Telematics: A Distinctive Discipline

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Abstract

The thesis of this paper is the identification of Telematics as a distinctive discipline, a discipline that shares a lot with Computer Science and with Electrical Engineering, but whose body of knowledge deserves being identified as such, since it is today already big enough and is expected to grow even more in future. We begin with the historical background of Telematics, continuing with a description of the years in which the convergence of Telecommunicacions and Informatics (or Computers and Communications) cristalized together with other elements to consolidate Telematics as a distinctive discipline. We then review the current international acceptance of the term Telematics to denote this discipline. In the next section, we perform a definition of what are the scientific and technical building blocks of Telematics, drawing a reasonably clear border with neighbouring disciplines. We end the article pointing out some of the paths through which Telematics may continue to evolve, and possibly subdivide in other new scientific disciplines.

Keywords: Telematics, Information and Communication Technologies, Discipline.

1. Introduction

In the Classical period, knowledge, art, and sports were considered in a holistic manner. A cultivated person was supposed to be a master in philosophy, science, literature, music, plastic arts, athletics, and even fight. The idea of a person mastering all the available arts, sports and sciences returned during the Renaissance, and it has since become specifically identified with the term "Renaissance man".

The later advances in science and humanities that ocurred along the 18th century, and which gave birth to the industrial revolution, made human knowledge so broad that the "Renaissance man" concept became an unfeasible idea in itself. It was no longer possible to educate experts in everything. Knowledge was therefore partitioned into different disciplines: biology, mathematics, physics, chemistry, geology and so on. A person could therefore become an expert on part of the corpus of human knowledge, being able to address complex problems in his area, and contributing to its advance with new discoveries.

Ever since, human knowledge has been in a state of permanent exponential increase, requiring a division and subdivision of disciplines, so that a given set of persons can become experts in each of them, along their lifetime. A given discipline is both an intellectual and administrative convention. The paradigmatic structure of disciplines arose in the period 1650-1875, and was inherited by subsequent eras without much critical assessment. The primary forces for disciplinary formation and sustainment since have been reductionism and specialization.

When a new discipline arises, it shares many of the principles and techniques of its ancestor disciplines in a unique mix. When Computer Science was born, it shared many principles and techniques with both Mathematics and Physics, in particular, Electronics. This is so because on the one hand, computers are physical devices, originally electro-mechanical and later electronic ones. To study and understand the building blocks of the computers it is necessary to master the theories developed in electronics, in their analogue, but most notably in their digital part. On the other hand, computing shares the abstraction and formality in reasoning and expression of Mathematics. This is why the discipline of Computer Science inherited from Mathematics theories of Logic and Algebra to treat the languages in a formal way (syntactically as well as semantically). But Computer Science or Computing Science, depending on the flavour you want to give it, is more than Mathematics and Electronics. Computer Science has developed its own well-founded theories, such as theories for compiler construction, or for databases or operating systems, etc. as well as their own practices and uses.

In the same way as Computer Science evolved from Electrical Engineering and Mathematics into a clearly identifiable and independent discipline, we show in this article that Telematics is also a distinctive discipline. A discipline that has its own history, that, as is always the case, is mixed with the histories of other disciplines, but that more and more is distinguished from the parent disciplines with its own evolving identity.

In the remaining sections of the paper, we first explore the history of Telematics. We begin with its historical background, continue with a description of the years in which the convergence of Telecommunicacions and Informatics (or Computers and Communications) cristalized together with other elements to consolidate Telematics as a distinctive discipline. We then review the current international acceptance

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of the term Telematics to denote this discipline. In the next section, we define what are the scientific and technical building blocks of Telematics, drawing a reasonably clear border with neighbouring disciplines. We end the article pointing out some directions towards which telematics may evolve in the future, and possibly subdivide in other new scientific disciplines.

2. Historical Roots of Telematics

The starting point for Telematics is usually considered to be 1832, when the invention of the electrical telegraph took place. Although many different types of optical telegraphs and other signaling equipment have been invented along the course of human history, the electrical telegraph is considered the first modern data communication system. The electrical telegraph contains several basic characteristics which are shared by most modern Telematic communication systems:

1. It relied on an electro-magnetic signal to convey the information.
2. It was based on the transmission of symbols from a discrete (alphanumeric) alphabet.
3. It used base two digital line coding: basic symbols were *dits* and *dahs*, plus timed silences (*letter-pause* and *word-pause*), resulting a basic quaternary digital line coding.
4. It incorporated the notion of optimal source coding (Morse Code, still in use today!).
5. Since 1845, it made use of compression codes: Morse's *Commercial Codes*, and others.
6. As early as 1863, encryption codes and devices were developed: Stager's *Union Route Cipher* to protect sensitive information [9].
7. In 1864, Baudot introduced the important concept of Time Division Multiplexing, allowing for several messages to be transmitted in parallel over a single physical line.

