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From the Binary Digit to Technological Convergence

MARTIN HILBERT[1] & OSVALDO CAIRO[2]

[1]Coordinator of the Information Society Programme
Economic Commission for Latin America and the Caribbean (ECLAC) – UN
Av. Dag Hammarskjöld 3477 - Vitacura - Santiago de Chile - Chile

[2]Department of Computer Science
Instituto Tecnológico Autónomo de México (ITAM)
Río Hondo 1 – 01080 México DF -Mexico

Abstract: - The digital paradigm began some decades ago with the introduction of the microprocessor and the manipulation of information. The progresses of science and technology have been fantastic since those years, and due to these tremendous advances, the digital paradigm is in transitions today. Whereas the omnipresent importance of information for physical and living systems is not neglected, it is claimed that recent technological advances introduced a qualitative and quantitative change in the nature of how we handle information, thus placing these processes at the forefront of human activities. In this paper, we present a renovated and updated overview of the scope of the digital paradigm. We focus on the old ideas that make it possible, but also in the new ones that will show the new road.

Keywords: - Digital paradigm, technological convergence.

1 Introduction

During the digital paradigm human kind is foremost focusing on the creation of technological solutions that process, transmit, store and translate information. By doing so, we are enhancing our understanding of what information and knowledge is and how they relate to cognitive process and intelligence.

The crux of information symbolization is the bit, the binary digit, the most efficient way to codify information. *A bit has no color, size, or weight, and it can travel at the speed of light… It is a state of being: on or off, true or false, up or down, in or out, black or white* [1]. The scientific community agreed to refer to the two states as 1 and 0. Shannon [2], liked to illustrate the power of the bit by describing the game of twenty questions, a children's game, whereas one is imagining the name of a city and the other can ask twenty yes-no questions to find out which one it is. Twenty answers elicit 20 bit of information, which in turn correspond to 1,048,576 equally probable alternatives. That would suffice to identify any city throughout the entire world. As uncertainty is the opposite of information and since the yes-no method is the most efficient way to reduce uncertainty, the transmission of information through the binary code is the most efficient way to transmit information. When talking about digitizing information it is meant that any kind of information is converted into a form using the binary code of 0 and 1.

Once digitized, it can be represented in different forms, for example by the existence or non-existence of electronic current or light in a fiber optic cable. The binary code is in fact so efficient, that colorful pictures, sound and voices, moving sequences of images and all other kind of information is increasingly represented in its form. In other word, the way we represent information is *converging* toward the digital paradigm.

The most powerful effect of conversion of information into the binary code stems from the fact that it allows to carry out all four basic operations of information on the basis of the same form of representations. The four basic operations consist in the (1) capture and translation of information, that is to interoperate or reproduce information from one form into another, for example sensors and monitors; (2) transmission of information, to reproduce at one point a message selected at another point, including all kind of telecommunications; (3) compute information that is to manipulate it according to an established procedure; and (4) store information in an artificial memory, as in a book or a CD. In the digital paradigm, all of four of these basic functions are closely related and interdependent, sharing the characteristic of being digital. However, to look at them separately has an advantage in the presentation and analysis of the different operations that can be done with information.

2 Capture and Translation of Information

In order to work with information it is necessary to capture it with sensors and present it through interfaces. To capture information there are different types of sensors. In general they are devices that detect or measure physical manifestations or phenomenon, such as lights, sounds, energy, speed or acceleration and convert those manifestations in a signal that represents the captured information. They are a kind of translator that transforms the magnitude of the subject of measurement in a quantifiable signal. Sensors can be a direct indication, for example mercury in a thermometer, or an indirect indication, for example by using an analogical to digital converter. One of the most noticeable characteristics of the digital paradigm is the increasing quantity of information produced by sensors without direct human intervention. A few decades ago a human creator authored almost all information that was captured in technological solutions such as paper or recordings. In the digital paradigm a great quantity of information is captured without human intervention and is pre-treated by artificial intelligence before humans extract value from it.

To show information there are an endless number of interfaces of audiovisual, haptic [3] and lately also cerebral nature. Licklider [4] proposes in his seminal work Man-Computer Symbiosis that computers should cooperate with users in decision-making and control of complex situations, without inflexible dependence on predetermined programs. In order to facilitate human-computer interaction he identifies ten priority problems that should be solved, among them the creation of interfaces for incoming and outgoing symbols and graphics; creation of systems for recognition of voice and manual direct writing; develop of systems that understand the syntactic and semantic of natural language. Almost fifty years later, the majority of problems posed by Licklider have been faced in a more or less successful way.

