An Information Model for Maps:
Towards Cartographic Production from GIS Databases

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Abstract

This paper presents an information model that describes maps and informs the definition of GIS databases to support automated map production. When GIS databases are constructed primarily for the inventory and analysis of geographic phenomena, the data requirements for map production are often not considered until after the data have been already been compiled. The resulting maps and production processes are therefore often approached by cobbling together the map data from any available GIS database. We present an alternative approach that considers the map requirements from the outset, then defines the unique characteristics and requirements for the GIS data to support mapping, as well as the process models to create the maps. Our information model is derived from a communication model that encompasses traditional cartographic design and production processes to transform information about the geographic environment to geospatial data to maps. It defines rules for cartographic abstraction, symbology and labeling, graphic refinements (e.g., legibility, visual contrast, hierarchical organization, visual balance), and map compilation. We tested our information model using a multi-scale GIS database to produce various map products. From our research, we find that the information model must be flexible so as to reflect the individualistic approaches of map makers in their design and compilation processes.

1. Introduction

Twenty years ago, when cartographers compiled a map, they also captured cartographic data or "representations" of the geographic environment. Most often, they created single purpose representations driven by the graphical requirements for publishing the map. With the advent of GIS, data started to be compiled very differently. Over time, it became more important to capture features as more "exact" geographic representations from aerial photography, satellite imagery, GPS and other direct or remote sensing methods. These data were registered to the ground, and GIS users were indisposed to displace, generalize or otherwise manipulate the data for cartographic purposes because any abstraction would compromise the utility of the data for geographic inventory and analysis. For many GIS users, the data were not far removed from "geographic reality"; for cartographers; however, they were representations of reality that required further abstraction in order for them to be appropriate for map making.

Cartographers began to invent ways to create multiple representations from the geographic data in order to use the limited number of available GIS data layers to create multiple and various types of maps (Kilpelainen 2000). At the same time, GIS databases were being compiled by scanning and digitizing paper maps, so a sizable amount of GIS data is really cartographic in nature. Because most GIS users and map makers use the data available to them, both the digital map data and the GIS data compiled from primary sources are often used together. This paper addresses in part the relationship between GIS data and cartographic data, which is something that many European mapping agencies have resolved through their understanding of "digital landscape models" and "digital cartographic models".

1.1. Digital Landscape Models and Digital Cartographic Models

The terms "digital landscape model" and "digital cartographic model" help clarify the distinction between data that is modeled for GIS and data for mapping (Figure 1). The terms come European cartographers and mapping agencies that have been developing these concepts over the past decade (Muller and Seyfert 1998).
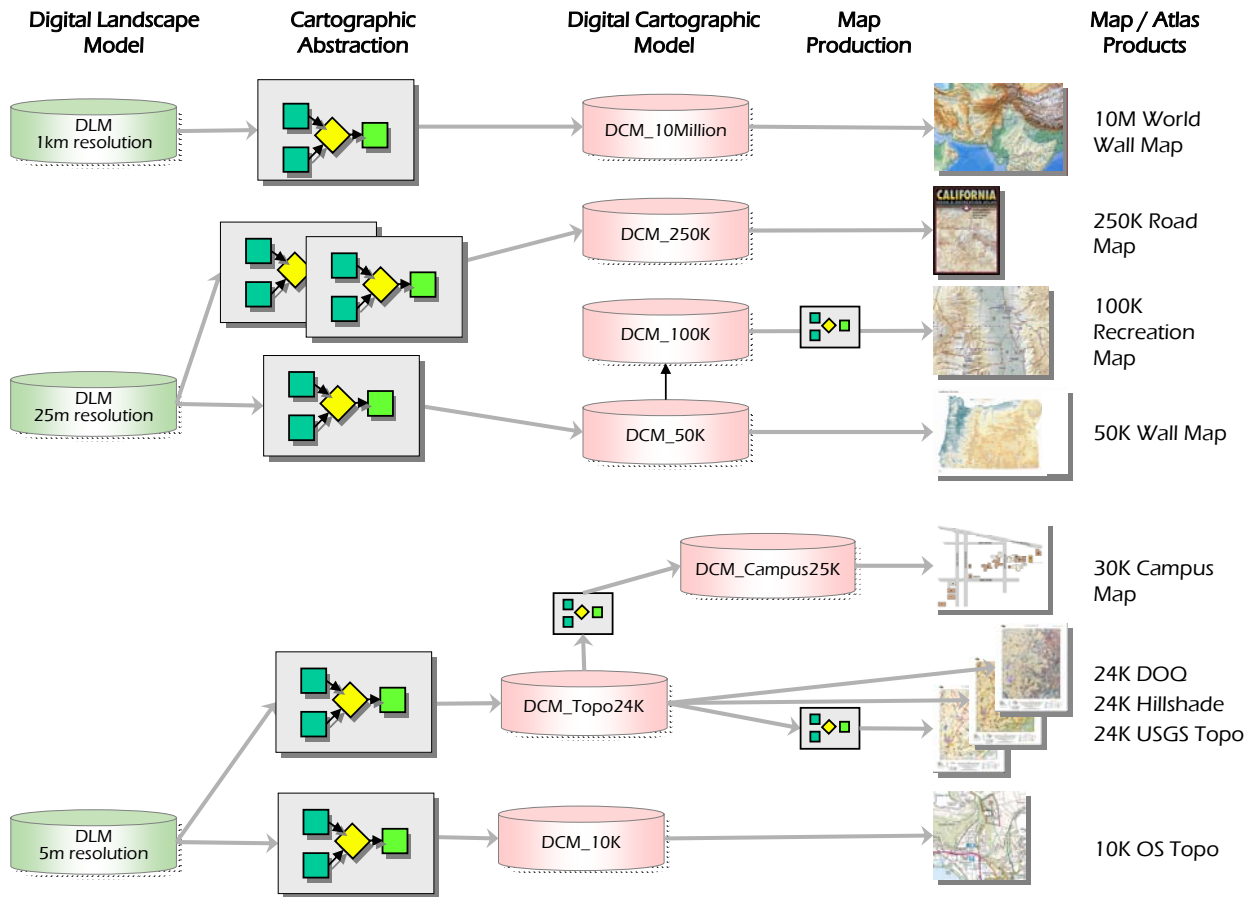

Figure 1. Digital cartographic models, or map product databases, are derived from digital landscape models, or base GIS data. Workflow models drive the derivations between data models and scales and allow the few DLMs to be transformed to the multiple DCMs that are used to create a variety of map products.

