Perspective

Disease mapping and innovation: A history from wood-block prints to Web 3.0

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SUMMARY
This paper presents a point in the transition of publicly available data and the means of its presentation. With syndromic mapping and new systems of data collection and distribution at all levels, previously privileged materials are now generally available. At the same time, the means of their analysis and presentation are being transformed by new systems of digital collaboration and presentation. With the coronavirus disease 2019 COVID-19) dashboard as an example, the history of both data and their presentation is presented as the backcloth against which the evolving systems of data collection and graphic presentation can be understood in a world of interactive research and Web 3.0.

INTRODUCTION
Technological evolution follows a complex but predictable pattern of change. In communications, for example, new, simpler modes of production decrease costs while increasing public access to previously privileged data. The result encourages new audiences and new forms of presentation. In the midst of these transformations, traditional, skilled crafts become superannuated skills. The result of the sixteenth century print revolution enabled by moveable type, for example, permitted relatively low-cost production of the first atlas, Ortelius’s, Theatrum Orbis Terrarum (seven guilders in black and white or 16 guilders for a hand-colored version). With it “huge swaths of territory were subjected to systematic surveys by newly self-conscious states.” Lost in the new, however, was the skill of traditional scribes and wood-block
 artisans who had labored to create incunabula, hand-illustrated texts, page by page. At the end of the eighteenth century, newer, faster print technologies enabled the increasingly low-cost production of books and journals, giving rise to the then-radical idea of the public professional writer, and focused public researcher. That resulted in officially published maps in disease studies in official reports and professional journals. Mapping as a tool of medical science proliferated in the 1830s in various studies, but especially that of pandemic cholera. That mapping was enabled by new systems of bureaucratic data collection—censuses, enumerations, disease-related records—that served as the material for this work. None of this would have been possible, of course, without an evolving system of international mails capable of carrying books, journals, and newsheets around the world.

As new technologies emerge, content is at first beholden to older styles and aesthetics until new forms and perspectives made possible by the evolving technologies are introduced. One sees this, for example, in the history of photography as the age of the daguerreotype, introduced in the 1840s, gave way to that of more sophisticated and eventually hand-held cameras of the 1920s and 1930s. Early photographers aped the style and subjects of a painterly world until a new generation sought “the reforming of any bit of reality” through the new idea of documentary photography.

In all these histories, three distinct stages are typically recorded. In the first, high costs and the necessity of specialized knowledge limit publication to official audiences. In the second, as a technology matures, new classes of experts are created as audiences receptive to their work are created. Third, those changes permit new perspectives to emerge and new ideas to be introduced. Understanding the longue durée not only situates the present in the past but makes clearer the possible direction of the effect of future innovations.

Within this broad frame, Edney describes three general periods of cartographic evolution. The first, in the eighteenth century, was a kind of pre-history with the introduction of mapping as a tool of the state, setting boundaries and serving governments and mariners. In the nineteenth century, increasingly comprehensive official data collection coupled with the mid-nineteenth-century use of basic statistics set mapping as a critical medium of analysis. The third and modern phase is marked by the digital revolution permitting the wholesale collection, storage, and distribution of data analyzed and presented through geographic information systems (GIS) mapping programs. That phase is now extended, I argue, since the ambient of an interactive medium, now Web 3.0, and progressively rigorous spatial analyses of a range of health phenomena from infectious diseases to the effect of water contamination on specific populations.

Here, the broad historical sweep is first reviewed and then focused on the history of mapping. In the first phase, the old skills of the scribes creating hand-drawn pages was lost with their sometimes-fanciful illustrations (“There be dragons, there!”). As mapping developed in the second, specialist cartographers and engravers translated authors’ data into maps printed in books, governmental reports, and professional journals. The modern phase began with the introduction in the 1980s of desktop map systems. In 1982, Environmental Systems Research Institute (ESRI) released Arc/INFO, the first commercial GIS program, and, in the same year, the US Army released Geographic Resources Analysis Support System (GRASS) as a tool for environmental research and the management of military lands. Finally, in 1987, Ronald Eastman created IDRISI, a sophisticated, raster-based GIS program. These are now being superseded by even newer digital technologies. Automated mapping from syndromic systems of increasingly publicly data collection return maps when specific datasets are queried (for example, healthmaps.org). There is also an explosive growth in geospatial languages like R with packages permitting mapping as a medium of statistical presentation. While first developed in 1975, in recent years, R’s popularity has increased as users developed myriad packages advancing geospatial and cartographic investigation. As a result, the sovereignty of GIS mapping as a unique science and specialized craft has begun to wither as the once-firm line that separated the work of cartographic amateurs and experts schooled in cartographic techniques. The dominance of GIS is now being transformed into a “citizen science” increasingly bypassing the GIS analyst cum technician. “What was once a craft has been democratized out of existence in precisely the way of other nineteenth century crafts like typesetting and manual layout.”

