The Production and Interpretation of ARPANET Maps

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A 20-year series of ARPANET maps produced by the firm Bolt Beranek and Newman (BBN) signifies the earliest efforts to represent an early and central piece of the modern Internet. Once a functional tool for engineers, they now serve as an aesthetic backdrop used without explicit recognition of their intended purpose.

An early map of the Advanced Research Projects Agency Network (ARPANET) appeared in September 1969 (Figure 1).[1] The map's origins are unclear, possibly a sketch drawn by someone at ARPA contractor Bolt, Beranek and Newman (BBN) or the University of California, Los Angeles (UCLA).[2] The diagram shows a circle tethered to a square by a single line, representing the connection between two machines: a time-shared computer system at UCLA, called a host, and an interface message processor (IMP).

The map outlines the basic topology of the ARPANET in its earliest form, a project that would soon be regarded as a massive success in computer networking, even though initially it was met with skepticism. At that time, computer networks were not entirely new, but the ARPANET introduced a general-purpose packet-switched network that connected heterogeneous, physically remote machines. According to its planners at ARPA, the primary benefit of participating in this experiment was resource sharing; rather than ARPA spending millions to duplicate computing resources across the country's "centers of excellence" that it funded, the ARPA Computer Network (as it was originally called) would enable researchers to access the resources of others remotely.[3] By the end of its life in 1989–1990, ARPANET technologies had served as a blueprint for a new generation of BBN networks for the private sector, the US Department of Defense, and the intelligence community, and more famously, it was a major source of the ideas, people, and technologies that led to the development of the modern Internet.[4]

Many subsequent maps would follow this initial sketch, in a 20-year series of maps produced by BBN, which published one or more a year throughout the network's life. The BBN maps signify some of the earliest efforts to represent the most significant antecedent of today's Internet. And while the ARPANET grew in scope and function during its 1969–1990 run—ultimately leading, by 1983, to it being a central component of the modern Internet—the official maps produced during its existence retained the same representational strategy. We have found no record of significantly alternate mapping strategies put forward by the ARPANET's active and technically sophisticated user community or by subsequent researchers, so the maps maintain over four decades of stability in the network's visual representation.[5]

We begin exploring the ARPANET maps' production by situating our work within critical cartography and science and technology studies (STS) to illustrate how the maps can be read for what they say about their material bases rather than acting as straightforward representations—what interpretive decisions led to their construction and influence the understanding of these artifacts after the fact? From there, we analyze the maps' historical origins. Specifically, we ask about the data-collection methods that preceded mapping, the design conventions used to visualize this data, and the parameterization work that determined what technical information the maps were intended to illuminate. Methodologically, this research includes analysis of primary source materials, such as the maps themselves. We also draw from discussions with those involved in the production of these maps and others working at BBN during the time of their use.[6] In our conclusion, we explore the significance of BBN's data-

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collection practices and the maps' network graph form in terms of wider ARPANET representation and how these representations function alongside a more comprehensive historiography. Namely, we believe that the maps' form and its focus on the network subnet reinforce a historiography that also focuses on early years, eclipsing many of the significant technical and sociocultural changes that occurred as the network grew and changed.

Critical Map Reading

What does a critical reading of ARPANET maps entail? First, we use the term *maps* deliberately, drawing from cartographers J.B. Harley and David Woodward, who describe them as "graphic representations that facilitate a spatial understanding of things, concepts, conditions, processes, or events in the human world."[7] Graphic representations such as maps are composed of what Johanna Drucker calls "capta," or organized and parameterized constructions in graphical expression.[8] (Drucker avoids using the term *data,* shrouded as it is in the common misperception that data are equivalent to phenomena in the world.) That is, graphic visualizations are always based on the selection of measurement criterion, data, and visual metaphors—on actions that involve interpretation. We therefore set out to examine maps not as passive records capturing a priori data about the world but as constructions reflecting the choices of their designers and the conventions of their time. We use the term *critical* in the tradition of theoretical critique, with nods both to the Frankfurt School and Michel Foucault. Here, critique becomes a means both to excavate the maps' implicit knowledge claims—the information their creators decided constitutes "the" ARPANET, as revealed through data selection and design—and also to challenge the casual use of these documents as visualizations of the ARPANET as a whole. An abundance of literature in areas such as critical cartography, digital humanities, and STS present similar orientations.

Feminist geographer Sara McLafferty, for instance, argues that geographic maps present a detached, God's-eye view, representing the efforts of individuals or groups as dots and complex activity patterns as linear pathways.[9] The design of a map cannot capture the variegated spatial experience of everyday network activity. The ARPANET maps deploy a distributed, topological network graph form, an analytic design deriving in part from 18th and 19th century graph theory developed in the fields of mathematics, electricity, and chemistry. The design is one that likewise privileges a geometric, spatial perspective over relational or causal dimensions, often hiding the complex agencies and directional flows involved in technological projects. Digital humanist Phillip Gochenour also points out the potential of network graph models to reify political and economic structures in a way that makes conflict, difference, or malfunction invisible: only connection and smooth technical or social functioning can be represented in the graph; any broken or odd parts are left out.[10]

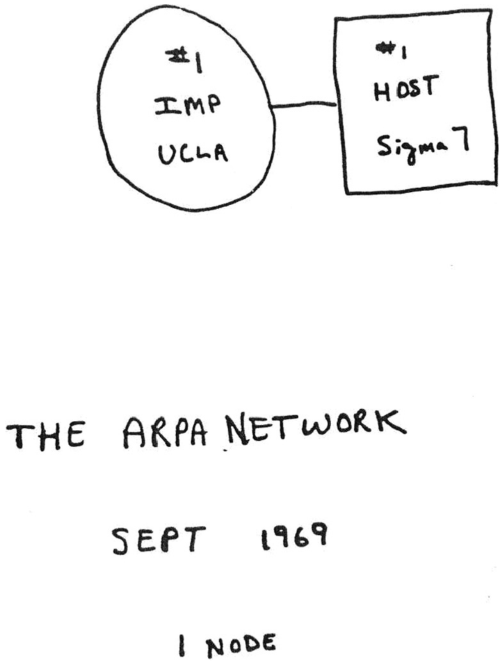

Figure 1. The first ARPANET node at the University of California, Los Angeles, September 1969.

