Geographic Information Science & Technology Body of Knowledge 2006

QUICK REFERENCE

UCGIS

Analytical Methods

AM1 Academic and analytical origins
- 1-1 Academic foundations
- 1-2 Analytical approaches

AM2 Query operations and query languages
- 2-1 Set theory
- 2-2 Structured Query Language (SQL) and attribute queries
- 2-3 Spatial queries

AM3 Geometric measures
- 3-1 Distances and lengths
- 3-2 Direction
- 3-3 Shape
- 3-4 Area
- 3-5 Proximity and distance decay
- 3-6 Adjacency and connectivity

AM4 Basic analytical operations
- 4-1 Buffers
- 4-2 Overlay
- 4-3 Neighborhoods
- 4-4 Map algebra

AM5 Basic analytical methods
- 5-1 Point pattern analysis
- 5-2 Kernels and density estimation
- 5-3 Spatial cluster analysis
- 5-4 Spatial interaction
- 5-5 Analyzing multidimensional attributes
- 5-6 Cartographic modeling
- 5-7 Multi-criteria evaluation
- 5-8 Spatial process models

AM6 Analysis of surfaces
- 6-1 Calculating surface derivatives
- 6-2 Interpolation of surfaces
- 6-3 Surface features
- 6-4 Intervisibility
- 6-5 Friction surfaces

AM7 Spatial statistics
- 7-1 Graphical methods
- 7-2 Stochastic processes
- 7-3 The spatial weights matrix
- 7-4 Global measures of spatial association
- 7-5 Local measures of spatial association
- 7-6 Outliers
- 7-7 Bayesian methods

AM8 Geostatistics
- 8-1 Spatial sampling for statistical analysis
- 8-2 Principles of semi-variogram construction
- 8-3 Semi-variogram modeling
- 8-4 Principles of kriging
- 8-5 Kriging variants

AM9 Spatial regression and econometrics
- 9-1 Principles of spatial econometrics
- 9-2 Spatial autoregressive models
- 9-3 Spatial filtering
- 9-4 Spatial expansion and Geographically Weighted Regression (GWR)

AM10 Data Mining
- 10-1 Problems of large spatial databases
- 10-2 Data mining approaches
- 10-3 Knowledge discovery
- 10-4 Pattern recognition and matching

AM11 Network analysis
- 11-1 Networks defined
- 11-2 Graph theoretic (descriptive) measures
- 11-3 Least-cost (shortest) path
- 11-4 Flow modeling
- 11-5 The Classic Transportation Problem
- 11-6 Other classic network problems
- 11-7 Accessibility Modeling

AM12 Optimization and location-allocation modeling
- 12-1 Operations research modeling and location modeling principles
- 12-2 Linear programming
- 12-3 Integer programming
- 12-4 Location-allocation modeling and p-median problems

Conceptual Foundations

CF1 Philosophical foundations
- 1-1 Metaphysics and ontology
- 1-2 Epistemology
- 1-3 Philosophical perspectives

CF2 Cognitive and social foundations
- 2-1 Perception and cognition of geographic phenomena
- 2-2 From concepts to data
- 2-3 Geography as a foundation for GIS
- 2-4 Place and landscape
- 2-5 Common-sense geographies
- 2-6 Cultural influences
- 2-7 Political influences

CF3 Domains of geographic information
- 3-1 Space
- 3-2 Time
- 3-3 Relationships between space and time
- 3-4 Properties

CF4 Elements of geographic information
- 4-1 Discrete entities
- 4-2 Events and processes
- 4-3 Fields in space and time
- 4-4 Integrated models

CF5 Relationships
- 5-1 Categories
- 5-2 Mereology: structural relationships
- 5-3 Genealogical relationships: lineage, inheritance
- 5-4 Topological relationships
- 5-5 Metrical relationships: distance and direction
- 5-6 Spatial distribution
- 5-7 Region
- 5-8 Spatial integration

CF6 Imperfections in geographic information
- 6-1 Vagueness
- 6-2 Mathematical models of vagueness: Fuzzy sets and rough sets
- 6-3 Error-based uncertainty
- 6-4 Mathematical models of uncertainty: Probability and statistics

Cartography and Visualization

CV1 History and trends
- 1-1 History of cartography
- 1-2 Technological transformations

CV2 Data considerations
- 2-1 Source materials for mapping
- 2-2 Data abstraction: classification, selection, and generalization
- 2-3 Projections as a map design issue

CV3 Principles of map design
- 3-1 Map design fundamentals
- 3-2 Basic concepts of symbolization
- 3-3 Color for cartography and visualization
- 3-4 Typography for cartography and visualization

CV4 Graphic representation techniques
- 4-1 Basic thematic mapping methods
- 4-2 Multivariate displays
- 4-3 Dynamic and interactive displays
- 4-4 Representing terrain
- 4-5 Web mapping and visualizations
- 4-6 Virtual and immersive environments
- 4-7 Spatialization
- 4-8 Visualization of temporal geographic data
- 4-9 Visualization of uncertainty

CV5 Map production
- 5-1 Computational issues
- 5-2 Map production
- 5-3 Map reproduction

CV6 Map use and evaluation
- 6-1 The power of maps
- 6-2 Map reading
- 6-3 Map interpretation
- 6-4 Map analysis
- 6-5 Evaluation and testing
- 6-6 Impact of uncertainty

Design Aspects

DA1 The scope of GI S&T system design
- 1-1 Using models to represent information and processes
- 1-2 Components of models: data, structures, procedures
- 1-3 The scope of GI S&T applications
- 1-4 The scope of GI S&T design
- 1-5 The process of GI S&T design

DA2 Project definition
- 2-1 Problem definition
- 2-2 Planning for design
- 2-3 Application/user assessment
- 2-4 Requirements analysis
- 2-5 Social, political, and cultural issues

DA3 Resource planning
- 3-1 Feasibility analysis
- 3-2 Software systems
- 3-3 Data costs
- 3-4 Labor and management
- 3-5 Capital: facilities and equipment
- 3-6 Funding

DA4 Database design
- 4-1 Modeling tools
- 4-2 Conceptual model
- 4-3 Logical models
- 4-4 Physical models

DA5 Analysis design
- 5-1 Recognizing analytical components
- 5-2 Identifying and designing analytical procedures
- 5-3 Coupling scientific models with GIS
- 5-4 Formalizing a procedure design

DA6 Application design
- 6-1 Workflow analysis and design
- 6-2 User interfaces
- 6-3 Development environments for geospatial applications
- 6-4 Computer-Aided Software Engineering (CASE) tools

DA7 System implementation
- 7-1 Implementation planning
- 7-2 Implementation tasks
- 7-3 System testing
- 7-4 System deployment

Data Modeling

DM1 Basic storage and retrieval structures
- 1-1 Basic data structures
- 1-2 Data retrieval strategies

DM2 Database management systems
- 2-1 Coevolution of DBMS and GIS
- 2-2 Relational DBMS
- 2-3 Object-oriented DBMS
- 2-4 Extensions of the relational model

DM3 Tessellation data models
- 3-1 Grid representations
- 3-2 The raster model
- 3-3 Grid compression methods
- 3-4 The hexagonal model
- 3-5 The Triangulated Irregular Network (TIN) model
- 3-6 Resolution
- 3-7 Hierarchical data models

DM4 Vector and object data models
- 4-1 Geometric primitives
- 4-2 The spaghetti model
- 4-3 The topological model
- 4-4 Classic vector data models
- 4-5 The network model
- 4-6 Linear referencing
- 4-7 Object-based spatial databases

DM5 Modeling 3D, uncertain, and temporal phenomena
- 5-1 Spatio-temporal GIS
- 5-2 Modeling uncertainty
- 5-3 Modeling three-dimensional entities

Data Manipulation

DN1 Representation transformation
1-1 Impacts of transformations
1-2 Data model and format conversion
1-3 Interpolation
1-4 Vector-to-raster and raster-to-vector conversions
1-5 Raster resampling
1-6 Coordinate transformations

DN2 Generalization and aggregation
2-1 Scale and generalization
2-2 Point, line, and area generalization
2-3 Classification and transformation of attribute measurement levels
2-4 Aggregation of spatial entities

DN3 Transaction management
3-1 Database change
3-2 Modeling database change
3-3 Reconciling database change
3-4 Managing versioned geospatial databases

Geocomputation

GC1 Emergence of geocomputation
1-1 Origins
1-2 Trends

GC2 Computational aspects and neurocomputing
2-1 High performance computing
2-2 Computational intelligence
2-3 Non-linearity relationships and non-Gaussian distributions
2-4 Pattern recognition
2-5 Geospatial data classification
2-6 Multi-layer feed-forward neutral networks
2-7 Space-scale algorithms
2-8 Rule learning
2-9 Neural network schemes

GC3 Cellular Automata (CA)
3-1 CA Model Structure
3-2 CA Transition Rule
3-3 CA simulation and calibration
3-4 Integration of CA and other geocomputation methods
3-5 Typical CA applications

GC4 Heuristics
4-1 Greedy heuristics
4-2 Interchange heuristics
4-3 Interchange with probability
4-4 Simulated annealing
4-5 Lagrangian relaxation

GC5 Genetic algorithms (GA)
5-1 GA and global solutions
5-2 Genetic algorithms and artificial genomes

GC6 Agent-based models
6-1 Structure of agent-based models
6-2 Specification of agent-based models
6-3 Adaptive agents
6-4 Microsimulation and calibration of agent activities
6-5 Encoding agent-based models

GC7 Simulation modeling
7-1 Simulation modeling

GC8 Uncertainty
8-1 Conceptual model of uncertainty
8-2 Error
8-3 Problems of scale and zoning
8-4 Propagation of error in geospatial modeling
8-5 Theory of error propagation
8-6 Problems of currency, source, and scale

GC9 Fuzzy sets
9-1 Fuzzy logic
9-2 Fuzzy measures
9-3 Fuzzy aggregation operators
9-4 Standardization
9-5 Weighting schemes

Geospatial Data

GD1 Earth geometry
1-1 History of understanding Earth's shape
1-2 Geoids
1-3 Spheres and ellipsoids

GD2 Land partitioning systems
2-1 Unsystematic methods
2-2 Systematic methods

GD3 Georeferencing systems
3-1 Geographic coordinate system
3-2 Plane coordinate systems
3-3 Tessellated referencing systems
3-4 Linear referencing systems

GD4 Datums
4-1 Horizontal datums
4-2 Vertical datums

GD5 Map projections
5-1 Map projection properties
5-2 Map projection classes
5-3 Map projection parameters
5-4 Georegistration

GD6 Data quality
6-1 Geometric accuracy
6-2 Thematic accuracy
6-3 Resolution
6-4 Precision
6-5 Primary and secondary sources

GD7 Land surveying and GPS
7-1 Survey theory and electro-optical methods
7-2 Land records
7-3 Global Positioning System

GD8 Digitizing
8-1 Tablet digitizing
8-2 On-screen digitizing
8-3 Scanning and automated vectorization

GD9 Field data collection
9-1 Sample size selection
9-2 Spatial sample types
9-3 Sample intervals
9-4 Field data technologies

GD10 Aerial imaging and photogrammetry
10-1 Nature of aerial image data
10-2 Platforms and sensors
10-3 Aerial image interpretation
10-4 Stereoscopy and orthoimagery
10-5 Vector data extraction
10-6 Mission planning

GD11 Satellite and shipboard remote sensing
11-1 Nature of multispectral image data
11-2 Platforms and sensors
11-3 Algorithms and processing
11-4 Ground verification and accuracy assessment
11-5 Applications and settings

GD12 Metadata, standards, and infrastructures
12-1 Metadata
12-2 Content standards
12-3 Data warehouses
12-4 Exchange specifications
12-5 Transport protocols
12-6 Spatial Data Infrastructures

