1991 Jayne Lecture

The Information Evolution in Perspective: A View From the Year 2091*

RALPH E. GOMORY

President
Alfred P. Sloan Foundation

It is a great pleasure to be here tonight, 24 January 2091, and to participate in this remarkable attempt, sponsored by the American Philosophical Society, to recreate some of the circumstances of the Jayne Lecture given a hundred years ago. That lecture was given for the trustees of the University of Pennsylvania in recognition of that university's contribution to the development of the computer. In that connection, I especially welcome the presence here of Eliot Stellar, and Herman Goldstine, the great-grandchildren of the Eliot Stellar, then president of the Society, and Herman Goldstine, then executive officer of the Society, who arranged and participated in the 1991 event.

I must admit that we cannot hope to create realistically the experience of a hundred years ago, or the experience that our great-grandparents felt in attending that lecture, because the world around us has changed so very much. But I am delighted that the Society is willing to make the attempt.

One significant difference between this lecture and that, is that this lecture is almost certainly the first one any of you has ever attended. A hundred years ago, on the other hand, lectures like this were commonplace, often rather boring, events. But the rapid evolution of screens and vision boxes changed all that. Today we stay home in comfort and view three-dimensional images of every event current or past, recorded or fabricated, and the lecture form has vanished. The last lecture that I am aware of was given almost fifty years ago. So I presume this is an interesting first for you.

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Nevertheless, I think you will find that this lecture form, though antiquated, has some mitigating features. There is something in the presence of real flesh and blood people making up an audience that the best of today's vision boxes, even equipped with their sound and odor cards, can barely capture. And I hope that this tends to compensate to some extent for the relative discomfort of the seating, which, I'm sure, doesn't compare with what you are used to at home, and, even more importantly, for your inability to turn the set off.

I am here to talk about how a profound change in the world came about. The people of the middle and late twentieth century referred to an Information Revolution. Today we call it the Information Evolution, reflecting a more modern viewpoint. The people of one hundred years ago almost always underestimated the evolutionary nature of the changes around them. This went with their overemphasis on political and military events. The use of words like "revolution" and "breakthrough," though well suited for their preoccupations, did not describe very well those steady advances that in the end completely transformed their world by changing it a little every day.

Today we refer to the Information Evolution as a continuous and profound series of evolutionary changes, which we can date roughly from the year 1950 to about the middle of this century, 1950 to 2050, during which the world was completely transformed. This was, of course, the second major technology-driven evolution, the first, the so-called Industrial Evolution, the transformation of manufacturing and transportation, was driven first by the steam engine, and then by chemical energy in all its motor forms. Building on this the next evolution, the Information Evolution, was driven mainly by progress in computers and communications and dealt with information in all its forms.

Now what lay behind these remarkable evolutions? In the case of the Industrial Evolution it was the steady technical progress of the steam engine. Over a span of some 120 to 150 years the steam engine turned from a fledgling object considerably less efficient than a horse in turning chemical energy into mechanical power, to something more than ten times more efficient, and also tremendously more powerful and more usable.* That ability to produce more and more mechanical work every year gradually but completely changed the world. Little by little, it destroyed that long-existing world in which ninety percent of the people lived in rural isolation and devoted themselves to growing food. That great agriculture-centered traditional world had disappeared in the evolved countries for some time before the coming of the second evolution, the Information Evolution.

* It is interesting to note that the true evolutionary development of the steam engine, which lasted from about 1690 to 1820, involved the ability to bore cylinders, the invention of the separate condenser, two stroke engines, the ability to deal with higher pressures, etc., etc. All this was replaced in the public mind of that period by the story of the child James Watt watching his mother's tea kettle and inventing the steam engine. This despite the fact that the steam engine had been in commercial use for a few decades before Watt was born.

Just as the improvement in the ability to do work through the steam engine was the driving technical force behind the Industrial Evolution, the astonishing, at least astonishing to the people of that time, rapidity of improvement in computation was the driving force for the second evolution. Over a period from 1950 to 2050, the ability to compute increased by a factor of a million. This is, of course, far more of an improvement than the steam engine had provided, and I certainly think from today's perspective we would say, that was because they were dealing with information rather than real physical work; while steam engines and their descendants did real physical work.

Engines do real physical work, but information only deals with marks, and it is a characteristic of marks, that, in fact, a small mark is just as good as a big mark. A "1" one foot high isn't actually any better than a "1" that is one inch high, or a "1" that is one micro inch high, or a "1" that is even smaller than that. And it was, in fact, the conscious or unconscious appreciation of this point embodied in the steady miniaturization of computer circuits, that enabled this millionfold improvement to take place. It was simply based on making the circuits smaller and smaller, fitting more and more of them into one square unit of the technology of the time for roughly the same price. Progress resulted from making "1"'s and "0"'s very, very small. About a hundred years ago was the period when for the first time people started dealing in a very primitive way with recording information at a molecular level, which we all know was ultimately the level that was reached, in a widespread practical way, around 2025.

