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ARPANET and its boundary devices: modems, IMPs, and the inter-structuralism of infrastructures

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ABSTRACT
Our paper focuses on the Interface Message Processor (IMP), an important device in the history of ARPANET. Designed as the interface between ARPANET nodes and the common carrier telephone system, the IMP actualized the ARPANET as an experimental packet-switching communication system. We conceptualize the IMP as historical boundary object that exposes ARPANET's close relationship to the telephone system. Our analysis offers a novel history of ARPANET as a repurposing of the existing telephone infrastructure. Beyond the historical contribution, this approach has wider implications for the theory of media infrastructures, specifically the "inter-structuralism" of ARPANET and the nature of borders between seemingly disparate social, political, and technological regimes.

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Introduction

[Around 1973, Lawrence Roberts] and I presented the economic study that we had done on how [store and forward computer networks] extrapolates into a major U.S. network. The results of the meeting were, if anybody was awake by the time we finished it, it was only because they were being courteous. And they said, "Go away." … If I had to characterize the thing, I mean they were telephone people—and that's what they were interested in.

- Howard Frank (1990) reflecting on attempts to convince a major telephone company of the benefits of ARPANET's packet-switching technology

In the late 1960s, the ARPANET was among the first data networks built at the juncture of telecommunications and computing. For decades, first-hand accounts of the relationship between these two technical spheres echoed Howard Frank, depicting "computer people" and "telephone people" living in "parallel universes" from one another (e.g., Alsop, 1993). Industry analysts and policy scholars discussed the rift

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between "Bellheads" and "Netheads" as a clash in organizational cultures, political commitments, and economic priorities (Steinberg, 1996; Bushaus, 1998; Frieden, 2002). By convention, these histories prominently feature the competition between the practical imaginary of telecommunications specialists and the utopian, or at least iconoclastic, imaginary of computer enthusiasts. From this perspective, the internet of the twenty-first century resulted from the triumph of an upstart computing culture over an entrenched telecom industry during the twentieth.

But a focus on the competition between Bellheads and Netheads obscures the extent to which the dynamic infrastructures of telecommunications and computing shaped one another during the 1970s and 1980s. Indeed, ARPANET's far-flung nodes depended on AT&T's robust long-distance network to convey their packets, and the practical demands of packet-switching presented Bell engineers with a novel application of the network's wideband services. ARPANET was among AT&T's most innovative applications, re-purposing the existing telephone network by treating it as a medium for real-time, on-line computing as well as non-interactive data transfers. In practice, there was no break between the two versions of telecommunications and computing; rather, the roots of the internet took hold in the borders between ARPANET and AT&T. By examining ARPANET's relation to the telephone system, this history reorients ARPANET's early design as a convergence of two socio-technical systems, providing a broader historical context for ARPANET's early design as well as an opportunity to question the nature of boundaries and the convergence of media infrastructures.

To investigate the relationship between ARPANET and the Bell System, we focus on the Interface Message Processor. The Interface Message Processor, or IMP, was a boundary object in both the practical and theoretical senses of the term. Positioned between the telephone network and local computers called "hosts", the IMPs carried out the defining functions of the ARPANET: addressing, routing, and switching packets between hosts, local and remote (Heart et al., 1970). Within the first IMP's industrial metal cabinet, the concerns of the Bellheads and Netheads met in a swirl of acoustic signals, electrical pulses, and digital bits, and the participation of both sets of stakeholders was necessary to bring an IMP online. Preparing to install an IMP required the prior coordination of computing and telecommunications engineers to run the proper lines, meet the room specifications and configure a host computer. All of this work preceded the ceremonial switch-flipping on the IMP that connected an organization to the ARPANET. Once installed, the IMP ran twenty-four hours a day, tirelessly managing the boundaries between the local computing system, the AT&T network, and the growing ARPANET.

Drawing on historical design documents from the Bell Technical Journal and public records describing the evolution of ARPANET, we explore how the IMP functioned as a *boundary device*, a special case of a boundary object designed intentionally to manage the point of contact between two distinct organizational and technical cultures. For future researchers, the history of the IMP offers an ideal conceptual tool for analyzing the work of other boundary devices that develop at the edges of formalized networks and cultures across many histories of computer networking.

Beyond its technical function, the IMP also acts as an historiographic gateway, illuminating the long history of interconnection and *inter-structuralism* of computing and telecommunication. This approach has wider implications for the theory of media infrastructures, specifically regarding the nature of boundaries between seemingly disparate social, political, and technological regimes. The IMP operated in the margins—to borrow a phrase from Susan Leigh Star—of telephony and computing. Caught between these two organization cultures, the IMP offers glimpses of a counterfactual ARPANET as well as better explanation of today’s de facto inter-networking. The reliance on AT&T suggests that ARPANET might have become a digital common carrier in the United States, setting in motion a different future for the transnational internet. Instead, the inter-structuralism of the IMP allowed for a more familiar reality-to-be, an inter-net made possible by other boundary devices known as gateways. As a conceptual interface, the IMPs provide a means to explore these competing possibilities of inter-networking.

From boundary objects to boundary devices

Computer networks are defined by boundaries—between devices, processes, people, and places—and, as Donna Haraway (1985) argued, there is pleasure in the confusion of these boundaries. The early ARPANET project allowed for precisely this sort of pleasurable confusion, aiming to blur the boundary between local and remote, resulting in a universal, boundary-free computing environment. “The goal of the computer network,” wrote Larry Roberts and Barry Wessler in 1970, “is … to make every local resource available to any computer in the net” (1970, p. 543). In pursuit of this goal, the ARPA team devised the IMP to “insulate” the computer from the problems of the network, and the network from the problems of the computer (Heart et al., 1970, p. 551). In this insulator role, the IMP internalized the complexities of boundary work, allowing the telecommunications and computing domains to interconnect without first adopting a common language.