GI S&T and Society

GS1 Legal aspects
1-1 The legal regime
1-2 Contract law
1-3 Liability
1-4 Privacy

GS2 Economic aspects
2-1 Economics and the role of information
2-2 Valuing and measuring benefits
2-3 Models of benefits
2-4 Agency, organizational, and individual perspectives
2-5 Measuring costs

GS3 Use of geospatial information in the public sector
3-1 Uses of geospatial information in government
3-2 Public participation in governing
3-3 Public participation GIS

GS4 Geospatial information as property
4-1 Property regimes
4-2 Mechanisms of control of geospatial information
4-3 Enforcing control

GS5 Dissemination of geospatial information
5-1 Incentives and barriers to sharing geospatial information
5-2 Data sharing among organizations and individuals
5-3 Legal mechanisms for sharing geospatial information
5-4 Balancing security and open access to geospatial information

GS6 Ethical aspects
6-1 Ethics and geospatial information
6-2 Codes of ethics for geospatial professionals

GS7 Critical GIS
7-1 Epistemological critiques
7-2 Ethical critiques
7-3 Feminist critiques
7-4 Social critiques

Organizational & Institutional Aspects

OI1 Origins of GI S&T
1-1 Public sector origins
1-2 Private sector origins
1-3 Academic origins
1-4 Learning from experience
1-5 Future trends

OI2 Managing the GI system operations and infrastructure
2-1 Managing the GI system operations and infrastructure
2-2 Ongoing GI system revision
2-3 Budgeting for GI system management
2-4 Database administration
2-5 System management
2-6 User support

OI3 Organizational structures and procedures
3-1 Organizational models for GI system management
3-2 Organizational models for coordinating GI systems and/or program participants and stakeholders
3-3 Integrating GI S&T with management information systems (MIS)

OI4 GI S&T workforce themes
4-1 GI S&T staff development
4-2 GI S&T positions and qualifications
4-3 GI S&T training and education
4-4 Incorporating GI S&T into existing job classifications

OI5 Institutional and inter-institutional aspects
5-1 Spatial data infrastructures
5-2 Adoption of standards
5-3 Technology transfer
5-4 Spatial data sharing among organizations
5-5 Openness
5-6 Balancing data access, security, and privacy
5-7 Implications of distributed GI S&T
5-8 Interorganizational and vendor GI systems

OI6 Coordinating organizations
6-1 Federal agencies and national and international organizations and programs
6-2 State and regional coordinating bodies
6-3 Professional organizations
6-4 Publications
6-5 The geospatial community
6-6 The geospatial industry

Knowledge Area

Unit
Topic
Topic

Core Unit
Topic
Topic

Conforms to 15 February 2006 manuscript Body of Knowledge
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CORE KNOWLEDGE AREAS ONLY

Knowledge Area AM. Analytical Methods

This knowledge area encompasses a wide variety of operations whose objective is to derive analytical results from geospatial data. Data analysis seeks to understand both first-order (environmental) effects and second-order (interaction) effects. Approaches that are both data-driven (exploration of geospatial data) and model-driven (testing hypotheses and creating models) are included. Data driven techniques derive summary descriptions of data, evoke insights about characteristics of data, contribute to the development of research hypotheses, and lead to the derivation of analytical results. The goal of model-driven analysis is to create and test geospatial process models. In general, model-driven analysis is an advanced knowledge area where previous experience with exploratory spatial data analysis would constitute a desired prerequisite. Visual tools for data analysis are covered in Knowledge Area CV Cartography and Visualization and many of the fundamental principles required to ground data analysis techniques are introduced in Knowledge Area CF Conceptual Foundations. Image processing techniques are considered in Knowledge Area GD Geospatial Data. All of the methods described in this knowledge area are more or less sensitive to data error and uncertainty, as covered in Unit GC8 Uncertainty and Unit GD6 Data quality. Mastery of the educational objectives outlined in this knowledge area requires knowledge and skills in mathematics, statistics, and computer programming.

***Unit AM3 Geometric measures**
For simple data exploration, GIS offers many basic geometric operations that help in extracting meaning from sets of data or for deriving new data for further analysis. Concepts on which these operations are based are addressed in Unit CF3 Domains of geographic information and Unit CF5 Relationships.

Topic AM3-1 Distances and lengths

- Describe several different measures of distance between two points (e.g., Euclidean, Manhattan, network distance, spherical)
- Explain how different measures of distance can be used to calculate the spatial weights matrix
- Explain why estimating the fractal dimension of a sinuous line has important implications for the measurement of its length
- Explain how fractal dimension can be used in practical applications of GIS
- Explain the differences in the calculated distance between the same two places when data used are in different projections
- Outline the implications of differences in distance calculations on real world applications of GIS, such as routing and determining boundary lengths and service areas
- Estimate the fractal dimension of a sinuous line

Topic AM3-2 Direction

- Define “direction” and its measurement in different angular measures
- Compare and contrast how direction is determined and stated in raster and vector data
- Describe operations that can be performed on qualitative representations of direction
- Explain any differences in the measured direction between two places when the data are presented in a GIS in different projections
- Compute the mean of directional data

Topic AM3-3 Shape

- Identify situations in which shape affects geometric operations
- Explain what is meant by the convex hull and minimum enclosing rectangle of a set of point data
- Explain why the shape of an object might be important in analysis
- Exemplify situations in which the centroid of a polygon falls outside its boundary

- Compare and contrast different shape indices, include examples of applications to which each could be applied
- Develop a method for describing the shape of a cluster of similarly valued points by using the concept of the convex hull
- Develop an algorithm to determine the skeleton of polygons
- Find centroids of polygons under different definitions of a centroid and different polygon shapes
- Calculate several different shape indices for a polygon dataset

Topic AM3-4 Area
- List reasons why the area of a polygon calculated in a GIS might not be the same as the real world object it describes
- Explain how variations in the calculation of area may have real world implications, such as calculating density
- Demonstrate how the area of a region calculated from a raster data set will vary by resolution and orientation
- Outline an algorithm to find the area of a polygon using the coordinates of its vertices

Topic AM3-5 Proximity and distance decay
- Describe real world applications where distance decay is an appropriate representation of the strength of spatial relationships (e.g., shopping behavior, property values)
- Describe real world applications where distance decay would NOT be an appropriate representation of the strength of spatial relationships (e.g., distance education, commuting, telecommunications)
- Explain the rationale for using different forms of distance decay functions
- Explain how a semi-variogram describes the distance decay in dependence between data values
- Outline the geometry implicit in classical “gravity” models of distance decay
- Plot typical forms for distance decay functions
- Write typical forms for distance decay functions
- Write a program to create a matrix of pair-wise distances among a set of points

Topic AM3-6 Adjacency and connectivity
- List different ways connectivity can be determined in a raster and in a polygon dataset
- Describe real world applications where adjacency and connectivity are a critical component of analysis
- Explain the nine-intersection model for spatial relationships
- Demonstrate how adjacency and connectivity can be recorded in matrices
- Calculate various measures of adjacency in a polygon dataset
- Create a matrix describing the pattern of adjacency in a set of planar enforced polygons

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***Unit AM4 Basic analytical operations**
This small set of analytical operations is so commonly applied to a broad range of problems that their inclusion in software products is often used to determine if that product is a “true” GIS. Concepts on which these operations are based are addressed in Unit CF3 Domains of geographic information and Unit CF5 Relationships.

Topic AM4-1 Buffers
- Compare and contrast raster and vector definitions of buffers
- Explain why a buffer is a contour on a distance surface
- Outline circumstances in which buffering around an object is useful in analysis

Topic AM4-2 Overlay
- Explain why the process “dissolve and merge” often follows vector overlay operations
- Explain what is meant by the term “planar enforcement”

- Outline the possible sources of error in overlay operations
- Exemplify applications in which overlay is useful, such as site suitability analysis
- Compare and contrast the concept of overlay as it is implemented in raster and vector domains
- Demonstrate how the geometric operations of intersection and overlay can be implemented in GIS
- Demonstrate why the registration of datasets is critical to the success of any map overlay operation
- Formalize the operation called map overlay using Boolean logic

Topic AM4-3 Neighborhoods
- Discuss the role of Voronoi polygons as the dual graph of the Delauney triangulation
- Explain how the range of map algebra operations (local, focal, zonal and global) relate to the concept of neighborhoods
- Explain how Voronoi polygons can be used to define neighborhoods around a set of points
- Outline methods that can be used to establish non-overlapping neighborhoods of similarity in raster datasets
- Create proximity polygons (Thiessen/Voronoi polygons) in point datasets
- Write algorithms to calculate neighborhood statistics (minimum, maximum, focal flow) using a moving window in raster datasets

Topic AM4-4 Map algebra
- Describe how map algebra performs mathematical functions on raster grids
- Describe a real modeling situation in which map algebra would be used (e.g., site selection, climate classification, least-cost path)
- Explain the categories of map algebra operations (i.e., local, focal, zonal, and global functions)
- Explain why georegistration is a precondition to map algebra
- Differentiate between map algebra and matrix algebra using real examples
- Perform a map algebra calculation using command line, form-based, and flow charting user interfaces

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Knowledge Area CF. Conceptual Foundations

The GIScience perspective is grounded in spatial thinking. The aim of this knowledge area is to recognize, identify, and appreciate the explicit spatial, spatio-temporal, and semantic components of the geographic environment at an ontological and epistemological level in preparation for modeling the environment with geographic data and analysis. In order to do this, one must understand the nature of space and time as a context for geographic phenomena. This knowledge area covers the ways in which views of the geographic environment depend on philosophical viewpoints, physics, human cognition, society, and the task at hand. This knowledge area also requires an understanding of the fundamental principles in the discipline of geography, the "language" of spatial tasks. On a more advanced level, this area incorporates mathematical and graphical models that formalize these concepts, such as set theory, algebra, and semantic nets.

Because of its wide range of foundational principles, this knowledge area forms a basis for the other knowledge areas. Wise design and use of geospatial technologies requires an understanding of the nature of geographic information, the social and philosophical context of geographic information, and the principles of geography. This knowledge area is especially closely tied to Knowledge Areas DM Data Modeling and DA Design Aspects, as generic data models (such as raster and vector) and application designs need to be grounded in sound conceptual models.

The foundations of geographic information have developed over several decades. Philosophical and scientific views on the nature of space and time have evolved since the ancient Greeks. Early papers during the quantitative revolution, such as Berry (1964), began to formalize the structure of information used in geographic inquiry. The fundamental data structures and algorithms comprising the GIS software developed in the 1960's and 1970's were based on implicit "common-sense" conceptual models of geographic information. During the 1980's, several researchers questioned these underlying assumptions. Some were refuted, other confirmed, and many extended. However, the most rapid pace of development in this area was during the 1990's with the rise of *GIScience* as a distinct discipline, and the many cooperative initiatives it comprised. The new millennium has seen some of these foundational principles incorporated into commercial software, thus making theoretical knowledge even more important for practitioners.

It is expected that the concepts in this knowledge area will be learned gradually. An introductory course would cover only a few topics in a cursory manner, an intermediate course on data modeling or data analysis would cover several theoretical topics of practical application, and a number of graduate courses could cover each topic in a research-oriented environment.

Discussion of this knowledge area includes several terms that can have multiple meanings. For the purposes of this document, two in particular require definition:

1. Geographic: Almost any subject or discourse involving earthly phenomena, studied from a spatial perspective at a medium scale (sub-astronomical and super-architectural).

2. Phenomenon: Any subject of geographic discourse that is perceived to be external to the individual, including entities, events, processes, social constructs, and the like.

***Unit CF3 Domains of geographic information**
Geographic phenomena, geographic information, and geographic tasks are described in terms of space, time, and properties. Different theories exist as to the nature and formal representation of these aspects, including space-like dimensions, sets, and phenomenology. Information in each of these three "aspects" is measured and reported with respect to one of several frames of reference or domains, including both absolute and relative approaches. Early frameworks such as that of Berry (1964) and Sinton (1978) were

influential in setting forth the importance of space, time, and theme in GIS. This unit is closely tied to the creation of data models in Knowledge Area DM Data Modeling.

