EXPERIENCES USING THE 168/E MICROPROCESSOR WITHIN THE EUROPEAN MUON COLLABORATION (EMC)

D.R. Botterill[1], A.W. Edwards[2]

Rutherford Laboratory[1], Chilton, Didcot, England
CERN[2], Geneva, Switzerland.

Abstract

The EMC has a large amount of data taken at the CERN SPS during 1980 still to be processed through its pattern recognition program. This program is large, about 700K decimal bytes and needs on average 350 milliseconds/event of C.P.U. time on an IBM 370/168. This program has recently been installed on a 168/E microprocessor at CERN. Experiences encountered in installing such a large program on a 168/E and in the subsequent data processing will be given.

Introduction

The European Muon Collaboration (EMC) is engaged in a program of experiments at the CERN SPS to study the features of deep inelastic muon scattering. Prior to the SPS shutdown in June 1980, the EMC was principally concerned with the determination of the nucleon structure function F_2 1]. The apparatus, a large magnetic spectrometer allowing multi-particle detection and identification in the forward direction 2], was designed to enable the experiment to run at very high data taking rates, thus enabling a significant increase in integrated luminosity to be achieved over previous experiments of this type. This increased data taking rate, aligned with the general nature of the experiment and the detector, typical of many new experiments approved today, presents severe problems, however, in later offline analysis load on conventional computing facilities, such as exist at CERN or the Rutherford Laboratory for example.

In this report we present one possible solution to this problem by using microprocessors which emulate the features of large mainframe computers such as an IBM 370/168. One such microprocessor is the 168/E developed at SLAC 3]. We shall first give some details about data taking at the EMC, describe the offline analysis programs and then deal with the installation and performance of one of these programs on a 168/E.

Data taking in EMC

The experiment NA2 ran continuously for the two years prior to the SPS shutdown. During this time most data were taken using a 6 metre H_2 target with incident muon beam energies of 120 GeV, 200 GeV, 240 GeV and 280 GeV. Other data were also taken at these energies using a 6 metre D_2 target and an iron plastic scintillator sandwich target (STAC). The spectrometer system has a large acceptance for the scattered muon. However, not only were muons accepted over a large range of interesting physics variables, but hadron tracks resulting from the interactions were also detected along with other produced muons. Certain results from the experiment have already been published 4]. The basic event trigger accepted events where an incident beam muon was scattered through an angle greater than 1/2°. This trigger, which was designed to be as bias free and general as possible, was at best 40% efficient, probably a very reasonable figure considering how general a trigger it was. Typical trigger rates were about 5×10^{-6} triggers/incident muon. The typical beam flux was of the order of 1×10^7 μ^+/second, an order of magnitude increase in fluxes used in previous muon experiments at F.N.A.L. The typical event length was 1000 to 1500 16 bit words so that it was possible to write one 1600 BPI data tape in 20 minutes. Even allowing for the 'normal efficiency' of data taking, this meant that over 500 data tapes could be written in a 10 day SPS running period. In total over the 2 years the EMC was able to take more than 10,000 data tapes.

The EMC offline software

To process events from the raw data tape to a final DST suitable for doing physics analyses involved 3 programs. The first program, RECONS, reconstructed tracks in the forward spectrometer, the second, GEOMETRY, performed a fit to each track to determine its χ^2 and momentum and then attempted to fit these tracks to a common vertex. The third program, SNOMUX, processed additional detector information for the event, e.g. Cerenkov counter data, and arranged the output into a suitable format for physics analysis.

A typical event required of the order of 300-350 milliseconds of CPU time on an IBM 370/168 for both RECONS and GEOMETRY. The processing time of SNOMUX was negligible in comparison. To process a full data tape through the reconstruction program therefore required about 45-60 minutes of IBM 370/168 CPU time. The time for GEOMETRY was typically a quarter to a third of this as RECONS filtered off those events when the trigger was inefficient, i.e. some combination of spurious hits had faked a real trigger. With more than 10,000 data tapes to analyse the EMC therefore required more than 2 years exclusive use of an IBM 370/168 just to process its events to DST.

Possible solutions to this problem

Large computing centres, with conventional mainframe computers, are clearly finding it more and more difficult to meet the requests of physicists to be able to process these data on a reasonable timescale, when they are confronted with the improved data taking capabilities of the more modern general purpose experiments. The physicist therefore has only two real choices, to accept that he must process his data at a slower rate than he would like, or to invest his money in providing his own CPU power.

Should a group choose the second option the immediate questions to answer are how much CPU power can be bought with the money, if any, available, this dictating how fast the data can be analyzed, and secondly what manpower will have to be involved from the group. An attractive proposition in answer to these questions might therefore appear to be the VAX 11/780. This could certainly run all EMC's programs and at a cost of about 400K SFr, including disc and tape drives, is within the budget range of certain experiments. If we consider the two questions above more carefully however then with a speed, at best, of 1/3 of an IBM 370/168 the VAX could only deliver about 50 hours equivalent CPU time/week. Further it would require extra investment on the part of the group to have manpower available to load tapes, for example, over night.

On the basis outlined above the 168/E microprocessor, designed at SLAC to emulate an IBM 370/168, appears attractive. It has a speed about 1/2 of an IBM 370, but as many 168/E's can be placed in series on one control system then, in effect, with 2 168/E's a group can buy the equivalent, in terms of CPU power, of an IBM 370/168 for the order of 150K SFr when the cost of the control computer, Bermuda triangle, buffer memory and other requirements are included. In terms of manpower the basic investment of the group need only be 1 person to install the program if an already working system is available. As the 168/E can be connected to an IBM mainframe it is possible to make use of the tape handling, loading and other facilities available normally in a central computer centre. At present however many groups using 168/E's have had to provide manpower in order to build up their systems and it should be said that if this effort was not readily available then the cost of hiring extra manpower would make the 168/E a much less attractive proposition.

