Assesing the usefulness of the ACM/IEEE-CS Computing Curricula for the Design of Computer-Related Engineering Curricula: an Experience in Telematics

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Abstract

This paper presents the rationale to build up a Telematics Engineering curriculum. Telematics is a strongly computing oriented area; then, the authors have initially intended to apply the common requirements described in the computing curricula elaborated by the ACM/IEEE-CS Joint Curriculum Task Force. This experience has revealed some problematic aspects in the ACM/IEEE-CS proposal.

From the analysis of these problems, a model to guide the selection and specially the approach of the Telematics curriculum contents is proposed. This model can be easily generalized to other strongly computing oriented curricula, whose number is growing everyday.

1 Introduction

It is now widely recognized [Shaw, 1990] that "Informatics education has obligations to all the communities that rely on information technology, not just the computing professionals". The word Telematics is mainly used (in Europe) to refer to the methods, techniques and tools and their underlying theory that allow the communication between computers and the development of distributed processing applications. So, Telematics can be properly considered as a strongly computing oriented field; however, it is not only and strictly a computing centered discipline.

In any case, we have analyzed the usefulness of the Computing Curricula [ACM, 1991] for the design of a curriculum on Telematics.

The **common requirements** constitute the essential contribution of the task force. They are distributed in nine subject areas: Algorithms and Data Structures (AL), Architecture (AR), Artificial Intelligence and Robotics (AI), Database and Information Retrieval (DB), Human-computer Communications (HU), Numerical and Symbolic Computation (NU), Operating Systems (OS), Programming Languages (PL), and Software Methodology and Engineering (SE). Each area is subdivided into several Knowledge Units (KU).

Literally, the common requirements form the basis for a curriculum in computing by providing a platform of knowledge that is considered essential for all students who concentrate in the discipline [Denning, 1989]. Adequate curricula will be implemented by combining those KUs and integrating other specific requirements and advanced or complementary topics.

The report specifies that the discipline of computing encompasses the labels computer science, computer science and engineering, computer engineering, informatics, and other similar designations. For us, this *universal definition* is one of the weakest points of the report. It does not reflect an objective analysis but the wish to reach a consensus between the two societies composing the task force.

2   A three layer computing curricula architecture as an alternative point of view

In [Sáez-Vacas, 1990], it is argued that "we might need several different curricula to face very different educational situations, and not just one or two curricula". The same author proposed a basic architecture to build a variety of curricula. Among the architectural elements is the principle quoted as follows: "any curriculum must offer with greater or lesser intensity three layers of topics: a) the essential layer, b) the instrumental layer, and c) the application layer (see figure 1, expressing bottom up decreasingly fundamental topics)".

The essential layer copes with fundamental topics related to information and its processing: what information is; how it is represented,
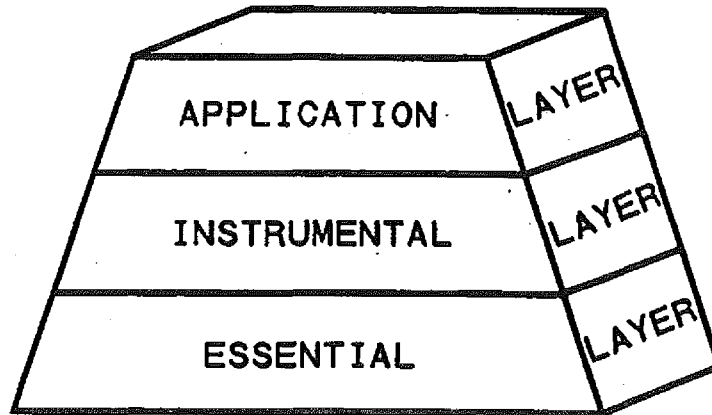
Figure 1: Computing curricula layers

stored, transmitted, measured and organized; what the limits of computations are; what the basic mechanisms to do all the previously mentioned operations are (at machine level, at symbolic computing level, at data structure level), etc.

The instrumental layer is the realm of the physical, logical and technological instruments with which we can integrate systems to solve a lot of information problems: languages, compilers, processors, circuits, devices, operating systems, data transmission protocols, data bases management systems, coders, computer and network architectures, etc.

The application layer points to the application areas where those instruments become purposeful. Some examples are the fields of Management Information Systems, Process Control, Image Processing, Computer Graphics, C.A.D., C.A.M. and Telematics. This layer is created with techniques and concepts taken from the computing (essential and instrumental layers) specifically adapted to enforce the application oriented functions.

