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A Special function coprocessor for Level-2

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1 Introduction

The idea of supplementing Level-2 filtering nodes with additional processing power has been alive within the D0 collaboration for some time now.¹ The utility of additional processing power became increasingly recognized as the Level-2 filtering code matures. Here we will describe one scenario of augmenting Level-2 nodes with coprocessing power within the framework of the present D0 data acquisition system. Primary data reduction, consisting of repetitive but simple tasks, form the major part of the first order Level-2 filter, in terms of its time budget. Such computing tasks are well suited to the coprocessor environment. In what follows we will use the term Special Function Coprocessor (SFC) to denote this additional processor.

¹D. Cutts, J.S. Hoftun, C.R. Johnson, R.T. Zeller, "A Microprocessor Farm Architecture for High Speed Data Acquisition and Analysis", presented at the IEEE 1988 Nuclear Science Symposium, Orlando (November 1988), D0 Note # 779;

D. Cutts, J.S. Hoftun, D. Nešić, C.R. Johnson, R.T. Zeller, "D0 Data Acquisition - High Speed Data Paths for D0", presented at the Eight Conference on Computing in High Energy Physics '90, Santa Fe (April 1990), D0 Note # 972;

for an alternate proposal see D. Schamberger, J. Linnemann, "Calorimeter Hardware Processor Proposal", (May 1988)

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2 The special function coprocessor environment

The Level-2 data acquisition system has been described elsewhere.² Figure 1 presents a schematic of the data acquisition system. For our purpose of assisting the Level-2 software filtering, the key location is the VME Multiport Memory (MPM). The MPM is central because the raw data arrives there from the digitizing crates and is not moved unless and until the event passes the Level-2 filter. A block diagram of the MPM is shown in Figure 2. A special function port on the MPM allows direct access to its data memory banks by devices communicating over a special bus. The size of the data memory banks is not fixed but is suited to the particular application. Digitized data from front end electronics will be transferred over the data cables to the MPM. It is a feature of the MPM that once the transfer is complete, memory access to the data memory banks is turned over to the VSB port. In that configuration the data memory bank appears as a transparent private memory to the Level-2 processor (currently a VAXstation 31xx). It should be noted that if a SFC is attached to the special function port then the data memory banks and VAXstation private memory are transparent to the SFC. At the same time the SFC can become a "slave" to the VAXstation in the sense that processes in the SFC can be initiated under control of the Level-2 processor.

3 General description of a special function coprocessor

We intend to implement a SFC which will be operating in the 100 Mflops range. To ensure maximum efficiency, the floating point format of the SFC will agree with the floating point format of the Level-2 processor. Typical processors which are available, use about 64 Kbyte of the control memory for program storage. The Level-2 processor has direct access to this control memory through the SFP and can invoke pre-programmed routines with a standard VAX Fortran function and/or subroutine call. It is this ease of communication and flexibility in programming the SFC that makes it a very nice tool for pre-filtering.

The programming of the SFC will be done in a high level language and will be

²D. Cutts, J.S. Hoftun, R.T. Zeller, T. Trojak, R. Van Berg, C.R. Johnson, "D0 Data Acquisition Design", Proceedings of Fourth Conference on Real-Time Computer Applications in Nuclear and Particle Physics, IEEE Transactions in Nuclear Science, Vol. NS-32, (1985).;

D. Cutts, J.S. Hoftun, C.R. Johnson, R.T. Zeller, "The MircoVAX Based Data Acquisition System for D0", Proceedings of Fifth Conference on Real-Time Computer Applications in Nuclear and Particle Physics, IEEE Transactions on Nuclear Science, Vol. NS-34, (1987);

D. Cutts, J.S. Hoftun, C.R. Johnson, R.T. Zeller, "Data Acquisition Hardware for the D0 MicroVAX Farm", presented at the International Conference on the Impact of Digital Microprocessors on Particle Physics, Trieste, Italy (March 1988)

D. Cutts, J.S. Hoftun, C.R. Johnson, R.T. Zeller, "Data Acquisition at D0", presented at the Computing in High Energy Physics Conference, Oxford, England (1989), Computer Physics Communications Vol. 57 (1989)

translated to the native SFC code with the appropriate compiler. Typical functions of the SFC would involve sequential or parallel (depending on the SFC) unpacking of digitized raw data, conversions to the floating point format with possible multiplications and additions and storing digested data into arrays which are convenient for further Level-2 filtering.

