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F.Fernandez Nodarse, Ivanov V.G.

# BLACKBOARD ARCHITECTURE AND QUALITATIVE MODEL IN A COMPUTER AIDED ASSISTANT DESIGNED TO DEFINE COMPUTERS FOR HEP COMPUTING

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# I-INTRODUCTION

"Computers and data communications networks are essential elements of high energy physics research... The diversity and sophistication of HEP's computing facilities and network must also increase if the potential for new physics discoveries by future experiments is to be realized". [1]

An ES is a knowledge-intensive symbolic computer program that solves problems of a limited domain normally requiring human expertise. Some of the common relevant ES characteristic are: to manipulate and reason about symbolic descriptions, solve difficult problems as good as human experts, reason heuristically, function with erroneous data and uncertain judgement rules, interact with humans in appropriate ways, contemplate multiple competing hypotheses simultaneously, ask and motivate its questions and justify its conclusions.

The goal of this study is to develop a friendly user computer aided assistant (COMEX) designed to define computers needed for High Energy Physics computing using blackboard architecture and qualitative model. This expert system requires an IBM AT personal computer or compatible with no less than 640 Kb RAM and hard disk.

During the development of our model, the main ideas described in the consulted papers from CERN, USA and Soviet Union about this topics had considerable influence.

# II- HEP COMPUTING BACKGROUND

## II.1- GENERAL ELEMENTS AND THE REQUIREMENTS ESTIMATED FOR HEP COMPUTING

The problem of planning for HEP experiments is not only financial, and indeed much of the discussion concentrated on the mismatch between the computer resources, the organization and the requirements of processing.

Classically, we can divide the HEP computing into the following main tasks or steps:

1- MONTE CARLO GENERATION AND PROCESSING OF MONTE CARLO EVENTS

There are a number of tasks in the process of analysing HEP data which will use Monte Carlo simulation. One of them deals with the prediction of those particles that will be observable, according to a given theoretical model. Other tasks deal with the response of the detectors in the experiment to measurable particles with different characteristics. When a physicist has a set of measured events, and he wishes to investigate a theory concerning the production of these events, then the strongest test requires that a Monte Carlo simulation should be performed which generates raw data, according to the theoretical model, in the same format as that used for real data acquired from the experiment. These data are then processed and analysed, in order to demonstrate that the measured and simulated data are statistically indistinguishable. Generally, more simulated than real events are needed in order to understand the errors in a given sample. One of the main challenges of HEP computing will be enough to do simulation. For example, we could use a model of the HEP experiment, that allows each experiment to generate, each year, twice as many Monte Carlo events as they acquire real events. Of these events, one half would be produced directly in team DST format (approximately 20 Kbytes/event), while the other half would be in raw data format( approximately 200 Kbytes/event), and would have to be passed through the analysis programs in order to generate the DSTs. The average processor time could be in the range of 60-80 seconds per event for the generation, being a balance between the 300 seconds more that a full simulation typically takes today, and the times for "fast" Monte Carlo generators.

## 2- ACQUIRING AND COMPRESSING THE RAW DATA

It is the task of the teams dealing with the online systems to make available for further processing a sample of events containing a minimum amount of "background", while ensuring that no "interesting" events are discarded in a biased way. This process, normally called "data acquisition", is complex and difficult. There are, however, two choices to be made here which will have a significant influence on the offline processing: a) the technology selected for recording the raw data is obviously a very strong candidate to be chosen for recording information at all subsequent stages of the experiment's data processing; and b) the decision on whether or not to install a dedicated high-speed link between the online computers at the HEP experiment and the computer center. It has a strong impact on the feasibility of generating the master DST in near-real time. For example, we could assume the experiments will succeed in keeping the total volume of events that they record down to twice the volume of the events. The accumulated volume of raw data would be 400 Gbytes at the beginning of the period, and 4000 Gbytes at the end. The average size of the raw data for each event would be in the range of 100-250 Kbytes.

To compress the raw data, we should take into account the possibility of running a filter / compress pass after acquiring the raw data, but prior to generating the master DST in order to remove background events to compress data from certain detectors, and to apply calibration corrections. For example, at least a factor of 4 would be needed in order to make such



a pass worthwhile. If a filter/ compress pass is carried out in real-near time at the experiment then it will have little effect on the computing resources needed. On the other hand, if the raw data are moved to a computer centre to run the filter/ compress programs, and we assume that 5 sec/event processing time is required and that the data from one beam period is completely processed before the next one starts, then the power processor requirements are still rather in the range of .15 MIPS in the first year, .5 MIPS in the second year and 1 MIPS in the last one.

