



ESRI® Cartography: Capabilities and Trends

An ESRI White Paper • June 2004

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Note: This is a forward-looking document, and some of the capabilities it describes are still under development. As such, it is intended to give guidance as to likely future direction and should not be interpreted as a commitment by ESRI to provide precise capabilities in specific releases.

ESRI Cartography: Capabilities and Trends

Introduction Cartography is the art and science of making maps. To create modern, high-quality cartography requires the use of appropriate technology. This provides efficient processes that amplify our human creative and expressive skills in order to communicate the essential spatial message.

ESRI has historic strengths in geography, geographic information system (GIS) technology, spatial data modeling, and data analysis. Many of these applications require the presentation of geographic data as a published map. ESRI® ArcGIS® software facilitates high-quality map generation through a wide range of cartographic and map publishing capabilities.

Cartography has been a developing human skill for more than 4,000 years. Over this time, a range of techniques has been evolved to ensure clarity of communication while maximizing the useful map content. ArcGIS embeds much of this accumulated knowledge of how to do good cartography. It releases cartographers from the drudgery of repetitive actions and hence frees them to concentrate on applying their unique human visual abilities for interpretation and design.

Many organizations involved in production cartography worldwide already use ESRI® software. The list includes national and regional mapping agencies (both civilian and military) and commercial providers. Examples include U.S. Geological Survey, National Geospatial-Intelligence Agency (NGA), Ordnance Survey in Great Britain, Rand McNally, National Geographic Society, and Automobile Club of America.

At the heart of ESRI's cartographic solution is the geodatabase, providing a logical, structured framework to hold the data for cartographic production, and the rules for its consistent presentation. However, in the past some organizations felt that they needed additional tools for the cartographic finishing stage, such as a vector graphics editor like Adobe® Illustrator®, text placement applications, and prepress tools.

Hence, ESRI embarked on an ambitious series of projects to provide the best of both worlds. The target is to provide the optimal tools and environment for the production cartographer, centered on the rigor of the geodatabase but allowing artistic freedom where needed. Many of these projects are coming to fruition in ArcGIS 9.

This document gives an overview of the cartographic production capabilities of ESRI ArcGIS software and highlights how the products are being enhanced to provide the world's leading solution for database driven map publishing.

Requirements

The needs of cartographic customers vary dramatically, but there is a common core of requirements that has emerged over the past few years:

- Capture the starting-point geographic information once into digital form, and store it in an open database so that it can be accessed for multiple purposes.
- Update this master data efficiently, as change happens in the real world.
- Derive paper and digital products from this master data using a maximum of automatic procedures to minimize labor costs.
- Store the derived map products in the database.
- Retain the ability for human intervention in the cartographic finishing processes so as to ensure clarity and elegance of the final product.
- Output the map products in the optimal form needed by the target printing, prepress, or online distribution system without needing further manual intervention.
- Carry out all these operations in an intuitive, uniform environment, providing WYSIWYG (what you see is what you get) from capture right through to print, thereby avoiding expensive repetitive edits or late corrections.

Capabilities

The ESRI cartographic capabilities described in the following sections address the core requirements. The facilities are evolving with ArcGIS 9 and subsequent releases to provide a unique and optimal blend of automated data handling with human overrides.

***Central Geodatabase,
Continuous Data,
With Versioning***

There has been a major push from most cartographic organizations to centralize their data holdings to avoid the fragmentation and inefficiencies of file- and sheet-based data held by departments and individuals. Related to this is the ongoing pressure to move GIS and cartography into the world of enterprise information technology (IT) and hence to take advantage of commodity facilities for backup, data replication, and data management.

