From Crayons to Computers

The Evolution of Computer Use in Redistricting

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Following the most recent round of redistricting, observers across the political spectrum warned that computing technology had fundamentally changed redistricting, for the worse. They are concerned that computers enable the creation of finely crafted redistricting plans that promote partisan and career goals, to the detriment of electoral competition, and that, ultimately, thwart voters' ability to express their will through the ballot box. In this article, we provide an overview of the use of computers in redistricting, from the earliest reports of their utilization, through today. We then report responses to our survey of state redistricting authorities' computer use in 1991 and 2001. With these data, we assess the use of computers in redistricting, and the fundamental capabilities of computer redistricting systems.

Keywords: redistricting; gerrymanders; information technology; computer systems; software; automated redistricting

The days of crayons and markers are gone, and during the past 3 decades, computers have emerged as an integral redistricting tool. The ability of current computer technology to manipulate large databases and to perform complex calculations quickly is well understood. This ability is of particular value to redistricters, who often find themselves required to manipulate large geo-spatial and demographic databases under tight deadlines. In the past decade, computer hardware and software designed specifically for redistricting has become more affordable and accessible, opening up this intrinsically political process to many participants who had traditionally been excluded.

Following the most recent round of redistricting, observers across the political spectrum warned that computing technology had fundamentally changed redistricting, for the worse. Scholars and journalists alike have pointed with alarm at computer programs that "can generate maps custom-fitted to meet any group's needs" (Buchman, 2003, p. 119) allow map-

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pers to "to specify a desired outcome . . . and have the program design a potential new district instantly" (Peck & Caitlin, 2004, p. 50), or simply to "preordain" elections (Fund, 2003). Legal scholars such as Pildes (1997), Karlan (1998), and Issacharoff (2002) worry (respectively) about the "astonishing precision" of technology, which has lead to "increasingly sophisticated" gerrymanders, causing "incumbent entrenchment." Some observers claim that computers have qualitatively changed the redistricting process. These concerns pervade even the Supreme Court, where in the recent partisan gerrymandering case, *Vieth* v. *Jubelirer* (2004), Justices Souter, Breyer, and Kennedy wrote independently of the corrosive effect of technology, which, in Souter's words, has led to gerrymanders that are "virtually impossible to dislodge."

These observers and others are concerned that computers enable the creation of finely crafted redistricting plans to promote partisan and career goals, to the detriment of electoral competition, and that, ultimately, thwart voter's ability to express their will through the ballot box. Although these fears are widespread and often repeated, there has been no systematic examination of the use and capabilities of computer systems in redistricting. When did computers enter the redistricting process? How are computers used in it? Where are computers used most heavily? Are they ubiquitous? What are the fundamental capabilities of computer programs? Are we now in a world of push-button redistricting, or does human expertise still play a significant role in creating districts?

To answer these questions, we gathered systematic data about the use and capabilities of redistricting software. We report responses to our survey of state redistricting authorities' computer use in 1991 and 2001 and enhance our data with a survey of computer use in 1991 conducted by the National Conference of State Legislatures. We further supplement these surveys with interviews of map drawers and redistricting experts, and with a survey of the capabilities of redistricting software packages, supplemented by communications with the redistricting software vendors and developers. These systematic data allow us to provide answers stripped of the rhetoric and political punditry all too common in writing about redistricting.

WHEN DID COMPUTERS ENTER THE REDISTRICTING PROCESS?

The use of computers in redistricting is not a recent phenomenon.[1] Computers were first used in redistricting in the 1960s; however, their use did not become widespread until the 1991 round of redistricting.

