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The Evolution of Cartography in the Digital Age: From Digitizing Vertices to Intelligent Maps

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Theoretical and Technical Developments in Cartography – Outline

Communication Paradigm – 1800s to 1990
- History 1800s to 1970s, before digitizing and computer mapping
- Digital Era history with USGS focus
- 1970s to 1990s, beginning of digitizing and automation

Analytical Cartography Paradigm

Deconstruction Paradigm 1990s to 2000

Web Mapping Paradigm 2000 – 2015,
- Map mashups, commoditized mapping

Semantic Mapping Paradigm
- Intelligent maps, map as a knowledgebase, post 2015

Conclusions

Paradigm

A distinct set of concepts or thought patterns, including theories, research methods, postulates, and standards for what constitutes legitimate contributions to a field.

Thesis of this work

Theoretical and technical developments in cartography, and advancements in computers, networks, and the Internet have resulted in the development of intelligent maps which will be pervasive and ubiquitous using Web technologies.

These developments bring a new paradigm to the field of cartography requiring new research and education approaches.

Communication Paradigm or Theory of Cartography

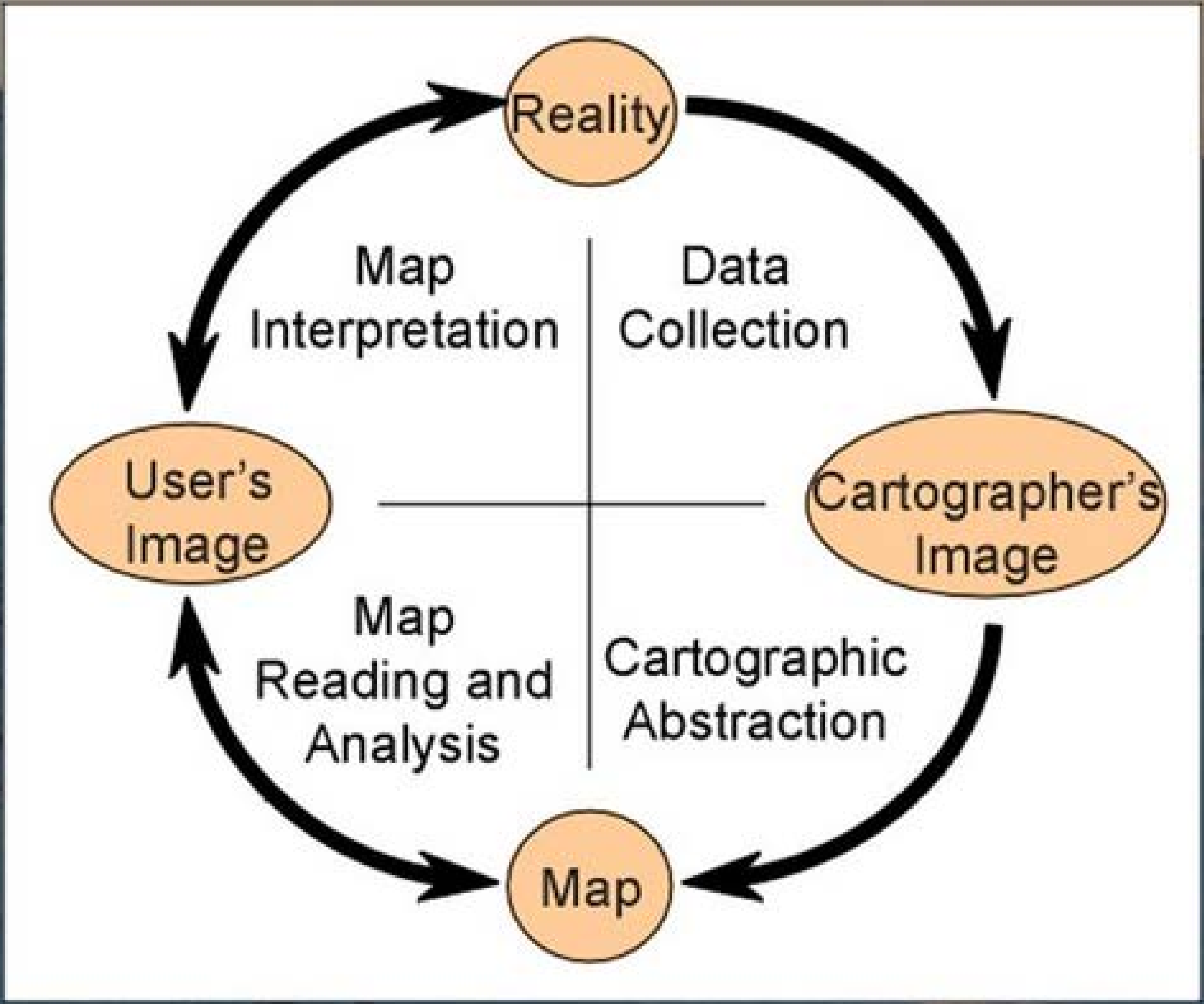
Introduced by Koláčný, 1968

Refined by Ratajski, 1970

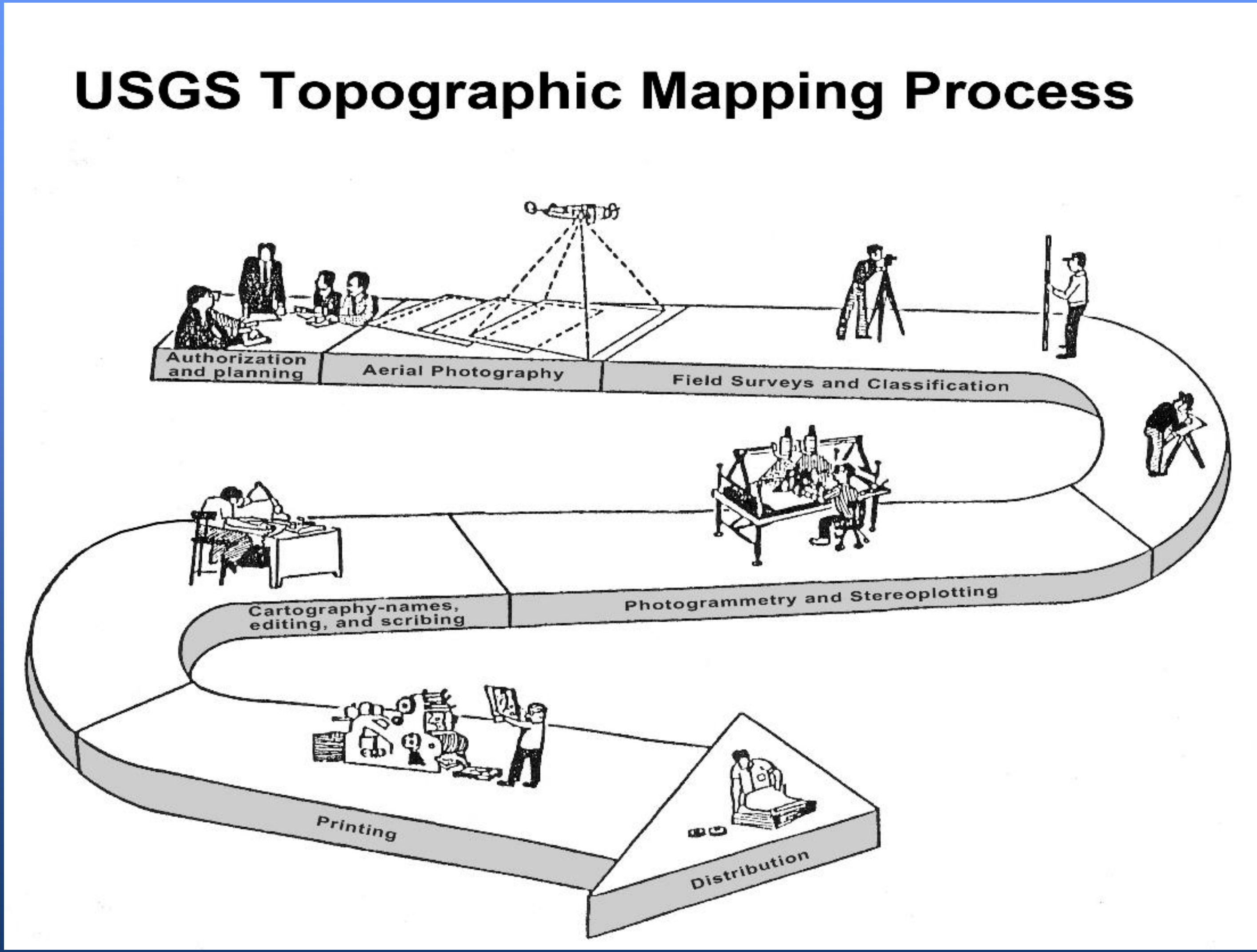
Presented and implemented by Robinson and others, 1970 to 2000

Applies to historical cartography and the processes to create a map

Cartographic Communication Process



Historical Map Factory – 1879 to 1990



Topographic Mapping Process , 1950-1990

	Planning	Field Surveys	Photogrammetry	Cartography	Reproduction
Methods	Photography Authorization Acquisition	Ground Control for Photos Classification of all features on photos	Aerotriangulation – control extension Stereocompilation of ground features and contours Mylar drawing with pantograph	Editing Names, Stickup/adhesive Symbolization Final scribing	5 color press Lithographic production
Products	Stereo Pair Photographs	Field Notes Controlled photographs Classified/annotated photographs Field jacket with all field information	Compilation manuscript Includes all content Control lists	Final scribecoat and color separation negatives	Printed lithographic map at various scales, primarily 1:24,000 in 7.5 minute format

Time to Product Release →

Year 1 | Year 2 | Year 3 | Year 4 | Year 5

Digital Era 1970s to 1990s, beginning of digitizing and automation

Initially digital cartography was developed and implemented in the Communication Paradigm of cartography.