A *digital landscape model* or DLM denotes the type of data that most of us consider as base GIS data compiled from source information that is registered to the ground. Rather than relying on a "golden feature" model, an organization would ideally compile base data at several standardized scales with accuracy and resolution as the determining factor. From these standard scales, additional DLMs could potentially be derived.

GIS data that is enhanced or modified for use in mapping is stored in a product database called a ***digital cartographic model*** or DCM. Each finished map product would be derived from its respective product database (i.e., DCM). A single DCM could be used to support the production of multiple map products if changes in the workflow model only were required. Major modifications to the data would necessitate the development of an additional DCM.

1.2. Information Transformations

Where the tension arises between GIS and cartography is in the graphic representation of the geographic environment, which leads to differences in the way that geographic reality is conceived, abstracted and displayed – in other words, how it is represented (Christ 1986; Forrest 1999). GIS encodes the geographic environment as features and their associated attributes. Those features are often grouped into themes that constitute various aspects of the world's geography, like hydrology, land cover, transportation, etc. From these data, analyses are performed and results are obtained.

An alternative view of geographic reality is cartographic in nature. The primary focus here is on displaying and communicating the features and their relationships. There are some basic differences between these two views that need to be understood so that both GIS and cartographic data can be used in concert.

For GIS data that is compiled for geographic inventory or analysis, the requirements for positional accuracy and logical consistency are paramount. Additionally, connectivity and other topological relationships as well as feature dependencies are also often encoded. Because cartographic data are more often compiled with the primary goal of communication, cartographers are comfortable abstracting from reality only those aspects of the features and their attributes that help relay the desired message to the intended audience. The principal requirements for cartographic data, therefore, are communicative adequacy and graphic or visual consistency. As a result, GIS data is often too general (not in the "generalization" sense) for cartography, and cartographic data is often too specific for GIS. The model we propose illustrates how GIS data can be transformed for cartographic purposes.

Our work fits neatly into the cartographic model based on information transformations for communication (Figure 2). In this model, the mapping process can be conceived of as a series of information transformations, each of which has the power to alter the appearance of the final product (Tobler 1979; Robinson et al. 1995). Environmental information is transformed to geospatial data through filters in the data compilation process. Map production further modifies the information through the cartographic abstraction processes of selection and generalization – generalization includes classification, simplification, exaggeration, etc. – and the resulting data is then symbolized and labeled. Finally, use of the map leads to transformation of the information through the processes of map reading, analysis, and interpretation.
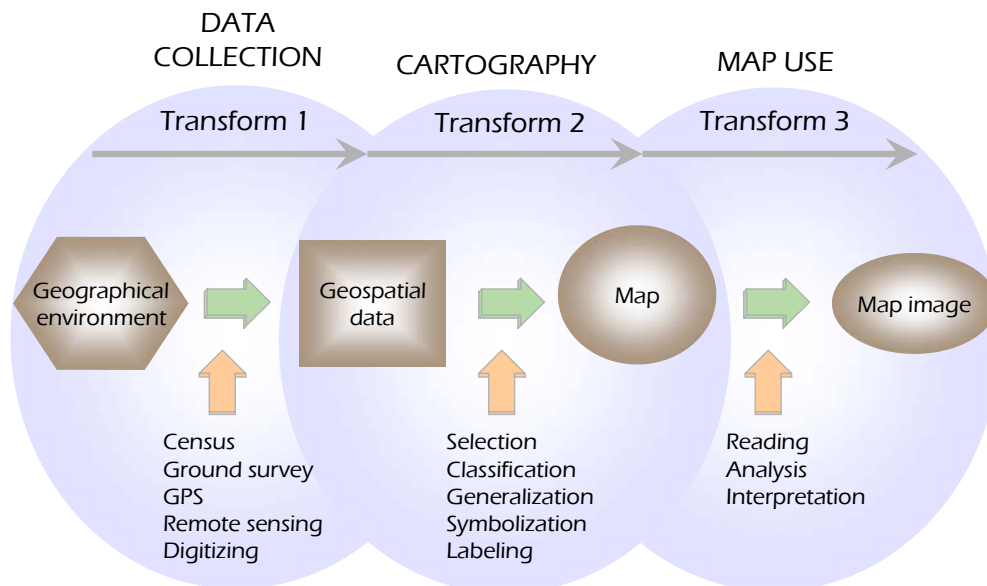
Figure 2. Fundamental information transformations in cartography based on a communication model (after Robinson, et al. 1995)

Minimal distortion should be maintained throughout the transformations. As Tobler notes, "Map use requires that the entire process is of high fidelity" (Tobler, 1979: 101). In today's mapping environment, distortions, inaccuracies and incompleteness in any analog and all digital transformations should be kept to a minimum.

The use of analog or digital methods depends on the requirements for the production process. If the transformation from geospatial data to map is computational, then digital data are required (Figure 3). If analog methods are used, then non-digital data compilation methods may suffice. If the map production process involves GIS, then any required data will need to be organized into a geographic database. Advantages of a computational approach are that it can lead to multi-step mapping and analysis and it supports batch mapping.

When GIS data are used for communication and graphic display, further abstraction is often required. For example, a road along a river may be displaced slightly to show the spatial relationship between the two geographic features. In the past, this additional abstraction was often done during data capture. With GIS, the cartographic abstraction process is separated from the capture process, and it is difficult to replicate in the production workflow the quality of generalization and abstraction cartographers achieved non-digitally in the past. It is necessary to figure out what cartographers were doing when they abstracted their representations so that we can better try to automate the map making process (Chamard 1981; Lilley 2003; Trainor 1990).
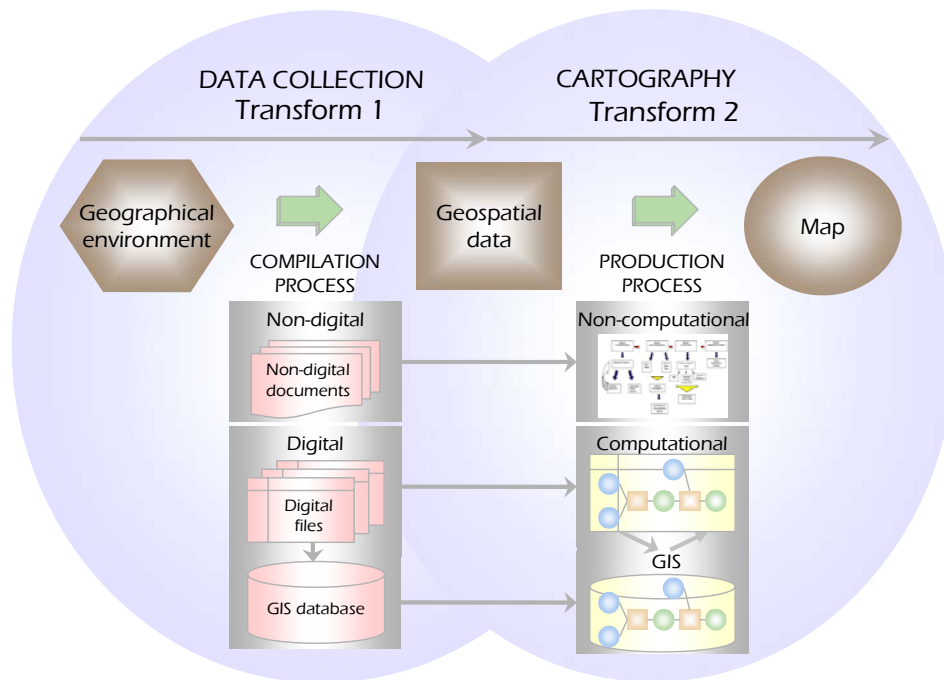
Figure 3. The first map transformation involves geospatial data compilation, and the second is the map production process.