One of the main socio-economic characteristics of interfaces is so-called lock-in effects and switching costs. Once the user is accustomed to a certain interface the inertia of the human psyche and habits can lead to high switching costs if the interface is exchanged for another solution. The complementary assets lock the user into this kind of solution. Switching costs can affect technological trajectories and strategies because the user demand will naturally try to minimize them and therefore prefer similar generations. Lock-in effects are well known as a tool to assure the market power of some software solutions in the operating systems market.
The actual tendency goes toward an ever more perfect symbiosis between humans and their machines. Since the 1980's, cochlear implants [5] have already helped more than 60,000 deaf or semi-deaf persons to communicate better with their surroundings. Since more than a decade, dozens of paraplegic persons communicates with the outside world trough direct brain-computer interfaces. In those solutions, sensors detect human-brain activity and interfaces convert it in machine binary code that allows these cyborgs, for example, to navigate the Internet with their thoughts.

3 Transmission of Information

Once translated to the binary code, this format can be used for extremely efficient transmission of information. The ideas of Shannon were the driving force in the endeavor. It is interesting to see that Shannon was the almost perfect embodiment of the technology-push explanation of technological change, as opposed to the much more popular demand-pull theory.
Shannon [2] showed that information can be transmitted efficiently through an alphabet that defines which questions to ask in which sequence to receive a piece of information on the receiving side of the communication channel. Coding has to give credit to the fact that some things are more probable than others. Efficient codes for information transmission go from the most probable to the least probable, eradicating the largest uncertainty first and working its way to the less probable possibilities. This shows the innate relation between uncertainty and information, with one opposing the other. Thus for agent who is trying to lower uncertainty, efficient communication means to ask about the most probable possibility first.
Shannon reasoned that one could still make the code more efficient. The nature of information defines that the following symbols depends on the preceding one. The search for the most efficient code for different messages is one of the core focuses of the challenge to *transmit information* from one place to another. An additional hard nut to crack is the best way to modulate the symbols in a technological solution.
Another challenge is the presence of *noise* in communication. Noise is understood as all the uncertainties introduced by the imperfections of instruments and observers into any measurement. If we cannot distinguish two sounds or colors of pictures, noise is the one to blame. Noise is natural, whereas without it, every entity in the world would be perceived in its complete detail, making it impossible for us to recognize concrete objects as we do [6]. Too many details can distract from the information carried by a certain message. Any measurement distraction is however undesirable when trying to transmit a concrete message. Instead of filtering noise from information, Shannon proposed mechanisms of control that work through sophisticated methods of adding checks and additional information. *Indeed, the whole problem of efficient and error-free communication turns out to be that of removing from messages the somewhat inefficient redundancy which they have and then adding redundancy of the right sort in order to allow correction of errors made in transmission* [7]. In other words, Shannon's theory minimizes the size of the part of the message that reduces the uncertainty of the receiver, meaning to take away things the receiver already knows as this would not be information for the receiver, and adds other parts to ensure that the information that the receiver does not yet have, will get there correctly. This is the basic idea behind the *digital transmission of information*.
It has several characteristics that can result in a reorganization of several social and economic coordination mechanisms. For example, in the digital format information can be transmitted in *real time,* which is the speed of light, thus accelerating communication immensely. The new way of transmitting information permits the often-cited new space-time management of information flow, only restricted by the processing medium -bandwidth and extension of the network-. Digitized information, products and services experience therefore the *death of distance*. No digital information on the other hand remains

subject to the laws of nature in their physical transportation. Conversations and discussions, shopping, financial transactions, voting, music, movies, gaming and many others are all disguisable processes, and thus also subject to the death of distance.
A further characteristic of digital interaction lies in the nature of *multidirectional networks* [8]. Unlike traditional uni or bi-directional communication (*one-to-many*), multidirectional communication structures enable the flow of information both as comprehensive individual communication (*one-to-one*) and also among many at the same time (*many-to-many*). For example, email or videoconferences can be used as digitized *face-to-face* communication in all of these communication directions. Unlike paper-based letters, emails can be sent *one-to-one*, *many-to-one*, and thanks to the non-rivalry of bits also *one-to-many* or *many-to-many*. All four-communication channels can now be used very quickly and practically at the same time, but above all in a media frictionless manner, that is without the need to change the information-carrying medium.
At present, the different existing networks converge toward a common network. This is due to the superiority of the transmission of information in the form of binary digits, leading to the so-called convergence of all previous network standards, such as broadcast, voice or several data standards. The technical implications of this convergence result in gigantic technological changes, including radical alterations in the architectures of networks, in the protocols of operation and the integration of the different functionalities of the networks. This implies important investments, be it for the upgrade of existing networks or for the installation of new ones. This leads to what is known as NGNs -Next Generation Networks-, which is completely structured on basis of the Internet Protocol –IP-.