Here the history of technological innovation is focused on the effect of its broad paradigm of change affecting mapping of studies of disease and health. This approach invites questions about the future of GIS as a craft and of mapping as a specialized mode of exploration and argumentation. In considering the future, it is useful first to review the long history of disease mapping with the framework of the broad historical pattern of technological evolutions.

**STAGE ONE: 1600s–1800s**

Mapping was an early beneficiary of the introduction of moveable-type systems of mechanized printing, permitting production of texts with hand-drawn illustrations. In 1570, for example, Abraham Ortelius’s *Theatrum Orbis Terrarum* offered in the then-new atlas format a relatively affordable collection of standardized map sheets based upon surveys by explorers and mariners. The primary markets were administrative, maritime, and mercantile: here were known political jurisdictions as well as less-known areas of exploration and potential exploitation.

Maps of territory also were the basis of the earliest surviving maps of a disease event (Figure 1). In 1694, Filippo Arrieta, royal auditor and military governor for the Italian province of Bari, Italy, included in a report to his liege two wood-block maps describing (and justifying) the expensive deployment of military troops to contain a plague pandemic. The maps (Figure 2) presented a complex set of containment fields enforced by the military and designed first to limit the further introduction of plague, and, simultaneously, control its spread where present in provincial cities. The mapmaker is unknown, presumably a member of Arrieta’s staff. The report was not made public but was presented to his liege and others in his administration.

By the early 1700s, European officials in other nations were producing hand-colored, administrative maps of coastal quarantine stations, although none carried the depth and complexity of Arietta’s multi-level containment system (Figure 2). These hand-colored maps typically included text describing cordon
sanitaires restricting foreign trade and travelers during periods of plague. Again, the audience was limited to officials and the mariners and traders whose entry to this or that mapped port would be restricted.

LATE 1700S TO 1800

At the very end of the eighteenth century, printing technologies had evolved to permit the use of evidentiary maps in more public texts. These required the existence of city or state “base maps,” a definition of this or that disease being studied, and a record of its incidence in a city or region. The earliest surviving example included two copperplate maps published in Dr. Valentine Seaman’s 1798 study of yellow fever. The article was published in The Medical Repository, the first for-profit medical journal with a national and international medical audience.

This was the first scientific use of cartography, a map in which disease incidence was set against possible contagion sites in an attempt to ascertain its source and argue a theory of disease. In one, Seaman located a limited set of cases in the New Slip area of New York harbor where the disease first appeared (Figure 3). In a companion map (not included here), he located a series of odorous human and animal waste sites he believed were the source of the disease. Looking at one map and then the other, seeing the proximity of yellow fever cases to the waste sites proved, Seaman believed, that yellow fever was generated in the local, fouled airs. With these maps he introduced the idea of spatial correlation as a graphic, analytic technique formally later codified by Francis Galton almost a century later.

Seaman lamented that the copperplate technology limited the inclusion of a larger number of known cases in the maps produced for him by a professional engraver in a base map previously constructed in a city whose merchants and officials were enthusiastic users of mapping as an administrative tool (Figure 3). The result was limited as well by the absence of a robust system of population statistics and clinical data collection that would, in the first half of the nineteenth century, become a
critical feature of European and North American governments. Seaman’s study was enabled not only by the existing, if limited, print technologies of the day but also by the evolving efficiencies of an international mail system extending the geography of readers globally.

**Cholera**

Beginning in the 1830s, the first cholera pandemic was for three decades a major subject of disease mapping in studies published in European and American journals, monographs, and official reports. Among the first was an 1831 map (Figure 4) in The Lancet showing cholera’s expansion from its 1819 origin in India through the Middle East and then Europe in the late 1820s. The authors argued the progress of the pandemic was so extensive that cholera could not be kept out of England and thus that quarantine laws proposed by the government would be ineffective. Through the 1850s, scores, if not hundreds, of cholera maps were produced describing the pandemic’s progress internationally, nationally, and locally. Many of those posted cholera’s passage along rail and sea lines as well as its relation to the incidence of other diseases and socioeconomic conditions believed to generally promote or inhibit health states.