The compilation of GIS data for map making is complicated by the realization that an infinite number and variety of maps can be produced from a single GIS database; therefore, the abstraction requirements for map making become even more complex and the ability to maintain high fidelity in the transformations is further compromised. If a number of cartographers were given the task of creating a map with a specific audience and purpose from the same data set, they would no doubt produce very different maps and probably all of them would be acceptable to varying degrees. We do not yet have the ability to encode the artistic element to the expression of the map – nor perhaps should we!

The goal of our study was to advance automation of the cartographic abstraction process with high fidelity, allowing the map maker to use a GIS database for automated intelligent mapping, thereby releasing the cartographer from the drudgery of the prescribed methodology and allowing him or her to focus on the artistic and interpretive side of cartography. In essence, this would require the computer to handle the science of cartography and allow the human to handle the art of cartography.

1.3. Scope of Work

In our work, we have focused on a data model for a particular type of maps, specifically reference maps, because they are perhaps the most complex of maps in terms of the number of features they contain, and therefore the complexity of the relationships between those features, and the number of uses they have to support (Figure 4). If we can model the data and processes

for compiling reference maps, then it should be possible to handle data and process modeling for less complex types of maps.
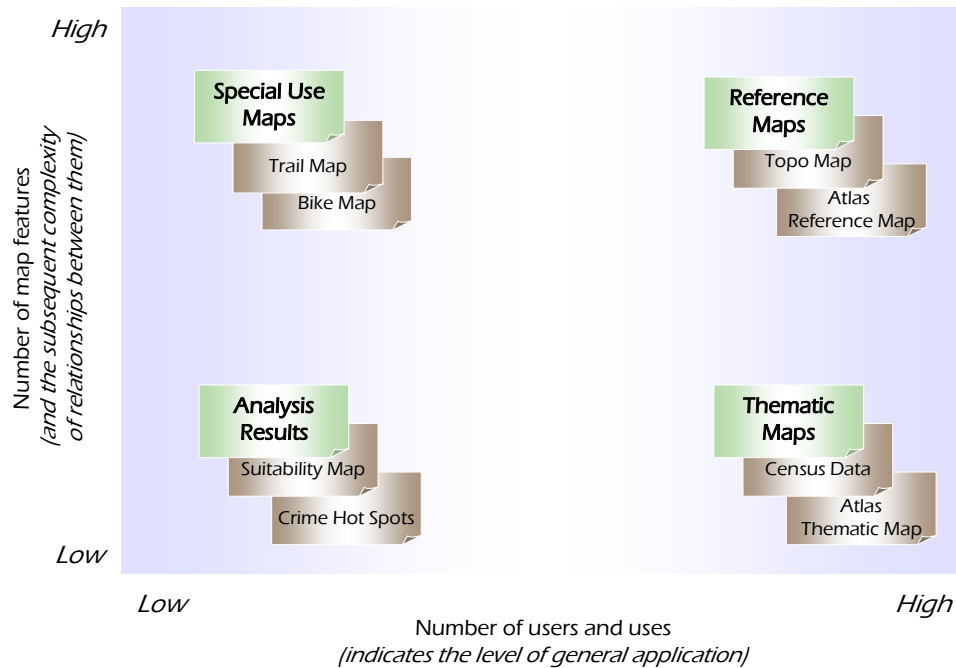

The figure shows a two-by-two matrix. The vertical axis is labeled "Number of map features (and the subsequent complexity of relationships between them)" ranging from Low to High. The horizontal axis is labeled "Number of users and uses (indicates the level of general application)" ranging from Low to High.

Top-left (High features, Low users): **Special Use Maps** — Trail Map, Bike Map.
Top-right (High features, High users): **Reference Maps** — Topo Map, Atlas Reference Map.
Bottom-left (Low features, Low users): **Analysis Results** — Suitability Map, Crime Hot Spots.
Bottom-right (Low features, High users): **Thematic Maps** — Census Data, Atlas Thematic Map.

Figure 4. Types of maps indicating that reference maps contain the most map features and relationships between features, as well as the most potential uses and users.

2. The Information Model

In the past, cartographic products were viewed as by-products of a GIS database that was primarily designed for some purpose other than mapping, such as hydrological analysis, parcel-based tax assessment, land use inventory and analysis or census data collection and archiving. In all of these examples, the maps used to communicate the inventory of geographic features or the results of the spatial analysis were not central to the GIS database design. In our model, the map is the central unit and it is what drives the requirements for the GIS database. We developed an information model to conceptualize geographic data for mapping as well as to conceptualize the use of those data in workflows that result in the production of maps on paper or on screen. Together the data and process models constitute the framework for understanding how GIS can be not just used but rather designed for cartography.

An information model is a repository-independent definition of entities (i.e., objects), and the relationships and interactions between these entities, that models a set of problems in a given domain (Hackos 2002). An information model differs from a data model which is repository-specific. An information model is designed to accomplish three specific activities. The first is to

represent the problem with the required degree of complexity, which in our model is to replicate through automation to the greatest extent possible the decisions made and processes used in map making. The second activity is to browse or search the model to identify objects of interest, discover their information, and make required changes. For our model, the objects of interest are map features and surrounds. The third activity is to solve problems using the model, in our case, compiling a map with cartographic objects that are symbolized and labeled appropriately and whose relationships to other cartographic objects are also adequate.