4 Computation of Information

Shannon also played an important role in the exploration of how information in binary form can be manipulated and transformed. Shannon proved during his studies at MIT, in 1937, that Boolean algebra and binary arithmetic could be used to simplify the arrangement of the electromechanical relays then used in telephone routing switches. He also turned the concept upside down and also proved that it should be possible to use arrangements of relays to solve Boolean algebra problems. He therefore proposes to use the properties of electrical switches to do logic. These kinds of logic gates are the basic design for what we understand today as *computer hardware.*
The most important functionality is to control what goes in, and what goes out. A modern digital computer aligns millions of such operations in a sequential manner and is called digital because it converts a certain combination of information into other information on the basis of binary digits. This system innovation greatly reduced the cost of such devices and therefore enabled the design of much more complex sequences of logic gates, thus opening a new technologic paradigm. This is the reason some researchers take the year of the invention of the microprocessor as the beginning of the digital long wave.
In the same year in which Shannon showed how to implement logic gates in electromechanical devices, Alan Turing [9] published a paper *on computable numbers, with an application to the Entscheidungsproblem*, which extended work done independently by Alonzo Church [10]. Following this line of thought, Turing created a formal model of a machine that can compute information. It is an abstract symbol-manipulating device, which, despite their simplicity, can be adapted to simulate the logic of any computer that could possibly be constructed.
The socio-economic importance of computing consists in the complementarities of the artificial solutions with the most precious and mystical thing human kind possesses: human intelligence. Today we use both in a complementary manner. A modern economy is based on the right combination of artificial and biological intelligence. Given the only gradual advancement of biological intelligence, but the exponential growth of artificial systems, it is generally expected that the proportions will continue to shift towards the increase of importance of the latter one. This is in accordance with the renowned theorem of Hofstadter [11]: any intellectual activity that can be executed by a machine looses importance for human intelligence.

It is well known that the performance of this technological system has been one of the main drivers of all other advances of the larger ICT systems. The so-called Moore's law characterized the exponential increase during the technological paradigm of the microprocessor and resulted as one of the most continuous *learning by scaling innovations* of the history of technological developments. The key of the continuous innovation is miniaturization, a process of structural innovation. While this model has been successful for more than 40 years, this continuous way to improve the performance this technological system is soon coming to an end. During the next 15 years a layer in a chip would need to get to be finer than few atoms, bringing Moore's law to a stop in its traditional sense. While some claim that this one would be the end of exponential growth in the development of the technological progress in computation, others point to the time before the microprocessors paradigm. As with any other technology, the technological trajectory of computation has several predecessors and the microprocessor silicon paradigm is not expected to abruptly end this longstanding evolution, but to eventually be replaced by a more efficient technology. Several candidates in the horizon of the present development exist. Three dimensional silicon chips are the most conservative bet to assure the continuity of increasing performance of artificial computational power. Among other solutions are various circuits on molecular or DNA bases. Besides, quantum computations hold up the promise to replace the binary bit with three-positioned Qubit, which does not only promise to increase the computation power of computing devices by many scales, but also introduced alternatives like teleportation through quantum entanglement. As this solution show, material innovations are currently needed in the field of computation, as the long and gradually advancing trajectory of learning by scaling on silicon comes to an end. Nano, molecular, gene and quantum technology are considered. This might most probably also require systems innovations and therefore lead to a new paradigm for hardware. Another challenge is posed not by the hardware, but the software development. The long-standing challenge of parallel computing is still not sufficiently tackled. This includes the complementary approach of traditional AI systems, based on programmed intelligence and speed, on the one hand, and machine learning mechanisms based on the emergence of machine intelligence on the other hand. It might lead to recognition that a computer does not necessarily need to build on Von Neumann architecture, including powerful and vast neural networks among others.