## 3-GENERATING AND MAINTAINING THE MASTER DST

When an event has been captured by the online system, or generated by a simulation program, it must be processed to produce a concise summary of all of the information (DST for Data Summary Tape) that is likely to be useful in the subsequent physics analysis. The master DST is the reference copy from which all other DSTs are derived. The experiments are studying carefully the information that will need to be retained in the master DST. It will, in general, be important to be able to carry out some reprocessing on these data, since the cost of having to re-access the raw data in a random way is likely to be prohibitive on any large scale. Economic factors will impose the use of two-level storage hierarchy for handling this huge volume of summary data. The phase of the processing from raw to master DST, that was often considered as the main batch production load, involves heavy CPU and I/O requirements. Generally each experiment would have, worldwide, 100 - 300 collaborators working heavily on computers and the physicists would be working in about 15 - 30 small teams, each of them working on an area of the physics analysis. A considerable proportion of these teams operates offsite. The team DST formats will normally contain a set of data extracted from the master DST, consisting either of a subset of the events, or of a subset of summary data for each event. When the size of this team DST exceeds a certain threshold, it will be necessary to split the team DST into a full team DST and a condensed team DST. Each individual physicist working on an analysis will have a personal set of summary data selected from the team DST and dealing with events of interest named personal DST. Generally at this level, most of the data retained will be interactively selected components (or "n-tuples") of the summary data.

For example, provided that the experiments can really manage to keep the volume of the data maintained in the master DST down to 20 Kbytes/events ( the average size of each event on the master DST would be in the range of 10-120 Kbytes) then the overall volume of each experiment's master DST would be about 20 Gbytes at the end of the first year, 80 Ggytes at the end of the second year and 200 Gbytes at the end of the last one. We could also estimate that the personal DST has a volume of 100 Mbytes, corresponding to roughly 200K events with 500 bytes of data per event, or 2 M events with 50 bytes of data each. Since the time for physics would be limited to some 3000 hours/year this processing capacity needed to generate the DST in near-real time will be potentially available, outside the beam periods, to re-run the processing roughly twice. The time to process one event from the raw data to the master DST stage could be estimated in the range of 20-40 sec and the time to fully simulate an event might be reduced to 60-180 sec . It is possible to generate "fast" Monte Carlo events in time of 0.3 - 5 sec. Using the 30 sec processor time estimate and the average data taking rates for events during beam periods of 330 events/hours in the first year, 1000 event/hours in the second one and 2000 event/hours in the last one, it can be seen that the requirement for the processor power is 3 MIPS, 8MIPS and 16 MIPS respectively.

4-ACCESSING THE DSTs

In the selection of the computing resources needed to access the summary data, we must take into account two main factors: a) the extremely long batch jobs which run through the master DST in order to generate team DSTs, which are , in turn, processed to generate personal DSTs; and b) the interactive workload of the individual physicist. Because of the processor resources and long real-time needed to run the batch jobs it will be important for the experiments to optimise their working methods. Very long batch jobs will be needed to select information or event subsets from the master DST, and to finalise physics analyses. Because of the importance of efficient DST access for high-statistics physics we would certainly expect that in HEP experiments considerable attention is focussed on organising this access. It is recommendable, that the heavy searches through the DSTs should be carried out using batch jobs (which could be generated on the workstation) running on a mainframe. These DST data must be managed automatically, and it would be highly desirable for all of the subset DSTs to be held on direct access storage. For example, some tests show that making the first simple selection from among the events in a master DST requires about 20-40 minutes of processor time per Gbyte, corresponding to a processing time of about 35 msec to deal with each event. The far more complex criteria needed for subsequent selections typically require 60-90 minutes of processor time per Gbyte of DST. The data transfer between the personal DSTs and workstation could average some 25-30 Kbyte/sec for each experiment, assuming that each physicist is allowed to reload his 5 Mbytes active event sample twice daily. "For comparison, the CERN computer Center was equipped with a total of about 150 Gbytes of disk space, and the total tape mounting averaged some 60/hour" [2] in 1988.