It is theoretically possible to conceive of many curricula as being structured around these three layers. Each curriculum would require

a peculiar density and composition configuration of the layers. We can symbolically represent this approach by a concentric circles model whose ring thickness tries to stress the idea of relative emphasis (perhaps quantified in number of credit-hours) assigned to each layer, not the ordering of topics in a curriculum.

3 Some criticisms

Figure 2 illustrates as an abstract example three extreme curricula profiles. In our opinion, the common requirements proposed in the ACM/IEEE-CS curricula model share topics in the essential and instrumental layers, being so forth in an eclectic position between the leftmost profile and the centered profile of figure 2. Then, it is evident that they can not be appropriate for all the computing academic community.

The rightmost profile ideally represents other strongly computing oriented curricula. They need to include proper contents of the essential and instrumental layers, but not the same or with similar proportions. This is the case for Telematics as some authors have shown [Sáez-Vacas, 1991b].

We would like to emphasize two other weak aspects of the ACM/IEE] CS proposal.

First, several essential concepts relevant to nowadays computing are missing. It is specially relevant to have forgotten the consideration of the computer as a *communicating machine* when, in reality, computers and communications (C&C) are strongly linked in practice. Related to it, the Task Force has adopted a very conservative role. This role also appears when considering the relevance of the complexity of the computing technology. Precisely, the Association for Computing Machinery devoted to this topic its first Conference on Critical Issues [Frailey, 1991]. The Task Force could have perfectly include a subject area on techniques for understanding and managing complexity (we will came back to this point later).

Second, and in spite of a first reading, the ACM/IEEE-CS is only contents-oriented. It is true that, for each KU, the model suggests using a subset of recurring concepts, like binding, complexity, consistency, levels of abstraction, ordering, reuse, tradeoffs, etc., but nothing about how to apply them; in this sense it is very soft and useless for

a) Computing or
Information Science

b) Computer Science
or Engineering

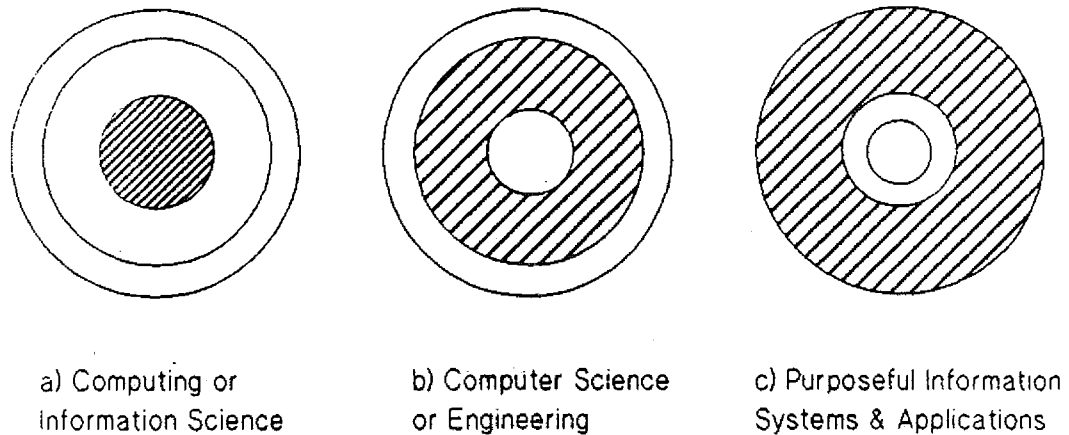c) Purposeful Information
Systems & Applications

Figure 2: Three archetypical computing curricula

teachers when they need to apply them.

We believe that those concepts are, besides others not considered by the Task Force, the elements that condition the selection and approach of the chosen contents.

4 A more comprehensive model for computing curricula

Until now, we have considered an architecture for computing curricula based on three layers: essential, instrumental and application. From now on, we will use the figure 2c synthesized as figure 3.

Roughly, the essential and instrumental layers constitute a domain or tuned kernel on general computing. It will be as wide or dense as necessary for a non strictly computing curriculum. To complete an architecture oriented to such a field, we propose a model based on three domains, similar to the three layers model depicted in figure 1.