The rudimentary usage of digital processing, source coding, data compression, and encryption codes has led to corresponding areas of knowledge of the Telematics of today: information theory, optimal source coding, compression algorithms and techniques, encryption and network security theories.

The electrical telegraph incorporated as an implicit concept the notion of message switching. However, it was performed manually, and therefore it lacked the automated signalling and switching characteristics that are inherent to Telematics. This is the only essential functional characteristic that the electrical telegraph did not possess in relation to those systems which came later.

Figure 1. Strowger's Automatic Telephone Exchange, 1891.

The year 1891 marks the second relevant milestone of Telematics, with the invention of the automatic telephone exchange by Strowger (see Figure 1). The automatic exchange, first crudely electro-mechanical, and later on fully electronic, incorporated the notion of signalling between systems that enabled the automatic establishment of end-to-end communication. The concept of swichting is fundamental to Telematics, as it is a key element in network design and implementation. The development of the switch opened new fields of research that led to the birth of new elements: circuit switching architecture, routing techniques and teletraffic theory are areas of knowledge in Telematics that arose from the basic concept of automatic switching. These have later evolved to the modern and complex theories of packet switching theory, routing theory, general traffic theory, statistical traffic models, and traffic engineering, all components of the discipline of Telematics.

The convergence between data transmission and automatic switching functionality was brought about through the development of Telex systems. Telex networks began in the 1920's as improvements of the electrical telegraph, first, to the terminal equipment and, later, transmission techniques. In the late 1930's the integration of automatic switching, signaling systems (*type A Telex signaling*), and message buffering made of the Telex the first truely Telematic communication system. The teletype was widely used in the business, military and administration sectors. It is the ancestor of modern e-mail systems, allowing at that time even for photographs to be sent, using quite sophisticated picture digitization techniques.

3. Computing and Communications Fusing into Telematics

Telex systems in the 1930's were based on electro-mechanical processing and storage. "Mass-storage" was based on paper tape punchers and readers, while "random access storage" was based on electro-mechanical relays. Processing was based on dedicated hardware electro-mechanical devices that were capable of handling elemental signaling, switch control, message switching and terminal control operations. Therefore, the capabilities of the system were largely limited, and their versatility very low. The potential of switching and signaling only began to be realised with the development of electronic cybernetic and computation systems. The concepts and theories of computation are therefore essential for Telematics.

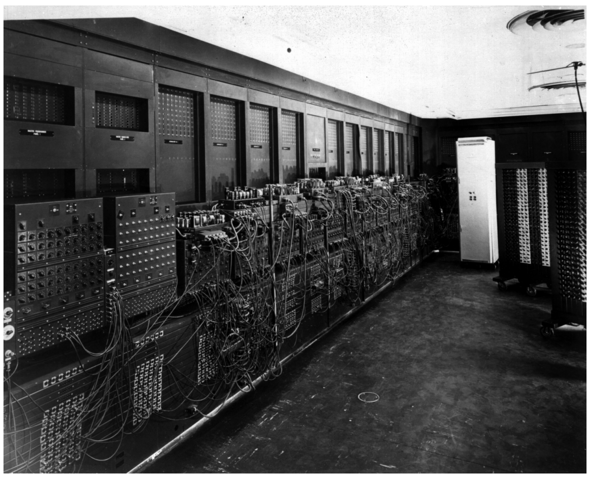

Figure 2. ENIAC, 1945.

This is why the birth of the first digital electronic calculator, the ENIAC, in 1945, fired a very fast process of convergence between computation and communication, consolidating the discipline of Telematics. The development of electronic processing and storage technologies boosted the potential for a large number of customizable Telematic communication services, departing from the humble Teletype and Telephone services of the time.

Convergence between true computers and communications began with the need to remotely access a computing facility: teleprocessing. Teleprocessing was based on decoupling peripherals from the main computing facility by connecting them to computers through a point-to-point transmission link. The low utilization factor of the link, and the high cost of point-to-point links, led to the deployment of concentration equipment, introducing the concept of Statistical Time Division Multiplexing. Telematic theory was then applied to computer communications in order to allow, first, the remote location of mainframe peripheral devices, and, later on, fully interactive remote access using Cathode Ray Tube terminals based on packet networks with tree topologies, rooted at the mainframe.