History of Theoretical and Technical Developments in Cartography – Initial digitized linework advances

Current state of the art and science of cartography began with digitizing vertices of lines on paper maps into x and y coordinates to represent their basic geometry in computer

Advanced to include identifiers for points, lines, and areas with the associated coordinates.

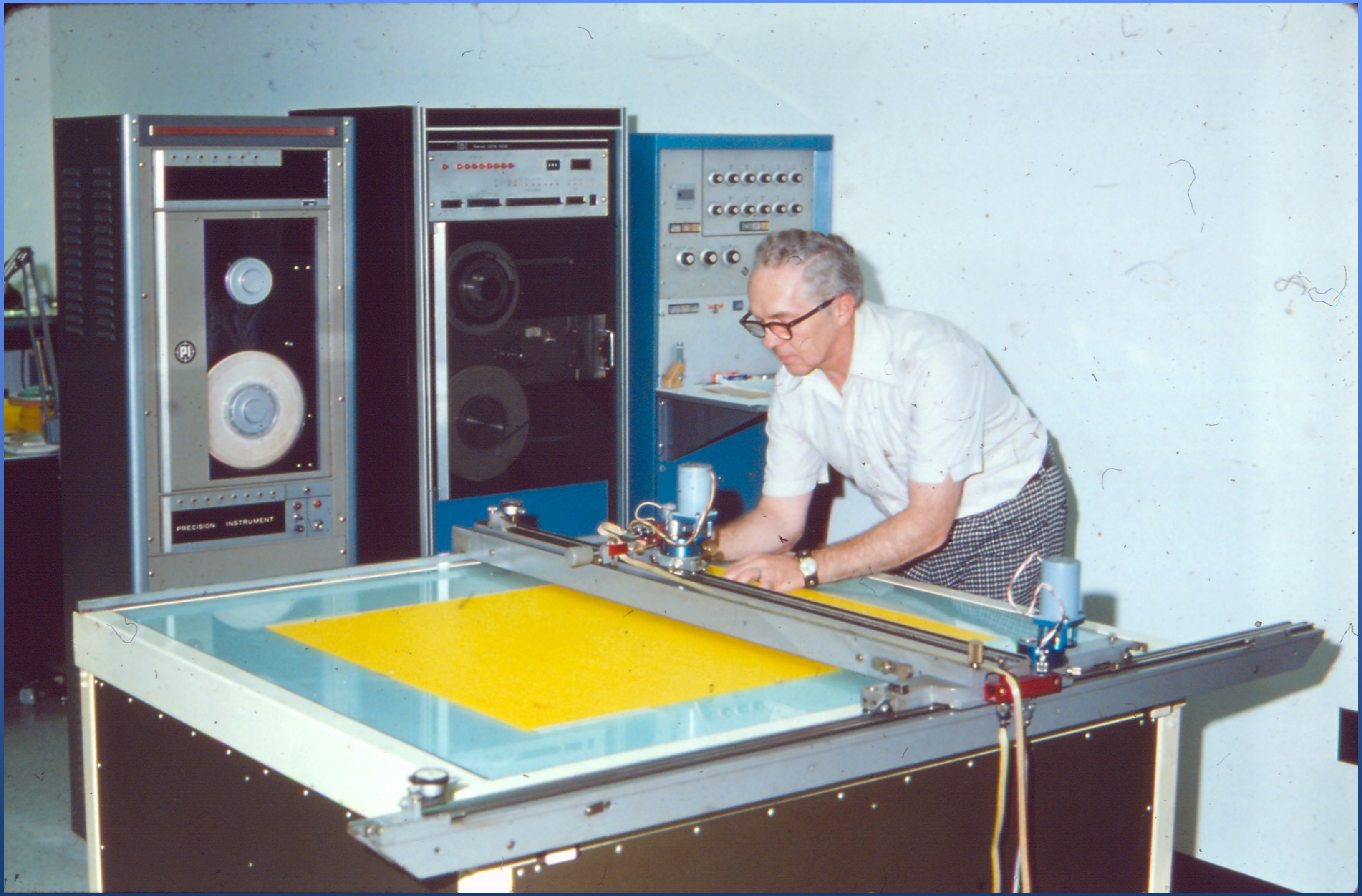
Attributes of these shapes were then added to the identifiers.

Advanced to consider the topology of these basic geometries, and relational databases were adopted to handle the attributes and topological relationships among the spatial objects.

The Digital Era Begins 1960s

Autoplot

Automatically plot neatline (bounding lines of latitude and longitude) and control and pass points on a scribecoat base