The 1960s were a time of much interest in the emergence of computing technology and coincided with the Supreme Court's articulation of one of the first computational constraints on redistricting: equal population among districts.[2] Political scientists in the early 1960s advocated the use of computers, at first, as an so-called antidote to gerrymandering (Vickrey, 1961). Software capable of performing automated redistricting, of a limited sort, was developed shortly thereafter (Weaver & Hess, 1963; also see Altman, 1997, for an overview of early redistricting software approaches).[3] In 1971, state legislatures of Iowa, Delaware, and Washington commissioned computerized redistricting systems, as did the legislatures of Illinois, Michigan, and New York in 1981.[4]

What could these early systems do? Although the precise details of each system were not published, we are certain that these early redistricting operations were labor intensive—that automated redistricting was largely an academic enterprise, and that computers were used primarily as tabulating machines. Almost all districts were drawn by hand, while census geography was assigned to them using punchcards. This process required teams of people and limited map drawing to one new map a day, if all went well. One innovative implementation, created for the California Republicans in 1971, presaged modern on-screen Geographic Information Systems (GIS) software by utilizing transparencies overlaid on an analog digitizer to assign census tracts to districts.[5] When census geography was entered, the computer would tabulate population and election data within districts.

Prior to the widespread use of electronic computers in redistricting, people provided the computing power for redistricting. For example, Cain (1984) documented that the architect of California's 1981 congressional map, Philip Burton, used teams of individuals to analyze massive hard-copy reports of voter registration data, election results, census data, and precinct maps using simple calculators and colored markers. Because of the sheer volume of data and the constraints on time available to process them, Burton often relied on his personal knowledge of the state's political geography to assess a political outcome for a proposed district. Burton's map was an effective partisan gerrymander that resulted in Democrats swinging five congressional seats in their direction (Cain, 1985).

WHERE AND HOW ARE COMPUTERS USED IN REDISTRICTING?

To study the use of computers in redistricting, in the fall of 2004 we surveyed redistricting authorities in all 50 states concerning their use of computers in the 1990 and 2000 rounds of redistricting. For some states, the information we sought was provided entirely on a state's redistricting web page. Where information was inaccessible, we contacted a state's redistricting authority to locate a person or group of persons willing to respond to our survey.[6] We found that persons who had worked and retained accurate information on the 1990 round of redistricting were difficult to locate. For example, some respondents assured us that they had used software in 1991 that was not developed until 1998. We used due diligence in eliminating responses that were obviously inaccurate and attempted, whenever possible, to conduct follow-up surveys with additional sources. We also validated responses with a survey of 1991 redistricting usage conducted by the National Conference of State Legislatures.

By the early 1990s, changes in computer technology had a tremendous effect on redistricting.[7] The first GIS that provided on-screen line drawing capabilities, which greatly reduced data entry effort, were developed during the mid-to-late 1980s. By the 1991 round of redistricting, according to our survey, all but four states—Idaho, New Hampshire, New Jersey, and Vermont—used a computerized system for their congressional or state legislative redistricting. Various GIS's were in use (See Tables 1 and 2 for various software packages used in 2000); however, extensive customization was needed to make them capable of performing redistricting—and almost one third of states contracted out to consultants to perform these customizations (Table 3):

(The difference in the use of computing between congressional and legislative redistricting was slight, based on answers to the questions we asked—with the exception that six states did not conduct congressional redistricting at all. We report statistics based on the congressional districts here because they are the subject of the most controversy and discussion. Comparison data for legislative redistricting, however, are available from our replication data set. See Note 1.)

In the 1990 round of redistricting, system customizations and capabilities varied tremendously. Some states used the state planning departments' own software; however, these systems were not specialized for redistricting and required modification to calculate newly imposed redistricting criteria, such as compactness. (At times, compactness was simply not computed because the feature was not available.) Some states hired small consulting firms to

TABLE 1
Geographic Information Systems (GIS) Software Used by States, and States Contracting Out to Perform Congressional Redistricting in 1990.

GIS Software Packages	*Number of States*	*Percentage of Those Surveyed*
Entirely custom	7	18.4
ESRI Product	8	21.1
Geodist	9	23.7
Mapinfo	1	2.6
None used	2	5.3
Plan 90	9	23.7
REAPS	2	5.3

SOURCE: Authors' survey, on file. See Authors' Note.
NOTE: REAPS = survey response as given.