Next domain is composed by the application layer linked to the techniques and essential or instrumental concepts relevant to this ap-
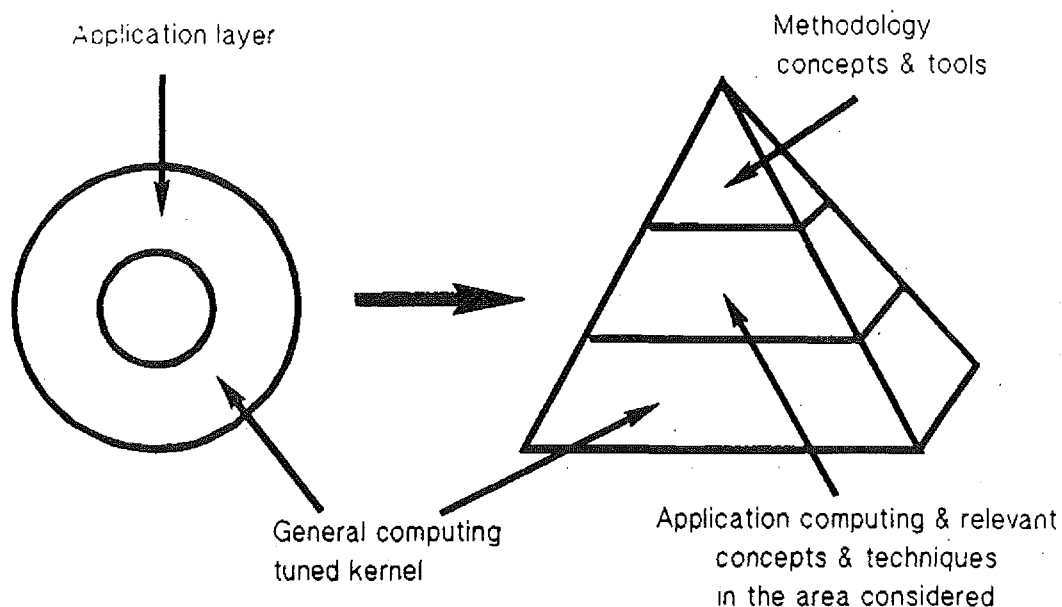
Application layer

Methodology
concepts & tools

General computing
tuned kernel

Application computing & relevant
concepts & techniques
in the area considered

Figure 3: Three domains model for a strongly computing oriented curriculum

plication area[1].

The third domain contains some elements that become this architecture in a sharp instrument in society. In fact, some emerging traits (unquestionable companions of the computing discipline) seem to have been missed:

- **Complexity,** a constant and growing feature in the analysis, design and management of computer-based systems.

- **Human factors,** an aspect of capital consideration in the whole process of producing and using these systems. This aspect is broader than the area of Human-Computer Communication (already included in the ACM/IEEE-CS common requirements).

It is a fact widely recognized by professionals that complexity is a pervasive and quasi-exponentially increasing feature of computing:

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[1] There are areas that, by tradition or by their genuine importance, can be configured themselves as a three layers architecture; those layers will be combined with the computing layers to build up the curriculum. Notice that Telematics is one of the computing application areas that, due to its deep interleaving with computing, has the propriety to feedback and modify the essential and instrumental layers of computing.

the complexity of an algorithm, the complexity of a program, the complexity of an integrated circuit as a powerful microprocessor, the complexity of highly parallel computers, the complexity of managing a software development project, the complex interactions between technology and economy, etc.

First, in each of those situations, part of the complexity is in the observer's mind. So, we can conclude that an inadequate or overly specialized education of the observers is a complexity source that should be to some extent avoided. Second, it is obvious that these observers (i.e., the computing scientists and professionals) need to be educated in the abstract methods and techniques of complexity management: hierarchies, abstractions, systems thinking, problem solving, modelling, uncertainty understanding, etc.

Finally, human considerations are key issues. Some examples will illustrate this fact:

- The production of large computer-based systems is a collective effort. Effective manpower management is therefore an important factor in the success of any project.

- A second ingredient of success is the accomplishment of user's needs. In this sense, techniques for an efficient communication and understanding of user requirements or for man—machine interfacing are clearly necessary.

- Third, the deep impact of this technology on man and society challenges the fields of psychology, sociology, economy and philosophy, and requires from computing professionals a high degree of knowledge, understanding and responsibility.

We are of the opinion that an adequate attention and coverage of these dimensions in the curricula is essential for the successful education of tomorrow computing professionals.