4 Application to Calorimeter

As an application of the SFC to the calorimeter filtering we have developed an algorithm for the calculation of energy (E) and transverse energy (E_t). We plan to expand the algorithm to include the filling of a pointer array (PTCAEP) and we will examine the feasibility of calculating missing energy. Before describing the algorithm it is useful to recall one of the features of the data organization in the calorimeter banks. During data acquisition, the sequencer is scanning the VME crates to see if digitization is done and data is ready for transfer. Therefore the order of reading out the 12 ADC crates is, for all practical purposes, random—whichever is ready first will be read out first. Also, in a zero suppressed and pedestal subtracted mode, not all $12 \times 8 \times 4 \times 12 = 4608$ channels from a single crate are going to be digitized. All these features suggest that the unpacking of the address has to be based on the full address of every channel: 21 bits.

For the calorimeter application we estimate that 512 Kbyte per data cable is necessary on the MPM. Some fraction of that memory is occupied by the data transferred over two data cables from the calorimeter's VME crates. The rest is used for storing results of the SFC calculations and for tables needed in performing calculations. A possible division of these memory banks is given in Table 1. Raw data entry in the table corresponds to the space needed for storage of the data from the VME crates. In a typical event only $\approx 20\%$ of the cells will have some energy deposited in them. Energy and E_t entries will each take the same amount of space as raw data. In a typical event these three entries together will take ≈ 57 Kbyte. For the calculation of E and E_t there are two tables (arrays) which are large enough to deserve attention. One is the table of gain constants for each cell in the calorimeter and the other is the table of $\sin \theta$ values of each cell in the calorimeter.

D0 calorimeters have 55,296 instrumented channels of electronics but only 46,314 are connected to readout cells in the calorimeters. If gain constants are needed to an accuracy of $\approx 1.5\%$ then there are less than 256 different ones and one can use a byte of storage per channel to point to the appropriate constant. Since the address of each channel is given by 17 bits, 128 Kbyte of storage space is needed for gain pointers. The space for $\sin \theta$ tables is based on the requirement that pointers to the $\sin \theta$ values for each channel should be at most one byte long. As a consequence every cell in the detector will have its $\sin \theta$ to precision better than $\approx 1.5\%$ (See Appendix A). Exploiting the symmetry of D0, for a given vertex position one needs to know only

CAD1 North Half 512 Kbyte	CAD2 South Half 512 Kbyte
Raw data 94 Kbyte (max)	Raw data 94 Kbyte (max)
Energy 94 Kbyte (max)	Energy 94 Kbyte (max)
E_t 94 Kbyte (max)	E_t 94 Kbyte (max)
Free space 139 Kbyte (min)	Free space 139 Kbyte (min)
$\sin \theta$ pointers & constants 27 Kbyte	$\sin \theta$ pointers & constants 27 Kbyte
Gain pointers and constants 64 Kbyte	Gain pointers and constants 64 Kbyte

Table 1: Block diagram of data memory banks in MPM

2304 different pointers to $\sin \theta$ values. For NZ vertex positions, the number of pointers is $2304 \times \text{NZ}$. We are assuming that vertex position will be passed from Level-0 as a 5 bit number so that $\text{NZ}=32$, so the total space needed for $\sin \theta$ pointers is 73,728 bytes.

Please note that with all cells alive there are 278 Kbyte of free memory in the data memory banks in the MPM associated with calorimeter data. The PTCAEP array needs 81,600 32 bit words of storage, ($75 \times 64 \times 17$), which is 326,400 bytes. If one routinely wants to fill the PTCAEP array every time a pre-filtering routine is called, then there is not enough memory to do so. But a typical event is expected to populate only $\approx 20\%$ cells. If we decide to process through pre-filtering only events which have no more than 50% cells populated then the PTCAEP array can be accomodated. An undesirable alternative would be to fill the PTCAEP array in a separate call to SFC after the data from the MPM is moved elsewhere.