To understand the role of the Interface Message Processor in the intertwined histories of AT&T and the ARPANET, we take up the concept of the “boundary object” from the social study of science and technology (Star & Griesemer, 1989; Bowker & Star, 1999; Lampland & Star, 2008; Star, 1990). Boundary objects—which may take a variety of forms—enable groups who do not share a language or set of commitments to nevertheless come together in cooperation. The boundary object exists in tension between two forms: an “ill structured” form that straddles the various incompatible social worlds, and a “well structured” form that enables each group to get down to work (Star, 1990). With cables running from its cabinet to both the local computer system and telephone network interfaces, the IMP provides an especially clear example of a boundary object. During the course of this research, we have come describe the IMP as a *boundary device,* a special case of the boundary object designed overtly to facilitate “cooperation without consensus” (Star, 1990, p. 605). Boundary devices inhabit the thresholds between networks, enabling communication between otherwise incompatible peers by translating, reformatting, and relaying messages. In short, they connect different infrastructures together.

Boundary devices reveal the processes by which networks formalize as well as help to define what remains outside these formations. By creating ad-hoc collaboration, a successful boundary object invites a regulator or administrator to step in and formalize its work (much like how ad-hoc networking may result in the production of standards).

Standardization reduces the interpretive flexibility of the object which may create the need for new boundary objects to facilitate future collaborative work. The IMP follows this pattern. Between 1969 and 1974, the IMP was the site of considerable negotiation, experimentation, and innovation but with the transition of control to the Defense Communication Agency (DCA) in 1975, the IMP began to look more like a standard (Heart et al., 1981; Fidler & Russell, 2018). Meanwhile, the attention of the heterogeneous groups of researchers previously gathered around the IMP shifted to the challenges of inter-networking and the new boundary objects that emerged there: gateways, protocols, regulation, and commercialization.

The concept of the boundary device also helps us to understand how the ARPANET gave rise to the Internet. The ARPANET was produced through the interconnection of time-sharing computers, IMPs, and the telephone network, but it was not, technically, an "inter-networking" project. Inter-networking emerged in the 1970s with a proliferation of packet-switched networking projects in the United States and elsewhere (Cerf & Kahn, 1974; Abbate, 1999). Just as the ARPANET was enabled by the use of IMPs as boundary devices, early Inter-networking efforts were enabled by the creation of "gateways," special-purpose computers tasked with forwarding packets between otherwise disconnected networks (Boggs et al., 1980, p. 613). Functionally, internet gateways resemble boundary objects, allowing different networks to share data without sharing all of the same standards; the logistical coordinator of a junction in the inter-network. During the 1980s, a proliferation of networks, gateways, and protocols left contemporary users searching for a term to describe the emerging infrastructure. Science fiction authors suggested the Grid, the Metaverse, and the Net (Shirley, 1985; Stephenson, 1992; Sterling, 1988); network cartographer John S. Quarterman (1990) titled his atlas, *The Matrix*. Each term reflects a fundamental awareness of the tension between unity and plurality among the emerging networks. As boundary devices, gateways enabled cooperation between heterogeneous network operators, but they were still caught up between their ill- and well-structured forms. The standardization process had yet to take hold.

Beyond illuminating a hidden device in the history of computing, we use the IMP to better understand the *inter*-structuralism of networks. Inter-structualism refers to the confusion at the margins between infrastructures that destabilizes standards and cultures. Between infrastructures, in this flux, we find the possibilities for new infrastructures. Our present attention to the inter-structuralism of ARPANET and AT&T reveals a lost possibility of a digital common carrier different from today's internet. As evidenced by its very name, the internet is defined by the construction of gateways enabling interconnection among heterogeneous network infrastructures. To understand this process of inter-structuralism and the effort to obscure boundaries, we turn to the ideal case of a boundary device, the Interface Message Processor.

The telephonic platform for ARPANET

ARPANET could not have been imagined or built without a common carrier telephone system. By the late 1960s, the Bell System resembled what we call a "platform" today (Bogost & Montfort, 2009; Gillespie, 2010). Innovations in dialing, switching, numbering, and terminal equipment functioned together like an application programming interface (API), providing a standard set of tools for the development of new telecommunications devices and services. Switching stations of the 1960s like the Crossbar No. 5 were large electromechanical systems, often the size of a city block (Lapsley, 2013).[1] The Bell System also built early stored program computers, like the ESS-1, to digitize electromechanical switching (Paulsen, 2014). Pulse-generating handsets enabled home customers to "speak" the technical language of switching, keying in commands for the Crossbar No. 5 to follow, rather than conversing with a human operator. In forward-looking reports, Bell researchers envisioned the "Touch-Tone" device as a remote control interface to "practically any electric equipment" attached to the network (Benson et al., 1962).

