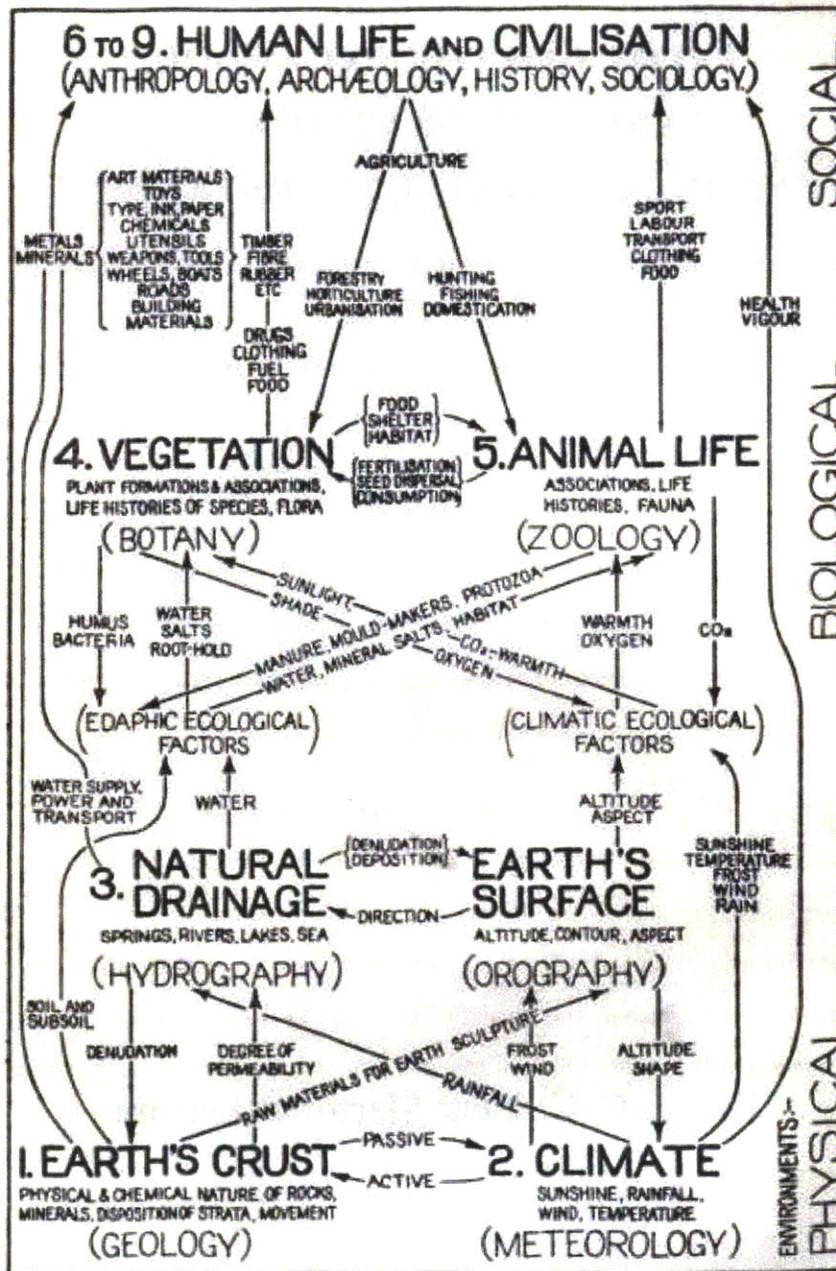


Fig. 5 Patrick Geddes. Diagram to show the links between the various branches of regional study. (Wheeler, *From Goethe to Geddes and the Search for Environmental Understanding*, 410.)

Reclus's, Kropotkin's, and Haeckel's views of man and nature in unity came to have significant influence on the work of one of the 19<sup>th</sup> Century's most innovative pioneer town-planners, Sir Patrick Geddes. Central to the work of Geddes, who was a Scottish biologist, sociologist, geographer and philanthropist, was the idea that social processes and spatial form are intimately related.<sup>68</sup> Geddes argued that the city should be studied in the context of the region, an idea which became very influential also in North America, where it was strongly advocated for by Lewis Mumford and the Regional Planning Association.<sup>69</sup> Geddes was a generalist and one of his key contributions is his development of a new and potentially powerful methodology with which to study the connections between all disciplines<sup>70</sup>. This synthesis of knowledge took place with the help of so called "thinking machines," i.e., various diagrams and graphic methods invented to encourage different ways of thinking. Examples of such "thinking machines" include Geddes' Valley Section and his diagrams of the relatedness among disciplines and phenomena in city-regional surveys (Fig. 5, Fig.6). The Valley section, which was the first drawn section to show natural conditions life associated with the exploitive impact of human presence, was developed in 1909, a century after Humboldt's transect of Mount Chimborazo.

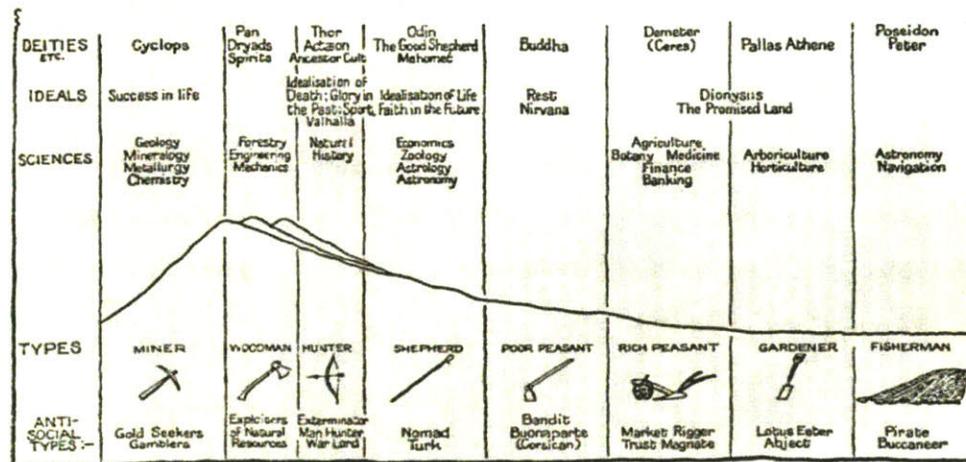


Fig. 6 Patrick Geddes. *The Valley Section* (1951)

<sup>68</sup> Helen Meller, *Patrick Geddes: Social evolutionist and city planner* (New York: Routledge, 1990), 1.

<sup>69</sup> Spiro, Ian McHarg, *Landscape Architecture, and Environmentalism: Ideas and Methods in Context*, in *Environmentalism in Landscape Architecture*, ed. Michel Conan (Washington, D.C.: Dumbarton Oaks Research Library and Collection, 2000), 100.

<sup>70</sup> Meller, *Patrick Geddes: Social evolutionist and city planner*, 45.

In 1892 Geddes, acquired the possession of a five story tower located on top of the hill in Edinburgh<sup>71</sup>. The tower had belonged to the Short's, a family with a long tradition as scientific instrument makers in South Edinburgh. The main reason for Geddes acquisition of the building was that the tower had a working *camera obscura* installed in the cupola of the roof. It was Geddes intention to implement, with the help of the *camera obscura*, an experiment which would help the people of Edinburgh gain a different perspective on their city, a new outlook of the physical environment in which they lived- a crowded and dense environment, which in Geddes' opinion was in urgent need of improvement.

It was Geddes' view that change would occur only through the means of education, from experience of and within an environment. As a generalist he professed a unified and holistic view of man and his environments, natural as well as manmade. Geddes argued that most adults lose their ability to see things as they really are, either because their awareness has been dulled by conventional education, or because they have become too narrowly specialist in their interests and thereby overwhelmed by what he referred to as the "tyranny of detail."<sup>72</sup> Ultimately, Geddes claimed that specialism destroyed the ability to understand life and its meaning. For example, Geddes wanted to replace the typical encyclopedia, with its emphasis on fragmented information, with an "encyclopedia synthetic"<sup>73</sup> which would show the relatedness among things. This idea was later implemented, not in the form of a book but by designing and implementing the experiment of the *Outlook Tower*, sometimes called "the first sociological laboratory in the world."<sup>74</sup>

Drawing on the scientific method, Geddes encouraged close observation as the way to discover and work with the relationships among place, work and folk, an idea he had conceived under the influence of the French sociologist Frederic Le Play.<sup>75</sup> These ideas would come to be tested in the implementation of the experiment known as the Outlook Tower.

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<sup>71</sup> Charles Zueblin, "The World's First Sociological Laboratory", in *American Journal of Sociology*, 4 (1899): 577-592.

<sup>72</sup> Wheeler, *From Goethe to Geddes and the Search for Environmental Understanding*, 415.

<sup>73</sup> Ibid.

<sup>74</sup> Zueblin, *The World's First Sociological Laboratory*, 577.

<sup>75</sup> Wheeler, *From Goethe to Geddes and the Search for Environmental Understanding*, 411.



Fig. 7 Sir. Patrick Geddes. The Outlook Tower, Edinburgh. (Photos from collection of Hari Docherty)

When visiting the Outlook Tower a visitor would be immediately brought to the top floor of the edifice. In the foyer outside of the room where the *camera obscura* was installed the tower walls were perforated with colored glass windows showing panes of different scientific subjects, such as botany, geology etc. Both Reclus and Kropotkin had contributed to the displays in this room.

Once allowed to enter the room with the *camera obscura*, the visitor could observe a “live” image of the city projected down on a large table at the center of the room. Geddes aim was for the visitor to be immersed in all “colors” of the world at once, which he thought would encourage visitors to stop seeing life only through their own interest, or one colored window, and instead to grasp the wholeness and interdependency of life. In Geddes’ view, the camera obscura showed the visitor the reality and after seeing the camera Obscura, the visitors would sit in a darkened meditation room called “the Inlook Room”, to internalize what they had learned, making it their own. After spending time in the Inlook Room, visitors went down through the Tower and reentered into the world.<sup>76</sup>

Although never explicitly acknowledged, Geddes’ ideas are most likely to have played a significant role for Ian L. McHarg,<sup>77</sup> often claimed to be the “the father of ecological planning.”<sup>78</sup> The link between the two is most likely Lewis Mumford, who was a close friend of both Geddes and McHarg.<sup>79</sup> Like Geddes, McHarg was a generalist, and similarities between their methods, such as Geddes’ “Valley Section” and McHarg’s section drawings for landscape synthesis, are striking (Fig. 7). The similarity between their representations is pointed out by Anne Spirn in her essay *Ian McHarg, Landscape Architecture, and Environmentalism*.

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<sup>76</sup> Wheeler, *From Goethe to Geddes and the Search for Environmental Understanding*, 416.

<sup>77</sup> Spirn, *Ian McHarg, Landscape Architecture, and Environmentalism*, 102.

<sup>78</sup> Foresman, *the History of Geographic Information Systems: Perspectives from the Pioneers*, ix.

<sup>79</sup> Correspondence between Geddes and Mumford is published in Frank G. Novak Jr., *Lewis Mumford and Patrick Geddes: the Correspondence* (London: Routledge, 1995). In accordance, Mumford wrote the introduction to Ian McHarg’s book *Design with Nature* (1969).



Fig. 8 Ian McHarg. Section of the Great Valley, the Rockies. (*Design with Nature*, 60.)

Ian L. McHarg was a Scottish landscape architect, educated in landscape architecture and city planning at Harvard University from 1946 to 1949.<sup>80</sup> In 1954 McHarg was appointed Assistant Professor of City Planning at the University of Pennsylvania's School of Fine Arts, where he in 1956 came to reestablish the Department of Landscape Architecture and the Master of Landscape Architecture program.<sup>81</sup> The scene around McHarg during this period was as high-profile as eclectic, and his collaborators included members such as Lewis Mumford, Louis Kahn, J.B. Jackson, Aldo Van Eyck, Denise Scott-Brown, Garrett Eckbo, and Philip Johnson. The cross-disciplinary approach to education and to landscape as a discipline in general, was to become one of the fundamentals of McHarg's work both as an educator and as practitioner. McHarg was motivated by a holistic view of evolution, based on processes of mutual aid and creative alignment of species, rather than the Darwinian concept of survival of the fittest.

McHarg was deeply distrustful of what he saw as the modern anthropocentric worldview. He states, "We have but one explicit model of the world and that is that built upon economics"<sup>82</sup>. He continues,

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<sup>80</sup> Spirn, *Ian McHarg, Landscape Architecture, and Environmentalism*, 98.

<sup>81</sup> *Ibid.*

<sup>82</sup> Austin Hoyt, John B. Calhoun and Ian L. McHarg, *Multiply and Subdue the Earth* (1969; New York, NY: National Educational Television and Radio Center), Film.

“Money is our measure, convenience is its cohort, the short term is its span, and the devil may take the hindmost is the morality [...] Neither love nor compassion, health nor beauty, dignity nor freedom, grace nor delight are important unless they can be priced.”<sup>83</sup> As such, McHarg was a strong believer that the destructive acts of man against nature were due to an ignorance or incapacity of humans to handle and consider all the parameters involved and all possible consequences simultaneously, i.e., an ecological mindset in its true Haeckelian sense. Landscape architect Anne Whiston-Spirn,<sup>84</sup> who studied with and worked directly with McHarg, writes that McHarg “promoted landscape architecture as the instrument of environmentalism.”<sup>85</sup> As such, McHarg argued for what he saw as a “desperate need for professionals who are conservationists by instinct, but who care not only to preserve but to create and manage.”<sup>86</sup> In the introduction to McHarg’s *Design with Nature* (Fig. 9), Lewis Mumford writes, “McHarg’s emphasis is not on either design or nature by itself, but upon the preposition with, which implies human cooperation and biological partnership.”<sup>87</sup> Mumford continues, “He seeks, not arbitrarily to impose design, but to use to the fullest the potentials – and with them, necessarily, the restrictive conditions – that nature offers. So, too, in embracing nature, he knows that man’s own mind, which is part of nature, has something precious to add that is not to be found at such a high point of development in raw nature, untouched by man.”<sup>88</sup>

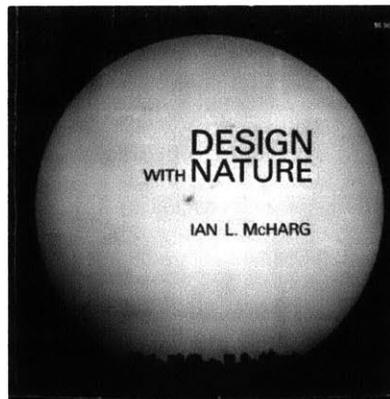


Fig. 9 Ian L. McHarg, *Design with Nature*, (1969).  
Original cover.

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<sup>83</sup> McHarg, *Design with Nature*, 25.

<sup>84</sup> Anne Whiston Spirn, is a Professor of Landscape Architecture and Planning at MIT.

<sup>85</sup> Spirn, *Ian McHarg, Landscape Architecture, and Environmentalism*, 97.

<sup>86</sup> McHarg, *Design with Nature*, 151.

<sup>87</sup> *Ibid.*, viii.

<sup>88</sup> *Ibid.*

In the theory that McHarg developed, creativity constituted the driving factor and his concept of “creative fitting” the most important characteristic for successful planning. Creativity, according to McHarg, could be defined as “the employment of energy and matter to raise matter and energy to higher levels of order,”<sup>89</sup> a process which according to McHarg has an inherent directionality. Thus, McHarg argued that if one can observe the directionality of a process, then one can determine whether or not it is creative. The criterion to be used to judge whether or not a process is creative McHarg calls “to fit.” He writes, “The ability to find of all environments the most fit, and to adapt that environment and oneself, is in fact a creative process.”<sup>90</sup> In order to determine whether or not a system is exhibiting creative fitting, a holistic attribute is needed. To McHarg this holistic attribute was health. McHarg argued that creativity and creative fitting is “absolutely required for [the survival of] any system, be it a social system or a natural system.”<sup>91</sup>

According to Spirn, the ideas and methods of McHarg’s “evolved in a dynamic dialogue between theory and practice. The university studio was a place of theoretical experiment; the professional office, a place to test ideas in actual places, with real clients and programs.”<sup>92</sup> In 1969, McHarg published *Design with Nature*, which would come to have immense impact on the development of a shared ecological mindset, particularly in North America. The success of *Design with Nature* was threefold. First, it addressed the absence of an environmental dimension in planning, which previously was primarily an applied socio-economic process. Second, it addressed the lack of integration within the environmental sciences, in particular with human adaptations, and third, it provided a method for incorporating environmental data into a planning process, i.e., provided for an ecological planning method. This practical method, developed by McHarg to put his theory into practice, will be discussed in detail in Chapter 7.

#### 4.2 Trajectory 2: Engagement through Analysis

The history of the systematization of the world, i.e., the history of the formation of scientific disciplines, is of course too big a topic to briefly summarize in its totality. For the purpose of this thesis, a few historical key ideas are highlighted, as foundational theories that the present author sees would come to

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<sup>89</sup> Lynn Margulis, James Corner and Brian Hawthorne, *Ian McHarg Conversations with students* (New York: Princeton University Press, 2007), 21.

<sup>90</sup> *Ibid.*, 24.

<sup>91</sup> *Ibid.*, 25.

<sup>92</sup> Spirn, *Ian McHarg, Landscape Architecture, and Environmentalism*, 103.

inform the analytical approach which guided the implementation of digital GIS. The three main ideas, argued to be the main precursors to this development, include the invention of taxonomy in systematics, theories for mathematical spatial analysis, and the idea of competition as a driver for change.

The year 1707 marked the birth of both Leonhard Euler, the great German mathematician and physician, and Carl von Linnaeus, often claimed to be the father of modern botanical taxonomy. Euler lived in Königsberg, today the Russian city of Kaliningrad, which would come to have a significant impact on the discovery of a new branch of mathematics that concerns connectivity and adjacency, i.e., topology. A famous problem, to which Euler published his negative resolution in 1735, is known as the “The Seven Bridges of Königsberg”.