STS scholar Geoffrey Bowker has proposed a similar critical approach when examining classification systems. Classifications are information infrastructures constructed silently behind the scenes, operating transparently through common use. Yet when foregrounded—a method Bowker terms "infrastructural inversion"—the standard categories of a classification scheme become objects of historical examination.[11] Rather than telling us about the order of the world, their categories are contingent reflections of their time. Bowker and Leigh Starr argue that classifications have consequences both as a political force and as an organizing schema that shape social identities and technical possibilities. In no way neutral, classifications embody ethical and aesthetic decisions and myriad compromises. To study classifications, a researcher must ask what their schemas render visible and what they leave out, as well as how their use spreads. Classification research, in other words, provides a method with which to view the processes of classifications as an ongoing "crafting of treaties" and a lens through which to examine the ethical or social impacts of any classification schema.[12]

With our reading of ARPANET maps, then, we propose a similar tactic of inversion. We read the consistency of the map design as a choice selected from a growing body of available data. The continuities and systematic nature of BBN's depiction of the ARPANET allow us to read the maps as proposing a certain perspective of the network's operational years that may affect retrospective histories. Namely, the maps parameterize the ARPANET based on a crucial, but limited, set of technologies, as we explain below. Similar to a classification scheme, the maps' parameters as visualized in the network graph form will exclude what is not deemed to fit, and this exclusion can have subtle consequences. In this article, we focus on the context of the maps' production at BBN, leaving a closer look at the maps' ellipses—the information they make invisible—for a forthcoming paper on the topic.

Such a critical reading is salient because these maps have come to circulate as straightforward representations in the literature on the ARPANET. In *Mapping Cyberspace,* for instance, Martin Dodge and Rob Kitchin reproduce six maps over the course of six years to exemplify how the ARPANET grew from four to over 50 nodes.[13] Peter Salus's *Casting the Net* and Arthur Norberg and Judy O'Neill's *Transforming Computer Technology* also use these maps to illustrate the network's scope,[14] while Martin Campbell-Kelly and William Aspray's *Computer: A History of the Information Machine* deploys the maps to depict the ARPANET as a whole.[15] In *Inventing the Internet,* the maps illustrate the inclusion of DARPA's "centers of excellence" in the early network design.[16] DARPA itself features the map as its main representation of the network on its history section webpage, as does the ARPANET Wikipedia page.[17] A technical retrospective of the ARPANET and other DARPA projects, funded by DARPA and completed by the Institute for Defense Analysis, also uses these maps to illustrate the network.[18] The maps have also circulated as Web ephemera in social media posts, showing up as a constant Twitter fixture and in online journalism.[19] In all these examples, the maps are presented as straightforward signs, with little qualifications about their limited representational aims, or as an aesthetic backdrop for descriptions of the early ARPANET of 1969–1975, but not its later, more ubiquitous (and perhaps more influential) form. As we will explain here, characterizing the ARPANET's history based on this particular view introduces problems if it diverts historiography to a set of concerns from this earlier time period.

BBN's engineers designed the maps for specific purposes, never to represent the ARPANET as a whole. The maps were highly effective in fulfilling their role during the ARPANET's life and circulated among ARPANET engineers and users who surely understood, through experience, the difference between these maps and the broader ARPANET infrastructure, as well as the network's social complexities. Now, these representations should be viewed as partial constructs, especially for observers without experience using the network. The ARPANET map designers made the task of defining and revealing the network seem like a simple representational matter, and a noncritical reproduction of the maps does not complicate this assumption.

Map Design and Production

BBN, the Cambridge-based ARPA contractor that built, maintained, and ran the ARPANET, began its work in 1968 after it won the ARPA contract to develop the network; its initial charge was to make operational the network's basic functions of moving data from computer to computer. On Labor Day weekend in 1969, BBN delivered UCLA's IMP and connected it to the SDS Sigma 7 host.[20] The IMP acted as a minicomputer, slightly narrower and taller than a consumer refrigerator, and was engineered to serve as the host's link to the future network of other IMPs and hosts. The physical infrastructure depicted in the single-node map in Figure 1 was now in place. Within the same year, other computing centers joined the UCLA node, including the Stanford Research Institute, University of California, Santa Barbara, and the University of Utah.[21] These first four nodes appear on an increasingly iconic four-node map of similarly obscure origins as the single node map

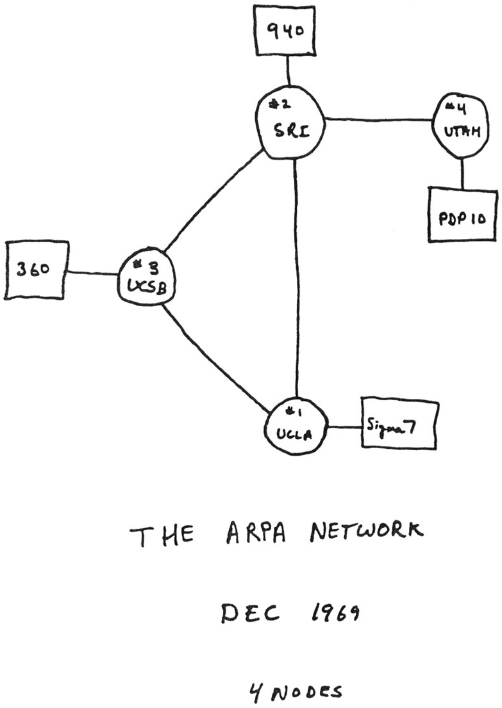

Figure 2. The first four nodes of the ARPANET, December 1969.