Because our information model describes the entities on a map and the relationships and interactions between those entities, it is different from GIS data modeling for other applications (e.g., Wright et al. 1997). That is, the *symbolized* features are the primary entities. Although they may be derived from non-cartographic GIS databases, the map entities are the central unit of concern.

2.1. Cartographic Data Modeling

Cartographic data modeling is similar to the process used in geographic data modeling (Burrough 1992; Goodchild 1992; Hadzilacos and Tryfona 1996; Peuquet 1984). It involves a transformation of the geographic environment to a Conceptual Cartographic Data Model, then to a Logical Cartographic Data Model and finally to a Physical Cartographic Data Model. The resulting data model is used with a Functional Cartographic Data Model to produce a map or maps (Simsion 1994; Figure 5).
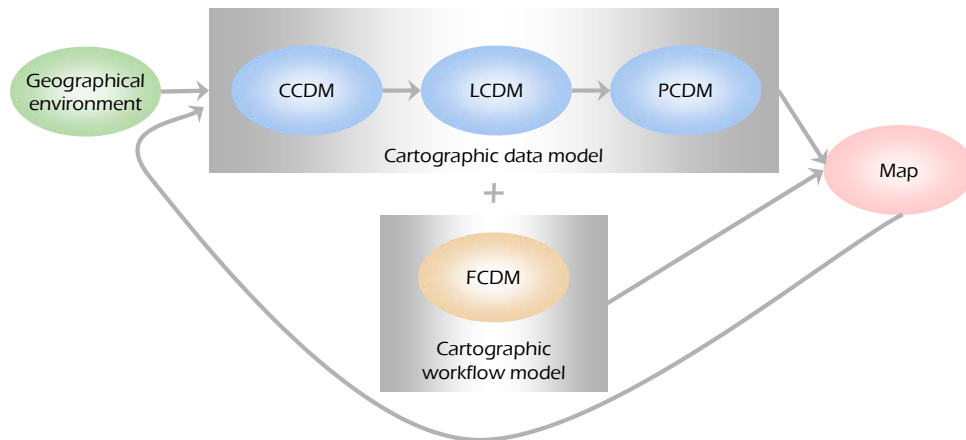

Figure 5. In this two-tiered diagram, the cartographic data modeling process represents how to articulate and adhere to the vision of the map, while the workflow model defines how the cartographic data model is used in the map production process.

The ***Conceptual Cartographic Data Model*** (CCDM), also sometimes referred to as "the data model", represents the overall logical structure of the map, independent of any software or data storage structures. This conceptual model often contains cartographic features not yet implemented in the physical databases. It gives a formal representation of the features needed to make a map as well as the associations between cartographic features. It also gives a formal representation of the layout and supporting elements on the map page. The CCDM represents a map conceptually, the way the map reader sees it, rather than how computers store it.

The ***Logical Cartographic Data Model*** (LCDM), also sometimes referred to as "the data structure", bridges the gap between the conceptual (CCDM) and physical (PCDM) cartographic data models. CCDMs are devoid of database-level information while PCDMs are designed for software-specific database management systems, including GIS. Since certain characteristics of databases and graphics software are generic in nature (such as indexes and foreign keys, strokes and Bezier curves), a LCDM stores those specifications without adding anything that is specific to a particular software system. For a cartographic model, the types of cartographic features, their representations (point, line polygon, Bezier curves, etc.), their relationships, and their attributes (e.g., names used for labels), can be defined regardless of the specific software system to be used.

The ***Physical Cartographic Data Model*** (PCDM), also sometimes referred to as the "file structure", specifies the physical implementation of the data to support cartography. With the PCDM, the details of actual physical implementation are taken into consideration, including both software and data storage structures. The PCDM can be modified to better suit performance or physical constraints. For cartographic modeling, capabilities of software such as ArcGIS can be incorporated into the data specifications at this point.

The data model is one part of the conceptual design process; the other is the functional or workflow model (Traettenberg 1999). The data model focuses on what data should be stored in the database while the functional model defines how the data are processed. The ***Functional Cartographic Data Model*** (FCDM) defines how the cartographic data is derived from the GIS data, as well as how the map is derived from the cartographic data. Examples of cartographic functions include line generalization, data classification, symbol specification and labeling expressions.

2.2. Conceptualization of the Map

A very important aspect of cartography is missing from the data model as described above – conceptualization of the final map product. For many GIS users, this is not something that is carefully considered before database compilation; for cartographers, this is the first step in the map making process. Determining what data to use and how to use it is a function of the map being made. Conceptualization of the map therefore drives the entire map making process; without it, the chances of ultimately producing the desired product are speculative at best.

Map conceptualization essentially defines how the final map will look. This is a function of the map use and the map user which dictates how the cartographer considers setting the rules for data compilation and map production. The map is designed to communicate a particular

message, and each feature on the map is manipulated to add meaning to that message. Once conceptualization of the map is complete, the map features, their symbology and labeling, their relationships with each other, the map surrounds, the layout, the output format, all other components of the map can be modeled.

Map conceptualization is an inventive and artistic process that marries cartographic knowledge with basic graphic design concepts (Figure 6). The first step after identifying the map audience and purpose is *graphic ideation*, an intuitive process that results in a general design for the map (Robinson et al. 1995). The map maker uses imagination and creativity to decide on the type of map, the projection, the data to be represented, the basic page layout and so on. This is followed by development of the *graphic plan*, which outlines the steps and choices that will manifest the map in a coherent graphic display. Decisions include the classing technique, color use, typography and other major cartographic and graphic design choices.
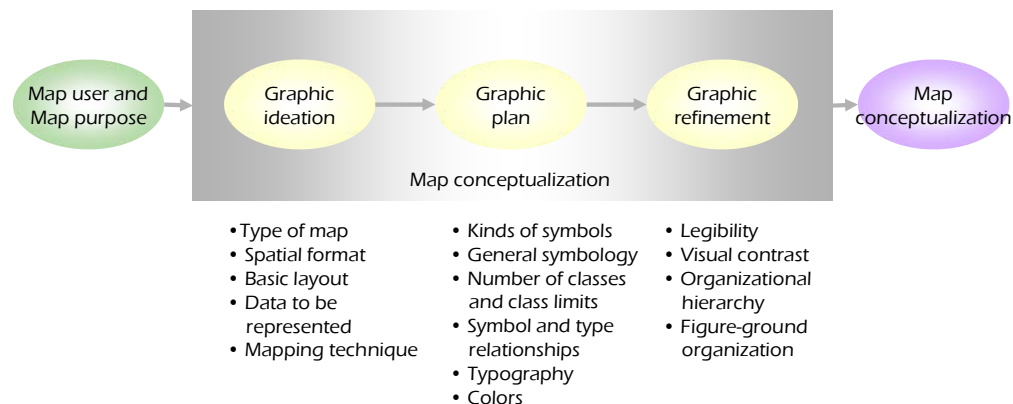
| Map user and Map purpose | Graphic ideation | Graphic plan | Graphic refinement | Map conceptualization |