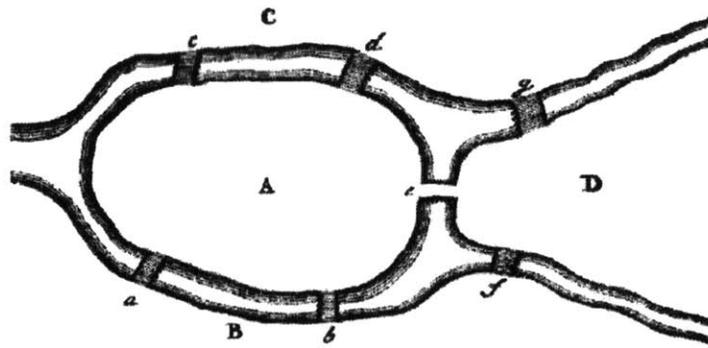


Fig. 10 Leonhard Euler. *The Seven Bridges of Königsberg*. (Euler's publication, fig. 3.<sup>93</sup>)

The setting of the problem was the city of Königsberg, which is traversed by the Pregel River in such a way that an island is created. (Fig. 10) Because of this separated land mass, seven bridges are built to connect all land areas. The problem under consideration concerned whether or not it was possible to walk through the town in such a way as to cross over each of the seven only once. Euler approached the problem by drawing a graph on which he indicated each land area by a point, i.e., a node, and each bridge by a connecting line, i.e., an edge. By studying the graph, Euler discovered that when a node is visited in “mid process” of the walk, there must be an edge coming in to that node and another edge leaving it, meaning that the number of edges connecting to that node must be even. Euler found that

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<sup>93</sup> Leonhard Euler, "Solutio problematis ad geometriam situs pertinentis" [The solution of a problem relating to the geometry of position], in *Commentarii academiae scientiarum Petropolitanae*, vol. 8, (1736): 128-140.

this condition must be satisfied for all except for a maximum of 2 of the nodes, the starting point and the end point. Thus, a connected graph is traversable if, and only if, it has at most two vertices of odd order. Euler found that this condition was not satisfied by the layout of the bridges in Königsberg, and therefore drew the conclusion that the graph could not be traced, i.e., the desired walk was not possible.<sup>94</sup> With the publication of his negative resolution, Euler showed that questions concerning connectivity in geographic space could be analyzed numerically, which marked the beginning for spatial analysis as a new sub discipline of mathematics.

Relationships among entities, are also a key characteristic in the scientific field of taxonomy. Taxonomy is a major component of systematics, and encompasses the description, identification, nomenclature, and classification of entities<sup>95</sup>. Michael G. Simpson, author of *Plant Systematics*,<sup>96</sup> points out that “the four components of taxonomy are not limited to formal systematics studies but are the foundation of virtually all intellectual endeavors in all fields, in which conceptual entities are described, identified, named, and classified.”<sup>97</sup>

In botany, a major breakthrough in classification occurred through the invention of Linnaean taxonomy, which arranged and named species in “a hierarchical scheme based largely on similarities in their forms and other traits that usually, but not always, reflect evolutionary relationships.”<sup>98</sup> In this system, the ranks, i.e., the ordering of species within genus, genus within family, family within class and so on, all imply the evolutionary relationships among species.<sup>99</sup> This organizational structure provides for a system of seemingly fixed descriptions, which is reflected in the etymological meaning of the name given to the field. Etymologically, the term “taxonomy” comes from the marriage of two Greek words, *taxis*, which means “arrangement” and *nomos*, which means law or rule.<sup>100</sup> This concept of fixed descriptions of entities, arranged in hierarchical structures, is a prerequisite for an analytical worldview, allowing for arrangement and combination but not for easy re-description or renaming of entities once they have

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<sup>94</sup> Irina Gribkovskaia, Oyvind Halskau Sr. and Gilbert Laporte, “The bridges of Königsberg—A historical perspective”, in *Networks - Special Issue: Dedicated to Leonhard Euler (1707–1783)*, vol. 49, iss. 3, May (2007): 199–203.

<sup>95</sup> Michael G. Simpson, *Plant Systematics* (Burlington, MA: Elsevier Academic Press, 2006), 10.

<sup>96</sup> *Ibid.*

<sup>97</sup> *Ibid.*, 12.

<sup>98</sup> Roger Harris, “Attacks on Taxonomy: A contentious biological classification system may make cataloging biodiversity tricky”, in *The American Scientist*, (July-August, 2005): 311.

<sup>99</sup> *Ibid.*

<sup>100</sup> “Taxonomy”, in *Random House Webster's Unabridged Dictionary*. 2nd ed. (New York, NY: Random House Reference, 1993).

been named. For lack of such possibility, it is often suggested, most notably by Charles Darwin, that the evolution of entities occur through a framework of competition and succession.

In 1859, the same year Alexander von Humboldt's died, Darwin published his key work titled *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, later renamed *Of the Origin of Species*. With this publication, Darwin proposed a new theory of evolutionary biology, which claimed that populations of species evolve over generations due to a process of transmutation in accordance with two phenomena characterized as natural and sexual selection. The key idea of Darwin's was that species evolve through gradual adaptation, both in relation to the environment and to other species. He writes, "This preservation of favourable variations and the rejection of injurious variations, I call Natural Selection"<sup>101</sup>. Due to the variety of traits of different species or individual entities, the adaptation of one species will be more likely to succeed in conquering an ecological niche, which in turn leads to the "survival of the fittest". In *Plant Systematics*, Simpson points out that "the ability to describe, identify, name and classify things undoubtedly has evolved by natural selection."<sup>102</sup> With the theory of natural selection, Darwin solved a great problem posed by Immanuel Kant, concerning how a purposefully directed form of organization can arise without the aid of a purposefully effective cause,<sup>103</sup> i.e., religion. Darwin is selected in this thesis as a precursor for the analytical world view, due to his novel idea of competition as a driver for change.

#### 4.2.1. Map Analysis

Throughout history, one of the key purposes for map-making, i.e., cartography, was for increased political or social control.<sup>104</sup> Those with capacity to describe and map geographic features of-, and relations between, territories would more likely succeed in obtaining control over those areas. This territorial aspect of mapping has already been pointed out in the etymological definition of the term "landscape" (Chapter 2). In this context an important distinction is required between mapping as a depiction process of "what is and [...] what is not yet,"<sup>105</sup> as pointed out by James Corner in his essay *The Agency of Mapping: Speculation, Critique and Invention*. That said, in the process of creating map

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<sup>101</sup> Charles Darwin, *On the Origin of Species* (New York, NY: P.F. Collier & Son, 1909), 79.

<sup>102</sup> Simpson, *Plant Systematics*, 12.

<sup>103</sup> Immanuel Kant, *Critique of Judgment* (Oxford: Oxford University Press, 1957, 2007).

<sup>104</sup> Juliana Maantay and John Ziegler, *GIS for the urban environment* (Redlands, CA: ESRI Press, 2006), 6.

<sup>105</sup> James Corner, *Mappings* (London: Reaktion Books, 1999), 214.

artifacts, for either surveying or prediction purposes, the decisions made by the map-maker always result from a process that involves both artistic and technical judgments. Inherent to the process of map-making, is that the act of representing three-dimensional information on a flat surface automatically entails some degree of distortion of the reality which it is intended to portray. In his book titled *How to lie with maps*, Mark Monmonier states that “As a scale model, the map must use symbols that almost always are proportionally much bigger or thicker than the features they represent. To avoid hiding critical information in a fog of detail, the map must offer a selective, incomplete view of reality. There is no escape from [this] cartographic paradox.”<sup>106</sup>

At the time when GIS was implemented digitally, computers were already widely used as calculating machines. In early attempts to use the computer in cartography, computer scientists were required to operate the machines. In the proceedings of the *International Symposium on Automation in Cartography*, held at Reston, Virginia, in 1974, Dr. Joel L. Morrison of the Department of Geography, University of Wisconsin, notes that “It would be useful for the cartographer to be a programmer, but I doubt that all the requirements on his time would allow him to be a skilled programmer. In most automated cartographic work, the cartographer directs a programmer who is a member of his support staff.”<sup>107</sup> During this period, a normal procedure of map-making would start with the designer describing to the computer scientist the output he desired - a classic attempt at knowledge acquisition. At the time when punch cards were still used, the designer would fill out a detailed form indicating his preferences for output (Fig.11). The technician would then transcribe the annotation from the form into code and produce the perforated cards required for the computer. After the cards had been processed in the computer, maps would be printed using large flatbed printers. The turnaround time for this process, from handing in the punch cards to the collection of the produced hardcopy map, would sometimes be as fast as one day.<sup>108</sup>

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<sup>106</sup> Mark Monmonier, *How to Lie with Maps*, 2nd ed. (Chicago, IL: University Of Chicago Press, 1996), 1.

<sup>107</sup> Joel L. Morrison, “Implications of Automation in Cartography”, in *the American Cartographer*, 2, no.1 (1975): 83.

<sup>108</sup> Chrisman, *Charting the Unknown*, 23.

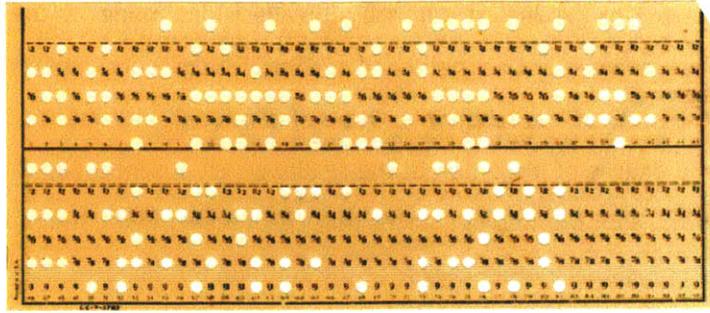


Fig. 11 Punch card from the Canada Geographic Information System (CGIS)  
(Source: <http://www.digitalurban.org>)

Timothy Foresman, author of *the History of Geographic Information Systems: perspectives from the pioneers*, notes that “The advent of geographic information systems was the result not of academic inquiry but rather of the growing societal need for geographical information, of a change in the technology that made such systems possible, and of private sector vision and government foresight that initiated and sustained their development. This conjunction of conditions took place in Canada in the early 1960’s.”<sup>109</sup> The event that Foresman refers to is the system developed for the Canada Land Inventory in the early 1960’s. The Canada Land Inventory was initiated to address a concern for the national land resources available. In the “commercially accessible parts of the country,”<sup>110</sup> the seemingly endless resources were now under threat because competition had arisen between different land uses on the same areas. The Canadian government faced its responsibility and accepted the role as decision makers for land use and planning issues. To survey all of Canada in sufficient detail at a national or regional scale, maps were required to a scale between 1:125,000 and 1:20,000.<sup>111</sup> The estimated amount of maps required for such an undertaking was found to be enormous. In a short film titled “Data for Decision,”<sup>112</sup> produced in 1967, Roger Tomlinson stated that to map all of Canada would require the efforts of “556 people, 8 hours per day for 3 years. It would cost 8 million dollars.”<sup>113</sup> At a time when map-making was considered both laborious and expensive, the numbers provided by Tomlinson, became a significant economic incentive for the Canadian government to further invest in the new technology.

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<sup>109</sup> Foresman, *The History of Geographic Information Systems*, 21.

<sup>110</sup> *Ibid.*

<sup>111</sup> Foresman, *The History of Geographic Information Systems*, 21.

<sup>112</sup> *Ibid.*, 31.

<sup>113</sup> Roger Tomlinson, *Data for Decision* (1967, Ottawa: National Film Board of Canada), Film.

In the beginning of the 1960's Edgar Horwood, Professor of Urban Planning and Civil Engineering at the University of Washington, hosted a number of training sessions in computer mapping. These training sessions aimed to teach students how to use two utilitarian cartographic programs, the "Card Mapping Program" and the "Tape Mapping Program."<sup>114</sup> Both of these programs used geographic mapping units (GMU) to display thematic data. The GMU's were represented by points, and at each GMU a string of characters resulting from the computed data of that particular location, would be printed. Later, in a separate session, the map would be overprinted by a map indicating the boundaries of census tracts, streets, rivers, and similar. In 1963, Howard Fisher attended one of Horwood's training sessions at Northwestern University,<sup>115</sup> which sparked his enthusiasm for creating more efficient computer mapping software.<sup>116</sup> Throughout his career Fisher would credit Horwood as a key inspiration for his contributions to digital GIS.

In December 1965, Howard Fisher was confirmed recipient of a grant from the Ford Foundation to set up the Harvard Laboratory for Computer Graphics (LCG). With the invention of digital memory, the problems that arose from limited scope for symbolism on hardcopy maps seemed to have found its solution. When applying for the grant, Fisher was motivated by a desire to "reform thematic cartography"<sup>117</sup> by providing "a more logical framework for graphic display of geographic facts."

Fisher's Lab, would be the first point of confluence in "a hybrid environment that mixed theories of spatial structure with the artifacts of the emerging computer technology."<sup>118</sup> The importance of the social relations among participants of this environment ought not to be underestimated, as pointed out by David Rhind in his essay "Personality as a Factor in the Development of a Discipline: Example of Computer-Assisted Cartography."<sup>119</sup> The Ford Foundation Grant specified a staffing of one director, three senior specialists, three intermediate specialists, and five other staff.<sup>120</sup> The first senior specialist was specified to focus on "factual information, its gathering manipulation, and analysis,"<sup>121</sup> and was expected to be an urban geographer with a strong mathematical underpinning. The grant stated that the two other senior specialists would be a statistician and expert on decision theory and a specialist in

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<sup>114</sup> Chrisman, *Charting the Unknown*, 4.

<sup>115</sup> Ibid.

<sup>116</sup> Ibid.

<sup>117</sup> Ibid., 2.

<sup>118</sup> Ibid., 15.

<sup>119</sup> David Rhind, "Personality as a Factor in the Development of a Discipline: Example of Computer-Assisted Cartography", in *the American Cartographer*, vol. 15, iss. 3 (July 1988): 277-288.

<sup>120</sup> Chrisman, *Charting the Unknown*, 12.

<sup>121</sup> Ibid.

computer science. Fisher appointed William Wartz as his first senior specialist, and with funds of his own, Wartz hired a set of scientist research fellows. Therefore, rather than following the staff specifications from the Ford Foundation, Fisher hired three individuals who would link the Lab to the three departments of the Harvard Graduate School of Design: Allen Bernholz from the Department of Architecture, Peter Rogers from the Department of City and Regional Planning, and Carl Steinitz, who had just completed a Ph.D. in urban planning at MIT, was assigned to work with the Department of Landscape Architecture.<sup>122</sup> This cross-disciplinary setting created a social context that, without doubt contributed immensely to the development of computer-based GIS<sup>123</sup> and to what today might be known as Geographical Information Science. Albeit, as stated by Bruno Latour, “The virtues that we are prepared nowadays to grant the scientific and technical enterprises bear little relation with what the founders of the social sciences had in mind when they invented their disciplines.”<sup>124</sup> As such, the technological and scientific successes are easier to count and hence technological progress becomes the key criterion for success.

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<sup>122</sup> Chrisman, *Charting the Unknown*, 12.

<sup>123</sup> Rhind, *Personality as a Factor in the Development of a Discipline*, 277-288.

<sup>124</sup> Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (Oxford: Oxford Press, 2005), 2.

## 05. Description: Three Models for Operating in Cross-Disciplinary Contexts



## Foreword to Chapter 5

The data structure used to represent spatial features is important in a GIS because it determines the range of operations for manipulation and interpretation provided<sup>125</sup>. In the preface of Dana Tomlin's, 2012 edition of his original Ph.D. thesis, titled *GIS and Cartographic Modeling*,<sup>126</sup> Tomlin points out that "cartographic modeling [i.e., modeling with thematic layers] is oriented more towards process than product."<sup>127</sup> As such, he notes that the major concern for modeling with geographical data is "not the way in which data are gathered, maintained, or conveyed but the way in which data are used."<sup>128</sup> However, before discussing the details of how the two approaches to cross-disciplinary information modeling have been implemented, the data itself should be examined.

Naturally, before cross-disciplinary data can be related and evaluated, a format allowing for integration without loss of integrity is required. How to communicate and use data from different sources in a territory shared by multiple actors or communities, has been widely discussed in the social sciences, notably by Susan Leigh Star and James R. Griesemer. Motivated by the heterogeneous nature of science, and the inherent involvement of numerous actors and viewpoints, as well as by the need for collaboration in such environments, Star and Griesemer introduced the concept of "boundary objects."<sup>129</sup>

The concept of a boundary object is used to describe information that is used in different ways by different communities. The authors explain, "Boundary objects are objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use." Boundary objects can be either abstract or concrete, and a few examples of such objects include a repository in a library or museum, a diagram, a scientific atlas, or a map. In all of these, the importance of boundary objects is their capacity to enable collaboration, without the need for shared consensus among participants. According to this definition and in the context of GIS, where data from different disciplines are related through coinciding

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<sup>125</sup> David M. Theobald, "Topology revisited: Representing Spatial Relations," in *International Journal of Geographical Information Science*, vol. 15, no. 8 (2001): 690.

<sup>126</sup> Tomlin, Dana, *GIS and Cartographic Modeling* (Redlands, CA: ESRI Press, 1990, 2012).

<sup>127</sup> *Ibid.*, 9.

<sup>128</sup> *Ibid.*

<sup>129</sup> Susan Leigh Star and James R. Griesemer, "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39", in *Social Studies of Science*, vol. 19, iss. 3 (August, 1989): 387-420.

geographic coordinates, any representation of such territories could potentially constitute a boundary object. This statement opens up a series of interesting questions, such as the following:

- What constitutes a boundary object in digital GIS, the software integrating the data into a stratified digital environment, and/or the map and tabular representations generated?
- Can the composite drawing generated in McHarg's Ecological Method, in which scientific data, represented on transparent overlays, are destratified into a single composite drawing, be considered a boundary object?