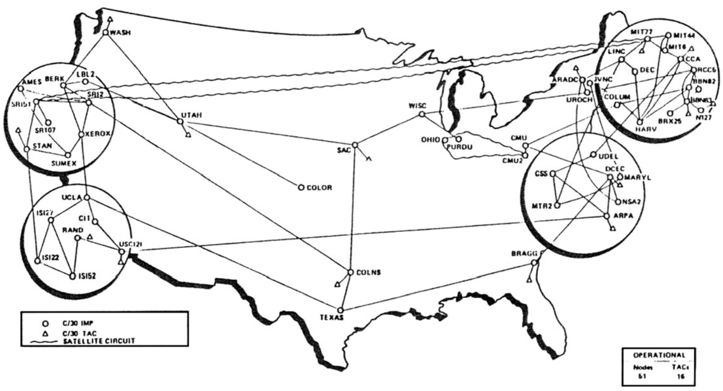

Figure 3. ARPANET geographic map, 30 April 1988.

(Figure 2); it serves as a simple schema of the network formed by the first four sites. BBN joined as the fifth node in January 1970. By March 1972, the network had 25 nodes.[22]

One of BBN's early tasks, a massive one, involved establishing a working subnetwork and maintaining and increasing its reliability as the ARPANET grew in size and complexity.[23] The subnetwork—or subnet—included all the IMPs and links that interconnected them, comprising the core physical infrastructure responsible for transporting data between the hosts. Building a working subnet entailed more than simply putting hardware into place. To ensure that packets of data would flow successfully through the IMP network, BBN developed custom IMP hardware and software, including the crucial routing algorithm. Importantly, the subnet had to be invisible to users, shuttling data between hosts automatically.

Bob Brooks, who managed the creation of BBN's ARPANET maps, locates their production in this early stage of the network's development.[24] It's perhaps not surprising, then, that the maps largely reflect BBN's responsibility at that time for the ARPANET subnet. This focus is evident in both of the two types of network graphs or maps BBN used to characterize this landscape, even though they visualize the subnet in slightly different ways. On geographic maps, set against an outline of the continental United States, the subnet's representation was limited to IMPs and the links connecting them (Figure 3). Logical maps, sometimes referred to as topological maps, represented the ARPANET sites much as a schematic subway map does subway stops: the connections between sites are maintained, although distances and relative locations are not proportional. Logical maps, however, also revealed each IMP's connection to a host, integrated within a representational scheme ordered by the IMP subnet (Figure 4). Yet ultimately the form taken by both maps relies on a small number of main components forming, and related to, the subnet: IMPs, hosts, links between IMPs and hosts, and links between IMPs (of these, only the hosts are not the subnet proper). Minor adjustments were made to represent certain changes to core technologies and to accommodate the growing number of nodes. To this end, the logical maps' underwent a stylistic update during 1974, displayed here in a 1977 map (Figure 5), yet the fundamental design of both map types remained focused on the subnet throughout the network's life, from the first months the network became operational until 1989, when its shutdown was nearing completion.[25]

Although the maps were likely originally produced on an ad hoc basis,[26] their use quickly spread as a medium that was "simple to understand, easy to distribute, and served a multitude of purposes," according to Elizabeth Feinler, who was familiar with the maps as director of the Network Information Systems Center (NIC) at SRI.[27] By 1975, both logical and geographic maps were released in official publications, such as the ARPANET Information Brochure and the ARPANET

