The Perfect Cartography Software, and How We Live Without It

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Cartographers have a proud tradition of finding new solutions to difficult problems. According to Keates (1996, 211), design is all about using creativity to balance conflicting demands and overcome obstacles. Unlike many other art forms, cartographers must produce quality despite constraints in medium, symbology, and the necessary ties to the real world. The ever-improving technology of Cartography has provided one means to improving map design and production.

We are rarely the creators of new technology, but have been very adept at adopting the latest available tools, and finding ways to use them to make good maps (Monmonier 1985, 11). Maps have been among the first applications of new printing technologies, from the earliest woodcuts, to copperplate, to photolithography, to color laser copiers, and even the Internet (Plewe 1997, 6). We have quickly adopted new production technologies, whether they were peel-coats, typesetters, PostScript, or GIS. These technologies have given the professional (and casual) cartographer a set of tools for producing increasingly better maps in less time at less cost.

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However, professional cartography today is still not in an ideal situation. It may seem paradoxical, but as life seems to get better, the number of "problems" and "obstacles" always seems to stay the same. There are several reasons for this. Our hopes and dreams quickly become our basic expectations, and the lack thereof is deemed a failure. Small issues that we didn't have time to worry about yesterday turn into major roadblocks to reaching "the next level." In addition, new technologies can actually introduce new problems.

This paradox has certainly happened in Cartography. The issues that professional and academic cartographers worry about today would be completely foreign (and probably trivial) to Ortelius, Mercator or the Blaeus. While the technology available for cartographic design is much more powerful and efficient than it once was, we are more keenly aware of what we lack. We can accomplish great things, but we always have some idea of how it could be better.

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This paper looks at the relationship between professional cartographers and the available design technology. What are our expectations from software? What are our ideals for future technology? How do we make do with what we have now? The Practical Cartography Day at the 2002 meetings of the North American Cartographic Information Society showcased a number of tools, techniques, and tricks that we are using to produce high-quality maps; but the very existence of these tricks attests to the fact that current technology is not ideally suited to cartography.

This paper focuses on the "small-shop" cartographer, whether a freelancer, in a small cartography businesses, or as part of a GIS operation. Large map publishers have the resources to develop software solutions specialized to their operations, while small shops must rely on off-the-shelf solutions with only minor specialization. Also, large publishers tend to have standardized designs in which interactive design tools are not as crucial, while small-shop cartographers spend most of their time doing custom design.

Cartographic Projects

To develop an idea of what the perfect cartography software would look like, we should first understand how it would be used. The typical small-shop cartographer is asked to do a variety of projects, which fall into three basic types:

1. **The One-off**. The request is unique, in terms of source information and product. The cartographer enters data specifically for this project, designs a custom map, and delivers it. The file is not intended to ever be used again.

2. **The Cartographic Database**. For many reasons, cartographers tend to specialize in certain regions and certain themes (e.g., street maps of Cincinnati, recreation maps of Idaho). Over time, a common collection of data is developed and maintained, from which a variety of maps may be produced for various purposes and clients.

3. **The Permanent Map**. Some clients, whether they be customers or employers, have recurring requests. A map may be designed once, but then every so often, it must be updated and redelivered.

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Each of these projects requires many capabilities of cartographic tools. Some requirements are unique to a particular type, but many are shared. In addition, some projects make use of more than one type. For example, a cartographic database is often used to support one or two permanent maps as well as several one-off maps. Therefore, a successful cartography shop needs to have the tools necessary to meet the requirements of all three projects.

The Ideal Solution

To develop an idea of what the perfect cartography software would look like, we should first understand how it would be used. This program would be easy to use, but also very powerful. It would need to support all three phases in the process of digital cartographic production (Robinson *et al* 1995, 18): data collection, map design, and output. Each type of project dictates many capabilities that are needed in tools of each phase.

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1. Data Collection Tools

Cartographers need to enter new geographic data, import data from existing sources, and store those data permanently in a cartographic database that can be used for a variety of map layouts and designs. Several specific requirements are listed below:

Data Entry: support for digitizer tablets; image display for heads-up digitizing; tools for easy editing of existing datasets; able to replicate final map symbologies so that the final appearance of items can be previewed as they are entered; automated label placement; automated generalization, at least line simplification.