Equipped with these questions, we can begin to evaluate three general schemes of organization of cross-disciplinary data in GIS. The first model is the destratified model of McHarg's Ecological Method, which, from the perspective of the user, generates a holistic representation of the environment in map form. In general, the term "destratification" refers to a process in which the information from separate scientific disciplines is brought together and fused. In ecology, the concept of destratification refers to a process of vertical mixing within a medium such as a lake or reservoir to totally or partially eliminate separate layers of temperature, plant, or animal life. The mixing of layers, in this context, usually results in a universal increase of health in the body of water. In McHarg's model, as further discussed in Chapter 7, the layers appear stratified until the phase of interpretation by the designer, at which point the information is fused into one holistic construct.

The second model is characterized by a stratified assembly, and is exemplified by two models from digital GIS, namely, SYMAP and the ODYSSEY system. Typically, a stratified arrangement is characterized by distinguishable layers. In such a model, information has been entered through different channels and classified according to source and characteristics. The layers can relate, but do at all times maintain their integrity. In stratified GIS, the thematic data input remain layered at all phases from data entry until processing and interpretation.

As we will see in Section 6.2, SYMAP and ODYSSEY were also designed to operate differently. While SYMAP was designed as a software primarily for data display purposes, ODYSSEY was designed to be a system made up of independent but interlinked packages. These packages were designed as software modules, to be used in the construction of new Geographic Information Systems. The software modules were developed to deal with different areas of processing, display, and analysis, but all followed a topological and hierarchical data structure.

## 5.1 Description of Model 1: Destratified GIS – McHarg’s Ecological Method

### 5.1.1 Introduction to Destratified GIS

Methods using transparent overlays were in use long before Ian McHarg invented his Ecological Method. An early example is Warren Manning’s work to record and classify site information across all of America, undertaken during his employment as a horticulturist at the firm of landscape architect Frederick Law Olmsted.<sup>130</sup> Manning collected a vast amount of maps of soil, river, forest and other landscape characteristics and had them redrawn to one scale. By laying out selected maps together on a light table, Manning constructed a landscape plan for the entire United States. The resulting “National Plan,”<sup>131</sup> was published in the *Landscape Architecture* journal, in June 1923. Other early examples of how map overlay techniques were used in design were described by Jaqueline Tyrwhitt, a disciple of Patrick Geddes, in her book *Town and Country Planning Textbook*, published in 1950.<sup>132</sup> Two additional examples, which are often mentioned together with Ian L. McHarg’s work, as precursors to digital GIS, are the methods developed by G. Angus Hills and Philip H. Lewis.

Angus Hills was a Canadian soil scientist, physical geographer and forest ecologist, who until 1967 held the position of Chief Research Scientist at the Ontario department of Land and Forests.<sup>133</sup> The main focus of Hills’ research was the study of land and water productivity, in respect to their biological and ecological affordances. One of the results from Hills long-term commitment to land-use planning is the so-called Hills System of Land Classification, “a highly scientific approach to supply aspects of land inventory and analysis.”<sup>134</sup>

Philip H. Lewis, Chairman of the Department and Professor of Landscape Architecture at the University of Wisconsin, also developed a method using map overlays, to better assess how “environmental qualities and values of the natural and man-made landscape developed into broad patterns.”<sup>135</sup> This

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<sup>130</sup> Carl Steinitz, “Landscape planning: A brief history of influential ideas”, in *Journal of Landscape Architecture*, vol. 3, iss.1 (2012): 71.

<sup>131</sup> *Ibid.*

<sup>132</sup> Ellen Shoshkes, “Jaqueline Tyrwhitt: a founding mother of modern urban design”, in *Planning Perspectives*, vol. 21, iss. 2 (2006), 180.

<sup>133</sup> Raymond K. Belknap and John G. Furtado, *Three approaches to environmental resource analysis*, (Washington D.C.: The Conservation Foundation, 1967).

<sup>134</sup> *Ibid.*, 7.

<sup>135</sup> *Ibid.*, 3.

method would in turn inform planning and development. Salient in Lewis's method was the incorporation and mapping of perceptually significant features of landscapes into the analysis.

Viewed in the context of these related methods utilizing map overlays, it is clear that McHarg was not the first to use such techniques. However, McHarg's method, arguably, exhibits the most fully developed model for handling and organization of cross-disciplinary data, and has, as a result, had the greatest influence on the creation of environmental policy in America.<sup>136</sup>

One of McHarg's most influential ideas was his view of nature as a dynamic construct and that "the place, the plants, animals and men upon it are only comprehensible in terms of physical and biological evolution,"<sup>137</sup> i.e., nature as a process of adaptation and creative fit. For him, ecology provided "the indispensable basis"<sup>138</sup> for landscape design and planning. According to McHarg, what can be found at a particular site are the traces of forces which have shaped it into its present state, such as the formation of mountains and seas, forces of uplifting, folding, sinking, and erosion of land. To McHarg, these events are key to understanding a site and the tools which can explain a site in terms of where it came from, where it is today, and where it is going. Landscape architect Anne Whiston Spirn argues that "Unlike McHarg, most landscape architects have neither the knowledge nor the interest to embrace the entire scope of the discipline—the shaping of landscape from garden to region—within their practices and theories,"<sup>139</sup> which points to the uniqueness of McHarg's approach to environmental planning and design.

Having been appointed to a lectureship at the University of Pennsylvania in 1954,<sup>140</sup> Ian McHarg was faced with the task of teaching people about the environment. The problem, he realized at once, was that "nobody knew where the environment was."<sup>141</sup> McHarg's solution to this problem, which sought to locate and represent the environment at particular locations, proved simple: map it. To McHarg, the Ecological Method was a "composite teacher."<sup>142</sup> He believed that no one specialist alone could deal with issues concerning the environment, but by merging the judgments of many through a process of amalgamation the composite teacher could be created.

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<sup>136</sup> Spirn, *Ian McHarg, Landscape Architecture, and Environmentalism*, 103.

<sup>137</sup> McHarg, *An Ecological Method*, 39.

<sup>138</sup> *Ibid.*, 38.

<sup>139</sup> Spirn, *Ian McHarg, Landscape Architecture, and Environmentalism*, 100.

<sup>140</sup> *Ibid.*, 98.

<sup>141</sup> Ian McHarg, (presentation at the ESRI User Conference, San Diego Convention Center, San Diego, CA, July 8-11, 1997).

<sup>142</sup> *Ibid.*

With a grant from the Ford Foundation, McHarg recruited a meteorologist, a geologist, a geomorphologist, a hydrologist, a soil scientist, a plant ecologist, an animal ecologist, an ethologist, an ethnographer, a cultural anthropologist, and an epidemiologist. In order to succeed in his attempt, McHarg needed to find a way for these numerous and highly specialized scientists to work together. McHarg says, "I discovered that there was one device by which the disparate insights of all these incredible people could be made causal and consequential; I discovered chronology. [--t]ime used as a unifying rubric."<sup>143</sup>

The method using transparent overlays, arranged in sequence according to chronological causality in nature, was instrumental in bringing about a new holistic view of ecology, landscape, planning and design. In 1969 McHarg published his key work "Design with Nature," a title which speaks of the collaborative intentions towards sustainable symbiosis between humans and the environment.

#### 5.1.2 Organization of Data in McHarg's Ecological Method

Ian McHarg's Ecological Method involves the layering of transparent map overlays, in a sequence according to chronological causalities in nature. The method, he notes "consists, in essence, of identifying both social and natural processes as social values,"<sup>144</sup> and aims to create a map artifact that can reveal which areas have "the maximum social benefit at the least social cost."<sup>145</sup>

In the resulting stack, each map layer contains information that pertains to one specific discipline. McHarg notes, "All of these data gathered from many sources describe one whole system, only divided by language and by science. Our job is to reconstitute the region and all its processes again."<sup>146</sup> To achieve the reconstruction of the environment, the information of the individual layers has to be evaluated. Although the system of evaluation required calibration on a case-by-case basis, McHarg could establish four major values that can be attributed to natural processes: First, "inherent qualities of the process itself (i.e., the landscape is and had value for scenic beauty or education), second, "Productivity of the process (e.g., agriculture, forestry, recreation)," third, "Maintenance of the ecological balance (e.g., water catchment, purification and storage)," and fourth, "potential hazards arising from improper

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<sup>143</sup> Ian McHarg, (presentation at the ESRI User Conference, 1997).

<sup>144</sup> McHarg, *Design with Nature*, 33.

<sup>145</sup> *Ibid.*, 32.

<sup>146</sup> *Ibid.*, 31.

use of natural processes or resources (i.e., negative value)."<sup>147</sup> The specialist from each field would conduct the weighing and from their judgment, a gray scale map overlay displaying a gradient of Gray tones, would be produced. With all the information "parsed" into this format, the maps could be combined holistically.

In the stack, the maps that represented the (in evolutionary terms) slowest processes were placed at the bottom, such as those representing geology and bedrock, and those McHarg deemed to be the quickest evolving processes, such as social and cultural phenomena, were placed at the top. The stack typically comprised eight layers, including {from the bottom up) maps representing geology, physiography, soil characteristics, hydrology, climate, vegetation, wildlife and socio-cultural phenomena (Fig. 12).

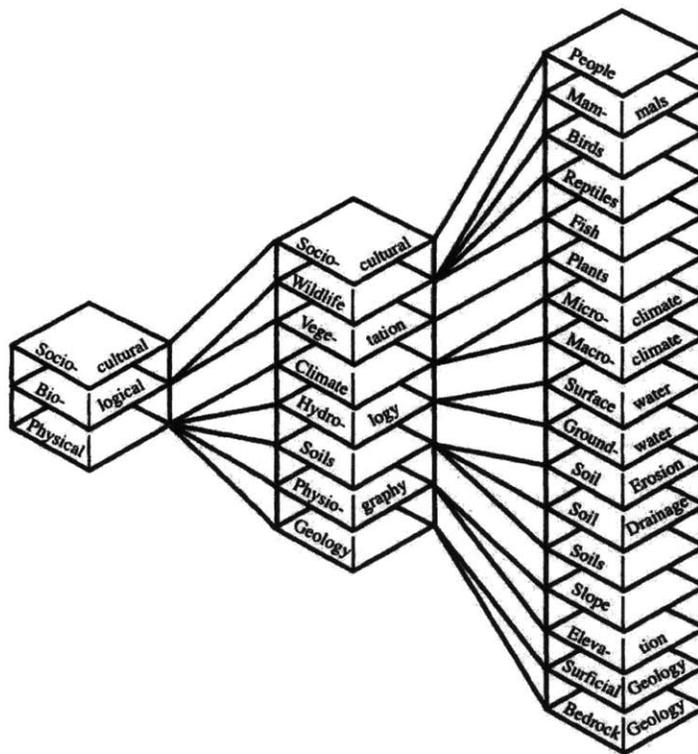


Fig. 12 Chronological integration of cross-disciplinary data in the Ecological Method. Reproduced from McHarg (1969)

The method and order of layering was based directly on the causalities McHarg observed in nature. The starting point in this process was always to decipher the traces of evolution, as related to geology and

<sup>147</sup> Belknap and Furtado, *Three approaches to environmental resource analysis*, 61-62.

bedrock. Once the historical geology had been deciphered, this knowledge could be merged with the acquired knowledge of climate, to interpret the current configuration of a place, i.e., its physiography. With knowledge of physiography, the patterns of rivers and aquifers could be traced and understood. Knowledge of the hydrology of the site would in turn lead to a better understanding of the soil conditions of the area. At this point, with a reconstructed understanding of the physiography, the climate, and the soil conditions, one could begin to assess the distribution of constituent plant communities,<sup>148</sup> which would allow for the assessment of wildlife on the site as, according to McHarg, “animals eat the plants or they eat the animals that eat the plants.”<sup>149</sup>

Commenting on the method, McHarg states, “The information so acquired is a gross ecological inventory and contains the database for all further investigations.”<sup>150</sup>

After data collection in the Ecological Method, the next step involves the interpretation of the chronologically linked information. The first task in the process of interpretation is to identify “unique and scarce phenomena” of the site, an approach in essence similar to that of Philip Lewis. The result after assessment would be “a map of unique sites [...], the location of water resources, a slope and exposure map, a map of agricultural suitability by types, a similar map for forestry, one each for recreation and urbanization.”<sup>151</sup> In addition to these maps, the output from McHarg’s synthesis would include a series of other representations, including transects and perspective views, as well as a matrix in which each identified site of a studied region would be evaluated in terms of its suitability in relation to all possible land uses.

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<sup>148</sup> McHarg, *An Ecological Method*, 40.

<sup>149</sup> Margulis, Corner and Hawthorne, *Ian McHarg Conversations with Students*, 30.

<sup>150</sup> McHarg, *An Ecological Method*, 40.

<sup>151</sup> *Ibid.*

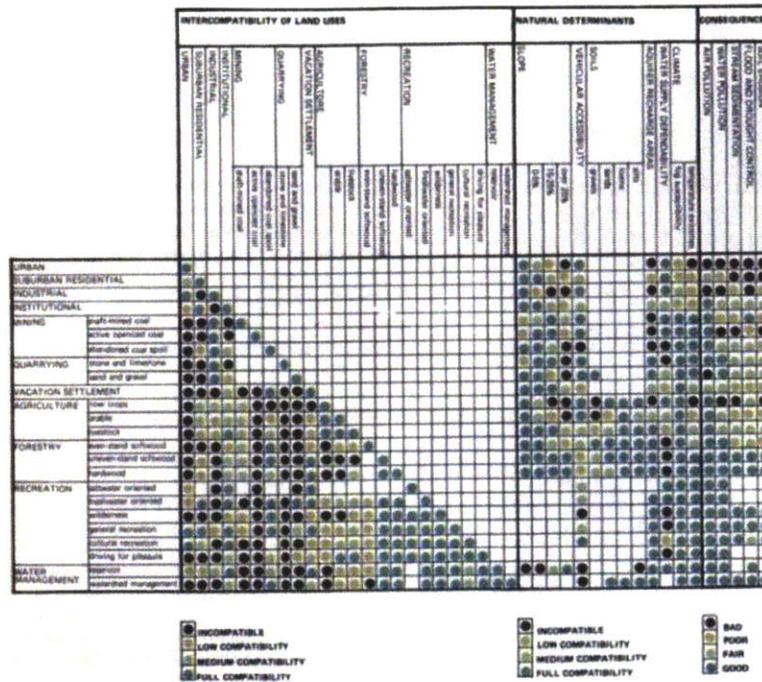


Fig. 13 Intercompatibility Matrix of Land Uses. (McHarg, *Design with Nature*, 144.)

### 5.1.3 Typical User Method of McHarg’s Ecological Method

On the topic of design, McHarg argues that “where the landscape architect commands ecology he is the only bridge between the natural sciences and the planning and design professions, the proprietor of the most perceptive view of the natural world which science or art has provided.” Equipped with this essential bridging function, the ornamental and scenic aspects of landscape design and planning become irrelevant, or in the words of McHarg, “ecology offers emancipation for landscape architecture”<sup>152</sup>

McHarg implemented his techniques using sheets of transparent film on which maps were created for each factor. As described above the information was evaluated by a specialist from each field and represented through grayscale encoding in which light areas showed the areas of greatest social value at the least environmental impact, if developed.<sup>153</sup> Finally in the hands of a typical user, i.e., planner or designer, the assembled transparencies would be placed on a light table. When lit up, the lightest areas would be revealed which indicated zones most suitable for development. McHarg describes that at the

<sup>152</sup> McHarg, *An Ecological Method*, 39.

<sup>153</sup> McHarg, *Design with Nature*, 33.

outset of a study nothing is known about a site, except for the method. On the example of the route selection of the Bronx River Parkway, as illustrated in Fig. 14-35, McHarg notes, "The method was known but the evidence was not. It was necessary to await its compilation, make the transparent maps, superimpose them over a light table and scrutinize them for their conclusion. One after another they were laid down, layer after layer of social values, an elaborate representation of the Island, like a complex X-ray photograph with dark and light tones. Yet in the increasing opacity there were always lighter areas and we can see their conclusion."<sup>154</sup>

According to McHarg the Ecological Method provides two key achievements: first, it is a tool for capturing and describing nature as process, and second, it reveals causality among the layered information. Most importantly the process allows a designer to interpret natural processes as resources. According to McHarg, "the ecological method is the sine qua non for all landscape architecture."<sup>155</sup>



Fig. 14 Richmond Parkway Highway Alignment Study. Ecological Method employed in study for the Borough of Richmond in NY. Bedrock Foundation (at bottom) (McHarg, *Design with Nature*, 36-41)



Fig. 15 Slope

<sup>154</sup> McHarg, *Design with Nature*, 35.

<sup>155</sup> *Ibid.*, 41.