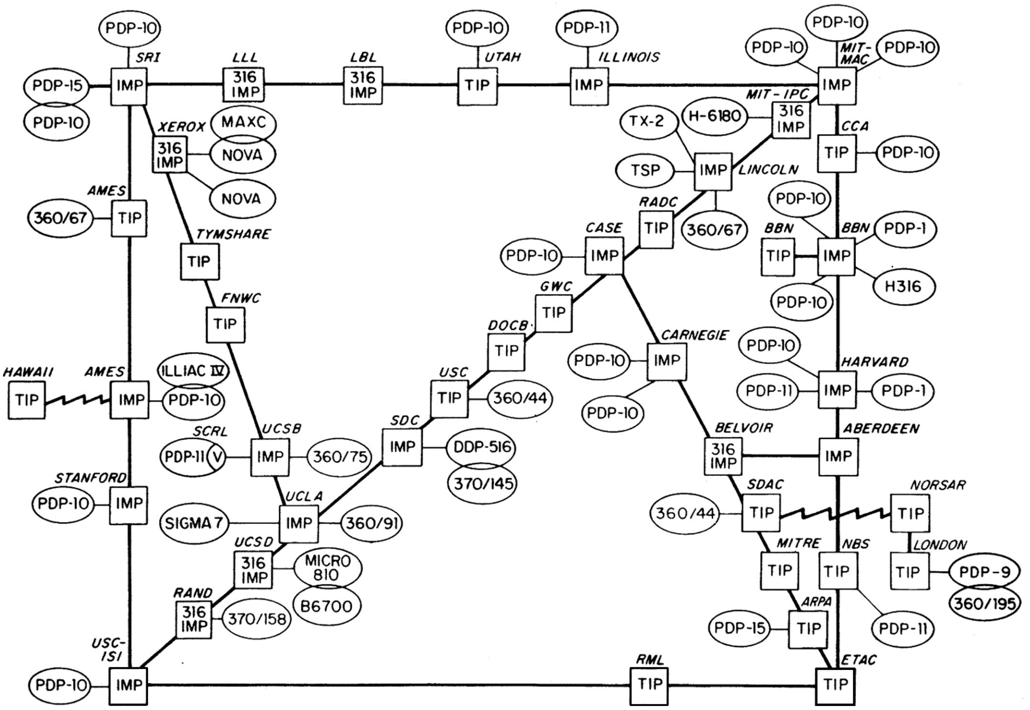

Figure 4. ARPANET logical map, September 1973.

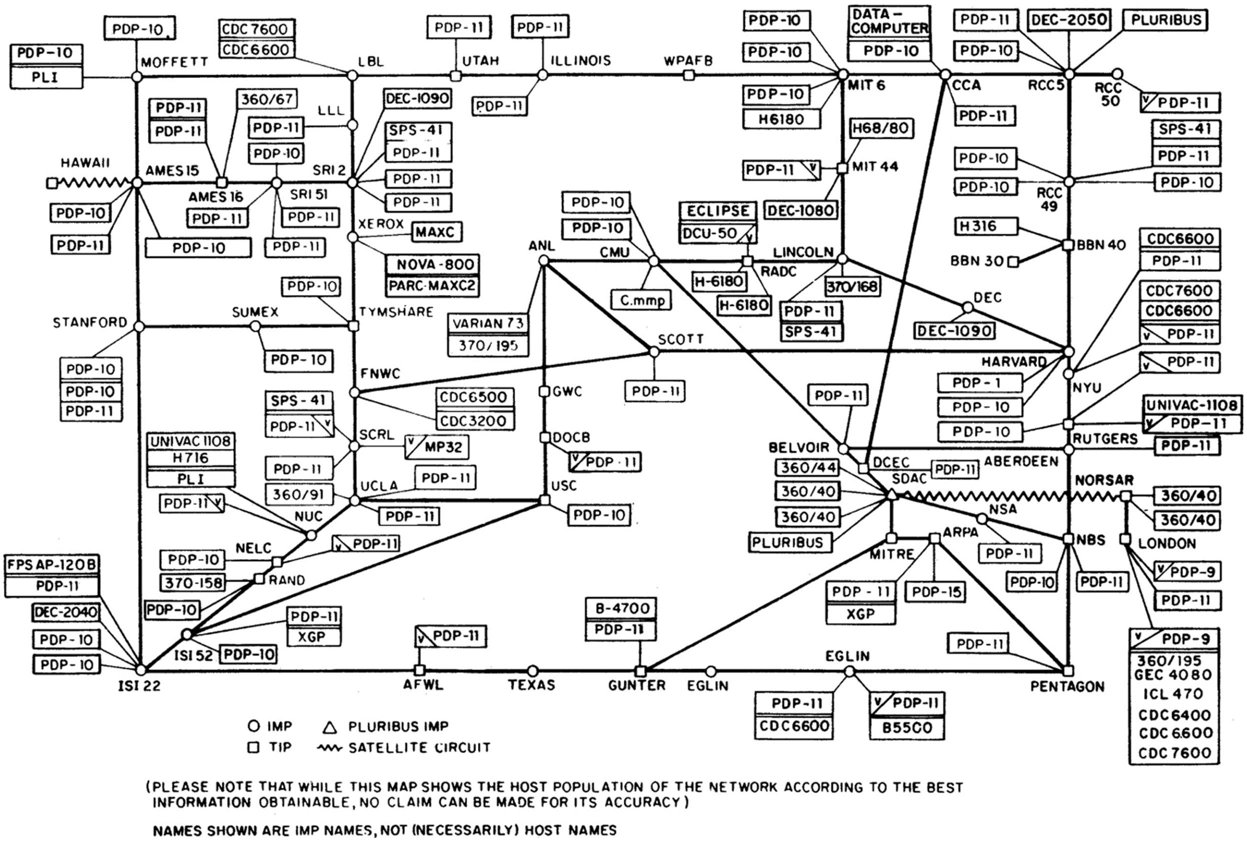

Figure 5. ARPANET logical map, March 1974.

Resources Handbook, documents that provided a range of information about the ARPANET for the user community.[28]

In sum, the mapping practices emerged during the earliest and most informal stage of BBN's management of the ARPANET. Especially in the early years of the network, implementing and improving the subnet—and keeping it functioning on a day-to-day basis—were a major priority for the BBN staff responsible for developing the IMPs.[29] The maps' network graph design represents this focus, as does the early data collection and selection practices. BBN retained the maps' design throughout their lifetime, even during the course of major changes as the ARPANET itself grew in complexity and as BBN became more sophisticated in its data collection and processing.

