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The Application of Artificial Intelligent Techniques to Accelerator Operations at McMaster University*

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In an era of downsizing and a limited pool of skilled accelerator personnel from which to draw replacements for an aging workforce, the impetus to integrate intelligent computer automation into the accelerator operator's repertoire is strong. However, successful deployment of an "Operator's Companion" is not trivial. Both graphical and human factors need to be recognized as critical areas that require extra care when formulating the Companion. They include: interactive graphical user's interface that mimics, for the operator, familiar accelerator controls; knowledge acquisition phases during development must acknowledge the expert's mental model of machine operation; and automated operations must be seen as improvements to the operator's environment rather than threats of ultimate replacement.

Experiences with the PACES Accelerator Operator Companion developed at two sites over the past three years are related and graphical examples are given. The scale of the work involves multi-computer control of various start-up/shutdown and tuning procedures for Model FN and KN van de Graaff Accelerators. The response from licensing agencies has been encouraging.

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1. Introduction

In an era of downsizing and with a limited pool of skills accelerator personnel from which to draw replacements for an aging workforce, the impetus to integrate intelligent computer-based automation into the accelerator operator's repertoire is strong. For most process control situations this takes the form of computer aided monitoring and control task operations. Equally prevalent is the role that artificial intelligent techniques, and more specifically expert systems, play in these supervisory and control systems (SCS)[1]. Advantages include providing the SCS with a reasoned directed behaviour, the ability to communicate effectively and the ability to adapt in the light of experience[2]. For the accelerator, expert operation capabilities encapsulated in the SCS allow less skilled individuals to perform at seasoned levels, keeps knowledge on-line 24 hours per day and allows consistent and safe machine operation which bears directly on licensing considerations.

The development of SCS must deal with two main issues: (1)what information must be presented and (2)how it is to be presented. The former involves an expert system in the traditional role of dispensing expert decisions based on knowledge gleaned from a domain expert. The latter is a relatively new field which is a hybrid involving both domain and human factor experts.

Human factor considerations cover a large range from workplace layout to video display organization. Usually an expert in human factors' engineering can be instrumental in realizing such advantages to the human computer interface. This "design based on human characteristics"[3] can be significantly augmented by user modelling [1,4] where the SCS alters information presentation based on some explicit assumption about the user. These assumptions are usually determined from a knowledge-base derived from a domain expert.

Under the heading of "The What" of information presentation, it is generally recognized that two forms are prevalent in SCS and both involve domain expert knowledge. They are (1)process control decisions and (2)intelligent monitoring duties[1]. For the purposes of this discussion, the former involves automating tedious operator tasks through direct control while the latter aids the operator by monitoring process conditions, detecting faults and diagnosing malfunctions. In both cases, the capability of real-time response is crucial. One definition of this requirement is that the system must reach its conclusion faster than the plant does[5].

A final trend in SCSs is also noteworthy and that is the shift of emphasis in design philosophy from machine centred system towards human centred considerations[6]. No longer are the process operational details paramount (which are usually determined solely by the design engineers) but rather it is the process operator's mental model of the system that the SCS must manipulate. That is, just as the electronic engineer will match impedances at the interface for maximum signal transfer, a knowledge engineer must create an intelligent SCS which presents and manipulates the operator's mental model of the process for optimum information transfer at the man-machine interface.

In the above milieu, the following sections outline the design strategies and implementation considerations for a SCS called PACES, Particle Accelerator Control Expert System, which has been successfully installed at several Model KN Van de Graaff accelerator sites (Ottawa, Defence Research Establishment and McMaster University, Hamilton, Ontario, Canada). Details of components and operation are given elsewhere[7,8,9,10], however briefly, the personal computer (PC) knowledge-based system uses a graphical user interface (GUI) based on Microsoft Windows (v3.1) and employs embedded single board computers (SBC) to facilitate real-time operation.