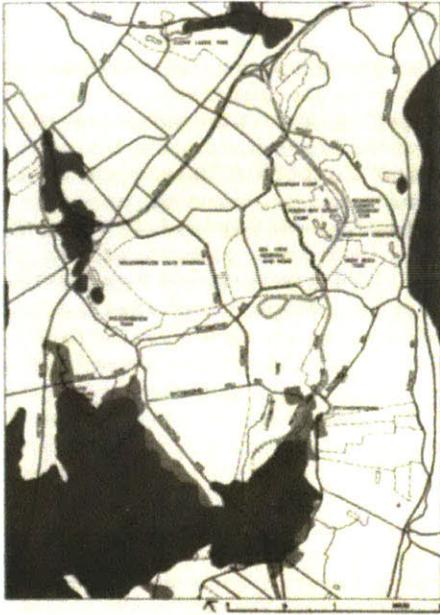


Fig 16 Soil Foundation



Fig. 17 Soils



Fig. 18 Surface Drainage



Fig. 19 Erosion



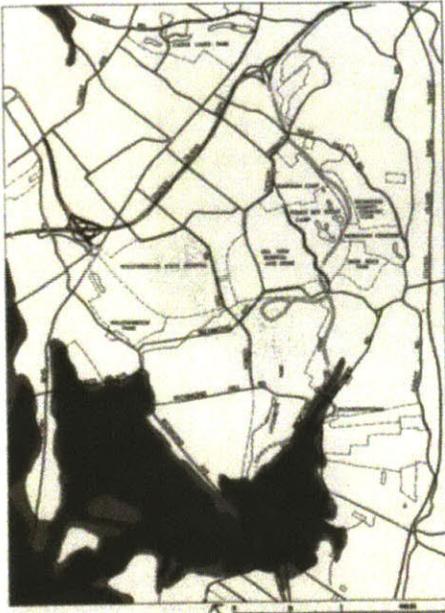


Fig. 21 Tidal Inundation



Fig. 22 Water



Fig. 23 Forest



Fig. 24 Wildlife



Fig. 25 Recreation



Fig. 26 Historic Values



Fig. 27 Institutional Values

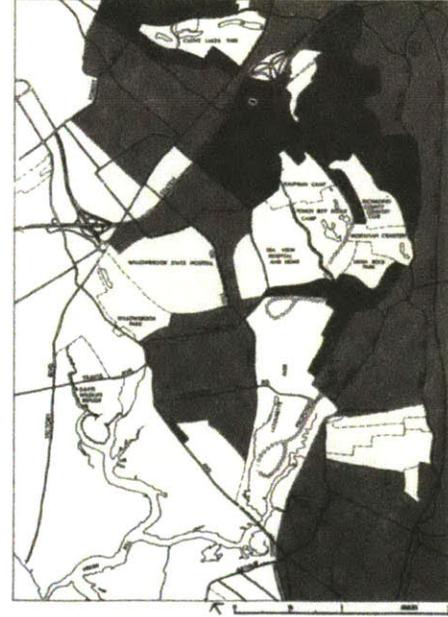


Fig. 28 Residential Values



Fig. 29 Scenic Values



Fig. 30 Land Values



Fig. 31 Recommended Highway Alignment



Fig. 32 Richmond Parkway Study. Composite Drawing of All Social Values (McHarg, *Design with Nature*, 40.)

## 5.2 Description of Model 2: Stratified GIS – SYMAP & ODYSSEY

### 5.2.1 Introduction to Stratified GIS

Digital GIS are traditionally either raster- or vector-based, two models which differ mainly in the data structures employed for storage of information.<sup>156</sup> A raster data structure for GIS, Foresman explains, “may be thought of as a computer photograph where each image picture element (pixel) has a value that is associated with a specific geographic location.”<sup>157</sup> As such, each pixel can be regarded as representing a “discrete area of the surface of the Earth.”<sup>158</sup> Accordingly, the geographic location of each pixel can be found by finding its location coordinates, i.e., X and Y values, in a 2D matrix with origin at the top left corner of the raster. Traditionally, in the data sets that were derived from hardcopy maps, the resolution of the final pixels would be a function of the scale of the hardcopy map input and the resolution of the scanner used. In the raster-based SYMAP era, the datasets linked with cartographic software contained only the minimum amount of information necessary to produce the desired maps. In their simplest form these data structures were “nonanalytic, device-specific and as a result short-lived.”<sup>159</sup>

In 1968, the same year Howard Fisher retired, the *Harvard Laboratory for Computer Graphics* appended “and Spatial Analysis” to the name.<sup>160</sup> This change was initiated by William Warntz, who had just been appointed Director of LCG. Warntz had been affiliated with Harvard University since 1966, when he was hired, requesting the title of Professor of Theoretical Geography. The title of his professorship is interesting, considering that the Harvard Department of Geography had been discontinued in 1948, almost two decades earlier. The reasons for closing of the department, as communicated by the University, were vague. Chrisman notes that “The official report from Harvard included intimations that geography involved mere description, and had no theoretical basis.”<sup>161</sup> Although Warntz lasted only three years as Director of the LCG, the beginnings of a new direction in digital GIS were established under his direction.

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<sup>156</sup> Foresman, *The History of Geographic Information Systems*, 59.

<sup>157</sup> *Ibid.*, 60.

<sup>158</sup> *Ibid.*

<sup>159</sup> Keith C. Clarke, “Map data Structures”, in *Analytical and Computer Cartography* (Upper Saddle River, NJ: Prentice Hall, 1995), 133.

<sup>160</sup> Chrisman, *Charting the Unknown*, 56.

<sup>161</sup> *Ibid.*, 57.

During this period and in search of more advanced analysis functionalities, the LCG shifted focus from raster data structures to the mathematical nature of spatial distributions and the numerical properties of surfaces, i.e. topology.<sup>162</sup> This shift of focus was the beginning of a period which is sometimes referred to as the second phase of the Harvard Lab.<sup>163</sup> The first steps towards a vector-based GIS, the ODYSSEY system, grew out of this early research on topological data structures, an approach to GIS which at present is still the primary model of digital GIS.

### 5.2.2 SYMAP – Raster-based GIS

Having established the Harvard Laboratory for Computer Graphics in 1965,<sup>164</sup> Howard Fisher continued development of his *Synagraphic Mapping System (SYMAP)*,<sup>165</sup> which would remain the best-known thematic mapping package for about a decade<sup>166</sup>. SYMAP was developed to handle raster data sets and used geographic mapping units (GMU) to display thematic data. Chrisman notes, “Because the line printer displays printed one size of character at fixed spacing across the lines and down the page, maps were cellular (raster) images with each character position filled by a particular symbol.”<sup>167</sup> As such, SYMAP was primarily designed for data display and query, and essentially lacked capabilities for numerical analysis.

SYMAP did not allow for input of already existing digital base maps. Instead, all input was to enter the system through paper punch cards, with one card for each point, i.e., pixel, on the map.<sup>168</sup> The input to the system comprised an OUTLINE which demarcated the boundary of the area to map, CONFORMLINES, which included points, lines, and areas to be filled with symbolism, VALUES of thematic information, and MAP instructions for output preferences.<sup>169</sup> Judged from the current perspective, one can hardly argue that SYMAP had a user interface, although the user would be allowed to “structure

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<sup>162</sup> Chrisman, *Charting the Unknown*, 59.

<sup>163</sup> *Ibid.*, 115.

<sup>164</sup> The title was later concatenated with “and Spatial Analysis” under the leadership of William Warntz.

<sup>165</sup> Foresman, *The History of Geographic Information Systems*, 61.

<sup>166</sup> Chrisman, *Charting the Unknown*, 19.

<sup>167</sup> *Ibid.*, 20.

<sup>168</sup> *Ibid.*, 25.

<sup>169</sup> *Ibid.*, 23.

their work conceptually.<sup>170</sup> The process was heavily constrained by formal rules and technological limitations of both the software and the hardware available at the time.

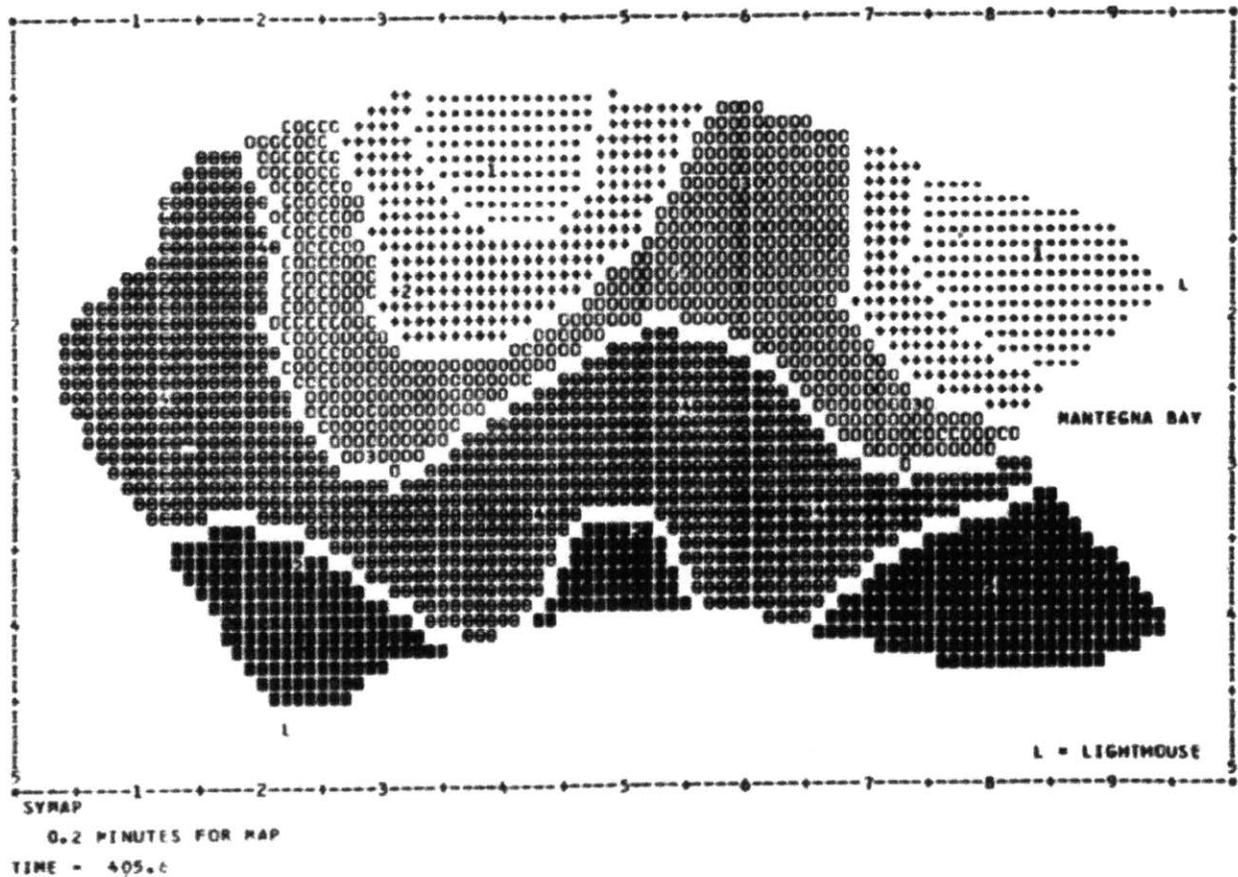


Fig. 33 Interpolation with SYMAP, (Chrisman, *Charting the Unknown*, 31.)

### 5.2.3 Typical Organization and User Method of SYMAP

A typical user of SYMAP would begin his work by using a digitizing board to record coordinates for control points from hard copy source maps. These coordinates would be noted on a special coding form. (Fig. 34) After recording, the user would transfer the data from the coding form to punch cards. To prevent human errors, the user would list the cards and run them through the machine. A printer would then print out the character output of each point, i.e., the information from each punch card, which the

<sup>170</sup> Chrisman, *Charting the Unknown*, 29.

user could then use to double check that his cards were correctly punched.<sup>171</sup> Finally, the user would carefully sort the stack of cards and hand them in to the Harvard Computing Center for processing. After approximately a day the user could pick up the produced hardcopy map. Nick Chrisman, who was active at the Lab at the time, notes that in these early days of SYMAP, “Computing operated like a service industry, much like a dry-cleaners.”<sup>172</sup>

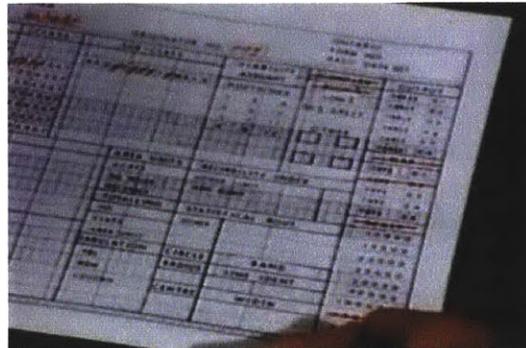


Fig. 34 Special Coding Form, CGIS. Screenshot from video titled *Data for Decision*, Tomlinson (1967)

The output from this process, especially the size of the pixels printed, was determined and constrained by the limitations of the printer available. All character symbols were of the same width and height and the printer would output 10 characters per inch in the horizontal and 8 or 6 characters per inch in the vertical direction. The standard set of characters printed could be significantly expanded through a process of overprinting, i.e., the printing of many characters on the same location on the paper. In SYMAP each location, i.e., GMU, could be overprinted a maximum of 3 times. Semi dark areas were often produced through the overprinting of characters O, X, A and V, and the darkest by the overprinting of M, W, and I<sup>173</sup> (Fig. 35).

Development of SYMAP was eventually discontinued and the Lab moved on to develop more sophisticated systems. The primary shortcomings of SYMAP were considered to be its lack of analysis functions and its rather utilitarian method of overprinting. Ian McHarg, in retrospect, sharply recalled

<sup>171</sup> Chrisman, *Charting the Unknown*, 24.

<sup>172</sup> Chrisman, *Charting the Unknown*, 22.

<sup>173</sup> *Ibid.*, 26.

SYMAP as “An enormous amount of intelligence in a barbarous product.”<sup>174</sup> Many versions of the software were developed at Harvard and elsewhere, and in 1973 the Lab was aware of “24 distinct conversions of SYMAP.”<sup>175</sup> While the software remained on the market for a while longer, the focus of development was continued in other programs, such as the ODYSSEY system.

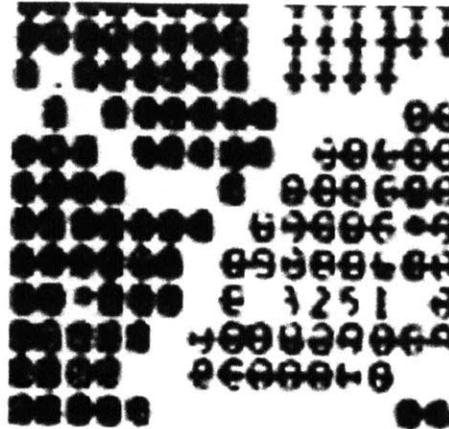


Fig. 35 Detail of overprinting symbolism,  
1975 SYMAP Manual,  
(Chrisman, *Charting the Unknown*, 26.)

#### 5.2.4 ODYSSEY – Vector-based GIS

After SYMAP, and many more developments in between, e.g., GRID and POLYVRT, a common view started to be voiced, claiming, for better or worse, that “We have not really designed our maps today to fit the machines that are producing them. We are designing the machines to do what we have been doing manually.”<sup>176</sup> In essence, the critique demanded that more advantage could and should be taken of the machine, which meant that new and more mathematically elegant programs were required.

In the mid-1970’s, with the aim to develop the most complete GIS to date, Nick Chrisman and Denis White from the Harvard Lab began the work on the ODYSSEY system, the first ever vector-based GIS. In

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<sup>174</sup> GEO World, *In Memoriam: Ian McHarg Reflects on the Past, Present and Future of GIS*, 2.

<sup>175</sup> Chrisman, *Charting the Unknown*, 37.

<sup>176</sup> Morrison, “Implications of Automation in Cartography”, in *The American Cartographer*, 87.



The first implementations of vector-based GIS, e.g., CGIS,<sup>180</sup> used the so-called entity-by-entity data structure which, due to its simplistic model, often generated so called slivers, i.e., small and narrow polygons that appeared along the borders of polygons following the overlay of two or more entities.<sup>181</sup> Due to the large amount of slivers generated, the process of analysis, if executing at all, became very time-consuming and error-prone. Topology, a branch of mathematics dealing with adjacency and connectivity, was found to be the solution to these problems.

In their article from 1975, "Cartographic Data Structures,"<sup>182</sup> Chrisman and Peucker present a way in which the information required for topological encoding of cartographic data could be organized in a data structure that was particularly well suited for geographically referenced data. The article would come to have significant influence on the new direction in digital GIS. While other data structures, such as the grid structure, the quad tree, and tessellations,<sup>183</sup> have subsequently been developed and explored in digital GIS, the topological data structure is the focus of this section of the thesis, due to its significant and pervasive influence on digital GIS as we know it today.

### 5.2.5 Topological Organization of Data

Today, a key feature of digital GIS is the ability to create and manipulate topological data structures for vector-based data sets,<sup>184</sup> i.e., points, lines, and polygons. Topology is a branch of mathematics which describes the location of objects in relation to other objects.<sup>185</sup> In digital GIS, topology is used to explicitly describe how points, lines, and polygons share coincident geometry, such as boundaries between adjacent polygons. These rules that define the relationships of spatial connectivity and adjacency, and as a result the behavior of geometrical features, are used to explicitly describe continuity and connectivity in a digital model. The principles of topology can be used to "determine whether an object is adjacent to, connected to, contained by, or containing another object, irrespective of their size

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<sup>180</sup> CGIS utilized vector and raster data structures; see Chrisman, *Charting the Unknown*, 118.

<sup>181</sup> "ESRI online GIS Dictionary", Support.esri.com. Visited May 21<sup>st</sup>, 2013.

<http://support.esri.com/en/knowledgebase/GISDictionary/term/sliver%20polygon>. URL.

<sup>182</sup> Peucker and Chrisman, *Cartographic Data Structures*.

<sup>183</sup> Clarke, "Analytical and Computer Cartography", in *Map data Structures*, 134.

<sup>184</sup> Theobald, *Topology Revisited*, 689.