Computers, as we all know, did then and do now, only rather simple things. They simply add and subtract. They store things in memory, they bring them up, they compare them with other things, they put them back in memory. It was surprising to the people of the mid-twentieth century that this very simple activity could have so many important consequences, most of which were in fact not foreseen at all during the early phases of the Information Evolution. Today we take it for granted that complex activities, even thought itself, can be built up from a great number of these very simple actions. So we understand that everything depends on the rapidity and cheapness with which those actions are done. And it was the steady improvement in that rapidity and cheapness that was the basis of the Information Evolution.

However, it is one thing to say that complex things can be done by a sequence of simple steps, and something else to actually find that sequence of simple steps. That was and is the task of software, a task that became more difficult each year of the Information Evolution as more and more complex tasks became economically attractive for a computer. The role of software was still a source of considerable confusion a hundred years ago. People of that time, using as a measure lines of code per programmer, used to ask why software didn't make progress at the same rate as hardware. This confusion was intensified by a verbal linkage—software, hardware—which is, in fact, nothing more than an unfortunate accident.

Actually nothing could be more different than hardware and software. Hardware was built, and even today is still built, to do repetitious simple tasks. Because it does them so well, very complicated things, like running an entire factory, become economically possible for a computer to do, and it is the task of software to reduce the actions of running an entire factory into a sequence of adds and subtracts. So software and hardware are totally different technologies and their histories over the last 150 years is, of course, totally different.

The evolution of software was less a purely technical process than it was a gradual exploration of the world. Much of the enormous progress that was made was made by more or less empirically finding those fragments of software that were used over and over again. This could be in terms of actions within the computer itself, as in the early development of storage systems that were a common element in many applications, or in the development of code that mimicked faithfully some aspect of the external world, as in the case of code fragments that represented many of the aspects of a vehicle or a building. The purely technical side of this was to make these fragments reusable by many people in many programs, and to make the vast mass of fragments that were developed available and accessible, and their functions comprehensible to potential users. However, this task, while difficult, was far from impossible, so that the ability to create programs, which became of course a vast industry, easily kept up with the progress in hardware although that could not be seen by measuring lines of code written per person.

I have used as an example the problem of software running a factory. Now, of course, at that time, the second half of the twentieth century, there was a very curious, curious by modern standards, set of circumstances. We would say today that at that time no one and no computer program knew how to do anything complicated. For example, it was a true statement in the year 1990 that no one knew how to build an automobile and no one knew how to build a disk file, or anything like that. The knowledge required to do that was scattered through the heads of hundreds, or occasionally thousands, of people, who collaborated in a sort of loose human-to-human fashion, to make an automobile. There was no one person who understood in detail how to make an automobile, there was not even one person who understood in detail all the workings of every part of a motor, there was no one person who knew how to machine all the parts, rather many people each of whom knew how to machine some. A person knew something, and would call for more information if things got beyond that. Often a significant part of his knowledge consisted in knowing whom to call; and there we are very close to software notions. Today, with the evolution of software, all of these things that I mentioned are a part of one large program, and the interaction is subprogram to subprogram, not human to human. So while it still is true that no one person knows how to build an automobile, it is now true that there is a single program that knows how to manufacture automobiles. And, of course, this development has completely transformed the nature of work.

A significant byproduct of the evolution of software during this period was the development, induced by the necessity of creating software for very complex situations, of a more precise feeling for how the world works. If people have constructed a program that does everything in an automobile factory, because they have modeled or reproduced each part of it in infinite detail in that program, *then the whole thing works at that same level of detail.* It is in this respect that it differed from the human to human method of running a factory. There the person at the top did not know what the others knew at the level of detail that they knew it, so that even in his thoughts he was incapable of simulating the process at that level of detail, though he was capable of making it operate through a hierarchical system of management. So the ability to model the whole in great detail and make variations on it did not exist, either in computers or in anyone's mind.

The new ability to model or reproduce within software perfectly detailed huge models was not limited to the work world. It was new for that period to be able to model in that utterly detailed way many other activities—economic activities, political activities, and so forth. It was startling for the people of that period to find that these enormously detailed models gave at times utterly unpredictable and even unrepeatable results. For the people of that time this was a very profound and, at the time, very disturbing outcome because the people of that period tended to underestimate the complexity and inherent unpredictability of the world around them.

I say they underestimated it because, if you listen to the broadcast tapes and other recordings that we have from that period, they are full of explanations that we would laugh at today. Predictions and postdictions of an incredibly simple nature. It is laughable today to listen to a broadcast full of phrases like this—"The stock market went down today because—." Only the people of that period with their very simplistic view could possibly have believed these statements, because what was revealed, as the more detailed modeling went on, is that many things, though understood and simulated in great detail, are still inherently unpredictable. It is curious that those people who attended football games and could see before their very eyes that the bounce of a fumble—football, of course, having more or less vanished, I should remind you that the football was not round and, therefore, the bounce of a dropped ball was inherently somewhat unpredictable—whereas they all knew that the random bounce of the football could easily decide the outcome of a game, none of them believed that such random events in the rest of the world rendered it inherently unpredictable. Those facts only emerged later as a byproduct of having to grind out these huge pieces of software to make the world work.