2. Design Philosophy

Consider first, the generation of information in PACES. As with most SCSs, the act of design is intimately coupled with accommodating constraints. Of significant importance in this work is the desire to employ expert system intelligence with minimum impact on the real-time system response. Certain fundamental principles can be applied to aid this coupling of slow knowledge transactions to high speed real-time data processing. Prime among these principles are the concepts of both temporal and functional abstractions. Design principles, for the purposes of this work, can be defined as application independent heuristics which address key issues by constructively constraining the system hardware and software realizations[11]. As Fig.1 and Fig.2

illustrate, the migration of these principles into the implementation domain underscores the trade-off between the above abstractions and the speed/intelligence attributes of the SCS. This is perhaps best explained at the implementation level.

Other strategies employed, these at the human factor level, include the incorporation of user modelling. More sophisticated systems have been constructed to acquire a model of the system user (operator) automatically[12]. However for PACES, as shown below, a manual mode for user description has been incorporated under the envelope of site customization, so that human factor input is guided by the system but originates with the domain expert.

3. Implementation Considerations

For the enhancement of real-time performance within an intelligent control system and deliverability on a personal computer platform, a two-tiered multiprocessor architectural hardware structure has been adopted for PACES. At the lowest level, algorithmic procedures are vested in single-board computers (SBC). At the highest level of control, an expert personal computer (PC) assimilates the monitoring information and reacts with control directives that are carried out in detail at the SBC level. The latter processor uses traditional assembly language programming to accomplish time critical control tasks. The former processor operates more slowly but manipulates symbolically. Hence, the knowledge processor can be said to be operating with a higher level of temporal abstraction. Such a realization of this abstraction is given in Fig.3.

Software design includes the traditional modular development but is additionally clustered into functional layering schemes so as to conform to the hierarchical architectural platform on which the system is implemented. When viewed on a more global plane, such considerations prove to be examples of functional abstraction where information hiding at appropriate levels also aids real-time operation. For PACES, the three natural modes of operation are STARTUP, SHUTDOWN, and TUNE. The latter layer is concerned with maintaining beam parameters or modifying them as desired by operator request. In all cases, any non-nominal behaviour is detected by a failure-driven SBC asynchronous routine and dealt with under a set of diagnostic procedures as extracted from the human expert. A set of tolerance windows, indicating nominal parameter behaviour, has been determined from knowledge illicitation of the expert for numerous contexts which the expert system has been able to recognize. In this manner, some dynamic algorithmic decision-based capability has been shifted into the SBC for rapid abnormal condition detection.

An investigation into intelligent interfacing provided the concept of user modelling techniques[12], where capability proved to be adequately implemented in real-time using a traditional programming approach. Specifically, the seasoned site administrator has the freedom to customize attributes of various staff operators according to experiential levels of accelerator expertise. For example, for novice operators, a ceiling on beam energy tuning can be set. Other facets of the developed GUI (implemented in Borland's Turbo PASCAL) made extensive use of object-oriented features (Eg. inheritance).

4. Conclusions

The development of multiprocessor control systems which marry the contained human expertise of symbolic processors and the speed of real-time systems involved in numeric processors allows the creation of intelligent resource management systems that directly and constructively affect the controlled environment.

Such complex system development is eased by adherence to certain fundamental design principles. Paramount among them, for real-time knowledge-based control systems, are abstractions of both functional and temporal natures. Guidelines which aid these structures include intelligent partitioning strategies and natural planning considerations that follow normal operating modes of the application. A modicum of user modelling techniques and graphical interfaces serve to constructively enhance manipulation of the expert operator's mental model of the process. Such human centred activity has been shown to be more beneficial for intercommunication at the man-machine interface level than has the more traditional machine centred approach.