<sup>185</sup> Maantay and Ziegler, *GIS for the Urban Environment*, 10.

or shape.”<sup>186</sup> Further, a topological data structure is widely claimed to provide rigorous and automatic methods to handle doughnut-shaped polygons, islands, self-intersecting polygons, overshoots and undershoots, slivers, and gaps.<sup>187</sup> Goodchild argues that topological data structures have been one of GIS’s “intellectual breakthroughs of lasting significance.”<sup>188</sup> However, David Theobald, among others, argues that “although explicit storage of adjacent features increases performance of adjacency analyses, it is not required to conduct these operations.”<sup>189</sup>

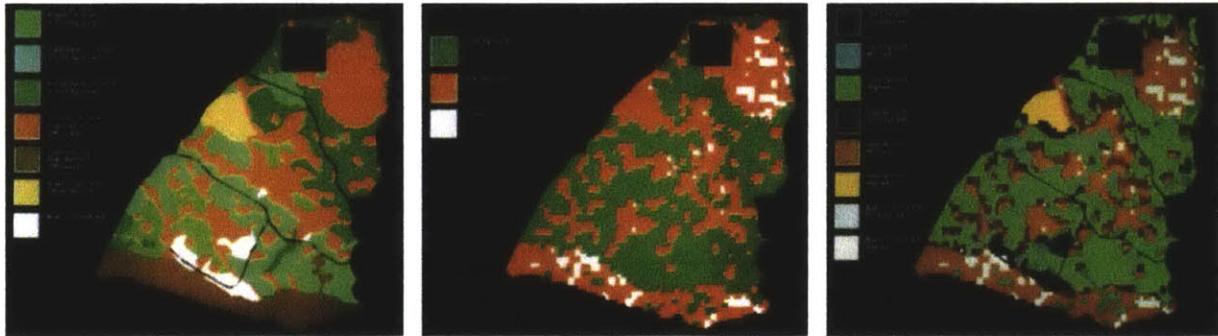


Fig. 37 ODYSSEY vector output. (Chrisman, *Charting the Unknown*, 131.)

In the proceedings of the 1977 *First International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems*, Nick Chrisman explains the developments at the LCG by noting that “the ODYSSEY system [...] is developed around a set of modules and simple data structures in hopes that they can provide a toolbox for geographic information systems.”<sup>190</sup> While most of the efforts of ODYSSEY went into the service modules, two modules named CYCLONE and CYCLOPS were developed to form the system’s editor and output facilities, and WHIRLPOOL was designed to handle the multitude of layers required.<sup>191</sup> Chrisman notes, “Once the basic services were provided, the polygon overlay capability was a major concern – the acid test of GIS at the time”.<sup>192</sup> The polygon overlay had turned out to be a major concern, due to the realization that “the more highly detailed one’s digital boundaries are,

<sup>186</sup> Maantay and Ziegler, *GIS for the Urban Environment*, 17.

<sup>187</sup> Theobald, (2001), Chrisman (1997), Burrough and McDonnell (1998)

<sup>188</sup> Michael F. Goodchild, “Geographical information science”, in *International Journal of Geographical Information Systems*, vol. 6, no. 1 (1992): 37.

<sup>189</sup> Theobald, *Topology Revisited*, 689.

<sup>190</sup> Dutton, *Harvard papers on Geographic Information Systems*, 122.

<sup>191</sup> Chrisman, *Charting the Unknown*, 124.

<sup>192</sup> *Ibid.*, 125.

the more spurious (sliver) polygons will inevitable result from overlaying them (because of positional measurement errors, which may differ within and between layers).<sup>193</sup> The polygon overlay problem quickly became the most important challenge for the completion of the ODYSSEY system, and for digital GIS in general. In an interview conducted for his book, *Charting the Unknown: How computer mapping at Harvard became GIS*, Nick Chrisman recalls:

*On a night in December 1975, Denis White and I were sitting in the Computer Center and the first version of a program I called CYCLONE had just worked. CYCLONE cycled nodes, it was technically the way of solving the segment problem, [i.e.] that you would have two segments that were going to join [...] at a node. Nodes were the center of our lives. We were thinking that the nodes would be the thing that would link everything [in ODYSSEY] together. [...] We proved that CYCLONE worked, and from that point, [...] we designed the whole rest. [...] We weren't designing a program anymore. We were designing a system of processors, [...] and we knew that it had to solve the polygon overlay problem, or it was nothing.<sup>194</sup>*

The importance of this problem, in relation to the wider context of GIS, will be discussed further in the analysis section of this thesis.

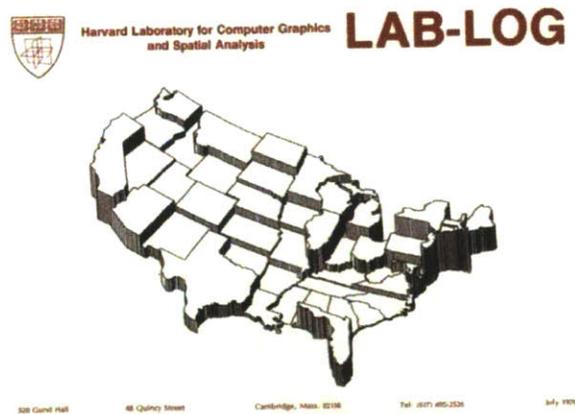


Fig. 38 Front cover of the 1978 LAB-LOG catalog.  
(Chrisman, *Charting the Unknown*, 184.)

<sup>193</sup> Chrisman, *Charting the Unknown*, 129.

<sup>194</sup> Nick Chrisman, interview, *Charting the Unknown*, CD.

In 1979 ODYSSEY entered the commercial market under the name LAB-LOG, which would be the first GIS package to have professionally written user documentation in addition to complete programmer documentation<sup>195</sup> (Fig. 38).

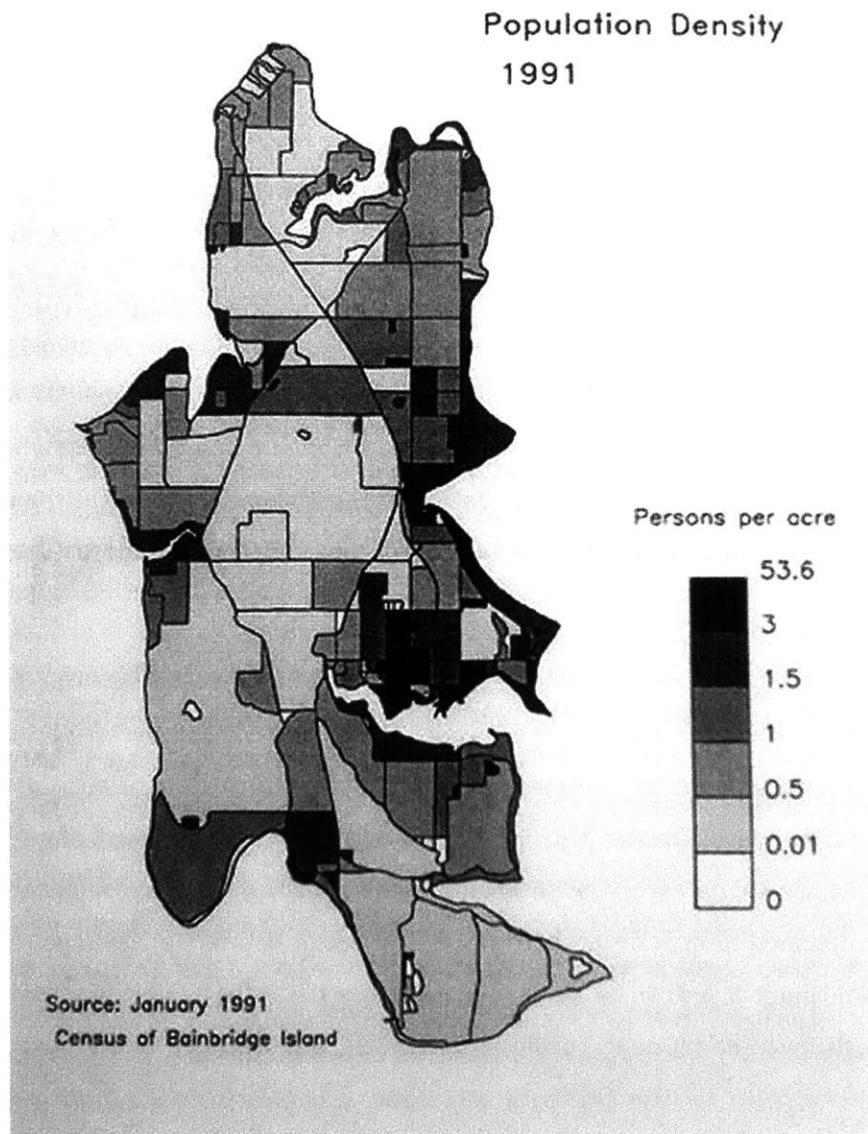


Fig. 39 Sample output from POLYPS (Chrisman, *Charting the Unknown*, 135.)

<sup>195</sup> Chrisman, *Charting the Unknown*, 136.

### 5.2.6 Typical User Method of ODYSSEY

According to Dana Tomlin, “Techniques for the analysis and synthesis of cartographic data have much in common with general statistical methods.”<sup>196</sup> This characterization is also appropriate also for the methods for typical use allowed for in ODYSSEY.

A typical user of ODYSSEY would interact with the system through the command line or by using a digitized tablet. The editor package was called HOMER, “after the author of the original Odyssey”<sup>197</sup>. ODYSSEY also had two programs for display, POLYPS, which displayed choropleth maps, and PRISM, which could extrude polygons in three-dimensional ways.

In ODYSSEY a typical user would retrieve data from the different layers according to their titles, and combine several spatial datasets, i.e., points, lines, or polygons, through basic operations of elementary set theory, after which new vector output was created. The features could be manipulated through basic operations such as union, intersection, or symmetric difference. A union overlay would combine the geographic features and attribute tables of both inputs into a single new output, whereas intersect overlay would output the area of overlap from both features while retaining the attributes in separate layers. Finally, symmetric difference overlay would output the combined areas of features, but with the area of overlap omitted.

Further developments of user manipulation, developed in the wake of the ODYSSEY system, include processes for data extraction, which can be used in both raster- and vector-based GIS. In data extraction, a clip mask is used to combine properties and features from several data sets. These techniques were further developed by Dana Tomlin in the 1980’s in the framework of his Ph.D. thesis on Map Algebra.<sup>198</sup> Tomlin’s data extraction techniques were initially developed for raster data sets but were eventually designed to operate on both raster and vector datasets. A key invention in Tomlin’s system is that some input layers can be assigned more weight than others in the processing. The details of Map Algebra, as invented by Dana Tomlin in the 1980’s, are described in the next section of this chapter.

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<sup>196</sup> Dana Tomlin, *GIS and Cartographic Modeling*, (Redlands, CA: ESRI Press, 1990, 2012), 125.

<sup>197</sup> Chrisman, *Charting the Unknown*, 134.

<sup>198</sup> Tomlin, *GIS and Cartographic Modeling* (1990).

### 5.3 Description of Model 3: Hybrid GIS

#### 5.3.1 Introduction to Hybrid GIS

De-stratified and stratified GIS, to be discussed in chapters 8 and 9, have been named in accordance with the state in which data are organized, or appear to be organized, from the perspective of a typical user, at the time he/she interacts with the data. For instance, to a typical user, McHarg's Ecological Method would not appear de-stratified at all stages of the process, but rather, as evident in its characterization, as a method in which layers did exist at an earlier stage. The organization of data is important because it determines the possibilities and limitations of the operations available to the user for interaction with the data.

In *GIS and Cartographic Modeling*,<sup>199</sup> Dana Tomlin states that "Among cartographic modeling techniques whose purpose is to describe, a broad distinction can be drawn between those that analyze and those that synthesize cartographic data. Analytic techniques decompose data into finer levels of meaning, while synthetic techniques re-compose data for use in particular contexts." Considering that both analysis and synthesis are essential to design and decision making in cross-disciplinary contexts, it is only natural that hybrid models of GIS exist between the two presented approaches. In terms of organization, it is assumed that a hybrid approach would mean that a typical user can choose the approach he/she uses to engage with the data, i.e., a user can choose to handle data in its totality in de-stratified form, or analytically with stratified entities.

To exemplify this approach, Dana Tomlin's "linguistic" approach to data manipulation, termed *Map Algebra*, will be highlighted. It is argued that Map Algebra can be used in any GIS; or as Bruns and Egenhofer note, "Map algebra is a relatively new expression for a practice going back for over 100 years."<sup>200</sup> An interesting anecdote is that Tomlin chose to share his work on Map Algebra freely, with hope that the ideas would be picked up and developed further in many different initiatives. As a result, and as an indication of the success of the FORTRAN inspired language, Map Algebra is today used in almost all commercial GIS applications.<sup>201</sup>

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<sup>199</sup> Tomlin, *GIS and Cartographic Modeling* (2012), 125.

<sup>200</sup> Thomas H. Bruns, and Max J. Egenhofer, "User Interfaces for Map Algebra", in *Journal of the Urban and Regional Information Systems Association*, vol. 9, no. 1 (1997): 44.

<sup>201</sup> Tomlin, *GIS and Cartographic Modeling* (2012), vii.

### 5.3.2 Dana Tomlin's Map Algebra

In the 1980's and 1990's, before GIS software was designed to incorporate user-friendly interfaces, it was common to interact with the system through a command-line interface. One such approach was Dana Tomlin's Map Algebra, which was originally developed for raster manipulation. Developed through the 1980's, as part of his Ph.D. studies at Yale University, Map Algebra is a high-level programming language which provides a vocabulary and conceptual framework for classifying ways to combine map data, i.e., map layers. Map Algebra was developed to conduct more intuitive operations between two or more map layers, but without reduced mathematical rigor.

Map Algebra consists of operations which can be classified as local, focal, or zonal.<sup>202</sup> The *LocalFUNCTION* operations work on one location at a time and without consideration of neighboring cells in a raster, while the *FocalFUNCTION* operations work on larger neighborhood areas, and the *ZonalFUNCTION* on areas that can vary both in size and shape and are not organized according to any logical or spatial structure.<sup>203</sup> All of the operations in these three groups manipulate map data or combine maps in ways that always result in the creation of a new map. The fact that all operations of Map Algebra result in a new map makes it easy to group functions together in larger sets.

### 5.3.3 Typical User Method of Map Algebra

Map Algebra is a high level programming which works with stratified GIS. It has been incorporated into most commercial GIS systems today. As discussed by Bruns and Egenhofer, Map Algebra applications vary in their user interfaces, from command line to graphical interfaces.<sup>204</sup> In his Ph.D. dissertation, Tomlin specifies a general scheme for cartographic modeling, which is "not specific to any one GIS in particular."<sup>205</sup> Map Algebra defines a programming syntax for combining map layers by applying mathematical operations and analytical functions. The expressions used are a combination of mathematical, logical, or Boolean operators.<sup>206</sup>

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<sup>202</sup> Tomlin, *GIS and Cartographic Modeling* (2012), 114.

<sup>203</sup> *Ibid.*, 113.

<sup>204</sup> Bruns and Egenhofer, *User Interfaces for Map Algebra* (1997).

<sup>205</sup> Tomlin, *GIS and Cartographic Modeling* (2012), 1.

<sup>206</sup> "ESRI online GIS Dictionary", Support.esri.com. Visited May 21<sup>st</sup>, 2013.

<http://support.esri.com/en/knowledgebase/GISDictionary/term/map%20algebra>. URL.