Topic CF3-1 Space

- Define the four basic dimensions or shapes used to describe spatial objects (i.e., points, lines, regions, volumes)
- Differentiate between *absolute* and *relative* descriptions of location
- Differentiate between common-sense, Cartesian/metric, relational, relativistic, phenomenological, social constructivist, and other theories of the nature of space
- Discuss the contributions that different perspectives on the nature of space bring to an understanding of geographic phenomenon
- Justify the discrepancies between the nature of locations in the real world and representations thereof (e.g., towns as points)
- Select appropriate spatial metaphors and models of phenomena to be represented in GIS
- Develop methods for representing non-cartesian models of space in GIS
- Discuss the advantages and disadvantages of the use of cartesian/metric space as a basis for GIS and related technologies

Topic CF3-2 Time

- Differentiate between mathematical and phenomenological theories of the nature of time
- Exemplify different temporal frames of reference: linear and cyclical, absolute and relative
- Recognize the role that time plays in “static” GISystems
- Compare and contrast models of a given spatial process using continuous and discrete perspectives of time
- Select the temporal elements of geographic phenomena that need to be represented in particular GIS applications

Topic CF3-3 Relationships between space and time

- Discuss common prepositions and adjectives (in any particular language) that signify either spatial or temporal relations but are used for both kinds, such as “after” or “longer”
- Compare and contrast the characteristics of spatial and temporal dimensions
- Identify various types of geographic interactions in space and time
- Describe different types of movement and change
- Understand the physical notions of velocity and acceleration which are fundamentally about movement across space through time

Topic CF3-4 Properties

- Define Stevens’ four scales of measurement (nominal, ordinal, interval, ratio)
- Recognize attribute domains that do not fit well into Stevens’ four scales of measurement (nominal, ordinal, interval, ratio), such as cycles, indexes, and hierarchies
- Describe particular geographic phenomena in terms of attributes
- Characterize the domains of attributes in a GIS, including continuous and discrete, qualitative and quantitative, absolute and relative
- Determine the proper uses of attributes based on their domains
- Recognize situations and phenomena in the landscape which cannot be adequately represented by formal attributes, such as aesthetics
- Formalize attribute values and domains in terms of Set Theory
- Compare and contrast the theory that properties are fundamental (and objects are human simplifications of patterns thereof) with the theory that objects are fundamental (and properties are attributes thereof)
- Develop alternative forms of representations for situations in which attributes do not adequately capture meaning

***Unit CF4 Elements of geographic information**

The concepts below form the basic elements of common human conceptions of geographic phenomena. Concepts from many units in this knowledge area have been synthesized to create general conceptual models of geographic information. Attempts to resolve the “object-field debate” have led to attempts to create comprehensive models that bridge these views. Consideration of this unit should also include formal models of these elements in mathematics and other fields. Knowledge Area DM Data Modeling discusses the representation of these elements in digital models.

Topic CF4-1 Discrete entities

- Discuss the human predilection to conceptualize geographic phenomena in terms of discrete entities
- Describe particular entities in terms of space, time, and properties
- Describe the perceptual processes (e.g., edge detection) that aid cognitive objectification
- Compare and contrast differing epistemological and metaphysical viewpoints on the “reality” of geographic entities
- Identify the types of features that need to be modeled in a particular GIS application or procedure
- Identify phenomena that are difficult or impossible to conceptualize in terms of entities
- Describe the difficulties in modeling entities with ill-defined edges
- Describe the difficulties inherent in extending the “tabletop” metaphor of objects to the geographic environment
- Evaluate the effectiveness of GIS data models for representing the identity, existence, and lifespan of entities
- Justify or refute the conception of fields (e.g., temperature, density) as spatially-intensive attributes of (sometimes amorphous and anonymous) entities
- Model “gray area” phenomena, such as categorical coverages (a.k.a. discrete fields), in terms of objects
- Evaluate the influence of scale on the conceptualization of entities

Topic CF4-2 Events and processes

- Compare and contrast the concepts of *continuants* (entities) and *occurrents* (events)
- Compare and contrast the concepts of *event* and *process*
- Describe particular events or processes in terms of identity, categories, attributes, locations, etc.
- Evaluate the assertion that “events and processes are the same thing, but viewed at different temporal scales”
- Apply or develop formal systems for describing continuous spatio-temporal processes
- Describe the “actor” role that entities and fields play in events and processes
- Discuss the difficulty of integrating process models into GIS software based on the entity and field views, and methods used to do so

Topic CF4-3 Fields in space and time

- Define a field in terms of properties, space, and time
- Identify applications and phenomena that are not adequately modeled by the field view
- Identify examples of discrete and continuous change found in spatial, temporal, and spatio-temporal fields
- Differentiate various sources of fields, such as substance properties (e.g., temperature), artificial constructs (e.g., population density), and fields of potential or influence (e.g., gravity)
- Formalize the notion of field using mathematical functions and Calculus
- Relate the notion of field in GIS to the mathematical notions of scalar and vector fields
- Recognize the influences of scale on the perception and meaning of fields
- Evaluate the representation of movement as a field of location over time [e.g. $<x,y,z> = f(t)$]
- Evaluate the field view’s description of “objects” as conceptual discretizations of continuous patterns

Topic CF4-4 Integrated models

- Discuss the contributions of early attempts to integrate the concepts of space, time, and attribute in geographic information, such as Berry (1964) and Sinton (1978)
- Illustrate major integrated models of geographic information, such as Peuquet's Triad, Mennis' Pyramid, and Yuan's Three-Domain
- Determine whether phenomena or applications exist that are not adequately represented in an existing comprehensive model
- Discuss the degree to which these models can be implemented using current technologies
- Design data models for specific applications based on these comprehensive general models

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Knowledge Area CV. Cartography and Visualization

Cartography and visualization primarily relate to the visual display of geographic information. This knowledge area addresses the complex issues involved in effective visual thinking and communication of geospatial data and of the results of geospatial analysis. This knowledge area reflects much of the domain of cartography and visualization, although some concepts and skills in these areas can be found in other knowledge areas. For example, the process of visualization encompasses aspects of analysis as well as cartography. Specifically, visualization is currently being reformulated as *visual analytics* in the context of homeland security.

***Unit CV2 Data considerations**
This unit relates to data compilation and management for cartography and visualization. Certain data manipulations can, and should, be made prior to symbolization and labeling, although they are not made without consideration of the symbolization and labeling that will be applied. The symbolization and labeling requirements will shape the way the data used in the displays are selected, generalized, classified, projected, and otherwise manipulated. In this section, the considerations for data selection, subsequent abstraction for cartographic and visualization purposes, and manipulations for display are considered. Note that fundamental related topics such as projections and datums are introduced in Knowledge Area GD Geospatial Data rather than here. The procedures for implementing the tasks described in this unit are primarily covered in Unit DN2 Generalization and aggregation.

Topic CV2-1 Source materials for mapping

- List the data required to compile a map that conveys a specified message
- List the data required to explore a specified problem
- Discuss the extent, classification and currency of government data sources and their influence on mapping
- Discuss the issue of conflation of data from different sources or for different uses as it relates to mapping
- Describe a situation in which it would be acceptable to use smaller scale data source for compilation to compile a larger scale map
- Describe the copyright issues involved in various cartographic source materials
- Explain how data acquired from primary sources, such as satellite imagery and GPS, differ from data compiled for map sources such as Digital Line Graphs (DLGs)
- Explain how data acquired from primary sources, such as satellite imagery and GPS, differ from data compiled from maps, such as DLGs
- Explain how digital data compiled from map sources (such as DLGs) influences how subsidiary maps are compiled and used
- Explain how geographic names databases (i.e., gazetteer) are used for mapping
- Explain how the inherent properties of digital data (such as Digital Elevation Models, DEMs) influences how maps can be compiled from them
- Identify the types of attributes that will be required to map a particular distribution for selected geographic features
- Determine the standard scale of compilation of government data sources
- Assess the data quality of a source dataset for appropriateness for a given mapping task, including an evaluation of the data resolution, extent, currency or date of compilation, and level of generalization in the attribute classification
- Compile a map using at least three data sources

Topic CV2-2 Data abstraction: classification, selection, and generalization

- Discuss advantages and disadvantages of various data classification methods for choropleth mapping, including equal interval, quantiles, mean-standard deviation, natural breaks, and “optimal” methods

- Discuss the limitations of current technological approaches to generalization for mapping purposes
- Explain how generalization of one data theme can and must be reflected across multiple themes (e.g., if the river moves, the boundary, roads and towns also need to move)
- Explain how the decisions for selection and generalization are made with regard to symbolization in mapping
- Explain why the reduction of map scale sometimes results in the need for mapped features to be reduced in size and moved
- Identify mapping tasks that require each of the following: smoothing, aggregation, simplification, and displacement
- Illustrate specific examples of feature elimination and simplification suited to mapping at smaller scales
- Demonstrate how different classification schemes produce very different maps from a single set of interval or ratio data
- Apply appropriate selection criteria to change the display of map data to a smaller scale
- Write algorithms to perform equal interval, quantiles, mean-standard deviation, natural breaks, and “optimal” classification for choropleth mapping

Topic CV2-3 Projections as a map design issue

- Identify the map projections commonly used for certain types of maps
- Identify the most salient projection property of various generic mapping goals (e.g., choropleth map, navigation chart, flow map, etc.)
- Explain why certain map projection properties have been associated with specific map types
- Select appropriate projections for world or regional scales that are suited to specific map purposes and phenomena with specific directional orientations or thematic areal aggregations
- Determine the parameters needed to optimize the pattern of scale distortion that is associated with a given map projection for a particular mapping goal and area of interest
- Diagnose an inappropriate projection choice for a given map and suggest an alternative
- Construct a map projection suited to a given purpose and geographic location

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***Unit CV3 Principles of map design**

This topic covers basic design principles that are used in mapping and visualization, as well as cartographic design principles specific to the display of geographic data. Both page layout design and data display are addressed.