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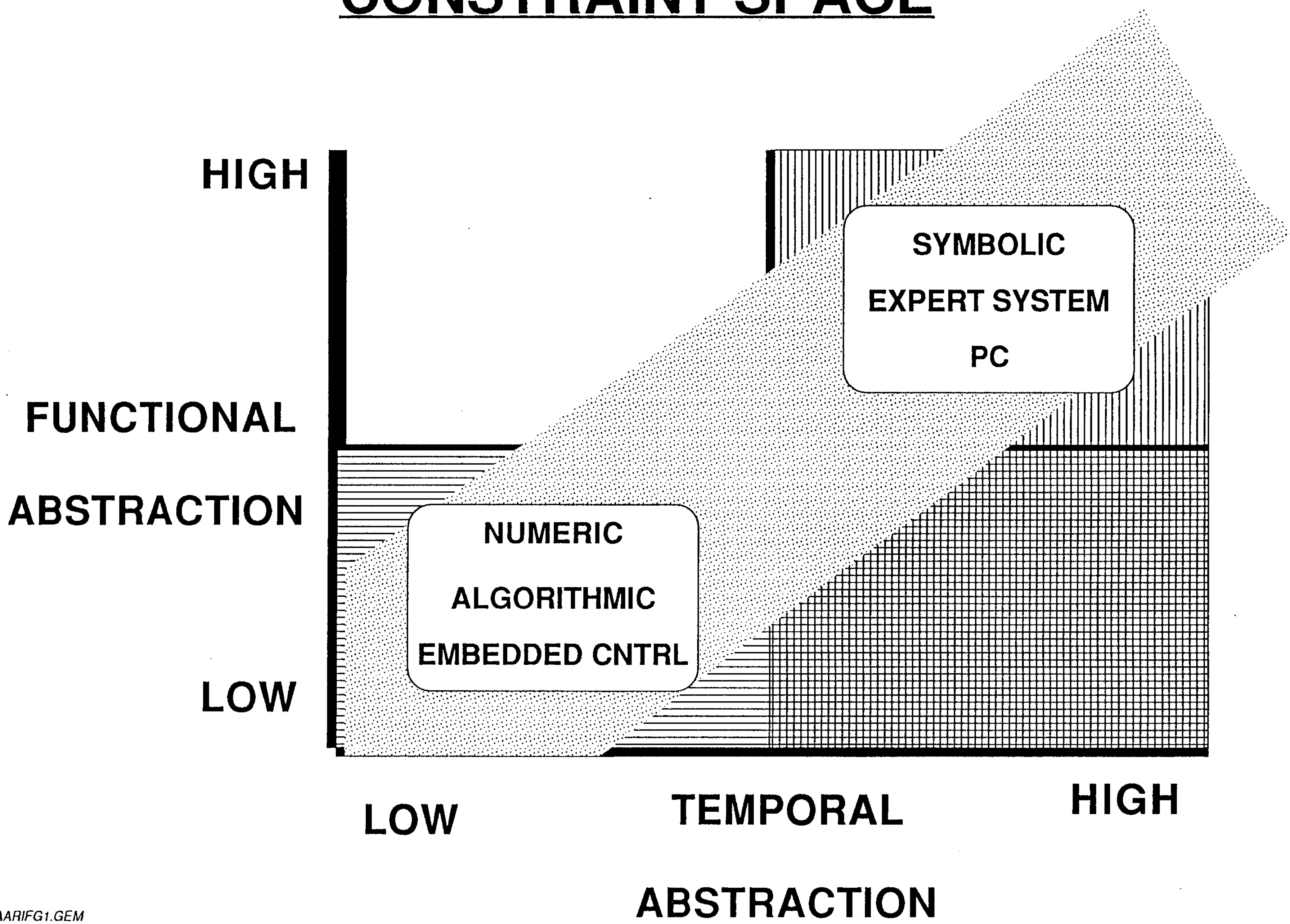
Figure Captions

Fig.1. Design strategies focussing on both temporal and functional abstractions as provided by symbolic and numeric processors. For a supervisory and control system the desirable operational space is denoted by the diagonal dotted ribbon.

Fig.2. Implementation considerations that originate from the design space of Fig.1 is illustrated by the two dimensions involving intelligent behaviour and real time performance as exhibited by the supervisory and control system.

Fig.3. Example of an application based (PACES) mapping from design strategy to implementation approach.