Data Import: support for many common national and international data formats; transfer from GPS units; connection to live web-based data services (such as ESRI Geography Network and OGC's Web Feature Server).

- **Database Structure**: support for raster and vector data; keeps data georeferenced to any projection or coordinate system; stores annotation (including curved text) and other "nongeographic" map elements; able to store different representations of each feature, such as for different scales; support for a variety of geometry types, such as spline curves; able to store and manipulate attributes of features for categorical symbolization.

- **Data Storage**: a stable platform so that data is not lost; scaleable to support data of many themes for many regions (several million records); modular so that a project doesn't tax the system by loading unnecessary data; conversion between projections and coordinate systems; versioned so that updates can be managed and reported.

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2. Design Tools

The digital cartographer then uses these stored data to create maps. The primary advantage of digital design tools is that they automate many of the repetitive and computational tasks. The best tools should do this without adding significantly to file sizes (which are large enough already with all of the features on the map). Some of the tools and capabilities are listed below:

- **Integrated with Cartographic Database**. Changes to features are often made late in the design process, when "tinkering" with drafts. These changes should be stored in the original database, either as updates to the original feature or as alternative versions of the feature.

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- **Graphic Techniques**. Some of the capabilities needed include: transparency, lines and fills with composite patterns (e.g. railroad hatching, cased roads), point symbols, controlled blocking behind text, text controls such as kerning.

- **Controllable Display Order**. Certainly should have layers, and ordering within layers, but the latter should be able to be controlled parametrically (e.g., "show all major highways on top of minor streets"); also, one should be able to make exceptions, either manually or parametrically, so that roads could go over bridges over other roads, or boundaries could go under small lakes but over large ones.

- **Advanced Visualizations**. Cartography today is about much more than flat paper maps. We must be able to produce three-dimensional views, animations, interactive websites, and spatializations of non-geographic phenomena.

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- **User Interfaces**. Creative design happens best in an interactive environment, in which the cartographer can experiment with new ideas and see results immediately. This is crucial for new maps. However, when designs become standardized, the process works best if the design implementation (layer and feature selection, symbolization, layout, etc.) can be automated, using either templates created during an interactive session or high-level program scripts.

3. Output Tools

The third phase of production is to deliver the finished design to its intended audience. This final product can have many forms, each of which makes its own requirements of cartography software:

- **Personal Printer**. The vast majority of digitally produced maps are destined for a laser or ink-jet printer, producing only a few copies to be used by a limited audience. The most difficult obstacle here is not the printer hardware–it is matching the monitor image to the printed image. There are many tools to assist in this matching, even though a perfect match is physically impossible.

- **Press**. Traditionally, a map intended for a large audience would be sent to the press. While other forms discussed here have grown at its expense, there are still a lot of maps that are mass-printed. To support this, cartographic software must include extensive pre-press capabilities, including separations, registration, trapping, reliable text sizing and spacing, and of course the color control mentioned above, with support for several color processes (4- color and 6-color process, spot, and various color matching systems such as Pantone).

- **Other Software**. Frequently, cartographers work with other design professionals, as maps are often one part of a broader product (such as an advertisement or a telephone book). Thus, the map needs to be sent out as a digital file capable of being read *and altered* using graphic design software with as little translation loss as possible. This means more than just EPS; a good program would be able to export maps in the native formats of programs such as FreeHand, Illustrator, Quark Express, and Corel Draw with all the layering and other graphic tricks intact.

- **Digital**. When maps are dynamic or interactive, or when they need to reach a large audience inexpensively, the best medium may be digital, usually either CD-ROM or the Internet. To support these, cartographic software would need to export maps in the *de facto* and *de jure* standards of those media, including raster formats such as JPEG, PNG, and GIF, but also in vector formats such as PDF, Flash, and SVG. It would also be nice if the software could assist in building the entire interactive interface, which one may consider as part of the map.

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Together, these three phases result in a rather large wish list of capabilities. However, none of these is a pie-in-the-sky dream (that would be a much longer list). All of the capabilities above are currently available in one program or another. The question is whether they can be effectively collected to complete a cartographic project.