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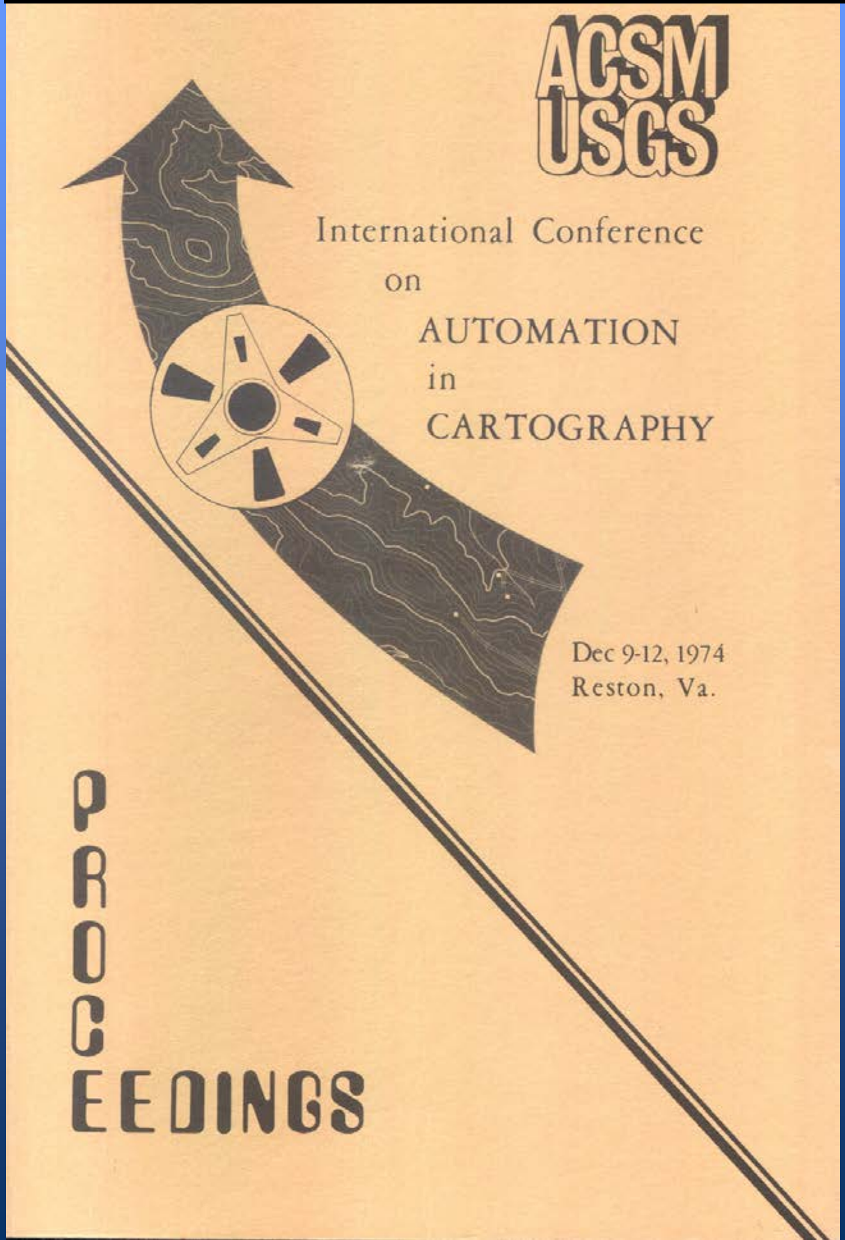
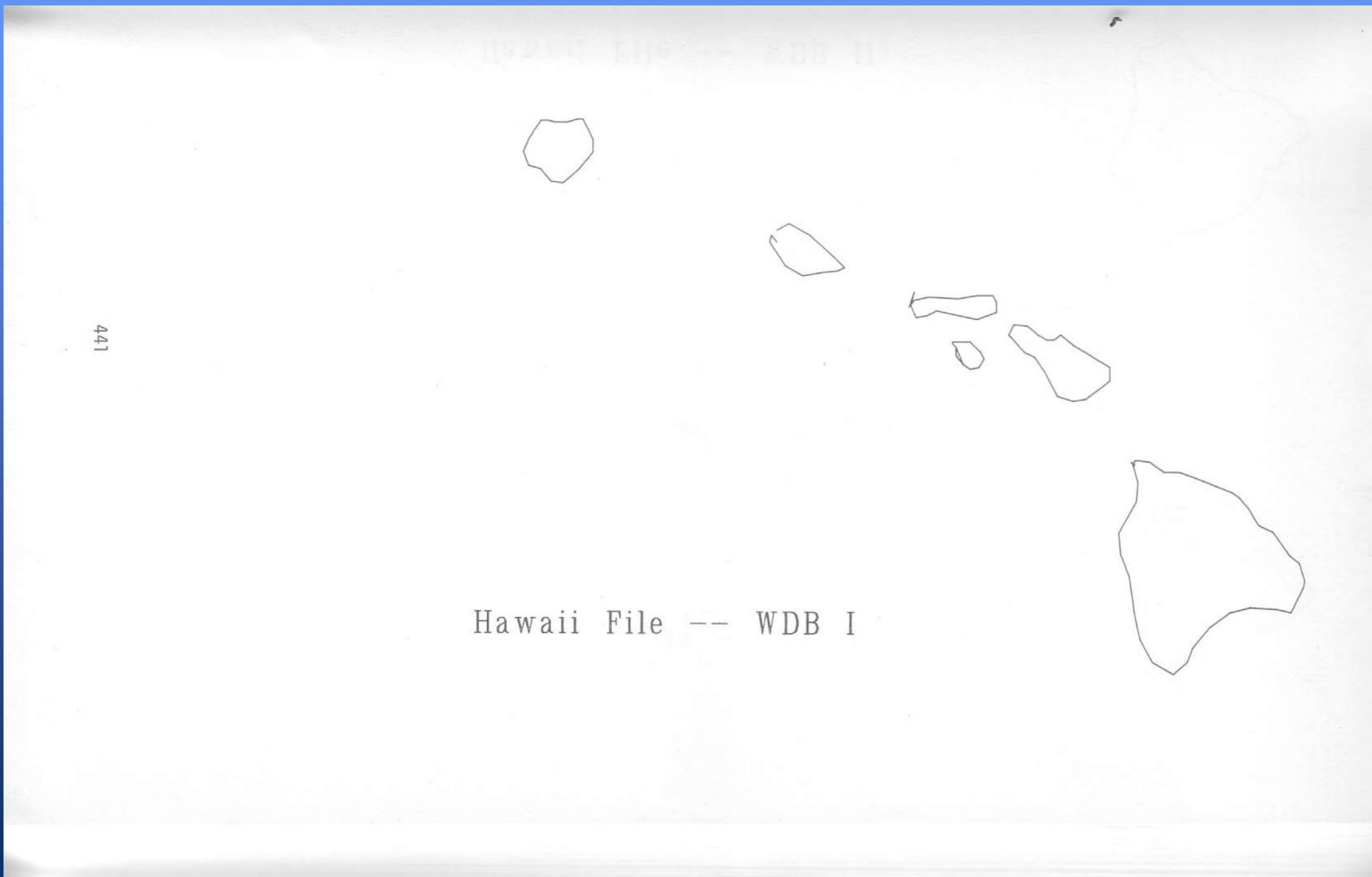
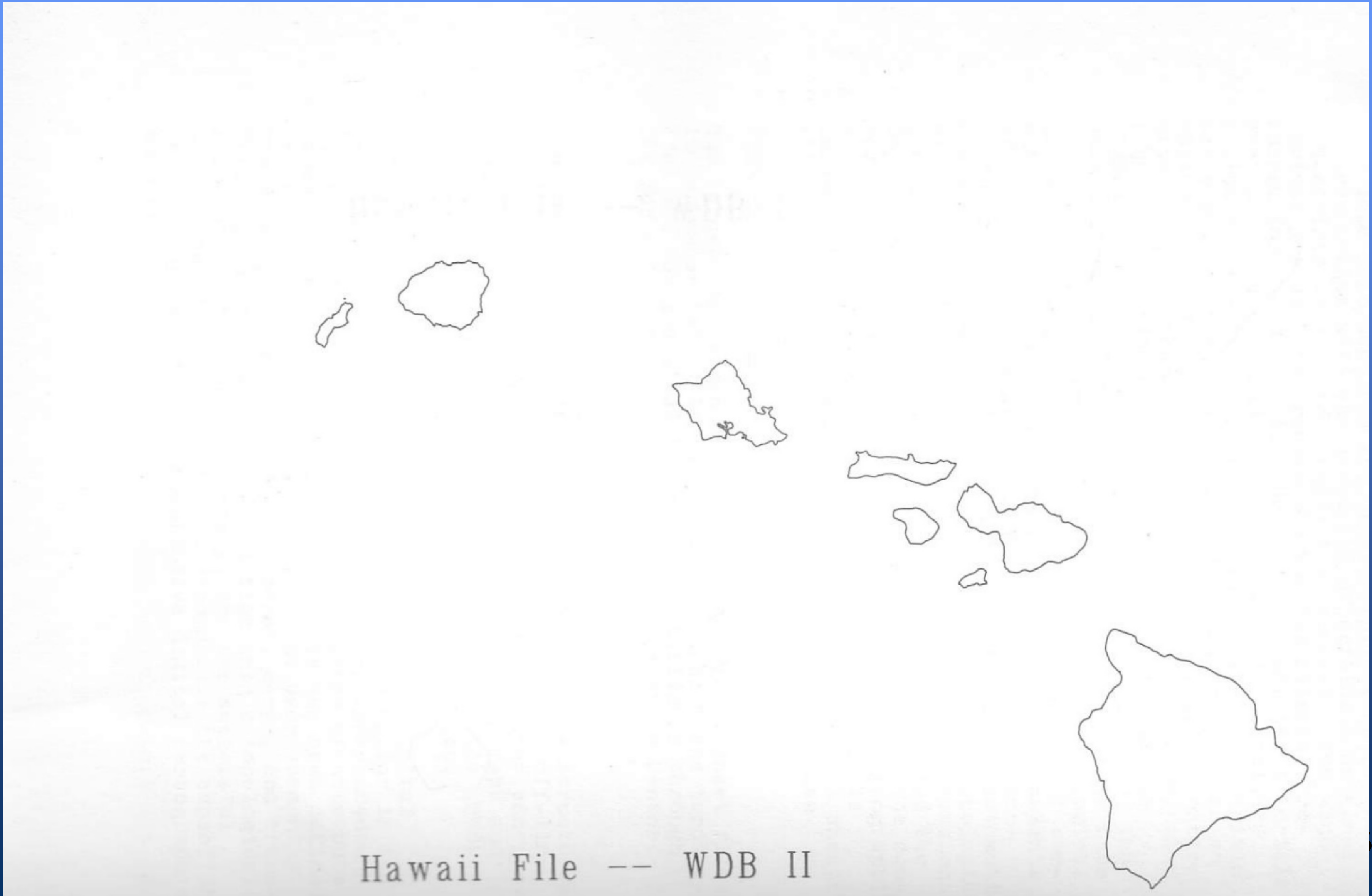
Automated Cartography took hold in the 1970s – First AutoCarto 1974