5-EXTRACTING THE PHYSICS

When the information on events of interest has been reduced to a manageable size it can be manipulated by the individual physicist with a view to understanding and extracting the physics information from the events. The activities involved are many, and include data histograming, data fitting, simulation of physics processes , consideration of detector and analysis program responses, event scanning, assembly of graphic and textual results to generate publications, and so forth. Taking into account the relative merits of mainframes and workstations for carrying out these tasks, we now have a consensus about much better functionality and performance of workstations, and especially from the much improved working environment that they provide for the program development, program testing, and graphics, areas which are clearly crucial for this aspect of HEP computing. Workstations offer a good deal of flexibility to the HEP experiments since they can, at rather short notice, install more, and adjust the mix of simple and advanced graphics capabilities that they obtain, while remaining with a range of compatible products. For interactive physics analysis," Personal Workstations with a capacity of 1MIPS are considered more cost effective than big mainframes of 30 MIPS supporting 300 users or superminis of 4 MIPS supporting 40 users".[3]

II.2- HEP NEEDS FOR DATA COMMUNTCATIONS NETWORKS

"Networking between computers at the experiment, at the Computer Center in each HEP laboratory is essential for the functioning of the field".[1] Computer networks must provide physicists with the following functions: a) terminal access to remote computing resources; b) electronic mail; c) file transfer between any two computers; d) remote job entry and output retrieval; e) automatic updates, and status reporting, between remote program libraries and databases; f) and interprocess communications between tasks running on remote computers.

To transfer large volumes (Gbytes) of data at high speed (up to 1 Mbytes/sec) between the data acquisition computers at the HEP pit and the computers (where the experiments will carry out the subsequent processing) will be likely essential. Generally a significant fraction of the computing for HEP experiments should be carried out offsite. The true decentralisation of HEP processing will not take place unless high bandwidth communication channels are in place. While 64 Kbits/sec connections may be sufficient for individual institutes, all powerful regional centres aiming to take a major role in HEP processing will need connections running at least at 2 Mbits/sec.

III- THE QUALITATIVE MODEL OF EXPERIMENTAL DATA PROCESSING AND BB - ARCHITECTURE IN THE COMEX SYSTEM

Since much of HEP analysis is a continuing multi-user developmental activity, a general computing facility will not be effective unless it possesses a wide variety of productivity - enhancing features as fast interactive response, large memory space (real and virtual) per user, adequate file space, multiprocess services for individual users, systems managements, and process monitoring tools available to many users, networking, graphics facilities and high precision computing. Among the many elements of the HEP computing environment, personal workstation will revolutionize the physicists working methods as their power increases and their cost falls.

The following issues are crucial for the HEP experiments: a) Will this processing be performed in near-real time ? b) Which tasks will be processed - at the computers belonging to the experiment, at (or close to) the computer center, at the personal workstation or at regional / individual institutes; and which links / communications bandwidth will be used ? c) Do the raw data have to be recorded using the same storage medium as the master DST (the degree of media compatibility) ? d) Will it be necessary to re-process the raw data, and where would such re-processing be carried out ? and e) Will it be necessary to consider the computer resources that already exist in the Institute or outside ?

In figure 1 we can see a general view of the COMEX Computer Aided Assistant designed to define computers for HEP experiments.

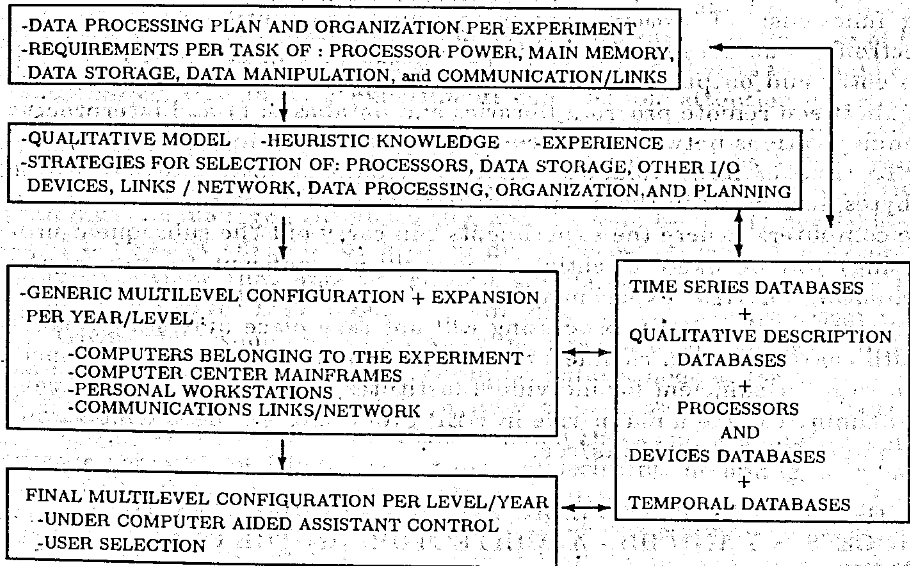


Fig. 1.General view of the COMEX Computer Aided Assistant

## III.1- QUALITATIVE MODEL

In the mathematical models, numerical or analytical calculations (which will be referred to as quantitative reasoning) are made. A mathematical