To provide an example, the *LocalVariety* function can be used to assess how much diversity exists among values of specified coinciding map layers at a specific location. The function generates a single value for the variety based on all scored available in that location. An example from Tomlin's book illustrates that if map layers at a particular location are associated with values 7,2,4,3,3,5,2 then the generated output would be 5.<sup>207</sup> Expressed in pseudo code, i.e., in wording that more closely reflects natural language, the *LocalVariety* function can be written:

```
NEWLAYER = LocalVariety of 1STLAYER [and NEXTLAYER] ETC
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The *LocalVariety* function can assess only similarities or dissimilarities among existing values, regardless of their magnitude<sup>208</sup> and, as can be seen in Fig. 40, a new map is generated which displays all varieties in a single layer.

The four images in Fig. 39 show four separate maps displaying development-suitability scores on the same land area. The four data layers, 1stScore, 2<sup>nd</sup>Score, 3rdScore and 4thScore (Fig. 40), are graded numerically but displayed in gradient gray scale. In the analysis of the *LocalVariety* function, each of the four layers are weighted and a final value is calculated according to the values from each map location and assigned weights. The combination of layers is not affected by the size of the land areas in each quote of a layer. After processing, a new map (Fig. 41) is generated. This new map can be used for interpretation, and also be used as input in further calculations. It is interesting to note that explicit subjective judgment, in this type of operation in Map Algebra, can be incorporated either in the formation of the individual map inputs or in the process of their combination.

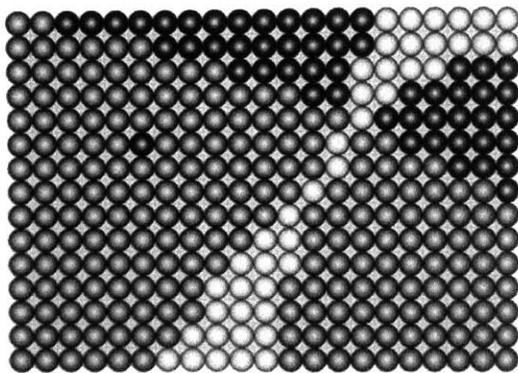


Fig. 40 Grid Square, Map Algebra. (Tomlin, *GIS and Cartographic Modeling*, 11.)

<sup>207</sup> Tomlin, *GIS and Cartographic Modeling* (2012), 58.

<sup>208</sup> *Ibid.*, 59.

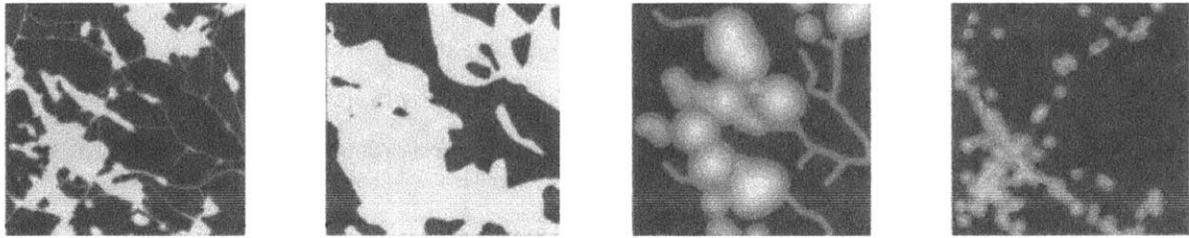


Fig. 40 Source maps: 1<sup>st</sup> Score, 2<sup>nd</sup> Score, 3<sup>rd</sup> Score, and 4<sup>th</sup> Score.

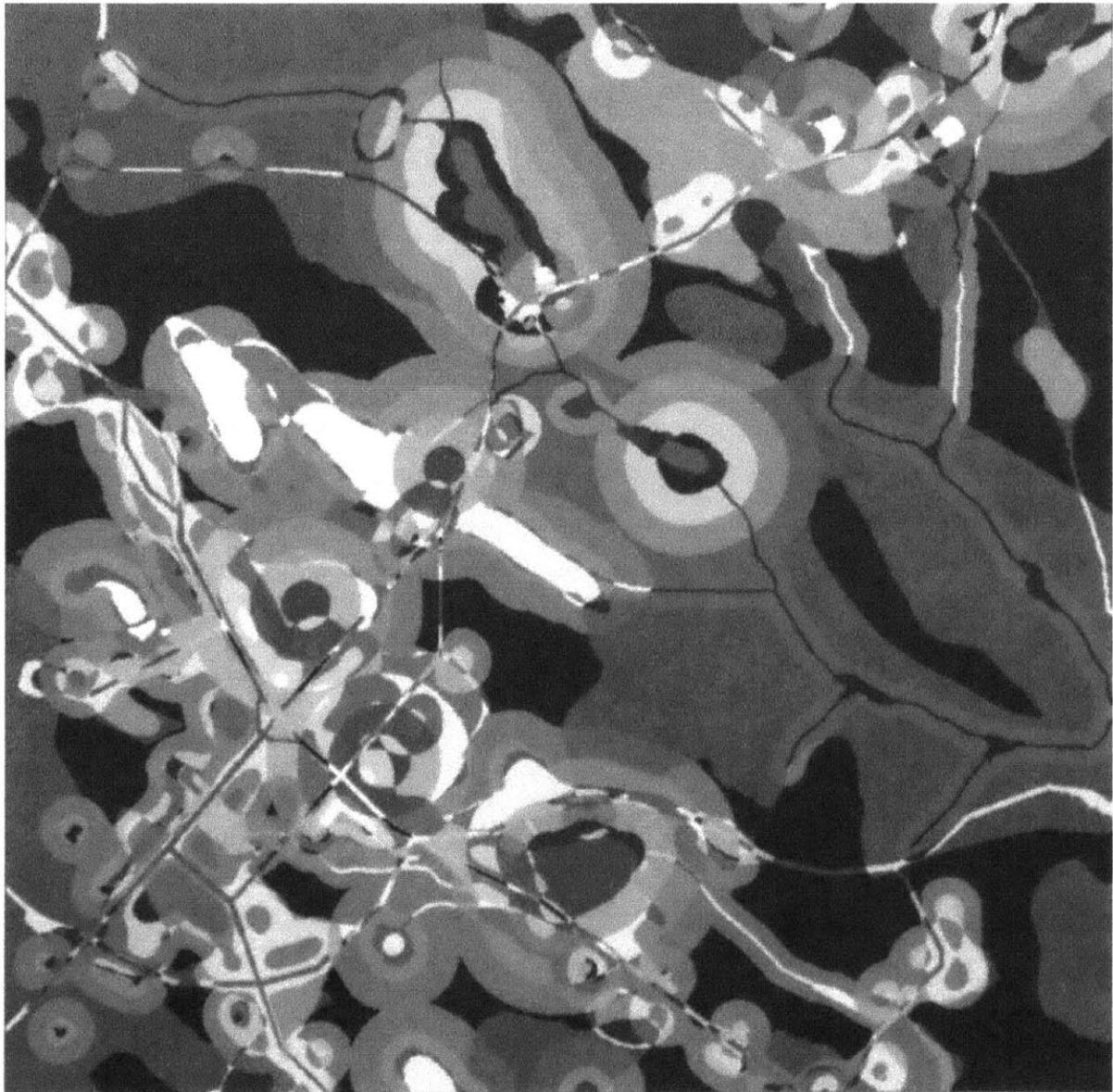


Fig. 41 Generated Composite Map. (Tomlin, GIS and Cartographic Modeling (2012), 57.)

## 06. Analysis



## Foreword to Chapter 6

This thesis hypothesizes that the computerization of the formerly analogue GIS in the 1960's, which emerged with *CGIS* and initiatives at the *Harvard Laboratory for Computer Graphics and Spatial Analysis*, can be read as the establishment of a pre-existing analytical conception of the environment, over its synthetic and holistic counterpart. In this thesis the two approaches are exemplified by two models of GIS and, in addition, a hybrid approach is highlighted, which attempts to bridge the benefits of the de-stratified and stratified models. The general schemes of these three models exhibit different logic and user interaction, which will be further analyzed in the following sections of this chapter.

The main aim for the thesis is to challenge the common conception that the term GIS refers to computer software, by highlighting that different model co-existed at the time of the shift from analogue to digital techniques. To Carl Steinitz and his colleagues at the Landscape Architecture Research Office (LARO), at Harvard University Graduate School of Design, analogue map overlay techniques were seen as precursors to digital GIS, and as such formed "a logical and obvious basis for analyzing relationships among different elements of the landscape."<sup>209</sup> In the following sections the logics of the three studied models will be discussed and the technological and social findings will be used to speculate around possible future technologies for design and information modeling in cross-disciplinary contexts.

### 6.1 Shift of Logic – Analogue to Digital Techniques

Three years after Darwin published *On the Origin of Species*, and twelve years after Charles Babbage had designed the first Difference Engine, the author Samuel Butler published his iconoclastic essay titled *Darwin Among the Machines*.<sup>210</sup> In his essay, Butler argues that computers have become, or might evolve into, a form of mechanical life which with time might replace humans as the dominant species on Earth. Although Butler's theory might be considered too satirical for serious consideration, it is interesting that at present, although in no way similar to what Butler imagined, the inherent logics of digital machines firmly guide and constrain our operations in digital environments. The resulting affordances and constraints from these logics are not often challenged, and are usually taken as constants. The result, seen from the perspective of a typical user, is that we seek to transpose information from the world to fit the conventions of digital machines rather than adapt the machines to

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<sup>209</sup> Foresman, *The History of Geographic Information Systems*, 4.

<sup>210</sup> Samuel Butler, *Darwin Among the Machines* (Christchurch: Fairfax Media, 1863).

fit the world as we see and experience it. Dana Tomlin, inventor of Map Algebra, states, “In cartographic modeling, as in any game, you start by becoming familiar with the necessary equipment. Next, you try to understand the basic rules of play. Only then can playing skills and strategies be developed”.<sup>211</sup>

In the video titled *Data for Decision*, produced in 1967 to promote the Canada Geographic Information System, a voice narrates that “the computer can be an instant library, a bank of information, information that is stored as numbers, on tape in this case. It can store statistics, and these statistics can be filed for immediate access at any time. However, so much of information about land resources comes only in maps. How can we store them as numbers?”<sup>212</sup> The question posed in the video is relevant from the perspective of digital GIS, because in order to operate, digital computers require explicit data, and information without ambiguity.

In the special July 1988 issue of the *American Cartographer*, “Reflections of a revolution: the transition from analogue to digital representations of space, 1958-1988,” a series of perspectives of the period is provided. The accounts presented are written by American and British practitioners and academics who participated and contributed first-hand to the shift from analogue to digital GIS. In the foreword to the issue, Roger Tomlinson notes that, “[s]ometimes technological change occurs so gradually that even the individuals responsible for it are scarcely aware of what is happening. But at other times major change occurs at a perceptible rate. We tend to think of the former as evolutionary change, the latter as revolutionary.”<sup>213</sup> Although Tomlinson categorizes the digitization of GIS as revolutionary, he is careful to point out that the progress was not due solely to the appropriation of computers, but rather to a more profound shift in forms of representation. Tomlinson states that “there has been a significant change in spatial knowledge representation from an essentially analog form (the map) to computerized digital forms (including spatial databases and the various information forms to which they can be transformed).”<sup>214</sup> From a cartographer or geographer’s point of view, the shift from analogue to digital GIS in the 1960’s was the culmination of several decade-long trends in the discipline. However, seen from the point of view of a designer, the digitization imposed a set of methods with constraints and limitations, which quickly came to supplant the previous techniques of analog map overlays (Fig. 42).

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<sup>211</sup> Tomlin, *GIS and Cartographic Modeling* (2012), xx.

<sup>212</sup> Roger Tomlinson, *Data for Decision*, (1967; Ottawa: National Film Board of Canada), Film.

<sup>213</sup> Roger Tomlinson, ed., “Reflections of a Revolution: the Transition from Analogue to Digital Representations of Space, 1958-1988”, in *the American Cartographer*, vol. 15, iss. 3 (July, 1988): 245.

<sup>214</sup> *Ibid.*

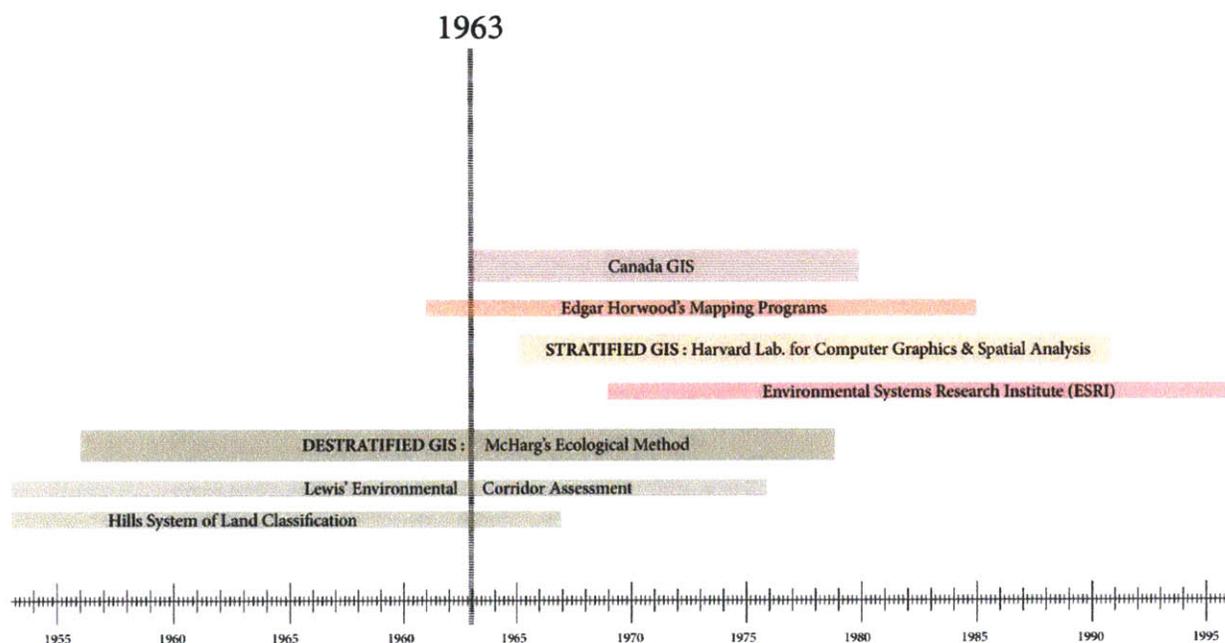


Fig. 42 History of ideas illustrating historical discontinuity in shift from analogue to digital GIS.

The discontinuity in the history of GIS becomes evident mainly through examination of the logics implemented before or after the shift from analogue to digital, as discussed in Chapters 5, but also through the study of the potential shift of agency, from the human designer to the digital machine. The logic of analogue and destratified GIS techniques can be traced by a comparison of transects of Alexander von Humboldt, Sir Patrick Geddes, and Ian McHarg's Ecological Model. The transects of Humboldt's, such as the section drawing of Mount Chimborazo, constitutes an early attempt to combine landscape representation with information modeling. In Humboldt's transect, the study area is populated with the names of plant species which grow in specific conditions on the mountain side. The details of these conditions are noted in tabular form, to the sides of the drawing. (Fig. 43) The combination of information in text and graphical form in one artifact is also often attempted by Sir. Patrick Geddes in some of his "thinking machines." One example is the *Specimen Transect Chart* (Fig. 44), which was constructed for a regional survey in Limpsfield, Surrey. It is evident that the main purpose is to communicate the relations between layers of information, arranged in the transect to give a holistic view of the area and its characteristics.



Fig. 43 Alexander von Humboldt. Transect of Mount Chimborazo. Detail. (Geographie des Plantes Equinoxiales, 1807)

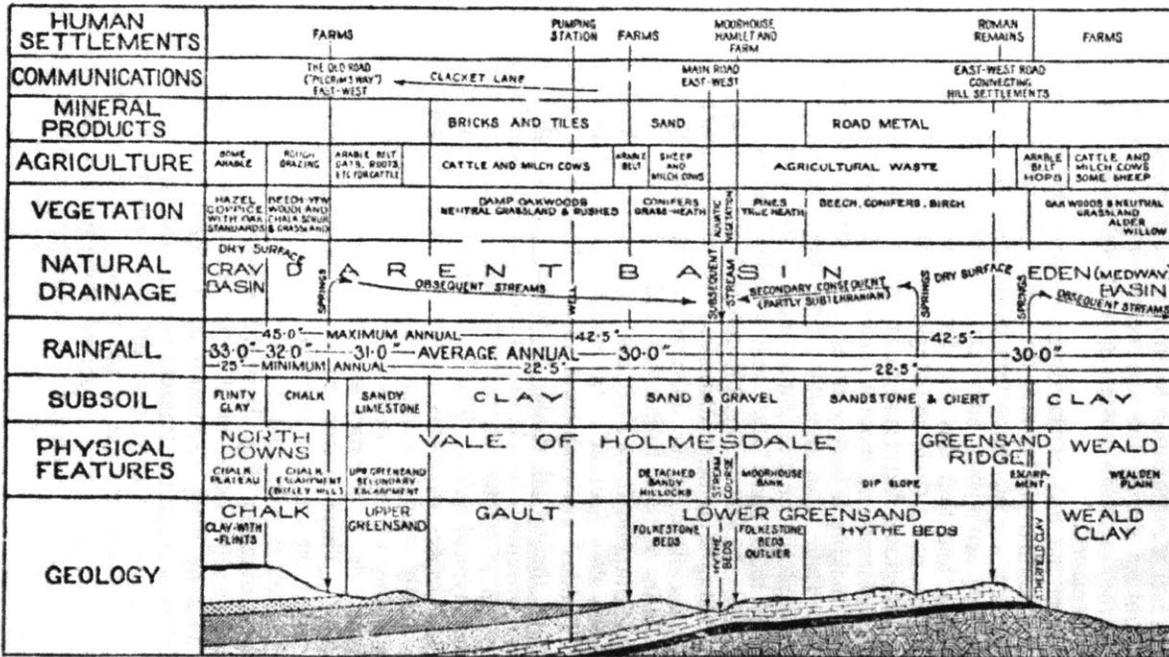


Fig. 44 Patrick Geddes. Specimen transect chart, Limpsfield, Surrey.. (Wheeler, From Goethe to Geddes and the search for Environmental Understanding, 414.)

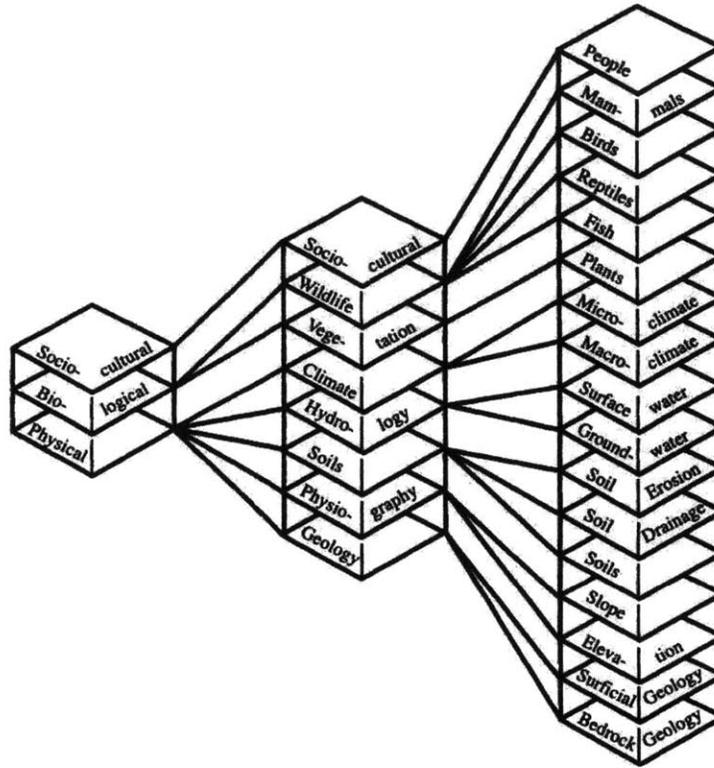


Fig. 45 Ian L. Mcharg. The Ecological Method. (Reproduced from *Design with Nature*, 1969)

This method of combining synthetic and representational aspects of the process was further refined and developed by Ian Mcharg into a practical method which could be implemented on any study area (Fig. 45). The importance of Mcharg's method is that even as a practical method, the process of synthesis is never separated from the process of representation, i.e., it is all part of the same computational construct.

The second, destratified logic is a method which separates the processes of analysis from representation. The current separation between a calculation- and a representation engine, dates back to the development of the first analogue computers, such as the Dalton Calculation Machine (Fig. 46) and Charles Babbage's Difference Engine<sup>215</sup> (Fig. 47). The Difference Engine, which was designed to be the first automatic computing engine, was designed to not only perform calculations, but also to print out an inked hard copy of the 31-digit result of each calculation and to output an imprinted plate of the

<sup>215</sup> Babbage never lived to see the difference engine completed. In 2002 a complete model was constructed in London, UK, following Babbage's original drawings.

result on a soft material. The imprinted plate made it easy to make a printing plate of the tabular information.



Fig. 46 Dalton Analogue Calculation Machine (1902) (Photograph: Steve Behr and Sarah Robinson )

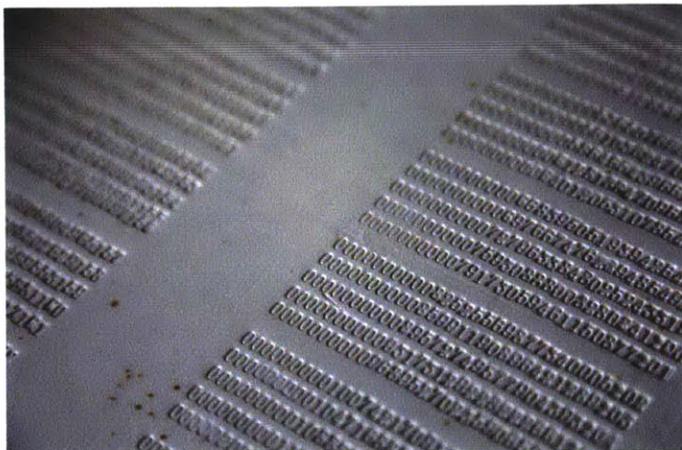


Fig. 47 Imprinted output plate from Charles Babbage's Difference Engine. (Computer History Museum, Mountain View, CA.)

In the Afterword to the 1988 special edition of *The American Cartographer*, Barbara Petchenik states that "For the most part, the analogue-to-digital revolution implies a focus away from the visual toward the numerical or the narrative. Enthralled as we still are by the power and flexibility of computer-processed digital data, and by the utility of these data as input for other digit-consuming systems, it is easy to lose sight of the unique value and utility of the image . . . of the map."<sup>216</sup>

The separation of calculation and representation indicates an analytical process, in which information is broken down into subcomponents and handled in separate scientific disciplines and subject areas.

In digital GIS, calculation is separated from the representations, and in addition, the digital information pertaining to different fields is stored in independent layers, i.e., in stratified formats. The data in the stratified model is organized in topological structures which ensure efficiency in calculation and display. When analyzing data in this model, several data sets are retrieved and analyzed numerically, and data from different fields or categories are contrasted and compared. Over time, the logic of digital GIS

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<sup>216</sup> Petchenik, B. Barbara, "Afterword", "Reflections of a revolution: the transition from analogue to digital representations of space, 1958-1988", *The American Cartographer*, vol. 15, iss. 3 (July, 1988): 321.

supplanted the logic of destratified GIS. The reasons for this shift vary depending on who is asked, but generally it is agreed that the ambiguity in the earlier methods was deemed too hard to incorporate into the digital domain, and hence such efforts were abandoned.

## 6.2 Criterion for evaluation of GIS models

In his text, *The Impact of the Transition from Analogue to Digital Cartographic Representation*, the inventor of CGIS, Roger Tomlinson argues that,

*Mapped and related statistical data do form the greatest storehouse of knowledge about the condition of the living space of mankind. Data handling and data analysis of such data are the essential bridges between those data and their effective use in decisions about that living space.*<sup>217</sup>

This data-centric description of the goals of GIS pertains to the common conception, during the mid-1900's, that hardcopy maps were becoming redundant and ought to be replaced by digital equivalents. The two main critiques of hardcopy maps were, first, that the amount of information which could be stored and displayed symbolically, without loss of map legibility, was limited, and second, that "data in a hardcopy map format has to be retrieved visually and manually."<sup>218</sup>

The second criticism highlights the main point of inquiry which will be used to compare and evaluate the affordances and limitations of the three models studied, i.e., destratified, stratified, and hybrid GIS: Ian McHarg's Ecological Model, the topological model of ODYSSEY, and Dana Tomlin's Map Algebra. It is essential to understand that both the destratified and the stratified model were designed with the aim of becoming integral to the planning and decision process, on questions concerning land use, city planning, resource- and regional surveys, preservation, and the effects of urbanization in general. In this respect, both models have proved highly successful, each according to its own merits. Although Ian McHarg's model might not have been as widely adopted as digital GIS, his method, writings, and public

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<sup>217</sup> Tomlinson, "The Impact of the Transition from Analogue to Digital Cartographic Representation", *The American Cartographer*, vol. 15, iss. 3 (July, 1988): 249.

<sup>218</sup> *Ibid.*, 250.

engagement came to have significant impact in shaping national environmental policy in North America.<sup>219</sup>

The success of digital GIS, on the other hand, need not be argued for. Since its commercialization in the 1980's, the system has infiltrated decision making on a global scale. As noted earlier, according to Jack Dangermond, "hundreds of thousands of organizations, big and small, have now embraced it and use it to guide their decision making."<sup>220</sup> Although Dangermond's choice of words might not be so deliberately chosen, his description of digital GIS as a "guide" to planning and design, requires further scrutiny. By studying how a de-stratified and a stratified example are used in practice, a comparative evaluation of their merits can start to take form.