TABLE 2
Software Packages Used in the 2000 Congressional Redistricting

Redistricting Software Packages	*Number of States*	*Percentage of Those Surveyed*
Autobound (Digital Engineering Corp.)	19	45.2
Custom	6	14.3
Maptitude (Caliper Corp.)	5	11.9
Maptitude for redistricting (Caliper Corp.)	10	23.8
Plan 2000	2	4.7

SOURCE: Authors' survey, on file. See Authors' Note.

develop specialized redistricting applications. These applications were expensive because they required considerable computing power available only from mainframe computers or high-end workstations, and needed ongoing programming assistance and technical support.

In a redistricting survey in the 1990s conducted by the National Conference of State Legislatures, states reported spending more than US$500,000 on average for redistricting computer-systems, including purchasing software, hardware, training, and support (see Figure 1 for the distribution).[8]

By 2000, the necessary computing power could be delivered by a relatively inexpensive laptop running a few thousand dollars worth of software. (At least one package capable of basic redistricting functions, Manifold, is now available for several hundred dollars.) As hardware costs declined, the range of potential users increased to include substate jurisdictions, such as counties, cities, and interest groups. A greater supply of clients facilitated the entry of smaller competitors into the niche market of redistricting software. Software prices dropped, as redistricting applications became over-the-counter merchandise, and most states (with the exceptions of Florida, Mississippi, New York, North Carolina, Rhode Island, and Texas) adopted off-the-shelf software, as Table 2 shows. Furthermore, the percentage of states contracting out for redistricting computing services dropped significantly (Table 3):

Current mapping software has become more user friendly. Although still not as easy to use as a word processor, a computer novice could learn to draw a redistricting plan in a few

TABLE 3
Summary of Survey Results Regarding Congressional Redistricters' Use of Data and Consultants (Numbers In Parentheses Are Absolute Counts)

Year	*Used Voting Data*	*Used Registration Data*	*Used Other Data*	*Used Block Data*	*Used Consultants to Perform Redistricting*
1992	71.4% (30)	64.3% (27)	21% (8)	66.7% (24)	31.6% (12)
2002	72.7% (32)	75% (35)	26.2% (11)	71% (27)	13.2% (5)

SOURCE: Authors' survey, on file. See Authors' Note.

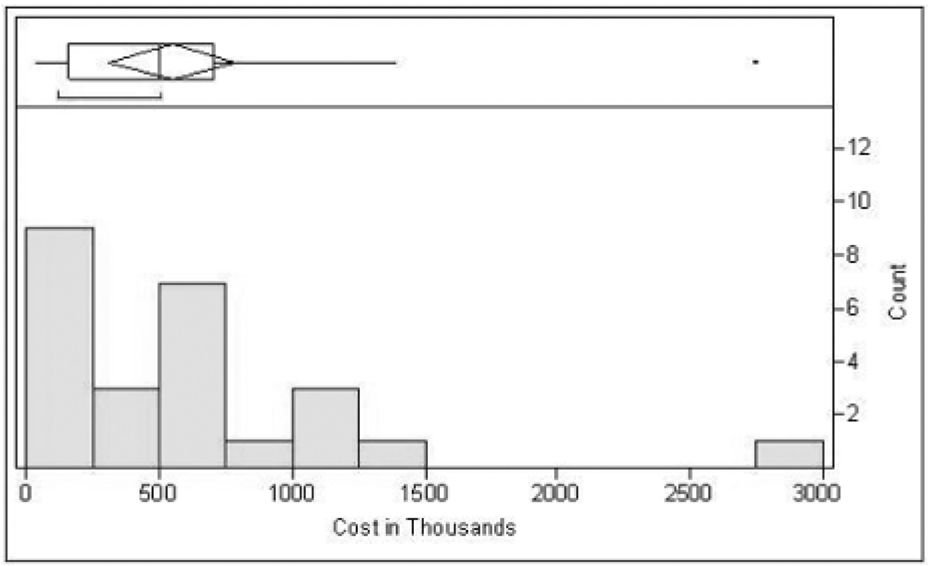

Figure 1: Cost of 1992 Congressional Redistricting. (Source: National Conference of State Legislatures, on file. See Authors' Note.)

