

A History of Twentieth-Century American Academic Cartography

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ABSTRACT: The academic discipline of cartography is a twentieth-century phenomenon. From its incipient roots in landscape representation in geology and the mapping of socio-economic data in geography, it grew into its own sub-discipline with graduate programs, research paradigms, and a scientific literature of its own. It came close to establishing a national center for cartography in the late 1960s. After rather sporadic activity before World War II, the period from 1946 to 1986 saw the building of major graduate programs at the universities of Wisconsin, Kansas, and Washington. Other programs were created, often with the doctoral students from those three. At the end of the twentieth century, cartography underwent significant changes in relation to the emerging discipline of geographic information science. The future for academic cartography is less certain, as graduate programs adjust the balances among the many components of mapping science, including cartography, geovisualization, GI science, GIS systems, spatial analysis/statistics, and remote sensing.

KEYWORDS: John Paul Goode, Erwin Raisz, Richard Edes Harrison, Arthur Robinson, George Jenks, John Sherman, Waldo Tobler, analytical cartography

Introduction

This paper details the history and development of U.S. academic cartography in the twentieth century. Although one can find formal education in cartography dating back to the nineteenth century, including coursework at Princeton and the United States Military and Naval Academies, the building of core programs and faculty is a relatively new development. As pointed out in 1987, "Academic cartography in the United States is largely a twentieth-century phenomenon, although it builds on an earlier foundation of governmental, service academy, and private map making" (McMaster and Thrower 1987, p. 345). Since that publication there has been little research on how this discipline grew from a single individual, J. Paul Goode at the University of Chicago, to one of the more significant influences in academic geography. One exception is the 1991 United States National Report to the International Cartographic Association, entitled "History and Development of Academic Cartography in the United States" and published in *Cartography and Geographic Information Systems (CaGIS)* (McMaster

1991). This particular issue of *CaGIS* detailed the earlier programs at Wisconsin, Kansas, and Washington, as well as those at the universities of South Carolina, Northern Illinois, Southwest Texas State, Michigan State, Oregon State, Penn State, SUNY at Buffalo, Ohio State, Syracuse, and Minnesota. Histories of other significant programs, including UCLA, the University of California at Santa Barbara, Clark University, University of Georgia, San Diego State University, and George Mason University, remain to be told.

The scope of this paper does not allow documentation of the very rich cartographic activity in other countries such as the United Kingdom, France, the Netherlands, the former Soviet Union, and China. We leave the identification, documentation, and analysis of such programs to those more knowledgeable about their significance. We also constrain this paper to a particular approach—that of identifying and documenting key individuals and programs in academic cartography. Our approach is to carefully document the individuals, programs, and some of the cartographic events, providing interpretation where possible; it is not a "critical history" that proposes multiple realities of these events.

Further research will allow for a deeper analysis of this history and a careful documentation of the linkages among the various intellectual threads. One example would be to critically evaluate the paradigm of experimental cartography that is detailed briefly in this paper and expanded on in Daniel Montello's paper in this volume. From its roots with Arthur

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Robinson's *The Look of Maps* (1950) to its dominance as a research paradigm—particularly at the Universities of Wisconsin, Kansas, and Washington—to a significant decrease in its emphasis in the late 1980s, a critical assessment of its dissemination and true impact on the field is needed. We also note that the emphasis in this paper focuses on thematic cartography, and we do not delve into the education of topographic cartographers, surveyors, or remote sensing specialists. Although the main development of thematic mapping can be traced to nineteenth-century Europe, it is in the twentieth-century United States that thematic cartography evolved as an academic discipline. It is this unique history that focuses on thematic and statistical cartography—and the education of individuals in these fields—that we document.

Four Major Periods of U.S. Academic Cartography

We review developments in the history of U.S. academic cartography by identifying and discussing four major periods. The incipient period, from the early part of the century to the 1940s, represents what might be called nodal activity, in which academic cartography was centered at only two to three institutions under the leadership of individuals not necessarily educated in cartography. Outstanding examples were J. Paul Goode at the University of Chicago, John Leighly at the University of California, Berkeley, and Guy-Harold Smith at Ohio State. A second period, from the 1940s to the 1960s, saw the building of core programs with multiple faculty, strong graduate programs, and Ph.D. students who ventured off to create their own programs. Three core programs stand out—those at the Universities of Wisconsin, Kansas, and Washington. Other universities developed cartographic programs in the third period, including UCLA, Michigan, and Syracuse. This third period, from the 1960s to the 1980s, also witnessed rapid growth in academic cartography in terms of faculty hired, students trained, journals started, and development within professional societies. It is in this period that cartography emerges as a true academic, nurtured within academic geography departments with strong research programs and well-established graduate education. The pinnacle of academic cartography in the United States occurred in the mid-1980s, when cartography had reached its maximum growth, but the effect of the emerging discipline of geographic information systems/science (GIS) had not yet been felt. Finally, a fourth period was one of transition, whereby car-

The Incipient Period (1900-1940)

- > J. Paul Goode
- > Erwin Raisz
- > Guy-Harold Smith
- > Richard Edes Harrison

The Post War Era of Core Graduate Programs (1940-1985)

- > University of Wisconsin
- > University of Kansas
- > University of Washington

Secondary Programs (1975-1990)

- > UCLA
- > University of Michigan
- > University of South Carolina
- > Syracuse University

Synthesis with GIS Curricula (1990-2000)

- > UCSB
- > University of South Carolina
- > SUNY Buffalo
- > Pennsylvania State University

Table 1. The four major periods of American academic cartography.

tography became increasingly integrated within GIS curricula. The result has been fewer academic positions in cartography, fewer students educated as thoroughly in thematic cartography, and a growth in what is now called geovisualization. In short, from the perspective of academic geography, as we have now left the twentieth century, we can confirm that cartography witnessed remarkable growth from the 1940s to the 1980s, but has, in the past decade, seen a decline as a direct result of the rapid rise of the new related discipline, geographic information science. However, as we approach the next millennium, it appears that a synthesis of the two is slowly emerging with the development of integrated cartography-GIS curricula. In the second part of the paper, we identify several of the major twentieth-century research paradigms (including experimental cartography, analytical cartography, and critical and social cartography), and we specifically document the development of analytical cartography (Table 1).

Period 1. The Incipient Period

The incipient period runs from the very early part of the century to the early 1940s, when much of the cartographic activity in the United States was focused on a few individuals with a strong interest in thematic mapping (McMaster and Thrower 1991). Three of the key individuals are

A. Projections by perspective or by perspective and development	
I.	Orthographic
II.	Stereographic
III.	Gnomonic or Central Projection
IV.	Equidistant, or globular
V.	Cylindrical
1.	Central Cylindrical
2.	Cylinder intersecting the earth's surface
3.	Gall's Cylindrical
VI.	Conic Projections
1.	Simple Conic
2.	Intersecting Conic
B. Conventional or arbitrary projections	
I.	With Straight Meridians and Parallels
1.	Square projection
2.	Rectangular projection
3.	With converging meridians
4.	Mercator's projection
II.	One System of Right Lines
1.	De Lisle's Conic Projection
2.	Lambert's Conformal Conic
3.	The Sinusoidal Projection
4.	Homolographic Projection
5.	Goode's Interruption of the Homolographic Projection
6.	The Homosine projection
III.	Arbitrary Projections with Both Systems of Coordinates Shown as Curved Lines
1.	Globular
2.	Bonne's Projection
3.	Werner's Projection
4.	The Polyconic Projection
5.	Lambert's Azimuthal Equal-Area Projection
6.	Cahill's Octahedral Projection

Table 2. Outline for J. Paul Goode's 1928 course in cartography. [Source: Goode 1928].

