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# Centralization and Decentralization in the TRIUMF Control System

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## 1.0 INTRODUCTION

The increased demands of an expanding accelerator laboratory have made it timely to consider strategies for expansion of the TRIUMF Control System. These requirements have led to reflections on one of the major themes of this conference - centralized vs distributed digital control systems for accelerators. This paper discusses the way in which the TRIUMF system successfully combines elements of both approaches.

## 2.0 CENTRALIZED AND DISTRIBUTED CONTROL

The phrase "distributed processing" does not have any single, simple and precise meaning. We have identified four aspects of digital control systems; hardware, software, data bases, and operator control stations, all of which may be distributed to varying degrees in different system configurations.

**2.1 Hardware.** Multiple distributed processors economically provide more CPU and Input/Output cycles per unit time, as well as the possibility of hardware redundancy. The degree of centralization, however, is not determined by the power of the processors, nor by their geographic distribution.

What most clearly characterizes such a system is the topology of the communication system linking its processors. Some topologies may require all messages to pass through a single computer node, whereas others may permit any processor to communicate directly with any other. Topology and software together should be designed to minimize the interprocessor communication required.

**2.2 Software.** The software analogue to the distribution of processors is the distribution of "tasks," which may be grouped according to geography, equipment type or by function. The amount and level of task grouping determines the selection of an operating system, which may range from multi-user multi-task to dedicated single task systems. One advantage of the former is the ease of intertask and application-driver communication. However considerable overhead results from task and process switching and the possibility exists of one task or user interfering with another. A potential disadvantage of the latter case is the overhead of increased communication, which can be minimized by designing tasks which are as independent as possible.

**2.3 Data Base.** An element of any control system which may be more or less distributed is its data bases. Several data base types, each of which may be distributed to a different extent, are discussed below.

Firstly, there is a fixed data base frequently referred to as the "device tables," which describes machine parameters such as device name, access method, and operational limits. Closely associated with this data is the software required to use it. These tables and associated software might exist in one place only or could be distributed for easy access by those processors requiring them.

A second conceptually distinct fixed data base describes console devices, such as buttons, knobs, and displays. Again, this requires fixed, descriptive data, and programs which refer to it.

A third data base describes complete machine parameterizations required to achieve specific operating conditions, such as energies and timing structures. In situations where the operating mode requires rapid or frequent changes, this must be immediately accessible to the processors using it.

The final type of data base is the "live" or variable data which represents the current state of the accelerator. This includes raw single parameters, such as magnet fields or beam current, as well as calculated parameters, such as beam polarization or emittance.

**2.4 Consoles.** The widespread use of redundant, fully assignable operator consoles imposes constraints on the distribution of hardware, software, and data bases. A completely general console must have access to all accelerator processors, processes, and data. This may be achieved in several ways, ranging from one processor responsible for all consoles, to a number of interconnected processors, each responsible for a separate part of the console process. Some degree of local control is also required for many subsystems. This may be achieved by truly local control stations having access only to the hardware, software, and data required; or by the "soft" dedication of an otherwise fully assignable console.

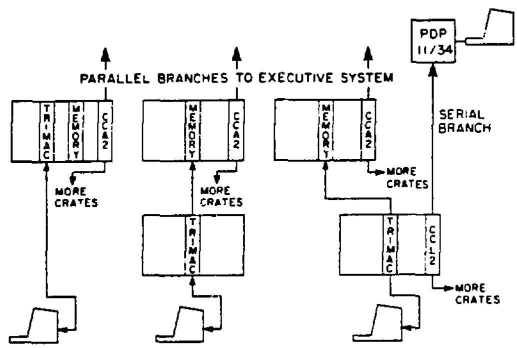
Regardless of how multiple control stations are implemented, the possibility of conflicts between different stations requesting access to the same parameter must be resolved. The complexity of the resulting protocols will depend largely upon strategies adopted for the distribution of processors, tasks and data bases.

## 3.0 THE TRIUMF CASE

The TRIUMF control system is considered to have three levels: a CAMAC level, an executive level, and an applications level. Each level is discussed with a view to showing how its design has incorporated characteristics of both "centralized" and "distributed" digital control. Figure 2 is a schematic representation of the complete system, showing the rather arbitrary division between levels.

**3.1 The CAMAC level.** The lowest, or CAMAC, level is a conventional parallel branch system having seven branches and 43 crates. No attempt is made to centrally store the distributed "live" data base of raw machine parameters contained within this system.