These innovations fundamentally changed the possible usages of a telephone line, notably, for data communication. By the 1950s, AT&T's research unit Bell Labs had begun to publish research articles about adapting the voice telephone system to high-speed data transmission. With the announcement of the DATA-PHONE product in 1962, AT&T made digital communications commercially available on a limited basis (American Telephone and Telegraph Company, 1964, p. 103; Baker, 1962; Horton & Vaughan, 1955). Research at Bell focused on the reliable exchange of "bits," rather than the meanings conveyed by those bits. The typical scenario detailed in research reports of the early 1960s depicted streams of data passing between tape machines attached to batch processing computers, also known as "tape-to-tape" communications (Baldwin & Snow, 1962; Travis & Yaeger, 1965, p. 1584). AT&T tended to portray data communications as a convenient complement to voice. The DATA-PHONE, for example, was advertised as a device for swapping files during business-oriented telephone calls. "Can my machine talk to your machine?" asks an office worker in a 1961 industrial film showcasing the new technology (Wilmot, 1961).

Beyond file-sharing, digital connections offered real-time remote access to increasingly dispersed time-sharing systems. In the mid-1960s, campus computer labs and other research units supported by ARPA's Information Techniques Processing Office, or IPTO, were already merging their time-sharing systems with the telephone network (Corbato, Merwin-Daggett, & Daley, 1992; Lee, Fano, Scherr, Corbato, & Vyssotsky, 1992). Further blurring the boundaries between computing and communications equipment, users accessed the interactive time-sharing systems installed at Dartmouth, MIT, and elsewhere using appropriated teletype terminal equipment (Brammer, 2015; Campbell-Kelly & Garcia-Swartz, 2006; Rankin, 2018). Teleprinters such as the Teletype Corporation Model 33 and the Friden Flexowriter combined keyboard entry and an automatic typewriter with a modem for communication by telephone line (Friden, 1964; Teletype Corporation, 1957). Teletype expanded the boundaries of time-sharing systems too. Often named after their institutional homes—e.g., the Michigan Terminal System—these systems grew across towns and states, collapsing geographies among a distributed population of users. A key justification of the early investment in ARPANET was to make better use of these existing resources, transforming them from a collection of independent projects into a unified information infrastructure (Roberts, 1967). The Bell System provided a common meeting space for computers and their users, a platform for prototyping the inter-networked future.

Initially, data communications by telephone were limited to the products and services sold by AT&T itself, but the monopoly was under growing pressure to loosen its control of the Bell System platform. In 1959, the Carter Electronics company introduced a boundary device linking two-way radio communications and the telephone system. After nearly a decade of legal conflict, the FCC decided that AT&T should permit third-party “interconnection devices” so long as attaching these devices did not adversely affect the telephone network (USE OF THE CARTERFONE DEVICE IN MESSAGE TOLL TELEPHONE SERVICE, 1968). The so-called “Carterfone decision” opened the Bell platform to third-party innovation by professionals and amateurs alike. By 1976, a DATA-PHONE compatible modem could be built with consumer components for less than the cost of a decent home stereo system (e.g., Felsenstein, 1976). These technical and regulatory changes enabled the telephonic platform for early computer networking.

Rugged, plastic, and technically portable: the interface message processor

The Interface Message Processor (IMP) was the product of early ARPANET research aiming to provide data communication between otherwise incompatible computer systems. Interactive, multi-user time-sharing systems such as Project Genie at Berkeley and Project Mac at MIT were thriving with ARPA support but they were isolated from one another (Fano, 1965; Lampson, Lichtenberger, & Pirtle, 1966). While telephones and teleprinters enabled far-flung users to access a single, central time-sharing machine, the ARPANET research program imagined far-flung *machines* in a network autonomously exchanging data with one another. To realize this goal, the IPTO commissioned a report by Thomas Marill and Lawrence Roberts entitled “A Cooperative Network of Time-Sharing Computers.” Written in 1966, their report drew on experimental research linking a TX-2 computer at Lincoln Laboratory in Lexington, Massachusetts, with a Q-32 computer at the System Development Corporation in Santa Monica, California using the existing telephone infrastructure. The TX-2 and the Q-32 communicated directly though 1200-baud modems over a full-duplex “four-wire” line leased from Western Union, a regulated common carrier (Abbate, 1999, pp. 48–49; Cox, 1972). Each end of the connection behaved like an interactive time-sharing console and the host machines treated them like any other human interface, reading and writing characters to the connection one at a time (Roberts & Wessler, 1970, p. 543).

The Marill and Roberts experiment shaped the relationship between telephony and computing in the design of ARPANET. Like the experiment, ARPANET’s design required “long lines” leased from AT&T to carry packets between its potential nodes at campuses across the country. Long lines refer to the exclusive long-distance lines that AT&T built and controlled to establish its national monopoly power (Temin & Peters, 1985). By the early 1960s, Bell operated numerous long-distance routes using coaxial cable and microwave radio (Figure 1). The ARPANET design required close consideration of the capacities of these long lines to carry its signals. In design documents, ARPANET researchers usually made only a passing reference to the telephone system, obscuring the AT&T system (McKelvey, 2018; Callon, 1990). Researchers treated the underlying telephone infrastructure like a black box. Indeed, when the telephone company installed leased lines at an ARPA computer center, they delivered a literal box, called a “data station” or “modem cabinet,” housing the terminal points of the Bell System’s circuits (Interface Message Processor, 1976, 2-1; Bell System Data Communications, 1966; 1969).