J. Paul Goode at the University of Chicago, Erwin Raisz at Harvard, Virginia, and the University of Florida, and Richard Edes Harrison of *Time* and *Fortune* Magazines, who also taught at Syracuse University.

John Paul Goode

Although basic training in cartography started in the United States around 1900, it could be argued that the first genuine American academic cartographer was John Paul Goode at the University of Chicago (McMaster and Thrower 1987, p. 346). Goode was educated at the University of Minnesota (B.A.) and the University of Pennsylvania (Ph.D.), but he spent most of his career at the University of Chicago. Although best known for the homolo-

sine projection and the initiator of Goode's School Atlas, he taught some of the first courses on thematic cartography and graphics at Chicago. Goode's 1924 course at the University of Chicago (Geography 32), entitled "A Course in Graphics," included four major themes: The Graph, The Picture, Preparation of Illustrative Material for Reproduction, and Processes of Reproduction. It is clear that Goode used this "Graphics" course as the prerequisite to his more traditional cartography class, Geography 381.

In 1928 Goode's Geography 381 course was mostly a tutorial on map projections, as seen from both the reading list and outline of the course (Goode, 1928). This is hardly surprising, given that he was active in the development of his own homologous projection at this time. He does provide an early, albeit rather narrow, definition of a map:

A map is: (a) a representation in a plane surface, (b) on a reduced scale, and (c) with all possible accuracy, of the relative positions of points and lines on the earth's surface. Such points are located by spherical coordinates. The primary purpose of a projection is the delineation of these circles of reference (Goode 1928, p. 11).

Goode classifies projections into two categories: A. Projections by perspective, or by development perspective, and B. Conventional or arbitrary projections. His outline (Table 2) is organized around this classification.

What do these outlines tell us about Goode's teaching of cartography? Whereas he does provide information on both statistical presentation and the creation of base maps (through the projection process), it was certainly not what we would consider a comprehensive course in cartography today. One can also see from the nature of Goode's exercises that he does, in fact, teach basic principles of statistical mapping. His exercise Number 1 asks students to map the total mineral output of the United States for the latest year on record, with the requirement that the circles be proportional to production within each state. A similar exercise requires students to map the great seaports of the world by net registered tonnage entered and cleared. The circles were to be centered on each port, with the area of the circle proportional to the traffic. He had similar types of exercises with isolines of intensity applied to the map and the areal distribution of intensity shown by small uniform unit areas, e.g., dots.

Goode's influence was extended through his students at Chicago, most of whom did not devote themselves to cartography specifically. However, some of them were able to influence the course

of the field through positions in the private sector, government, and academia. Two of Goode's students, Henry Leppard (University of Chicago, Washington, and UCLA) and Edward Espenshade (Northwestern University) devoted their careers to cartographic education and continued Goode's work with both base map development and the many generations of the *Goode's School and World Atlas*, published by Rand McNally. Goode's successor in cartography at Chicago was Leppard, who stayed at the University of Chicago until after World War II, when he went first to the University of Washington (where he worked with John Sherman) and later to UCLA. Espenshade spent his entire career at Northwestern University, where he continued to edit *Goode's School Atlas*, later *Goode's World Atlas*.

Erwin Raisz

Following World War I, Erwin Raisz, a Hungarian educated in civil engineering, immigrated to the United States, where he was employed by a map company in New York City while working on his master's degree at Columbia, which he received in 1923. While studying for his Ph.D. in geology at Columbia, Raisz studied with Douglas Johnson, who had studied geomorphology with William Morris Davis at Harvard, and who had strong interests in the construction of block diagrams and the representation of landscapes. As an instructor at Columbia, Raisz offered the first cartography course there. Thus the seeds for Raisz's approach to landscape representation had been acquired from multiple disciplines, including civil engineering and geology.

Based on this work and the recommendation of his mentor Johnson, Raisz was recruited by Davis himself as a lecturer in cartography in the Institute of Geographical Exploration at Harvard, where, during the 1930s, he continued to publish and work on his techniques. In 1938, he published his first edition of the influential book, *General Cartography*, which was to remain the only general English textbook on cartography for fifteen years. This singular event indicates that, at that time, there was sufficient interest in academic cartography to warrant the publication of a specific book on the subject. The second edition of *General Cartography*, reprinted as an education manual (MB771) for the United States Armed Forces Institute, was published as part of the McGraw-Hill series in geography, which at the same time was publishing such seminal works as Finch and Trewartha's *Physical Elements of Geography*, Platt's *Latin America*, and Whitbeck and Finch's *Economic Geography*. Clearly, this major publisher was willing to "invest" in a major cartographic project. In the 1940s, the geography department at Harvard was

eliminated (Smith 1987), but Raisz remained in the Boston area, teaching at Clark University until 1961. In 1952 and 1953 he also was a visiting lecturer at the University of Virginia where he was a member of the Virginia Geographical Institute. In the early 1950s, he was influential in establishing the Association of American Geographers' Committee on Cartography for which he received the AAG Meritorious Service Award in 1955. Finally, Raisz taught at the University of Florida—he started in 1957—until his death in 1968. While at Florida, he was able to publish his second textbook, *Principles of Cartography*, in 1962, and the *Atlas of Florida*.

Raisz never held a regular academic appointment. Thus he was unable to produce a generation of students that would perpetuate his brand of cartography. It was really through his textbooks, his role with the AAG, and mostly through his maps that Raisz's influence was felt. He is best known for the production of his "landforms" maps of various parts of the world. His "Landform outline map of the United States" (1954), perhaps one of the best examples of academic cartography from the twentieth century, has become a standard reference in United States geography classes. Other Raisz landform maps include England (1948), Central America (1953), and the Greater Antilles (1953). He continued a tradition of landform mapping in the United States, and Robinson and Sale (1969) asserted that landform maps or physiographic diagrams, such as those created by William Morris Davis, Armin Lobeck, Guy-Harold Smith, and Raisz, were "One of the more distinctive contributions of American cartography" (Robinson and Sale 1969, p. 187).

Richard Edes Harrison

Richard Edes Harrison (Figure 1), born in Baltimore in 1901, was the son of Ross Granville Harrison—one of the most distinguished biologists of his time. Although Harrison graduated with a degree in architecture from Yale University in 1930, his interests quickly turned to scientific illustration, and he drew his first map for *Time* magazine in 1932. This initial exposure to mapping piqued his curiosity, and he soon became a free-lance cartographer for *Time* and *Fortune* magazines, and from 1936 to 1938 was on the staff of *Fortune*. During the 1940s and 1950s he was a map consultant to the Geographer of the State Department, to the Office of Strategic Services, to *Life* and *Fortune*, and to the Museum of Modern Art. He was also a Fellow of the American Geographical Society and the Royal Geographical Society (United Kingdom).

In the late 1940s Harrison would fly to Syracuse University once a week to teach the course in cartog-

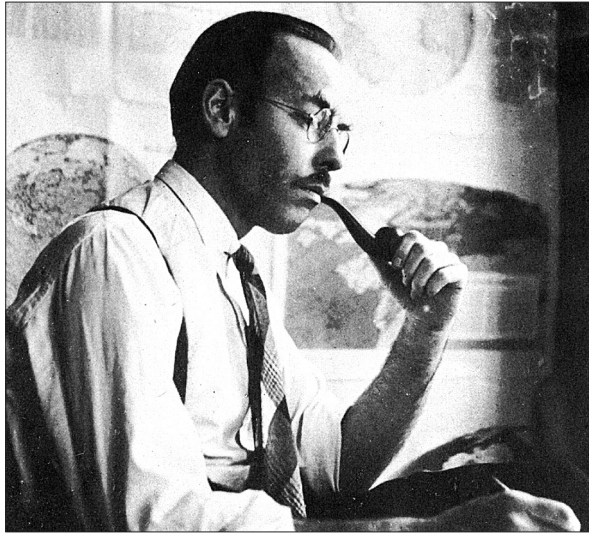


Figure 1. Richard Edes Harrison.

raphy—George Jenks was one of his students—and he also lectured at Clark, Trinity, and Columbia Universities. Although not formally an educator, Harrison nonetheless influenced the discipline of cartography through his specific technique and intrinsic cartographic abilities. He might also be considered one of the first “popular” cartographers in the United States for his work in media mapping.