The Current Solution

Needless to say, the perfect specialized cartography software, a single program that seamlessly integrates all the above capabilities, does not currently exist. Probably the closest product to this ideal is Mercator S/A from Barco Graphics (www.barcographics.com), but even it does not meet all the standards, and it is priced out of the range of most small cartography shops. In fact, the perfect software will probably not appear for a long time, if ever. The main reason is that cartography is a relatively small

market; developing a new program that combines the relevant features of GIS and Graphics software would be a very expensive process. Therefore, cartographers have to use general-purpose software to create maps for the foreseeable future.

Our current toolkit includes four basic kinds of software: Geographic Information Systems, such as MapInfo (www.mapinfo.com) and ESRI's ArcView (www.esri.com); graphic design programs, such as Adobe Illustrator (www.adobe.com), Macromedia FreeHand (www.macromedia.com), and CorelDRAW (www.corel.com); specialized cartographic production software such as Mercator S/A and MAPublisher from Avenza (www.avenza.com); and specialized tools, such as Bryce and World Construction Set for 3-D visualization or any number of web design tools. The specialized products will not be discussed herein because they are designed for a specific task rather than general cartography.

"Our current toolkit includes four basic kinds of software: Geographic Information Systems, graphic design programs, specialized cartographic production software, and specialized software."

GIS software and graphics software operate in very different ways; this has a profound influence on what they can and cannot do with maps. GIS software uses an "include-by-reference" philosophy, in which the map layers are references to data files, stored permanently and separately from the map itself, and often filtered by attribute and/or spatial criteria. Symbolization, layout, and such are displayed on-the-fly, without modifying the underlying data. Graphics software uses an "object collection" philosophy, in which data are entered (drawn or imported) into one single file, and subsequently modified to select and symbolize objects, and compose the map layout. Once they are brought in, the graphics objects maintain no link to the source data. MAPublisher is an add-on to graphics software that does not change this mode of operation, but extends the import, selection, and symbolization capabilities. Mercator S/A works in much the same way as graphics software with MAPublisher, except that it has the ability to store each map layer as a separate file.

Each type of software has its advantages. The GIS model enables easier update, since changes to a dataset are immediately reflected in any maps that use it. The graphics model is more flexible (e.g., displacement generalization is okay because it doesn't tamper with the original data) and easier to transfer, since everything is contained in a single file. The specialized software has features that are designed specifically for cartography. However, each of these software genres also has its own problems for cartography.

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Tables 1, 2, and 3 show how well each of the above types of software supports each of the requirements listed earlier.

The tables show that none of the standalone packages comprises a complete cartographic software solution. Each is lacking in at least one vital area. Mercator seems to meet the most requirements, but is still lacking some data management capabilities, and is very expensive. For the GIS software, the largest holes are in design and output capabilities (although recent software such as ArcGIS 8 have significantly improved the former). For the graphics software, the greatest obstacle is in data processing, although MAPublisher helps somewhat.

Does this matter? In some situations these holes are not crucial, such as when a cartographer is in a GIS department where quality and distribution of maps is not a high priority; or in a small cartography business that produces one-off maps exclusively, in which permanent data management is not a concern. Certainly, some capabilities are a higher priority than others. However, a cartography shop needs almost all these capabilities to serve the full range of requests from a wide range of clients. This can be accomplished to some degree with the available software in two ways.

Table 1: Data Management Requirements

Capability		Low-end GIS (e.g ArcView)	High-end GIS (e.g ArcGIS 8)	Graphics (e.g. FreeHand)	Graphics w/ MAPublisher	Mercator S/A
Data Entry	Digitizer support	3	3	0	0	0
	On-screen digitizing	2	3	3	3	3
	Editing tools	2	3	3	3	3
	Editing map display	2	2	3	3	3
	Label placement	1	2	0	1	0
	Generalization	1	2	2	2	2
Data Import	GIS data import	2	3	0	2	2
	GPS transfer	2	2	0	2	0
	Web data services	0	2	0	0	0
Data Structure	Raster/Vector	3	3	2	2	3
	Georeferenced	2	3	0	3	0
	Annotation	1	2	3	3	3
	Multiple representations	1	1	0	0	0
	Complex geometrics	1	1	3	3	3
	Attributes	3	3	0	2	2
Data Storage	Stable	3	3	3	1	3
	Scaleable	2	3	1	1	2
	Modular	2	2	1	1	2
	Re-projection	2	3	0	2	0
	Versioning	1	3	1	1	0