hours, and the software does not require extensive ongoing technical support. In 2001, all states except Michigan officially used redistricting software (and although the state government of Michigan did not officially purchase redistricting software, the political parties did). These new redistricting packages were quite sophisticated in providing various features such as multiple measures of compactness, contiguity checks, and assignment verifications.[9]

In Table 3, we summarize the answers given to our survey regarding redistricters' use of data and consultants. From 1992 to 2002, the use of voting, registration, and other data for redistricting increased, albeit slightly. And in 2002, more states used the finest-grained data available, block-level data (while none moved toward using coarser data).

In Table 4, we summarize the answers to our survey questions regarding the publics' access to the redistricting process. These results suggest that technology has increased public access to the redistricting process. The number of states that reported accepting public

TABLE 4
Summary of Survey Results Regarding Voter Access to Congressional Redistricting (Numbers In Parentheses Are Absolute Counts)

Year	*Made Data Available Publicly*	*Provided Substantive Web Site*	*Provided Public Terminals, Web Sites or Software for Plan Creation*	*Accepted Public Submissions*
1992	68.8% (22)	0% (0)	38.5% (15)	61.5% (24)
2002	78.8% (26)	79.1% (34)	42.9% (18)	81% (34)

SOURCE: Authors' survey, on file. See Authors' Note.

submissions of redistricting plans increased substantially. In addition, the number of states that reported offering public terminals that enabled people to craft their own plans increased. Notably, four states—Florida, Hawaii, Ohio, and Wisconsin—provided software that individuals could use on their own computers (or in the case of Wisconsin, using their own web browser) to create and submit district plans.

Public access to general information about redistricting fundamentally changed with the ascendance of the World Wide Web. The great majority of states released state legislative or congressional redistricting information on government-sponsored web sites in 2000 (Table 4). A typical redistricting web site provided information about the redistricting process, legal information, data, hearing notices, and, of course, maps. For those who purchased redistricting software, census data often came with it. Specific redistricting data could be downloaded from many of the web sites, and the PL94-171 data set could also be accessed directly via the Census Bureau's web site. (One state discontinued use of a public terminal in 2000 and offered the improvements in access to data and software afforded by the web as justification.)

There is an apparent pattern to the overall level of access afforded by a particular state's redistricting process. And the presence of a substantive web site is revealing. Among the states involved in the 2002 congressional redistricting that did not provide public web sites, only six permitted public submissions, three offered public terminals, and two provided access to data, rates far below the national average.

WHAT ARE THE CAPABILITIES OF REDISTRICTING COMPUTER SYSTEMS?

Redistricting is a difficult, detailed, time-consuming, data-intensive task. By law, the decennial census of the population is used to calculate district population. To achieve strict population balance, districts are constructed from the smallest unit of census geography, the census block, which is equivalent to a city block in urban areas. (The census block is much larger in rural than in urban regions. Some states, such as California, can comprise more than a half-million blocks.) Manually assigning census geography to districts and then calculating district populations by hand is time-consuming and error prone.

Redistricting often involves integration and analysis of additional data including voter registration statistics and election returns. In many cases, there is no direct relationship between census and electoral geography, and election data may be collected within two separate geographies: registration and election precincts. This greatly complicates the manual incorporation of such data into districts.

Specialized software can aid this complicated task. As Handley (2000) aptly summarized, the capabilities provide by current redistricting packages fall into categories:[10]

1. Tabulation: This usually includes displaying a running tally of district population and the population deviation from district targets. Some packages support tabulations of other variables, such as partisan registration or minority registration percentage, or other mathematical analyses.
2. Thematic mapping: Most packages provide the ability to map colored density-overlays (variables) to identify concentrated areas of partisanship, minority populations, communities, and so on.
3. Geographic reports and error checking: Most packages can check a redistricting plan for discontinuities (or lack of contiguity) and for population units that have not been assigned to a district (holes). Some packages can compare two plans for differences, or compute geographic compactness scores using one of a number of formulas.
4. Automated redistricting: A number of packages offer the ability to automatically draw district lines based on selected criteria.