There are few accounts of what exactly was taught by Harrison at Syracuse University. But both Mark Monmonier, in a personal interview with Harrison, and George Jenks, in a 1991 *Cartography and Geographic Information Systems* paper, provide glimpses into Harrison’s classes. Monmonier (1991, p. 205) writes that Harrison remembers Jenks well, and that he seemed more interested in the “nuts and bolts” of cartography than the artistic component that was a major focus of Harrison’s work. A sense of art must have been a critical part of Harrison’s lectures. In a 1991 paper, Jenks writes:

In one demonstration he discussed editorial sessions with the editors of *Fortune* magazine. The editors were interested in military movements in Africa, Europe, Japan, and East Asia, and as they talked, Harrison would sketch maps of these areas from memory. His memory of geographic features was phenomenal. His lectures on map projections led to various exercises we conducted between his visits to the campus. One exercise was the construction of an azimuthal equidistant projection centered on Syracuse, which took us a full semester to complete (Jenks 1991, p. 161).

In the early 1950s, Harrison completed a survey of twenty-four cartographers in the New York City

area to determine what their training had been. He found that virtually none had been trained in cartography, but had drifted into the discipline. He also observed that none of those interviewed had a background in geography. Harrison’s conclusions were quite emphatic about the state of American academic cartography. Since at this time he felt there was no true comprehensive training, he writes, “There remains only the necessity of stating the dismal fact that cartography, as a well rounded profession, does not exist in this country” (Harrison 1953, p. 15). It is clear that Harrison was extremely well connected in American geography. In his seminal work *Look at the World: The Fortune Atlas for World Strategy* (1944), he acknowledges the influence of Wallace W. Atwood, S. Whittemore Boggs, William Briesemeister, George B. Cressey, Richard Hartshorne, Lawrence Martin, O. M. Miller, Erwin Raisz, Arthur H. Robinson, John K. Wright, and others. Harrison was active in the professional cartographic community, assisting with the incipient Committee on Cartography of the Association of American Geographers, for which he was appointed as the first Map Supplement Editor of the *Annals of the Association of American Geographers*.

Period 2. Post World War II Graduate Education Centers of Excellence

Cartography in the 1950s: The Building of a Discipline

The period following World War II is associated with a great expansion of geography departments in many U.S. universities and colleges, especially Wisconsin, Kansas, and Washington, as well as a decline at others, such as Harvard, which dissolved its geography program in 1947 (Smith 1987). It was after the war that Erwin Raisz and other members of the AAG sought to establish a more permanent base for cartography within that organization. A seminal event in the evolution of American academic cartography—the first ever meeting of the Committee on Cartography—was organized by Erwin Raisz on April 6, 1950, at Clark University during the national meetings of the Association of American Geographers. Five speakers gave presentations at this meeting, including Erwin Raisz (an “Introduction”); Richard Edes Harrison (“Cartography in Art and Advertising”); Carl Mapes (“Cartography in Map Companies”); Clarence B. Odell (“Cartography and Cartographers in Commercial Map Companies”); and George Kish (“Teaching of Cartography in the United States and Canada”) published in a 1950 issue of the *Professional Geographer*. Raisz writes:

This is for us a historic event—our first official meeting as a distinct Committee in Cartography, and may the sapling become a strong tree with many branches and with rich and abundant fruit. It all started before the war, when we first discussed the necessity of a national organization. During the war the profession grew by leaps and bounds, but academic cartography was not quite prepared to lead the way. More and more geographers became interested in cartography and time was ripe for some consolidation of the profession (Raisz 1950, p. 9).

Perhaps one can point to this as one of the first philosophical discussions as to what cartography really was. Raisz felt that cartographers fell into two categories: “geographer cartographers,” who wish to express their ideas with graphs, charts, maps, globes, models, and birds’-eye views; and “carto-technicians,” who “help produce maps, models, and globes by doing the color-separation or cardboard cutting” (Raisz 1950, p.10). He proposes the idea of different types of cartographers, including the cartologist, cartosophist, toponymist, map compiler, map designer, draftsman, letterist, engravers, map printers, and cartothesarian [map librarian].

What we see during this decade is an attempt for cartography to position itself in relation to geography and other disciplines. Raisz attempts to delimit the geographic cartographer, to differentiate him/her from surveyors, and to describe the essence of the modern mapmaker. Unquestionably, at this point in the history of academic cartography, Raisz was a national and even an international leader. His two editions of *General Cartography* had been published, and he was in a position of organizing other professionals. Yet cartography at this moment can be seen as atheoretical, and mostly descriptive. The significant problems were associated with drafting media and production techniques. Most of the methods for symbolization, including the dot, graduated symbol, isarithmic, choropleth, and even dasymetric methods, were developed in Europe, in the nineteenth century or before. Fortunately, a series of academic cartographers with strong interests in more conceptual/theoretical issues emerged during the 1950s and led the way for basic research programs.

In the early 1950s, George Kish reported in the *Professional Geographer* on the first detailed survey designed to determine the status of academic cartography in America. The survey, distributed in 1950 by Erwin Raisz, requested responses to the following questions:

1. Is cartography taught as an independent course?
2. Are advanced degrees (M.A. or Ph.D.) in cartography given as a major or minor subject?

3. Names of cartography concentrators?
4. Is cartography taught as a part of other courses?
5. Is the institution interested in establishing a course in cartography?
6. Amazingly, ninety-four institutions in the United States and Canada returned questionnaires (along with Oxford University and the University of Sydney) (Kish 1950, p. 20).

This 1950 special issue of the *Professional Geographer* also provides us with a sense of current cartographic activity in the United States. Books reviewed included *An Introduction to Map Projections*, *Maps and Map-Makers*, *Modern Cartography*, and *Base Maps for World Needs*. News from Cartographic Centers detailed activity at Michigan State College, Yale University, Denoyer-Gepper Company, and Rand McNally. Perhaps most interesting, the current activities of several American cartographers are provided, from which we learn of the work of Edward Espenshade Jr., Richard Edes Harrison, G. Donald Hudson, Armin Lobeck, Allen K. Philbrick, Erwin Raisz, Arthur Robinson, and John K. Wright (News from Cartographic Centers, 1950). The status of cartographic education at the beginning of the 1950s was promising. From a sporadic set of institutions offering courses in cartography before World War II, the demand of the War had accelerated the development of cartographic curricula. What would occur during the 1950s was the emergence of three major programs at the Universities of Wisconsin, Kansas, and Washington, as well as other programs that enjoyed less influence.

University of Wisconsin

Arthur Robinson (Figure 2) traces the teaching of cartography at the University of Wisconsin—Madison back to 1937, with Verner Finch being a strong influence. Cartography at Wisconsin in 1937, Robinson writes:

...consisted of a one-semester course covering map projections mostly and some statistical mapping. This is comparable, I assume, to the few courses taught elsewhere. As far as I am aware, no institution offered instruction in the handling, analysis, and evaluation of topographic and other map materials, which was an important aspect of cartography called “map information” and “map intelligence” during World War II (Robinson 1991, p. 156).

