ENABLING REDISTRICTING REFORM: A COMPUTATIONAL STUDY OF ZONING OPTIMIZATION

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EXECUTIVE SUMMARY

We have developed a scalable computational tool for redistricting that synthesizes and organizes massive amounts of computation and data to evaluate redistricting schemes. The tool allows one to create high-quality maps and tailor them to notions of "fairness" and democratic rule. It can also be used as an evaluation tool by courts, advocates, and the public to ensure nondiscriminatory representation. Specifically, we developed a scalable, parallel, evolutionary algorithm for redistricting that includes a set of spatial evolutionary algorithm operators to handle the costly spatial configuration of redistricting maps. These maps provide the basis for additional statistical analyses.

RESEARCH CHALLENGE

In the United States, political redistricting occurs at the national level every 10 years following the decennial census. It is intended to provide fair representation in Congress to all communities and interest groups. Gerrymandering occurs when districts are drawn in a manner that discriminates against a partisan or racial group. Both partisan and racial gerrymanders are commonly alleged. Despite broad disdain for the practice of gerrymandering, the Supreme Court has found it difficult to identify a workable standard by which we might regulate gerrymandering. We lack sufficient tools to analyze and synthesize redistricting data, in part, because the requisite computation is massive. Without the tools to quantify the effect of electoral maps, the court is left without the ability to issue legal and consistent judgments. As a result, despite the five decades since the Supreme Court declared gerrymandering to be capable of being decided by legal principles or by a court, the court has yet to identify manageable standards under which one could measure and thus declare a partisan gerrymander. The failure of the legal system in this political realm has significant ramifications for our democratic system of governance.

Figure 1: The algorithm is able to produce billions of high-quality, viable redistricting maps that may be used by the Courts in adjudicating partisan gerrymandering cases. Image credit: Carlos Waters/Vox.

Using the Supreme Court's articulated legal reasoning and mandates, we have developed a computational redistricting tool. The redistricting problem can be formulated as a combinatorial optimization problem, with objectives and constraints defined to meet legal requirements. Drawing electoral maps amounts to arranging a finite number of indivisible geographic units of a region into a small number of districts. Since every unit must belong to exactly one district, a districting map is a partition of the set of all units into a preestablished number of nonempty districts. The redistricting problem is an application of the set-partitioning problem that is known to be NP-complete and, thus, the time required to solve the problem increases very quickly as the size of the problem grows. We have developed a scalable, evolutionary computational approach utilizing massively parallel high-performance computing for redistricting optimization and analysis at fine levels of granularity.

METHODS & CODES

Our algorithm, PEAR, or Parallel Evolutionary Algorithm for Redistricting, is implemented in ANSI C. It can be compiled on Linux, OS X, and Windows as a standard *makefile* project. PEAR uses MPI nonblocking functions for asynchronous migration for load balancing and efficiency. It uses the C SPRNG 2.0 library to provide a unique random number sequence for each MPI process, which is necessary for running a large number of evolutionary algorithm (EA) iterations.

Since the spatial configuration plays a critical role in the effectiveness and numerical efficiency of redistricting algorithms, we designed spatial EA operators that incorporate spatial characteristics to effectively search the solution space. Our parallelization of the algorithm further harnesses massive parallel computing power via the coupling of EA search processes and a highly scalable message-passing model that maximizes the overlapping of computing and communication at runtime.

RESULTS & IMPACT

Our approach is designed to identify redistricting maps that satisfy a set of user-defined criteria with a particular focus on addressing fine levels of spatial granularity. We leveraged and enhanced a scalable Parallel Genetic Algorithm (PGA) library to develop PEAR for the computationally intensive redistricting problem. By incorporating a set of spatial configuration operators and spatial EA operators to handle spatial characteristics and the associated computational challenges, and harnessing massive computing power, PEAR provides a powerful and computationally scalable redistricting tool that has never existed before. In the substantive realm, our computational model allows us to synthesize and organize massive amounts of computation and data to evaluate redistricting schemes and tailor them to notions of "fairness" and democratic rule.

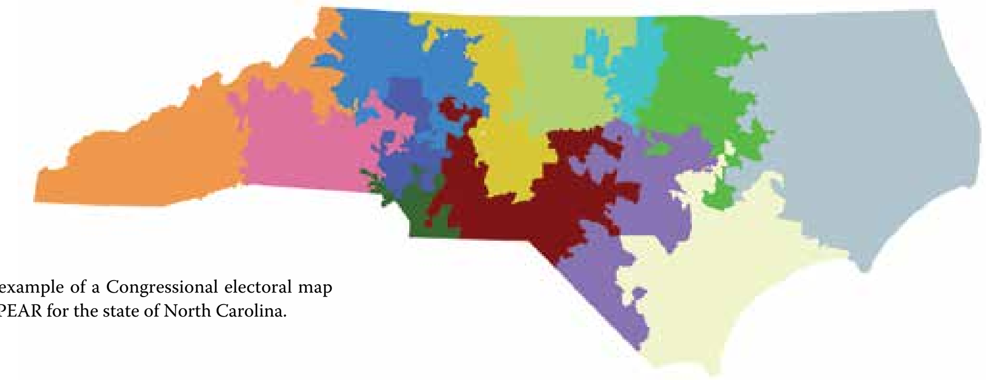

Figure 2: An example of a Congressional electoral map generated by PEAR for the state of North Carolina.

The discrete optimization framework identifies large sets of quality electoral maps. This set of plans is useful at the districting drawing stage as well as for judges who are adjudicating the constitutionality of a redistricting plan. At the drawing stage, this information suitably drives an iterative bargaining process whether that process involves partisan legislators or members of an independent redistricting commission. When this bounded set of plans can be identified, the redistricting process is imbued with valuable structure that is otherwise nonexistent. That structure alone makes the redistricting process more transparent and may serve to reduce legal challenges. When a legal challenge is mounted, this large set of reasonably imperfect plans produces the relevant background and allows one to place and understand the proposed plan in context. The purpose of our optimization strategy, then, is to search, synthesize, and organize massive amounts of information that will supply a common base of knowledge to guide informed and intelligent debate and decisions.

The impact of our project is yet to be determined, but the project has thus far been well received. Our proposal for a new partisan gerrymandering standard, based on our computational tool, won the first place prize in Common Cause's "Gerrymander Standard" writing competition that was judged by law school deans, law professors, and lawyers. The project has also received some media coverage.

WHY BLUE WATERS

Our PEAR library is designed for extreme-scale redistricting applications. From the beginning, it was intended to scale to all of the processor cores on Blue Waters through nonblocking MPI communication calls. The computational approach we implemented in our solution requires generating a very large number of electoral maps for quantitative study of redistricting phenomena. Identifying quality electoral maps requires significant computing in the combinatorial optimization process. Generating a large number of statistically independent maps is only feasible on a supercomputer at Blue Waters' scale.

PUBLICATIONS AND DATA SETS

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