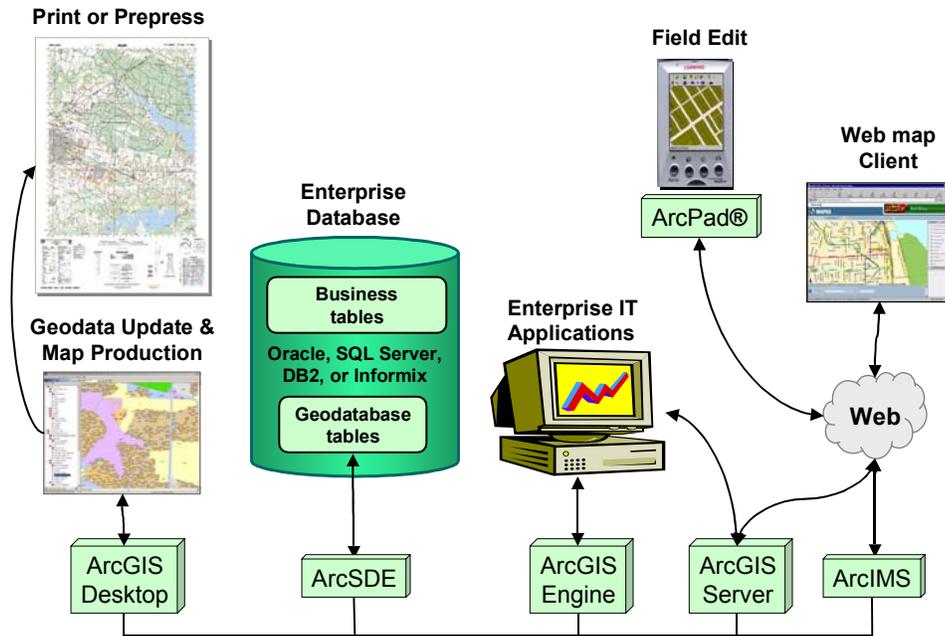
ESRI has recognized this need and provided the enterprise geodatabase as the central repository for spatial data, handling continuous data without tile edges, in an open relational database such as DB2[®], Oracle[®], Informix[®], or SQL Server[™]. The use of commodity database technology allows the close integration of spatial data with other business data vital to the enterprise, and it facilitates the production of a wide range of valuable analytical and cartographic products.

The data stored in the geodatabase can be versioned to allow multiple users to carry out simultaneous update with optimistic long transactions to prevent unnecessary locking or data copies. Versioning is important to allow cartographic product generation and map finishing to meet publishing deadlines, while continuing in parallel with ongoing database update.

In ArcGIS 9, the geodatabase has a range of performance and scalability improvements. It becomes even more powerful for cartography with integration of raster data such as imagery or terrain models. New facilities for defining and maintaining unique feature identifiers facilitate tracking of parentage and other feature-to-feature relationships. Open access to data is guaranteed by provision of new capabilities to transfer all geodatabase information in XML form.

Client-Server Architecture

The ESRI architecture supports a network of clients and servers accessing the geodatabase, providing the flexibility and fast responses of interactive desktop clients, together with the scalable power of back end servers tuned for database or Web serving.



The ArcGIS Family of Products, Working Together to Provide Cartographic Productivity

ESRI ArcSDE® provides access to an enterprise geodatabase, operating either as a dedicated server process or distributed into the client applications. It is the gateway that facilitates managing spatial data in a database management system, providing efficient storage of continuous map data with spatial searches and transaction locking.

For smaller cartographic projects or during fieldwork, development and testing, the versatility of a personal geodatabase is vital. In this mode, data is stored in a Microsoft® Access database but appears to the user through the same uniform user interfaces. Checkout/Check-in facilities are used to support field edit and ground checking of geographic or cartographic data, allowing consistent use of the central database by handheld or tablet clients. Such disconnected editing is made easier in ArcGIS 9 by new capabilities using XML to transfer change-only (delta) information.

Internet services are provided by ArcIMS®. This includes not just display of Web mapping but also query, analysis, and data delivery services. Such services are becoming ever more important to cartographic production agencies, and ArcIMS provides a smooth path to serving cartographic products generated via ArcMap™ to Intranet and Internet customers. In ArcGIS 9, the ArcIMS product becomes even more integrated into the ArcGIS family, joining the release cycle of ArcGIS Desktop and ArcSDE.