5 Storage of Information

The memory function is essential for doing computations. In this sense, the storage technology significantly defines the performance of the machine. Without storage the device would be a simple digital signal-processing device like a traditional calculator or media player and not a computer in the definition we use today. The ability to store instructions and the symbols that are manipulated according to this program is what makes a computer versatile and distinguishes it from traditional calculators.

So far, no practical universal storage medium exists, and all forms of storage have some strengths and drawbacks. An advantage of digitally stored information is that bits are non-rivaling, in other words they cannot be used up or consumed. Digital data can be read again and again, they may be divided up, abridged, mixed and redistributed, but they cannot be consumed. This leads to almost infinite scale effects. It makes take millions of Dollars to produce digital information, but simple commands like copy and paste suffice to duplicate it as often as necessary. In difference to industrial goods, the cost structure of digital information is almost 100 percent fixed costs for its production, whilst the variable costs for reproduction are practically non-existent. This has a major effect on the transparency of public acts, There are hardly any additional costs for providing a public document or report to either one or many, for example by posting it on storage linked to a website.

The combination of real-time transmission of digital information with the possibility of practically unlimited digital data storage on computer server's lead to a new time management of the information flow. On the one hand, information can be transmitted instantaneously and on the other hand asynchronous information exchange is made possible. The stored information can be transmitted and

processed or edited with any desired time lag. This combines the advantage of traditional telecommunications with the information storing and distributing advantages of printing and the classic library. In this sense, digital storages enable new ways to accumulate, selectively process and access information.
The use of magnetic technology has been dominating solution for storage devices, while currently optical technology is increasingly considered. The current trend of information storage goes toward in increased network design. A substitution takes place between the necessity of having the memory as close as possible to the processing agent and the availability of broadband networks. The prohibitively high cost of memory devices and the network effects of sharing storage space foster this. Mass storage built on hard disk technology and external databases or removable storage devices are parts of the network that can be connected to the computing agent. Large databases or data warehouses in enterprises or academy can be accessed this way trough a specific network. The bandwidth is decisive here, showing the interdependency between the storage and the employed transmission system. The transmission speed between the processing unit and the memory becomes the bottleneck of today's computation power. If the bandwidth problem could be solved, it would not matter where in the network the information is stored. The non-rivalry of bits could then enfold its exponential powers, which are well known from peer-to-peer file-sharing platforms such as Napster, KaZaA or BitTorrent.

6 Conclusions

The idea to represent information in binary digits for its transmission, manipulation, storage and interoperation led to a series of systems innovations in the following decades, most of them profoundly interdependent and mutually enforcing or restricting. Their convergence and combination into what is nowadays referred to as ICT is the driving force behind the digital paradigm. The technological system referred to as ICT is in fact the convergence of four longstanding technological trajectories. The unifying concept is the representation of information through the binary digit, the bit, which is the underlying scientific paradigm.
Technologies to capture and display information translate content into bits. The current challenge consists in the complete extirpation of media-friction between biological and artificial information processes, by taping sensors into the center of human intelligence, the nervous and neuronal system. For the end-user, interfaces become the most characteristic differentiation between the various technological solutions referred to as ICT. Current ICT are most easily distinguishable because of a certain type of sensor and display (voice, text, visual, brain-computer-interface, etc) and a certain degree of sensibility (resolution, decibel, etc).
Technologies to transmit and exchange information use the binary code to maximize the velocity of communication. The mathematical theory of binary communication results as efficient as that all kinds of communication networks converge toward this protocol, including voice, text, images and even olfactory information. The limits of communication are not anymore defined by geography, such as during the times of Aristotle who famously claimed that any political and socio-economic influence had to be restricted to a maximum of 70 kilometers because a person could not travel further than that in one day. The limits are defined by the rollout of the network and by its bandwidth.
Technologies to compute information have seen an impressive improvement over the recent century, with a doubling of their capacity every other year. Extrapolating this trend, it is estimated that in the year 2023 a computer for US$ 1,000 would make as many computation per second as a human brain makes neuronal synapses. In 2049 a computer for US$ 1,000 would make as many computations per second as the entire human race performs its most basic neuronal computation [12]. In terms of computational brute force, the technological solutions become much more powerful than our biological possibilities. The difference becomes qualitatively in nature, with each kind of intelligence perform different tasks. Complementarity becomes the name of the game.
Finally, *technologies to store information* become the exchange points of the network and the non-rivalry of digital information and networks effects in the usage of memory provides sufficient incentive to connect the formally separate units.

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