Table 5 summarizes the capabilities of every commercial package used in the 2000 redistricting cycle:[11]

Custom software systems developed or contracted out by North Carolina, Rhode Island, and Florida were described as having core mapping, tabulation, and geographic reporting capabilities, similar to those above, but did not include automated redistricting functions.[12] A system developed in Texas, TARGET, had automated redistricting capabilities, which we describe in the next section. We were not able to obtain information about the capabilities of the New York and Mississippi systems.

In the 1991 round of redistricting, commercial GIS packages generally lacked all but the thematic mapping capabilities described above. Consultants or legislative staff typically customized software to provide tabulations and geographic reports, although the precise capabilities of each set of customizations could no longer be determined.[13]

ARE THERE LIMITS TO AUTOMATED REDISTRICTING?

Computers can automatically create districts, of a sort. A number of commercially available redistricting packages provide automated algorithms either as a component of their redistricting software, or as an addition to their redistricting packages. The Texas Legislative Council, too, developed in-house automated software for the state's 2001 redistricting. Despite the availability of these algorithms, most states chose software packages that did not have an automated redistricting capability. Across the board, with the exception of Texas, automated redistricting was peripheral to the most recent round of redistricting.

Practical and political considerations are obstacles to widespread use of automated redistricting algorithms. Automated algorithms typically implement a maximization algorithm to generate compact districts using a single user-supplied constraint, such as equal population. In practice, a redistricting plan must simultaneously satisfy several, often conflicting criteria, such as equal population, compactness, the Voting Rights Act, and (depending on each state's constitution) other goals such as respect for existing political boundaries and communities of interest. Current commercially available automated software can only maximize one criterion and cannot balance between competing criteria (Table 6).[14] Our selected trials of these packages, as well as anecdotal reports by users and software developers, suggests that even with regard to a single criterion, software performance fell well short of what an expert could achieve.

TABLE 5
Capabilities of the Redistricting Software Packages Used in Congressional and Legislative Redistricting

Software Package	*Thematic Mapping*	*Tabulation*	*Geographic Reporting*	*Automated Redistricting*
Autobound (Digital Engineering Corp.)	Yes	Yes. Static and dynamic	Yes. Compactness (9 types); Comparisons; Holes	Yes. Limited to single variable, and single level of geography
Maptitude (Caliper Corp.)	Yes	No	No	No
Maptitude for Redistricting (Caliper Corp.)	Yes	Yes. Static and dynamic.	Yes. Compactness (7 types);	No
			Comparisons; Holes	No
Plan 2000 (Public Systems Associates)	Yes	Yes. Static and dynamic.	Yes. Compactness (2 types); Comparisons; Holes	No

SOURCE: Vendor's documentation, supplemented by personal communications with software developers.

TABLE 6
Software Packages for Automated Redistricting

Software Package	*Heuristic/ Algorithm Used*	*Capable of Producing Optimal Plans*	*Single Criterion Only*
Transcad (Caliper)	Steepest Ascent (based on Horn, 1995)	No	Yes
Autobound (Digital Engineering Corporation)	Appears to be steepest ascent, based on fixed kernels (sketched in Hejazi, 1996)	No	Yes. In addition, limited to a single level of geographical unit.
Geobalance (Corona Solutions)	Genetic algorithm (heuristic)	No	Yes
TARGET (Texas Redistricting Council)	Simulated annealing (originally based on Hayes, 1996, but much extended)	No	No
Manifold (Manifold Systems)	Not known. Appears to be steepest ascent heuristic	No	Yes

SOURCE: Vendor's documentation, supplemented by personal communications with software developers.