Map conceptualization

| • Type of map
• Spatial format
• Basic layout
• Data to be represented
• Mapping technique | • Kinds of symbols
• General symbology
• Number of classes and class limits
• Symbol and type relationships
• Typography
• Colors | • Legibility
• Visual contrast
• Organizational hierarchy
• Figure-ground organization |

Figure 6. Map and graphic design is an intuitive and creative process that leads to conceptualization of the map. (After Robinson, et al. 1995).

The map conceptualization can be seen as an important primary input in the cartographic data modeling process (Figure 7). It is the first step in the process as it defines the map. The map is not only the output of the modeling process, it is also a required input. Contrary to the belief of some GIS users, the map is not just the product of the modeling process, it is also a driver, and cartographers understand that it must be conceptualized before it can be modeled.
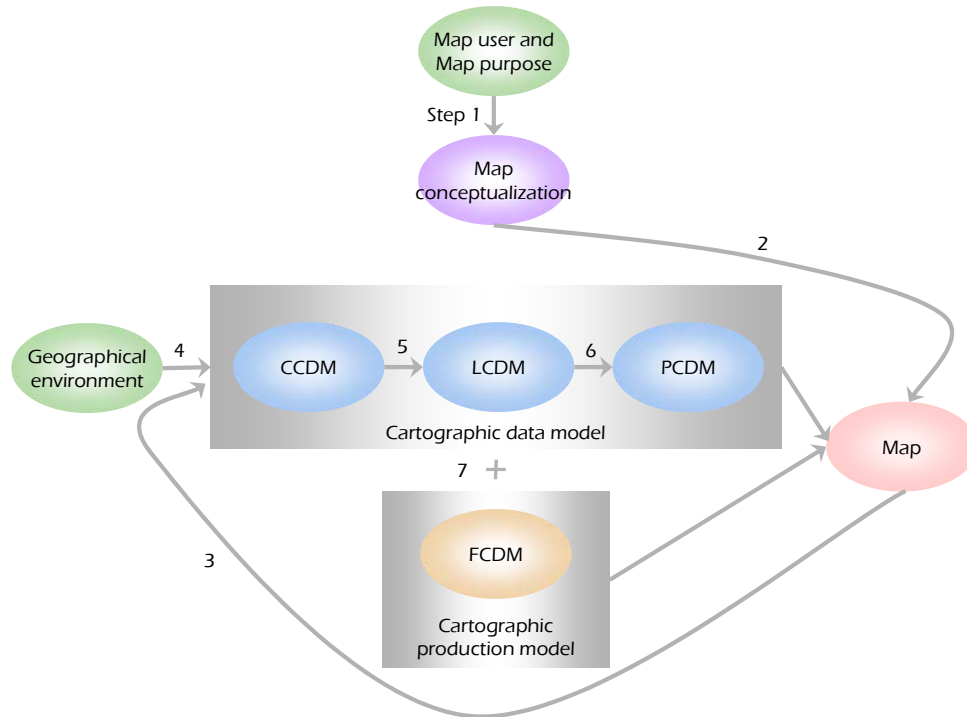
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Figure 7. Map conceptualization is the first step in the cartographic data modeling process, but many GIS users are not familiar with this requirement for mapping.

2.3. The Information Model for Maps

It is now possible to see how cartographic data modeling and workflows fit together with map conceptualization (Figure 8). Something is still missing, however. Map making is not a linear process, and simply stringing together the decisions made to conceptualize the map and model the data does not usually result in a product that is satisfactory to the cartographer the first time through. Once the results of the various graphic decisions can be seen simultaneously, multiple iterations of the map are often made in an effort to refine the graphic display. The map maker may choose to refine the initial concept (in which case the loop cycles back through the map conceptualization process) or the map symbolization (in which case the loop cycles through the map production but not the conceptualization process).

With this more complete picture of fluid process of map making, it is now possible to apply this understanding in the automation of map production. It is can then be determined to what extent the information model for maps supports map making.
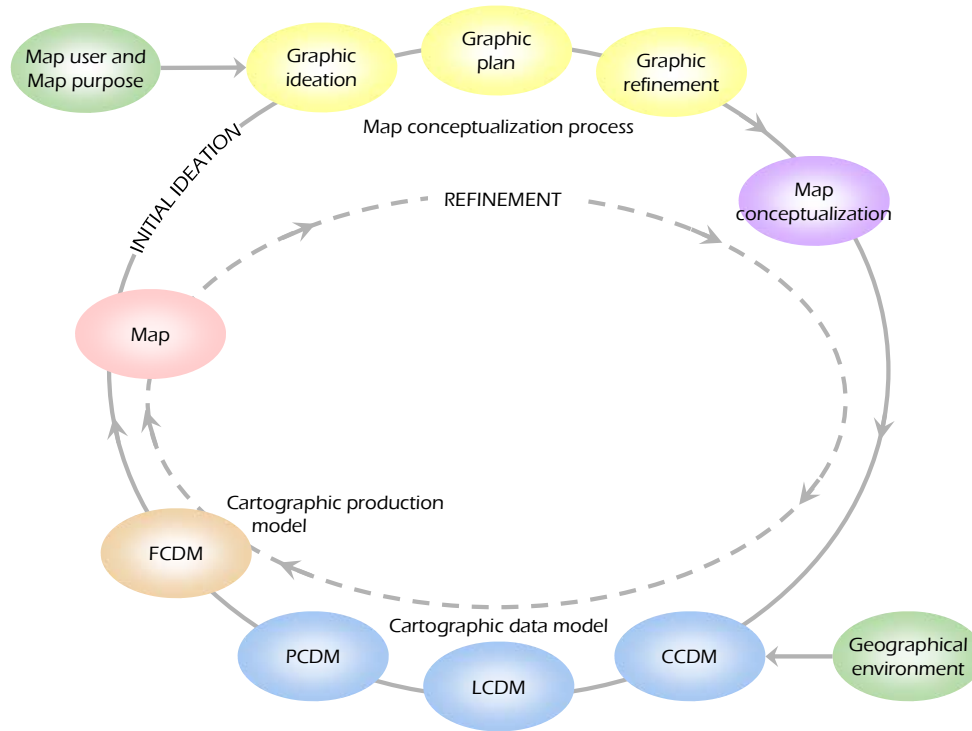
Figure 8. The cartographic information model incorporates conceptualization of the map. The iterative nature of map making is evident through repeated refinements to the map through the cartographic production process.