Cholera mapping exploded in 1849 with the beginning of the second pandemic as researchers sought not only to trace its progress but, through mapping, understand its cause (Figure 4). Famously, in 1855, John Snow published *On the Communication of Cholera* with two evidentiary maps. The first posted a severe cholera outbreak, centered on a local public water pump on Broad Street in his Soho neighborhood. The second, more ambitious, map attempted to correlate cholera incidence with principal water sources across South London. Both argued cholera was water borne, not airborne as many at that time believed. Both were based on public data collected by the General Registrar Office and made freely available to all by its administrator, William Farr.

An amended version of the Broad Street map later was included in a formal inquiry by officials of St. James Parish, in which the outbreak occurred. It included an innovative boundary around the central pump based on walking time to emphasize the relation between deaths and the Broad Street pump. Here, like Seaman, Snow believed the map itself was sufficient proof of a thesis on disease origin and subsequent spread. Despite their later fame, Snow’s maps were not particularly convincing to contemporaries and compared unfavorably with the work of others, like John Simon’s more precise, statistical analysis of the South London epidemic. Also more convincing was the work of William Farr (1853) who found a consistent inverse relationship between altitude above sea level and disease incidence that served both descriptively and predictably. Farr demonstrated his conclusion with innovative graphics, including a map (Figure 5) in which all data potentially pertinent to understanding the pandemic were included. That wealth of data...
came from both a national census and local mortality reports submitted to Farr’s office.

Figure 5 and scores of other maps reflected the growth of official data caches developed by official bureaucracies and made available to researchers. These, in turn, relied on both census data and on reports on health and illness collected by government agencies at every scale. The results were often mapped using elementary health statistics (deaths per 100,000 citizens, for example) in an early marriage of cartographic and statistical methodologies. All this depended on, first, the collection of and then access to a wealth of public statistics, and, second, a new class of artisan cartographers and lithographers who replaced the copperplate artisans of Seaman’s time less than a century earlier. The result was a new medium of descriptive and statistical mapping in studies of health and disease published occasionally in journals and frequently in official reports.

THE MODERN TURN

Eighteenth and nineteenth century broadsheets gave way to twentieth century newspapers with black and white maps on varying subjects, principally weather and, of course, wars. Increases in the speed and decreases in the cost of print production in mid-century made mapping more generally available through an increasing range of public as well as professional or official publications. Through the 1980s, these were typically hand drawn by cartographers based in the main on official data from, for example, the emerging national weather service or, in the case of conflicts, military officials for whom public maps served as a form of popular propaganda. Maps of disease incidence, epidemic or endemic, were, if not absent, then rare in popular publications.

The digital evolution

Beginning in the 1990s, the then-ongoing digital revolution that had begun in the 1960s gave rise to three new technologies that would transform cartography and its modes of both production and publication. The first was the move from hot to cold type, composition and typesetting done without metal castings but with photo composition. This simultaneously lowered the cost of production for journals, news, and books while enabling the increased use of graphics. Second was the increasing digital format in which public data, previously available only from officials and in print form, were made broadly available digitally. The third was the introduction of low-cost desktop mapping...
programs with which those unschooled in the niceties of clas-
sical cartography could generate maps on their own.

Progressively sophisticated iterations of desktop mapping
programs evolved as prices for desktop computers declined
while computing power and program capability increased, year
by year. Facility with these programs gave rise to GIS experts
whose instruction typically focused on traditional map aesthetics
and a view of maps as objective representations of reality.
Progressively lost, in the transition, was the expert trained in
traditional, paper-based cartography. At the same time, an ex-
panding range of social data were being transposed into digital
formats easily introduced into ready-made GIS base maps of ter-
ritory included with most commercial desktop programs.

This progression—print to digital—is easily seen in the trans-
formation of influenza data and their study. As early as 1948,
the World Health Organization (WHO) created a network of
print-based influenza reportage with data submitted by partici-
pating member nations. In the 1990s, the 53 nations of WHO’s
European region began not only sharing but aggregating annual
data into a single, coordinated database. Later it became part
of the digital Global Influenza Surveillance and Response Sys-
tem, forerunner of the current Web-based and publicly acces-
sible FluNet and its automatic mapping of global influenza.