According to Tomlinson, "Management of any kind involves making decisions."<sup>221</sup> Seen from this geographer's point of view, the classic steps to arrive at decisions based on observed phenomena include observation, measurement, description, explanation, forecasting, and decision.<sup>222</sup> These can, according to Tomlinson, be further categorized as "data gathering, handling, data analysis models (mental and formal) and decision making process"<sup>223</sup> (Fig. 48). For the purpose of this thesis, to compare different schemes of organization of data, seen from the perspective of a typical user, Tomlinson's categories will be reformulated as data organization, processing, representation, and interpretation. These four categories form the criteria, by which the models described will be analyzed and evaluated in the next sections of this chapter.

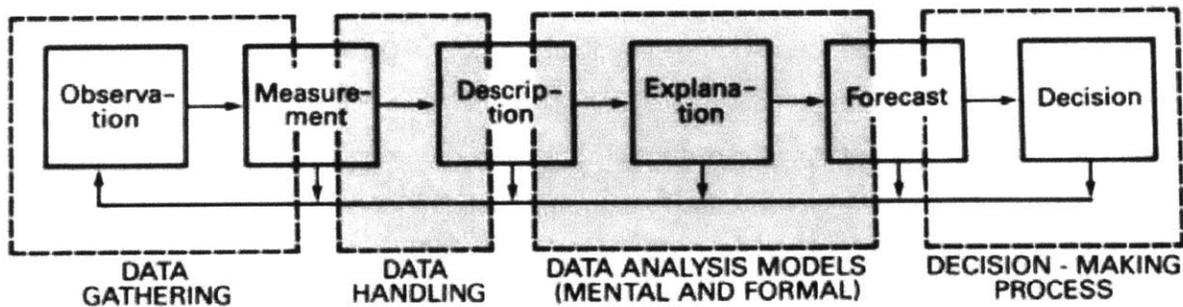


Fig. 48 Roger Tomlinson, Diagram of "Steps Necessary to Arrive at Decision Based on Observed Phenomena" (*The American Cartographer*, July, 1988)

<sup>219</sup> Spirn, Ian McHarg, *Landscape Architecture, and Environmentalism*, 103.

<sup>220</sup> Carl Steinitz, *A Framework for GeoDesign: Changing Geography by Design* (Redlands, CA: ESRI Press, 2012), vii.

<sup>221</sup> Tomlinson, *The Impact of the Transition from Analogue to Digital Cartographic Representation*, 249.

<sup>222</sup> Ibid.

<sup>223</sup> Ibid.

### 6.2.1 McHarg's Ecological Method: Analogue Computation

In his own view, McHarg's key contribution to ecological planning was his method developed to make map layers that are causal and linked by chronology. While acknowledging the stratified nature of most digital GIS, McHarg noted that the most important characteristic of his planning method was that the layers were united by time: "this is certainly something that [digital GIS] graphics don't show. They simply show layers. But I think my contribution was to make sure the layers were extensive, first of all, and united by time. [...] And it was a really valuable one, because up to that point all of the sciences were fragmented, and all of the proponents were certainly representing their own disciplines."<sup>224</sup> Like Geddes, McHarg was skeptical to the disciplinary divisions of science.

In McHarg's model, information from a group of disciplines is fused in a composite drawing, consisting of Mylar transparencies displaying grayscale encoding and arranged by time as the unifying metric. A crucial step in this process, and one subject to much debate,<sup>225</sup> is the evaluation of the disciplinary information. During evaluation a specialist from each discipline would produce a grayscale map which through varying opacities indicated the areas that, from that discipline's perspective, would result in the least or most environmental impact, if developed. McHarg notes, "I wanted colors to be numerical, the gray tones to be numerical, so every value we gave was actually meaningful. I could see then by the color what was meant by the portrayal."<sup>226</sup> As such, one can argue that the main contributions of McHarg's were, first, his proposed process of fusing cross-disciplinary information, and second, the output from such a process in the form of the composite map. This composite map was McHarg's method to locate and give shape to the environment. A designer or planner would then draw on top of the stack, using the composite drawing as a canvas. Anyone, without prior scientific knowledge, could use the map as all information was contained in the varying opacities of the composite drawing.

As such, the assessment of data in McHarg's method is founded in observation, during all phases from data gathering and evaluation to the interpretation of their composite effects. In this respect, the human expert could never be omitted from the process, which becomes evident when assessing the method from the perspective of Tomlinson's recast categories (Fig. 49).

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<sup>224</sup> GEO World, interview, *In Memoriam: Ian McHarg Reflects on the Past, Present and Future of GIS*.

<sup>225</sup> Chrisman, *Charting the Unknown* (2006), and Belknap and Furtado, *Three approaches to environmental resource analysis* (1967).

<sup>226</sup> GEO World, interview, *In Memoriam: Ian McHarg Reflects on the Past, Present and Future of GIS*.

**DESTRATIFIED MODEL: McHarg's Ecological Method**

	organization (source data)	processing	representation	interpretation
fused			Cross-disciplinary data fused through chronology (analogue domain)	Composite map with varying opacity assessed holistically
layered	Disciplines collect data individually from same study area	Disciplines evaluate and map data individually. Boundary object: gray scale representation		

Fig. 49 Organization of data in destratified GIS

In the data collection phase, information is gathered individually by the different disciplines. After collection, the data is processed and evaluated separately in the different disciplines, which means that the organization of information is stratified during these two phases. After the evaluation has been completed, and all of the maps from the different disciplines have been collected, the transparent maps are arranged according to chronological sequence. At this point, when the layers are stacked, the transparency of the maps fuses the information, which allows the interrelations between the different layers to emerge. The key is the use of transparency as a method to fuse knowledge and subjective judgments from a plethora of different fields. In the final phase of data interpretation, the organization of data is still fused and the resulting composite map is used by the designer to holistically assess the environment. This logic provides both a process for integrating cross-disciplinary data and a representation of the environment in its totality. A salient point is that the generated composite map could be used by anyone without scientific knowledge, as all information was contained in the transparencies.

6.2.2 SYMAP and ODYSSEY: Digital Computation

In 1965 Fisher named his *Synagraphic Mapping System* SYMAP due to its etymological meaning of “together” and “graphics.” The intention of Fisher was to provide a “new way of seeing things as a

whole.<sup>227</sup> An interesting difference is that Fisher, unlike McHarg, did not develop his software specifically with the environment in mind. His focus at the outset was urban planning.<sup>228</sup>

Both SYMAP and the ODYSSEY system were developed at a time when environmental issues were emerging with great frequency and new systems were required that could keep up with the demand for assessments. At this time CGIS was already in use, as the first operational GIS, in Ottawa, Canada.

The big breakthrough in ODYSSEY, as described in the previous chapter, was the use of topology to create vector features, which allowed for faster and more accurate data analysis. Chrisman notes that ODYSSEY was “not presented as a GIS, but a geographic information processing system.”<sup>229</sup> In its final configuration, ODYSSEY operated “in a file environment using sequential access, not a database environment using random access.”<sup>230</sup> The file environment was stratified similar to a database as files were organized in hierarchical structures. Consequently, the file environment acts as a library of information, providing instant access. Each file in this structure stores explicit data that pertain to topological features, which in turn define the rules of adjacency and connectivity among features. This means that, because rules of adjacency and connectivity are explicitly described, one needs to execute a series of operations, before visible geometrical overlaps, between features of different layers, can be obtained. In addition, topological features do not allow for display of continuous conditions such as altitude or slope conditions.

The overlay functionalities in digital GIS allow for integration of data from cross-disciplinary sources, if success in the following three tasks can be confirmed: first, that the layers are registered and contingent to the same spatial reference system, i.e., geographical coordinate system; second, that the calculations of geometric intersections are possible; and third, that the corresponding attributes in the databases can be combined.

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<sup>227</sup> Chrisman, *Charting the Unknown*, 20.

<sup>228</sup> *Ibid.*, 42.

<sup>229</sup> Nick Chrisman, “Lessons for the Design of Polygon Overlay Processing from the Odyssey Whirlpool Algorithm,” in the proceedings of: *Proceedings 5th SDH*, vol. 2, Charleston, SC (1992): 401.

<sup>230</sup> *Ibid.*, 402.

**STRATIFIED MODEL: Digital and Topological GIS**

	organization (source data)	processing	representation	interpretation
fused	Data collected via aerial photo, census or sim.			
layered	Disciplines collect data individually	Data digitized and structured hierarchically in database	Topological and stratified data display (digital domain)	Map and tabular output Topological data sets queried and manipulated

Fig. 50 Organization of data in stratified GIS

During the phase of data collection the source data is usually obtained in fused form, as either aerial photographs or in the form of hard copy maps, which need to be digitized before processing. In the processing phase the fused data, collected from the source, is filtered and stored in a hierarchical file environment, i.e., data goes through a process of stratification. The stratified data is then represented in the digital environment as separate data layers, i.e., files, which can be switched on and off or manipulated by the user (Fig. 50). The attributes of geometrical features can be accessed on demand. Finally, in the process of interpretation, the stratified data is queried with the result of new map layers being generated or via the output of results in tabular format. All queries to the information, of both geometrical features and in the linked attribute table, occur through numerical calculations. In this system one needs to know what to search for, so to speak, as no information except for the displayed geometrical features will reveal itself without query.

6.2.3 Map Algebra – Tomlin’s Hybrid GIS

Map Algebra is a set-based algebra for manipulating geographically referenced data implemented through a high level programming language. The model should be viewed as an extension to stratified GIS, as it operates on map layers linked to databases, i.e., attribute tables, in the same way.

A key invention in Tomlin’s system is that data layers can be assigned weights in processing, which allows for subjective input by a user, not only in the input of values in the database but also in the calculations of data, initiated by a user.

When evaluating the logic of this model we see many of the same benefits as from ODYSSEY, with the mentioned additions that Tomlin’s system provides for subjective weighting of layers and that a new map layer is generated with each operation, similarly to McHarg’s Ecological Method. A downside of the model is that although considered a high-level programming language, a command-line approach is not suitable for a typical user. However, it should be noted that the functionality of Map Algebra is currently incorporated into most commercial digital GIS applications.

**HYBRID MODEL: Tomlin's Map Algebra**

	organization (source data)	processing	representation	interpretation
fused	Data collected via aerial photo., census or sim.		Topological composite map	Composite map produced after each operation
layered	Disciplines collect data individually	Data digitized and structured hierarchically in database	Source layers retained (digital or analogue domain)	Source layers retained

Fig. 51 Organization of data in Hybrid GIS

Like ODYSSEY, Map Algebra operates on layers stored in a digital data base. However, a salient feature of the hybrid model is that although a new map is generated with each manipulation of data, the generated composite map is then added back into the database as a new layer, ready for further manipulations just like any other of the stored layers (Fig. 52). This process makes the system well suited for linking larger sets of operations together. As we can see in the diagram in Fig. 51, the organization of data provides a possibility to alternate between layered and fused configurations.

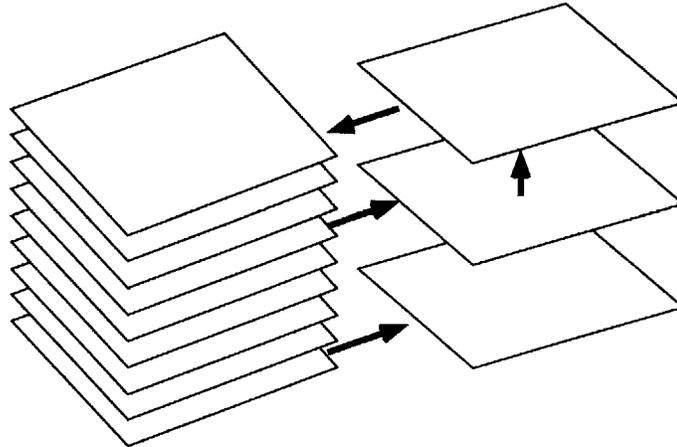


Fig. 52 Sequence for manipulation of layers in Map Algebra

### 6.3 Comparing Models – Destratified, Stratified, and Hybrid GIS

In the three previous sections, three examples of cross-disciplinary data modeling have been discussed. The present research argues that although these models differ in logic and user engagement, they should be considered as equally computational constructs.

In the evaluation of the three models simultaneously, categorized in the phases required to arrive at decision based on observed phenomenon (Fig. 53), it is apparent that organization of data is not either stratified or destratified in all phases of the three different models.

A fused organization of data seems to be particularly well-suited for landscape design as it allows for all parameters to be displayed simultaneously. In this sense, one can argue that the relations between different information are made explicit only in the models exhibiting destratified characteristics in the final phases. Despite its shortcomings, the hybrid model seems like an interesting attempt at cross-disciplinary information modeling because it alternates between a fused and a layered organization of data. This hybrid approach, which attempts to bridge the benefits of the destratified and stratified models, invites future computational investigations.

**DESTRATIFIED MODEL: McHarg's Ecological Method**

	organization (source data)	processing	representation	interpretation
fused			<b>X</b>	<b>X</b>
layered	<b>X</b>	<b>X</b>		

**STRATIFIED MODEL: Digital and Topological GIS**

	organization (source data)	processing	representation	interpretation
fused	<b>X</b>			
layered	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>

**HYBRID MODEL: Tomlin's Map Algebra**

	organization (source data)	processing	representation	interpretation
fused	<b>X</b>		<b>X</b>	<b>X</b>
layered	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>

Fig. 53 Comparison: Organization of data in destratified, stratified and hybrid GIS

Furthermore, the Ecological Method of Ian McHarg is the only model of the three which provides not only a process for integrating cross-disciplinary data, but also, a holistic representation of the environment. The Ecological Method is contingent on the designer as observer and “meaning-maker” of the composite drawing. When lit up, the composite drawing displays areas with the most social benefits and with the least environmental impact if developed. Because all of the information from the evaluation process is encoded in the grayscale, the composite map contains all information from the different fields. Consequently, anyone can use the map without prior scientific knowledge, which in terms of user-engagement, separates this model from the destratified and the hybrid models. In the destratified and the hybrid models, a user need to know, not only what data is stored, but also how to query the different layers to reach a conclusion (Fig. 54).

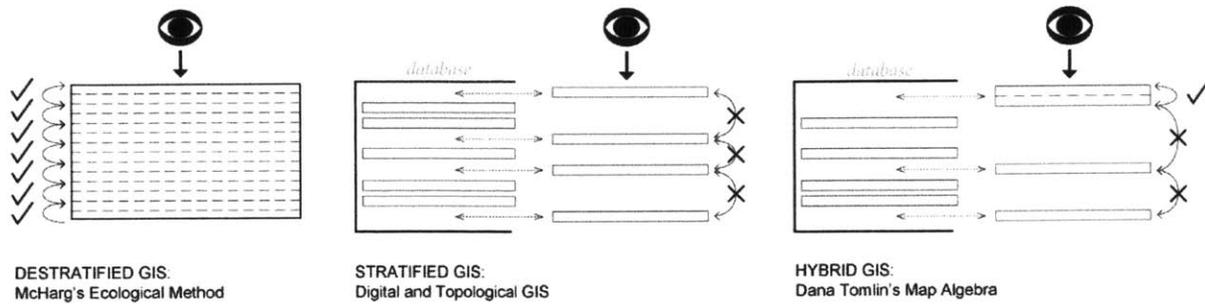


Fig. 54 Organization of data in destratified, stratified and hybrid GIS, from the perspective of a typical user

#### 6.4 Importance of the Polygon Overlay Problem

In the early period of GIS, when analogue map overlays were still used in planning and design, a typical user would interpret data by observing the effects emerging in a composite drawing of cross-disciplinary information and drawing with a pen on a transparent film on top of the stack of Mylar sheets. Later, when hardcopy maps were to be used as input for digital GIS, digitizing machines were used to record and store coordinates which were then used to reconstruct the hard copy map in digital form.

In this process of transposing analogue data to fit a digital domain, the imperfections in recordings became a significant problem. The digitization of hard copy maps often resulted in the numerous generation of so-called sliver polygons, which would produce significant errors in the digital calculations. As mentioned, sliver polygons were long and narrow polygons that emerged in overlays, because datasets were generated at different scales, by different people, at different times, or through different processes. As pointed out by Burroughs and McDonnell,<sup>231</sup> an interesting observation about sliver polygons is that the more vertices recorded polygons consist of, the more sliver polygons are likely to be generated. This means that increased precision in digitizing resulted in increased risk for errors due to sliver polygons.<sup>232</sup>