solution or result is obtained which in some way models the actual behaviour of the system. During the last years work has been carried out on the development of qualitative models of HEP experimental data processing systems. In these the mathematical model is replaced by a structural description of the system. Qualitative reasoning is used to provide a behavioural description which reflects the actual behaviour of the system itself. In our problem, we combine the mathematical and the qualitative model in order to efficiently use their properties. Qualitative and quantitative approaches to modelling are depicted in fig.2. [4]

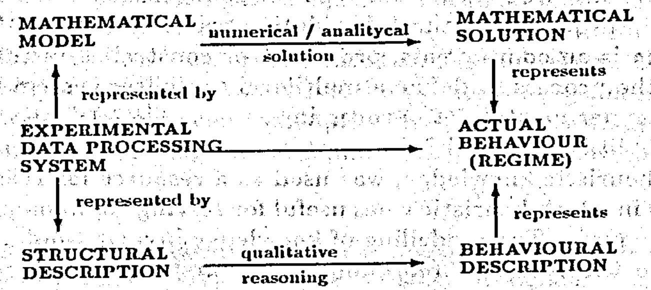


Figure 2. Qualitative and quantitative approaches to modeling

The use of a qualitative reasoning rather than a quantitative approach was necessary to make inferences on the basis of little information (in such cases a quantitative approach would not be feasible); in order to be able to express justifications in appropiate terms; and where complete information necessary for quantitative modelling is unavailable or unobtainable, where it is too complex to be used usefully, or where it is irrelevant to the purpose of the modelling exercise. The uncertainties in all estimates of HEP computing requirements are based at least on the following factors: a) In experimental physics it is impossible to plan for the computing requirements of the HEP experiments in too much detail, because many things may change between the beginning and the end of the experiment, including ideas about data rates, detector performance, accelerator schedules, and the physics topics of crucial interest. b) The rate of accumulation of events is likely to increase significantly between the beginning and the end of the period, and there will be a steady growth in the number of events accumulated (which governs the size of the master DST). c) The place where the various computing tasks should be carried out is always open to discussion. d) Some of the estimates appear so high that the researchers making them have been tempted to understate some expansion factors which experience tells us will be required. e) The system is not without feedback. As researchers start to understand some of the problems of dealing with the data they may want to take different approaches. Qualitative reasoning operates on structural description of the experimental data processing system being modelled. Structural descriptions are composed of descriptions of system components, their behaviours, and the connections between components. The result of application of conflicting qualitative influences on a parameter was indeterminable without further qualification of the qualitative influences to determine whether the next influence on the parameter causes it to increase or decrease. The combinatorial explosion caused by the branching paths generated in the production of all possible behaviours was tackled using domain specific knowledge to prune the number of plausible behaviours. The behaviour of the system as a whole is described through the interaction of component behaviours propagating through the connections. The representation of systems through structural description are characterised by their central emphasis on components, processes, or constraints of the model that describe the process to define a multilevel computer system required and the HEP experimental data processing.

The qualitative model incorporated in this expert system which also included heuristic knowledge, was used as a resource for reasoning about situations in which heuristic rules useful for solving common problem cases were inadequate. The modelling of knowledge in a task-independent form to provide the basis for reasoning from "first principles" was resolved with the use of task specific expertise. Furthermore the use of heuristic knowledge was needed to guide recourse to "first principle" when the experience failed.[5] In the qualitative models of experimental data processing system the selection of qualitative descriptions depended on the chosen perspective which focuses upon particular states and state changes which are interesting. The aspiration was to capture expertise in the HEP experimental data processing and in the design of the optimal configuration of the multilevel computer system required to process it. It is this desire which directs the choice of the qualitative state descriptions and the modelling primitives.

## III.2- COMEX IMPLEMENTATION

To provide the experimental data processing requirements and resources, the model includes three variants of multilevel computer system:
1- computers belonging to the experiments (first level) + computer center mainframes (second level) + personal workstation (third level) + communications links
2- computer center mainframes + personal workstation + communications links
3- computer center mainframes + communications links.
We used the term "personal workstation" to identify workstation with powerful independent processing facilities, for example 1 MIPS of processor power, 150 Mbytes of data storage , 4 Mbytes of main memory and input/output devices.