Topic CV3-1 Map design fundamentals

- List the major factors that should be considered in preparing a map
- Describe the design needs of special purpose maps such as subdivision plans, cadastral mapping, drainage plans, nautical charts, aeronautical charts, geological maps, military maps, wire-mesh volume maps, and 3D plans of urban change
- Describe differences in design needed for a map that is to be viewed on the Internet versus as a 5x7 foot poster, including a discussion of the effect of viewing distance, lighting, and media type
- Discuss how to create an intellectual and visual hierarchy on maps
- Discuss the differences between maps that use the same data but are for different purposes and intended audiences
- Discuss Tufte’s influence (or lack thereof) on cartographic design
- Critique the graphic design of several maps in terms of balance, legibility, clarity, visual contrast, figure-ground organization, and hierarchal organization
- Critique the layout of several maps, taking into account the map audience and purpose and the graphic design (visual balance, hierarchy, figure-ground), as well as the map components (north arrow, scale bar, and legend)
- Design maps that are appropriate for users with vision limitations
- Apply one or more Gestalt principles to achieve appropriate figure-ground for map elements

- Prepare different map layouts using the same map components (main map area, inset maps, titles, legends, scale bars, north arrows, grids and graticule) to produce maps with very distinctive purposes
- Prepare different maps using the same data for different purposes and intended audiences (e.g. expert and novice hikers)

Topic CV3-2 Basic concepts of symbolization
- List the variables used in the symbolization of map data for visual, tactile, haptic, auditory, and dynamic display
- Identify the visual variables (size, lightness, shape, hue, etc.) and graphic primitives (points, lines, areas) commonly used in maps to represent various geographic features at all attribute measurement scales (nominal, ordinal, interval, ratio)
- Illustrate how a single geographic feature can be represented by various graphic primitives e.g. land surface as a set of elevation points, as contour lines, as hypsometric layers or tints, and as a hillshaded surface)
- Select effective symbols for map features based on the dimensionality and attributes of the geographic phenomena being mapped
- Design map symbols with sufficient contrast to be distinguishable by typical users

Topic CV3-3 Color for cartography and visualization
- List the range of factors that should be considered in selecting colors
- Describe color decisions made for various production workflows
- Describe how cultural differences with respect to color associations impact map design
- Describe the common color models used in mapping
- Determine the CMYK (cyan, magenta, yellow, and black) primary amounts in a selection of colors
- Discuss the role of “gamut“ in choosing colors that can be reproduced on various devices and media
- Explain how real-world connotations (e.g. blue=water, white=snow) can be used to determine color selections on maps
- Exemplify colors for different forms of harmony, concordance, and balance
- Estimate RGB (red, green, blue) primary amounts in a selection of colors
- Plan color proofing suited for checking a map publication job
- Select a color scheme (e.g., qualitative, sequential, diverging, spectral) that is appropriate for a given map purpose and variable
- Select colors appropriate for map readers with color limitations
- Specify a set of colors in device-independent Commision Internationale de L'Eclairage (CIE) specifications

Topic CV3-4 Typography for cartography and visualization
- Name the authorities used to confirm the spelling of geographic names for a specific mapping project
- Describe the role of labels in assisting readers in understanding feature locations (e.g., label to the right of point, label follows line indicating its position, area label assists understanding extent of feature and feature type)
- Compare and contrast the strengths and limitations of methods for automatic label placement
- Compare and contrast the relative merits of having map labels placed dynamically versus having them saved as annotation data
- Explain how text properties can be used as visual variables to graphically represent the type and attributes of geographic features
- Explain how to label features with indeterminate boundaries (canyons, oceans, etc.)
- Position labels on a map to name point, line, and area features
- Apply the appropriate technology to place name labels on a map using a geographic names database

- Set type font, size, style and color for labels on a map by applying basic typography design principles
- Create a set of mapping problems that can be used to illustrate point, line, and area label conventions for placing text on maps
- Solve a labeling problem for a dense collection of features on a map using minimal leader lines

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***Unit CV6 Map use and evaluation**
Map use addresses how the user utilizes the map or visualization for map reading, analysis, discovery and interpretation. Map reading is the translation of the graphic or other representation of features into a mental image of the environment. It involves the identification of map symbols and the interpretation of the symbology to understand the geographic phenomena. Map analysis allows the reader to analyze and understand the spatial structure of and relationships among features on a map. Visualizations often allow discovery of unexpected patterns and associations in data sets. Interpretation allows the reader to seek explanations for unusual or interesting patterns on maps. The reader can either look at one map and seek explanations for the patterns observed or look at several maps and seek understanding of the variations (perhaps through time) between the maps. Evaluation leads to better understanding of the user experience with the map or visualization. This unit also examines the impact of uncertainty in the data on the map use and evaluation of the use of the displayed data by the map reader. Technical aspects of uncertainty are covered in more depth in Unit GC8 Uncertainty and Unit GD6 Data quality.

Topic CV6-1The power of maps
- Describe how maps such as topographic maps are produced within certain relations of power and knowledge.
- Discuss how the choices used in the design of a road map will influence the experience visitors may have of the area
- Explain how legal issues impact the design and content of such special purpose maps as subdivision plans, nautical charts and cadastral maps
- Exemplify maps that illustrate the provocative, propaganda, political, and persuasive nature of maps and geospatial data
- Demonstrate how different methods of data classification for a single dataset can produce maps that will be interpreted very differently by the user
- Deconstruct the silences (feature omissions) on a map of a personally well known area
- Construct two maps about a conflict or war producing one supportive of each side’s viewpoint

Topic CV6-2 Map reading
- Discuss the pros and cons of using conventional symbols (e.g., blue is water, green is vegetation, Swiss cross is a hospital) on a map
- Explain how the anatomy of the eye and its visual sensor cells affect how one sees maps, in terms of attention, acuity, focus, and color
- Explain how memory limitations effect map reading tasks
- Find specified features on a topographic map (e.g., gravel pit, mine entrance, well, land grant)
- Match map labels to the corresponding features
- Match the symbols on a map to the corresponding explanations in the legend
- Execute a well designed legend that facilitates map reading

Topic CV6-3 Map interpretation
- Compare and contrast the interpretation of landscape, geomorphic features, and human settlement types shown on a series of topographic maps from several different countries
- Match features on a map to corresponding features in the world
- Identify the landforms represented by specific patterns in contours on a topographic map
- Hypothesize about geographic processes by synthesizing the patterns found on one or more thematic maps or data visualizations

Topic CV6-4 Map analysis

- Describe maps that can be used to find direction, distance, or position, plan routes, calculate area or volume, or describe shape
- Describe the differences between azimuths, bearings, and other systems for indicating directions
- Explain how maps can be used in determining an optimal route or facility selection
- Explain how maps can be used in terrain analysis (e.g., elevation determination, surface profiles, slope, viewsheds, and gradient)
- Explain how the types of distortion indicated by projection metadata on a map will affect map measurements
- Explain the differences between true north, magnetic north, and grid north directional references
- Compare and contrast the manual measurement of the areas of polygons on a map printed from a GIS with those calculated by the computer and discuss the implications these variations in measurement might have on map use
- Determine feature counts of point, line, and area features on maps
- Analyze spatial patterns of selected point, line and area feature arrangements on maps
- Calculate slope using a topographic map and a DEM
- Calculate the planimetric and actual road distances between two locations on a topographic map
- Create a profile of a cross section through a terrain using a topographic map and a digital elevation model (DEM)
- Measure point-feature movement and point-feature diffusion on maps
- Plan an orienteering tour of a specific length that traverses slopes of an appropriate steepness and crosses streams in places that can be forded based on a topographic map

Topic CV6-5 Evaluation and testing

- Describe the baseline expectations that a particular map makes of its audience
- Discuss the use limitations of the USGS map accuracy standards for a range of projects demanding different levels of precision (e.g., driving directions versus excavation planning)
- Compare and contrast the interpretive dangers (e.g., ecological fallacy, modifiable areal unit problem) that are inherent to different types of maps or visualizations and their underlying geographic data
- Identify several uses for which a particular map is or is not effective
- Identify the particular design choices that make a map more or less effective
- Evaluate the effectiveness of a map for its audience and purpose
- Design a testing protocol to evaluate the usability of a simple graphical user interface
- Perform a rigorous sampled field-check of the accuracy of a map

Topic CV6-6 Impact of uncertainty

- Describe a scenario in which possible errors in a map may impact subsequent decision making, such as a land use decision based on a soils map
- Compare the decisions made using a map with a reliability overlay from those made using a map pair separating data and reliability, both drawn from the same dataset
- Critique the assumption that maps can or should be “accurate”
- Evaluate the uncertainty inherent in a map

Knowledge Area DA. Design Aspects

Proper design, and the validation and verification of design activities, are critical components of work in all areas related to GI S&T. Design failures can negate the best efforts of members of the GIScience community to apply GIScience concepts and technology to the solution of real-world problems. While sharing a number of concerns with general systems analysis, the unique and complex spatial elements of geospatial information provide significant additional challenges. Viable design methodologies are required in GI S&T for building tools to solve real-world problems. The focus of this knowledge area is on the design of applications and databases for a particular need; the design of general-purpose models and tools (e.g., raster, vector) is covered in Knowledge Area DM Data Modeling. In the context of specific implementations, design activities fall into three general classes:

1. Application Design addresses the development of workflows, procedures, and customized software tools for using geospatial technologies and methods to accomplish both routine and unique tasks that are inherently geographic.

2. Analytic Model Design incorporates methods for developing effective mathematical and other models of spatial situations and processes. The design of the analytic model is often influenced by decisions that are made about data models and structures.

3. Database Design concerns the optimal organization of the necessary spatial data in a computer environment in order to efficiently sustain a particular application or enterprise.

Several units in Knowledge Area GD Geospatial Data follow from Knowledge Area DA Design Aspects, especially those that discuss the collection of data in conformance with the designs discussed herein. This knowledge area is also closely related to Knowledge Area OI Organizational and Institutional Aspects, which discusses several issues relating to the management of systems in organizations after they are designed and implemented. Beyond GI S&T, this knowledge area has strong ties to information science and technology (see Gorgone, G. B. & others, 2002, *IS 2000: Model Curriculum Guidelines for Undergraduate Programs in Information Systems,* and Gorgone, G. B. & Gray, P., 2000, *MSIS 2000: Model Curriculum and Guidelines for Graduate Degree Programs in Information Systems),* and to business management in the area of resource planning. Some of the methods of geospatial system design are identical to established methods in information system design, while others are unique.

***Unit DA4 Database design**

The effective design of geospatial databases should follow the established methods and principles of database modeling and design developed in computer science. The basic method is a three-step process, generally called the conceptual, logical, and physical models, transforming the application from very human-oriented to machine-oriented. Several standards and software tools exist to aid the process of database design. This unit relies heavily on the concepts developed in Knowledge Area CF Conceptual Foundations and the general-purpose data models developed in Knowledge Area DM Data Modeling.

Topic DA4-1 Modeling tools

- Compare and contrast the relative merits of various textual and graphical tools for data modeling, including E-R diagrams, UML, and XML
- Create conceptual, logical, and physical data models using automated software tools
- Create E-R and UML diagrams of database designs

Topic DA4-2 Conceptual model

- Define entities and relationships as used in conceptual data models
- Describe the degree to which attributes need to be modeled in the conceptual modeling phase
- Explain the goals behind the conceptual modeling phase of design
- Deconstruct an application use case into conceptual components

- Create a conceptual model diagram of data needed in a geospatial application or enterprise database
- Design application-specific conceptual models

Topic DA4-3 Logical models

- Differentiate between conceptual and logical models, in terms of the level of detail, constraints, and range of information included
- Define the cardinality of relationships
- Explain the various types of cardinality found in databases
- Distinguish between the incidental and structural relationships found in a conceptual model
- Determine which relationships need to be stored explicitly in the database
- Evaluate the various general data models common in GI S&T for a given project, and select the most appropriate solutions
- Create logical models based on conceptual models and general data models using UML or other tools

Topic DA4-4 Physical models

- Differentiate between logical and physical models, in terms of the level of detail, constraints, and range of information included
- Recognize the constraints and opportunities of a particular choice of software for implementing a logical model
- Create physical model diagrams, using UML or other tools, based on logical model diagrams and software requirements
- Create a complete design document ready for implementation

Knowledge Area DM. Data Modeling

This knowledge area deals with representation of formalized spatial and spatio-temporal reality through data models and the translation of these data models into data structures that are capable of being implemented within a computational environment (i.e., within a GIS). Data models provide the means for formalizing the spatio-temporal conceptualizations that will be translated into computational data structures. Examples of spatial data model types are discrete (object–based), continuous (location–based), dynamic, and probabilistic. Database management systems and their application to geospatial data are included within this knowledge area. Data structures represent the operational implementation of data models within a computational environment. Mastery of the objectives presented in this knowledge area require knowledge and skills presented in the bodies of knowledge of allied fields, including Computer Science (ACM/IEEE-CS Joint Task Force, 2001) and Information Systems (Gorgone & Gray, 2000; Gorgone & others, 2002). The topics presented here are based on concepts covered in Knowledge Area CF Conceptual Foundations.

***Unit DM2 Database management systems**
This unit is considers the use of database management systems (DBMS) in a geographic context, in particular, and evolution of modern database design technologies to better handle geographic data in its various forms. The form of structured query language (SQL) and its use in querying databases is covered in Unit AM2 Query operations and query languages. The design of databases specific to a particular application is discussed in Unit DA4 Database Design. These concepts are also considered in the body of knowledge of the allied field of Computer Science (ACM/IEEE 2001).