Data from disease-dedicated online databases like FluNet
came enfolded, in their turn, into even larger data caches
like healthmap.org, a publicly accessible digital library of global
infectious disease incidence. The sheer magnitude of data
collected for this and other sources increasingly relied on syn-
dromic programs whose algorithms searched official and popu-
lar sources for reports of infectious disease incidence, locating
each case in a specific geography identified by latitude and
longitude coordinates. By 2020, the data, available for general

Figure 4. Published in The Lancet in 1831, the authors boasted this map of cholera included over 1,000 locations where cholera had been reported. The data were collected largely from official, governmental reports with cases located within an existing map of Europe, the Middle East, and North Africa. The use here of grid lines of meridian degrees was also an innovation in this area of subject mapping.
download were, in most systems, also automatically available in cartographic form.

The COVID dashboard

On January 22, 2020, Johns Hopkins University launched its online coronavirus disease 2019 (COVID-19) dashboard to track in near real time what had begun the previous month as the regional outbreak of a novel coronavirus in Wuhan, China (https://coronavirus.jhu.edu/map.html). As the outbreak expanded globally, a wealth of international data were collected by syndromic programs whose precise algorithms sorted official and popular reports of disease incidence.28 The result was posted in a dashboard, a compact visual display of data derived from a linked database of national and then also regional data constantly updated automatically. In it, a map of COVID-19 was flanked by tables of reported cases flanked with a summarizing graph or chart below (Figure 5). The continuous updating of the data and their map advanced from simple reportage (so many cases here), presented in dot maps, to those including more precise health statistics (e.g., incidence per 100,000; hospitalization by population). While this was certainly geographic, or more precisely spatial, it was not GIS in the sense of maps or graphics produced by cartographers or GIS experts but instead the output of computer-based systems of continuous data collection and presentation.

The dashboard format was quickly adopted (and adapted) by other institutions, including the WHO, ESRI,30 and the Centers for Disease Control and Prevention (CDC) (Figure 6). In Canada, there was the COVID-19 Open Data Working Group (https://opencovid.ca); in the United States, the New York Times made public an extremely comprehensive resource, focused on the US, replete with maps, charts, and graphs of disease incidence at various scales and resolutions.31 It immediately was well used by epidemiologists, medical professionals, government officials, and journalists in reports and stories focused on, for example, risk analysis by state and disease incidence in congregate settings. Less ambitious, more targeted dashboards and analytics were posted by local health agencies and then reported in local newspapers and television broadcasts.

Studies that earlier would have taken years or at least months to prepare, submit, and finally publish in academic journals were now rapidly completed and distributed online as academic preprints and, more slowly, in journals. In many cases, similar work was being completed and published by journalists writing in national and regional newspapers. Public use of the dashboard data transformed covering COVID from the passive reportage of official statements to the active investigation of the pandemic's effect in specific counties and regions.32 Sophisticated analyses were produced in news reports by those using both GIS programs and geostatistical languages like R with packages permitting maps (and charts or graphs) as output options.

Figure 5. A detail of William Farr's abstraction of London districts imposed upon the full map

In it he included deaths from cholera (c), elevation above sea level (e), annual deaths per 1,000 persons (m), density of persons per acre (d), and rent per person (L). Capital letters refer to primary sources of water from regional water companies. Author collection.
User-generated data

Maturation of the online, digital universe created a range of new media in which these and other maps might be generated and shared. In 1999, DiNucci described Web 2.0 as a new, popular medium of evolving Web-accessible platforms with increasingly interactive processes. A “read-write” online environment transformed once-passive readers and viewers into active and often collaborative partners producing potentially useful maps. Volunteers to the OpenStreetMap project, for example, participated in an interactive mapping project in which participants would add streets and local buildings seen in aerial photographs to maps otherwise unavailable but critical to on-site epidemiologists and public health officials (https://www.openstreetmap.org). During the 2014–2015 Ebola epidemic in West Africa, for example, participants were assigned a location and constructed maps of affected areas in remote rural outbreak locales. The result provided a basis for study of and work in the disease in those locations.

More recently, online participation has increased as Web 2.0 matured into its successor (Figure 7). With these new environments and their citizen participants, new modes of presentation and argument began to appear. The “story map” promoted by ESRI is an example of a Web-based format in which map and text are integrated in a manner designed for mutual sharing and modification (https://storymaps.arcgis.com). Mapping of traditional indigenous territories by the Indigenious Mapping Collection (https://network.indigenousmaps.com), mixing user-generated and official data, is another example of the active participation in map production formally reserved for specialists. Participants map the boundaries of traditional territories over existing, taken-for-granted political boundaries, populating the resulting areas with whatever data they believe relevant. The results of these new online resources may become, in turn, the stuff of broadcast or print news stories and, of course, political initiatives.