A Specific Parameterization

The maps' focus on the subnet stayed in place while the ARPANET grew in complexity with the introduction of new applications such as email and FTP, as it began connecting to both external and local networks, and as it reconfigured its institutional governance and access control policies (to name just a few developments). BBN had no reason to alter its interpretive strategies as staff could access more encompassing data that reflected these changes. Rather, BBN parameterized its maps by selecting from a larger set of static data it maintained on the configuration of the network, such as IMPs and their interconnections (the subnet), the type of IMP connection to its hosts, the name of each host, as well as line and modem numbers.

The maps themselves focused on three of these types of data, all related to the subnet. First, IMPs, as explained earlier, comprise the nodes around which the maps are structured. Interconnected IMPs are the ARPANET's backbone: repurposed minicomputers linked together to form the subnet and to ensure that a host's message travels to the destination host through the best available path of IMPs that lie between them. The maps reveal detail about IMP types, such as the terminal IMP (TIP), which allowed users direct terminal access to the network, sidestepping the need to go through a host machine, and newer IMPs, with more processing power and memory, such as Pluribus and C/30 IMPs. This subnet infrastructure, however, was invisible by design to those using the ARPANET. (Users would not, for example, need to know the path their data would take to reach a destination host.)

Second, hosts, found on the logical maps, were a common point of access to the ARPANET; by logging on to a host, users could access the network to connect to other hosts across the network. Hosts sent data to intermediating IMPs, indicating the distant receiver host to which a packet would be delivered. The maps reflect how hosts' relations to IMPs changed gradually from their original configuration in the early years of the network, when access was often through terminals in the same room as the host, to 1970, when the number of hosts per IMP began to increase and spread further from IMPs. For instance, the distant interface allowed up to 2,000 feet and appears on the maps as a D; the very distant host interface permitted arbitrary length and appears as VDHI.[30] Entire local networks of hosts that were increasingly attached to one IMP, such as the Stanford University Network, also show up on the maps but only as one entity, SU-NET.[31] Other specialized host functions appear as private line interfaces (PLIs) beginning in 1976 and terminal access controllers (TACs) in 1982. BBN labeled these different connections on the maps because the kind of interface, whether standard and distant host-IMP interfaces, would impact the NCC's diagnostic practices if a malfunctioning host was interfering with an IMP. In other words, these details were significant to the subnet,[32] while functions of the hosts that indicate ARPANET's infrastructure beyond the subnet were not represented.

Finally, the links on the map represent leased lines from telephone carriers, the connections between the subnet. The geographic maps appear to privilege geography to show these connections, although geography is pushed aside in the case of nodes in Hawaii or London, which simply show up as "outside the continental United States"; concentrations of nodes, power centers of the US network, are magnified to fit the nodes on the printed map. On later geographic maps, satellite connections were represented as uneven links (and experimental satellite connections were not shown at all.[33] In the case of both maps, all links between IMPs, even on geographic maps, are displayed logically, only revealing their origins and destinations: the actual geographic route of the ARPANET's leased lines, and the connections and transfers across the line's routes, were unknown to BBN. Indeed, even though the maps show complete, static links, a 1980 paper on the NCC's Network Utilities (NU) described the static network state, wherein all components are working and properly connected, as only an "ideal"—in reality, network components may, at any given time, have been malfunctioning or inoperative.[34]

All told, the maps focused on the ARPANET subnet, as they were structured around the IMPs and the IMP-to-IMP links that connect them. The maps do not, nor were they ever intended to, describe the broader ARPANET of users interacting with their host machines in an increasing number of ways nor, for example, the social and political hierarchies between them.

BBN's Wealth of Data

We also want to point out that the maps' focus on the subnet was based on conscious choices by BBN engineers, especially given that BBN increasingly had more access to different types of data. Moreover, BBN's data collection became more automated and sophisticated throughout the 1970s and in 1980, yet over the course of two decades, the maps' representational method and mode of production remained a job of manual selection among static data collected by BBN.

Significantly, the static map data described in the section earlier was not the only data collected by BBN. Throughout the ARPANET's life, BBN monitored and recorded two other distinct categories of information about the network. The second type of information collected was data on dynamic, temporary changes in the network, traffic flows, and errors such as line or IMP outages. A third type of data collected by BBN consisted of contact information of people responsible for each node as well as the telephone company responsible for the lines connecting them. The maps portrayed a selection only of the static data.

BBN also continued to select the static data put on its maps manually, even as data collection gradually became systematized and automated thanks to the pragmatic requirements of running the network. At first, BBN monitored information without any electronic link to the network, instead gathering that information ad hoc with calls to the individual nodes and based on reports from institutions and contractors that were installing IMPs,[35] but a series of incremental adjustments improved BBN's technical abilities to monitor the network. The first occurred when the firm joined the ARPANET as the fifth node, connecting its own IMP in January 1970. Through its IMP, BBN received human-readable status reports from each IMP on the network, alerting BBN staff to any errors. Then, BBN engineer Alex McKenzie led further efforts to develop new monitoring techniques in response to a growing demand for the network's reliability as the ARPANET grew,[36] creating the Network Control Center. The NCC allowed BBN engineers to gain knowledge of the networks' topology increasingly through direct access to the network's infrastructure.[37] In 1971, monitoring techniques improved again, as an NCC host compiled the IMP status messages for the staff, and expanded to include more information that helped BBN understand the actual state of the network.[38]

By 1980, the NCC used a UNIX NU program, which became the sole monitoring and control system in 1983. The NU monitored the static network state, such as the IMPs, lines, and now, more information about hosts, but also dynamic changes to the network, such as outages and traffic rates in a manner that was far more integrated than before. NCC staff could now centralize the three types of network information collected and stored through different means in the early NIC into a single database.[39] A broader set of monitoring techniques, combined with a centralized database, also allowed BBN to generate customized reports, such as traffic between nodes over a week or month.[40] It could even visualize these custom status reports on CRT displays as well as create a dynamically updated map of the network or of any component on the network, in an array of formats.[41]

