Electronic Communication and Scientific Research
Precursors of the Nineteenth Century

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At the National Computer Conference[1] of 1972, the scientific community witnessed some of the first public discussion of packet-switched communications protocols, the technology that would eventually form the basis for ARPA-net and the Internet. Midst the technical discussions and the plans for a large national research network, the developers of these protocols discussed the benefits of computer communications to the practice of scientific research. They argued that the proposed computer networks would provide researchers with instantaneous, or near instantaneous communication. Such communication, they suggested, would promote three fundamental changes in the practice of science and in the structure of scientific laboratories.

First, they suggested that the computer networks would allow researchers to use scientific instruments at a distance. Most commonly, they mentioned the ILLIAC IV, a large parallel processor in Champaign-Urbana, Illinois, and the symbolic mathematical programs at the Massachusetts of Technology. In 1972, neither tool could be easily used at a distance. The ILLIAC IV had a unique instruction set and hence could not easily execute programs that were prepared for other machines. Likewise the programs at MIT were unique to the Institute's machines and had not been ported to other environments.

Second, the participants in the National Computer Conference argued that computer networks would allow researchers to coordinate large studies, notably studies of meteorology, earth science and public health. All of such studies were large, data gathering exercises that could benefit from collecting information in a short period of time.

Finally, the network developers described how computer networks would allow for more collaboration in science. The networks could keep scientists in communication with each other. It could circulate early drafts of papers and would encourage scientists, when they needed a certain expertise in their work, to contact the best specialists in the world.

In fact, none of these three benefits were unique to packet switched computer networks nor novel to the world of 1972. All had been suggested by two prior forms of instantaneous communication: the radio and the electrical telegraph. Of these two, the telegraph had made the more visible contribution to scientific research. From its inception, it was a widely used tool of astronomers and geographers. In its own way, the telegraph brought the same three benefits to scientific research: the use of equipment at a distance, the coordination of large scientific studies and the collaboration of scientists. In each of these settings, nineteenth century scientists quickly learned that instantaneous communication was not the unqualified boon they had imagined. They discovered that instantaneous communication could be expensive and hard to manage.

Almost as fast as they adopted the telegraph, they directed their efforts towards mediating telegraphic communication, towards developing a combination of social structures and technology that loosened the connections between the senders and receivers of data.

The Distant use of Telescopes

In the United States, the telegraphic era began on May 24, 1844, when Samuel Morse demonstrated his electric telegraph in Washington, DC.[2] Morse had been developing this technology for almost a decade and had been assisted by several prominent American scientists, including Joseph Henry, who would shortly be appointed the first secretary of the Smithsonian Institution. For his demonstration, Morse had constructed a line that connected Washington with Baltimore, Maryland, an industrial center that lay not quite fifty miles to the north east. His first public message across the line was the famous quote from the book of Jeremiah, "What hath God wrought?" a verse that would suggest that the new telegraph was something more than a mere human invention.

At the demonstration were at least three individuals who understood that the telegraph could be an important tool for science. In addition to Joseph Henry, the demonstration was attended by representatives of Washington's nascent scientific institutions: the Naval Observatory and the Coast and Geodetic Survey. After Morse completed his first message, they urged him to send a second, "What is your time?" [3] Time was a measure of longitude. Baltimore stood roughly four tenths of a degree to the east of Washington. Both cities set their clocks to the sun as it passed across the local meridian at noon. A quick comparison of the two times should give an accurate determination of the longitudinal difference between the two.

Though the 1840s and 1850s, astronomers and surveyors shared the sense that the telegraph would allow them to use observatories at a distance in order to compute differences in astronomical measurements. For surveyors, those differences would be used for longitudinal calculations. For astronomers, these values would be used for parallax determination, for the computation of distances within the solar system. During the 1850s, a few observatories undertook some well publicized experiments that used two telescopes to measure a common set of objects. The Naval Observatory in Washington used a telescope at the Philadelphia High School[4]. The Harvard Observatory installed a telegraph line directly into its building and placed a telegraph key on the observer's chair. "The arrangement includes all the combinations needed for longitude operations," wrote the observatory director, "for communicating signals to Boston by the local battery as well as for the ordinary work of the Observatory."[5] During the first months of the Civil War, the Dudley observatory in Albany, NY, conducted a well publicized series of experiments with a telescope in New York City. Over six weeks of observing, the team completed double measurements on 385 stars.[6]