Installation of the EMC reconstruction program on a 168/E

As more than 1/2 of the CPU time required to process 1 tape to DST goes in the reconstruction program this was the obvious program to attempt to install on a 168/E.

The first question to be answered was would the program fit easily into a 168/E. Ideally one would like to load each overlay only once per event, and one should certainly avoid such things as swapping overlays in and out many times within a FORTRAN DO LOOP for example. If the program will not however break down into convenient overlays which fit into the 168/E program memory then a lot of effort will be involved in order to change the structure of a program to achieve this. Indeed many groups may not consider such effort worthwhile and so this point should always be considered when installing a program on a 168/E.

The table below shows the five main 'packages' that the reconstruction program naturally breaks up into. Also given are the size of each package, or overlay, when translated into 168/E microcode and the percentage of time spent in each overlay when muon reconstruction alone is done, or when full event reconstruction is performed.

Overlay	Overlay Description	Size K bytes	μ RECONS	Full RECONS
1	Decode Raw Data into x,y,z coordinates	97	10	7.5
2	Reconstruct incident beam tracks	45	10	7.5
3	Muon identification and reconstruction	90	60	40
4	Track reconstruction through the magnetic field to the target. Output of lines found	120	20	30
5	Hadron identification and reconstruction	60		15

As the size of the 168E program memory is 128K bytes it can be seen from the table that each obvious overlay will fit into the 168E without any major structural alterations to the program. The rest of the work is basically tedious and involves such things as the removal of all I/O statements from that part of the code to be excecuted on the 168/E, plus certain other instructions. The removal of all MIXED common blocks, i.e. those commons that contain both constant and variable data, must also be done as the constants have to be downloaded from the IBM 370 at the start of each run and are subsequently loaded into the 168/E data memory for the relevant overlay each time that overlay is called for.

Software, written at SLAC, facilitates much of this work, e.g. identifying MIXED commons and a complete writeup is in preparation giving a full guide to the use of this software and the steps to be followed in preparing a program for installation on the 168E[5]. A reasonable estimate, therefore, of the timescale for installing a program, which does not need restructuring, on a working 168/E would be about 1 month which does not compare too unfavourably with the time taken to install any large program on a new computer, especially going from a large virtual memory machine such as the IBM 3032 say to a CDC 7600 where the program must be overlayed, just as on the 168/E.

Indeed for the EMC reconstruction program this is what was done, the program having been prepared at CERN over the period of 1 month was then installed at SLAC during a period of 1 week on a 168/E there. The status of the CERN project will be outlined in more detail in another report to this conference (see D. Lord et al.).

The main point to make here is that the hardware should be fully set up and tested before attempting to install any new program. Whilst this may sound obvious it was unfortunately true that the production software jobs found many errors in the hardware at CERN which the diagnostic software at that time could not find. The diagnostic software has since been updated to trap these errors but there is still a feeling that the most severe test of the hardware is provided by the production software. For groups building their own hardware they should be aware of this and indeed may benefit from taking existing production software working at CERN on 168/E's and running it on their own hardware to verify its performance, before installing their own production software. Much time can be lost and a great deal of confusion generated if hardware development is taking place at the same time as the installation of a new program.

168/E Performance

Up to the 1st of May the EMC had processed 500,000 events on the 168/E processor available to it at CERN. The time to process 1 1600 BPI data tape was typically just under 2 hrs compared to 55 minutes CPU time required to process the same data on the IBM 370/168. This gives a ratio of about 2.2:1 between the 168/E and the IBM 370/168. Included in the 168/E processing time is however the time to load each overlay into memory for every event. Whilst the real ratio to a user is therefore 2.2:1 the ratio of the 168/E processor speed to that of the IBM 370/168 is closer to 2:1. This ratio is dependant on waht type of code is being executed, i.e. the mix between integer and floating point instructions, but in the case of EMC can probably be improved upon as the highest optimisation level has not yet been used in the TRANSLATOR which converts the users FORTRAN written code into microcode instructions. The job that executes in the IBM 370/168 during processing requires 4 minutes CPU time per run, basically to read and write data from and to tape. The 168/E therefore does more than 90% of the computation involved in processing a single event.

In a typical week with 1 processor available for the evenings and nights during working days and over the whole weekend about 60 data tapes can be processed. This means that 1

SPS running period could be processed in about 2 months. EMC hopes to have a second processor available soon enabling the capacity to be doubled to 120 data tapes/week. In the longer term if EMC were not to rely on larger mainframe computers at all to do some of its reconstruction then a system with 3 or 4 168/E's would be required. Looking even further ahead one could imagine doing full analysis to the DST level and Monte-Carlo generation all on 168/E's if a system of 6 168/E's were available full time to EMC.

References

1] The EMC CERN/SPSC/74-78;
The EMC SPSC/P-18/Add. 1, CERN/SPSC/77-113 (1977).

2] The EMC Nucl. Inst. and Methods 179 (1981) 445.

3] P.F. Kunz et al., SLAC-PUB-2198 (1978);
P.F. Kunz et al., SLAC-PUB-2418 (1979).

4] The EMC Phys. Lett. 89B (1980) 267;
The EMC Phys. Lett. 94B (1980) 96;
The EMC Phys. Lett. 94B (1980) 101.

5] A. Edwards, J. Porte CERN DD Division 168E/81-3.