An original set of digitized vertices in World Databank I by the CIA, circa 1972

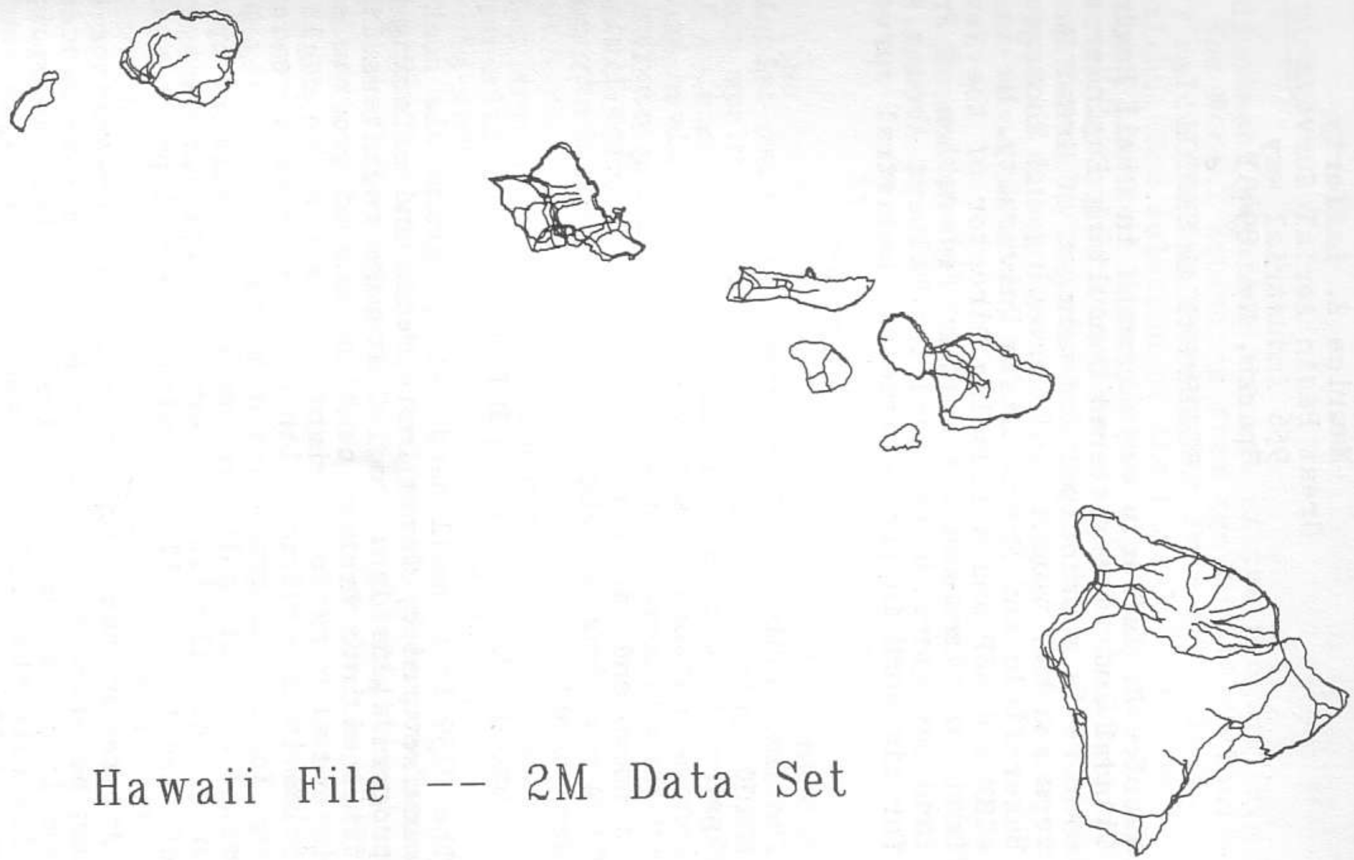


An original set of digitized vertices in World Databank 2 by the CIA, circa 1974



CIA World Databank, 2004

USGS 1:2,000,000 from National Atlas



Hawaii File -- 2M Data Set

Digitized Land Cover Polygons

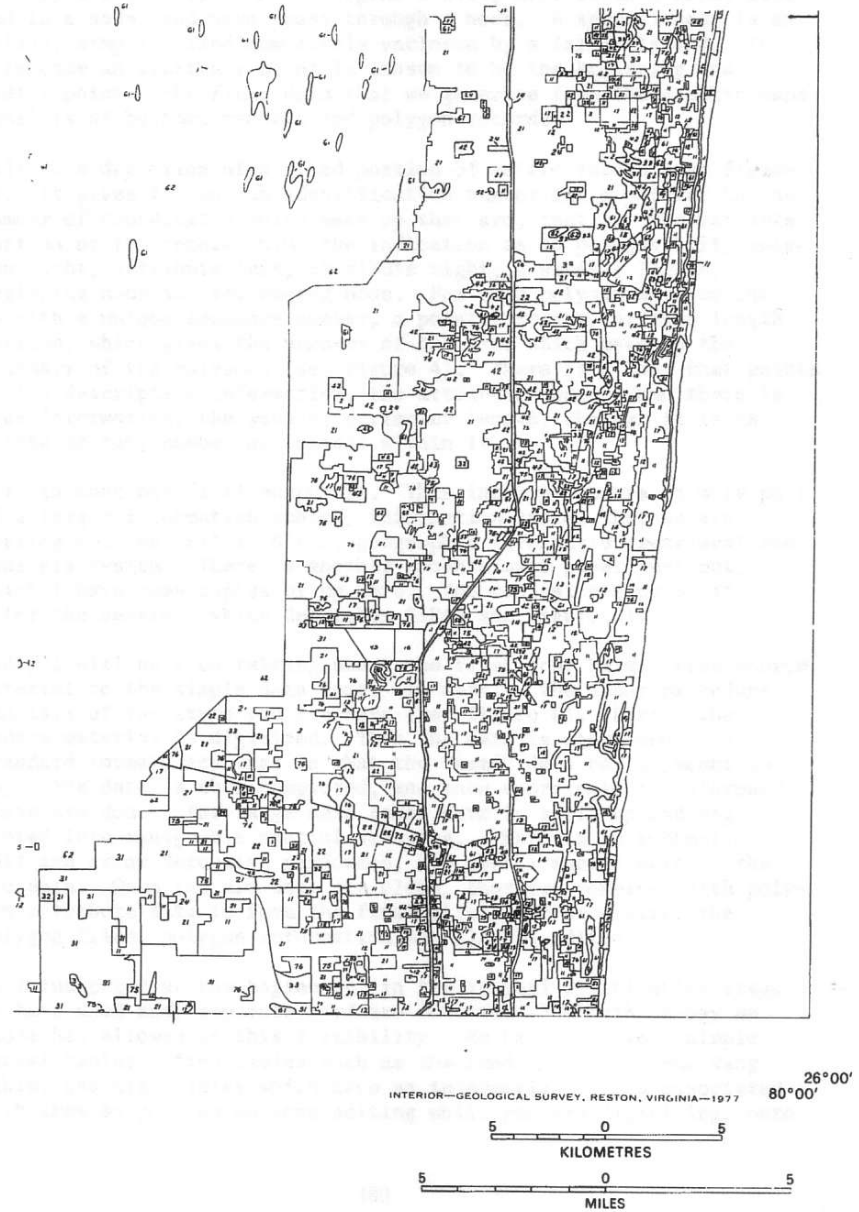


Figure 1.--A Portion of the West Palm Beach 1:250,000 Land use and Land Cover Map

USGS Digital Research and Development – 1970s

Convert existing printed maps to digital form – Digital Line Graphs (DLG)

Generate land cover for all of United States – LUDA

Generate terrain data in digital form – orthophotographs and Digital Elevation Models (DEMs)

Automate existing production processes – DCASS/GRAMPS

Digital Line Graphs

DLGs represented linework from topographic maps

Manual line following on digitizers, initially Gradicon, later Altek

DLG data fully topologically structured

Standard format IBM mainframe

User demand led to Optional Format in ASCII to be used on all computers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Addition of Topology

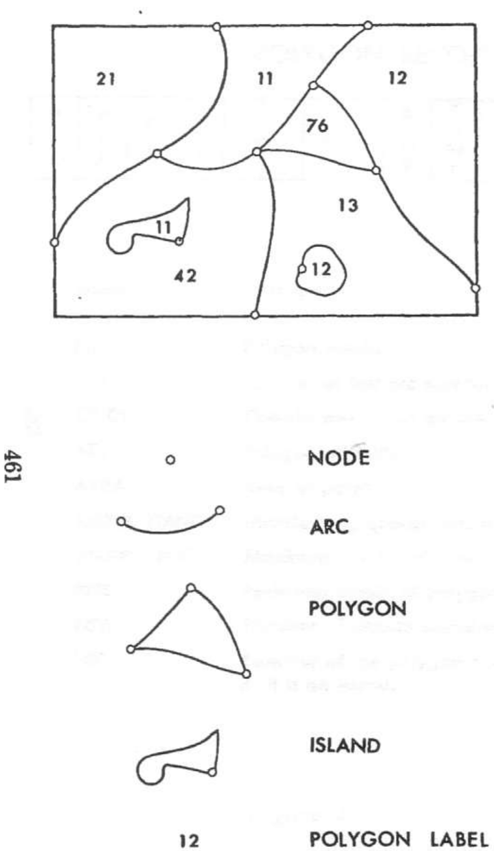

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Figure 2.--Elements of a Polygon Map

ARC RECORD

AID	PLC	PL	PR	PAL	PAR	XMNA	YMNA	XMXA	YMXA	ALEN	SN	FN

Name	Description
AID	Arc number.
PLC	Position of last arc coordinate in COORD file.
PL	Polygon number of polygon to left of arc.
PR	Polygon number of polygon to right of arc.
PAL	Attribute of polygon to left of arc.
PAR	Attribute of polygon to right of arc.
XMNA, YMNA	Minimum x,y coordinates in arc.
XMXA, YMXA	Maximum x,y coordinates in arc.
ALEN	Arc length in coordinate units.
SN	Node number at beginning of arc.
FN	Node number at end of arc.