DISCUSSION

Clearly, mapping across the broad outline of Edney’s categories followed an often-repeated pattern of general technological evolution. The early days of the printing revolution gave rise to atlases and then, with printing advances, to the inclusion of maps in, first, official reports and, later, books and professional journals. The introduction of desktop mapping promoted the engagement of GIS specialists and others accessing an increasing wealth of data stored online rather than on paper alone. The class of mapmakers expanded, as did venues for the presentation of resulting maps. With the introduction of technologies automatically generating maps, the craft of the old map expert is now giving way to new forms of mapping by collaborative groups in an expanding range of media. The story of medical cartography is simply a specific case within the more general history of technological change.

In 2003, Denis Wood announced the death of the nineteenth century idea of mapmaking as a craft whose practitioners sought to present a value-free representation of an environment. In the
new “critical cartography,” mapping was to be understood instead as the presentation of a mapmaker’s view of this or that worldly phenomenon; each map a singular image based on a view of the real and not a portrait of the real itself.36 At least in theory, gone would be what Hathaway called the “God trick” by which the mapmaker’s knowledge was presented as austere, abstract, and objective.37 How could it be if, as Harley argued in 1988, the data employed by mapmakers were officially collected and thus reflected the perspective of officialdom?38 All this paid little attention to the then-ongoing revolution in the technologies of map production, however. With GIS “what was once a craft has been democratized [or at least popularized] out of existence in precisely the way of other nineteenth century crafts like typesetting and manual layout.”13 For almost two generations, GIS desktop mapping ruled the cartographic world, and yet practitioners of the new typically maintained a classical perspective, promoting GIS as a dispassionate, impartial, and scientific presentation of the real.11 As a science, it promoted users to the role of scientific specialists, reproducing the faux objectivity and straight-jacketing scientism those like Harley and Wood earlier had criticized. However, as happened in photography, “obtaining increasingly complex results while the handling of the apparatus becomes more and more simple”39 opened mapping to new ideas, new ways of seeing with data increasingly stored and disseminated in digital form.

With these changes, the official data cache or report, and underlying geographic boundaries, all became subjects to be not reflexively accepted but interrogated. Mapping and “counter-mapping” by different groups increasingly presented not “the real” but a range of distinct, authorial perspectives. The algorithms used in both collecting and analyzing data are, in turn, now being analyzed and criticized for racial and socioeconomic bias.10 This wholesale refiguring of the “techno-cartographic” follows, in the main, the pattern of technical innovation in other, older media.

Past histories—those of photography and printing, for example—suggest mapping will become less a distinct discipline, or profession, and more one of a series of presentation modes employed by experts in one or another subject. GIS will wither as an exclusive, cartographic specialty just as other, older trades died in the face of evolving technologies. In the same way Microsoft’s Multiplan, an early spreadsheet of the 1980s, matured into Excel with its range of statistical formulae and graphic outputs,42 mapping will be embedded in new programs of statistical and locational analysis. The CRAN Spatial Task View, for example, lists 175 user-contributed packages for geospatial analysis and mapping in R.

Just as IBM transformed itself from primarily a producer of mainframe computers into a data storage and analysis consultancy, the spatial analyst of the future will be first a data specialist knowledgeable in computational languages and, as importantly, the data caches available for this or that study. As epidemiologist Nancy Krieger wrote in an article on public health, “counting and categorizing are the currency of durable knowledge, and the empirical study of variegated humanity—chock full of irreducibly unique individuals—can uncover universal truths.”43 That will not
change. Knowing what is where remains essential and essentially cartographic. Mapping with the best data possible will remain a critical tool in disease studies in the future. However, in a world of “neogeographies” and new technologies, tomorrow’s medical geographer’s first skill will be to acquire knowledge of the subject itself; the first task will be a critique of potentially relevant data returned by this or that syndromic or other, official program. 

The resulting analysis, however it is computed, will be presented with COVID-like dashboards replete with maps, data, charts, and graphs of either the specific data (deaths per 1,000) or related analyses (deaths related to ethnicity, income, housing, etc.). The role of the today’s GIS professional—a mapmaker often with little expertise in a data area—will become that of a data librarian, analyst, and critic whose work results in maps as one element of the greater presentation of the presentation of a health event.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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