The problem with sliver polygons emerged as a new problem in GIS in the 1970's, and was a result of the precision of digital computers. The problem was born out of the realization that the explicit and exact order of digital domains cannot be perfectly matched to the "messiness" of the physical world. As such, one may argue that the polygon overlay problem, in essence, concerns how we deal with ambiguity.

<sup>231</sup> Burroughs and McDonnell, *Principles of GIS* (Oxford: Oxford University Press, 1998).

<sup>232</sup> Ibid.

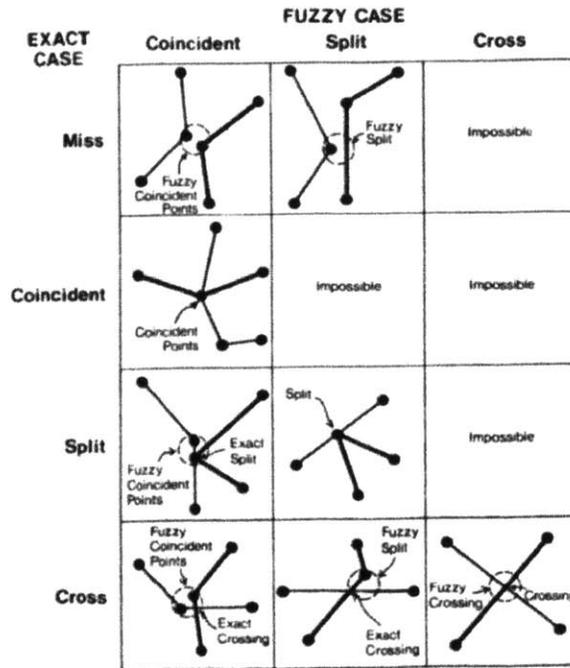


Fig. 55 Fuzzy tolerance for “enhanced intersection processing,” WHIRLPOOL Manual, (Chrisman, *Charting the Unknown*, 129.)

In an interview conducted for his book, *Charting the Unknown: How computer mapping at Harvard became GIS*,<sup>233</sup> Nick Chrisman states that “the Polygon Overlay Problem was ‘the’ core problem”<sup>234</sup> in the development of digital GIS. Discovered at a time when digital GIS systems, e.g., CGIS and SYMAP, had already shown great promise for the potential benefit of using computers in GIS, the polygon problem turned into a substantial challenge for the realization of the desired systems. To overcome the polygon overlay problem became so important to the GIS community that in retrospect one can argue that, due to the attention it received and the focus it generated, the problem acted as a hugely successful promotion device for the digital system. The abstractness of the problem also had a seductive quality and as such it was generally assumed that if only this one mathematical problem was solved, a tool would shortly be made available, that could help solve large and difficult problems in society. In a political environment of big problems and big expectations, a solution to the polygon overlay problem was required, and with ODYSSEY the Lab at Harvard became its privileged inventor.

<sup>233</sup> Chrisman, *Charting the Unknown* (2006).

<sup>234</sup> Interview, Nick Chrisman; *Charting the Unknown*, CD.

## 6.5 Explicit vs. Implicit Information

Things in the real world do not line up perfectly, but as human beings we have a capacity, especially through our perceptual modalities, to generate meaning from the messiness, on the fly. With our eyes we navigate through a world that seems continuous but is not always familiar to us.

In the introduction to McHarg's *Design with Nature*, Lewis Mumford notes that McHarg's

*is a mind that not merely looks at all nature and human activity from the external vantage point of ecology, but who likewise sees this world from within, as a participant and an actor, bringing to the cold, dry, colorless world of science the special contribution that differentiates the higher mammals, above all human beings, from all other animate things: vivid color and passion, emotions, feelings, sensitivities, erotic and esthetic delights – all that makes the human mind at its fullest so immensely superior to a computer, or to under-dimensioned minds that have adapted themselves to a computer's limitations.*<sup>235</sup>

These special traits, to which Mumford refers, are usually characterized as creativity and subjectivity. It is a common conception that subjectivity is too hard to transpose into computer logic, because of its implicit nature. Yet it's widely acknowledged that "the human eye and brain can scan and interpret information on a map more rapidly than the most elegant software can process the equivalent digital data."<sup>236</sup>

In his Ph.D. dissertation on Map Algebra, Dana Tomlin writes,

*It is important to note that a cartographic model conveys information about its study area in both implicit and explicit form. The data within such a model can explicitly record any number of facts pertaining to that study area. In the relationships among those data and the meanings attributed to them, however, there will also be additional information that is never explicitly recorded – at least not at first. Ultimately, the role of Cartographic Modeling is to convert such implicit information into explicit form.*<sup>237</sup>

A proven method for studying something is to examine the technicalities of how it operates - in the case of GIS, the focus is how a user interacts with the data. Typically, in digital GIS, data layers are concrete

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<sup>235</sup> McHarg, *Design with Nature*, vii.

<sup>236</sup> Michael F. Goodchild, "Stepping over the line: Technological constraints and the new cartography", in *Cartography and Geographic Information Science*, vol. 15, no. 3 (July, 1988): 311.

<sup>237</sup> Tomlin, *GIS and Cartographic Modeling*, 4.

and explicit but their interaction and relations are not, unless generated through query. Consequently, these relations are constructed by the viewer of the information: the links are drawn by the observer. In this respect it can be argued that McHarg's Ecological Model can be regarded as the model which most clearly represent relations between data layers, as it provides not only a framework for how to relate data but also generates an explicit and holistic representation of their interactions. The result of the process is a destratified model of the environment, i.e., the composite drawing: a shape is assigned to the environment. The shape, per se, may not be explicitly stated, but as George Stiny points out, "Shapes are fine by themselves without underlying descriptions or representations."<sup>238</sup> And as such the shape of the environment is equivalent to any other shape in design, which makes McHarg's model a suitable environment to exercise to called "flexible purposing", as described by John Dewey<sup>239</sup>.

In his book *Experience and Education* John Dewey emphasizes the importance of freedom of thought, desire, and purpose. He states, "The only freedom that is of enduring importance is freedom of intelligence, that is to say, freedom of observation and of judgment exercised in behalf of purposes that are intrinsically worthwhile."<sup>240</sup> Although it is evident that the topic of Dewey's concerns is education his concept of freedom and flexibility in generation of purposes, as well as freedom in execution of actions, can be made relevant also to design.

On the importance of flexible purposing, Dewey argues that there is "no point in the philosophy of progressive education which is sounder than its emphasis upon the importance of the participation of the learner in the formation of the purposes which directs his activities."<sup>241</sup> However, Dewey is careful to point out that the meaning of purposes and ends is not self-evident and self-explanatory. An impulse is always the start of a genuine purpose. Dewey sums up the intellectual operations involved in the transformation from impulse to purpose as, "(1) observation of surrounding conditions; (2) knowledge of what has happened in similar situations in the past [...] and (3) judgment which puts together what is observed and what is recalled to see what they signify."<sup>242</sup>

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<sup>238</sup> George Stiny, *Shape: Talking about Seeing and Doing* (Cambridge, MA: MIT Press, 2006), 311.

<sup>239</sup> Dewey, *Experience and Education*, 68.

<sup>240</sup> *Ibid.*, 61.

<sup>241</sup> *Ibid.*, 67.

<sup>242</sup> *Ibid.*, 69.

This freedom is, according to Dewey, a means of “Power to frame purposes, to judge wisely, to evaluate desires by the consequences which will result from acting upon them; power to select and order means to carry chosen ends into operation.”<sup>243</sup>

Due to the manifold of interrelated disciplines and purposes which inform landscape design, as well as the changeability of the medium, there are often conflicting sub-sets of purposes which require a process of inherent flexibility, i.e., flexible purposing<sup>244</sup>. Appropriating Dewey’s approach is not an attempt to make landscape whimsical, but rather to point to its sophisticated capacity of hosting a multitude of purposes and intents, arranged in fluid hierarchies, in one single scheme. This capacity is still to be implemented in a digital technology for design.



Fig. 56 Digitizing of hard copy maps.  
(Source: NOAA's National Climatic Data Center)

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<sup>243</sup> Ibid., 64.

<sup>244</sup> Dewey, *Experience and Education*, (1938)

# 07. Reflections: Computer as Prosthetic – Computer as Brain



## Concluding Remarks

The motivation for contrasting the logic of McHarg's Ecological Method to that of digital GIS, as currently implemented, was to illustrate more facets of a technology commonly associated with just one digital framework. By highlight different co-existing models of cross-disciplinary information modeling in GIS, more informed discussions about the present, and future, state of the enterprise could be initiated.

Landscape Information Modeling, i.e. LIM, is an emerging approach to Information Modeling, specifically for landscape. It is my hope that this thesis will contribute to the discussions about its possible specification. To date, no protocol exists which defines the model and specification of LIM. The most popular definition, promoted mainly by BIM software developers, is that LIM is to be implemented as an extension to BIM, as currently implemented, by incorporating landscape objects in the BIM database of building components<sup>245</sup>. Following the steady increase of BIM-usage in AEC industries, landscape architects, together with most other consulting fields, are required to adapt to current BIM information flow in order to compete and collaborate<sup>246</sup>. An example of this enforced adoption is the UK Government strategy to mandate the use of BIM in major building projects by 2016<sup>247</sup>. To better understand what the alternatives are, we need to first examine other technologies which have made the a similar transition, e.g., GIS.

In this context, this thesis has discussed the logic of data organization in three models of GIS from the perspective of a typical user, which in turn provides a new lens to look at the current technologies and how we, as designers, interact with them. In the present, when digital computer technologies have infiltrated design on its most fundamental level, a return to the formation of the digital systems can bring forth questions about current assumptions which may be answered by revisiting intentions, still waiting to be implemented.

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<sup>245</sup> Ahmad and Aliyu, *The Need for Landscape Information Modelling (LIM) in Landscape Architecture*, (2012).

<sup>246</sup> Sipes, *Integrating BIM Technology into Landscape Architecture* (2008).

<sup>247</sup> Ibid.



## 08. Contributions

## 8.1 Contributions

The Geographical Information System (GIS), as currently implemented, constitutes the main computational software for landscape architecture and environmental design. Although commonly associated with computer software, this thesis argues that the principles of GIS existed long before it was implemented on a computer. This thesis aims to challenge the common conception that the developments in the history of GIS are subsumed by one technological continuum, by arguing that the shift from analogue to digital techniques in the 1960's resulted in a discontinuity and a distinct shift from one logic to another.

Accordingly, this thesis hypothesizes that the computerization of the formerly analogue GIS in the 1960's, which emerged with *CGIS* and initiatives at the *Harvard Laboratory for Computer Graphics and Spatial Analysis*, can be read as the establishment of a pre-existing analytical conception of the environment over its synthetic and holistic counterpart. By constructing a historical timeline of the key developments in the history of GIS, it is illustrated that two distinct approaches to GIS existed, exhibiting different logic and user engagement, but which are argued to be equally computational constructs. This alternative approach to GIS opens up a new perspective on GIS which allows for a critical comparison between two different approaches and between three different models, and for a critical evaluation of the system in its current digital form.

The lineage of the first "destratified" approach to GIS is argued to have originated with the holistic views of Johann Wolfgang von Goethe (1749-1832) and the geo-poetic representations by Alexander von Humboldt (1769-1859), inspired by early anarchistic ideas of progress through mutual-aid professed by Élisée Reclus (1830-1905) and Prince Pyotr Alexeyevich Kropotkin (1842-1921), informed by the ideas of holistic causality in nature as proposed by Ernst Haeckel (1834-1919), brought into sociology, regionalism, and planning via Patrick Geddes<sup>248</sup> (1854-1932), finally to be developed for landscape synthesis by Ian L. McHarg (1920-2001) through his "Ecological Method." It is argued that this holistic and destratified approach became supplanted, but not outdated, by the implementation of digital GIS in the 1960's.

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<sup>248</sup> Wheeler, *From Goethe to Geddes and the Search for Environmental Understanding*, (1972).

The second, and today predominant, analytical approach, is argued to have derived from taxonomical ideas, the study of connectivity and spatial analysis, and the concept of competition as a driver for change. Rather than tracing an uninterrupted historical trajectory of this approach, it is argued that its principles are derived from the influence of, among other events, the development of taxonomy in systematics, particularly Linnaeus's taxonomy (1735), Euler's invention of topology, the theory of natural selection by Charles Darwin (1809-1882), the invention and adapted use of spatial analysis and computer graphics, as well as of pressures from large regional and national planning initiatives in both Britain and North America. It is argued that this approach culminated in the implementation of the principles of GIS on a digital computer, first by Roger Tomlinson in the Canada GIS and later by Howard Fisher at the Harvard Laboratory for Computer Graphics and Spatial Analysis<sup>249</sup> and the work on SYMAP and the ODYSSEY system. Although developed in various directions since, it is argued that this stratified approach to cross-disciplinary information modeling is still at present the predominant approach to GIS today, both as a technology and in theory.

These two parallel trajectories of analytical and synthetic/holistic methods are examined through two general schemes by which cross-disciplinary geographical information is organized, from the perspective of a general user. These two approaches to cross disciplinary information modeling are exemplified by a critical comparative analyze of three models of GIS; the stratified model, the destratified model, and the hybrid model. By provided examples, it is illustrated how the three models operate as well as how information is, or appears to be, organized, from the perspective of a typical user. Further, the three models are discussed according to their role as a tool in the design process to arrive at decisions based on observed phenomenon. A salient finding of the research is that in the comparative analysis of the three models, the Ecological Method of Ian McHarg can be considered the most explicit model, because his is the only model which provides not only a process for integration of cross-disciplinary data, but also a representation of such, in form of the composite map; i.e., McHarg gives shape to the environment, available for manipulation in its totality. In digital GIS, on the other hand, while the data is stored in explicit hierarchical structures, the relations between data are not made explicit. As such, while data can be contrasted and overlaid, both the geometrical and the theoretical overlaps can never be reached, unless deliberately generated.

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<sup>249</sup> Tomlinson, ed., "Reflections of a Revolution," in *The American Cartographer* (1988) & Chrisman, *Charting the Unknown* (2006).

The findings of the present research do not only open up new perspectives on GIS, but also invites for speculations about possible future systems. A salient finding of the research worth further considerations, is that although a model can present information to a user in destratified form, a computational model does not necessarily need to exhibit the same state of data organization throughout all phases and, hence, can alternate between stratified or destratified configurations at the will of the user.

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# Appendix

Fig. 57 History of Ideas (by the author).