Figure 3

Topology in graphic and table form

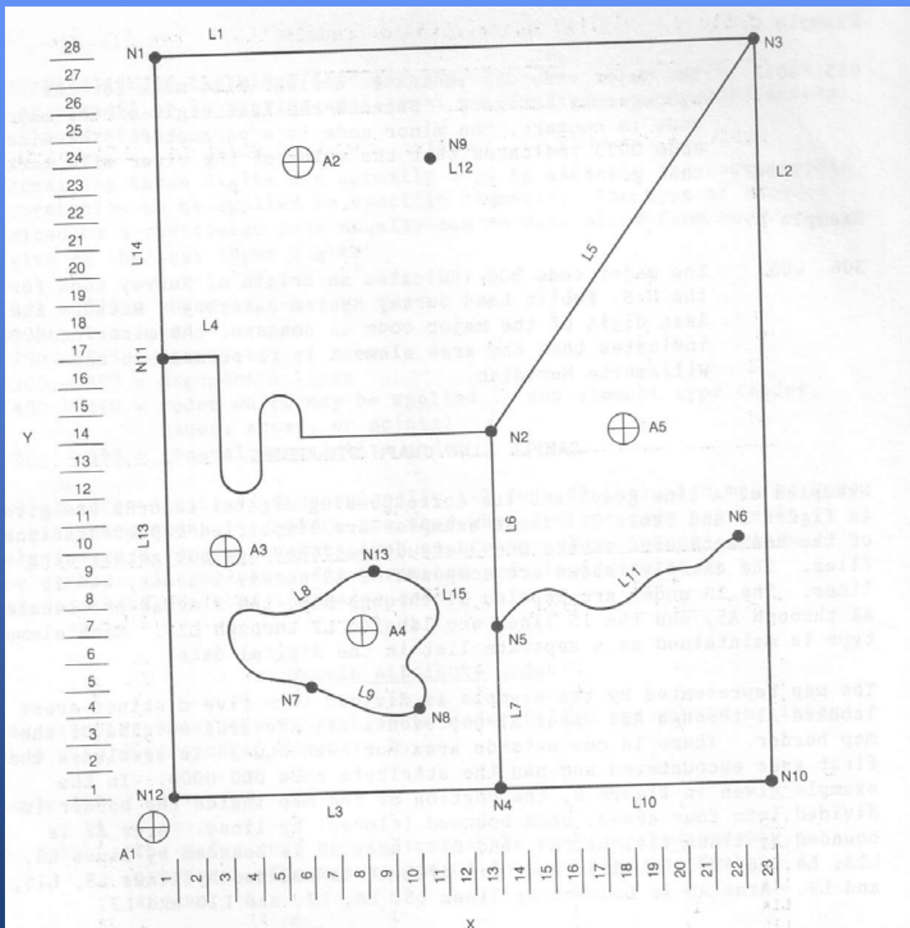


Figure 2.--Sample line graph.

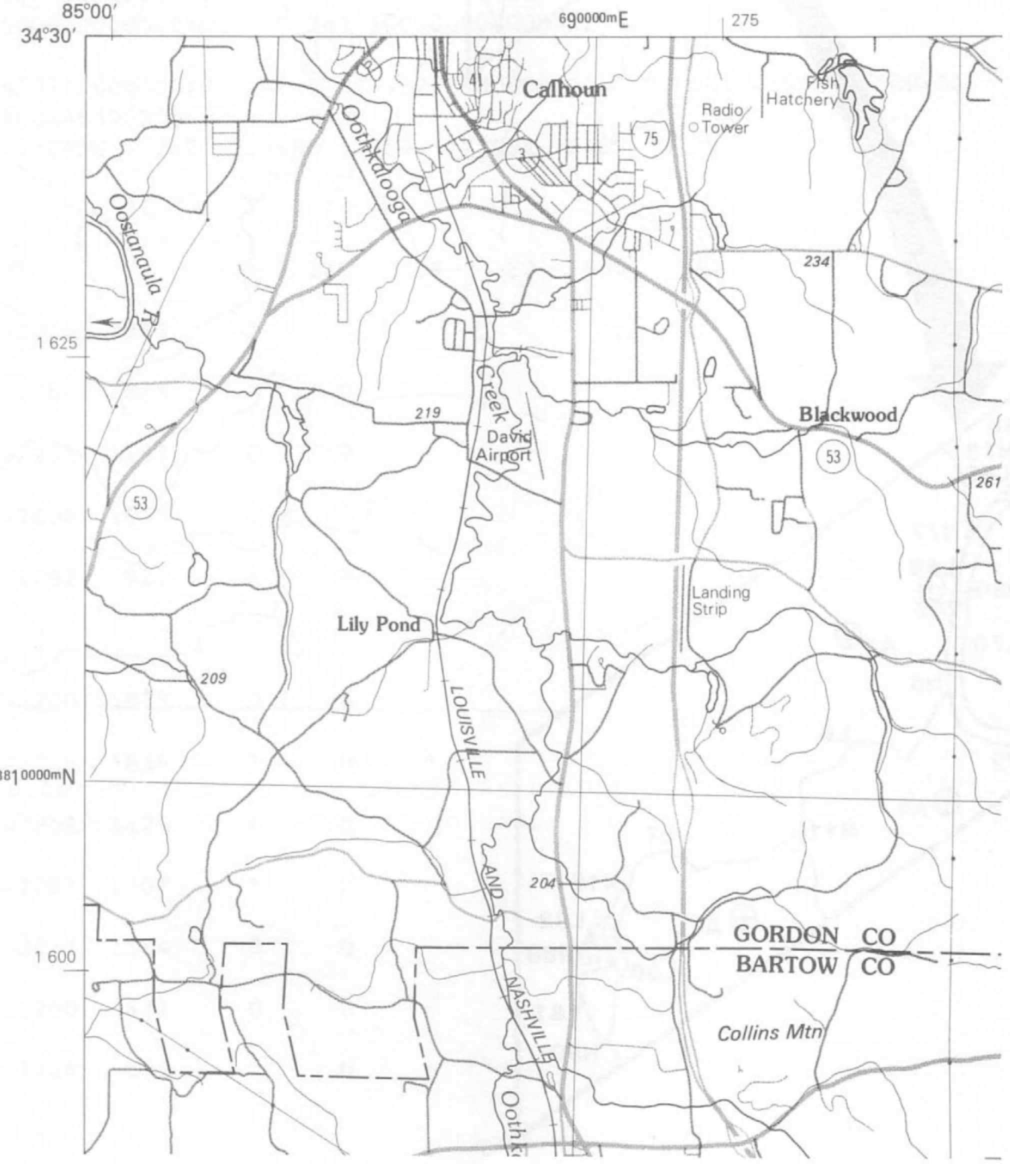
Table 2.--Digital description of sample DLG-3 (see fig. 2)

Nodes			Areas		
Number	X Coordinate	Y Coordinate	Number	X Coordinate	Y Coordinate
N1	1	28	A1	0	0
N2	13	14	A2	6	24
N3	23	28	A3	3	10
N4	13	1	A4	8	7
N5	13	7	A5	18	14
N6	22	10			
N7	6	5			
N8	10	4			
N9	11	24			
N10	23	1			
N11	1	17			
N12	1	1			
N13	9	9			

Lines

	Nodes		Area		Coordinates		
Number	Starting	Ending	Left	Right	(first x y		last x y)
L1	1	3	1	2	1, 28		23, 28
L2	3	10	1	5	23, 28		23, 1
L3	4	12	1	3	13, 1		1, 1
L4	11	2	2	3	1, 17	....	13, 14
L5	2	3	2	5	13, 14		23, 28
L6	2	5	5	3	13, 14		13, 7
L7	5	4	5	3	13, 7		13, 1
L8	13	7	4	3	9 9	....	6, 5
L9	7	8	4	3	6, 5	....	10, 4
L10	4	10	5	1	13, 1		23, 1
L11	5	6	5	5	13, 7	....	22, 10
L12	9	9	2	2	11, 24		11, 24
L13	12	11	1	3	1, 1		1, 17
L14	11	1	1	2	1, 17		1, 28
L15	8	13	4	3	10, 4	....	9, 9

CARTERSVILLE, GEORGIA



Production Automation

Collect digital data from stereocompilation processes

Drive automatic plotter to scribe photogrammetric manuscript

Data passed to cartographic unit for interactive editing

Automatically generate 5 color separates on Gerber 4477 plotter for printing process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Further Evolution of Digital Data from 1970s Beginnings

USGS 1:100,000 scale topographic maps raster scanned (Scitex systems), vectorized, topologically structured and attributed to become the U.S. Census TIGER files for 1990

Key organizations, including the U.S. Bureau of the Census, the U.S. Geological Survey, the Harvard Laboratory for Computer Graphics, and the Experimental Cartography Unit (UK) helped catalyze GIS industry.