3. Using the Information Model in the Map Production Process

An advantage of modeling the cartographic process is to see what is or can be supported through computer automation and the use of GIS (Chamard 1981; Quak et al. 2002; Trainor 1990). It is also useful to understand what parts of the process must be tackled outside of the digital environment. Clearly, the conceptualization process does not require a computer and in fact may better accomplished using pencil and paper, inventiveness and imagination. Other steps in the process may be executed with more efficiency and higher quality if done digitally. In this section of the paper, we consider how to implement our understanding of the cartographic process in a digital environment, and we demonstrate how the model can be used to support map making with GIS, specifically with ArcGIS software (Figure 9).

To accomplish this, we constructed a relational table we called the Cartography Table (Buckley 2004). This table qualifies the types of features found on the map, how they are symbolized and labeled, how they can be filtered to create smaller scale maps, and more. This table serves as an input to the map making process and specifies many of the cartographic decisions made in the map conceptualization process. An additional input is a Style which is a database repository used by ArcGIS software for the various feature and cartographic symbols (e.g., point, line and area features as well as graticules, scale bars, north arrows and more).
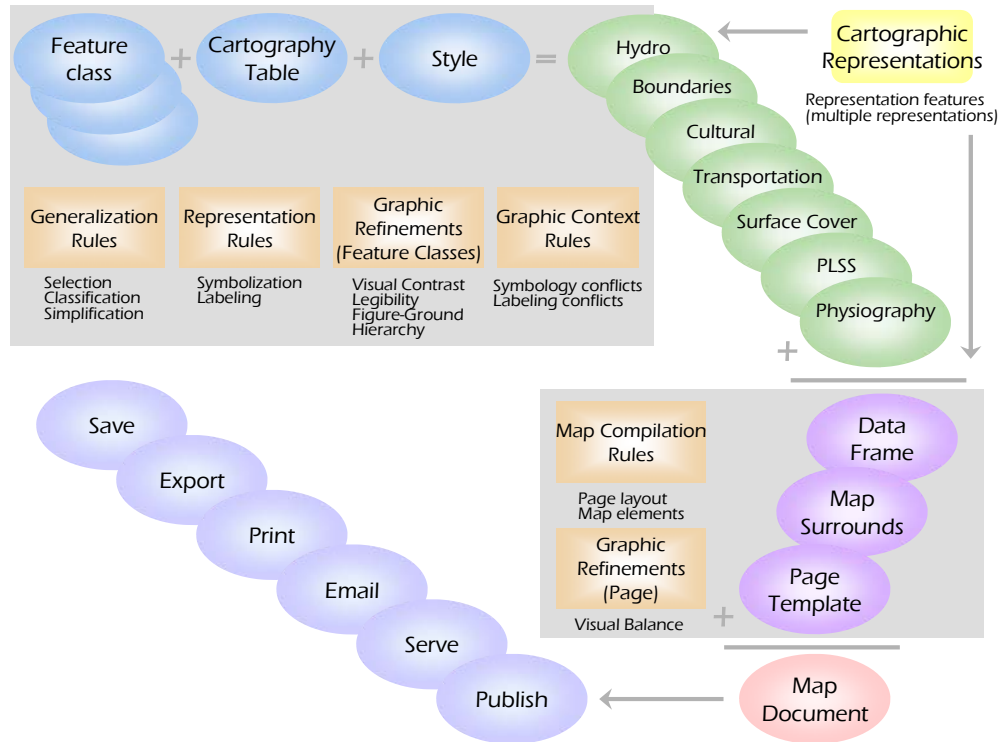
Figure 9. The map production process can be supported with ArcGIS software.

Map production can begin the application of rules to help ensure that features on the map are limited to those that serve the map's purpose and are represented at the level of detail appropriate for the map. For the purposes of this paper, we have defined these as the ***generalization rules***, which include (Buttenfield 2005):

- Simplification (reduction of detail or modification that reduces clutter)
    - Elimination (e.g., n^{th} point removal algorithms)
    - Selection (e.g., Douglas routine)
    - Displacement or Repositioning
- Classification (modification of the taxonomy or map legend categories)
    - Aggregation (typification, collapsing, merging, resampling)
    - Partitioning (using metric or non-metric class breaks)
    - Overlay (in vector space and in raster space)
- Enhancement (systematic introduction of detail)
    - Smoothing (e.g., high- or low-pass filter, or DEM pit-pass fill-in)
    - Exaggeration (e.g., retaining features even if they might not maintain visibility "at scale")
    - Refinement (e.g., adding road casing to symbology to highlight highways)
    - Generation (e.g., adding detail through fractal models)
    - Interpolation (e.g., generating a terrain grid or contour lines from individual elevation points)

After the features have been modified to eliminate or de-emphasize unwanted details and enhance or exaggerate others in accordance with the purpose of the map, it is then possible to apply rules of symbology and labeling. We call these ***representation rules***. As mentioned above, once the results the generalization and representation rules can be seen simultaneously, the graphic display can be refined (i.e., ***graphic refinements***) to assure high quality cartographic design and to promote the design predicate (for example, changing the prominence of a class of features by moving it to a more prominent visual plane). Predicate actions involve changing the gestalt, such as visual contrast, hierarchical organization or figure-ground differentiation (Buttenfield 2005.)

The resulting display can also be evaluated for ***graphic conflicts***. These conflicts may be within class (e.g., cased symbols for ramps and highway should be merged) or between classes (e.g., black house symbols should be offset from black road lines when they overlap). This conflict detection is performed on the symbolized representation of the features not on the base GIS representations.

Application of the rules described above to the GIS features results in cartographic representations of the various themes used on the map (Collier et al. 1998; Collier et al. 2003; Forrest 1999). These are then combined into a data frame which is then placed on a page with a specified page layout. Map compilation rules govern the appearance and location of various map surrounds on the page. The layout may be stored in a template which specifies various map components, such as the title, legend, and scale bar. Others map components may be added to the template or assembled together on a map that does not make use of a template.