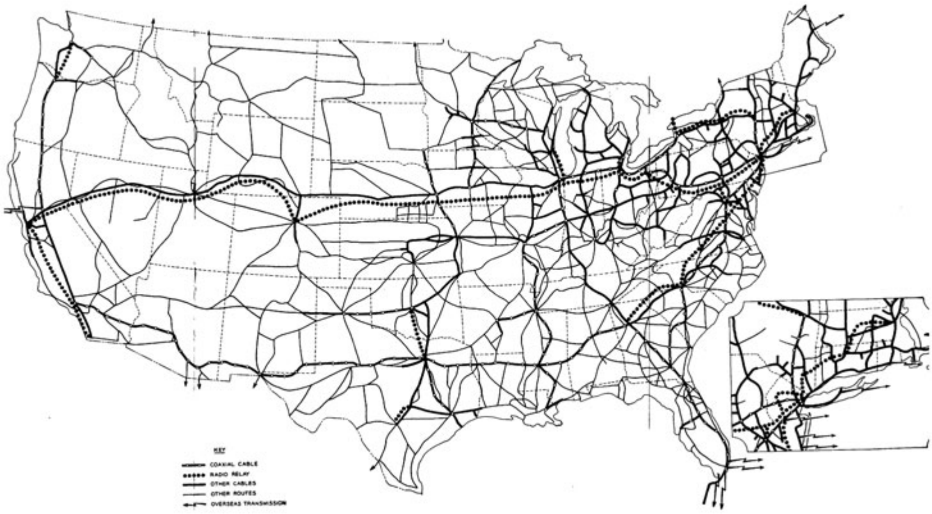

Figure 1. Major long distance toll routes through the Bell System, reproduced from Pilliod (1952).

Where the experiment put computers in close contact with the telephone system, the IPTO proposed the Interface Message Processor as a way to insulate the host computer from the complexities of networking. Rather than directly connect incompatible computers, a "subnetwork" of computers called IMPs provided a standard interface between local hosts and the network. The IMP was the first piece of the ARPANET to be built and a key formalization of the theories of packet switching (McKelvey, 2018). The IMP's design document stated that it would be responsible for "error checking, retransmission, routing and verification" (Roberts, 1967, p. 4), all functions related to managing packet-switched communication over a telephone system. The IPTO submitted these designs, which became a Request for Quotation (RFQ) released to bidders in July 1968 (Norberg & O'Neill, 1996, p. 167). IBM, the Control Data Corporation, and Raytheon bid on the contract to build IMPs, but a firm associated with many of the IPTO staff, Bolt Beranek and Newman (BBN), won the bid (Hafner & Lyon, 1996). They delivered the first IMP to Leonard Kleinrock at the University of California in Los Angeles in 1969 around Labor Day (Kleinrock, 2010, p. 30). The installation and configuration of this IMP provided the preconditions for the fabled "first message" sent by Leonard Kleinrock of "LO" in October 1969 (Walker, 2014)—a very human-centric telling of ARPANET's history as IMPs had been communicating with each other well before then.

BBN developed at least four different version of the IMP, continuously expanding the machine's capacity for interconnection. The first IMPs, based on the Honeywell 516 microcomputer, were conceived in a "one Host-one IMP" arrangement (Fidler & Currie, 2015). The option to connect up to four host computers to the same IMP was added "somewhat belatedly" to the IMP's design. By sharing an IMPs, hosts formed a local network in the ARPANET, and this "intranode" traffic between computers at the same site averaged between twenty and forty percent of all network traffic during the 1970s (Ornstein et al., 1972, p. 244; Kleinrock & Naylor, 1974; Heart et al., 1981, pp. III–77). From the 1970s to the late 1980s, BBN and its affiliates built several other IMPs: a less expensive IMP with the Honeywell 316 minicomputer, a multi-processing

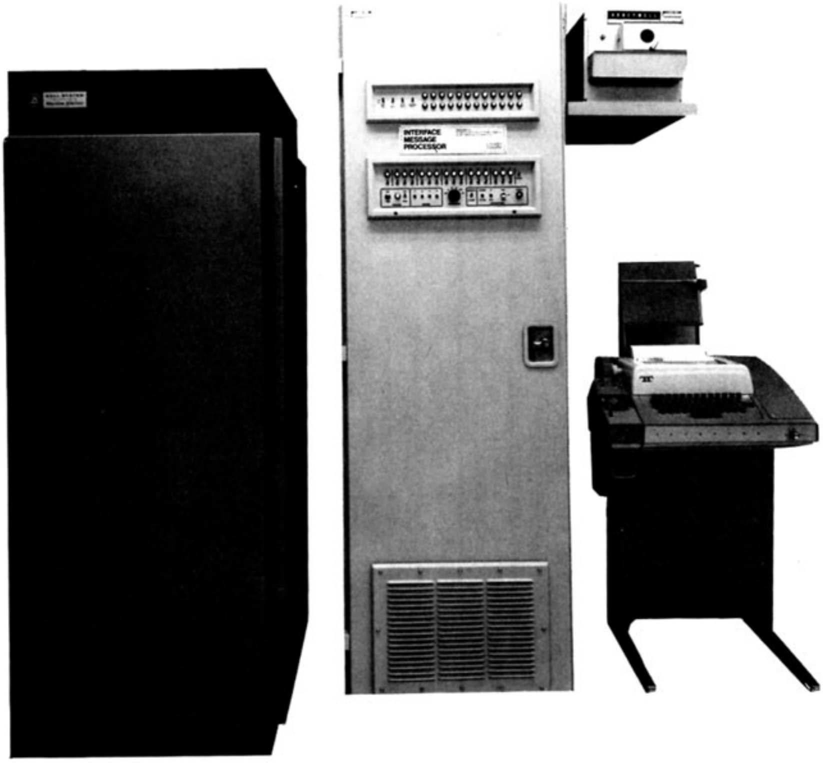

Figure 2. An Interface Message Processor positioned between a Bell System modem cabinet and a Teletype terminal, reproduced from BBN Report 1877.