It was not until the proliferation of computing centers that the need of computers to communicate among themselves was felt. This need implied that communication had become no longer a privilege of human beings. Machines could also "talk" to each other, engaging in quite complex interactions. This need of machines to communicate with their siblings required the development of "languages" that machines could use to have fruitful "conversations". These "languages" are nothing else than communication protocols, that are based on the formalization of the exchange of information between humans in such a way that it can be implemented at machine level.

The development of communication protocols marks a fundamental milestone in the history of Telematics, as protocol architectures and protocol theory is now one of its most fundamental concepts. Digital communications, based on communication protocols, have since been coping with an ever larger fraction of the total modern communication spectrum. The term protocol was coined in 1967 in the article *A protocol for use in the NPL data communications networks* [1] published by K.A. Barlett, from the National Physics Laboratory (UK). That article contains basic notions of the functional and operational semantics of communication protocols that still persist in modern computer networks.

We have just seen that computer networks are a very relevant application of the discipline of Telematics, but a not less important one is the embedding of computers within general communication systems. The late sixties saw the development and deployment of the first computer based telephone switching equipment: the so-called Stored Programme Controlled Exchanges. One of the very first, the Ericsson AKE 12, was installed in Tumba (Sweden), in 1968. The guiding concept was to apply the flexibility and versatility of computers to the management and control of telecommunication systems. The success of this initial application later led to a complete redesign of telephone signaling, leading it to becoming completely based on packet networks and communication protocols, as in the revolutionary "Signaling System number 7". The application of computers was then introduced also to automate in a very flexible way the management functions of communications systems. Remote network management could be performed in order to automatically control the performance, failures, configuration, security and accounting of communication networks.

To complete the overlap between computing and communications, in 1969 computer systems were also applied to the data plane of telecommunication networks: the ARPANET was deployed. Using the then revolutionary 32 bit microprocessor-based processing systems as network nodes, it was possible to perform data switching, signaling and management of the whole network in an integrated manner. The ARPANET incorporated at the same time another revolutionary concept: packet switching communications. The ARPANET was the first modern network specifically designed following the theories and principles of the discipline of Telematics. Its flexibility, reliability, and cost-effectiveness made it one of the most successful and long lasting modern communication technologies. Many experts that lacked vision despised ARPANET for providing connectionless unreliable delivery of packets based on a "best effort" approach, and firmly stated that this was just a university toy that would never be even close to a commercial service. Time has shown only how wrong they were, as ARPANET quickly evolved to become what now is considered to be the basis of a global socio-economic revolution: the Internet.

Using the Internet Protocol (IP) as the network service workhorse, the year 1971 saw the beginning of the explosion of computer-based Telematic communication services. Remote Job Entry, Remote Terminal (Telnet), File Transfer (ftp), abstract syntax notations (EBCDIC [15] to ASCII) and E-mail (Mail Box Protocol), based on Internet were all born in this emblematic year (see RFC-0088 [3], RFC-0158 [11], RFC-0172 [4], RFC-0183 [Winett 1971], RFC-0184 [8] and RFC-0221 [13]). Using the Internet Society and the Internet Engineering Task Force (IETF) as its standardization body, the number of protocols and services associated with Internet has continued to grow exponentially, and still continues to do so.

Likewise, the proliferation of Stored Program Control Exchanges using common channel signalling, led in the Telephony world to the Intelligent Network concept, opening the possibility of more services over phone networks, thus overcoming a century of rigid single-service infrastructure. Both the Intelligent Network concept and the Internet are examples of the flexibility and versatility achieved by combining concepts and theories coming from the technical areas of communications and the computing. This trend of inventing ever new Telematic services that are offered over a common infrastructure based on the Internet Protocol has continued until today, and will certainly continue in the future.

The introduction of the Telematic discipline thus inverted the entrophic tendency towards a distinct telecommunication technology and infrastructure for each telecom functionality offered to the user. Service digitalization and abstraction have led to the source-coding of all types of information, followed by its compression and packetization in order to be transported, stored, accessed or processed over increasingly integrated networks technologies and infrastructures. The logical separation of the control plane and the user plane of protocol architectures allows for an independent evolution of both the technology and the infrastructure that controls and transports the user information, being both of them orthogonal to the management protocol plane, that allows the automated management of the whole network and its supported services.