CONSTRAINT SPACE



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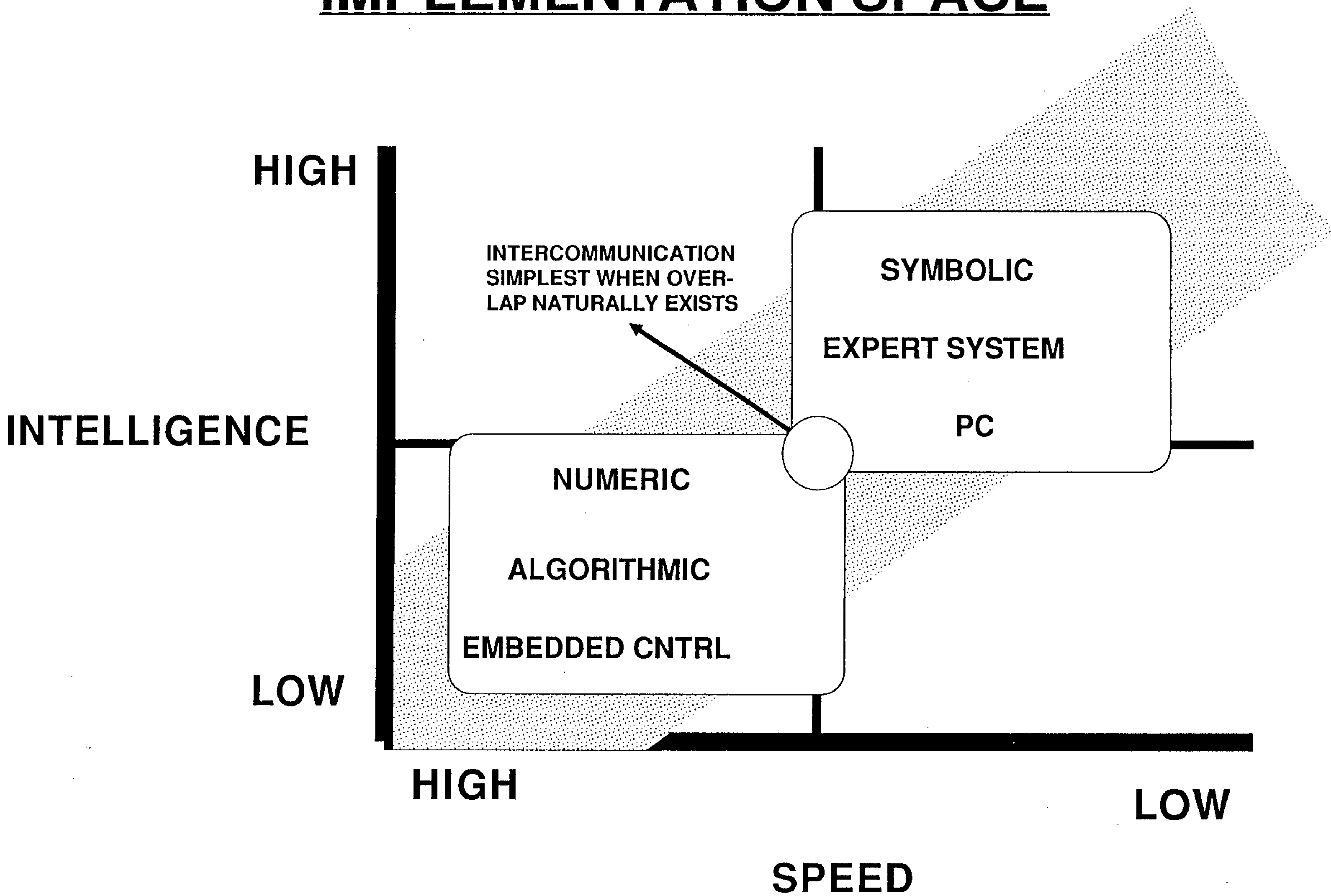
IMPLEMENTATION SPACE