Pluribus IMP, an enhanced Terminal IMP and a series of commercial IMPs such as the C/30 (Ornstein et al., 1972, 1975; Heart et al., 1973; Levy, 2005; Walden, 2011, 2014). In addition to the standard features, the Terminal IMP, or TIP, also allowed up to sixty-three simultaneous connections from teleprinter or video terminals wired directly to one of sixty-four RS-232C serial ports or linked by telephone to one of sixteen optional modems that again re-purposed the telephone platform to allow distance users to dial-in as seen in Figure 2 (Ornstein et al., 1972).

Twisted pairs: IMPs and long lines

The IMP gave weight and dimension to an otherwise invisible boundary between a local computing and a national network. Before delivering an IMP seen in Figure 3, BBN instructed customers to provision at least thirty square feet for all of its components: a teleprinter, tape reader, external modem cabinet, rolling chair, and lockable storage container for documentation and tools (Bolt, Baranek and Newman, 1976, pp. 2–4, 2–9). JCR Licklider, the first director of the IPTO, recalled his first impression of the IMP as being “built like a battleship” (Licklider, 1970). When it arrived at MIT, the movers dropped the heavy computer. “The shock didn’t hurt the IMP, but it put two nearby ‘nonruggedized’ computers out of action for several hours” (Licklider, 1970).

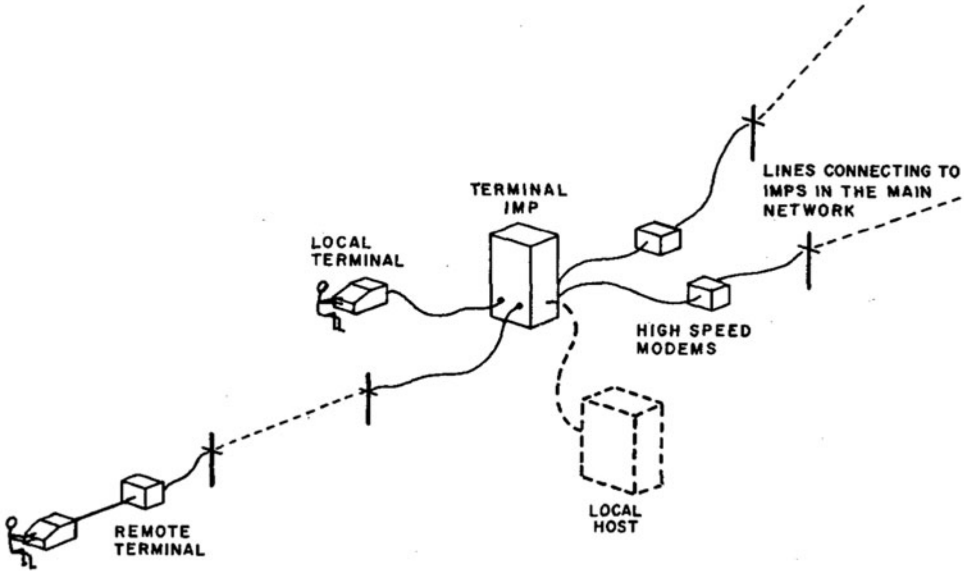

Figure 3. The terminal IMP and its remote users, reproduced from Ornstein et al. (1972).

Licklider's anecdote nicely captures the theoretical function of the IMP as a boundary device. One imagines administrators, movers, research scientists, students, and engineers, each representing the university, AT&T, or BBN, cracking open wooden crates, rolling dollies from place to place, shouting instructions, trying not to trip over any cabling or injure one another in the process. While all of this activity focused on a single computer center, the installation of the IMP represented an opening of a gateway into a new way of experiencing distance, confusing local and remote. As the same drama played out at computer centers across the United States, IMPs appropriated the Bell System to bring local networks into communication with each other; to become ARPANET.

Within the typical six-foot-tall, nine-hundred-pound, military-grade cabinet, a minimally-configured IMP 516 housed interfaces for one computer and two modems (Bolt Beranek and Newman, 1969; Interface Message Processor, 1976). Each modem interface corresponded to another IMP installed somewhere elsewhere in the network. Usually two connections were required at each site to maintain the ARPANET's distributed topology (Baran, 1964). A diagram produced by BBN in 1973, seen in Figure 4, depicts communication between two hosts by way of the packet-switching IMP subnet.

This diagram highlights the moment-to-moment work of the IMP as a boundary device. Host A connected to IMP B which connected to IMP C and then IMP D and finally Host E. IMPs encoded messages (up to 8095 bits in length) into packets up to 1008 bits and vice versa. The store-and-forward architecture involved IMPs routinely acting as intermediaries, buffering and transmitting packets among neighboring nodes, such as the role of IMP C in the transmission from IMP A to IMP D in Figure 4. The diagram notably omits the common carrier links between these IMPs. The complexity of the AT&T telephone system is reduced to a few crude lines connecting the IMPs. In operation, IMPs had to manage their telephone link, translating from the local idiom to the ARPANET as well as keeping packets flowing between nodes.