Topic DM2-1 Coevolution of DBMS and GIS

- Demonstrate how DBMS are currently used in conjunction with GIS
- Explain why some of the older DBMS are now of limited use within GIS
- Diagram Hierarchical DBMS architecture
- Diagram network DBMS architecture
- Differentiate among network, hierarchical and relational database structures, and their uses and limitations for geographic data storage and processing
- Describe the geo-relational model (or dual architecture) approach to GIS DBMS

Topic DM2-2 Relational DBMS

- Explain the advantage of the relational model over earlier database structures including spreadsheets
- Demonstrate how search and relational join operations provide results for a typical GIS query and other simple operations using the relational DBMS within a GIS software application
- Define the basic terms used in relational database management systems (e.g., tuple, relation, foreign key, SQL, relational join)
- Discuss the efficiency and costs of normalization
- Describe the entity-relationship diagram approach to data modeling
- Explain how entity-relationship diagrams are translated into relational tables
- Describe the problems associated with failure to follow the first and second normal forms (including data confusion, redundancy, and retrieval difficulties)
- Create an SQL query that extracts data from related tables

Topic DM2-3 Object-oriented DBMS

- Describe the basic elements of the object-oriented paradigm, such as inheritance, encapsulation, methods, and composition
- Differentiate between object-oriented programming and object-oriented databases
- Evaluate the degree to which the object oriented paradigm does or does not approximate cognitive structures

- Explain how the principle of inheritance can be implemented using an object-oriented programming approach
- Defend or refute the notion that the Extensible Markup Language (XML) is a form of object-oriented database
- Explain how the properties of object orientation allows for combining and generalizing objects
- Evaluate the advantages and disadvantages of object-oriented databases compared to relational databases, focusing on representational power, data entry, storage efficiency, and query performance
- Implement a GIS database design in an off-the-shelf object-oriented database

Topic DM2-4 Extensions of the relational model

- Explain why early attempts to store geographic data in standard relational tables failed
- Describe extensions of the relational model designed to represent geospatial and other semi-structured data, such as stored procedures, Binary Large Objects (BLOBs), nested tables, abstract data types, and spatial data types
- Describe standards efforts relating to relational extensions, such as SQL:1999 and SQL-MM
- Evaluate the degree to which an available object-relational database management system approximates a true object-oriented paradigm
- Evaluate the adequacy of contemporary proprietary database schemes to manage geospatial data

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***Unit DM3 Tessellation data models**
"Tessellation" partitions a continuous surface into a set of non-overlapping polygons that cover the surface without gaps. Tessellation data models represent continuous surfaces with sets of data values that correspond to partitions. The theoretical foundations for a field-centered view of geographic information are covered in Knowledge Area CF Conceptual Foundations. Tessellated georeferencing systems are considered in Knowledge Area GD Geospatial Data, Unit GD3. Analytical methods for surfaces and other tessellations are considered in Knowledge Area AM Analytical Methods.

Topic DM3-1 Grid representations

- Explain how grid representations embody the field-based view
- Differentiate among a lattice, a tessellation, and a grid
- Explain how terrain elevation can be represented by a regular tessellation and by an irregular tessellation
- Identify the national framework datasets based on a grid model

Topic DM3-2 The raster model

- Define basic terms used in the raster data model (e.g., cell, row, column, value)
- Explain how the raster data model instantiates a grid representation
- Interpret the header of a standard raster data file
- Compare and contrast the raster with other types of regular tessellations for geographic data storage
- Compare and contrast the raster with other types of regular tessellations for geographic data analysis
- Write a program to read and write a raster data file

Topic DM3-3 Grid compression methods

- Illustrate the existing methods for compressing gridded data (e.g., run length encoding, Lempel-Ziv, wavelets)
- Differentiate between lossy and lossless compression methods
- Evaluate the relative merits of grid compression methods for storage
- Explain the advantage of wavelet compression

Topic DM3-4 The hexagonal model

- Illustrate the hexagonal model
- Exemplify the uses (past and potential) of the hexagonal model
- Explain the limitations of the grid model compared to the hexagonal model

Topic DM3-5 The Triangulated Irregular Network (TIN) model

- Describe the architecture of the TIN model
- Demonstrate the use of the TIN model for different statistical surfaces (e.g., terrain elevation, population density, disease incidence) in a GIS software application
- Describe how to generate a unique TIN solution using Delauney triangulation
- Construct a TIN manually from a set of spot elevations
- Delineate a set of break lines that improve the accuracy of a TIN
- Describe the conditions under which a TIN might be more practical than GRID

Topic DM3-6 Resolution

- Relate the concept of grid cell resolution to the more general concept of "support" and granularity
- Illustrate the impact of grid cell resolution on the information that can be portrayed
- Evaluate the implications of changing grid cell resolution on the results of analytical applications by using GIS software
- Evaluate the ease of measuring resolution in different types of tessellations

Topic DM3-7 Hierarchical data models

- Illustrate the quadtree model
- Describe the advantages and disadvantages of the quadtree model for geographic database representation and modeling
- Describe alternatives to quadtrees for representing hierarchical tessellations (e.g., hextrees, r-trees, pyramids)
- Explain how quadtrees and other hierarchical tessellations can be used to index large volumes of raster or vector data
- Implement a format for encoding quadtrees in a data file

***Unit DM4 Vector and object data models**

Vector data models represent discrete entities by delineating points, lines, boundaries, and nodes as sets of coordinate values with associated attributes. This unit also examines recent methods and strategies for representing information in a more human-centered and natural way that goes beyond traditional vector models for representing an object-based view. Linear referencing systems are considered in Unit GD3 Georeferencing systems, and analytical methods for vector data are considered in Knowledge Area AM Analytical Methods. The theoretical foundations for an object-centered view of geographic information are covered in Knowledge Area CF Conceptual Foundations. Topics in this unit are also considered in the body of knowledge of the allied field of Computer Science (ACM/IEEE-CS Joint Task Force, 2001).

Topic DM4-1 Geometric primitives

- Identify the three fundamental dimensionalities used to represent points, lines, and areas
- Describe the data models used to encode coordinates as points, lines, or polygons
- Critique the assumptions that are made in representing the world as points, lines, and polygons
- Evaluate the correspondence between geographic phenomena and the shapes used to represent them

Topic DM4-2 The spaghetti model

- Identify a widely-used example of the spaghetti model (e.g., AutoCAD DWF, ESRI shapefile)
- Describe how geometric primitives are implemented in the spaghetti model as independent objects without topology
- Explain how the spaghetti data model embodies an object-based view of the world

- Explain the conditions under which the spaghetti model is useful
- Write a program to read and write a vector data file using a common published format

Topic DM4-3 The topological model
- Define terms related to topology (e.g., adjacency, connectivity, overlap, intersect, logical consistency)
- Illustrate a topological relation
- Explain the advantages and disadvantages of topological data models
- Demonstrate how a topological structure can be represented in a relational database structure
- Exemplify the concept of planar enforcement (e.g., TIN triangles)
- Discuss the role of graph theory in topological structures
- Describe the integrity constraints of integrated topological models (e.g., POLYVRT)
- Discuss the historical roots of the Census Bureau's creation of GBF/DIME as the foundation for the development of topological data structures
- Explain why integrated topological models have lost favor in commercial GIS software, and evaluate the positive and negative impacts of this shift

Topic DM4-4 Classic vector data models
- Illustrate the GBF/DIME data model
- Explain what makes POLYVRT a hierarchical vector data model
- Discuss the advantages and disadvantages of POLYVRT
- Describe the relationship between the GBF/DIME and TIGER structures, the rationale for their design, and their intended primary uses, paying particular attention to the role of graph theory in establishing the difference between GBF/DIME and TIGER files
- Describe a Freeman-Huffman chain code
- Describe the relationship of Freeman-Huffman chain codes to the raster model
- Discuss the impact of early prototype data models (e.g., POLYVRT and GBF/DIME) on contemporary vector formats

Topic DM4-5 The network model
- Define the following terms pertaining to a network: Loops, multiple edges, the degree of a vertex, walk, trail, path, cycle, fundamental cycle
- Demonstrate how a network is a connected set of edges and vertices
- List definitions of networks that apply to specific applications or industries
- Create an adjacency table from a sample network
- Explain how a graph can be written as an adjacency matrix and how this can be used to calculate topological shortest paths in the graph
- Create an incidence matrix from a sample network
- Explain how a graph (network) may be directed or undirected
- Demonstrate how attributes of networks can be used to represent cost, time, distance, or many other measures
- Demonstrate how the star (or forward star) data structure, which is often employed when digitally storing network information, violates relational normal form, but allows for much faster search and retrieval in network databases
- Discuss some of the difficulties of applying the standard process-pattern concept to lines and networks

Topic DM4-6 Linear referencing
- Construct a data structure to contain point or linear geometry for database record events that are referenced by their position along a linear feature
- Demonstrate how linear referenced locations are often much more intuitive and easy to find in the real world than geographic coordinates
- Explain how linear referencing allows attributes to be displayed and analyzed that do not correspond precisely with the underlying segmentation of the network features

- Discuss dynamic segmentation as a process for transforming between linear and planar coordinate systems
- Describe how linear referencing can eliminate unnecessary segmentation of the underlying network features due to attribute value changes over time

Topic DM 4-7 Object-based spatial databases

- Discuss the merits of storing geometric data in the same location as attribute data
- Evaluate the advantages and disadvantages of the object–based data model compared to the layer-based vector data model (topological or spaghetti)
- Describe the architectures of various object-relational spatial data models, including spatial extensions of DBMS, proprietary object-based data models from GIS vendors, and open-source and standards-based efforts
- Discuss the degree to which various object-relational spatial data models approximate a true object-oriented paradigm, and whether they should
- Differentiate between the topological vector data model and spaghetti object data with topological rulebases
- Write a script (in a GIS, database, or Web environment) to read and write data in an object-based spatial database
- Transfer geospatial data from an XML schema to a database

Knowledge Area DN. Data Manipulation

GIS is a cyclical rather than a linear system such as computer aided drafting (CAD) and Computer Assisted Cartographic Systems. Changes in projection, grid systems, data forms, and formats take place during the modeling process for which GIS was designed. Many non-analytical manipulations are necessary to accommodate the analytical power of the GIS. The manipulations of spatial and spatio–temporal data involve three general classes of operation:

1. Their transformation into formats that facilitate subsequent analysis,

2. Generalization and aggregation that affect the accuracy and integrity of the data used for analysis, and

3. Transaction management that allows for the tracking of changes, versioning, and updating without loss of the original data.

Practitioners frequently need to make decisions on when and how to engage in data manipulation. The ability to switch between raster and vector systems without substantial information loss is necessary for effective spatial analysis. Furthermore, knowledge of how particular data types respond to changes in format, organization, scale, resolution, and quality is often paramount to the ability to perform modeling and spatial analysis. During data manipulation operations, it is extremely important to know how to handle error propagation, as discussed in Knowledge Area GC Geocomputation Unit GC8 Uncertainty.

***Unit DN1 Representation transformation**
Other knowledge areas have identified different forms of data structures, data models, projections, and other forms of geospatial data representation. These differences present both opportunities and challenges for analysis and modeling. The ability to transform one representation to another, in a manner that maintains the integrity of the information as much as possible, can enhance the analysis and visualization of geospatial data. The raster and vector data models are described in Units DM3 Tesselation data models and DM4 Vector and object data models. The principles of coordinate systems, datums, and projections are also considered in Knowledge Area GD Geospatial Data.