In a 1979 paper on the influence of World War II on cartography, Robinson comments on these early years:

In the development of cartography in American academic geography, probably the most notable event prior to World War II was the publication of Erwin Raisz’s *General*

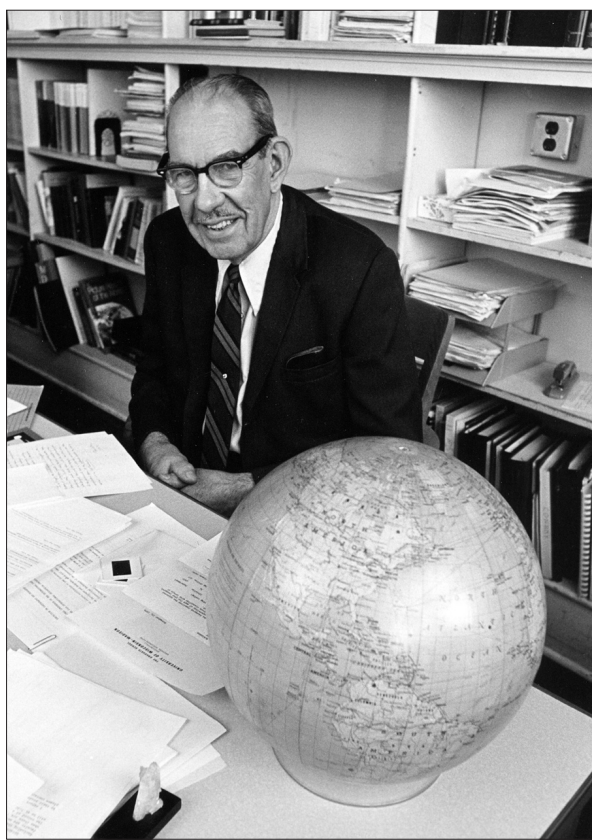


Figure 2. Arthur Robinson.

Cartography in 1938. By the mid-1930s the majority of graduate students in geography (probably few if any undergraduates) took one course in cartography. Mine, at Wisconsin, came before Raisz's book appeared and our "textbooks" were Deetz and Adams's *Elements of Map Projections* and Lobeck's *Block Diagrams*. Besides constructing map projections and making crude dot maps, isopleth maps, and pie chart maps, we were taught how to tint glass lantern slides with Japanese water colors. When I transferred to Ohio State University for doctoral work, I was not allowed to take the cartography course because I already had one! Raisz's pioneering book provided a small beginning for an academic program in cartography, but nothing really got started before World War II began (Robinson 1979, p. 97).

In a turn of events, Richard Hartshorne, on leave from the University of Minnesota in 1941, established the Geography Division in the branch of Research and Analysis of the Office of Strategic Services (OSS) and attracted Robinson, then a graduate student at The Ohio State University, to join him. Robinson (1991) noted that an independent map division was created within the OSS that worked closely with geographers, historians, economists, and regional specialists, and

grew to a staff of 100—with at least 50 professional cartographers. Upon his return to academic life and appointment at the University of Wisconsin in 1945, and in part based on his experience in the OSS, Hartshorne decided to develop a cartography program through a new faculty position. This position included the responsibility of establishing a cartography and map use instructional/curricular program that at the outset included two basic cartography courses (i.e., introductory and intermediate cartography), as well as an aerial photo interpretation course. Robinson was hired in 1945 after concluding his position as Chief of the Map Division of the Office of Strategic Services, and he completed his Ph.D. in 1947 at The Ohio State University, under the direction of Guy-Harold Smith and Roderick Peattie. Later, other courses were added, including Seminar in Cartography, Cartographic Production, and Use and Evaluation of Maps. These were followed by another series of courses in Map Projections and Coordinate Systems, Problems in Cartography, Computer Cartography, History of Map Making, and Cartographic Design. In the mid-1960s, the staff in cartography was increased when Randall Sale became associate director of the University of Wisconsin Cartographic Laboratory and, eventually, rose through the ranks to Professor.

Arthur Robinson established himself as the unofficial "Dean" of American academic cartographers, building the program in cartography at the University of Wisconsin into the very best in the United States during the 1970s and early 1980s. His seminal volume, *The Look of Maps*, based on his doctoral dissertation at The Ohio State University, was the seed for three decades of cartographic research. He established the first American journal in cartography, *The American Cartographer*, in 1974. His six editions of *Elements of Cartography* and his presidency of the International Cartographic Association attest to his leadership. Robinson also had strong research interests in map projections, map perception, the history and philosophy of cartography, and cartographic symbolization. It was the Robinson projection, for instance, that was adopted as the world projection of choice by the National Geographic Society. Robinson's 1976 book with Barbara Petchenik, *The Nature of Maps*, delved deeply into the fundamental principles of cartographic communication. Robinson also influenced several generations of students who ventured off and established graduate programs in cartography. Robinson and Sale guided the cartography program at Madison until 1968, when Joel Morrison, a Robinson Ph.D., began teaching, and Philip Muehrcke joined them in 1973 (when Robinson reduced his appointment to 60 percent). After com-

pleting his Ph.D. degree under Robinson, Morrison had spent several semesters teaching at UCLA and Michigan, while Muehrcke, a Waldo Tobler Ph.D. from the University of Michigan, had worked for several years with John Sherman building the program at the University of Washington. Both brought strong mathematical expertise to the program. Thus in the mid-1970s, when many geography departments struggled to maintain a cartography program with a single faculty member, Wisconsin had four. By that time, separate B.S. and M.S. degrees in cartography existed, and Wisconsin had the very best cartography laboratory (within a geography department), as well as a campus laden with faculty talent in the mapping sciences, including positions in surveying, photogrammetry, and remotes sensing. It was a cartographic *tour de force*.

Wisconsin is recognized as one of only a few institutions to have separate cartography degree programs at the bachelor's and master's level. This was the first time, as Robinson points out, that a major geography department in a large state university offered baccalaureate and master's diplomas in the discipline of cartography (Robinson 1979). Although the program initially offered both the B.A./B.S. and M.A./M.S. degrees, the B.A. was dropped in 1983. All students were required to take calculus, remote sensing/photogrammetry, and breadth courses in geography (Muehrcke 1991). The graduate degree (M.A./M.S.) in cartography, also established in 1972, grew to between 30 and 40 students before a non-thesis option was added in 1977 (Muehrcke 1991). Muehrcke notes that, because of both the B.A. and non-thesis options, tensions developed between the cartography and geography faculty as the number of non-thesis students increased. To ameliorate this problem, the non-thesis option was dropped in 1983, and the M.A. option in 1984. After preliminary discussions, the faculty in cartography decided not to offer the Ph.D. in cartography.

Overall, the cartography program at Wisconsin has produced several hundred students with master's degrees in cartography and well over twenty students with doctoral degrees in geography, but specializing in cartography. The first master's degree with a cartography emphasis was awarded in 1949 and the first doctoral degree in 1956 (James Flannery with his graduated circle dissertation). Other Ph.D.s from Wisconsin included Norman J.W. Thrower (UCLA), Richard Dahlberg (UCLA, Syracuse University, and Northern Illinois University), Henry Castner (Queens University), Mei-Ling Hsu (University of Minnesota), George McCleary (Clark University and the University of Kansas), David Woodward (Newberry Library and Wisconsin), Barbara Bartz Petchenik (R.R. Donnelley),

Joel Morrison (Wisconsin, USGS, the Bureau of the Census, and the Center for Mapping at Ohio State University), Judy Olson (Boston University and the Michigan State University), A.Jon Kimerling (Oregon State University), and Karen Severud (Pearson) Cook (Alaska Geological Survey, British Library, University of Kansas Spencer Library).

An important factor in the development of cartographic instruction at Wisconsin was associated with the awarding of several National Defense Education Act Fellowships in the 1960s to support graduate work in cartography. Each fellowship, which included a generous three-year stipend and a grant to support the development of the cartography instructional program, attracted some of the very best graduate students who, upon completing their Ph.D.s, created their own undergraduate and graduate programs in cartography.