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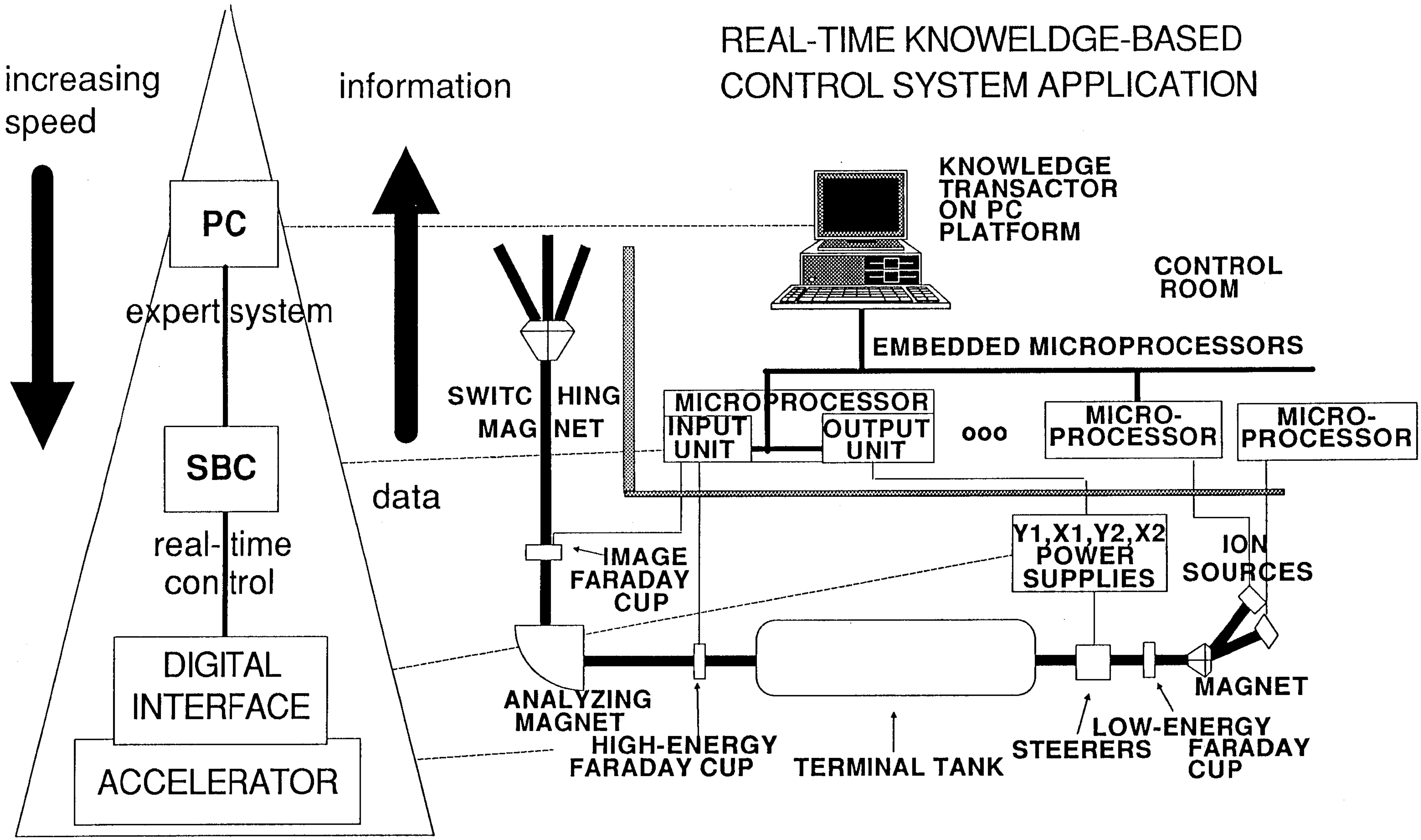

KNOWLEDGE-BASED REAL-TIME SYSTEM
DESIGN STRATEGY

AARIFG3.GEM
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