In ArcGIS 9 comes a new ArcGIS Server product to increase the flexibility of distributing applications across a network. Also new in ArcGIS 9 is ArcGIS Engine,

which is a powerful collection of embeddable mapping and GIS components. Built from the same code as ArcGIS Desktop, these two additions facilitate plugging serverside GIS and cartographic tools into enterprise IT environments.

Data Models and Topological Structure

A map is a visual model of the real world, and within the geodatabase, the world can be modeled flexibly as a set of feature classes or layers, each with its appropriate attributes and relationships. Tools are available to group layers together or to set up subtypes, to model the hierarchical family relationships of the real world.

The geodatabase supports a wide range of data types including continuous raster images and terrain models as well as vector objects and networks. The spatial relationships of data are also modeled, with recent tools now available to define the topological rules of the data—the way roads or rivers form into networks, administrative areas share common boundaries, or many buildings exist within urban areas.

ESRI already provides a family of standard starting point data models for different vertical markets. A standard multiscale data model is currently being developed, aimed directly at cartography and particularly relevant to the task of deriving multiple cartographic and data products from a single GIS database.

Many national mapping agencies have the concept of a digital landscape model (DLM) at full detail (e.g., scale of 1:10,000), with derived DLMs at coarser resolutions (scales of 1:50,000 and 1:250,000). Each DLM is in turn the starting point for one or more derived digital cartographic models (DCM or DKM), in which the need for visual clarity outweighs the need for ground-truth. ESRI understands and supports this logical framework for multiscale mapping. The new capabilities described in the later sections on stored representation and geoprocessing and generalization will facilitate the construction and maintenance of DLMs and DCMs.

Data Capture, Management, and Update

A database is useless unless populated with appropriate data and kept up-to-date with changes happening in the real world. ESRI has a strong set of closely integrated products, components, and extensions to cover the full range of data sources:

- **ArcView[®], ArcEditor[™], and ArcInfo[™]** are the three product levels of **ArcGIS Desktop**, each providing an appropriate level of functionality for a range of cartographic tasks. Each level presents three integrated applications to the user:
 - **ArcMap** for screen digitizing from imagery or existing maps and for interactive feature editing with its intuitive task-oriented user interface.
 - **ArcCatalog[™]** for management and import of GIS data sets and Internet sources.
 - **ArcToolbox[™]** for import and processing of data from computer-aided design or engineering systems. In ArcGIS 9, ArcToolbox is greatly extended and is available in ArcMap and ArcCatalog.
- **ArcGIS Data Interoperability** extension is new in ArcGIS 9 and provides direct read and import from 65 formats including GML, XML, DWG, DXF, DGN, MID, MIF, TAB, Oracle Spatial, and GeoMedia Warehouse.
- **ArcScan[™] for ArcGIS** provides raster to vector conversion to automate the capture of existing paper mapping.

- **ArcGIS Spatial Analyst** provides tools to map and analyze grid data and terrain models. In ArcGIS 9, more than 100 spatial analyst tools are available in the new ArcToolbox geoprocessing environment.
- **ArcGIS Survey Analyst** for managing and utilizing inputs from ground surveyors.
- **ArcMap global positioning system (GPS) support** for accepting features and control points from satellite positioning systems. With ArcGIS 9, this becomes a standard capability.
- **ESRI data** provides a range of starting point data for many cartographic projects including world basemap data, shaded relief, boundaries, and streets.

In addition to the direct ESRI products, there are also relevant extensions provided by business partners, such as **ArcGIS Image Analysis** from Leica Geosystems, for enhancing, analyzing, and extracting data from satellite imagery, aerial photography, or orthoimagery. Also available are photogrammetry interfaces for capture from stereophotography and stereoimagery.

The ArcCatalog application is the principal spatial data management tool of ArcGIS. It integrates all kinds of spatial data, whether geographic, cartographic, engineering, landscape models, surfaces, grids, triangulated networks, or imagery. Data can be managed whether in self-contained files, sets of tiles, ArcSDE layers in relational databases, enterprise or personal geodatabases, or live services from the Internet or local networks. New in ArcGIS 9 is management of continuous raster data in a geodatabase and connections to data and map services from the new ArcGIS Server application. All these data sets and data sources are then available to use in compiling cartographic products using ArcMap.