Many crates house TRIUMF designed intelligent controllers known as TRIMAC (2), which has recently been upgraded to accommodate 5K of RAM and 32K of EPROM. Figure 1 shows three sample applications of TRIMAC processors in the CAMAC layer, where distributed architecture is most clearly represented at TRIUMF. Each interacts with the CAMAC system and executive layer in a somewhat different fashion, and represents differing degrees of distributed control. One (fig. 1b) is a stand-alone system, passing data to a dual-ported memory in a central system crate. Another (fig. 1c) is an independent control system using a PDP 11/34 and serial CAMAC highway, with TRIMACs for local control.




1a 1b 1c

**Figure 1**
**Typical TRIMAC System Configurations**

Figure 1a represents a dedicated TRIMAC based beam steering system designed to centre and align the low intensity polarized proton beam being delivered to a sensitive asymmetry measuring experiment. Signals read from secondary emission plates (SEMs) are averaged, misalignments determined, and a matrix inversion used to calculate corrections to four beam steering elements.

Control is passed from the operators to this loop by the setting of a flag, matrix elements and other loop parameters in the shared memory. In this case the "local" control console is located in the experimental data acquisition room. The data is also made available in machine readable form to the data acquisition system. All relevant loop parameters are directly available to the TRIMAC, except for one steering magnet whose controller is housed in another crate, and whose TRIMAC calculated set point must be moved by an executive level computer. The overall system configuration makes this extremely easy to do, but it is annoying nonetheless. Another bus structure, such as FASTBUS, would eliminate this limitation which is imposed by the CAMAC system structure.

**3.2 The Executive Layer.** Elements of both centralization and decentralization are to be found in the "executive" layer, which is discussed under the headings used to characterize distributed processing: hardware, software, data base, and consoles.

3.2.1 Hardware. The distinguishing feature of the executive level hardware is the use of multiple mini-computers, all centrally located in the main control room, and of three independent interprocessor channels: the Multi-processor Communications Adaptor or "MCA"; the Multiport memory or "MPM": and CAMAC (See figure 2).

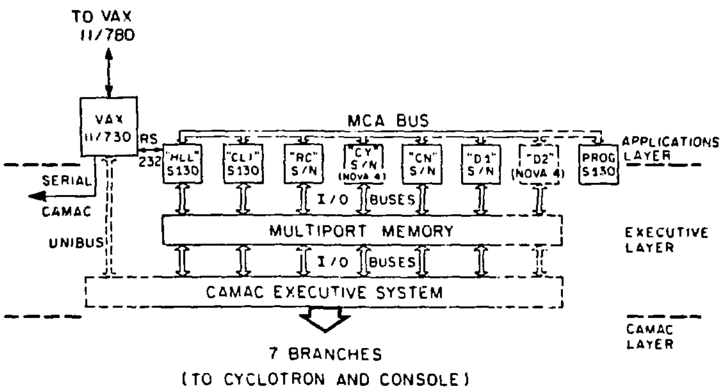



**Figure 2**
**The TRIUMF Control System**

The MCA is a vendor supplied parallel direct memory access bus which links the executive level computers, and allows several processors to work together in truly distributed fashion to perform a single function. For example the "CY" computer collects data which is passed to "CN" for display on the main console. The link also allows programs to be loaded quickly and easily directly from the program development computer.

The MPM is a TRIUMF designed multi-ported memory, housed in a CAMAC crate (2). In principle, ports adapted to any computer bus could be designed compatibly. Programmed I/O, DMA, and message passing modes are all available.

The TRIUMF CAMAC interface is a multi-sourced system based upon the GEC Elliott "Executive Crate" architecture, which provides a versatile multi-processor data flow node. The present system of six computers is soon to be expanded to eight by the addition of two active executive crate extenders, and of a third crate to accommodate new source interfaces. This extension will permit direct interfacing of the 32 bit VAX 11/730. Further expansion is limited by bandwidth (now only 15 - 20% used) to a maximum of 30 sources.

3.2.2 Software. Executive level software consists of a small, real-time multi-tasking scheduler as well as the common subroutines in the Supernovas. These routines, which together occupy about 14 K words in each 32 K word computer, give access to the MCA, MPM and CAMAC. TRIUMF has examples of three types of operating systems: multi-user, multi-task in the VAX and Eclipses; single-user multi-task in the Novas and some TRIMACs; and single task in other TRIMACs. Program development is carefully isolated in a separate system.