Another aspect of this period, which I want to comment on, is communication, which also went through a profound transformation. Communication, of course, is very, very old and nowadays we tend to look at it as divided into two parts, communication to people and communi-

cation to data or programs, although even that distinction is becoming something of a blur. Communication has a long history. If you go back far enough, well before the period we are discussing, which is 1950 to 2050, communication was largely person to person. There was almost no data separate from people, so they didn't really have that distinction, which we make so much of nowadays. It was largely person to person and it was also largely one to one. There was essentially no broadcast; you could shout or you could occasionally put on a performance in an amphitheater. It wasn't until the invention of printing that broadcast became technically possible, in the sense that one person with one message could reach a very, very large number of persons. Then there was the development over several hundred years of printing, leading to books, pamphlets at the time of the French Revolution, and finally newspapers, radio, and television. The television of some one hundred years ago and the cheapness of this many-one communication was also the transforming force in the period that we are discussing, as it reduced the particularities of place by showing, in some sense, on the screens of that period, a model and a standard language, and it made larger political units possible.

The development of broadcast was usually paralleled by the development of one-to-one communication. Examples, beyond direct human speech itself, are mail, and then the telephone. There were periods when one-to-one was ahead of broadcast, as in the case of the distant transmission of sound, telephone preceded radio for example, but it was often the other way around as was the case at the beginning of the period of the Information Evolution when broadcast image in the form of television was common and already a major factor in people's lives at a time when one-to-one image was almost non-existent. Then in the period around 2000 we start to see it emerge in the one-to-one form. That change too had a profound transforming effect, because people no longer had to take their images as they were given, but rather it became possible to find any image or any person. If you are interested in movies today, you can find any movie ever made, all you have to do is hook on to it. Any image over the past, roughly, eighty years, since all of these things have been automatically recorded, is now available to you at your choice. Then there is the access to images of other people. It is possible today to be a seen and seeing participant in other's lives for hours at a time, for example participating in the home life of one's children or grandchildren, though they may be living on the other side of the world.

This too has profoundly changed our social structure. That there has been enormous change is clear, though it is inherently very hard to understand many aspects of social change, even in retrospect. The nature of the difficulty can be illustrated by the specific example of the telephone. For example in histories of the coming of the telephone, its true social effect is still a subject of debate. Were people linked better to each other before or after the development of the telephone? Certainly if the social arrangements stayed the same after the invention, they would be better

linked, but did people move more and families split and move to different places more easily because they knew they could phone home? So we can see change more easily than we can describe its fundamental impact.

I have now mentioned both computers and communications, but putting the two together also had a remarkable effect, although each was completely remarkable in its own right. While miniaturization drove the computer, communication also leaped forward by a factor of a million. Communication is again sending information, it's not doing physical work. You don't really have to do very much to send information, and we take that for granted today.

The combination of the computer with communication made possible whole new social structures. Before this period you got to know people by bumping into them and you knew them by name. If you wanted to get in touch with them you got their name or their phone number and you talked to them, and you talked only, basically, to the people you knew. Since the combination came into being, of course, we have a totally different way of communicating, and its earliest applications, I think, illustrate the notion. It became possible to enter into your machine a question like—Who wants to play chess tonight? An unlikely statement coming from anyone, of course, but the point was that you would get a response from people you did not know. Through the medium of the computer and communications it was possible to contact people you did not know and play chess or other games of the period with them, to communicate with people who had a common interest instead of a common geography or a common workplace, and so a new type of social structure emerged along these lines.

You could see the rudiments of it a hundred or so years ago, in the workplace, on bulletin boards, in forums and things of that sort, where people who didn't know each other answered questions about, how do you do this? This became a very powerful transforming event, so that with the improvement of communication, which in some sense annihilated distance, with the ability to talk to people one didn't know, with the use of computers to do automatic language translation, which came in about 2010, in a practical way, it became possible for people all over the world who did not know each other but had *common interests*, to form interest groups. That revised the political structure in a certain sense. I do not mean that we have a one-world structure today, but instead of being based entirely on geographical or language affinities, it is based far more than it was in the past on other types of affinities, and so the political process too has been somewhat restructured.

I hope this brief glimpse of the past has been helpful. While it is hard to recapture the feelings of a period so different from our own, I am very pleased that the Society has made the attempt. I hope that all of you have not only found looking back at the Information Evolution interesting, but, also, that you have enjoyed actually coming to a real lecture and feeling to some extent, and for a short while, something of what it was like to live in that primitive past.