Representation and Symbolization

Symbolization is at the heart of visual cartography. ArcGIS provides a rich set of functions for defining and applying symbolization styles to point, line, or area data. It includes vector and bit mapped symbols, line styles allowing patterned and pecked lines with control over end and join styles, and areas filled with solid color or patterns. Raster symbolization is also strong, with capabilities important to cartography such as terrain height banding and hillshading.

Vector symbolization may be complex, with the representation being built up by drawing multiple representation parts, each with its own drawing priority level. Enhancements in ArcGIS 9 include new group layers and symbol level controls, which together allow clean handling of standard cartographic styles, such as road casings, and under and over sections such as road bridges and tunnels. Symbolization is not determined solely by the feature class but can be determined by combinations of attributes, allowing exceptions for categories such as "primary dual road under construction."

ESRI's traditional strengths in GIS mean that versatile symbolization capabilities are provided for thematic, statistical, and analytical presentation—vital for atlas producers as well as mapping agencies covering natural and human resources. These capabilities are being extended by current projects working on multivariate representations and on handling of uncertainty.

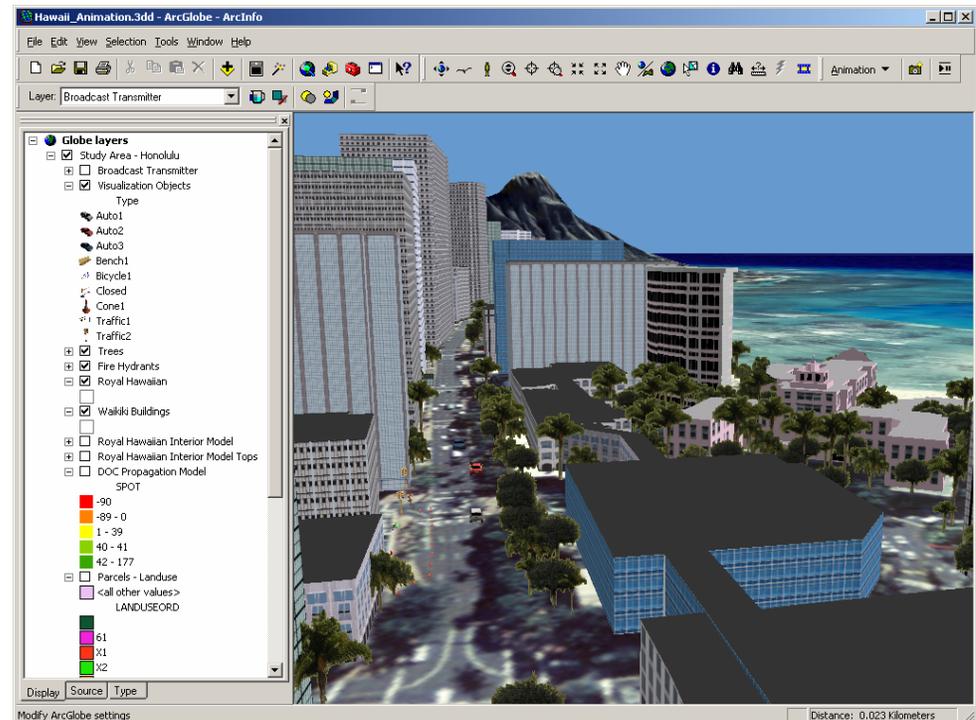
For those few categories of features for which the provided static representation capabilities are insufficient, a plug-in custom-made renderer can be added, using the full power of the underlying ArcObjects™ toolkit to determine the visual appearance.

Beyond ArcGIS 9, work is under way for new, advanced cartographic symbolization mechanisms associated with the cartographic layer facilities that are described in a later section. These use parameterized filters to derive cartographic geometries and representations from the original GIS feature geometry. An example might be to take a road centerline and offset it to one side, then use the offset line to generate a dashed line while adjusting the length of the dashes to always start and end the line with the solid part of the dash pattern. All this will be done automatically and dynamically.