The HEP experimental data processing can be divided in six main tasks or steps: a) acquiring and compressing the raw data, b) Monte Carlo generation, c) processing of Monte Carlo events, d) generating and maintaining the master DST, e) accessing the DSTs, f) and extracting the physics. Generally, in a multilevel organization of experimental data processing, the computers belonging to the experiments are used to acquire and compress the raw data and the computer center mainframes are used to generate and process Monte Carlo events, generate and maintain the master DST, access the DSTs and to provide a part of the processing requirements corresponding to the extracting the physics. The personal workstations are generally used to provide the interactive workload and to extract the physics. For COMEX system, in every level we can perform every task or a part of it. Only the restrictions are based on the logical user conception of the task distribution on the multilevel data processing system. For each variable of model, the user can take optionally the expert values that assign traditional values taking into account other variables correlated. (See fig.3)

THE COMPUTERS BELONGING TO THE EXPERIMENT
SHOULD BE USED TO PERFORM THE FOLLOWING TASKS:

1 ACQUIRING AND COMPRESSING THE RAW DATA
2 MONTE CARLO GENERATION
3 PROCESSING AND MAINTAINING OF MC EVENTS
4 GENERATING THE MASTER DST
5 ACCESSING THE DST's
6 EXTRACTING THE PHYSICS
7 DEFINED BY THE EXPERT SYSTEM

Enter number(s) of value(s), WHY for information on the rule, QUIT to save data entered or < H > for help

Figure 3

The input data are:
1) Time series per task (their lengths are less than ten years,due to technological and price reasons) corresponding to the processor power needed (See fig. 4), the average size and the minimum segment size of files, the accumulated data volume, the data transfer rate required, the number of physicists and teams, the daily average interactive workload per physics and the disk storage required.

| INPUT REQUIREMENTS OF CPU POWER in MIPS per TASK | | | | | | |
|---|---|---|---|---|---|---|
| YEAR | ACQ&COMP RAW DATA | MONTE CARLO GENERATION | PROCESSING MC EVENTS | GENERATION DST | ACCESSING DST's | EXTRACT. PHYSICS |
| 1989 | 0.5 | 16.0 | 4.0 | 12.0 | 32.0 | 8.0 |
| 1990 | 1.0 | 48.0 | 12.0 | 32.0 | 36.0 | 8.0 |
| 1991 | 1.5 | 96.0 | 24.0 | 64.0 | 52.0 | 8.0 |

—> UPDATE ANOTHER YEAR? (Y/N) : Y

Figure 4

To input these data a special module was developed that offers two formats : the first oriented to the physicist terminology based on the number of events and runs; and the second oriented to users with elemental knowledge about computers. With user friendly interactive menus (see fig.5), this module additionally offers per experiment the following facilities: -to display the histogram and tendency of the time series ; -to input the computer resources that already exist; -to update (including delete and append functions); erase and copy the time series; -to update (including append and delete functions) the processors and devices databases (that describe the processor, external data storage media/units, other I/O devices and network characteristics) used to select the multilevel computer configuration; -to access to the Main Menu of the Final Configuration Module; -and to compare the time series and COMEX result database corresponding to different experiments. It also includes a help option that describes the main hypotheses and strategies used in the model.

MAIN MENU

| OPTION | DESCRIPTION |
|---|---|
| 1 | -INPUT TIME SERIE DATA UNDER HEP MODEL |
| 2 | -STANDARD INPUT TIME SERIE DATA |
| 3 | -INPUT EXISTING COMPUTING RESOURCES |
| 4 | -TIME SERIES HISTOGRAMS |
| 5 | -UPDATE THE TIME SERIES VALUES |
| 6 | -UPDATE COMPUTER DATABASES |
| 7 | -COMEX RESULTS DATABASE |
| 8 | -CHANGE THE EXPERIMENT |
| 9 | -HELP |
| Q | -QUIT TO EXPERT SYSTEM |

SELECT ONE OPTION:

Figure 5

2) Qualitative description of the experimental data processing model, that is obtained from the user answers during the running of the COMEX expert system based on user friendly menus. If you wonder why the system needs to know the information it is requesting, ask it by typing WHY, instead of making a selection from the list of values and press the [ENTER] key. (See fig.3). This COMEX system was developed using an expert system shell with forward and backward chaining, external program calls for data acquisition or program execution, numerical and string variable, and rule editor program. The knowledge base consists of IF - THEN - ELSE production rules with probability/confidence coefficient. There are two main types of conditions: text and mathematical. A text condition is a sentence that may be true or false. The condition is made up of two parts, a qualifier and one or more values. The qualifier is usually the part of the condition up to and including the verb. The values are the possible completions of the sentence started by the qualifier. The choices are all the possible solutions to the problem among which the expert system will



decide. The goal of the expert system is to select the most likely choice based on the data input, or to provide a list of possible choices arranged in order of likelihood. The choices can be item, actions, etc.depending on the sub-problem. The system keeps track of the probability of all possible solutions and displays a list of all possible solutions arranged in order of probability. The user can check to see what effect a particular answer had on the conclusion using "change and rerun" command. You may then change any of your answers and rerun the system with the rest of the answer held constant (See Fig.6).

**RULE NUMBER: 121**

IF:

(1) THE COMPUTING FACILITIES OF THE COMPUTER SYSTEM WILL INCLUDE COMPUTERS BELONGING TO THE EXPERIMENT + COMPUTER CENTER MAINFRAMES + PERSONAL WORKSTATIONS + COMMUNICATIONS LINKS or COMPUTER CENTER MAINFRAMES + PERSONAL WORKSTATIONS + COMMUNICATIONS LINKS

and (2) THE DATA PROCESSING ORGANIZATION OF THE HEP EXPERIMENT IS BASED ON THE RESOURCES IN THE INSTITUTE WITH MEDIUM SIZE NUCLEAR EXPERIMENTAL FACILITIES or THE RESOURCES IN THE INSTITUTE WITH SMALL SIZE EXPERIMENTAL FACILITIES

and (3) FOR CARRYING OUT INTERACTIVE COMPUTING TASK WILL BE USED MAINLY COMPUTER TERMINALS or COMPUTER TERMINALS AND PERSONAL WORKSTATION

THEN:

THE DECENTRALISATION OF HEP PROCESSING SHOULD BE MADE USING FLEXIBLE ACCESS WITH MEDIUM DATA TRANSFER RATE CHANNELS (64 Kbits/sec)

IF line # for derivation, < K > – known data, < C > – choices or - prev. or next rule,< J > – jump, < H > – help or< ENTER > to continue:

Figure 6

The COMEX system takes into account the annual cost decrease factor per device type in his calculation and the error percent in the input data which affects the level of certainty in the results.

During the running, if necessary, the COMEX system asks about and offers to the user the facility to input: - the data corresponding to the resources that already exist for experimental data processing; - the aditional requirements needed to perform in near-real time after data taking the generation and maintenance of master DST; - and the additional requirements derived from terminal / workstation proportion and the interactive workload when they were not taken into account at the initial data input. To do this, the COMEX system displays per year and task, the time series values corresponding to the accumulated data volume, the average size of files, the minimum segment in which the files can be divided, the disk storage required, and the processor power needed; and requests the new input values for updating purposes.

The variables of the model are:

1) For the strategy of terminal/workstation distribution:

The number of physicists and teams, the hours of daily interactive workload per physicist, the average in hours of the daily terminal / workstation workload, the proportion of the terminal and workstation assigned to each level and the proportion of graphic terminal / workstation for each level. The terminal / workstation distribution algorithm defines and displays the terminal / workstation configuration per level and year (including which of them should be graphic or not). The user can chance all the calculated values including the additional processor power and data storage that the interactive workload represents, and take into account these values for the following calculations and decisions.

**REQUIREMENTS OF CPU POWER in MIPS per TASK**

| YEAR | RAW DATA | MC GENER. | PROCESS. MC EVENTS | GENER. DST | ACCESSING DST | EXTRACT. PHYSICS | TOTAL CPU |
|---|---|---|---|---|---|---|---|
| 1990 | 1.0 | 48.0 | 12.0 | 32.0 | 36.0 | 8.0 | 137.0 |

—> TO MODIFYING THE EXPERT PORCENT LOAD TABLE <—

PORCENT TABLE FOR THE YEAR : 1990

| | | | | | | |
|---|---|---|---|---|---|---|
| -EXPERIMENT COMPUTERS | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| -COMPUTER CENTER | 0.0 | 100.0 | 100.0 | 100.0 | 100.0 | 23.8 |
| PERSONAL WORKSTATION | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 76.3 |