As impressive as such experiments were, they appear to be the exception rather than the rule. Though observers did undertake double telescope observations, they seem to have done so, at times, to demonstrate their prowess rather than perform serious scientific work. Double telescope observations were difficult and inefficient. Observers had to spend valuable time confirming that they had identified a common star and that they were ready to record positions as the star crossed over their meridian. If one observer made a mistake, the work of the other would be wasted. The Harvard telegraph line, though it was eventually used for the dissemination of a local time signal, may have started as evidence that the observatory was relatively wealthy. The Dudley experiments may have been an attempt to demonstrate the technical skill of its director, Benjamin Gould, who was involved with a substantial disagreement with the observatory trustees. "The programme was thoroughly carried out in all points," wrote Gould of his telegraphic work, "notwithstanding various obstacles which embarrassed our operations to an extraordinary degree." [7]

Rather than use the telegraph for simultaneous observation, astronomers soon preferred to use a clock to mediate their work. Rather than work together, two astronomers would set a clock to the passage of the star. Once they had set the clock, they would compare the differences over a telegraph. This method was codified in 1848 by Sears Cook Walker, who was then working with the Coast and Geodetic Survey.[8] It was used regularly throughout the century, including by the 1874 and 1882 exhibitions to view the Transit of Venus.[9]

Coordinated Data Collection for the Study of the Weather

The one branch of nineteenth century science that had an immediate need for large scale collection of data was meteorology. Scientists had grasped that weather was at least a regional phenomena, if not a global one, and that data needed to be gathered quickly, in a disciplined fashion and over a short period of time. For this work, the telegraph again proved to be an invaluable tool but, like the experience with astronomical measurements, the telegraph needed to be mediated to be an effective collector of weather data. In this case, the mediator was not a clock, but boxes, codes and a collection of clerks.

In his role as secretary of the Smithsonian, Joseph Henry began a project of collecting weather data in 1848. He recruited 412 observers, several of whom were also astronomical observers, prepared a standard form for the recording of data and arranged for these forms to carried by the U. S. Post Office, with the bill paid by the Navy. He instructed the observers to record the temperature, precipitation, humidity and wind direction at specific hour of the day and mail the form to Washington. In Washington, at the Smithsonian, the forms were sorted by clerks and then shipped to Lafayette College in Pennsylvania, where an office of women calculated summary statistics.[10]

Henry's system, though it produced several important early studies of American weather, suffered from two major problems that could be addressed by the telegraph. Both problems were caused by the fact that the cards required from one day to two weeks to travel to Washington. First, the delay caused the data to become intermingled and require sorting. The mails would combine forms that were only one day old with those that had been completed 14 days before. The effort required to separate the cards from different days was substantial. Second, the delay prevented the data from being used for prediction. Henry probably had little concern about this second problem, as there was much to learn about the weather before predictions could be made. However, the delay in transporting the forms encouraged him to worry about the quality of the data. He wrote that the work of data collection, “requiring more perseverance and punctuality than most persons are willing to bestow, we have a very large number of applications of this kind have proved barren of any results.” The delay masked the lack of discipline in his volunteers. Though they were instructed to collect the data at a specific time of day, they could collect the data at their leisure or even forge the data entirely. Henry would had little way of checking the numbers.[11]

In 1852, Joseph Henry began collecting some of his weather data by means of the telegraph. “We propose to furnish the most important offices along the lines with sets of instruments and to give the operators special instructions for the observation of particular phenomena,” he explained. “It is hoped by this means to obtain results not otherwise accessible.”[12] The telegraph lines of the era were limited and connected only the major cities of the Eastern United States. Telegraph messages were also expensive, so Henry arranged to receive his data at night, when the lines were less used. As a whole, this process seems to have been a minor improvement over its predecessor, which relied entirely on the mails. However, it was suspended during the Civil War, when the southern observers were isolated from Washington and the telegraph lines were required for military purposes.

