The Design and Implementation of ORBIS: The Stanford Geospatial Network Model of the Roman World
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EDITOR’S SUMMARY
ORBIS is a geospatial model of the Roman world representing the network of cities and travel routes that enabled movement across the Roman Empire. It is an example of neogeography, use of geographic information systems and mapmaking techniques by non-experts. ORBIS was created using data from both primary sources and computational geography simulations about travel, wind and sea patterns, seasonal access, costs and other considerations to plot realistic transport networks. Through the development process, server infrastructure and user interface upgrades supported the volume of data, user needs and extended functionalities, such as revealing the most efficient routes between points. The result provides scholarly information on life and travel in the Roman era. ORBIS illustrates how network and hierarchical data can be used to visualize complex, multilayered geospatial information.

KEYWORDS
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Creating a network model of the Roman world presented an exciting opportunity to implement techniques for the study of the past that had only previously been seen in computational geography departments and as interactive toy demos. Such a visualization would allow scholars the capacity to explore how the Roman world may appear differently from different perspectives within the system, highlighting a sense of distance and space that was inherently topological and perspectival.

The role of neogeography in disseminating radical cartography and GIS methods outside of academic geography departments cannot be overstated. Radical cartography refers to challenging the implied neutrality of geographic systems and functions, such as map projection. Neogeography, in contrast, refers to the use of geographic information systems (GIS) and map-making by journalists, artists and designers outside of the professional community of cartographers and the academic community of geographers. Both of these developments factored into the creation of ORBIS, a network model that represents the movement of goods and people in the Roman world.

In 2011, Walter Scheidel, classics professor at Stanford University, was exposed to the concept of a distance cartogram via the work of designer Tom Carden [1]. Carden, well-entrenched in the field of information visualization and web mapping, had produced a geospatial information visualization of the London subway system that showed the routes using a traditional geographic projection but then distorted the geographic location of each subway stop and line to reflect the time taken from one stop to another. Cartograms are not new in academic geography circles, but the accessibility of this relatively simple information visualization was what allowed someone in Scheidel’s position to understand and use such a representation, which was more in line with the manner in which Romans would have historically viewed space.
How ORBIS Was Made

To create such a map is relatively easy for modern transportation networks, where the components and costs can be accessed using modern application programming interfaces (APIs) and GIS applications. For the Roman world, the map would require significant effort to create the necessary data and data models. The tracks of Roman roads were gathered from the Barrington atlas [2], the river routes by which goods and people flowed in Roman times were taken from modern river courses [3] and the cost in time for the movement of peoples and the cost to ship goods were gathered from primary sources such as the Antonine Itinerary and Diocletian’s Edict on Costs [4]. But for sea travel, which is of primary importance for understanding the Roman transportation network, the speed and course of sea routes needed to be simulated based on the performance of historical sea vessels and calibrated with the scant evidence available. This sea model relied on network path-finding calculations utilizing modern wind and sea patterns, which match well with historically known environmental conditions [5].

Upon completion of this network, the second technical hurdle was making it accessible in a manner that allowed scholars to explore the effect of varying priorities, times of year and accessibility of travel modes (sea, road and river). By leveraging a robust spatial database linked to a web map that could run in any browser, ORBIS provided just such access. But the computational cost of calculating one-to-many pathfinding meant that the initial version of ORBIS could only show a few pre-calculated distortions of the Roman world using distance cartograms. It did, however, allow any user to calculate any one route from one site to another within the system using any variation on the parameters of the model. As a result, even though ORBIS was designed for dynamic representations of the entire world, it proved most popular as a Google map for the Roman Empire. It allows scholars and the general public to see the cost in time and money to move from one part of the Roman world to another based on different priorities and times of year.

A significant upgrade to both the server infrastructure and user interface of ORBIS in 2014 (ORBIS v2) finally allowed users to not only compute cost from one site to another using any parameters but also from one site to many. This improvement afforded the capacity to represent distance in time or money using not only the distance cartogram method (Figure 1) but also by grouping sites of similar cost into regions and representing the results using isochronal (contours indicating cost in time) and isophoretic (contours indicating cost in expense to ship goods or individuals) maps (Figure 2).
Two new pieces of functionality are also provided in ORBIS v2: clustering and flow maps. Clustering (Figure 3) provides users with the ability to create simple maps of the Roman world wherein sites or regions are shown that are closer to one center than another. (Note: The custom algorithm used to determine clusters in ORBIS assigns sites to groups based on the closest calculated center, with the capacity to designate sites within a user-defined threshold to a frontier cluster if the cost to reach a site plus the threshold value is within the cost to reach the site from multiple centers.) Flow maps (Figure 4) utilize the network statistic of edge betweenness centrality to highlight the main arterial routes by calculating the most efficient routes from one site to the rest of the model and aggregating shared routes onto segments. This is not a typical definition of flow, which relies on demographics of movement or the results of flow models that simulate such demographics, but seems to align well with the traditional definition, although this relationship has not yet been studied.