As a consequence of this evolution of knowledge, in 1976 Telematics was first formally identified as a distinctive discipline, and the term *Telematique* was coined in a report requested in December 1976 by a French President. In that visionary report [10], it was foreseen that the convergence of Telecommunications and Informatics that had ocurred in the three previous decades had opened a new distinctive discipline based on a vast research and development field, setting the foundations for an emerging huge business sector. Telematics is therefore the field of knowledge that studies the interrelation between Computing and Communications, and, what is more important, their synergistic effect.

4. Computing and Communications Evolving Together

The first computing systems were sequential, monoprocessor and localized. Later came (pseudo-concurrent and) concurrent processing, multiprocessors, real-time computing, and distributed computing, successively introducing increasing complexity of reasoning and design. Concurrency and distribution introduced the concepts of synchronization and communication in computing.

Seen at the microlevel, computation and communication cannot be distinguished since one goes necessarily with the other. Signal changes are transformed and combined through devices to changes at output signals, thus performing computation (the value at the output differs from the input values) and communication at the same time (input and output signals are not at the same location).

At the macroscopic level, computation and communication cannot be understood nowadays one without the other. Here are some examples:

With the client-server model, where programs reside in servers, but are called from clients elsewhere, computation and communication are mixed and intermingled. Also the web, first *"just"* a distributed publishing platform based on two concepts, http and html, a communication protocol and a mark-up language, soon converted into a platform for distributed computing. This trend is seen even further in paradigms such as P2P (peer-to-peer computing, or should we stress peer-to-peer networking?) or grid computing. Grids aim at exploiting synergies that result from the ability to share and aggregate distributed computational capabilities and deliver them as services. The grid gives rise to models like *utility computing*, which enables the leasing of computing resources by customers on an on-demand-basis based on QoS requirements.

Another example is that of mobile terminals, minute devices for communication and computation. Computation is not only performed in so-called computers, but increasingly also in embedded systems and a multiplicity of diverse devices. If the 70's and 80's were the decades of the isolated mainframe (one computer, many persons), and the 90's and 00's the period of the more and more connected personal computer (one computer, one person), we are entering the era of ubiquitous computing [14] (many computers, one person), of multiple computing devices that cannot be conceived of without being connected with one another through networks, be they wired or wireless, with infrastructure or ad-hoc. The tradeoff will often arise, whether to recompute a piece of information or to get it from somewhere else. The network of interconnected devices will grow so much that new ways of handling, managing and configuring these networks will be needed. Autonomic computing [6], planetary computing or recovery-oriented computing are initiatives in this direction.

5. Telematics Today

Telematics today is recognized as a distinctive discipline. Although the term Telematics is internationlly accepted, it is not used with equal profusion in all regions. In most European countries there exists a common understanding about the theories and techniques that form the knowledge bodies of the discipline of Telematics. This is reflected in the usage of Telematics to distinguish university degrees, research programmes and new tools of the Information Society.

In France, where the term originated, *Telematique* was initially used to denote the different services based on the Minitel, a precursor of the Internet for the mass-public. It is also used to denote university degrees at different French universities.

In Spain, the teaching and research in universities is divided into so-called knowledge areas with a nationwide denomination, "Telematics Engineering" being one of them. There is also an accredited bachelor degree currently offered at fifteen universities called "Ingeniero Técnico de Telecomunicación: Telemática". A government programme for research was also issued nationwide with the term "Aplicaciones y Servicios Telemáticos". The term "Telematic delivery" is used to denote the delivery through Internet, mobile phone or other remote means of the different e-administration programs of the Spanish government.

In the Netherlands, there are both bachelor and master degrees being offered with the term *Telematics Engineering*. Bachelor degrees in Telematics are also offered in different European countries, like Portugal, United Kingdom, Spain, Norway, Italy and Austria. Likewise, almost every European country has Telematics Research Groups in their universities, or use it as a denomination of academic fields, like it is done in Spain or Norway.

The particular case of Germany may be pointed out, where Telematics is widely accepted with its specific meaning, but for some reason mainly if applied to its use within the automotive area of application. In spite of this currently restricted use, Telematics in Germany is increasingly being used in its internationlly accepted sense to span all its areas of application.