Yet even with these new capabilities and types of data, the original map formats, created with the practices and technologies of the early 1970s, remained the same. Indeed, during 1971, the NCC mounted a large steel board on the wall in the front of the room to aid in monitoring, to which it manually transferred network information. Here, staff plotted the static network configuration as well as temporary changes or difficulties.[42] The board displayed information the NCC staff felt most relevant, such as recent problems or experimental code loaded in particular IMPs, and the names of the people working on particular issues.[43] Once the steel board was installed, it provided the site from which the map information was retrieved (although, later, presumably the information derived from the NU program), before being transferred to the BBN art department for illustration.[44]

In a further step of refinement, beginning in late 1969 or early 1970, Bob Brooks became responsible for transferring a subset of information about the network, such as topological information and site names, from BBN ARPANET staff to the art department for final illustration. Laura Selvitella, a long-time illustrator for BBN, received sketches of the broad strokes of data to be included and then organized them in the topological layout form, making decisions that rendered the sketches into the final illustration.[45] Her designs added a graphic formality to the data, rendering them as authoritative or at least seemingly comprehensive documents to audiences with less familiarity with the network.

In sum, the original choices about the kind of information to visualize in the maps were a deliberate selection from an increasingly broad set of data available to and collected by BBN. Among this data, whether gathered manually, directly from IMPs, or eventually by the NU application, staff made choices about what was relevant for inclusion in the maps, choices that remained consistent over the life of the network. This design remained the case, although not for lack of data or different visualization techniques. Nonetheless, the configuration of the first available logical map of 1970 would remain for the duration of the network's life. Below (or above) the surface of these maps, then, lies a world of additional detail at hand: different traffic levels between sites, extremely popular hosts versus those that were barely used outside of their institution, the extent to which a node carried purely localized traffic, or the distribution of ARPANET access throughout an institution (for example, through distant terminals or a local network), to name just some areas. We're reminded again of what Bowker and Star call the continual crafting of treaties; the maps' narrow selection of data and network graph form emphasize an infrastructure that was central to a functional network, but they meant little to a user's everyday experience with that technology as it grew and shifted over time. A wealth of other concerns and technologies arose as the network expanded in size and differentiated beyond the subnet; here, we focus briefly on two.

First, the maps do not depict the different connections and densities of flow that diversified within the ARPANET. The maps do not visualize the network's widening sociotechnical infrastructure, one no longer composed of one host per IMP (as the maps originally denoted) but of hosts' diversifying user base and the interconnected networks of hosts, both locally and internationally. Durable patterns of highly local network use, for instance, emerged early in the ARPANET's history and remained at varying degrees in different places well into the early 1980s.[46] These practices, which were measured quantitatively by both the NCC and the UCLA Network Measurement Center, reflect local networks of multiple hosts connected to the ARPANET through a single IMP—connections that are not represented on the maps.[47] By the early 1980s, this trend expanded as local networks, such as SU-NET, and external networks, such as ALOHANET in Hawaii and the UK's University College of London, were connected to the ARPANET.[48,49]

Second, the maps' network graph model, in which all nodes appear equal, does not illustrate these hierarchies of control as ARPANET governance shifted. As the network developed, especially from 1975, access control regimes and security became major concerns. The major site of research into the properties of the network, UCLA's Network Measurement Center, was phased out, and the SRI NIC took on an increasingly influential role in implementing network policies and regulating access to the network. The rise of the SRI NIC related to the major shift in governance that occurred in 1975, when management of the ARPANET passed to the Defense Communications Agency (DCA), the defense agency that ran the network as an operational rather than experimental infrastructure.[50] This marked a time period that has been given little attention in the historiography of the ARPANET, when interest in controlling remote access to the network led to, among other things, the institutionalizing authentication of users in 1984.[51]

These are just some examples of major shifts in ARPANET use, technologies, and management that were not present in the first few years of the network's operation, from 1969 to 1970, when the maps were formalized. What is more, most ARPANET historiography parallels these maps by focusing on a structure of the network drawn from its early years, rather than the multifaceted phenomena that arose later.[52] The famous first four nodes are easily knowable, with the personalities of the people who operated them and specialized functions widely reported. But even though the ARPANET grew and diversified, little has been reported in depth on the changing points of control and technological characteristics of the network. Reading these maps for the traces of these later uses, technologies, and management shifts that occurred in the ARPANET's final years highlights the need for further research.

Conclusions

As historically situated records, maps reveal much about the context of their production, including what they neglect to represent. As such, by reading maps critically, we can also imagine possible recuperations of the historical narratives that they've neglected. The case of the ARPANET maps is no different. We have demonstrated that BBN's priorities, data-collection practices, and mapping strategies were oriented around the ARPANET subnet, an early technological challenge of the network, and an infrastructure that was intentionally opaque to the hosts and, when functioning properly, invisible to users as well. There were other goals and priorities alive on the network at that time, but as argued, the subnet was at one point a central task and a major technological achievement of the network.