In ORBIS v1 and especially in ORBIS v2, the application provides a representation of the Roman world as one where the shape of the world is
dependent on priority (for example, the cheapest or fastest route), time of year (Atlantic coastal travel is restricted during the winter, as are mountain passes) and the perspective on the model. (By virtue of their location in the model, some sites, such as Rome, experience little change, whereas others, like London, have a highly contingent place in the network.) This distinction is demonstrated in Figure 5.

The dramatic difference between modern travel times and costs in comparison to Roman-era times and costs is apparent even to the lay user, as reflected in numerous references to ORBIS in social media. For scholars, the topography of cost, both in individual routes and the aggregate, has proved useful for the purpose of better informing historical climate models or the movement of specialized materials such as marble.

Creating an Application like ORBIS

The sophistication of ORBIS, which is among the most complex pieces of geospatial information visualization on the web, makes it difficult to replicate. Some similarly exemplary projects are Earth, which shows global wind and current patterns (http://earth.nullschool.net/) and the geospatial information visualization experiments of Jason Davies (http://www.jasondavies.com/maps/). The ORBIS codebase, while open-source (https://github.com/emeeks/orbis_v2), is poorly documented and specific to this single application. However, some of the principles in place that proved so successful, such as using topologically aware geospatial features to create regions or the calculation and representation of system-wide travel costs, have been made available in better documented and more accessible libraries such as d3.carto (https://github.com/emeeks/d3-carto-map) and orbis-in-a-box. (Note: The only current examples of orbis-in-a-box are these experiments with 19C United States postal routes: http://bl.ocks.org/emeeks/8edaa27a121dc2a227ec; http://bl.ocks.org/emeeks/b8da1d56fd9c21244fd)

The strength of ORBIS is its existence as a network model – an explicit system that represents and annotates the connection between sites. This network model influenced the creation of Kindred Britain (http://kindred.stanford.edu), which uses many of the same network cost principles to understand not physical distance but genealogical distance between British cultural elites.

The Future of Science and Technology Mapping

ORBIS represents a transition away from web mapping toward geospatial information visualization. The distinction, arbitrary and declared, is not only the focus of applications such as the attempt to use maps as a view into a model, but also in the integration of techniques such as convex hulls, Voronoi tessellation and cartograms into the map interface (Figure 6).

Traditional web mapping relies on a leveraging of layers to allow users to compare and contrast the distribution of spatial phenomena. Geospatial information visualization requires more sophisticated network and hierarchical data to provide radically different views into spatialized phenomena that can look like a traditional web map in one mode and much more like abstract information visualization in other modes. By necessity, this technique requires practitioners who are familiar not only with spatial analysis but also with network analysis and information visualization. There is not yet as strong a community of practice for geospatial information
visualization as there is for web mapping. ORBIS takes advantage of the D3 information visualization library (www.d3js.org), which provides robust capacity not only for traditional data visualization but also for network visualization and geospatial visualization. In contrast, web mapping libraries like Leaflet (http://leafletjs.com/) focus on providing convenient representation of geospatial data and require significant effort to integrate with cutting-edge network and data visualization.

Outlook

Google maps taught many how to read and use geospatial maps online. This novel map reading literacy can be used to integrate more abstract representations of space and place growth. These more sophisticated representations require more sophisticated material. If one only has simple data in point of polygon form, then that is all that can be shown on a map. In contrast, building a system operationalizes the relationship between elements in that system and therefore formalizes claims in a way that can intimidate academic and journalistic practitioners. It is also simply easier to acquire and deploy simple spatial datasets, whereas models require more effort to create. But if a system like the model underlying ORBIS is available, then a map can represent views into that system using the methods developed and explored in computational geography, as well as methods used for information visualization in other domains.

Resources Mentioned in the Article