Topic DN1-1 Impacts of transformations
- Compare and contrast the impacts of different conversion approaches, including the effect on spatial components
- Prioritize a set of algorithms designed to perform transformations based on the need to maintain data integrity [e.g., converting a digital elevation model (DEM) into a TIN]
- Create a flowchart showing the sequence of transformations on a data set (e.g., geometric and radiometric correction and mosaicking of remotely sensed data)

Topic DN1-2 Data model and format conversion
- Identify the conceptual and practical difficulties associated with data model and format conversion
- Describe a workflow for converting a implementing a data model in a GIS involving an Entity-Relationship (E-R) diagram and the Universal Modeling Language (UML)
- Discuss the role of metadata in facilitating conversation of data models and data structures between systems.
- Convert a data set from the native format of one GIS product to another

Topic DN1-3 Interpolation
- Differentiate among common interpolation techniques (e.g., nearest neighbor, bilinear, bicubic)
- Explain how the elevation values in a digital elevation model (DEM) are derived by interpolation from irregular arrays of spot elevations

- Discuss the pitfalls of using secondary data that has been generated using interpolations (e.g., Level 1 USGS DEMs)
- Estimate a value between two known values using linear interpolation (e.g., spot elevations, population between census years)

Topic DN1-4 Vector-to-raster and raster-to-vector conversions

- Explain how the vector/raster/vector conversion process of graphic images and algorithms takes place and how the results are achieved
- Convert vector data to raster format and back using GIS software
- Illustrate the impact of vector/raster/vector conversions on the quality of a dataset
- Create estimated tessellated data sets from point samples or isolines using interpolation operations that are appropriate to the specific situation

Topic DN1-5 Raster resampling

- Discuss the consequences of increasing and decreasing resolution
- Evaluate methods used by contemporary GIS software to resample raster data on-the-fly during display
- Select appropriate interpolation techniques to resample particular types of values in raster data (e.g., nominal using nearest neighbor)
- Resample multiple raster data sets to a single resolution to enable overlay
- Resample raster data sets (e.g., terrain, satellite imagery) to a resolution appropriate for a map of a particular scale

Topic DN1-6 Coordinate transformations

- Cite appropriate applications of several coordinate transformation techniques (e.g., affine, similarity, Molodenski, Helmert)
- Differentiate between polynomial coordinate transformations (including linear) and rubbersheeting
- Describe the impact of map projection transformation on raster and vector data

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***Unit DN2 Generalization and aggregation**

All geospatial data are generalized. Even the most detailed data represent only subsets of reality. Furthermore, data are further generalized for purposes of mapping, visualization, and efficient storage. A variety of generalization techniques have been developed to facilitate this process. All are scale dependent. Aggregation is one form of generalization that transforms large numbers of individual objects into summarized groups. This unit is concerned with the nature of these procedures and their implications for professional practice. Generalization is an important part of cartography (and is therefore discussed conceptually in Unit CV2 Data considerations), but is also a transformation common to many GIS procedures.

Topic DN2-1 Scale and generalization

- Differentiate among the concepts of scale (as in map scale), support, scope, and resolution
- Determine the mathematical relationships among scale, scope, and resolution, including Töpfer's Radical Law
- Defend or refute the statement "GIS data are scaleless"
- Discuss the implications of tradeoff between data detail and data volume
- Select a level of data detail and accuracy appropriate for a particular application (e.g., viewshed analysis, continental land cover change)

Topic DN2-2 Approaches to point, line, and area generalization

- Describe the basic forms of generalization used in applications in addition to cartography (e.g., selection, simplification)
- Discuss the possible effects of generalizing data sets on topological integrity
- Explain why areal generalization is more difficult than line simplification

- Explain the logic of the Douglas-Poiker line simplification algorithm
- Explain the pitfalls of using data generalized for small scale display in a large scale application
- Design an experiment that allows one to evaluate the effect of traditional approaches of cartographic generalization on the quality of digital data sets created from analog originals
- Evaluate various line simplification algorithms by their usefulness in different applications

Topic DN2-3 Classification and transformation of attribute measurement levels

- Identify a variety of likely measurement level transformations (e.g., the classification of ratio data yields ordinal data)
- Discuss the relationship of attribute measurement levels to database query operations
- Describe the pitfalls, in terms of information loss and analytical options, of transforming attribute measurement levels
- Reclassify (group) a nominal attribute domain to fewer, broader classes

Topic DN2-4 Aggregation of spatial entities

- Discuss the conditions that require individual spatial entities to be aggregated (e.g., privacy, security, proprietary interests, data simplification)
- Demonstrate the relationship between district size (resolution/support) and patterns in aggregate data
- Summarize the attributes of individuals within regions using spatial joins
- Demonstrate how changing the geometry of regions changes the data values (e.g., voting patterns before and after redistricting)
- Discuss the potential pitfalls of using regions to aggregate geographic information (e.g., census data)
- Explain the nature and causes of the Modifiable Areal Unit Problem (MAUP)
- Attempt to design aggregation regions that overcome the Modifiable Areal Unit Problem (MAUP)

Knowledge Area GD. Geospatial Data

Geospatial data represent measurements of the locations and attributes of phenomena at or near Earth's surface. Information is data made meaningful in the context of a question or problem. Information is rendered from data by analytical methods. Information quality and value depends to a large extent on the quality and currency of data (though historical data are valuable for many applications). Geospatial data may have spatial, temporal, and attribute (descriptive) components as well as associated metadata. Data may be acquired from primary or secondary data sources. Examples of primary data sources include surveying, remote sensing (including aerial and satellite imaging), the global positioning system (GPS), work logs (e.g., police traffic crash reports), environmental monitoring stations and field surveys. Secondary geospatial or geospatial-temporal data can be acquired by digitizing and scanning analog maps, as well as from other sources, such as governmental agencies.

The legitimacy of geographic information science as a discrete field has been claimed in terms of the unique properties of geospatial data. In a paper in which he coined the term GIScience, Goodchild (1992) identified several such properties, including:

1. Geospatial data represent spatial locations and non-spatial attributes measured at certain times.

2. The Earth's surface is highly complex in shape and continuous in extent.

3. Geospatial data tend to be spatially autocorrelated.

It has long been said that data account for the largest portion of geospatial project costs. While this maxim remains true for many projects, practitioners and their clients now can reasonably expect certain kinds of data to be freely or cheaply available via the World Wide Web. Federal, state, regional, and local government agencies, as well as commercial geospatial data producers, operate clearinghouses that provide access to geospatial data. The U.S. Geological Survey envisions a "National Map" that is nationwide in coverage and updated continuously. Although geospatial data are much more abundant now than they were ten years ago, data quality issues persist. Good data are expensive to produce and to maintain. Proprietary interests impede data accessibility, especially beyond the U.S., where the notion of data as a public good is uncommon.

Standards for geospatial data and metadata are useful in facilitating effective search, retrieval, evaluation, integration with existing data, and appropriate uses. National and international organizations such as the Federal Geographic Data Committee (FGDC) and International Organization for Standards (ISO) develop and promulgate such standards.

***Unit GD1 Earth geometry**
Accurate geospatial data are based upon an accurate model of the shape of the Earth's surface. The Earth's shape is complex and difficult to measure. Approximations of the Earth's shape are used to minimize both positioning error and complexity.

Topic GD1-1 History of understanding Earth's shape

- Describe how man's understanding of the Earth's shape has evolved throughout history
- Describe and critique early efforts to measure the Earth's size and shape
- Explain how technological and mathematical advances have led to more sophisticated knowledge about the Earth's shape
- Describe the contributions of key individuals (e.g., Eratosthenes, Newton, Picard, Bouguer, LaPlace, La Candamine) to man's understanding of the Earth's shape

Topic GD1-2 Approximating the Earth's shape with geoids

- Explain why gravity varies over the Earth's surface

- Explain the concept of an equipotential gravity surface (i.e., a geoid)
- Explain how geoids are modeled
- Explain the role that the U.S. National Geodetic Survey plays in maintaining and developing geoid models

Topic GD1-3 Approximating the geoid with spheres and ellipsoids
- Distinguish between a geoid, an ellipsoid, a sphere, and the terrain surface
- Explain why spheres and ellipsoids are used to approximate geoids
- Describe an application for which it is acceptable to use a sphere rather than an ellipsoid
- Identify the parameters used to define an ellipsoid
- Differentiate the Clarke 1866 and WGS 84 ellipsoids in terms of ellipsoid parameters
- Differentiate between a bi-axial and tri-axial ellipsoid and their applications

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***Unit GD3 Georeferencing systems**
Geospatial referencing systems provide unique codes for every location on the surface of the Earth (or other celestial bodies). These codes are used to measure distances, areas, and volumes, to navigate, and to predict how and where phenomena on the Earth's surface may move, spread, or contract. Point-based, vector coordinate systems specify locations in relation to the origins of planar or spherical grids. Tessellated referencing systems specify locations hierarchically, as sequences of numbers that represent smaller and smaller subdivisions of two- or three dimensional surfaces that approximate the Earth's shape, Linear referencing systems specify locations in relation to distances along a path from a starting point. Tessellation data models are considered in Unit DM3 Tessellation data models, and linear referencing models are considered in Unit DM4 Vector data models.

Topic GD3-1 Geographic coordinate system
- Distinguish between various latitude definitions (e.g., geocentric, geodetic, astronomic latitudes)
- Explain the angular measurements represented by latitude and longitude coordinates
- Locate on a globe the positions represented by latitude and longitude coordinates
- Write an algorithm that converts geographic coordinates from decimal degrees (DD) to degrees, minutes, seconds (DMS) format.
- Using the coordinate grid ticks in the collar of a topographic map and the appropriate interpolation formula, calculate the coordinates of a given location on the map.
- Mathematically express the relationship between Cartesian coordinates and polar coordinates
- Calculate the uncertainty of a ground position defined by latitude and longitude coordinates specified in decimal degrees to a given number of decimal places

Topic GD3-2 Plane coordinate systems
- Explain why plane coordinates are sometimes preferable to geographic coordinates
- Explain what Universal Transverse Mercator (UTM) eastings and northings represent
- Associate UTM coordinates and zone specifications with corresponding position on a world map or globe
- Identify the map projection(s) upon which UTM coordinate systems are based, and explain the relationship between the projection(s) and the coordinate system grid
- Discuss the magnitude and cause of error associated with UTM coordinates
- Differentiate the characteristics and uses of the UTM coordinate system from the Military Grid Reference System (MGRS) and the World Geographic Reference System (GEOREF)
- Explain what State Plane Coordinates system (SPC) eastings and northings represent
- Associate SPC coordinates and zone specifications with corresponding position on a U.S. map or globe
- Identify the map projection(s) upon which SPC coordinate systems are based, and explain the relationship between the projection(s) and the coordinate system grid
- Discuss the magnitude and cause of error associated with SPC coordinates

- Recommend the most appropriate plane coordinate system for applications at different spatial extents and justify the recommendation
- Critique the U.S. Geological Survey's choice of UTM as the standard coordinate system for the U.S. National Map
- Describe the characteristics of the "national grids" of countries other than the U.S.

Topic GD3-3 Tessellated referencing systems
- Explain the concept "quadtree"
- Describe the octahedral quarternary triangulated mesh georeferencing system proposed by Dutton
- Discuss the advantages of hierarchical coordinates relative to geographic and plane coordinate systems

Topic GD3-4 Linear referencing systems
- Describe an application in which a linear referencing system is particularly useful
- Discuss the magnitude and cause of error generated in the transformation from linear to planar coordinate systems
- Explain how a network can be used as the basis for reference as opposed to the more common rectangular coordinate systems
- Explain how the datum associated with a linear referencing system differs from a horizontal or vertical datum
- Identify several different linear referencing methods (e.g., mileposts, reference posts, link and node) and compare them to planar grid systems
- Identify the characteristics that all linear referencing systems have in common

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***Unit GD4 Datums**
"Horizontal" datums define the geometric relationship between a coordinate system grid and the Earth's surface, where the Earth's surface is approximated by an ellipsoid or other figure. "Vertical" datums are elevation reference surfaces such as mean sea level.