**DISTRIBUTION OF CPU AND MAIN MEMORY**

| YEAR | EXPERIMENT COMPUTERS | | C.C MAINFRAMES | | PERSONAL WORKSTATION | |
|---|---|---|---|---|---|---|
| | MIPS | MBYTES | MIPS | MBYTES | MIPS | MBYTES |
| 1989 | 0.5 | 4.0 | 66.0 | 16.0 | 6.1 | 4.0 |
| 1990 | 1.0 | 4.0 | 129.9 | 16.0 | 6.1 | 4.0 |
| 1991 | 1.5 | 4.0 | 238.0 | 32.0 | 6.1 | 4.0 |

—> DO YOU WANT TO CHECK THE INPUT DATA AND PERCENT LOAD DISTRIBUTION TABLE ? (Y/N): Y

Figure 7

2) For the strategy of sequential and direct access external data storage media and units selection:

For each task : the accumulated data volume, the average size of files, the minimum segment size of files, the disk space required and the processor power in MIPS. The average data transfer rate, the cost, media volume and other technical unit characteristics, data manipulation, number of terminals assigned to a level and interface type required for the processors selected for each level are also considered. Based on the processor power and main memory requirements per tasks, the tasks distribution per level, and the percent of each task that must be performed in each level, the



COMEX system using a percent cross table (see fig.7) determines per year the processor power and main memory requirements in each level. At the beginning, the COMEX system assigns expert values to the percent cross table taking into account the tasks distribution per level and the interactive workload. The user can change these implicit values according to his criteria. Similarly, taking into account the task distribution per level and the data storage requirements per tasks, the COMEX system computes and displays per level and year the accumulated data volume, the average size of files, the minimum segment size of file, the disk space required and the data manipulation ( media mounts per hour). Optionally the user can adjust these calculated values (see fig.8), that will be considered as input data to the optimal data storage scheduler algorithm. It selects the external data storage media and units per level and year.

**TO UPDATING THE DATA STORAGE REQUIREMENTS TABLE in Mbytes**

| FOR THE YEAR : 1989 | AVERAGE SIZE | ACCUMULATED DATA VOLUME | MINIMUM SEGMENT | DISK STORAGE | DATA MANIPULATION |
|---|---|---|---|---|---|
| -COMPUTERS IN THE EXPERIMENT | 200.00 | 400000.0 | 100.0 | 100000.0 | 6.0 |
| -COMPUTER CENTER MAINFRAMES | 200.00 | 1740000.0 | 100.0 | 100000.0 | 11.0 |
| -PERSONAL WORKSTATIONS | 50.00 | 1000.0 | 5.0 | 100.0 | 2.0 |

Figure 8

3) For the strategy of processor selection :

The optimal scheduler algorithm determines the processors to use per level for each year of the time serie depending on: - the previous selection of the personal workstation/terminal configuration and the external data storage media and units; - the processor power requirements in MIPS; - the main memory needed per tasks; - the computing precision required; - and other processor characteristics ( for example, the recommended number of computers in a cluster, the processor power, the coprocessor power, the processor expansions, the coprocessor expansions, the number of channels, the data transfer rate of the channels, the minimum and maximum main memory size, the memory expansion size, the word/register length, and their costs).

4) For the strategy of other input / output devices selection:

The COMEX system defines the configuration of input/device needed taking into account, mainly, the previous selection of the terminal/personal workstation configuration, the multilevel structure and the graphics requirements per tasks. It includes the definition of the format, resolution, input/output data rate, graphics capabilities and recommended quantities per device and level.

5) For the strategy of links and networks selection:

The COMEX system defines the data communications network based on the multilevel structure, the organization of the processing, the volume of data handling, the data storage, the processor power, the data manipulation, the functions that the computer network must provide physicists with and the bandwidth communication channels.

The COMEX system always combines the selection criteria depending on values assigned to each variable of model as a filter condition in the cost minimization algorithm. In each step, the user can adjust the partial results . Finally the user can change the preliminary configuration defined by the COMEX expert system under the computer aided assistant control or without it.( See fig.9 Main Menu of the final configuration module). Both include user friendly interactive menus that offer the facilities to update , append and delete records on the COMEX result database (that storages the multilevel computer system configuration); to consult the processors and devices databases; to recalculate the cost per item taking into account the depreciation factor and quantities modified; and to display or print per year and per level the processors, the external data storage media and units, and other I/O devices ( including printers, digitizers, displays, plotters and scanners defining their format, resolution, input/output rate, and graphic facilities), their recommened quantities and their costs with subtotal per year and level. The particular technical characteristics of each processor, external data storage media/units and other I/O devices are taken into account during the processing of the COMEX result database based on the structure and content of the processors and devices databases.