Code meanings: ***3=strong support: exactly what we hope for***
2=some support: it can be done, but could be easier to use or more powerful
1=either there is no coherent support, but it can be done manually or using extra add-ons, or there is support, but performance does not meet basic standards
0=not possible

Table 2: Map Design Requirements

Capability		Low-end GIS (e.g ArcView)	High-end GIS (e.g ArcGIS 8)	Graphics (e.g. FreeHand)	Graphics w/ MAPublisher	Mercator S/A
2-Way database-design integration		3	3	1	2	2
Graphic Techniques	Complex line symbols	1	3	1	1	3
	Complex fill symbols	1	3	2	2	3
	Complex point symbols	1	2	0	2	3
	Text controls	1	1	3	3	3
Display Order	Layers	3	3	3	3	3
	Intralayer control	1	1	1	1	2
	Interlayer control	0	1?	0	0	2
Visualization	3-D Views	2	2	0	0	0
	Animation	1	1	1	1	0
	Website design	1	2	2	2	0
	Spatialization	1	1	0	0	0
Interface	Interactive	3	3	3	3	3
	Automated	1	2	1	0	2

Table 3: Output Requirements

Capability		Low-end GIS (e.g ArcView)	High-end GIS (e.g ArcGIS 8)	Graphics (e.g. FreeHand)	Graphics w/ MAPublisher	Mercator S/A
Printed Output	Color Matching	1	1	2	2	3
	Text Matching	1	1	3	3	3
	Pre-press controls	0	1	3	3	3
File Export	Graphics software	1	2	3	3	2
	Web formats	1	2	3	3	2

The first solution is the "patch" approach, developing custom tools and techniques for filling in the holes in one of the standalone solutions. Many of the presentations at 2001 Cartography Day showed the great accomplishments that cartographers have made in this regard. There are shareware and freeware programs for processing GIS data without a full GIS, such as GeoCart (for projection) and MicroDEM (for terrain analysis). Many cartographers have written macros in graphics programs, or developed manual procedures, for handling some of the data processing tasks. For example, MAPublisher can be considered a significant patch for graphics software.

Patch macros can also be written in GIS software to improve its capabilities for output and other current weaknesses. For example, I am currently developing SVG exporters for ArcView 3.x and Oracle Spatial, and shareware scripts are available for managing annotation in ArcView. The main problem with this approach is that there are still holes in each product that cannot be so easily filled, such as the color control in GIS, or the permanent data management in graphics software. Also, as the number of patches multiplies, the software can become quite cumbersome to use and manage.

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Alternatively, the two kinds of software can be combined to form a "hybrid" solution. GIS and graphics software are quite complimentary; where one side is lacking, the other side is typically very strong. If one can integrate both sides, almost all the needs are met. Currently, that means managing the permanent cartographic database in GIS, then importing selected datasets into a graphics program to produce a map. This is a process I frequently use for my own map projects. The difficulty with this approach is that the integration is weak, and in only one direction. That is, one cannot make changes back to the permanent database (in the GIS) during the design phase (in the graphics software). Also, since only raw datasets are imported, the design process has to start anew every time (with a few shortcuts such as styles and templates). Even specialized cartography software such as Mercator S/A has this one-way workflow, although it does have tools for automating a standard design. Another problem is that many cartographers and graphic designers are based on the Macintosh platform, for which no robust GIS is available.

Thus, neither the patch nor the hybrid solution is as powerful as a single, well-designed cartography program could be. The greatest weaknesses of each approach for the three types of projects are summarized in the table below. Major weaknesses, those that would keep most people from using the tool for that purpose, are shown in bold.

"One possible next-best solution is to further extend (or patch) graphics software to provide a complete solution."

As can be seen in Table 4, the current toolset is not equally satisfactory for all types of projects with all software solutions. Graphics software tends to do fairly well for one-off maps (especially simpler ones), and GIS can be effectively used (with some tweaking) to manage a permanent cartographic database. The Hybrid and Mercator solutions make the permanent map possible, but they are cumbersome at best.

The (Near) Future Solution

As mentioned above, a specialized, low-cost, powerful cartography program is not likely to appear soon. If not, then what can we expect (or hope) to see in the near future?