We believe that the map's network graph form reinforces the selections BBN made. The ARPANET subnet was designed to be hierarchically flat, at least in terms of its job to send packets to the right destination, since no IMP counted more than any other. This framework was explicitly conceptualized in the ARPANET's early design phase in 1968–1969: ARPA planners specified a flatly decentralized subnet, and BBN engineers made this possible. The ARPANET maps, which represent each node in similarly networked fashion, reinforce this description. Yet as Gouchenor argues, the network form also gives the impression of a smoothly functioning whole, and its white marginal space suggests completion. Rather than alluding to its narrow focus, the network graph form subtly reinforces a limited reading of the object it represents.

The subnet, a functionally nonhierarchical and homogenous infrastructure, with parts that operate equivalently, is therefore perfectly suited to the basic two-dimensional network graph form used in the maps' design. The network graph form does not easily accommodate other sociotechnical factors that operate on top of the subnet: the hierarchies of login access that developed among nodes or the directions of internal communication flows and flows from external sources. BBN's partial focus on the subnet suited a form that makes differences less evident. Yet as a result, the continuities and systematic nature in the maps' form, one so central to the subnet, encourage us to read them from a certain perspective based on the operational years, a view that may affect how retrospective histories depict the ARPANET's entire lifetime. Much of the literature that focuses on a time when the ARPANET was "generally non-hierarchical," "decentralized, collegial and informal,"[53] with "no central control point,"[54] neglects these later changes and the role that social ties and centers of privilege continued to have on its technical development. Although some authors are sensitive to the ARPANET's contradictory, heterogeneous parts,[55] what occurs in much of this writing is a conflation of early technical features with later social registers, not leaving room for the evaluation of lesser examined but vital points of control. It is the task of further historiography to excavate these features of the network.

Acknowledgments

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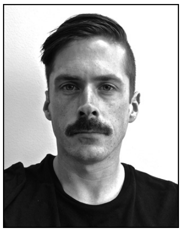
16. J. Abbate, *Inventing the Internet*, MIT Press, 2000.
17. See www.darpa.mil/About/History/History.aspx and https://en.wikipedia.org/wiki/ARPANET.
18. S.G. Reed, R.H. Van Atta, and S.J. Deitchman, "DARPA Technical Accomplishments, An Historical Review of Selected DARPA Projects," vol. 1, Feb. 1990; www.darpa.mil/WorkArea/DownloadAsset.aspx?id=2678.
19. Twitter search for "Internet map 1969," http://boingboing.net/2013/07/04/arpanet-map-march-1977.html, http://gizmodo.com/5733671/this-is-the-internet-when-it-was-just-a-baby, and www.businessinsider.com/internet-in-1969-2014-1.
20. Other ARPANET sites such as SRI, UCSB, and Utah were freed of BBN's same responsibility and could devote time instead to devising and improving technologies to use the ARPANET more usable, the major example being the Host-Host Protocol, also referred to as the Network Control Program (NCP).
21. L. Kleinrock, "Creating a Mathematical Theory of Computer Networks," *Operations Research*, vol. 50, no. 1, 2002, pp. 125–131.
22. "*ARPANET Completion Report*," tech. report 4799, BBN, Jan. 1978.
23. J.M. McQuillan and D.C. Walden, "The ARPA Network Design Decisions," *Computer Networks*, vol. 1, no. 5, 1976, pp. 243–289; doi:10.1016/0376-5075(77)90014–9.
24. B. Brooks to B. Fidler, email, Oct. 2013. "At the time I was hired, Frank Heart's group was just installing the beginnings of the ARPA Network—ARPANET—3 nodes in California and one in Utah. For the first relevant Quarterly Technical Report to ARPA, I was asked to prepare simple maps of where these nodes were located geographically and how they were connected logically."
25. The "ARPANET Completion Report" (1978) includes a December 1969 geographical map and a December 1970 logical map; both series conclude in 1977, the year before the report was released.
26. B. Fidler and A. McKenzie, discussion, Oct. 2013.
27. B. Fidler and E. Feinler, discussion, Mar. 2014. The maps originally circulated according to the needs of a handful of interest groups and as evidence of progress to ARPA, in particular through BBN's quarterly technical reports (Fidler-McKenzie discussion, Oct. 2013); they also appeared in various BBN presentations and proposals (B. Brooks to B. Fidler, email, Oct. 2013). Both types of map are prominent in informational materials provided for the major 1972 demonstration at the International Conference on Computer Communication in Washington, DC, that introduced the ARPANET to the broader computing community ("Honeywell at Bolt, Beranek and Newman, Inc.," Oct. 1972 brochure produced by Honeywell Information Systems, courtesy of J. Haverty). Because logical

maps added a further layer of detail by listing the hosts connected to the IMP subnet, they may have been an initial response to user requests for host information (Fidler-McKenzie discussion, Oct. 2013). The SRI Network Information Center (NIC) would also send out these maps to individual users who requested them for information about which sites were on the network (E. Feinler to B. Bidler, email, Aug. 2013 and Mar. 2014). They also appeared on BBN-produced t-shirts (B. Brooks to B. Fidler, email, Oct. 2013).