Scitex Scanning and Raster Editing System

Analytical Cartography Paradigm

The mathematical and analytical parts of cartography that remain independent of technology that applies to both paper and online maps and their digital databases

Defined in term of its development, origins, scope and conceptual content and applications

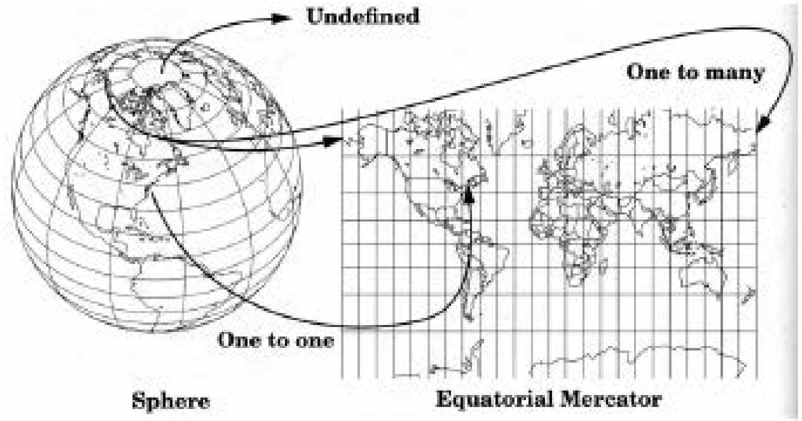
Flexible approach to GIScience and GeoComputation

Now has books, journal special issues, classes

Bridges Cartography and Computer Science

What have computers done to Cartography?
- The birth of Analytical Cartography & GIS

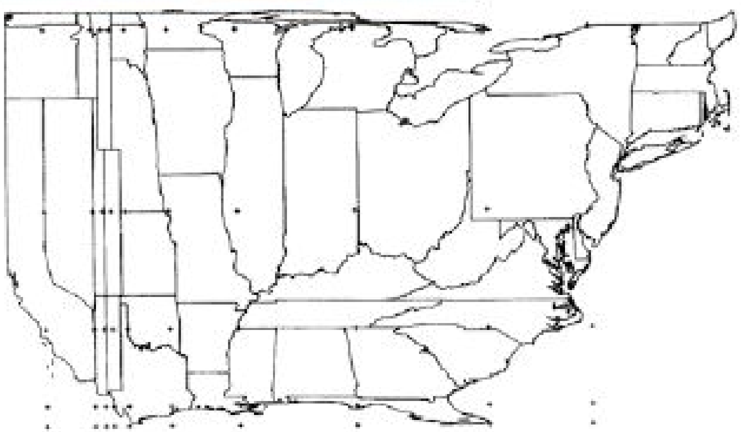
- Born in the 1960s and 1970s
- From technological focus to theoretical focus



- The early Geographic Information Systems are more like computer mapping programs plus a few data management functions.

What is Analytical Cartography?

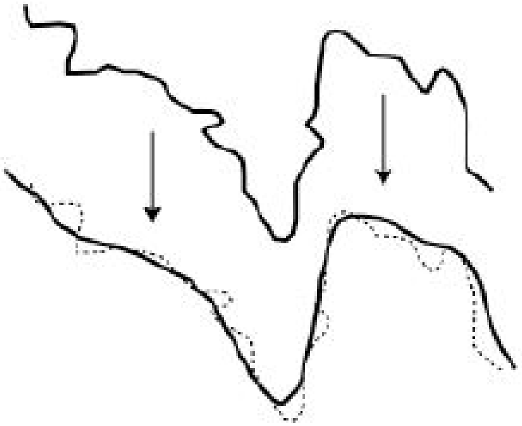
- Tobler (1966) – "solving cartographic problems"

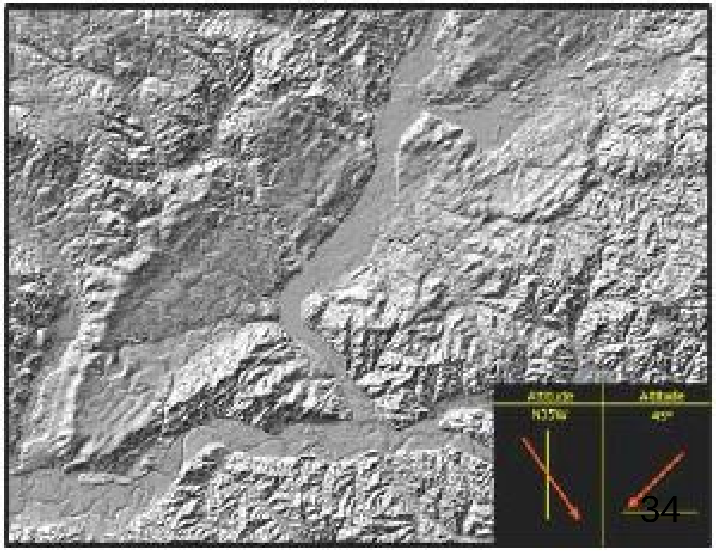


- Tobler (1976) – "mathematical and analytical parts of cartography that remain independent of technology"

Typical Topics in Analytical Cartography

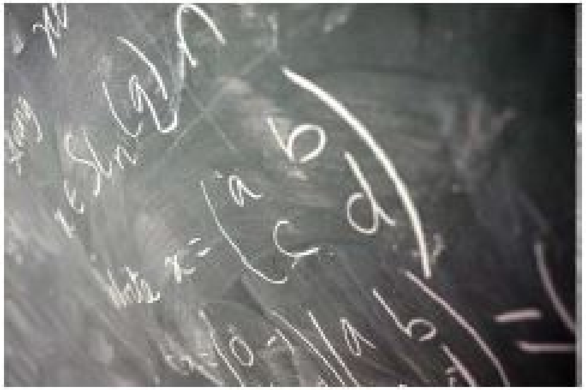
- Map Transformation
- Sampling
- Critical Features
- Map Generalization
- Shape Analysis
- Data Models and Structures
- Analytical Visualization
- A lot more …

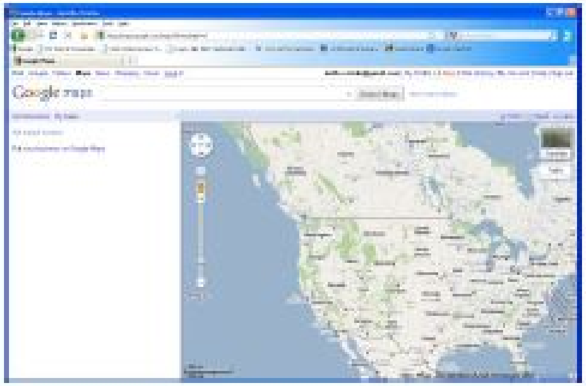


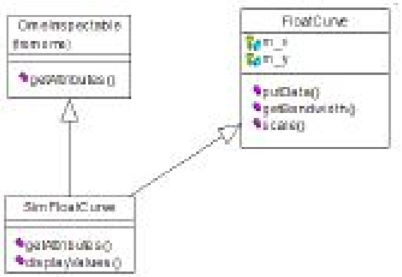


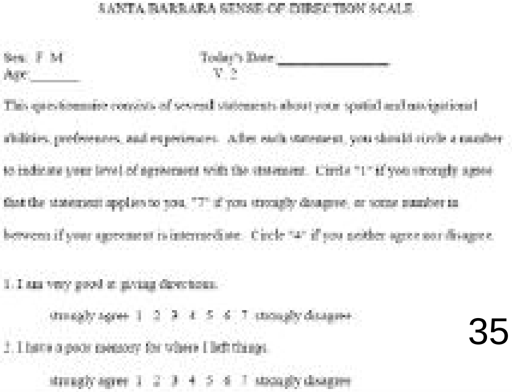
Methods of Analytical Cartography

- Computer science
  - Data base science
  - Computation
  - Logic and programming
- Mathematics and Statistics
  - Matrix theory
  - Set theory
  - Algebra
  - Trigonometry
  - Topology
  - Spatial statistics
- Cartography
  - Map data
  - Transformations
  - Representation
  - Symbolization
  - Layout and design
- Psychology
  - Map reading and interpretation
  - Navigation and route finding
  - User design









Advent of features as conceptual foundation of cartography

Point, line, and area objects became organized as geographic features of roads, streams, cities, mountains, and other natural and manmade entities.