With the retirement of Robinson in 1979, David Woodward, a former Robinson student who specialized in the history of cartography and map design, was hired in 1980. Sale retired in 1981, and Morrison left in 1983 for the United States Geological Survey. In the early 1980s, James Burt, a climatologist out of UCLA who specialized in computer graphics, and Barbara Battenfield, a John Sherman Ph.D. out of Washington, were hired. Battenfield left in 1987 for SUNY Buffalo, and Lynn Usery replaced her in 1988 until he left for the University of Georgia in 1994, to be replaced by Axing Zhu in 1995. Phillip Muehrcke, who had held an NDEA Fellowship at Michigan, and the last of the four core cartographers at Wisconsin—Robinson, Sale, Morrison, and Muehrcke—retired in 1998, and his introductory courses were taught by Hong Jiang. Woodward retired in 2002, to be replaced by Mark Harrower.

University of Kansas

The cartography program at the University of Kansas was started, and nurtured for over 35 years, by George Jenks (Figure 3). Jenks, who had received his Ph.D. in agricultural geography at Syracuse University, had also studied with Richard Edes Harrison, the cartographer for *Time* and *Fortune* magazines, at Syracuse. As Jenks discussed in his 1991 paper, "I attended Harrison's courses in cartography during 1946 and 1947. They were a mixture of lectures, demonstrations, drafting, and hand lettering. In the spring of 1946 there were five of us in his class, but attendance grew rapidly the following years. While his courses were interesting, I recall his demonstrations with fondness" (Jenks 1991, p.162). After a single year at the University of Arkansas, Jenks arrived in 1949 at a small, but talent-laden, department at Kansas

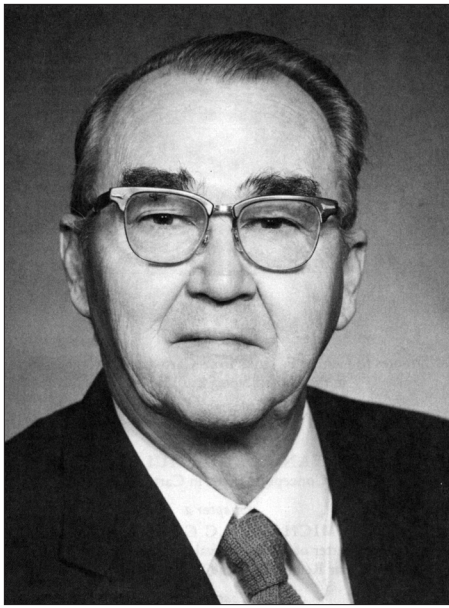


Figure 3. George Jenks.

and started building the cartography program. A significant event in Jenks's career, and for the program itself, was an award from the Fund for the Advancement of Science that allowed him to visit in 1951-1952 all major mapmaking establishments of the federal government, as well as a number of quasi-public laboratories. Since the objective of Jenks's study was to determine what subject matter should be included in a cartographic curriculum, a critical part of his study was the interview of eighty-eight individuals. The project was designed to answer a series of questions, including:

1. What are the major deficiencies in present-day cartographic training?
2. What should be the objectives of cartographic training?
3. Where does cartography best fit into the college curriculum?
4. What subject matter should be included in a program of cartographic training?

The information collected during this grant year was incorporated into an *Annals of the Association of American Geographers* paper entitled "An Improved Curriculum for Cartographic Training at the College and University Level," and was adopted in the cartography program at Kansas. This represents a second seminal event in the development of academic cartography from the early 1950s.

Jenks's project had identified a series of key problems for cartographers, including: 1) mass production techniques had to be improved; 2) new inks, papers, and other materials were needed; and 3) additional personnel had to be trained (Jenks 1953). He writes:

Increased demand for mapmakers has induced many American colleges and universities to add cartography courses to their curricula. Prior to World War II very few courses in cartography were offered in the United States, but now well over one hundred institutions of higher learning offer training in the subject. Unfortunately, increasing the number of courses does not solve the problem of poorly trained mapmakers. That cartographic instructors are cognizant of the need for improved cartographic training in mapmaking is evidenced by numerous articles in recent issues of professional journals and by the repeated attention this problem receives at national meetings (Jenks 1953, p. 317).

Jenks pointed out that, at the time, several factors served to impede cartographic training; the use of inexperienced instructors, poorly equipped cartographic facilities and map libraries, limited research and limited access to research, and too much emphasis on theory (Jenks 1953). It is interesting that Jenks, who spent much of his research career building cartographic theory in design, symbolization, and classification, would make such an argument. But he writes, "...too little time and effort has been spent on the practical application of theory. Theorizing on art does not make an artist, knowledge of medical theory does not make a qualified doctor, and talking about maps (and listening to lectures on cartography) does not mean that the student can execute a map" (Jenks 1953, p. 319).

Jenks's project led him to identify four key objectives of cartographic training:

1. Cartographic training should stress the fundamental principles of the field as a whole.
2. Cartographic training must include numerous opportunities for applying theory to actual map problems.
3. Cartographic training should encompass a wide range of general and technical courses in allied fields.
4. Cartographic training should be available to students in many disciplines and with varying degrees of intensity.

The results of the question, "What subject matter should be included in a college cartographic training program," are tabulated in his *Professional Geographer* paper, where Jenks proposed a five-course core sequence in cartography (see p. 314, top left).

The importance of this landmark study cannot be overemphasized. Cartography had emerged from World War II as a true discipline, in part due to the great demand for war-effort maps and mapping. Both those who had been practicing before the war, such as Arthur Robinson and Erwin Raisz,

- | | |
|-----------|--|
| Course 1: | Elementary training in projections, grids, scales, lettering, symbolization, and simple map drafting |
| Course 2: | The use, availability, and evaluation of maps |
| Course 3: | Planning, compiling, and constructing small-scale maps, primary subject matter maps |
| Course 4: | Planning, compiling, and constructing large-scale maps, primarily topographic maps |
| Course 5: | Non-technical training in the preparation of simple manuscript maps for persons wishing the minimum in the manipulative aspects of cartography |

and those who emerged after, such as George Jenks and John Sherman, realized that comprehensive cartographic curricula could be maintained within geography departments. Jenks's study, in parallel with the previously described efforts by Erwin Raisz and the Association of American Geographers, provided the intellectual infrastructure for those attempting to build cartography as a discipline in universities. During the 1950s, Jenks also discovered arguments for separate departments of cartography. George Harding felt that cartography would need to leave Civil Engineering and establish its own home (Harding 1951). Wilbur Zelinski (Pennsylvania State University) argued for a school of cartography (Cartographic Panel 1950). However, most proponents realized the impracticality—both politically and financially—of creating a separate department of cartography.

Another significant influence on Jenks's early career was his relationship with John Sherman of the University of Washington. In the summer of 1956, Sherman came to Kansas to teach, and later Jenks was in residence at Seattle. An important event during the 1960s was the establishment of the National Science Foundation-funded Summer Institutes for College Teachers. These summer institutes in cartography, organized under the direction of Sherman and Jenks, were offered first in Seattle in 1963. An advanced institute was offered in 1966. These two institutes—each nine weeks in length—were designed to educate college professors in the modern techniques of cartography. Jenks writes, "We were surprised to find that a number of professors had been assigned arbitrarily by their deans or chairmen to teach mapmaking that fall. Moreover, several were going to have to teach without a laboratory, equipment, or supplies. These activities greatly enhanced my teaching and were the basis for numerous changes in our curriculum" (Jenks 1963, p. 163).