The war greatly expanded the telegraph, laying the foundation for a collection of data from the entire eastern third of the United States. This effort was undertaken by the Signal Corps of the United States Army under the direction of Cleveland Abbe. The process was managed from Arlington Hall, across the Potomac from Washington, DC. Abbe assembled a teach of observers, instructed them to collect their data at three times during the day, 8:00 am, 11:00 am and 4:00 pm, and immediately to telegraph each observation to Arlington Hall.[13]

The data flowed through the telegraph network like water through the tributaries of a river. It began at the observation stations, moved to intermediate telegraph offices, collected in the big buildings in Boston, New York and Philadelphia before reaching Arlington Hall. The reports were written in a special code that captured all the data with a minimum number of characters. When all the data had reached its destination, a staff of six clerks would prepare summaries. One clerk would read each slip aloud while the remainder would record the data he needed for his part of the work. This method produced timely summaries of the weather while disciplining the observers to a strict schedule and eliminating the sorting of data forms. The “work is done as fast as the [clerk] can dictate,” wrote Abbe, “so that within an hour all the telegraphic reports are received and within the same hour all the translating and map making is done.”[14]

Abbe could not have easily removed the mediation from his system. To prevent the data from gathering at intermediate points, he would have had to create a telegraphic network with direct connections to Arlington Hall. Such a plan would have required too much funds to build and too many people to operate it, even though it would have produced a nearly instantaneous picture of the weather. As it did with the double astronomical observations, the process of mediating the telegraph substantially reduced the expense of gathering weather data.[15]

Collaboration in Astronomical Research

Scientists were slower to embrace the telegraph as a medium for collaboration. For the most part, their reluctance was supported by the twin problem of high expense and low bandwidth. The telegraph, even at its night rate, was an expensive form of communication. This expense enforced the idea that messages should be short and compact, an idea that was expressed in the adjective “telegraphic.” The economics of the nineteenth century telegraph would not permit the kinds of activities that have come to mark collaborative researcher over the Internet: the creating of research plans, the sharing of data, the circulation of papers.

The area of research that encouraged collaborative work over the telegraph was the study of comets. Comets were transient phenomena and were easily overlooked, especially if an observer was focusing on a different part of the sky. Under the best of circumstances, observers would have two or maybe three months to track the path of a comet. In worse cases, a comet might be visible for only a couple of days.

By the late1870s. astronomy had moved beyond the traditional study of orbital mechanics, though this subject remained an important part of the discipline. Astronomy also included photographic methods, for studying the brightness of objects, and spectroscopes, which could be used to analyze the light emitting from an object. These last tools were expensive and were not owned by all observatories. A full study of a comet would include measurements from both of these instruments plus as many positional measurements as possible. Multiple measurements of a comet’s progress would ensure the most accurate calculation of the orbit and remove errors induced by astronomical equipment, the situation of observatories or by the astronomers themselves.

Both the American Astronomical Society in the United States and the Royal Astronomical Society in the United Kingdom looked for ways to disseminate comet observations in a rapid manner. The most naïve method would have collected telegraph addresses, given the combined list to the individual observatories and encouraged each astronomer to announce the discovery of a new comet. This method was neither simple nor efficient. Individual observatories could easily lose or misinterpret their list of addresses. The smaller observatories might not have the funds to notify everyone on the list. Simultaneous discoveries could flood the observatories with identical announcements.

The solution to the problem came from the Harvard Observatory. The observatory director, Edward Pickering, established a telegraph notification service that might be described as a nineteenth century Listserv. “This Observatory has taken an important part in the early distribution of circulars relating to the comets recently discovered, by defraying the cost of telegrams, and by furnishing the necessary observations and computations,” explained Pickering. He collected telegraph addresses from observatories and developed a code for describing the position of the comet and observations that had been taken of it. When an observatory notified him of a comet, he would then telegraph the news to the remaining observatories. “The interval between the last of the observations needed to determine the orbit and the time of telegraphing the elements to Europe has been less than two days,” he claimed.[16]

The service greatly expanded the amount of data collected on comets but it also sowed a certain amount of confusion. In 1883, Pickering reported that the Harvard telegrams were often “the first intimation abroad of [a] discovery." In at least one case, European observers falsely concluded that Harvard was claiming to have discovered the comet. Pickering was embarrassed by the confusion and moved quickly to correct the error. "To guard against similar errors in the future," he wrote, "the dispatches are now made fuller, giving the facts of the discovery as well as the positions."[17]