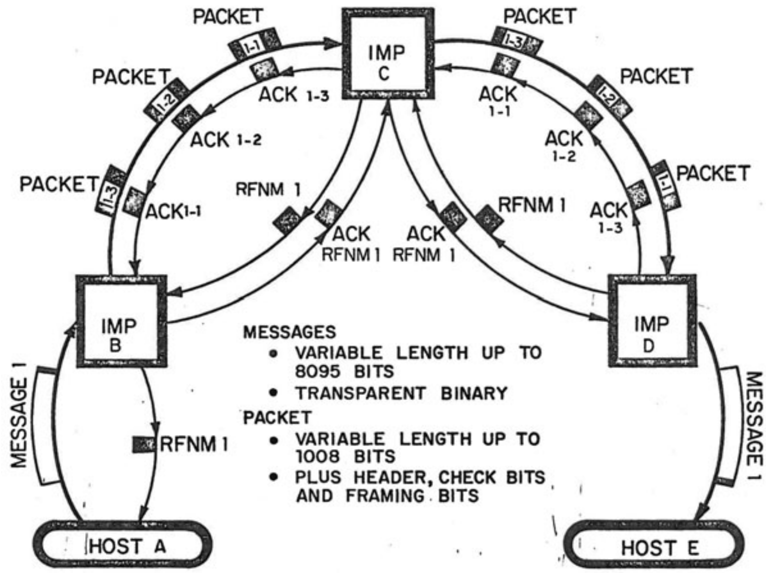

Figure 4. IMP to IMP communication, reproduced from BBN Technical Information Report No. 89 (Bolt Beranek and Newman, 1973b).

IPTO researchers invested in weaving optimal topologies for the ARPANET out of AT&T's long lines. Beginning in 1969, the IPTO retained the services of Howard Frank and his Network Analysis Corporation (NAC) to run topological optimizations of ARPANET to understand and improve its performance as well as forecast its growth (Norberg & O'Neill, 1996, pp. 172–176). NAC submitted six reports to the IPTO from 1970 to 1972, helping ARPANET anticipate how and where it would grow (Bolt Beranek and Newman, 1981). The problem was a version of the classic Travelling Salesman Problem in computer science—how to find the most efficient route between cities without having to visit any city more than once (Cook, 2015). NAC's optimization sought to find the most feasible and cheapest network design. Its computer model worked iteratively with the best-known solution becoming an input for the program to find even cheaper, workable solutions. Feasibility was set by the ARPANET performance guidelines, while cost depended on the price of leasing a long line. One 50-kilobit-per-second line, for example, cost $850 per month plus $4.20 per mile, whereas a 108-kilobit-per-second line cost $2400 per month plus $4.20 per mile (Frank, 1970, p. 15).

The cost and capacity of the lines leased from AT&T shaped the research priorities of ARPANET project. Whereas other data networks proposed new infrastructure with higher throughput, ARPANET aimed to make more efficient use of the existing telephone network. For example, whereas the IPTO choose 50-kilobit-per-second service from AT&T, Donald Davies of the National Physical Laboratory recommended building a new digital common carrier with higher capacity lines such as then-experimental coaxial long lines capable of 224 megabits per second (Davies, et al., 1967).

Delays in the lines put pressure on the IMP's internal performance. ARPANET sought a response time of less than one half-second, a threshold set in reference to "the human short-term memory span of one to two seconds" (Roberts & Wessler, 1970, p. 544). To achieve this responsiveness over duplex telephone lines of 50 kilobits (Waldrop, 2002, p. 276), IMPs had to operate as fast as possible to avoid adding any extra delays to the transmission. There was a propagation delay in sending a message as an electrical signal on the Bell telephone system (about ten microseconds per mile) and a delay from the modem (about 20 microseconds per bit on a 50-kilobit line). Since the telephone system was outside their control, programmers had to find time savings in the IMP's code instead (Heart et al., 1970).

ARPANET's relation to the phone system also influenced the design of the messages and packets sent among Hosts and IMPs. The discussion of these formats dated back to Marill and Roberts' 1966 report on interactive communication, which called for "a uniform agreed-upon manner of exchanging messages between two computers in the network" (Marill & Roberts, 1966, p. 428). One of the report's key topics was the number of lines to use for digital communication. In an effort to improve responsiveness (or what the report called "higher data-rates"), the authors wondered aloud whether it would be more efficient to use two lines: one a high-rate data-only line and the other a low-rate data-plus-command line. Rather than implement this design, however, IMPs were connected with a single line that carried both data and control information, or what is today called "metadata" (Interface Message Processor: Specifications for the Interconnection of a Host and an IMP, 3-1). In telecommunications nomenclature, ARPANET eventually used in-band signaling not unlike the tones already used in the AT&T system. Though perhaps originally a matter of economic efficiency and design simplicity, the combination of message and metadata endures in the internet packet, enabling much of the internet surveillance today (Fidler & Acker, 2014).

In spite of the constraints of using the Bell System, ARPANET succeeded as a proof of concept. Packet switching worked at scale, offering a solution to the problem of resource sharing. The initial IMP 516, the first version developed by BBN, however, did not fare as well. Four years after its launch, a report described prepared for ARPA described IMP hardware as "ten-year old technology" that was "aging fast" (Baran et al., 1974, p. 9). These limitations as well as commercial and foreign interest in packet-switching led to investment in new boundary devices, not just to improve the IMP but to undertake new boundary work altogether.