Despite faculty at Kansas with interests closely related to cartography—in particular, statistics and remote sensing—Jenks was still the only cartographer on staff at the end of the 1960s. Robert Aangeenbrug, with strong interests in computer and urban cartography,

joined the Kansas faculty in the 1960s and was later twice director of the International Symposium on Computer-Assisted Cartography (Auto-Carto) conferences. Thomas Smith, who had arrived in the department as its second hire in 1947, established coursework in the history of cartography during the 1970s and 1980s.

The Kansas program experienced rapid growth in the 1970s. As explained by Jenks, "George McCleary joined the staff, and with his help we renovated and broadened the offerings in cartography. More emphasis was placed on map design and map production, and new courses at the freshman and sophomore levels were added. Greater numbers of students with undergraduate training in other departments enrolled in our M.A. and Ph.D. programs in cartography" (Jenks 1991, p. 164). During this period, Jenks initiated research projects on three-dimensional maps, eye-movement research, thematic map communication, and geostatistics. By the end of the 1970s, Jenks had turned his attention to cartographic line generalization. Also during this period, he supervised 10 Ph.D.s, 15 M.A. candidates, and four postdoctoral cartographers. Many of these individuals accepted academic appointments and continued the "Jenks school" including Richard Wright (San Diego State University), Paul Crawford (Bowling Green), Michael Dobson (SUNY Albany and Rand McNally), Ted Steinke and Patricia Gilmartin (University of South Carolina), Carl Youngmann (University of Washington), Jean-Claude Muller (University of Alberta, the International Training Center [ITC] in Enschede, The Netherlands, and the University of Bochum), Barbara Shortridge (University of Kansas), Terry Slocum (University of Kansas), Joseph Poracsky (Portland State University), and Robert McMaster (UCLA, Syracuse, and the University of Minnesota). Jenks continued to teach and be engaged in research until his retirement at Kansas in 1986. Terry Slocum, one of Jenks's Ph.D.s who joined the faculty in 1982, remains on the faculty along with George McCleary.

Jenks continued to teach and complete research projects even after his formal retirement in 1986. In fact, in a 1987 Festschrift for Jenks—published as a special issue of the journal *Cartographica*—he revisited his 1953 curriculum. Based on three tenets upon which a revised curriculum should stand—cartographers should be trained in geography departments; freshman-sophomore coursework in geography should be broad-based; and technical training should not be allowed to dominate (Jenks 1987)—provided detailed outlines for four modern cartography courses (Jenks 1991):

Course Number 1:	Map Use and Appreciation
Course Number 2:	Visualization and Planning of Thematic Maps
Course Number 3:	Map Symbolization and Compilation
Course Number 4:	Map Composition

These four courses—really sub-areas of cartography—illustrate those core topics that Jenks felt should be emphasized. His use of the term “visualization,” many years before its common usage in the discipline, indicates he was thinking more broadly about the meaning of maps as a visual media. Thus there is one major thread throughout Jenks’s career: cartographers should have a broad base of geographic education as well as a clear understanding of cartographic communication. Most of his major research projects, including the data model concept, eye-movement studies, research into statistical mapping, and automated generalization, were based on this principle. Although Jenks never synthesized his work into a text, his influence was felt both through his careful seminal research papers, and through his graduate students. As with the University of Wisconsin school of cartography, Jenks’s students (the Jenks School) continued to have a profound effect on academic cartography.

University of Washington

Although the first formally identified “cartography” course at the University of Washington was offered by William Pierson in the geography department during the 1937-1938 academic year, it was John C. Sherman (Figure 4) who is the person primarily associated with developing the cartography program at the University of Washington, Seattle. Sherman received his B.A. degree from the University of Michigan in 1937, his M.A. from Clark University in 1944, and his Ph.D. from Washington in 1947. Unlike both Jenks and Robinson, who had received formal training in cartography, Sherman had never had coursework in this field.

When Donald Hudson came to the University of Washington from Chicago in 1951, he implemented a new program for the department with concentrations that included Anglo-America, the Far East, economic geography, and cartography. He asked Sherman, who was appointed to the faculty at Washington in 1950, to lead the new cartography concentration, and he also invited Henry Leppard, recently retired from Chicago, to join the department (Velikonja 2002). Leppard, who had studied under J. Paul Goode at the University of Chicago, had remained at Chicago after Goode’s death. By 1953, six cartography courses were in place, including

Maps and Map Reading, Introductory Cartography, Intermediate Cartography, Techniques in the Social Sciences, Map Reproduction, and Map Intelligence. In 1954, Leppard left for UCLA (soon to be joined there by Dahlberg and Thrower) and in 1958, Willis Heath, having completed his Ph.D. in the department, joined Sherman in conducting the cartography program (Sherman 1991, p. 169).

One seminal event in the early history of the program was Heath and Sherman’s participation in the Rand McNally-sponsored Second International Cartographic Conference at Northwestern University, held in June 1958. According to Sherman (1991, p. 169), a group of some 50 international cartographers were able to discuss “the graphic philosophy, functional analysis, and technological developments that were then influencing the field.” Based on discussions at the conference, changes and additions were made to the cartography program at Washington. Another event that influenced Sherman and the program in cartography at Washington was the first Summer Institute for College Teachers in Cartography. The goal of the Institute, held in Seattle in 1963 and again in 1966 under the direction of Jenks and Sherman, was to prepare young geography professors who had little or no training in the subject to teach cartography. Later, in 1968, Sherman developed a proposal to establish a National Institute of Cartography, which had been requested by the National Academy of Sciences/National Research Council (NAS/NRC) Committee on Geography. A panel of prestigious cartographers, including Arch Gerlach, Norman Thrower, Richard Dahlberg, Waldo Tobler, George McCleary, George Jenks, and Arthur Robinson, assisted Sherman. Unfortunately for the discipline of cartography, the proposed institute was never created. One can hardly help noticing, however, the similarity of the concept to the National Center for Geographic Information and Analysis (NCGIA) established two decades later.

A review of the University of Washington *Bulletins* shows the development of the cartography program during the building years of the 1950s. During the period 1953 to 1955 seven cartography (and cartography-related) courses were offered (Table 3).

In the next issue of the *Bulletin* (1957 to 1959), several new courses had been added to the geographic techniques section, one had changed its number (358 to 258), one had changed its name (Advanced Cartography to Map Compilation and Design), and Willis Heath had succeeded Leppard. Further adjustments to the course offerings can be found in the 1959-1961 *Bulletin*. Oddly, no reference is made to the Maps and Map Reading course, which was probably a foundation course in the department.

Introductory Cartography was changed to Principles of Cartography, a new course entitled Experimental Cartography was added, the words “Problems in” was added to Map Compilation and Map Reproduction, and finally a Research Seminar was added.

Thus, at a time when cartography was still emerging as a true academic field, one of America’s premier cartography programs was “self adjusting” itself in order to maintain currency. The program put together by Sherman and Heath had a strong emphasis on both design and production. Personal correspondence with Carlos Hagen (a graduate student at Washington during this period) supports this. Hagen writes, “One thing that particularly impressed me at that time was the importance that John Sherman and Bill Heath gave to a sort of sacred trilogy, ‘Drafting-Printing-Reproduction.’ In the Latin American and European traditions, these production techniques are certainly not considered part of the academic environment. They are very respected and much appreciated, but generally you will find them not in academia, but in the realm of a very professional and dedicated tradition of craftsmanship” (Hagen, personal communication, 1987). He continues, “When I look back, I feel the program of cartography at the University of Washington, with that heavy emphasis on production techniques, could stand rather unchallenged because, after all, that was the trend of the times.” Hagen later went to UCLA where, within the library, he initiated the Map Information Center.