Topic GD4-1 Horizontal datums
- Define "horizontal datum" in terms of the relationship between a coordinate system and an approximation of the Earth's surface
- Describe the limitations of a Molodenski transformation and in what circumstances a higher parameter transformation such as Helmert may be appropriate
- Discuss appropriate applications of the various datum transformation options
- Explain the difference between NAD 27 and NAD 83 in terms of ellipsoid parameters
- Explain the difference in coordinate specifications for the same position when referenced to NAD 27 and NAD 83
- Explain the methodology employed by the U.S. National Geodetic Survey to transform control points from NAD 27 to NAD 83
- Explain the rationale for updating NAD27 to NAD83
- Explain why all GPS data are originally referenced to the WGS 84 datum
- Identify which datum transformation options that are available and unavailable in a GIS software package
- Outline the historical development of horizontal datums
- Perform a Molodenski transformation manually
- Using a conversion routine maintained by the U.S. National Geodetic Survey, determine the impact of a datum transformation from NAD 27 to NAD 83 for a given location
- Use GIS software to perform a datum transformation

Topic GD4-2 Vertical datums
- Outline the historical development of vertical datums

- Explain how a vertical datum is established
- Differentiate between NAVD 29 and NAVD 88
- Illustrate the difference between a vertical datum and a geoid
- Illustrate the relationship among the concepts ellipsoidal (or geodetic) height, geoidal height, and orthometric elevation (See also Unit GD7-1)

***Unit GD5 Map projections**
Map projections are plane coordinate grids that have been transformed from spherical coordinate grids using mathematical formulae. Inverse projections transform plane coordinates to geographic. Plane coordinate systems are thus based upon map projections. Because transformation from a spherical grid to a flat grid inevitably distorts the geometry of the grid, and because different projection formulae produce different distortion patterns, knowledgeable selection of appropriate map projections for particular uses is critical. Selection criteria for small-scale thematic mapping are considered in Knowledge Area CV Cartography and Visualization, especially Unit CV2 Data considerations, while procedures for transforming data between projections are considered in Unit DN1 Representation transformation.

Topic GD5-1 Map projection properties

- Describe the visual appearance of the Earth's graticule
- Identify and define the four geometric properties of the globe that may be preserved or lost in projected coordinates
- Explain the concept of a "compromise" projection and for which purposes it is useful
- Discuss what a Tissot indicatrix represents and how it can be used to assess projection-induced error
- Interpret a given a projected graticule, continent outlines, and indicatrixes at each graticule intersection in terms of geometric properties preserved and distorted
- Illustrate distortion patterns associated with a given projection class
- Recognize distortion patterns on a map based upon the graticule arrangement
- Explain the kind of distortion that occurs when raster data are projected
- Explain the rationale for the selection of the geometric property that is preserved in map projections used as the basis of the UTM and SPC systems
- Recommend the map projection property that would be useful for various mapping applications, including parcel mapping, route mapping, etc., and justify your recommendations

Topic GD5-2 Map projection classes

- Explain the concept "developable surface" and "reference globe" as conceptual ways of projecting the Earth's surface
- Classify various map projection types by the three main classes of map projections based on developable surfaces
- Classify various map projection types according to the geometric properties preserved
- Illustrate the graticule configurations for "other" projection classes, such as polyconic, pseudocylindrical, etc.
- Explain the mathematical basis by which latitude and longitude locations are projected into *x* and *y* coordinate space

Topic GD5-3 Map projection parameters

- Define key terms such as "standard line," projection "case," latitude and longitude of origin
- Explain how the concepts of the tangent and secant cases relate to the idea of a standard line
- Identify the possible "aspects" of a projection and describe the graticule's appearance in each aspect
- Identify the parameters that allow one to focus a projection on an area of interest
- Use GIS software to produce a graticule that matches a target graticule
- Implement a given map projection formulae in a software program that reads geographic coordinates as input and produces projected (x, y) coordinates as output

Topic GD5-4 Georegistration

- Differentiate rectification and orthorectification
- Explain the role and selection criteria for “ground control points” (GCPs) in the georegistration of aerial imagery
- Identify and explain an equation used to perform image-to-map registration
- Identify and explain an equation used to perform image-to-image registration
- Use GIS software to transform a given dataset to a specified coordinate system, projection, and datum

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***Unit GD6 Data quality**

The ultimate standard of quality is the degree to which a geospatial data set is fit for use in a particular application. That standard varies from one application to another. In general, however, the key criteria are how much uncertainty is present in a data set and how much is acceptable. Judgments about fitness for use may be more difficult when data are acquired from secondary rather than primary sources. Aspects of data quality include accuracy, resolution, and precision. Concepts of data quality, error, and uncertainty are also covered in Knowledge Areas CF Conceptual Foundations (in a theoretical context) and GC Geocomputation (in the context of analysis); the focus here is on the measurement and assessment of data quality.

Topic GD6-1 Geometric accuracy

- State the geometric accuracies associated with the various orders of the U.S. horizontal geodetic control network
- Explain how geometric accuracies associated with the various orders of the U.S. horizontal geodetic control network are assured
- State the approximate number and spacing of control points in each order of the horizontal geodetic control network
- Explain the factors that influence the geometric accuracy of data produced with Global Positioning System (GPS) receivers
- Explain the concept of dilution of precision
- Describe the impact of the concept of dilution of precision on the uncertainty of GPS positioning
- Explain the principle of differential correction in relation to the global positioning system
- Apply the National Map Accuracy Standard to calculate the accuracy associated with the various USGS topographic map scales
- Compare the National Map Accuracy Standard with the ASPRS Coordinate Standard
- In contrast to the National Map Accuracy Standard, explain how the spatial accuracy of a digital road centerlines data set may be evaluated and documented
- Explain the formula for calculating root mean square error
- Compare the concepts of geometric accuracy and topological fidelity
- Describe how geometric accuracy should be documented in terms of the FGDC metadata standard

Topic GD6-2 Thematic accuracy

- Explain the distinction between thematic accuracy, geometric accuracy, and topological fidelity
- Describe the different measurement levels on which thematic accuracy is based
- Describe the component measures and the utility of a misclassification matrix
- Discuss how measures of spatial autocorrelation may be used to evaluate thematic accuracy
- Outline the SDTS and ISO TC211 standards for thematic accuracy

Topic GD6-3 Resolution

- Illustrate and explain the distinction between “resolution,” “precision,” and “accuracy”
- Illustrate and explain the distinctions between spatial resolution, thematic resolution, and temporal resolution

- Discuss the implications of the sampling theorem ($\lambda = 0.5\ \delta$) to the concept of resolution
- Differentiate among the spatial, spectral, radiometric, and temporal resolution of a remote sensing instrument
- Explain how resampling affects the resolution of image data
- Discuss the advantages and potential problems associated with the use of Minimum Mapping Unit (MMU) as a measure of the level of detail in land use, land cover, and soils maps

Topic GD6-4 Precision

- Calculate, in terms of ground area, the uncertainty associated with decimal coordinates specified to three, four, and five decimal places
- Explain the concept of error propagation
- Explain, in general terms, the difference between single and double precision and impacts on error propagation

Topic GD6-5 Primary and secondary sources

- Explain the distinction between primary and secondary data sources in terms of census data, cartographic data, and remotely sensed data
- Describe a scenario in which data from a secondary source may pose obstacles to effective and efficient use

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***Unit GD10 Aerial imaging and photogrammetry**

Since the 1940s aerial imagery has been the primary source of detailed geospatial data for extensive study areas. Photogrammetry is the profession concerned with producing precise measurements from aerial imagery. Aerial imaging and photogrammetry comprise a major component of the geospatial industry. The topics included in this unit do not comprise an exhaustive treatment of photogrammetry, but they are aspects of the field about which all geospatial professionals should be knowledgeable.

Topic GD10-1 Nature of aerial image data

- Explain the phenomenon that is recorded in an aerial image
- Compare and contrast digital and photographic imaging
- Explain the significance of "bit depth" in aerial imaging
- Differentiate oblique and vertical aerial imagery
- Describe the location and geometric characteristics of the “principal point” of an aerial image
- Recognize the distortions and implications of relief displacement and radial distortion in an aerial image

Topic GD10-2 Platforms and sensors

- Compare common sensors—including LIDAR, and airborne panchromatic and multispectral cameras and scanners—in terms of spatial resolution, spectral sensitivity, ground coverage, and temporal resolution

Topic GD10-3 Aerial image interpretation

- Describe the elements of image interpretation
- Use photo interpretation keys to interpret features on aerial photographs
- Using a vertical aerial image, produce a map of land use/land cover classes
- Calculate the nominal scale of a vertical aerial image
- Calculate heights and areas of objects and distances between objects shown in a vertical aerial image

Topic GD10-4 Stereoscopy and orthoimagery

- Explain the relevance of the concept "parallax" in stereoscopic aerial imagery

- Outline the sequence of tasks involved in generating an orthoimage from a vertical aerial photograph
- Evaluate the advantages and disadvantages of photogrammetric methods and LIDAR for production of terrain elevation data
- Specify the technical components of an aerotriangulation system

Topic GD10-5 Vector data extraction

- Describe the source data, instrumentation, and workflow involved in extracting vector data (features and elevations) from analog and digital stereoimagery
- Discuss the extent to which vector data extraction from aerial stereoimagery has been automated
- Discuss future prospects for automated feature extraction from aerial imagery

Topic GD10-6 Mission planning

- Plan an aerial imagery mission in response to a given RFP and map of a study area, taking into consideration vertical and horizontal control, atmospheric conditions, time of year, and time of day

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***Unit GD12 Metadata, standards, and infrastructures**
Governments and businesses alike invest large sums to produce the geospatial data on which much of their operations depend. To maximize returns on these investments, organizations seek to minimize redundancies and facilitate reuse of data resources. One way to achieve efficiencies is to standardize the methods by which organizations encode, structure, document, and exchange geospatial data. See also Knowledge Area OI5 Organizational and Institutional Aspects and OI6 Coordinating Organizations, and Knowledge Area GS GI S&T and Society (especially Unit GS5 Dissemination of geospatial information).