28. E. Feiner et al., "*ARPANET Resources Handbook*," tech. report NIC 45601, SRI Int'l ARPANET Network Information Center, 1978; ARPANET Information Brochure, Defense Communication Agency, 1978.
29. D. Walden with B. Fidler, discussion, Mar. 2014. Other staff at BBN were actively involved in the development of other areas of the ARPANET and related technologies, such as host-level protocols that made the network generally usable and advanced operating systems that became extremely popular on the network; Walden and Nickerson, *A Culture of Innovation*, chaps. "Data Networking at BBN," "Email," and "Distributed Communications"; www.cbi.umn.edu/hostedpublications/pdf/CultureInnovation_bbn.pdf.
30. "*Specification for the Interconnection of a host and an IMP*," BBN report 1822, May 1978. It is unclear how long VDHIs extended on the ARPANET.
31. This network is visible in the June 1983 logical map. Little is known about these local networks, and they remain an important focus for historical inquiry.
32. B. Fidler and A. McKenzie, discussion, Oct. 2013.
33. Satellite connections were used with satellite IMPs (SIMPs), which curiously do not show up on the maps. Satellite connections brought with them their own host of challenges.
34. P.J. Santos et al., "Architecture of a Network Monitoring, Control and Management System," *Proc. 5th Int'l Conf. Computer Communication*, 1980, pp. 831–836.
35. B. Fidler and M. Thrope, discussion, Feb. 2014 and Oct. 2013. A. McKenzie, "The ARPA Network Control Center," *Proc. 4th Data Communications Symp.*, 1975, pp. 5.1–5.6. BBN monitored unplanned events (such as outages) and often passed trouble calls to the homes of some of its employees.
36. B. Fidler and A. McKenzie, discussion, Oct. 2013. See also McKenzie, "The ARPA Network Control Center," pp. 5.1–5.6. Aside from the first node, the UCLA Network Measurement Center, other sites expected a stable and operational network. The NCC is sometimes referred to elsewhere as the Network Operations Center.
37. A detailed account of the early stages of the NCC, as well as a broader overview of its monitoring and control capabilities, can be found in A. McKenzie et al., "The Network Control Center for the ARPA Network," *Proc. 1st Int'l Conf. Computer Communication*, 1972, pp. 185–191.
38. McKenzie, "The ARPA Network Control Center," pp. 5.1–5.6. It appears that messages expanded again around 1974.
39. The 1978 inception date is listed in J.G. Herman's bio in S.L. Bernstein and J.G. Herman, "NU: A Network Monitoring, Control, and Management System," BBN, 1983, pp. 478–483. Although the details remain unclear, between the 1975 configuration and the 1980 implementation of NU, a TENEX-based "U program" may have been used in some aspect of network monitoring. J. Dempsey to B. Fidler, email, Oct. 2013.
40. Bernstein and Herman, "NU: A Network Monitoring, Control, and Management System," *Proc. IEEE Int'l Conf. Communications: Integrating Communication for World Progress* (ICC 83), vol. 1, June 1983, pp. 478–483. Thanks to James Dempsey for this source.
41. Santos et al., "Architecture of a Network Monitoring, Control and Management System," p. B5.2.6.
42. The large network map is also described in K. Hafner, *Where Wizards Stay Up Late: The Origins of the Internet*, Simon & Schuster, 1998, p. 168. Alex McKenzie corroborates this account.
43. J. Dempsey to B. Fidler, email, Oct. 2013.
44. B. Brooks to B. Fidler, email, Feb. 2014 and Oct. 2013. Bob Brooks had this role until 1986.
45. B. Fidler with Laura Selvitella, discussion, Feb. 2014.
46. A January 1993 BBN report of local traffic statistics is available in the William Naylor collection, KCIS Archives, UCLA Library Special Collections.
47. RFCs authored by A. McKenzie, starting at #378 (Aug. 1972) and ending at #612 (Dec. 1973); L. Kleinrock and W.E. Naylor, "On Measured Behavior of the ARPA Network," *Proc. Nat'l Computer Conf. and Exposition*, 1974, pp. 767–80; doi:10.1145/1500175.1500320.
48. See logical maps from 1983 and later. Accessed with permission from the Computer History Museum.
49. M. Schwartz and N. Abramson, "The Alohanet: Surfing for Wireless Data [History of Communications]," *IEEE Comm. Magazine*, vol. 47, no. 12, 2009, pp. 21–25; P.T. Kirstein, "The Early History of Packet Switching in the UK," *IEEE*

Comm. Magazine, vol. 47, no. 2, 2009, pp. 18–26.
50. The increasing role of the NIC in ARPANET operations and policy is illustrated in the DDN newsletter discussions; see www.rfc-editor.org/rfc/museum/ddn-news/ddn-news.n1.1, www.rfc-editor.org/rfc/museum/ddn-news/ddn-news.n1.1, www.rfc-editor.org/rfc/museum/ddn-news/ddn-news.n18.1, and www.rfc-editor.org/rfc/museum/ddn-news/ddn-news.n36.1.
51. Between 1973 and 1975, BBN developed a distributed system of access control and basic user metadata collection (see BBN reports 2869, 2976, and 3089, and R.E. Schantz, "BBN's Network Computing Software Infrastructure and Distributed Applications (1970-1990)," *IEEE Annals History of Computing*, vol. 28, no. 1, 2006, pp. 72–88.). The final 1984 implementation as TACACS is linked to these early efforts in Walden and Nickerson, *A Culture of Innovation*, p. 461.
52. A first generation of foundational works on the ARPANET emerged in the 1990s and, understandably, focused on the emergence and early operation of the network. See Hafner, *Where Wizards Stay Up Late*; Abbate, *Inventing the Internet.*
53. Abbate, Inventing the Internet, p. 54.
54. K.L. Hacker and J. van Dijk, *Digital Democracy: Issues of Theory and Practice*, Sage, 2000, p. 20.
55. See G. Downey for a nuanced portrait of the network's heterogeneous and homogenous parts in "Virtual Webs, Physical Technologies, and Hidden Workers: The Spaces of Labor in Information Internetworks," *Technology and Culture*, vol. 42, no. 2, 2001, pp. 209–235.



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