Three-Dimensional Cartography

ArcGIS 3D Analyst™ is an extension to ArcGIS that adds three-dimensional visualization, increasingly relevant to cartographic publishing. In ArcGIS 9, 3D Analyst adds dramatic three-dimensional symbology. This includes

- Three-dimensional points (rendered volumes or extrusions)
- Lines (volume shapes, such as pipes, and strip lines with image texture such as a realistic road)
- Polygons (textured fills draped over a surface)
- Standard three-dimensional styles for houses, street furniture, trees, and vehicles



Three-Dimensional Symbolization and Perspective Visualization (Data Courtesy of the City and County of Honolulu)

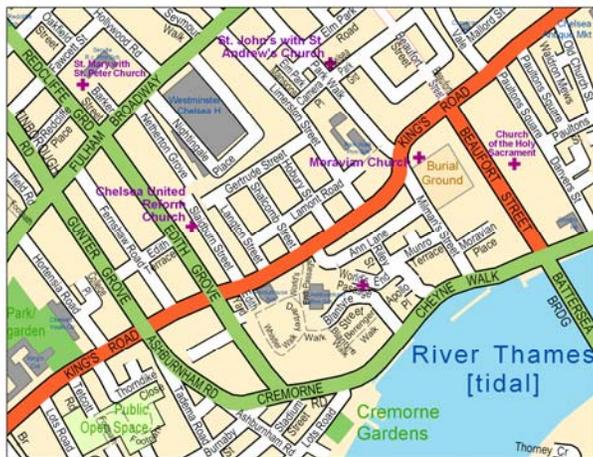
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Also new as part of ArcGIS 3D Analyst in ArcGIS 9 is ArcGlobe™, a dramatic application for visualizing large amounts of two-dimensional and three-dimensional data using three-dimensional fly-through techniques.

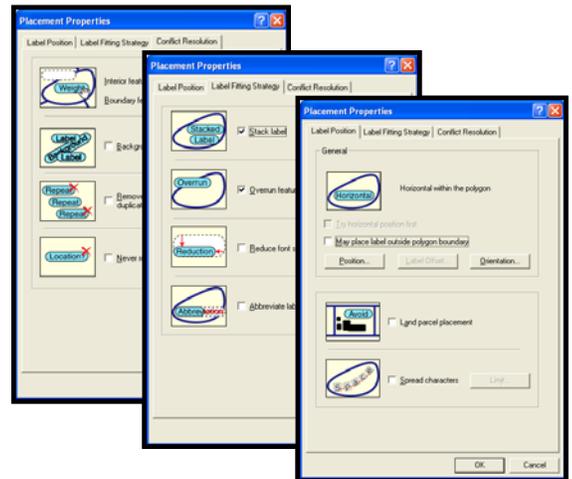
Labels, Text, and Annotation

ArcGIS has always had significant capabilities for text labeling, but with ArcGIS 9 these have been greatly extended in three areas.

- All the main text font types are now supported including TrueType®, Adobe Type 1 (PostScript® fonts), and the new OpenType standards. Font information can now be embedded in output formats, reducing risk of font substitutions.
- There are now clean and comprehensive capabilities for storing text in the database as annotations, which can be freestanding or feature linked. Feature-linked annotations are tied back to the GIS features from which they were created so that they can be automatically updated as change happens in the real world. Annotation support now includes such cartographic elements as callouts and leader lines.
- The world leading Maplex text placement engine has been built into ArcGIS as a label placement extension. This can massively reduce the previously labor-intensive task of generating and positioning text for cartographic clarity.



Clear, Well-Placed Labels (Data Courtesy of Collins Bartholomew Ltd)



Full Control Over Label Placement

Beyond ArcGIS 9, work continues on improving support for multiple languages and scripts and in providing consistent font handling across multiple platforms.