Gateways: toward the study of boundary devices

As ARPANET demonstrated an approach to packet switching within a network, research turned to the the boundaries between packet-switching networks. Efforts to connect heterogeneous networks resulted in a new category of boundary devices called gateways. The term "gateway" had already been used in telecommunications to describe important exchanges, often between international carriers (Halsey, 1964; Weber, 1964). In porting this concept into computer networking, computer engineering started a research agenda into the design and operation of gateways. Both the Request for Comments and the Internet Experiment Notes series—important distributed design documents between researchers and developers at BBN—included specifications for the design and operation of gateways. In the same paper that introduced

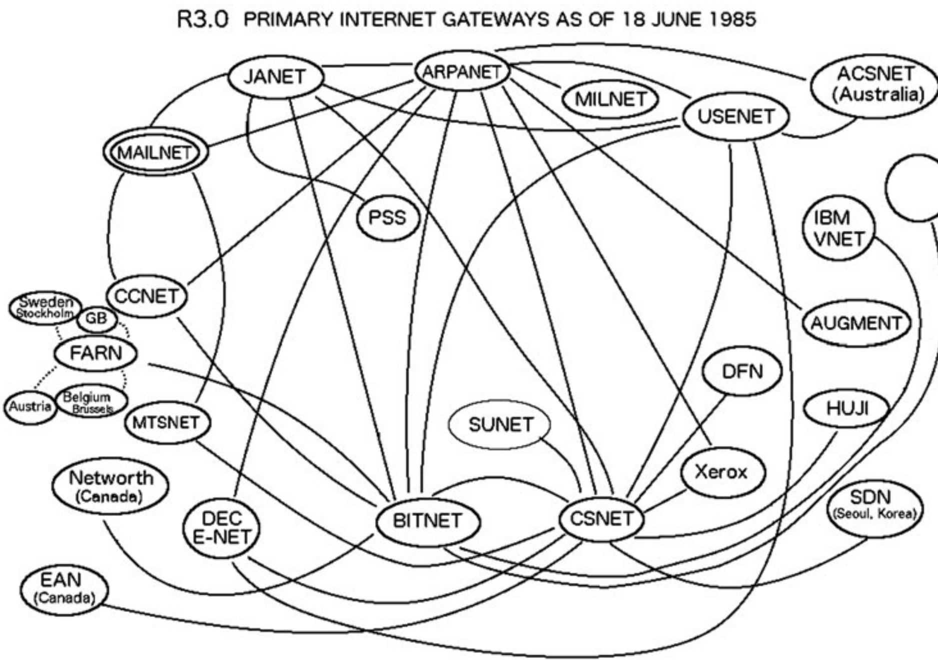

Figure 5. Internet gateways in 1985, based on a drawing by Lyons (1985).

an early version of the Internet Protocol Suite, Vinton Cerf and Robert Kahn popularized the "gateway" as a device that interconnected packet-switching infrastructures, routing packets between them (Cerf & Kahn, 1974). The term is still part of internet nomenclature.

Gateways, like IMPs, work the boundaries between networks. Their creation represents the will of two or more groups of stakeholders to interconnect. Thus, the study of gateways provides a clear opportunity to develop the concept of the boundary device. These overlooked devices remain understudied and we might look to a crude drawing of the state of computer networking in 1985 to understand their proliferation and variation. The diagram in Figure 5, a reproduction of a drawing by Marty Lyons, depicts ARPANET as just one computer communication system connected to many other similar networks. ARPANET clearly remains a hub at the top of the drawing, but BITNET and CSNET are also central points of internet connection between these different networks. More so, the lines between each network speak to the array of gateways at work in computer history that enabled these connections, often over AT&T's long lines.

The gateways in Lyons' drawing suggest the breadth of the gateway as a historiographic object in internet history. In particular, we see a number of different gateways that point to other inter-structuralisms missing in internet history. These gateways may include:

1. Connections between academic research networks and amateur or hobbyist networks that hypothetically links different political, entrepreneurial or leisurely uses of computing together

2. Links between the experimental and secure networks (such as NSFNET and SIPRNET) that reveal different and unequal approaches to computer encryption and privacy
3. Commercial exchanges that required gateways to play a financial function, suggesting alternative economics of bandwidth and data

This list merely provides some suggested places for future historical research that looks inter-structurally to the kinds of networks developing in between different socio-technical systems.

Inter-networking, gateways and common carriers

The study of boundary devices, specifically gateways and their inter-structualism, captures the historical dynamic of convergence that occurred in the twentieth century resulting in the Internet today. In one sense, boundary devices are instrumental to an overall process of convergence. The cycle of interpretive flexibility, standardization, and emergence of new boundary objects captures the dynamic by which the limits of one system becomes the impetus for something different, say from computer to local area network to internet. More specifically, inter-structuralism attends to the different possibilities of networking when different organizations, technologies and imaginaries mix. The history of the ARPANET illustrates both this general and specific contribution of the IMP.

The subnetwork of ARPANET IMPs, a borderland between time-sharing, ARPANET and AT&T, contained a multiplicity of possible visions of digital communication. One alternative future was the transfer of ARPANET to AT&T to be run as a common carrier. In the 1970s, the merit of running a regulated utility over a more experimental network was the subject of on-going debate among researchers working on packet networks like ARPANET (Braman, 2011, 2013). Today, even mentioning the internet as a common carrier is a controversial statement, at least in the United States, but AT&T's common carrier lines were essential to the success of the ARPANET experiment. Given this dependence on the Bell System, it was not inconceivable that control of the publicly-funded ARPANET would be transferred to the national telecommunications monopoly, or that AT&T would have launched a packet network of its own. Indeed, during the 1980s, TRANSPAC, a public data network in France, provided the infrastructure for a competitive marketplace of private Minitel service providers (Mailland & Driscoll, 2017).