An example of the code which could be run (after processor dependent compilation) in the SFC is included below. Here we calculate total energy and E_t for each event. The code was tested on GEANT events: 50 GeV electron (J version), 50 GeV pion (J version) and 120 GeV $t\bar{t}$ (I version) events. The testing was done by comparing the CPU time it takes to run D0USER package with and without CHECK_TABLES. The tests were done on D0HS09 (a VAXstation 3100 M38; its equivalent will be used as a Level-2 node in D0). For 50 GeV electron events CHECK_TABLES takes 10.35 ms/event. For 120 GeV $t\bar{t}$ events CHECK_TABLES takes 125 ms/event. The long

time needed on the general purpose system for this simple, repeditive calculation highlights the enormous gain available through the use of a dedicated coprocessor.³

Here we enclose the source code of the subroutine CHECK_TABLES. Comments in the code should make it readable. It provides an example of our strategy for the code development for a SFC.

³Our SFC prototype will be based on a 100 MFLOP chip. For comparison, the new Silicon Graphics 4D-300 system, with eight 33MHz RISC processors delivering more than 200 MIPS, claims a performance of 30 MFLOPs.

SUBROUTINE CHECK_TABLES

```

C-----
      IMPLICIT NONE

      INCLUDE 'DO$INC:ZEBCOM.INC'
      INCLUDE 'DO$INC:ZLINKC.INC'
      INCLUDE 'DO$LINKS:IZCAD1.LINK'
      INCLUDE 'DO$LINKS:IZCAD2.LINK'
      INCLUDE 'DO$PARAMS:CAL_OFFLINE.PARAMS'
      INCLUDE 'DO$PARAMS:CAL_ADC_NO.PARAMS'
      INCLUDE 'USER2:[NESIC.TABLES]FILL_TABLES.PARAM'
      INCLUDE 'USER2:[NESIC.TABLES]FILL_TABLES.INC'

      BYTE CONTR_BYTE(4)

      CHARACTER*80 FILE_NAME

      INTEGER*2 STA_VER(2)

      INTEGER
&      CONTRL, CRATE, ERR,
&      GINDEX, HEADER_LEN, I, II, INDEX, JBYT,
&      MODVAR, NADCS, NKANALA,
&      OK, PLSHT, POINT, STAVAR,
&      USUNIT, VERTEX, WRUN2, ZBIN

      LOGICAL OK_OPEN

      REAL
&      ENERGY, ET

      EXTERNAL USUNIT

      EQUIVALENCE (CONTRL,CONTR_BYTE)
      EQUIVALENCE (STAVAR,STA_VER)
C-----

C
C **** Initialize ENERGY, Et
C
      ENERGY = 0.0

```



```

      ET = 0.0
C
C ****  Get some info from event HEAD bank
C
C
C ****  Do CAD1 bank first (BANK=7)
C
      LCAD2 = 0
      LCAD1 = LQ(LHEAD - IZCAD1)
      POINT = LCAD1
C
C ****  Get HEADER LENGTH
C
      30 HEADER_LEN = IQ(POINT + 1)
C
C ****  Get CONTROLER word
C
      CONTRL = IQ(POINT + 3)
C
C ****  Extract Crate Number from CONTROLER word
C
      CRATE = CONTR_BYTE(4)
C
C ****  Set modulus variable for calculating indices
C
      IF ( (CRATE .EQ. 7) .OR. (CRATE .EQ. 17) .OR.
&        (CRATE .EQ. 8) .OR. (CRATE .EQ. 18) ) THEN
          MODVAR = 384
      ELSE
          MODVAR = 768
      ENDIF
C
C ****  Extract Number of ADC cards from CONTROLER word
C
      NADCS = CONTR_BYTE(3)
C
C ****  Get STATUS/VERTEX word
C
      STAVER = IQ(POINT + 4)
C
C ****  Extract Vertex position from STATUS/VERTEX word

```

```

C
  VERTEX = STA_VER(1)

  IF (VERTEX .NE. 0) THEN
    ZBIN = 0
  ELSE
    ZBIN = VERTEX
  ENDIF

C
C ***** Loop over cards in this crate
C
  POINT = POINT + HEADER_LEN + 2
  DO 10 I = 0, NADCS

C
C ***** Get NUMBER OF DATA/ADDRESS WORDS for this card in this crate
C
  NKANALA = IQ(POINT)

C
C ***** Loop over DATA/ADDRESS words
C
  DO 20 II = 1, NKANALA
    POINT = POINT + 1

C
C ***** Extract PULSE HIGHT and ADDRESS from
C ***** DATA/ADDRESS WORD = IQ(POINT)
C
C      DATA/ADDRESS word
C
C      |---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
C      |      ADC      |      BLS      |  ROTOW  |      DEPTH      |SCL|NEG|
C      |  (Only 4 bits)  |              |          |              |   |LIM|
C      |---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
C      32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17
C
    PLSHT = JBYT( IQ(POINT),1,16 )
    INDEX = JBYT(IQ(POINT),19,13)
    GINDEX = INDEX
    CALL CBYT(CRATE_ID(CRATE),1,GINDEX,14,3)
    INDEX = MOD(INDEX,MODVAR) + CRATE_OFFSET(CRATE_ID(CRATE))
    &      + (15+ZBIN)*2304
C