3.2.3 Data Base. The TRIUMF executive layer provides access to the various data base types described in section 2.3, and it is here that the blend of centralized and distributed concepts is most apparent. Device tables are located in the fully centralized MPM, yet each central system processor has direct access to them. The interpretation of these tables, however, is by common subroutines repeated in each computer.

There exists at present no data base in the TRIUMF system to describe console devices - each program contains its own dedicated subroutines for that purpose. This deficiency is characteristic of neither centralized nor distributed data bases - it is simply poor design.

Finally, the 'live' data base describing current machine parameters is distributed throughout the CAMAC system (1). Nonetheless, every parameter is directly accessible to any computer source on the CAMAC system. This includes calculated parameters which may be evaluated by any processor at any level and then stored either at a CAMAC address or in the MPM. Thus all machine parameters will be directly available to the VAX when it is interfaced to the executive crate, and any complex parameter which it might calculate, such as beam emittance, will be readily available to all central system computers, with no need for any communications protocol or overhead. This example demonstrates the value of an appropriate mix of centralized and distributed philosophies in the TRIUMF design.

3.2.4 Consoles. The implementation of several categories of operator consoles at TRIUMF provides another example of the mixture of centralized and distributed ideas at TRIUMF.

The unique main console is largely dedicated, requiring specialized software, not universally accessible, to interface to it. By interfacing the central console *to a CAMAC branch, it becomes directly available to all executive and applications* level computers. This permits a high level application to attach a complex control algorithm to a main console knob directly.

The REMCON consoles provide unsophisticated readback and control of all accelerator variables (1). They are perhaps the earliest examples of fully assignable, redundant consoles. Interfaced via CAMAC, but distributed geographically around the laboratory the panels are all serviced by the same computer, labled "RC" in figure 2. They offer truly distributed control as a result of their access to both the distributed (CAMAC) and centralized (MPM) data bases.

The TRIMAC-serviced operator consoles in the CAMAC layer are truly local, having access only to that data collected within the local subsystem.

Although the TRIUMF configuration would make a protocol to eliminate conflicts easy to implement, no such precaution has been taken. Conflicts seldom arise, and they are most efficiently resolved by direct oral-aural inter-operator communication on the voice band.

**3.3 The Applications Layer.** The applications layer currently consists of a DEC VAX and the six Data General Novas, linked to the executive level as shown in figure 2.

Application level software in the Novas is distributed by function, rather than by accelerator subsystem, and the symmetry of executive level interfacing allows any processor to run any program. A consequence is that if one computer should fail, some degree of control is maintained over all cyclotron subsystems.

The VAX has been added to introduce a more sophisticated level of accelerator physics into cyclotron development and operation. For these purposes a powerful CPU capable of executing complex fitting and analysis codes was required. A 32 bit VAX 11/730 was selected, in part because a large amount of relevant software, developed at other accelerator laboratories, was available. The VAX communicates with one Central Control System computer, known as "HLL," by an RS232 link. This allows HLL to act as a "front end" to the VAX for some processes, and provides an indirect connection to the MPM tables. The VAX has an independent serial CAMAC highway, and will shortly be interfaced directly to the central CAMAC system. In addition, it has a direct RS232 DECNET link with the TRIUMF Data Analysis Centre VAX 11/780.

Considered on its own, the VAX is a highly centralized system using a multi-user, multi-task operating system (VMS) to perform all operations in a single processor. It operates on its own higher level data bases incorporating logical beam dynamic parameters made up of combinations of single parameters.

The use of HLL as a "front end" and MPM port introduces some decentralization, as will the planned interface to the distributed CAMAC data base, which will also give the VAX access to the main control console, and make possible the development of a powerful graphics console on the VAX VT640 terminal.

Finally, a planned Ethernet local area network will expand the applications layer upward and make possible the distribution of a variety of applications throughout a network of processors large and small.

## 4.0 CONCLUSIONS

Distributed control is characterized by a number of different concepts relating to hardware, software, data bases, and control stations. Although some control system designs are more centralized than others, all contain elements of both approaches. In particular, the TRIUMF system contains a unique blend of centralized and distributed attributes, deriving primarily from the multi-sourced CAMAC and memory systems at its executive node.

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