Stored Cartographic Representations

Storing annotations in the database is but one step of a general ESRI plan to hold the full richness of all cartographic products in the geodatabase. This process was started in ArcGIS 9, but an immensely powerful generic capability for "cartographic layers" is currently available in prototype form and planned for inclusion in a future release.

These cartographic representation layers store the definition in the geodatabase of any representation elements that have been generated from the GIS features either by automated procedures or by manual intervention. They provide the cartographer with the freedom to override the strict rules of the GIS symbolization on a feature-by-feature basis

and hence produce the required visual quality, without affecting or unnecessarily copying the underlying master GIS data. In the same way as for feature-linked annotations, they relate back to the master GIS data, allowing overriding of particular properties and giving parentage and traceability to enable the efficient handling of incremental updates.

The stored representation capabilities are in addition to the inherent ArcGIS and geodatabase facilities to derive, create, and store cartographic features as layers of points, lines, or polygons. Such cartographic feature classes are often vital to the implementation of digital cartographic models from digital landscape models and can act as a source for subsequent stored representations.

The new mechanisms for generating cartographic feature representations from GIS features can greatly enhance cartographic clarity. Examples include automatic creation of masking areas and abutment symbols for bridges, adjustment of dashed lines to avoid ambiguities where lines would otherwise end or start with a gap, and generation of context sensitive symbology for slopes or embankments.

Cartographic Editing Tools

With the cartographic layers capability will come a set of editing tools aimed squarely at the cartographer, providing tools to reshape and override the GIS representation of features to meet the demanding requirements of production cartography. Many of these tools are modeled on the free-form drawing and intuitive tools familiar to users of desktop drawing packages such as Adobe Illustrator or Macromedia® FreeHand®.

These cartographic tools complement the rich set of editing tools of the core GIS, operating in full WYSIWYG mode, providing a consistent editing environment from the field through database update to cartographic finishing.

Sheet Layout and Marginalia

ArcGIS has had for many releases a comprehensive set of capabilities for laying out a map product onto a sheet including adding multiple map areas, legends, north arrows, titles, and so forth. These capabilities have been greatly extended by Production Line Tool Set (PLTS) (see Production Work Flow below).

ArcGIS 9 adds new capabilities for defining and manipulating graphic elements on the page including new support for text blocks formatted in paragraphs that flow within polygon, rectangle, or circle graphic shapes. In addition, work is underway to add dynamic text support to the layout mechanisms so items that vary from sheet to sheet can be automatically filled from database information.

Graphic Rendering

Underpinning the symbolization capabilities of ArcGIS is a powerful graphics output pipeline that handles stroking, filling, patterning, color, priority, transparency, visibility, masking, and much more. It drives screen output, plotting, and graphic export formats. With ArcGIS 9, the pipeline has been restructured to provide greater consistency between families of related formats and to remove limitations on size and complexity of plots.

Also new in ArcGIS 9 is selective masking, which allows the user to specify a set of target layers to be masked or erased for each source polygon layer. This can greatly increase cartographic clarity, for example, by suppressing road casings where crossed by text without suppressing the road infill.

Work continues to revise the graphics pipeline for greater performance, new functions, and platform portability. It will improve handling of complex graphics primitives, such as the clipping and merging of patterned fill areas, and hence reduce plot file sizes,

particularly on output to intelligent plotting devices. Support is also planned for new document color models to provide a framework for CMYK, spot, and Pantone® colors, and to facilitate the use of gradients and textures.

Printing and Prepress

The facilities of ArcGIS for printing and prepress output are also evolving rapidly. ArcGIS 9 includes a revised graphics pipeline (see Graphic Rendering above), implementing shared code for common operations for vector and image formats, and hence providing much greater consistency between different types of plot output.

The restructured output facilities of ArcGIS 9 remove previous restrictions on file or memory size for image formats. Raster formats supported now include GIF, PNG, TIFF, and JPG, while vector formats include EPS, Adobe Illustrator, and SVG. The primary format for cartographic production is Adobe Acrobat® PDF format, which has become the mainstay of prepress operations and Web publishing.