In the US, the main technological terms for degrees in the Information Technologies continue to be Electrical Engineering and Computer Science, in spite of its unnatural adaptation to the current technical scenario. This is why up to now in the US the Telematics discipline is denoted with the term "Computer and Communications" or "C&C", but equally recognized as in Europe. The 2004 IEEE Medal of Honor [7] has been awarded to Tadahiro Sekimoto, for championing, in IEEE words, "the integration of Computers and Communications". He was considered in NEC the leading evangelist for what was, in the 1960's, a revolutionary concept: "C&C", or the integration of computers and communications. More recently though, some usage of the terms Telematics is begining to gain momentum in the US. On the one hand, it is widely used in the automotive field of application. On the other hand, some universities are beginning to offer degrees in Telematics, using the term to identify the specific discipline being taught.

In the international area, Telematics is also widely used. The European Union launched the Telematics research programme under which dozens of research projects were developed to cover all the different application fields of Telematics, from aerospace to education, including automotive, culture, and administration. The International Telecommunication Union (ITU, formerly CCITT and CCIR) has a whole series of recommendations: the T series, called "Terminals for Telematic Services", that includes over 200 international recommendations in force. UNESCO, the Educational Scientific and Cultural Organization of the United Nations, recognises Telematics as a key discipline for the deployment of the Information Society, and has launched several Pilot Project on Access to Telematics Facilities in different parts of the world.

To reflect this shift in relevance, even the IEEE has changed its Constitution from

Its purposes are scientific and educational, directed toward the advancement of the theory and practice of electrical engineering, electronics, radio and the allied branches of engineering and the related arts and sciences

to

Its purposes are scientific and educational, directed toward the advancement of the theory and practice of electrical, electronics, communications and computer engineering, as well as computer science, the allied branches of engineering and the related arts and sciences.

6. The Fundamentals of Telematics

Telematics is a discipline founded on the specific application of generalistic mathematical theories combined with some intrinsic mathematical theories that were developed as the Telematics discipline was being formed. The binding element that allows to identify them as belonging to the Telematics field is that their subject of study is distributed information. Actually, the mathematical formulation of what information is constitutes itself a basic foundation of Telematics: Information Theory, laid down by Claude Shannon in his seminal article from 1948 [12].

Another fundamental theoretical foundation of Telematics is Systems Theory. The mathematical modelling of systems and their dynamics was needed to analyze the extremely complex interactions among the distributed elements that constituted Telematic Systems, even in their early stages. Systems Theory then evolved to a generalistic mathematical model that has been applied to many other disciplines, ranging from biology to aeronautics.

A third essential foundation of Telematics is Discrete Structures. Discrete Structures arises from the joint study of theoretical elements from areas as set theory, logic, graph theory, and combinatorics. The essentials of Discrete Structures is pervasive in most of the discipline of Telematics aspects, being for this reason its most characteristic theoretical body.

Telematics is also founded on other very specific theoretical bodies, although their are also applied on neighboring disciplines. We may cite among these Computability Theory, essential for Telematics, but also extensively used in Informatics. Alan M. Turing and contemporaries defined the limits of computation: with his “Turing Machine”, he described the capabilities of computing machinery, without constructing it and years before it was practically feasible.

Both (digital) computation and digital communication are founded on the same concept: the discretization of information, mostly based on the binary digit for technological reasons. The concept of computation and computability, which can traced back to Turing and contemporaries, and Shannons mathematical theory of communication were both formulated in the first half of the 20th century.

Kolmogorov linked both the Information Theory from Shannon, and Computability Theory from Turing, into the field of algorithmic information theory. Algorithmic Information Theory, also known as Kolmogorov complexity, gives a new way to grasp the mathematics of information. According to Kolmogorov, the complexity of an object is the length of the shortest computer program that can reproduce the object. Kolmogorov’s notion of complexity is a measure of randomness, one that is closely related to Claude Shannon’s entropy rate of an information source.

Queuing Theory is also a foundation of Telematics, while it may also be found as a basis for other fields. Finally, we may cite Graph Theory, that was developed for railroad traffic planning in the early 19th century, and later has evolved to an essential building block for the mathematical formulation of any kind of either physical or logical transportation systems.