One possible next-best solution is to further extend (or patch) graphics software to provide a complete solution. Vendors such as Adobe, Macromedia, and Corel are not likely to spend much time fulfilling the requests of such a small group. Third-party vendors such as Avenza and

Table 4. Shortcomings of Current Solutions

Method	One-off	Cartographic Database	Permanent Map
GIS w/patches	**poor pre-press, text control, few export formats**	transforming management-oriented GIS data	**same as one-off**
Graphics/MAPublisher/other patches	instability	**no data management**	**updates difficult**
GIS > MAPublisher > Graphics hybrid	instability	same as GIS	**1-way workflow, re-symbolizing updates**
Barco Mercator S/A alone	**Complex**	**no data management**	1-way workflow
GIS > Mercator S/A hybrid	**Complex**	same as GIS	1-way workflow

the many programmers in the cartography community itself have brought us a lot closer, and will continue to fill in the gaps. However, even these developers admit that there are inherent limitations in graphics software structures that prohibit them from imitating the best features of GIS. For example, changing categorical symbology (e.g., choropleth maps) in ArcView or GeoMedia is a one-step procedure. Since this approach cannot be implemented in the API's of FreeHand or Illustrator, MAPublisher requires a lengthy procedure to accomplish the same result.

Another possibility is for GIS vendors to solve their cartographic shortcomings. Many GIS vendors have recognized the need for high-quality cartography in recent years, and are adding more high-end capabilities that used to only be in graphics software. In fact, in some cases the GIS features are better, such as ArcMap's impressive tool for building composite line and fill patterns or GeoMedia's interactive classification tool. There do not appear to be any inherent structural limitations that would preclude them from filling in the rest of the holes in the chart above, although some additions (e.g., more export formats) are more likely than others (e.g., prepress tools like trapping and separations). As these capabilities are introduced, they are likely to initially appear in high-end software or as optional extensions, thus increasing the cost. Also, it would be helpful to have a GIS package for the Macintosh platform to allow a large segment of the custom cartography community to have this approach available at all.

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A third solution would be to improve the hybrid approach. One way to do this would be to design the map in the GIS, then export the finished map (not raw datasets) to graphics software for final preparation for the press or combination with other graphics materials. This would take advantage of the inherent connection to live source data (a great advantage for the permanent map and cartographic database) and the increasingly powerful symbolization tools in GIS. The one-way workflow would not be a problem, since no permanent editing would be done with the graphics file. However, it would require that the GIS software have high-quality export tools, that preserve layers, styles, attributes, etc., not just graphics, and that the results (esp. colors and text) be reliable.

Another way to improve the hybrid approach would be to create a streamlined automated production system from the graphics software.

One would store all the data (including annotation) in the GIS. Then one would use an interactive graphics tool to design the map, associating styles or procedures with attribute values, and creating a layout of the map and other pieces. This would generate a template for that map design. Then all one would have to do is start a small program, load the template and hit "Make Map," and a few seconds later, out pops a complete graphics file, or process separation negatives, or website. This is not the elusive "Automated Cartography:" the cartographer is the one doing the complete design; the computer is simply automating the application of that design to the source data. This is the approach of the high-end cartographic production software from Barco Graphics and some GIS vendors, but they are too expensive for the small shop, and too cumbersome for the variety of custom cartography projects.

As in the first approach, the one-way flow would not be a problem. There is no need to tinker with the final graphic file (and worry about how to make the tinkerings permanent); if a change is needed, it can be made to the original data or the template, and the graphics file can be easily regenerated. This solution could be reached in future versions of Mercator, or if some kind of scripting or parameterization capability could be added to MAPublisher.

The advantage of many of these augmentations of the current approach is that if necessary, we can do much of this ourselves. Both Graphics and GIS software have built-in high-level scripting environments, although some are simpler than others. Many of these extensions could be written by cartographers with moderate programming skills.

Although the perfect cartography software is not likely to appear soon, there is hope that the existing situation will improve. Fortunately, we as cartographers are not dependent on others to solve our problems for us. The 2001 Practical Cartography Day showed that cartographers are creating solutions. We should continue to leverage (and increase) our inherent creativity and talents to build the ideal tools for cartography.

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