It is perhaps for this reason that the Texas Legislative Council developed an automated algorithm for redistricting that could generate plans based on multiple criteria. This tool was far more powerful than any redistricting tool commercially available then, or now. However, even in Texas, it appears to have been used to produce maps only as a starting point for negotiations among legislators, rather than to produce the ultimate end product.[15]

Many computational methods that can be applied to multicriteria optimization already exist (for a survey, see Altman, 1997; Cortona, Manzi, Pennisi, Ricca, & Simeone, 1999), and it seems likely that some of these will be eventually incorporated in commercial products. Nevertheless, redistricting remains an extremely difficult computational problem. No algorithm is known to exist that produces optimal plans for any redistricting problem of realistic size, and because of the sheer mathematical complexity of redistricting, it is unlikely that the computational problem of redistricting will be solved, at least for tasks such as redistricting large states at the block level (Altman, 1997). Thus, as Table 6 illustrates, all currently available software use heuristics that are, essentially, methods of making computational guesses at the answer.

In addition, there appears to be some resistance by mappers to relinquishing their control of the mapping process to software. One developer of a popular redistricting package stated that the packages' automation features drew little interest in the 2000 round of redistricting and that mappers simply preferred to draw districts themselves. In our judgment, as well, it is likely that automated redistricting will continue to remain an adjunct to human mapping, rather than a push-button tool for creating perfect gerrymanders.

CONCLUSIONS

Redistricting in the 2000s has arrived at an interesting crossroads of computing technology, data availability, and legal constraint. To ascribe the blame for today's sophistication in redistricting to advances in computing is to oversimplify greatly.

As our research shows, computers are not a recent introduction to the redistricting process. However usage of computers has changed dramatically during the last several rounds of redistricting. In the 1981 round of redistricting, computers were rare, and even with then, redistricting was labor-intensive. By 1991, although computer and software systems had become all but ubiquitous in redistricting, these systems remained extremely expensive and were highly customized. In the current round of redistrict, redistricting computer systems were omnipresent, fast, almost "shrink-wrapped," relatively cheap, and standardized in their software capabilities.

Technological advances have made the process of creating viable redistricting plans easier, faster, less costly, and less error-prone. A decade ago, states typically spent hundreds of thousands of dollars on redistricting technology. Since then, the price of redistricting systems has dropped by more than two orders of magnitude. A decade ago, the programming and data manipulation skills needed were daunting. Now, off-the-shelf software comes supplied with the prerequisite census data, can instantly evaluate the population balance and geographical compactness of a plan, and can able to check automatically for common mistakes, such as leaving a so-called hole or failing to assign a block. Although all of this was possible before the so-called computer revolution, these functions can now be accessed at the push of a button and will give answers in a few seconds.

Despite these advances, we have been so far unable to uncover evidence that the current round of redistricting was affected to any significant extent by push-button redistricting. Although feared by observers, commercial automated redistricting software, our research suggests, was not used in most states and simply was not powerful enough to provide the perfect (or even a very good) map. Current automated algorithms cannot simultaneously balance the multiple criteria that must be respected when drawing districts. In addition, anecdotal evidence from our survey suggests that mappers had little interest in relinquishing this task to the computer. However, the sophistication of the TARGET system in Texas does suggest that this aspect of redistricting technology may have a greater impact in future rounds of redistricting.

If redistricting has become more sophisticated in this round over the last, computing technology seems unlikely to have been the primary cause. This is for the simple reason that the core capabilities of the redistricting software used in the current round of redistricting did not differ qualitatively from the capabilities of software used in the previous decade. Certainly, there has been a dramatic decrease in cost and gain in speed; however, there have been marginal changes only (with the exception of widespread but inadequate automated redistricting tools) in the range of features supported by the tool and in the power of the analyses provided.