A third trait, called Mathematics and Science requirements in the ACM/IEEE-CS curricula, can never be neglected as it provides knowledge, rigorous methods and intellectual abilities which are fundamental to master most of the computing topics.
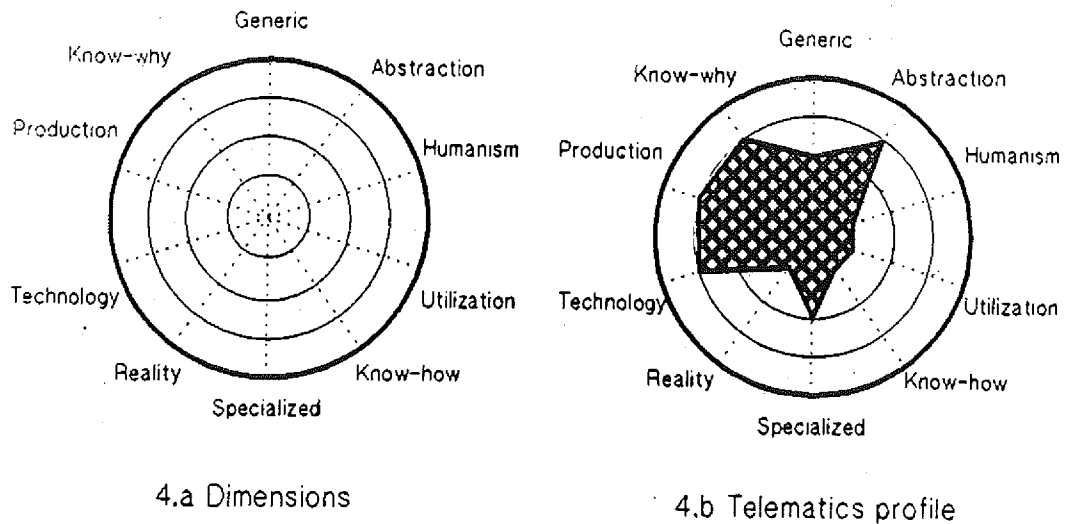
4.a Dimensions

4.b Telematics profile

Figure 4: Profile Characterization

5 Key criteria for the design of any high level curriculum

The design of any curriculum is something more than a choice of items from a menu, and it should produce something more than an annotated table of contents. Design criteria are at least as important as contents, these criteria being the guidelines that define the three aspects involved in curriculum design: objectives, contents and educational method.

The criteria affecting these aspects can be represented, in a simplified way, as axis or dimensions showing opposite but complementary views. The circle represents a framework to locate a profile inside the possibilities of a concrete curriculum. Obviously, this profile will evolve during the whole professional life of an individual. In a particular situation, it will be necessary to select the adequate amount of any of these extreme positions (see figure 4).

In this paper we will only address criteria about the aspect we have called *contents*.

According to usual criteria, contents can be classified in three

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groups: a) concepts, principles and facts; b) procedures; c) attitudes, norms and values. About the first two groups, we consider the following criteria:

- **Abstraction / Reality**
  As tasks and tools have become more complex, the work of computer scientists and engineers has become more analytic and abstract, enclosing them in a symbolic world, far from reality. Some kind of compromise is necessary to produce a balanced education.

- **Generic / Specialized knowledge**
  The same complexity and exponential increase of knowledge corpus that we find in information technologies, has forced a great degree of specialization. However, highly specialized knowledge in a rapidly evolving environment becomes obsolete in a few years.

- **Production / Utilization**
  Education for users and producers of computer-based technologies can not be obviously the same. Computer scientists and engineers are supposed to be, to some extent, producers of computer-related products; however, this production can only be made using computer-based tools.

- **Know-how / Know-why**
  Know-how (the set of technical knowledge necessary to carry out a production process) is the engine of any economy, while know-why (the basic knowledge and underlying mechanisms in those processes) is the engine for technical innovation. The desired product profile should determine on which aspect more emphasis is needed.

Concerning the aspect we have called attitudes, norms and values, one dimension can be highlighted:

- **Humanism / Technology**
  Computers are among the most important factors of social and economic change in our society. Computer-related professionals have to be conscious of this fact. Thereafter, this dimension can not be dismissed in any curriculum design.

6 Application to the Telematics Engineering curriculum

6.1 Professional context

Reports elaborated by many organizations around the world in the last years indicate that the introduction of new manufacturing methods and technologies in a specific industrial context is strongly dependent on the availability of professionals capable of understanding the effects of computers and communications on the design process. This is the realm of Telematics.

In Spain the situation is quite similar. Several meetings and workshops [Sáez-Vacas, 1991a] between academia and industry have been organized to evaluate the knowledge requirements for these professionals. From them, it was recognized that the human capital constitutes the key for innovation. Continuing education will constitute, in this framework, a growing percentage of the engineer activity and its costs are progressively accepted by the companies. Simultaneously, more than specific knowledge, industries appreciate the capability to learn. Any reorganization of the academic curricula should start from these premises.