Once the map is compiled on the page, graphic refinements can again be applied to assure effective presentation of the map composition. Graphic modifications at this step are made to promote visual balance and ensure that the graphic organization supports the objectives of the map. This includes selectively promoting or demoting various contextual items in order to better clarify, explain and support the map's purpose.

The rules for generalization, symbolization and labeling are applied not only at the feature class level, but also at the feature level (Figure 10). Although some parts of the cartographic process (generalization, symbology and labeling) are implemented for each feature class, graphic refinements and symbology and labeling conflicts cannot be resolved until all the features are displayed on the map.

Although we have a good understanding of many of the decisions cartographer make and we are able to implement them in a computation production process, there are still many that are unknown to us or are to difficult to encode digitally. Nonetheless, for those processes we do understand and are able to capture digitally, it is possible to envision the development of workflow models that derive cartographically abstracted features from the base GIS database. The ability to automate at least part of the mapping process will free cartographers from some of the drudgery of map making and allow them to focus on the more artistic and creative parts of the process. In this next section, we demonstrate the use of GIS software to build workflow models for parts of the map production process.
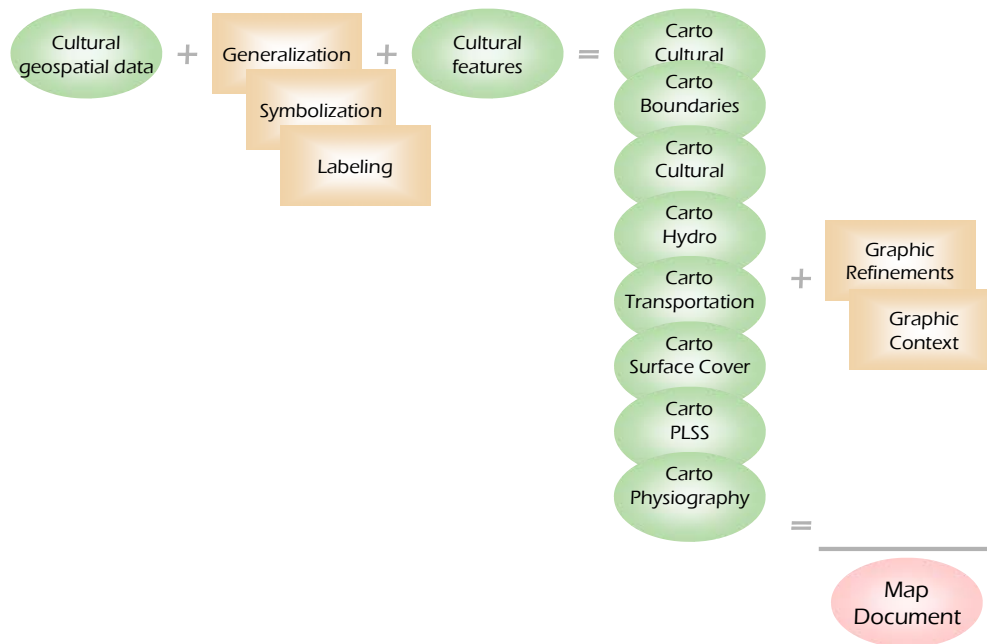
Figure 10. The modeling process is repeated on a feature-by-feature, layer-by-layer basis.

3.1. Generalization Rules in the Model

Cartographic data is often derived from the GIS database through a series of processes that include selection, generalization and classification – all core components of cartographic abstraction (Figure 11). Some of these processes can be captured through GIS data manipulation and analysis, while others have still not been automated adequately enough for map making (Brassel and Weibel 1988; Heisser et al. 1995; Meyer 1986; Muller and Seyfert 1998). For example, line generalization, though long studied, often provides results that do not satisfy the high graphic standards of some cartographers. In these cases, the cartographer may elect to override the output of the data analysis by digitizing the desired location of the line. In cases where the data manipulations can be automated, the cartographic model can be used to seed the workflow.

3.2. Representation Rules in the Model

GIS are currently better able to handle symbology and labeling than generalization (Forrest and Kinninment 2001; Hardy 2004). Representation rules can be used to set symbology through the linkage of a feature type to its related symbology (Figure 12). Modifications can be made on a layer-by-layer basis; but it is currently difficult to make edits at the feature level using ArcGIS (although software developments are underway to change this). Labeling specifies the content and placement of map text related to geographic features. Map text can be specified using a single field to specify a label or using an expression to compose a label from multiple fields in the database. For labeling, modifications can be made to individual features.
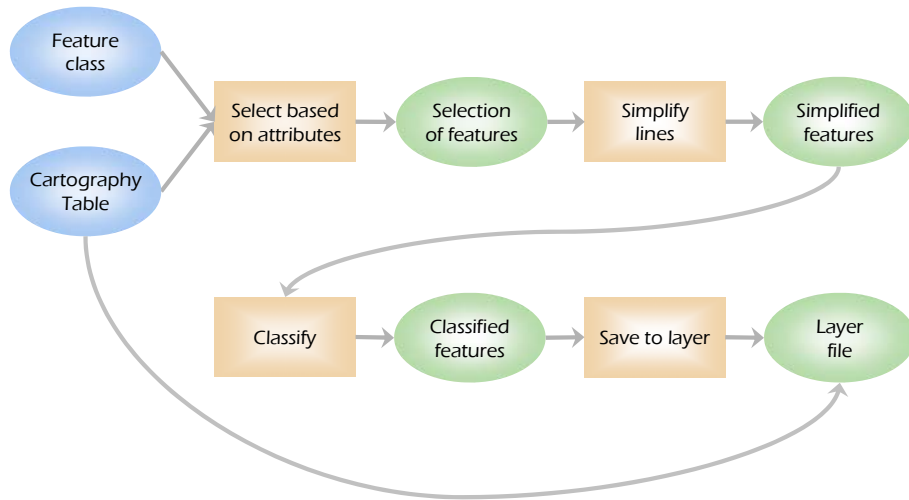
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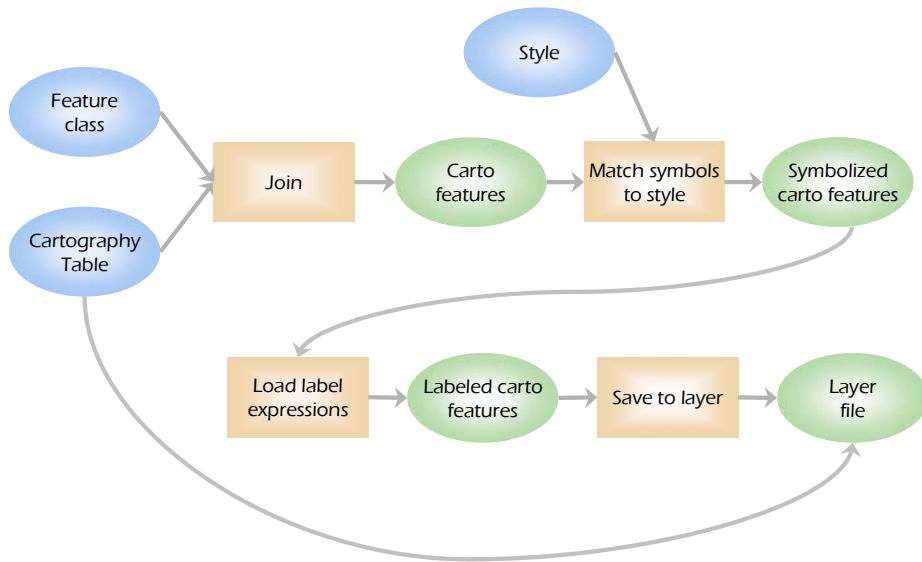**Figure 11**. Example of the automation of a variety of generalization rules in ArcGIS.