In addition, the timing of the widespread adoption of computing technology, which occurred after the 1980 round of redistricting and before 1990, does not correspond to the dramatic changes in district appearance that has drawn so much attention in recent rounds of redistricting. As Altman (1998) showed, the trend of decreased compactness and widespread deviation from so-called traditional boundaries[16] started in the mid-1960s: Conformance with traditional boundaries declined dramatically in the 1970s' round of redistricting, before any significant introduction of computers into the process. Compactness had declined substantially by the 1980s, and the continued decline in that decade was spread across regions of the country untouched by the limited use of computers that occurred in that round of redistricting. (The adoption of computing technology does, however, coincide with a sharp increase in the number of districts with questionable contiguity.[17]) This suggests that a sizeable share of the blame for the irregularities of modern districts must be placed elsewhere.

Advances in technology seemed to offer the potential for deeper change, in a number of ways that have not been widely discussed: First, computing technology has the potential to change how politicians deliberate over proposed districts, since changes to district maps that would have taken days to make in the 1980s and even 1990s can now be made in minutes or hours, and because software now allows plans to be quickly presented and accurately compared. (One software developer we interviewed even drew particular attention to the popularity of the feature that allowed two plans to be compared to determine exactly where they differed.) Second, computing technology has opened the door to electronic submissions of maps drawn by the public and by interest groups, since redistricting software is now relatively inexpensive and easy to use. Third, computing technology enables the use of richer data sources in a shorter period of time. In the past, because of the time-constraints under which redistricting takes place, and the difficulty of managing the computing and data, data-sources reflecting communities of interest were much more difficult to incorporate.

At the same time, there is no evidence that this potential has been realized to any great extent: Ease of deliberation is important only when political actors choose to deliberate. Public submission of plans makes a difference only when they are likely to be considered by a redistricting authority. A criterion such as "communities of interest" can only be applied when the appropriate data is collected and made available. These are, fundamentally, political issues, and we have not been able to uncover evidence that computing technology has, as yet, significantly altered them.

As the application of TurboTax to our 1040s made April 15th less daunting, computers have certainly simplified redistricting. This change is tantalizing because it suggests the potential for communities to examine the effects of plans on them, and to propose alternatives. However, in the last round of redistricting we see little in the pattern of computer use that suggests that these technological advances have led to changes of the fundamental political dynamics, or in the end results. The simple truth is that redistricting remains primarily a political process: What goes into districts is primarily based on political calculation.

NOTES

1. It is ironic to note, before the advent of modern technology, the term *computer* was applied to accountants who would perform calculations by hand.

2. See *Reynolds v. Sims* (1964) and *Wesberry v. Sanders* (1964). For congressional districts, strict equality of population is required, unless there is a compelling state interest to do otherwise, and even in these cases, a 1% deviation is the most allowed. State legislative districts are allowed a 10% population deviation under *Karcher v. Daggett* (1983), unless there is a compelling state interest to do otherwise.

3. Republicans developed automated redistricting applications in 1965 to aid in crafting a map for California. The program was given a map and would equalize districts on population, or some other criterion, by exchanging geography. The algorithm was limited to tract-level data because lower units such as blocks would consume too much computing time. However, precinct-level political data was allocated to tracts. The algorithm served as a tool to fine-tune proposed maps to satisfy the Supreme Court's equal population mandate (T. Hofeller, former Republican National Committee redistricting consultant, Personal communication, June 19, 2004). In addition, Democratic consultants developed an automated redistricting program as a response to the impending 1981 Massachusetts congressional redistricting, where population projections indicated a loss of a congressional seat to the 1980 apportionment. The same algorithm was used in 1979 to develop a district system for Houston's at-large city council districts (Brace, 2004). However, the algorithms developed maps with, for example, "snake-like district configurations" (Brace, 2004, p. 5) that were of little practical use.