Features have associated characteristics and relations to other features which have enabled the development of a semantic model of the underlying geospatial data.

Social construction of cartography

Expounded by Harley and others, 1980s to 1990s

Hidden map meanings

Deconstruction approaches

Web Mapping Paradigm

Map mashups

Taylor's Cybercartography

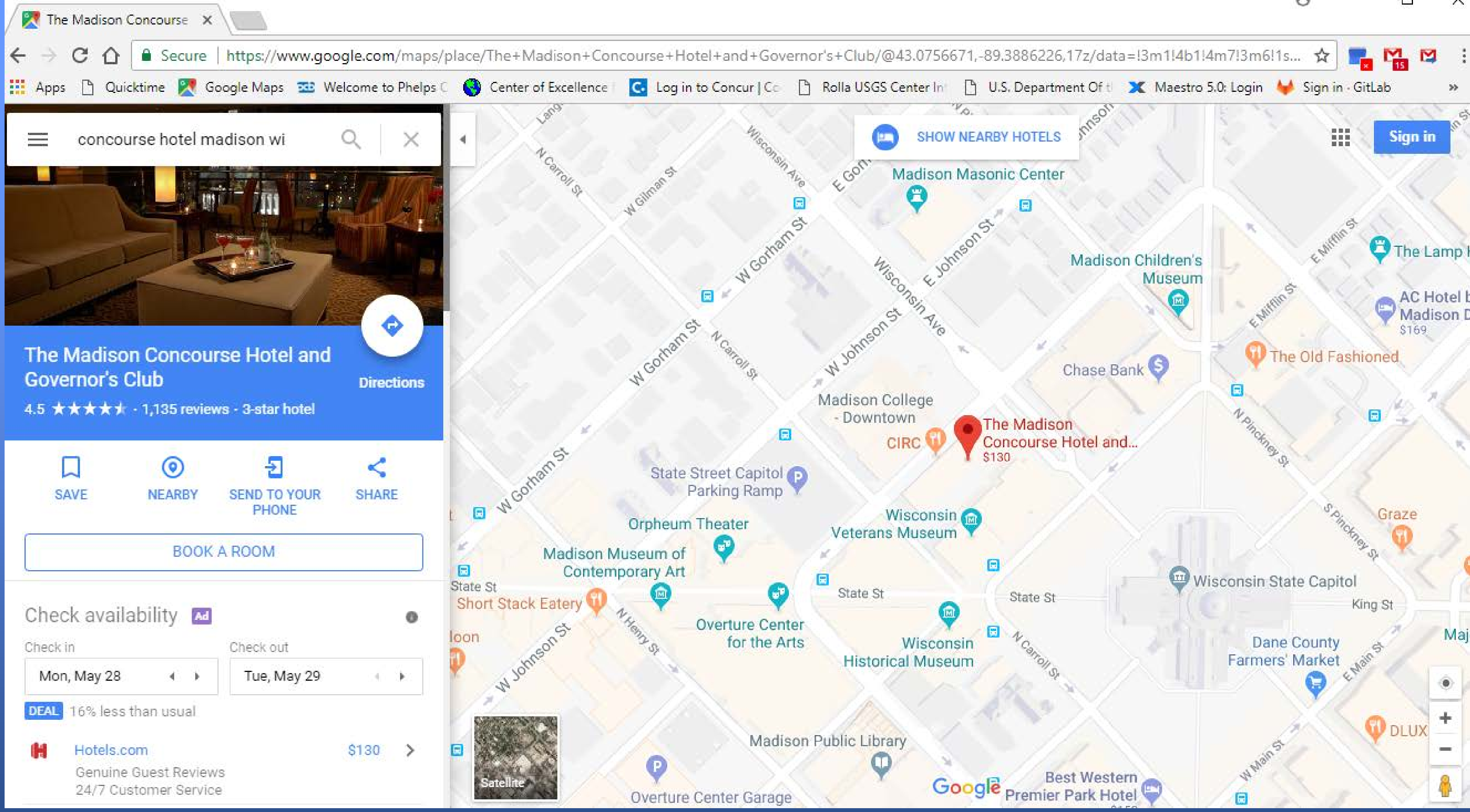
Commercial and Commoditized Mapping

MapQuest and others in 1990s

Navigation databases

Google Maps and others in 2005

Commercial applications and Location-Based Services



The Madison Concourse
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Apps Quicktime Google Maps Welcome to Phelps C Center of Excellence Log in to Concur | Co Rolla USGS Center In U.S. Department Of t Maestro 5.0: Login Sign in · GitLab
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SHOW NEARBY HOTELS
Sign in
The Madison Concourse Hotel and Governor's Club
4.5 ★★★★★ · 1,135 reviews · 3-star hotel
Directions
SAVE
NEARBY
SEND TO YOUR PHONE
SHARE
BOOK A ROOM
Check availability Ad
Check in
Check out
Mon, May 28
Tue, May 29
DEAL 16% less than usual
Hotels.com
$130
Genuine Guest Reviews
24/7 Customer Service
Madison Masonic Center
Madison Children's Museum
The Lamp
AC Hotel Madison D
$169
The Old Fashioned
Chase Bank
Madison College - Downtown
CIRC
The Madison Concourse Hotel and...
$130
State Street Capitol Parking Ramp
Orpheum Theater
Wisconsin Veterans Museum
Madison Museum of Contemporary Art
Short Stack Eatery
Overture Center for the Arts
Wisconsin Historical Museum
Wisconsin State Capitol
Dane County Farmers' Market
Graze
DLUX
Madison Public Library
Overture Center Garage
Best Western Premier Park Hotel
Satellite
Google
W Gorham St
W Johnson St
E Johnson St
Wisconsin Ave
N Carroll St
W Gilman St
N Henry St
State St
King St
N Pinckney St
S Pinckney St
E Mifflin St
E Main St
W Main St

Table 4.2 Main tendencies and changes in cartography and mapping during the second half of the twentieth century (After Azócar 2012)

Views on cartographic development	Tendencies and paradigm shifts of cartography and map conception
Traditional components and modern components (Ramirez 2004)	Cartographic language Cartographic modelling Cartographic communication Geo-spatial data manipulation Geo-spatial data processing Geo-spatial data visualisation
Cartographic research paradigm and research focus (Sui and Holt 2008)	The map as image The map as model The map as intent/social construction
Paradigm in cartography: cartographic research and internet (Peterson 2002)	Cartographic communication Analytical cartography Cartographic visualisation Power of maps Maps and Internet
Cartography: representation and visualisation (MacEachren, MacEachren 1995) (Kraak and Ormeling 1996, 2003)	Cartography as graphic communication Cartography as geo-visualisation
Cyber-cartography paradigm (Taylor 2005)	Traditional cartography Cyber-cartography
Paradigm changes in cartography (Ormeling 2007)	Production of maps Map production and map use Spatial information to support decision making
Cartographic trends and paradigms (Cauvin, Escobar and Serradj 2010)	The map as a channel of communication Rules of graphical semiology Theory of symbolisation and design Experimental and exploratory cartography Ethical and social aspects Geovisualisation

Table 6.1 Map conceptions according to historical periods and authors. (After Azócar 2012)

Period	Author	Map conception
Modern Cartography	Robinson (1955)	Maps as *objective*, *scientific* representations Maps as *truths* Maps are *transparent* and ideologically *neutral*
Post-Modern Cartography	Harley (1989)	Maps as *ideologically* laden representations Maps as cultural *texts*
	Crampton (2003)	Maps as *historical products* operating within 'a certain horizon of *possibilities*'
	Casti (2005)	Maps as locus of *semiosis*; *self-referential* through iconisation
	Wood and J. Fels (2008)	Maps as *constructions* that produce the world Maps as *propositions*
	Latour (1987, 1999)	Maps as *immutable* mobiles Maps as *actants*
	della Dora (2009)	Maps as *fluid* objects, always in the making Maps as *mnemonics*
Post-Representational Cartography [a]	Pickles (2004)	Maps as *inscriptions* Maps as unstable and complex *texts*
	Kitchin and M. Dodge (2007)	Maps as *practices* (spatial practices that do work in the world) Maps as suites of cultural practices involving *actions* and *affects* Maps as *mutable* mobiles

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Semantic Model of Cartography