6.2 Academic context

From the generic knowledge offered by a university (typically, a bachelor degree or first cycle depending on the country) until reaching the specific knowledge necessary to develop a professional activity in a company, several educational profiles can be identified [León, 1991]. These are:

- **Generic profile.** It is offered by a University during the first cycle. In the case of Engineering Schools, it is devoted to obtain sound knowledge on mathematics, physics and informatics. All of them constitute a basic set of conceptual tools to build up specific profiles.

- **Basic profile.** It is offered by a University during the second cycle. Usually, it starts from a generic profile and opens the curriculum in several directions, taking into account the industrial, social and technological environment.

- **Derivate profile.** The technological evolution of the Information Technology demands the mastering of new methods or techniques necessary to design systems within an application domain; they are difficult to accommodate in a five-year curriculum. Graduate programmes cover this gap.

- **Professional profile.** It is usually offered to learn the use of the tools, methods and procedures linked to a job. It is so dependent on the internal procedures and culture that it is very difficult to establish an open programme.

An engineer will design (actively or not) his/her own educational trajectory moving from a profile to another as a consequence of his/her needs or interests. In some cases, the gap between two professional profiles is so wide that a new derivate or even a basic profile is required.

We will focus this paper upon the design of the Telematics Engineering curriculum at the Telecommunications School of the Technical University of Madrid. Although it is not completely finished, its general structure, defined by the Spanish Government, is characterized by:

- Two cycles: 3 years + 2 years without intermediate degree (standardization within the EC).

- Elective and mandatory courses organized in semesters. These courses could be theoretical or practical (laboratories with independent evaluation). Most part of the elective courses are concentrated on the second·cycle.

- Several specializations will be offered during the second cycle (like Telematics, Radiocommunication, Digital Signal Processing or Microelectronics) although the student can partly configure their own curricula with elective subjects from other specializations or even from other curricula.

- A master project is mandatory at the end of the five years curriculum. It is freely chosen by the student and it is usually related to the specialization chosen during the second cycle.

6.3   Analysis from the curriculum model

The implementation of a new curriculum should start from the academic and professional context summarized above, and within the

framework of the chosen educational profiles. It is our responsibility to build up such a curriculum to cover the needs declared by the industry now and the future requirements that the technological evolution will present.

The Telematics profile is a basic profile derived from the generic profile on Information Technology (known in Spain as Telecommunication Engineering). Some derivative profiles as Communication Software Design or Communication & Switching Architectures are offered in a postgraduate programme on Communication Networks and Systems [Figueiras, 1991] designed with the collaboration of many Spanish industries.

The characterization of the Telematics profile can be done by applying the circular diagram proposed in the preceding section. According to it, figure 4b represents this characterization under the subjective perspective of the authors. Emphasis on abstraction, know-why, production and technology seems relevant.

Next step is to define the contents through the identification of its basic ingredients and quantities. In preceding sections a pyramidal model of curriculum was presented to combine the components of a curriculum. In this section we will apply such a model to explain and analyze the Telematics profile. The objectives and required knowledge at each level is as follows (only computing subjects are mentioned)[2]:

- **General Computing kernel**

    - Belonging to essential layer: programming, fundamentals of computers.

    - Belonging to instrumental layer: computer architecture, operating systems, microprocessor based systems, software engineering, databases, distributed processing.

- **Communications oriented computing & communications techniques**

    - Electronics (devices, analog and digital circuits), control systems.

    - Computer networks (OSI model, internetworking, proprietary networks), Communication Software Techniques (services and protocol design, ODP, formal description techniques), Switching systems (switching principles, signaling

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[2] A so-called infrastructure layer provides the general basis on mathematics and science.

techniques, ISDN, Broad band, etc.), Communication systems (LAN, MAN, mobile services, VSAT, etc.), Digital Transmission (codecs, packet switching, virtual circuits, ATM, error management, etc.).

- **Methodology concepts & tools**
  - Applied mathematics
  - Large systems design
  - Complexity management techniques
  - Social impact of Telematics

6.4 Comparison with the ACM/IEEE-CS curriculum

It is interesting to compare the topics covered in the Telematics profile with the international recommendation generated by ACM and IEEE-CS. This is a posteriori comparison because the Telematics curriculum was conceived well before the publication of the ACM/IEEE-CS curriculum (and with other perspective and constraints). However, this exercise provides a deep insight into the curriculum and its usefulness. The comparison is restricted to the computing requirements of the Telematics basic profile.