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——— MAIN MENU OF FINAL CONFIGURATION MODULE ———

OPTION              DESCRIPTION

  1     - FINAL CONFIGURATION USING COMPUTER AIDED ASSISTANT
  2     - FINAL CONFIGURATION WITHOUT COMPUTER AIDED ASSISTANT
  3     - CHECK AND CORRECT THE TOTAL COST PER ITEM
  4     - LIST THE COMEX RESULT DATABASE

  Q     - QUIT

—> SELECT ONE OPTION :
```

Figure 9

## III.3- BLACKBOARD ARCHITECTURE IN THE COMEX SYSTEM

The basic programming components of typical rule based ESs are: knowledge base; reasoning component (inference engine); and input, output and control facilities. The knowledge-base consists of conceptual taxonomic relationships and rules which have been extracted from one or



several experts. COMEX BB-system essentially consists of three components: blackboard data structure(BB), knowledge sources(KS) and control modules(CM). Blackboard - systems emphasize the use of multiple cooperating sub ESs, or knowledge sources. Each of them examines a global solution database, called the blackboard for intermediate relevant results. The purpose of the blackboard is to hold computational and solution data needed and produced by the KS. The blackboard was segmented into distinct levels of abstraction. Each independent KS then volunteers to make a contribution, and the potential actions of each are prioritized by a scheduling KS, which maintains an agenda.

The problem-solving data are thus kept in global database, the blackboard, whose data are hierarchically organized. In the COMEX blackboard structure, the solution space is organized into one or more application dependent hierarchies, called layers. The objects of the solution space are input-data, partial solutions, alternatives and final solutions, and control data. Each knowledge source uses the input-data from a particular layer of the structured blackboard and places its findings on another layer above or below. The knowledge needed to solve this problem was partitioned into several different knowledge sources taking into account the models of HEP computing, computer architectures, data storage and links strategies. Interaction between the KSs takes place solely through changes on the blackboard. Each KS is activated only when certain conditions exist on the blackboard, and is thus responsible for knowing when it can contribute to a partial solution. Since the KS can be arbitrarily complex and different in their internal operation, the most appropriate problem solving approach was implemented at any processing level. Each KS is a small knowledge based problem solver, and its internal processes have only local effects, rather than causing potential interactions with the rest of the system. The KS responds opportunistically to changes on the blackboard. A set of control modules monitors these changes and uses various kinds of information to determine the focus of attention (FA), i.e., which KS to process next, which partial solution island on the blackboard to pursue, or which KS to apply on which blackboard-object (BO). In the actual COMEX implementation, the control modules are incorporated as a part of knowlegde base and the associated external program calls for data acquisition or program execution. The problem solving activities occur in the following way: a) A KS makes changes on the blackboard, and these changes are monitored by the control unit. b) Based on the new solution state, the KSs volunteer their contributions. c) With the information from (a) and (b) a control module selects a FA which is a KS, or a BO, or both. d) Depending on the selected FA, an appropriate control module prepares for its execution: if FA = KS, then a particular object is selected to serve as a trigger, if FA = BO, the KS is executed with the BO as the trigger, and if FA = KS & BO, the KS is executed with the BO as the trigger. The problem solving behaviour of a BB-system is determined by the KS application strategy encoded in the control modules. Basically the control modules determines the blackboard region to focus on and the particular KS to work on that region.

## IV- FINAL REMARKS

The final remarks are :

1) It is impossible to plan for the computing requirements of HEP experiments in too much detail, but the assumptions and estimates used in this work have been accepted by the majority of the specialists consulted. These are, of course, differences between individual experiments, but the agreements are more striking than the discrepancies.

2) The qualitative model incorporated as components of COMEX expert system contributed to increase the problem solving flexibility and better system robustness through support for more than one type of problem solving activity, and to provide interpretations of observed behaviour of the experimental data processing system and as the basis of causal explanations.

3) The blackboard architecture was a usefull tool for solving this complex task and reducing the implementation time.

4) In practice, the results obtained using the COMEX system were acceptable and permit to simulate and compare different model solutions depending on the user criteria. The interactive and explanatory facilities are user friendly.

New facilities of the COMEX system are being developed, particulary the extension of the knowledge bases.

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