```

```

C **** Calculate energy and Et
C
      IF ( FLOAT(PLSHT)*GAIN_VAL(GAIN_INDEX(GINDEX)) .GT. 0.1)
&      THEN
      ENERGY = FLOAT(PLSHT)*GAIN_VAL(GAIN_INDEX(GINDEX))
&      + ENERGY
      ET = FLOAT(PLSHT)*GAIN_VAL(GAIN_INDEX(GINDEX))
&      * SIN_THETA_VAL(SIN_THETA_INDEX(INDEX)) + ET
      ENDIF
20  CONTINUE
      POINT = POINT + 1
10  CONTINUE
C
C **** Finished with all cards in this crate. POINT points to the first
C **** word in a crate trailer. Skip the crate trailer if there is one.
C
      IF (HEADER_LEN .GT. 3) THEN
      POINT = POINT + 3
      ! Points to the last word of
      ! the crate trailer
      ELSE
      POINT = POINT - 1
      ! Points to the last word in the
      ! last crate.
      ENDIF
      IF ( IQ(POINT+1) .EQ. HEADER_LEN ) GOTO 30
      ! Do the next crate
C
C **** Do CAD2 bank (BANK=8)
C
      IF ( LCAD2 .EQ. 0 ) THEN
      LCAD2 = LQ(LHEAD - IZCAD2)
      POINT = LCAD2
      GOTO 30
      ENDIF
C
C **** Print ENERGY and Et for this event
C
C      WRITE(USUNIT(),1001) ENERGY, ET

999 RETURN

1001 FORMAT(' **** ENERGY=',2PE10.4,2X,'Et =',2PE10.4)

```

END

5 Suggestions for code development

In order to utilize the SFC efficiently several decisions have to be made for each application. One general question concerns the siting of the SFC: piggybacked on the MPM board (servicing its two data cable channels), or on a separate board which would have access to all data cable channels. Separate SFC's can operate simultaneously on their local data and can be tailored to specific applications, but a general SFC serving all channels is less expensive.

As part of the process of specifying the hardware design, one needs to know the memory needs for the application, which in turn depends on the algorithm one intends to implement, which in turn fixes code to a large extent. It is useful to keep all arrays one-dimensional even at the expense of the more complicated indexing and introduction of additional tables. To summarize in a few steps:

1. Start with the assumption that there is 256 Kbyte of memory available for the SFC. (This is the default memory size of each MPM channel.)
2. Identify what is it that needs to be calculated. A repeditive, highly compute intensive task makes the best target.
3. Develop algorithm. Keep in mind that you want to make best use of available memory. Also try to eliminate logical branches impeded in the computation (make best use of the MFLOP capacity).
4. Check if it is consistent with 1. If not go to 3. and do it again.
5. When the algorithm is fixed, if it is consistent with 1., it gives everything you need to know to discuss the hardware design. If it is not consistent with 1., make a strong case that D0 should invest more in the memory and convince the financial control persons that if you do not get X Kbytes of memory we will never see the Wino.

A : Table for $\sin \theta$

Let us assume that there are only 8 bits available for pointing to the $\sin \theta$ of the cell. It means that there are only 256 different values of $\sin \theta$. Let us assume that $STMAX$ and $STMIN$ are the maximum and minimum values of $\sin \theta$ for cells in the D0 calorimeters and let us assume that there is an array $SIN(I)$, $I = 0, \dots, 255$ such that $SIN(0) = STMAX$ and $SIN(255) = STMIN$. Let us denote by ERR the ratio

$$ERR = \frac{SIN(I) - SIN(I+1)}{SIN(I)}.$$

Then with STMIN=0.0148 and STMAX=1.0

$$ERR = 1 - \left(\frac{STMIN}{STMAX}\right)^{\frac{1}{255}} = 0.0164.$$

ZRL STANDARD DATA ACQUISITION PLATFORM

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FIGURE 1.

FIGURE 2.