Topic GD12-1 Metadata

- Define “metadata” in the context of the geospatial data set
- Explain the ways in which metadata increases the value of geospatial data
- Outline the elements of the U.S. geospatial metadata standard
- Interpret the elements of an existing metadata document
- Identify software tools available to support metadata creation
- Use a metadata utility to create a geospatial metadata document for a digital database you created
- Formulate metadata for a graphic output that would be distributed to the general public
- Formulate metadata for a geostatistical analysis that would be released to an experienced audience
- Compose data integrity statements for a geostatistical or spatial analysis to be included in graphic output
- Explain why metadata production should be integrated into the data production and database development workflows, rather than treated as an ancillary activity

Topic GD12-2 Content standards

- Differentiate between a controlled vocabulary and an ontology
- Describe a domain ontology or vocabulary – i.e., land use classification systems, surveyor codes, data dictionaries, place names, or benthic habitat classification system
- Describe how a domain ontology or vocabulary facilitates data sharing
- Define “thesaurus” as it pertains to geospatial metadata
- Describe the primary focus of the following content standards: FGDC, Dublin Core Metadata Initiative, and ISO 19115
- Differentiate between a content standard and a profile
- Describe some of the profiles created for the Content Standard for Digital Geospatial Metadata (CSDGM)

Topic GD12-3 Data warehouse

- Differentiate a data warehouse from a database
- Discuss the appropriate use of a data warehouse versus a database
- Differentiate the retrieval mechanisms of data warehouses and databases
- Describe the functions that gazetteers support

Topic GD12-4 Exchange specifications

- Explain the purpose, history, and status of the Spatial Data Transfer Standard (SDTS)
- Describe the characteristics of the Geography Markup Language (GML)
- Identify different levels of information integration
- Identify the level of integration at which the Geography Markup Language (GML) operates
- Describe the geospatial elements of Earth science data exchange specifications, such as the Ecological Metadata Language (EML), Earth Science Markup Language (ESML), and Climate Science Modeling Language (CSML)
- Import data packaged in a standard transfer format to a GIS software package
- Export data from a GIS program to a standard exchange format

Topic GD12-5 Transport protocols

- Explain the relevance of transport protocols to GI S&T
- Describe the characteristics of the Simple Object Access Protocol (SOAP)
- Describe the characteristics of the Z39.50 protocol
- Describe the characteristics of the Open Digital Libraries (ODL) protocol
- Describe the characteristics of the Open Digital Resource Description Framework (RDF) protocol
- Describe the characteristics of the OpeN Data Access Protocol (OPenDAP)
- Describe the characteristics of the Web Ontology Language (OWL)
- Describe the characteristics of the Global Change Master Directory (GCMD)
- Describe the characteristics of the Web Feature Services (WFS) protocols
- Describe the characteristics of the Web Mapping Services (WMS) protocols
- Describe the characteristics of the Web Catalog Services (WCS) protocols
- Create a service that delivers geospatial data over the Internet using a standard transport protocol
- Create an application that consumes Web services using standards transport protocols

Topic GD12-6 Spatial Data Infrastructures

- Explain the vision, history, and status of the U.S. National Spatial Data Infrastructure
- Explain the vision, history, and status of the U.S. National Map
- Compare U.S. initiatives to European geographic information infrastructures
- Explain the vision, history, and status of the Global Spatial Data Infrastructure
- Obtain data from a spatial data infrastructure for a particular application

Knowledge Area GS. GI S&T and Society

Geographic Information Science and Technology exists to serve the society, but it is not a panacea. The history of its development is the sum of fragmented efforts, which have still not been fully integrated. Its potential benefits are often constrained by several factors, and its potential impacts are not fully understood.

Institutional and economic factors limit access to data, technology, and expertise by some of those who need it to make better decisions. Political, ideological, and personal issues aside, organizations invest in GI S&T when estimated benefits outweigh estimated costs. Evaluating costs and benefits is difficult and too often leads to nothing being done, however. For some individuals and groups, costs are prohibitive even though potential benefits are compelling.

The legal framework provides a structure for regulating a number of key aspects of geographic information science, technology, and applications. Legal regimes determine who can claim the exclusive right to hold and use geospatial data, the conditions under which others may have access to the data, and what subsequent uses are permitted. Political struggles arise from conflicting proprietary and public interests about who benefits from geospatial information, and how the power to allocate the use of this information is, or should be, distributed among members of a society. The need to choose among conflicting interests sometimes poses ethical dilemmas for GI S&T professionals.

Because so many public agencies and private organizations rely upon GI S&T for planning, decision-making, and management, GI S&T increasingly affects and is used to direct daily life. Critical approaches to understanding the role of GIS in society equip practitioners to employ GI S&T reflectively. The critical approach specifically questions the assumptions and premises that underlie the economic, legal, and political regimes and institutional structures within which GI S&T is implemented and are also considered in Knowledge Area OI Organizational and Institutional Aspects.

***Unit GS6 Ethical aspects of geospatial information and technology**
Ethics provide frameworks that help individuals and organizations make decisions when confronted with choices that have moral implications. Most professional organizations develop codes of ethics to help their members do the right thing, preserve their good reputation in the community, and help their members develop as a community.

Topic GS6-1 Ethics and geospatial information

- Describe a variety of philosophical frameworks upon which codes of professional ethics may be based
- Discuss the ethical implications of a local government's decision to charge fees for its data
- Describe a scenario in which you would find it necessary to report misconduct by a colleague or friend
- Describe the individuals or groups to which GI S&T professionals have ethical obligations

Topic GS6-2 Codes of ethics for geospatial professionals

- Compare and contrast the ethical guidelines promoted by the GIS Certification Institute (GISCI) and the American Society for Photogrammetry and Remote Sensing (ASPRS)
- Describe the sanctions imposed by ASPRS and GISCI on individuals whose professional actions violate the Codes of Ethics
- Explain how one or more obligations in the GIS Code of Ethics may conflict with organizations' proprietary interests
- Propose a resolution to a conflict between an obligation in the GIS Code of Ethics and organizations' proprietary interests

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Knowledge Area OI. Organizational and Institutional Aspects

This knowledge area considers the management of GI systems—including hardware, software, data, and workforce—within and among private and public organizations. Mastery of the educational objectives in this knowledge area requires complimentary competencies in the allied field of business management. Also considered are local, national, and international organizations concerned with the coordination and effectiveness of GI S&T. The success of these organizations in helping to fulfill the potential of GI S&T to improve the quality of life depends upon the participation and cooperation of GI S&T professionals and the public (see also Knowledge Area GS GI S&T and Society). The knowledge area begins with a consideration of the emergence of GI S&T as a distinct community of practice.

This knowledge area uses the term “GI system” to refer to a particular, semi-closed system of hardware, software, people, and business rules, such as an enterprise GIS. Related topics are considered in Knowledge Area GS GI S&T in Society and Knowledge Area DA Design Aspects.

***Unit OI5 Institutional and inter-institutional aspects**
As GI S&T use extends beyond the traditional in-house data warehouses and Web services (within one organization), the fuzzy boundary between formal and informal organizations and inter-institutional use will have societal and ethical implications within and beyond each organization (related issues are covered in Knowledge Area GS GI S&T in Society).

Topic OI5-1 Spatial data infrastructures

- Explain how clearing houses, metadata, and standards can help facilitate spatial data sharing
- Explain how privacy and commoditization of data impact influences decisions regarding spatial data infrastructures

Topic OI5-2 Adoption of standards

- Compare and contrast the impact effect of time for developing consensus-based standards with immediate operational needs
- Explain how resistance to change affects the adoption of standards in an organization coordinating a GI system
- Explain how a business case analysis can be used to justify the expense of implementing consensus-based standards
- Identify organizations that focus on developing standards related to GI S&T
- Identify standards that are used in GI S&T

Topic OI5-3 Technology transfer

- Explain how an understanding of use of current and proposed technology in other organizations can aid in implementing a GI system

Topic OI5-4 Spatial data sharing among organizations

- Describe the rationale for and against sharing data among organizations
- Describe methods used by organizations to facilitate data sharing
- Describe the barriers to information sharing

Topic OI5-5 Openness

- Assess the status of openness in the GI S&T field
- Differentiate “open standards,” “open source,” and “open systems”
- Discuss the advantages and disadvantages of adopting open systems in the context of a local government
- In the role of a consultant or chief information officer, respond to a client’s or colleague’s question about the future prospects of open standards and systems in GI S&T

Topic OI5-6 Balancing data access, security, and privacy

- Assess the effect of restricting data in the context of the availability of alternate sources of data
- Exemplify areas where post-9/11 changes in policies have restricted or expanded data access

Topic OI5-7 Implications of distributed GI S&T

- Describe the advantages and disadvantages to an organization in using GIS portal information from other organizations
- Describe how inter-organization GIS portals may impact or influence issues related to social equity, privacy and data access
- Discuss how distributed GI S&T may affect the nature of organizations and relationships among institutions.
- Suggest the possible societal and ethical implications of distributed GI S&T.

Topic OI5-8 Inter-organizational and vendor GI systems (software, hardware and systems)

- Describe the advantages and disadvantages to an organization in using GIS portal information from other organizations or entities (private, public, non-profit)
- Describe how inter-organization GIS portals may impact issues related to social equity, privacy and data access
- Discuss the mission, history, constituencies and activities of user conferences hosted by software vendors
- Discuss the roles traditionally performed by software vendors in developing professionals in GI S&T
- Discuss the history of major geospatial-centric companies, including software, hardware, and data vendors

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***Unit OI6 Coordinating organizations (national and international)**

A number of organizations (public, private, and non-profit) exist to coordinate, inform, and support geospatial activities of professionals, and entities using GI S&T. Informed geospatial professionals and organizations are familiar with the mission, history, constituencies, modes of operation, products, and levels of success of these organizations.

Topic OI6-1 Federal agencies and national and international organizations and programs

- Assess the current status of Gore's "digital earth"
- Describe the data programs provided by organizations such as The National Map, GeoSpatial One Stop, and National Integrated Land System
- Discuss the mission, history constituencies and activities of international organizations such as Association of Geographic Information Laboratories for Europe (AGILE) and the European GIS Education Seminar (EUGISES)
- Discuss the mission, history, constituencies, and activities of governmental entities such as the Bureau of Land Management (BLM), United States Geological Survey (USGS) and the Environmental Protection Agency as they related to support of professionals and organizations involved in GI S&T
- Discuss the mission, history, constituencies, and activities of GeoSpatial One Stop
- Discuss the mission, history, constituencies, and activities of the Open Geospatial Consortium (OGC), Inc.
- Discuss the mission, history, constituencies, and activities of the Nation Integrated Land System (NILS)
- Discuss the mission, history, constituencies, and activities of the Federal Geographic Data Committee (FGDC)
- Discuss the mission, history, constituencies, and activities of the National Academies of Science Mapping Science Committee
- Discuss the mission, history, constituencies, and activities of the USGS and its National Map vision

- Discuss the mission, history, constituencies, and activities of University Consortium of Geographic Science (UCGIS) and the National Center for Geographic Information and Analysis (NCGIA)
- Discuss the political, cultural, economic, and geographic characteristics of various countries that influence their adoption and use of GI S&T
- Identify National Science Foundation (NSF) programs that support GI S&T research and education
- Outline the principle concepts and goals of the "digital earth" vision articulated in 1998 by Vice President Al Gore

Topic OI6-2 State and regional coordinating bodies
- Describe how state GIS Councils can be used in enterprise GI S&T implementation processes
- Determine if your state has a Geospatial Information Office (GIO) and discuss the mission, history, constituencies and activities of a GIO
- Discuss how informal and formal regional bodies (e.g., Metro GIS) can help support GI S&T in an organization
- Discuss the mission, history, constituencies, and activities of National States Geographic Information Council (NSGIC)
- Explain the functions, mission, history, constituencies, and activities of your state GIS Council and related formal and informal bodies

Topic OI6-3 Professional organizations
- Compare and contrast the missions, histories, constituencies, and activities of professional organizations including Association of American Geographers (AAG), America Society for Photogrammetry and Remote Sensing (ASPRS), Geospatial Information and Technology Association (GITA), Management Association for Private Photogrammetric Surveyors (MAPPS), and Urban and Regional Information Systems Association (URISA)
- Discuss the mission, history, constituencies, and activities of the GIS Certification Institute (GISCI)
- Identify conferences that are related to GI S&T hosted by professional organizations

Topic OI6-4 Publications
- Describe the leading academic journals serving the GI S&T community
- Develop a bibliography of scholarly and professional articles and/or books that are relevant to a particular GI S&T project
- Select association and for-profit journals that are useful to entities managing enterprise GI systems
- Select and describe the leading trade journals serving the GI S&T community

Topic OI6-5 The geospatial community
- Describe possible benefits to an organization by participating in a given society that is related to GI S&T
- Discuss the value or effect of participation in societies, conferences, and informal communities to entities managing enterprise GI systems
- Identify conferences that are related to GI S&T

Topic OI6-6 The geospatial industry
- Assess the involvement of non-GIS companies (e.g., Microsoft, Google) in the geospatial industry
- Describe the U.S. geospatial industry including vendors, software, hardware and data
- Describe three applications of geospatial technology for different workforce domains (e.g., first responders, forestry, water resource management, facilities management)
- Explain why software products sold by U.S. companies may predominate in foreign markets, including Europe and Australia?