Figure 12. Example of the automation of a variety of representation rules in ArcGIS.

In the future, it would be desirable to have more robust automated label modification to support the types of labeling operations that cartographers employ in making their maps. For example, a labeling rule might state that the size and spacing of the text is dependent on the size and shape of the feature it labels.

3.3. Graphic Refinements and Graphic Conflict Rules in the Model

What is even more problematic to encode are the rules for graphical excellence that cartographers and other graphics artists use to assure the highest possible quality in their displays. For cartography these are especially important as they assure a higher level of communication about the geographic features and their attributes. Graphic refinements include such concepts as legibility, visual contrast, figure-ground differentiation and hierarchical organization of the map (Robinson et al. 1995).

Legibility is simply the ability to be seen and recognized. This clearly relates to the size of the graphic mark used to symbolize the geographic feature, but it also relates to the ability of the map reader to interpret the symbol. Visual contrast is the degree to which a symbol contrasts with its background and with other symbols. Figure-ground refers to the spontaneous organization of the image into a more visually dominant subject over an amorphous background. This can be achieved through a variety of techniques in cartography, but the primary concern is to help the map reader recognize features and direct his or her attention to the intended message of the map. Hierarchical organization refers to the internal structuring of the map into layers on information of varying importance. Although it is not currently possible to implement all of graphic refinements a GIS environment, there may be increased capability to support this in the future (Hardy 2004).

Graphic conflict rules would detect errors in overlapping symbols and labels. This is possible to some extent with specialized GIS software, but it is not yet part of the core capabilities. More often, cartographers find these problems though visual inspection; automation would both decrease the time it takes to find the problems and ensure that conflicts are detected with consistency.

3.4. Map Compilation Rules in the Model

The final set of rules pertain to the arrangement of the map feature and supporting map elements such as title, legend, scale bar, on the page. A pleasing layout and well executed organization are the optimal objectives (Figure 13).

Because the success of the layout is a function of all the elements on the page, it would be ideal if the placement of each individual element could be evaluated relative to the location of its surrounding elements. If the scale bar were moved, where should the north arrow be relocated to? Are these two features related and should they ideally be placed next to each other? Should the location of an element be modified independently of its neighbors? Relativistic rules of the placement of page elements should be employed where desirable, dynamic relative placement should be supported, and changes in the data should also be supported in a dynamic environment.

Maps can be quite complex and the number of map elements and their relationships can be equally complicated. As the number of elements and their interdependencies increases, the map itself becomes a more complex graphic display device. Nonetheless, it is possible to imagine the formalization of a set of basic cartographic map rules that can be implemented in a GIS. Some

of these rules already exist, and some are now more obvious to us and have been targeted for software development.
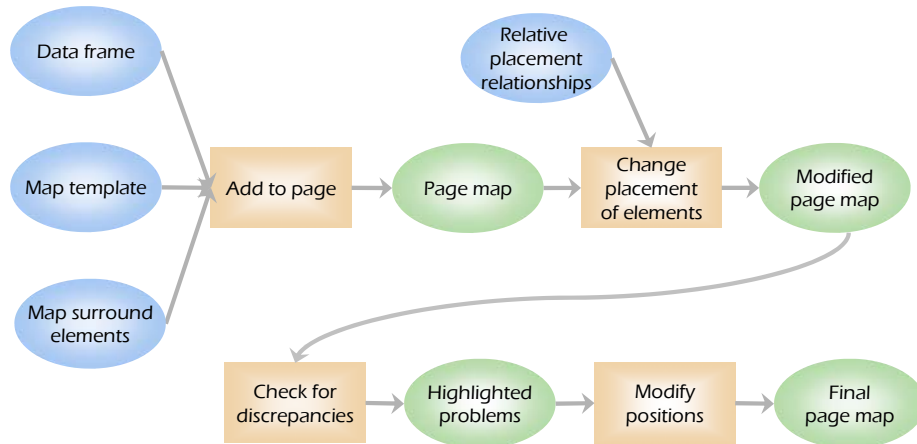

Figure 13. Example of the automation of a variety of map compilation rules in ArcGIS

4. Conclusions

This paper provides cartographers with an information model to describe the database requirements for map making from GIS data. We present a top-down approach that starts with the purpose and audience for the map which leads to map conceptualization, then defines the data requirements and finally allows the specification of the process model for map production. The information model is derived from a communication model that encompasses traditional cartographic design and production processes to transform geographic data to a map product. It defines rules for cartographic generalization, (such as classification, selection and simplification), representation (symbology and labeling), graphical refinements (such as legibility, visual contrast, hierarchical organization), and the resolution of graphical conflicts. It also specifies rules for page map compilation, including various elements of the map surrounds.

Formalization of the information model must allow for flexibility by reflecting the individualistic approaches that map makers take in their design and compilation processes. By automating some of the map production process, the cartographer may have greater freedom to focus on creative and artistic elements of cartography. Articulation of our information model is intended to provide map makers with an alternative way to consider database driven cartography.

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