In ArcGIS 9 is a rewritten ArcPress™ module, rasterizing from the ArcGIS graphic operators without involving an interim PostScript stage, which dramatically improves the performance and quality of the print output. The new architecture for ArcPress allows background printing, releasing the operator and the desktop application to continue with interactive work.

Beyond ArcGIS 9, further work on the graphics pipeline is under way to provide support for non-Windows platforms for ArcGIS Server, to simplify and extend color definitions, and to improve plot file output.

Production Work Flow

In a production cartographic organization, such as a national mapping agency or a commercial atlas producer, every button pressed by an operator costs money. PLTS has been developed by ESRI as a software layer on top of ArcGIS to optimize the cartographic work flow and the day-to-day tasks of operators.

PLTS provides a suite of facilities to automate and facilitate cartographic work flow.

- Data Loader for bulk loading original data and updates
- GIS Data ReViewer for automatically taking the operator to areas requiring update or error correction and recording actions taken
- Job Tracking for ArcGIS (JTX) to schedule operator sessions and tasks
- Intuitive toolbars to minimize button clicks or searching for the right button

Crucially for bulk cartographic production, PLTS provides database driven capabilities for validating attributes and using attribute combinations to select representation styles. It optionally provides standard data models and tailoring for defense and nautical data preparation. Also available are styles, layouts, and marginalia for common mapping formats in both civilian and defense styles.

Coming soon with PLTS 9 is a packaged solution for database driven aeronautical chart production with preprepared data model, representation, and tailored tools. Development is continuing on similar solutions for nautical charts.

***Map Series
and Atlas Definitions***

PLTS, using the underlying geodatabase, also provides facilities for defining a map series, then generating the various sheets automatically and inserting the appropriate marginalia and titles.

This capability is being extended for ArcGIS 9 in a new capability called PLTS Atlas, which stores more of the information defining the series in tables in the database. It can also handle an atlas made up of multiple pages with overlaps and page grids.

Also coming soon in PLTS is a new rule-based index generation capability, handling sorting, abbreviation, and duplicate removal. Further tools are on the way to facilitate production of complete cartographic publications by automating tasks such as adding and maintaining tables of map-related information.

***Geoprocessing and
Generalization for
Multiple Products***

Producing good cartography requires good starting point data, and here the historic strengths of ArcGIS for geographic data manipulation come to the fore. ArcGIS 9 introduces a new integrated ArcToolbox capability, with a visual model builder that simplifies the linking of geoprocessing operations into a process flow that can select, filter, merge, and manipulate GIS features.

Future releases of ArcGIS will add new tools to ArcToolbox. In particular, projects are under way to add more tools for intelligent generalization—the tasks involved in deriving simpler, lower resolution data in order to produce smaller scale mapping. The aim is to satisfy the stated goal of many cartographic agencies for the scale-free or multiple representation database, into which update happens once at the largest scale and from which all products at all scales are derived.

These geoprocessing generalization tools fit naturally into an overall multistage framework for deriving and storing map products, which also includes the cartographic layers with their automated filters.

***Data Products and
On-Demand Maps***

Mapping production agencies have increasing pressure from their customer base to produce vector and raster data products alongside the traditional cartographic paper products. The Web mapping strengths of ArcIMS are well proven, are continuing to advance, and will gain from many of the cartographic capabilities described above.

The strong generic geodata processing capabilities of ArcGIS, combined with its rich support for geodata transfer formats and the flow line optimizations of PLTS, provide a unified environment in which data products can share a common database and exploit work flow synergies with visual cartography for efficient production.

The ArcGIS Publisher extension and its associated free ArcReader™ application are enhanced in ArcGIS 9. They allow a cartographic publisher to package map data with instructions about the location and symbology of data layers (rendering rules, scale dependencies, etc.) including geodatabase connectivity and Internet sources.

New in ArcGIS 9 is the ArcGIS Data Interoperability extension, which provides export capabilities to more than 50 spatial data formats. An embedded semantic data translation engine is also included with 120 specialized transformers to diagram and model custom spatial data formats.