The very fundamental aspects cited up to now do speciallize into other theoretical bodies that, being not so broad, dig in a deeper way inside the specific formulation of the Telematic Discipline. These specific theories have been developed to allow the modeling in mathematical terms of the concepts interwound to form Telematics: Traffic, Coding, Switching, Protocols, Routing, Network Desigin and Performance Analysis. Traffic Theory, Switching Theory, Protocol Theory and Network Design Theory are almost exclusively used, developed, and contributed to, within the Telematics Discipline, constituting the essential elements of its knowledge. Coding Theory, Congestion Control Theory, and Performance Analysis Theory, although extensively used and continuouly contributed to by Telematics, share extensive usage and contributions with other neighouring disciplines.

To end this sucint definition of what the Telematics is considered to be, we may describe here the Telematic engineering fields, which are the areas of application of the theoretical generalistic knowledge described up to now. In this case, it is more difficult to perform a reasonably complete compilation. The reason is that the fields of application change rapidly, intermix and penetrate in new areas, and sometimes recede from industry and services.

We may cite, without any claime to producing an exhaustive listing, the following engineering areas:

- Switching Systems Engineering
- Multimedia Engineering
- Protocol Engineering
- Information Server Engineering
- Traffic Engineering
- Routing Engineering
- Security Engineering
- System Reliability Engineering

As for business sectors, Telematics is increadibly spread over the whole economical activity. Its natural area is telcos and ISPs, but also financial companies are very heavy users. Computer and telecom equipment manufacturers are also obvious and natural bussiness areas. Entertainment is another sector in which Telematics is constituting a core technology for the business. Medicine, aerospace, railroad and car makers are increasingly incorporating Telematic technologies into their sectors, and the same may be said about mass media companies. Finally, any company, administration, or independent organization uses Telematics for its internal information systems.

7. New Skills Needed

The identification of separate disciplines has an effect in education and labour. Already some groups when identifying the skills for future engineers have seen the need for graduates with a Telematics profile. For instance, the Career Space initiative stresses the fact [5] that “*the majority of graduates increasingly need a combined qualification from both cultures: engineering and informatics.*” One can also read, that “*the teaching of ICT curricula in universities has evolved from the development of natural and structural sciences. One main route comes from electrical engineering deriving from physics, and the other from informatics/computer science deriving from mathematics. Historically these two routes evolved in different departments/faculties and they developed different approaches, methodologies and cultures, even when tackling similar problems. It is not surprising that the aims and content of ICT related curricula coming from such different origins are also different.*”

It is as important to manage the internals of the computer as it is to manage its surroundings, i.e. the network. The study can go hand in hand: the study of computer architecture can go with the study of communication architecture or communication networks, the study of data and knowledge bases can go with that of storage area networks, the study of operating systems with the study of network management systems, the study compilers and interpreters can go with the study of coding techniques, etc. Furthermore, the basics of computing devices, nowadays basically the microelectronic technologies, should be studied as well as the basics of wireless or wired communications.

The existing structure of universities and other education institutions is sometimes a barrier for the clear identification of new curricula, although in some countries interesting developments that move in this direction can be seen. The need for a distinctive curriculum in Telematics does not eliminate the need for the classical ones in Computer Science or Electrical Engineering, even if they evolve and include contents resulting from the synergy of computation and communication (such as Distributed Computer Science or Intelligent Networks, for example, in one or the other case).

8. Conclusion

ICT, *Information and Communication Technologies* is sometimes used to refer jointly to Computer Science (Information Processing or *Informatics*) and Telecommunications. The term is rather misleading, since, as already noted, both technologies are based on information. *Computation and Communication Technologies*, or just *Information Technologies*, would be more appropriate. Whatever the name chosen, we feel that the convergence of both technologies entitles it to be called a discipline on its own. A new discipline that is more than the sum of their ancestor disciplines, but has to take the best practices from them, where the Church-Turing thesis is studied as a basis as well as Shannon's mathematical theory of communication. Such a discipline should be taught at educational institutes and universities.

The two pillars on which Telematics is based, computation and communication, are reaching their physical limits. The insulators in CMOS transistors cannot get much smaller or the insulating layers will stop insulating (at around 6 atoms thick). This is a limit to computation which might happen before 2010 or 2012, if we follow Moore's law of semiconductors. On the communications side, in optical fiber, we use ten thousand or so photons to represent a bit. There is an equivalent to Moore's law for fiber, too, and we will soon run out of photons. Maybe before 2010. These limitations will imply that computation will become necessarily more distributed.

Quantum mechanical effects will become important in just a few years! Then the classical bit will be replaced by the qubit, the quantum bit, that results from removing the approximation that the elements of information are independently manipulable [2]. Quantum computation and communication will then give rise to a new kind of Telematics. But, that's another story ...

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