The Internet as Bridge to the Nineteenth Century

Through the 1970s and 1980s, high speed computer networks grew to connect larger and larger numbers of researchers. Arpanet and NSFnet were at the center of this effort but smaller, less sophisticated networks also contributed to scientific research. Among them were Bitnet, a store and forward network largely built on IBM technology; Csnet, a network connecting computer science departments, uunet, a network of machines running the Unix operating system and Fidonet, a volunteer network that utilized personal computers. In 1991, the United States Congress passed the High Speed Computing Act, which provided for a "high-capacity and high-speed National Research and Education Network" and opened the way to commercialize and develop this technology.[18]

In response to the bill, the National Research Council commissioned a study of the current computing and communications technology. The council report called for a "National Collaboratory" with the same kinds of features that had been identified in the 1960s and that had appeared in the telegraph era.[19] The council argued that this new facility, as "a center without walls, in which the nation's researchers can perform their research without regard to physical location" and it identified the benefits of this facility for scientists as "interacting with colleagues, assessing data and computational resources."[20]

The report went on to identify the need for remote use of resources, the importance of sharing and combing large sets of data and the importance of collaborating with colleagues. After nearly 150 years of experience with electrical communication and two decades of history with computer networks, the report clearly grasped that this laboratory was more than the product of instantaneous communication. Many aspects of the collaboratory would need the assistance. The report stated that the facility would allow remote access to instruments but that instruments would need to be computer controlled and mediated to overcome the problems of time and distance. It described a space problem that would require computer control so that it could "make real-time decisions about how to use its resources." It talked about ways of collecting and combining data, and identified collaboration as perhaps the biggest challenge of the three tasks. The "single most critical resource for innovation is access to stimulating colleagues, particularly those in different disciplines," the report proclaimed, but added "we have a great deal to learn about how to support collaboration among researchers."[21] In a century and a half, the technology of electrical communication had changed radically but the goals remained very much the same.

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[2] Oslin, George P., The Story of Telecommunications, Macon, Georgia, Mercer University Press, 1992, p 33.
[3] Bartkey, Ian, *Selling True Time* ,Palo Alto, CA, Stanford University Press, 2000, p 33.
[4] Alexander Dallas Bache to Mathew Fontaine Maury, July 6, 1847, Naval Observatory Files, Library of Congress.
[5] *Report of the Harvard Observatory for 1859*, Cambridge, MA, Harvard University, 1859, p 15-16.
[6] *Report of the Coast Survey for 1861*, Washington, DC, Government Printing Office, p 221-232.
[7] *Ibid*..
[8] *Report of the Coast Survey for 1848*, Washington, DC, Government Printing Office, p 60.
[9] *Annual Report of the Secretary of the Navy for 1874*, Washington, DC, Department of the Navy, 1874, p 6; *Annual Report of the Secretary of the Navy for 1882*, Washington, DC, Department of the Navy, 1882, p 8.
[10] *Report of the Smithsonian Institution for 1851*,Washington, DC, Government Printing Office, 1851, p 6.
[11] *Ibid.* p 7.
[12] *Report of the Smithsonian Institution for 1852*,Washington, DC, Government Printing Office, 1852, p 168.
[13]"Examination of Cleveland Abbe," in *Testimony before the Joint Committee to consider the present organizations of the signal service, Geological Survey, Coast and Geodetic Survey and the Hydrographic Office of the Navy Department*, New York, Arno Press, 1980, p 258.
[14]"Examination of Cleveland Abbe," in *Testimony before the Joint Committee to consider the present organizations of the signal service, Geological Survey, Coast and Geodetic Survey and the Hydrographic Office of the Navy Department*, New York, Arno Press, 1980, p 258.
[15]Nebeker, Rick, *Calculating the weather : meteorology in the 20th century*, San Diego : Academic Press, 1995.
[16] *Report of the Harvard Observatory for 1881*, Cambridge, MA, Harvard University, 1882, p 6-7.
[17] *Report of the Harvard Observatory for 1882*, Cambridge, MA, Harvard University, 1883, p 6.
[18] Senate Bill S.272, 102nd Congress, First Session.
[19] National Research Council, "National Collaboratories: Applying Information Technology for Scientific Research," Washington, DC, National Academy Press, 1993
[20] Wulf, William, "The Collaboratory Opportunity," *Science* New Series, Vol 261, Issue 5123, August 13, 1993, p 854-855.
[21] Wulf, *op. cit.*