Much use is made of the new feature-linked annotation capabilities to produce clear textual information that changes automatically as the underlying geographic features and attributes change. The Maplex intelligent label placement engine positions the annotations while minimizing conflicts and maximizing clarity.

All the cartography is generated directly from geodatabase features including vignettes along coastlines. The chart surround information is automatically generated and placed and is automatically updated when the metadata in the geodatabase changes. Output is separated to four spot color inks and rendered to EPS files for transfer to printing plates. The result is an up-to-date, consistent, clear air chart product.

Conclusion

ArcGIS 9 provides the fundamental infrastructure and tools needed for quality cartographic production. These capabilities are being extended in future releases as part of the ESRI vision intent to provide the best cartographic tools and publishing environment in the world.

Introduction of new capabilities, such as representation layers and cartographic tools, will provide the highest quality of automated symbolization while permitting the cartographer to intervene to override the position, shape, and graphic style of individual features or even individual feature representation parts. This combination of database driven rigor with interactive flexibility is unique in the mapping industry and will enable high productivity together with optimal cartographic clarity.

The ESRI cartographic vision is of a single, consistent, intuitive, and efficient environment that is used from the start to the end of the cartographic process. It is one centered on a geodatabase that not only holds the master seamless GIS data but also holds the full specifications, processes, and results for all products, while providing the freedom and tools to create top-quality cartography.



For more than 30 years ESRI has been helping people manage and analyze geographic information. ESRI offers a framework for implementing GIS technology in any organization with a seamless link from personal GIS on the desktop to enterprisewide GIS client/server and data management systems. ESRI GIS solutions are flexible and can be customized to meet the needs of our users. ESRI is a full-service GIS company, ready to help you begin, grow, and build success with GIS.

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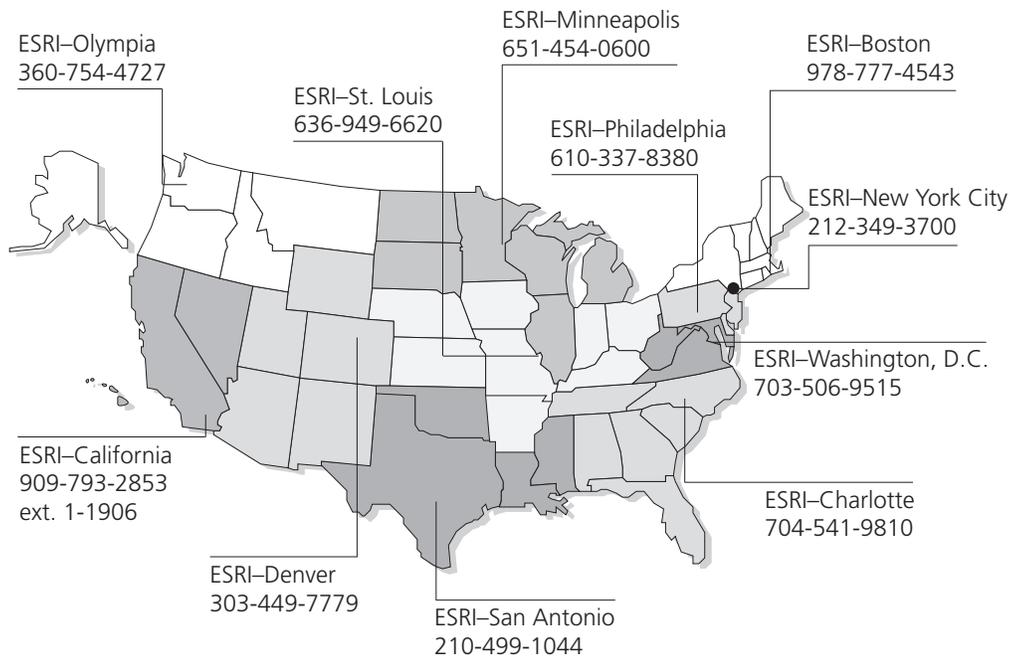
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