Although Sherman’s main research interests were in communication/map design and tactile mapping, many of his doctoral students pursued dissertation topics related to analytical and computer cartography. Sherman writes, “I cannot isolate and identify any one question that was the trigger for my concern for design. If we step back for a moment, our course on methods of map production was developed not in any sense to train technicians, but to familiarize students with the principles of reproduction techniques, from black and white to multicolor, sufficiently to enable them to translate this knowledge into greater freedom in map design” (Sherman, personal communication 1987). Sherman’s doctoral students included Waldo Tobler (University of Michigan and University of California, Santa Barbara), Richard Taketa (University of Michigan), Everett Wingert (University of Hawaii), Jois Child (SUNY Buffalo and Eastern Washington), and Barbara Battenfield (University of California, Santa Barbara, Wisconsin, SUNY Buffalo, and Colorado). Many others went into government and industry.

In more recent times Washington has seen a series of cartographers join and leave the department. Phillip Muehrcke, a student of Waldo Tobler’s at the University of Michigan, joined the faculty in



Figure 4. John Sherman discussing lunar modeling with a group of students.

1969 but left the department for the University of Wisconsin in 1972. While at Washington, however, “he offered our first course in computer cartography, expanded the seminar offerings, and amplified our interdisciplinary activities with computer scientists on campus and cartography-oriented computer users in state government agencies in Olympia” (Sherman 1991, p. 169). Heath became ill in the early 1970s and was replaced by Carl Youngmann, a Jenks-educated University of Kansas Ph.D. Youngmann stayed at Washington for ten years, and, after his resignation in 1983, was replaced in 1985 by Timothy Nyerges, an Ohio State Ph.D. who had studied with Harold Moellering. In 1987, Nyerges was joined by Nicholas Chrisman, who had spent many years at the Harvard Laboratory for Spatial Analysis and Computer Graphics and had received a Ph.D. from the University of Bristol in the United Kingdom.

Period 3. Diffusion of Cartographic Programs in Geography Departments

Thus during the 1970s and 1980s, a series of what might be called secondary programs, many established by Ph.D.s from Wisconsin, Kansas, and Washington, were created in the United States. Although not exhaustive, one can point to programs at UCLA with Norman J.W. Thrower (a Wisconsin Ph.D.); Michigan with Waldo Tobler (a Washington Ph.D.); South Carolina with Ted Steinke and Patricia Gilmartin (Kansas Ph.Ds); SUNY Buffalo with Kurt Brassel (a Zurich Ph.D.) and Duane Marble (a Washington Ph.D.); Michigan State with Richard Groop (a Kansas Ph.D.) and Judy Olson (a Wisconsin Ph.D.); Northern Illinois University with Richard Dahlberg (a Wisconsin

Geographic Techniques		
358	Maps and Map Reading	Leppard, Sherman
360	Introductory Cartography	Leppard, Sherman
363	Aerial Photographic Interpretation	Marts
425J	Graphic Techniques in the Social Sciences	Schmid
461	Intermediate Cartography	Leppard, Sherman
462	Advanced Cartography	Leppard, Sherman
464	Map Reproduction	Sherman

Table 3. Cartography courses offered at the University of Washington in 1953.

Ph.D.); Oregon State University with A. Jon Kimerling (a Wisconsin Ph.D.); Syracuse with Mark Monmonier (a Penn State Ph.D.); Penn State University with Alan MacEachren (a Kansas Ph.D.); and Ohio State with Harold Moellering (a Michigan Ph.D.). Although not possible in this short paper, one can point to several key activities in these departments, including Tobler's development of analytical cartography, Thrower's expertise in animated cartography, the history of cartography and remote sensing, Moellering's animated cartography and emphasis on a numerical cartography, Monmonier's statistical mapping, and Olson's work in cognitive research. Each of the institutions developed its own area of expertise where, unlike the earlier days when students would pursue a general graduate program in cartography, individual graduate programs were identified for their particular research specialty such as cognitive or analytical cartography.

Period 4. The Transition Period

The intellectual landscape of cartography has changed significantly over the past ten years, in large part owing to the rapid growth of geographic information science and systems. Fifteen years ago, the prognosis for a Ph.D. in cartography acquiring an academic position was excellent; today's job market seeks out the geographic information scientist. One can certainly still study cartography at most major institutions, but the number of courses has decreased as the number of GIS-related courses has increased. Additionally, the term geographic visualization, increasingly used by many departments instead of cartography, has caused a further erosion of the professional base of cartography. However, one hope for the discipline is that as GISs become almost ubiquitous in our society, there seems to be the realization that a deeper knowledge of maps, cartography, and map symbolization and design is still a crucial skill. Kraak and Ormeling (1996) in their textbook, *Cartography: Visualization of Spatial Data*, make the

following point with respect to the relationship between GIS and cartography:

Many of the concepts and functions of GIS were first conceived by cartographers. This is not only valid for the GIS output module, but for many of the processing actions (e.g., transformations, analyses) and input functions (e.g., digitizing, scanning) of a GIS as well. There are conflicting views regarding the relations between cartography and GIS, viz. whether GIS is a technical-analytical subset of cartography, or whether cartography is just a data visualization subset of GIS. For the purpose of this book, also written for GIS analysts who have to learn to use the cartographic method, cartography will be regarded as an essential support for nearly all aspects of handling geographical information (Kraak and Ormeling 1996, p. 16).

Major changes occurred in the way cartography was taught in American universities during the 1990s. A survey of six different universities with a focus on cartography and GIS education confirms the nature of these changes in U.S. cartographic education in general. Some of the most significant changes include: (1) a closer integration with education in GIS; (2) the nearly complete transition to digital methods; (3) a lesser emphasis on procedural programming (such as Fortran and Pascal), and greater emphasis on object-oriented, user interface, and windows programming; and (4) a greater emphasis on the dynamic aspects of cartography, including animation and multimedia.

Women in Academic Cartography

Like geography itself, the discipline of cartography was dominated by men, especially during the first half of the twentieth century. However, one can point to the significant and increasing importance of women in the discipline, starting in the 1960s and rapidly increasing. Many of the key women in cartography received their graduate education at the three centers detailed above. These included Mei-Ling Hsu, Barbara Petchenik, and Judy Olson, all Arthur Robinson students at the University of Wisconsin; Barbara Shortridge and Patricia Gilmartin, George Jenks students at the University of Kansas; and Barbara Battenfield, a John Sherman student at Washington.

Other prominent women in the discipline included Judy Tyner and Patricia Caldwell, both Norman Thrower Ph.D.s from UCLA; Nina Lam, a Michael Goodchild Ph.D. at the University of Western Ontario; and Kate Beard and Gail Langran, both Nick Chrisman Ph.D.s (from Wisconsin and

Washington, respectively). Many others received M.A. degrees in cartography. Although it is not possible to be comprehensive in this paper, a few accomplishments will be noted. Mei-Ling Hsu in the early 1960s became the first woman to receive a Ph.D. with a cartographic dissertation and spent her entire professional career at the University of Minnesota. Barbara Bartz Petchenik, who completed her Ph.D. with Arthur Robinson in the late 1960s, co-authored one of the most influential cartographic books of the century, *The Nature of Maps*. She also was the first American woman Vice President in the International Cartographic Association. Judy Olson, also a Robinson Ph.D., spent her academic career at the University of Georgia, Boston University, and Michigan State. She also served as a U.S. Vice President to the ICA and President of the Association of American Geographers.

Women were particularly significant in research associated with the experimental paradigm, including Olson's (1981) research on design and symbolization (in particular on spectrally encoded bivariate maps), Gilmartin's (1981) research on graduated circles, Caldwell's (1981) research on television maps, and Robinson and Petchenik's (1976) insightful philosophical approach to understanding maps. A younger generation of women influential in academic cartography includes Cynthia Brewer, an Olson Ph.D. currently at the Pennsylvania State University; Irina Vasiliev, a Mark Monmonier student currently at SUNY College at Geneseo; and Sona Andrews, currently at the University of Wisconsin—Milwaukee.