4. It is impossible to determine the precise extent of early computer usage because much institutional memory has been lost and we must rely, in part, on anecdotal accounts. California Republicans claim also to have developed automated redistricting software in 1965 (T. Hofeller, former Republican National Committee redistricting consultant, Personal communication, June 19, 2004). In 1971, Iowa's legislature chose among 12 congressional maps drawn by University of Iowa's computing center (Liittschwager, 1973). Hayes (1996) claimed that Iowa and Delaware developed an automated redistricting system in 1967 and 1968, respectively. Washington's state legislature commissioned a redistricting system from the University of Washington for the 1971 round of redistricting (J. Thurber, American University, personal communication, June 28, 2004). New York's state legislature programmed an in-house redistricting system for 1981 (T. Breitbart, New York Redistricting Legislative Task Force, personal communication, June 18, 2004). Democrats in Illinois and Michigan employed a consulting firm for redistricting in 1981. This consulting firm also consulted on creating districts for Houston's at-large city council in 1979 (Brace, 2004). California Republicans sponsored the development of automated redistricting software in the 1980s (see Rose Institute of State and Local Government, 1981, for a description) although the results did not surface in the 1980 California plan.

5. A similar, but faster, system was used for redistricting in Mississippi during *Connor v. Finch* (1977) and was used in 1981 by Republicans in California, Illinois, Mississippi, and Washington (T. Hofeller, former Republican National Committee redistricting consultant, personal communication, June 19, 2004).

6. All survey responses were collected in written format, either through email, mail or fax responses or from official websites. Responses were verified as much as possible. For most cases, we located a staffer from the redistricting authority willing to respond to our questionnaire. Where we could not locate such a person, we followed due diligence to find persons who might have worked on redistricting, including contacting the Secretary of State office, state legislative leadership offices, and members of Congress offices.

7. Between 1980 and 1991, there was also a large improvement in the usability and accessibility of the Census data needed for redistricting (Turner & LaMacchia, 1999).

8. Tim Storey of the National Conference of State Legislatures graciously provided hard copies of the state responses to their redistricting survey.

9. Computer software is used in other redistricting contexts, too. Concurrent with the growing use of computers to draw districts is the growing demand for statistical analyses to determine the constitutionality of those districts in court. Court challenges often involve claims of racial and partisan gerrymandering, and occasionally violation of a state constitutional provision. Specialized statistical analyses and software have been developed to evaluate these claims. For statistical techniques used to determine the presence of racial gerrymandering see Goodman (1953) and King (1997). For partisan gerrymandering, see Gelman and King (1994).

10. Here we adopt Handley's categories, for the most part. We differ in that Handley separates out political reports from population reports, where we categorize both as a form of tabulation.

11. The number of compactness scores that we found were available for each package differs occasionally from that of Handley (2000), potentially because she may have had access to earlier, prerelease, versions of these packages.

12. The capabilities of the Florida and North Carolina systems were described on their respective web sites. The Rhode Island system contracted with EDS, which used software with capabilities as described in Handley (2000).

13. Kim Brace, who was a consultant for more than a dozen states in 1990, described customizing the commercial Geodist software to add the following: simple tabulations and averages of political and demographic variable; racial bloc voting analysis (Goodman's regression) of selected precincts; compactness scores; contiguity checks; comparisons of two plans; and collinearity reports (which would measure the percentage of a district boundary collinear with another boundary, such as a road, or county border). (Personal communication, January 20, 2005.)

14. Information on Transcad, Geobalance, TARGET, and Autobound based on personal communication with the respective developers June 2000, February 2004, and January 2005, respectively. Manifold and Transcad are listed only for comparison purposes. Neither were used in the 2000 round of redistricting.

15. In 2000, one author, Altman, served, at the request of the Texas Legislative Council, as a tester and evaluator for the TARGET system. The early versions of TARGET evaluated by this author were relatively impressive but still not capable of generating entire plans from scratch at the block level. In addition, the public guide to redistricting issued by the council stated that "This program cannot produce an optimum redistricting plan, but rather is a tool to quickly generate a starting point, explore possibilities, or search for solutions to problems." (Texas Legislative Council, 2000).

16. The term *traditional districting* is used as in Altman (1998), following Justice O'Connor's use of the term.

17. Districts with questionable contiguity included those connected only at a single point, or those connected only by water.

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