While it is unclear how seriously AT&T considered taking over ARPANET, there are multiple and conflicting reasons for why the merger never happened. Disinterest, as the quote from Howard Frank in the introduction exemplifies, seems to have been one factor as AT&T did not understand nor care about packet switching. Later on, many telecommunications common carriers competed with ARPANET in a failed bid by the International Telecommunications Union to set packet-switching standards (Russell, 2014). In any case, the working IMP offered a glimpse of computing as a national utility, not unlike the taken-for-granted nature of the telephonic platform of the Bell System.

Gateways help explain the development of the internet that did happen. Instead of integrating packet networking with the telephone infrastructure, the internet of the 1980s and after maintained a political as well as a technical separation between the two. Paul Baran, one of the first researchers to study packet-switching and an advisor to the IPTO, submitted a management study of ARPA to BBN considering the future of the experimental network. Finding that "government regulation is a substitute for competition" (p. 2), the study recommended against public policy that would create a monopoly data network. "To this end," wrote the authors, "we recommend new means be created to permit the suppliers of packet switching to work together to create and maintain a healthy competitive environment while supplying competitive services" (Baran et al., 1974, p. iii). The vision of a competitive packet-switching marketplace made up of distinct networks connected through gateways depended on the availability of common carrier infrastructure such as AT&T's long lines.

The report foreshadows today's version of inter-networking. Gateways became the "rough consensus and running code" behind the beginnings of what today we call the internet. This tongue-in-cheek description of internet governance, attributed to David Clark in 1992, captures decades of inter-networking made possible by an ecology of gateways (Coleman, 2013; Russell, 2006). The internet enabled by the ad-hoc system of gateways stands in contrast to the alternative vision of ARPANET as the progenitor of a digital common carrier. Whereas AT&T would have converted ARPANET into its packet-switched backbone, boundary devices like the IMP, marketed by companies like BBN, enabled the creation of parallel packet-switched networks. As networks like TYMNET and CSNET began to create their own gateways, they gave rise to an international system of interconnected packet-switched systems. By the 1980s, these gateways had not created islands—to recall the metaphor behind the French packet-switching network CYCLADES (Russell & Schafer, 2014)—but an uneven topology of connections and peering. Lacking in any single top-down authority, the arrangement of gateways reflected a variety of institutional priorities, strategic needs, and personal relationships, resulting in the overlapping and redundant routes that animate the popular internet imaginary.

The competitive market of interconnected, yet distinct networks was technically short-lived, but the vision endured. Its market-oriented logic contributed to the eventual break-up of the Bell monopoly and later divestiture in the post-ARPANET research networks known as NSFNET (Abbate, 2010). The regulatory principles of minimal intervention and facilities-based competition underlying interconnection through gateways became a prototype for regulating the internet globally (with notable exceptions like the United Kingdom and Japan). The dream of open gateways, diverse networks and interconnection among competing networks gave way to concentration of private peering relationships, proprietary networks and market concentration. These problems did not begin with the IMP, of course, but a robust history of boundary devices like the IMP is necessary to break out of the conventional narrative pitting Bellheads against Netheads, revealing new visions, alternative futures, and paths-not-taken.

Conclusion

The Interface Message Processor, or IMP, provides an ideal case for developing the concept of the boundary device. As a machine running in the threshold between telephony and computing, designed to translate two seemingly incompatible technologies and cultures, a close look at the IMP reveals multiple layers of inter-connection necessary for the production of the ARPANET. While documentation of the IMP tends to focus on its role in the realization of packet-switching, the IMP was equally responsible for negotiating the hidden inter-structuralism of the established Bell System and the emerging ARPANET. The IMP's novel modem interface transformed the common carrier circuits leased from AT&T into a medium for the real-time, full-duplex exchange of data, demonstrating the existing platform's potential as an infrastructure for computer networking.

The history of the Interface Message Processor, or IMP, also provides a new context for ARPANET. In the place of the conventional Nethead v. Bellhead dichotomy, an IMP-centric history of ARPANET reveals the range and dynamism of networking research and experimentation during the 1960s. Time-sharing operating systems, high-speed telegraphy, automated switching, and secure voice communications all provide important influences and points of reference for the emerging vision of a packet-switched inter-network of heterogeneous computer systems. The IMP was one device at the margins among many, but it is perhaps the ideal case for analyzing gateways in the production and maintenance of communication networks. With its numerous modem and teletype connections, the IMP suggests an alternative conceptualization of ARPANET as a particularly clever application of the existing Bell Systems platform. The early internet was not a disruption but rather a realization of a long-running effort to interconnect dissimilar communications systems, from postal systems and telegraph networks, to long-distance telephones and two-way radios.

Attention to the IMP finally demonstrates why histories of networks must critically consider the place of boundaries. Just as this analysis of the IMP reveals the inter-structuralism between ARPANET and AT&T, we see the study of boundary devices as a means to find other missing "net histories" (Driscoll & Paloque-Berges, 2017). Future histories of networks might consider the boundary devices that made inter-networking possible: gateways as well as protocols, interfaces, bridges, switches, relays, beacons, and modems. What sorts of network imaginaries were inspired by the design, implementation, use, and maintenance of these quotidian machines? We cannot take for granted the boundaries suggested by a network's planners, name, or official map. Instead, we must look at how boundaries are confused in practice through the inter-structuralism of infrastructure. More so, boundaries provoke questions about the multiple identities always found in infrastructures. In uniting time-sharing computers and AT&T long lines, the IMP created new possibilities for communication, eventually creating "an internet" in the shadow of a national common carrier information system. What other possible internets could have been?

Note

1. As with many 20th century automation efforts, switching devices replaced the technical labor traditionally performed by women (Lipartito, 1994; Rakow, 1992; Russell, 2014).

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