The Paradigms of American Cartography

In the post World War II period, as academically oriented graduate programs emerged, basic research in cartography accelerated. Although many research paradigms could be documented, some of the more substantial efforts were in communication models, a theory of symbolization and design, cartographic design, experimental cartography, analytical cartography, and the recent series of debates in critical and social cartography. Table 4 provides some of the key research activities associated with these paradigms, each of which has a unique and complex history, dissemination, and set of outcomes. The final section of the paper focuses on the evolution of just one paradigm, analytical cartography.

Analytical Cartography

If any one paradigm within cartography has an "intellectual leader," it is analytical cartography.

The experimental cartography paradigm	
➤	Psychophysical research
➤	Eye-movement studies
➤	Cognitive approaches
The cartographic symbolization paradigm	
➤	The relationship between measurement scales and visual variables
➤	Formal models of data/symbolization
➤	4-dimensional approaches
The cartographic design paradigm	
➤	The establishment of a graphical hierarchy and figure-ground
➤	Conceptual frameworks for color use
➤	Knowledge of the visual elements
The analytical cartography paradigm	
➤	Geographic data models
➤	Terrain modeling
➤	Spatial interpolation
➤	Automated generalization
The postmodern/critical paradigm	
➤	Ethical considerations in mapping
➤	The power of cartographies
➤	Cartography as a form of state control

Table 4. Paradigms of American cartography.

Waldo Tobler (Figure 5) originated (in the 1960s) and nurtured (in the 1970s and 1980s) the idea of mathematical, transformational, or analytical approach to the subject. Tobler laid out the agenda for an analytical cartography in his seminal 1976 paper, "Analytical Cartography," published in the *American Cartographer*. This paper, and Tobler's ideas, had a profound effect on American academic cartography.

What exactly is an "analytical cartography"? Kimerling, in his 1989 *Geography in America* review of cartography, describes it as "the mathematical concepts and methods underlying cartography, and their application in map production and the solution of geographic problems" (Kimerling 1989, p. 697), which includes the topics of cartographic data models, digital cartographic data collection methods and standards, coordinate transformations, and map projections, geographic data interpolation, analytical generalization, and numerical map analysis and interpretation. Tobler's original syllabus describes a series of topics steeped in theory and mathematics. His goal for the course is futuristic:



Figure 5. Waldo Tobler.

What is easy, convenient, or difficult depends on the technology, circumstances, and problem. The teaching of cartography must reflect this dynamism, and the student can only remain flexible if he has command of a theoretical structure as well as specific implementation. The spirit of Analytical Cartography is to try to capture this theory, in anticipation of the many technological innovations which can be expected in the future; wrist watch latitude/longitude indicators, for example, and pocket calculators with maps displayed by colored light emitting diodes, do not seem impossible. In a university environment one should not spend too much time in describing how things are done today (Tobler 1976, p. 29).

Tobler had finished his Ph.D. degree in 1961 at the University of Washington under John Sherman, with a doctoral dissertation entitled, "Map Transformations of Geographic Space." While at Washington, Tobler was influenced by not only the strong quantitative emphasis among the faculty (Garrison, for instance), but also the large number of graduate students interested in mathematical geography, including Duane Marble, Arthur Getis, Brian Berry, and John Nystuen, among others. In the early 1960s, the Department of Geography at Washington was the headquarters of quantitative revolution in geography. Many of the students had enrolled in J. Ross MacKay's Statistical Cartography seminar, taught in the late 1950s. In a personal interview, Tobler (2001) also discussed the influence of Carlos Hagen, a graduate student at Washington who arrived from Chile in the late 1950s hoping to pursue graduate work in mathematical cartography. Tobler himself actually had little training in formal mathematics, but was self-taught, and

was intrigued by Hagen's work in projections. In addition to the strong influence of the faculty and graduate students at Washington, Tobler also gained experience working at RAND Corporation in Santa Monica, California, where he produced some of the first computer-generated maps that were exhibited at the Association of American Geographers annual meeting in that city, in 1958.

After completing his dissertation at Washington, Tobler joined the faculty at the University of Michigan, where his graduate student colleague from Washington, John Nystuen, had also moved. It is at Michigan that Tobler honed his ideas on analytical cartography, in part assisted by a relatively obscure event in American geography: the meetings of the Michigan IntraUniversity Community of Mathematical Geographers (MICMOG). Many of the topics presented at these Brighton-based (near Detroit) meetings were strongly cartographic in nature, including Gould's "Mental Maps," Perkal's "Epsilon Filtering," and Tobler's own work on generalization. His work, which had a significant influence on both the disciplines of cartography and geography, led to his election to the prestigious National Academy of Sciences, the only geographic cartographer to hold that honor.

What emerged from the concept of analytical cartography was a cadre of individuals working on problems that can be identified as analytical/computational-digital/mathematical in nature. Some were Tobler's own Ph.D. students or those who worked very closely with him, such as Stephen Guptill (United States Geological Survey), Harold Moellering (Ohio State University), and Phillip Muehrcke (University of Washington and University of Wisconsin). Others were immersed in the paradigm, without necessarily having formal education in it, such as Mark Monmonier, the author of the first textbook on computer cartography, Carl Youngmann (a Jenks-educated cartographer at Kansas who joined Sherman at Washington), and Jean-Claude Muller (another Jenks student who worked at the Universities of Georgia and Alberta, the International Training Center (ITC) in the Netherlands, and the University of Bochum in Germany). Additionally, a large group of individuals educated in the late 1970s through the early 1980s considered themselves computer or analytical cartographers, including Terry Slocum (Ph.D., University of Kansas), Keith Clarke (Ph.D., University of Michigan), Nicholas Chrisman (Ph.D., Bristol), Timothy Nyerges (Ph.D., Ohio State University), Marc Armstrong (Ph.D., University of Illinois), Barbara Buttenfield (Ph.D., University of Washington), and Robert McMaster (Ph.D., University of Kansas).

A strong argument can be made that the principles of numerical/analytical/digital cartography became the core of modern GISs. For instance, many of the basic ideas in analytical and computer cartography developed at the Harvard Laboratory for Spatial Analysis and Computer Graphics, including the concept of topological data structures, were directly translated into modern GISs, such as Environmental System Research Institute's ArcInfo software suite."

Summary

Dividing a history into categories is problematic and subjective. However, we feel that several logical periods may be identified in the history of United States academic cartography. One clear watershed is World War II. From a rather sporadic set of institutions offering one or, at most, two courses in cartography, the post-World War II era witnessed the creation of well established centers of excellence. Cartography before World War II was considered a relatively minor part of geography, with a small number of individuals focusing on the topic. Formal instruction in topographic mapping was rare, although certain institutions did develop some expertise in surveying, and Ohio State University established the program in geodetic science. The establishment of certain programs was only possible because of the interest of key individuals, such as Arthur Robinson, George Jenks, and John Sherman. A second line may be found when, upon maturation of these graduate programs, the centers began sending out Ph.D.s educated in cartography to establish other programs—a second generation of centers with intellectual children from the initial set. Finally, the discipline has witnessed significant changes in the late 1980s and early 1990s, as cartography has increasingly become a component—often a smaller component—of expanding programs in geographic information science.

Cartography in the United States saw the evolution of significant research paradigms during the latter half of the twentieth century. Three of these paradigms included: the development of an experimental cartography—based on principles and research designs from psychology; analytical cartography—which was influenced by the quantitative revolution in geography and the development of computer science; and a concern with "critical" cartography—rising from postmodern epistemologies and debates as applied to maps. However, other key research areas might be identified, including the paradigm of map symbolization and design, communication theory, and the history of cartography.

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