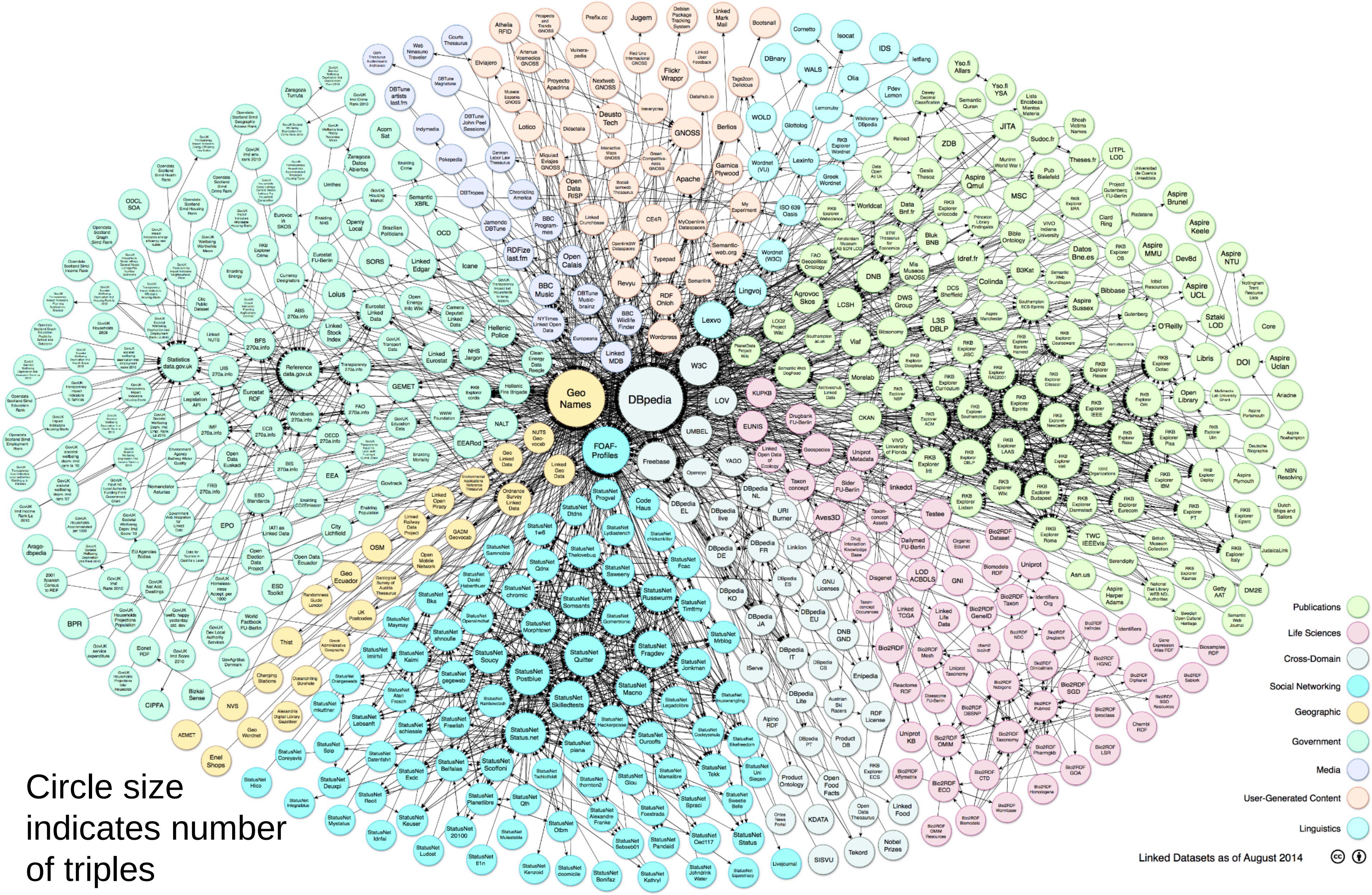
Semantic model has led to the concept of the “Map as a Knowledgebase” generating intelligent and self-reacting features.

Map features in semantic form can respond to logical inference creating new data through connections.

Automatically respond to symbolization requirements.

Connect with other features in response to user queries or machine requests.

Semantic model provides logical inference processing of cartographic data and basis for artificial intelligence



Circle size indicates number of triples

Map as a Knowledge Base

All map elements are represented in a triplestore, which is the knowledge base

Included in the triplestore are:

- Triples for ontology of map features (includes taxonomy and vocabulary)
- Triples for instances of features
  - Attributes and relationships (including topology) of the features
  - Coordinate geometry of features as dereferenceable IRIs

Map as a Knowledge Base

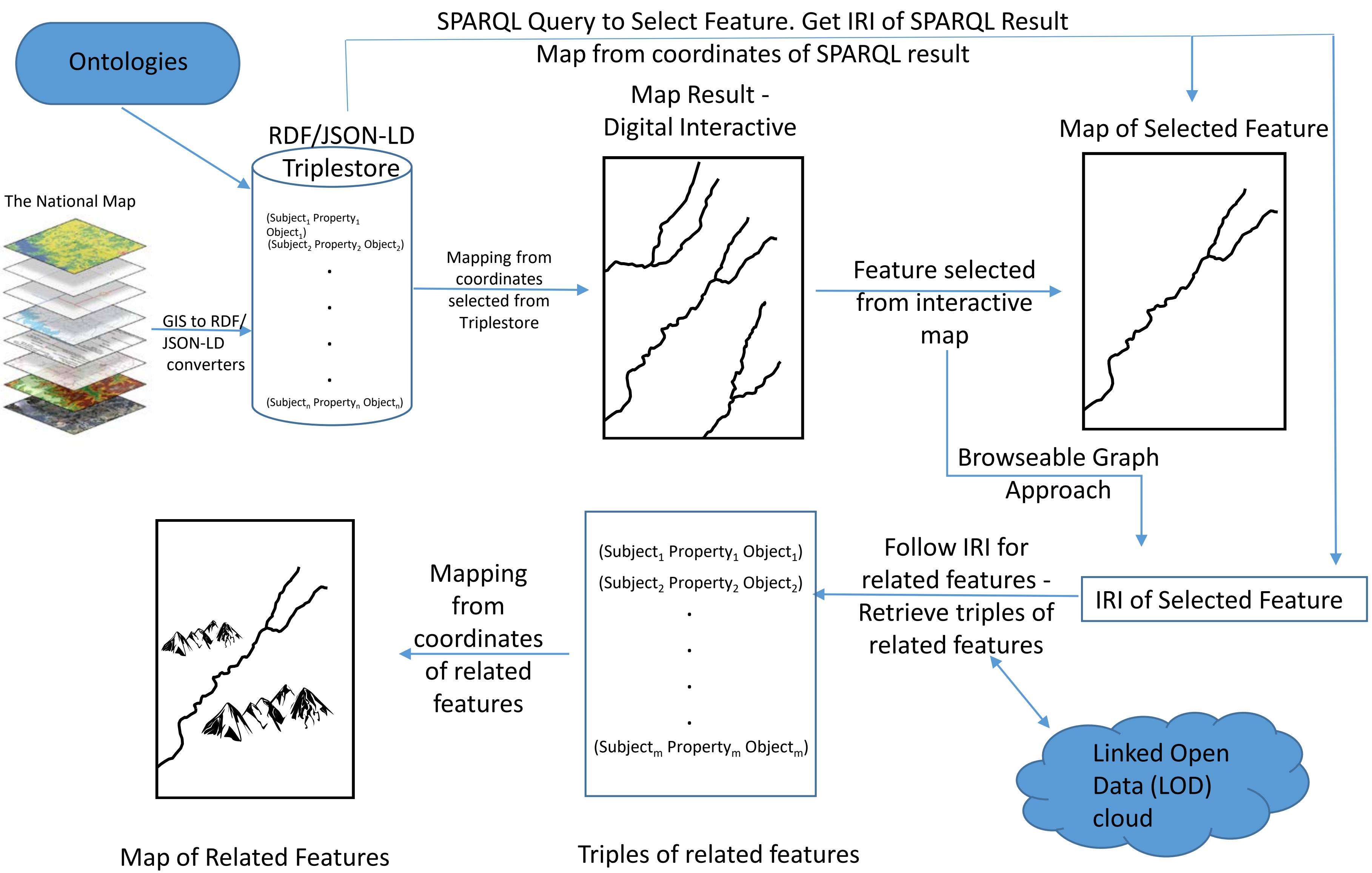
Triple store can be queried with SPARQL

- Results in a set of new triples and IRIs
- Results can be mapped from geometry objects in triple store and resulting from query

Triplestore allows browsing the graph or “follow-your-nose” through the linked data in the triplestore

Both methods result in IRI that can be followed into Linked Open Data Cloud to retrieve other linked data

Map as a Knowledge Base



Conclusions

Cartography has evolved from the communication paradigm through the Internet and social revolutions to the point that the map is now ubiquitous and provides a knowledge base with a graphical interface.

Semantic representation is a new cartographic paradigm and provides linked access to feature descriptions, attributes, and relationships and associated (linked) features through the Linked Open Data cloud and the Semantic Web.

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