Figure 5 shows graphically this comparison. In it, we can see some areas not covered by the common requirements (kernel) of the curriculum proposed by the ACM/IEEE-CS Task Force. These are, however, absolutely necessary to offer a basic Telematics profile. On the other hand, parts of the kernel are not relevant to the Telematics curriculum. It is true that the credits allocated to the common requirements are not a significant part of the total credits in a five-year curriculum. This fact only implies that emphasis should be placed on the communications part. The credits uncovered by the telematics kernel are intended to offer a broad perspective of the computing discipline and seem irrelevant to this kernel. In other words, ACM/IEEE-CS common requirements are not what we have called the Telematics computing kernel.

Specifically, the required extensions identified until now are:
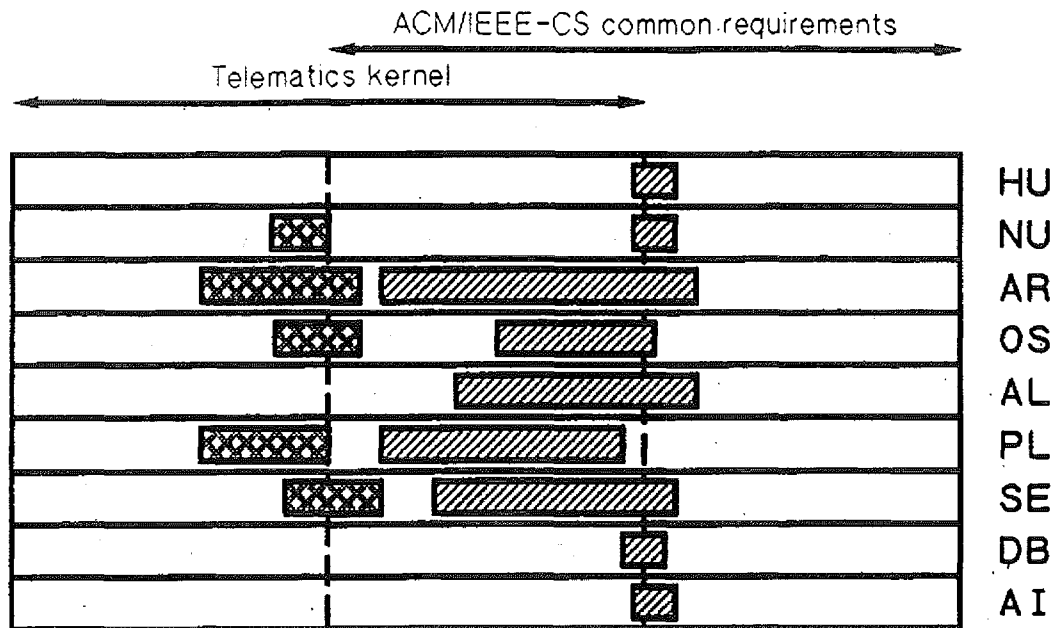
- **Extensions to NU: Symbolic computation.**

Figure 5: Comparison between ACM/IEEE-CS common requirements and the telematics computing kernel

- Extensions to AR: description of switching architectures (switching matrix) and gateways, routers, bridges, etc., under the OSI model.

- Extensions to OS: wider covering of the client-server model and distributed processing applications support.

- Extensions to PL: wider covering of concurrent and distributed programming. Formal description techniques (ISO or CCITT standards) and graphical notations.

- Extensions to SE: real time systems analysis and design.

The analysis of figure 5 also indicates the difficulty to adapt the proposed common requirements of the curriculum to educational profiles with a broader perspective than the considered there. This fact is not due to lesser emphasis on computing but the recognition of other common requirements.

7 Conclusions

This paper has presented a conceptual model of curricula design taking the proposal from ACM/IEEE-CS as a reference framework. The applicability of the conceptual model has been demonstrated during the analysis of the present curriculum on Telematics and during the design of a new curriculum (in progress) at Technical University of Madrid.

A parallel analysis of the IEEE-CS/ACM curriculum has revealed some weak points in their conception. First, some essential concepts relevant to computing seem missed, specially those related to the computer as a communicating machine (e.g., information theory fundamentals). Other drawback is the lack of emphasis to complexity as a proper aspect in computing technology. Second, and despite the outside (e.g., recurring concepts), the curricula proposed by the Joint Task Force is mostly contents-oriented.

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