AN EFFICIENT MULTIPROCESSOR MANAGEMENT
SYSTEM FOR EVENT-PARALLEL COMPUTING

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Performance of software using TCP/IP sockets to distribute events to UNIX workstations is described. This simple software was written at the University of Mississippi to control UMiss farm reconstruction of 8 billion raw events, part of Fermilab E791's data. E791 reconstructed HEP's largest data set to study charm physics.

Fermilab E791 wrote a big dataset (50 Terabytes, 20 billion events, 24000 8mm Exabyte tapes) in 1991 and early 1992. Reconstruction challenged available computing, requiring over $10^4$ mips-years. The task was larger than at colliders (Table 1). Reconstruction was nevertheless completed using four farm sites. Here we describe the multiprocessor management software developed and run at the University of Mississippi farm (Figs. 1 and 2 show hardware).

HEP events are usually independent. Interprocess I/O isn’t needed. An efficient parallel system just has to input and output events fast enough so clients are never idle. Management software had to do a lot of hard work in early HEP systems. Clients had minimal operating systems. All data had to be formatted in a server and downloaded into clients word by word. Moving from single to multiple CPUs was hard; the division between server and

Figure 1: Mississippi farm overview. Servers are on the four tables. Clients are on the racks shown and on desktops not shown. The espresso machine is on the left.
client code was intricate. With the advent of commercial workstation clients with real operating systems, most work inherent in moving to multiprocessors vanished. Using Network File System software, server disks can be cross-mounted so that files are accessible by multiple clients. In this model, even inexpensive diskless clients directly read an executable code file, a run number file, calibration files, a raw input record file of events, and write report files and reconstructed event files. The server writes input events from tape to disk files. At the end of a job, the server copies client output event files to tape and combines client reports, as clients work on the next job. Because 85% of E791 events were filtered away after reconstruction, disk output was fast enough for us. Event input by disk also worked, but too slowly. So, our multiprocessor manager bypasses disk for input using instead Transmission Control Protocol/Internet Protocol.

With TCP/IP, processes make a connection between themselves and pass data back and forth using read from connection and write through connection subroutine calls. A test of TCP/IP gave 900 kbyte/s, ending client idleness. Fig. 3 illustrates how the network I/O calls are used. As the server prepares to start a client, it uses make_socket to “have a phone put in”, so that it will be able to connect to the client. When the client starts, it too uses make_socket to “have a phone put in”. The server “lists its number” by binding its socket to a port (bind_socket), and “stays near the phone” listening for an attempt to connect (listen_socket). The client “calls up” the server (connect_socket) and the server “picks up the phone” establishing the connection (accept_socket). When it needs input data, the client “places its order” by writing a message to the server (write_socket). The server is continually monitoring all of the client connections for requests (select_socket). When a request comes in, the server “writes down the order” (read_socket), and

Figure 2: Mississippi farm architecture. Servers and clients are DECstation 5000 workstations running ULTRIX. Some have MIPS R3000 CPUs; others the more powerful MIPS R4000. Altogether, there are 68 processors organized into 4 farms isolated by Ethernet bridges. One typical farm is shown here. The two input tape drives alternate automatically. Each drive is only wearing itself out half the time. If an input tape drive fails, the next tape starts automatically. The output is staged through disk and streamed to tape. If the output tape drive fails output data can easily be recovered from disk. If a disk fills, processing is automatically paused until space appears. This I/O scheme avoids constant operator supervision.
Table 1: E791 raw data size and $p\bar{p}$, $e^-p$ and $e^+e^-$ collider experiment sizes. D0 saves digitized waveforms.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Events</th>
<th>Terabytes $× 10^6$</th>
<th>Recording Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>E791</td>
<td>20000</td>
<td>50</td>
<td>7/91 - 1/92</td>
</tr>
<tr>
<td>CDF</td>
<td>95</td>
<td>10</td>
<td>10/85 - 12/95</td>
</tr>
<tr>
<td>D0</td>
<td>80</td>
<td>40</td>
<td>2/92 - 12/95</td>
</tr>
<tr>
<td>H1</td>
<td>70</td>
<td>2.5</td>
<td>5/92 - 12/95</td>
</tr>
<tr>
<td>ZEUS</td>
<td>50</td>
<td>5</td>
<td>5/92 - 12/95</td>
</tr>
<tr>
<td>Aleph</td>
<td>60</td>
<td>1.7</td>
<td>8/89 - 11/95</td>
</tr>
<tr>
<td>Delphi</td>
<td>~30</td>
<td>~5</td>
<td>8/89 - 11/95</td>
</tr>
<tr>
<td>L3</td>
<td>83</td>
<td>3.4</td>
<td>8/89 - 11/95</td>
</tr>
<tr>
<td>OPAL</td>
<td>102</td>
<td>1.5</td>
<td>8/89 - 11/95</td>
</tr>
<tr>
<td>CLEO</td>
<td>600</td>
<td>5</td>
<td>10/79 - 12/95</td>
</tr>
</tbody>
</table>

The clients then finish their tasks, close their connections (close socket), and exit; the server finishes its tasks and exits. The Fortran-callable C routines that manipulate sockets and connections really are that simple to use. Only read_socket is more than a C to Fortran interface, and even its trivial. Most of the real work has already been done in UNIX, TCP/IP, and Berkeley Sockets.

Although most of our farm processors are in racks, some are on people’s desks. We have found it satisfactory to allow users to abruptly kill the client process whenever they find its activities on their workstations to be troublesome. A reconstruction code crash also kills a client. In either case, the server is quickly aware of the dead client and adjusts event distribution. A disadvantage of this approach is that a few input events are trapped and lost. Having 20 billion events, we take a rather cavalier attitude. In E791, processing raw events is rather like hauling corn to market in a truck. If a few grains of corn fall out of the truck, no one cares. The alternative approach – treating events as babies in a hospital nursery, where one normally expects a somewhat stricter accounting – only makes sense later with small selections of interesting events.

Before writing our own multiprocessor software we considered extracting...
the few features needed from large packages under development at Fermilab\textsuperscript{jk} and Argonne.\textsuperscript{l} However, offsite support was unavailable. So we focused on writing software which could do a limited number of things very well; e.g. run many clients per server efficiently and tolerate client crashes and operating system upgrades. Six man–weeks were spent coding. Farm operation required 5 hours over a day. After seeing our approach to moving farm data, the D0 experiment decided to follow a similar strategy.\textsuperscript{m}

Funding in June 1993 allowed an expansion of the UMiss farm from 1100 to 2900 mips. By July 1993, the increased computing was acquired and processing data. E791 reconstruction was completed in Sept. 1994. A total of 8 billion events on 10,000 raw data tapes were processed in Mississippi. Before running final reconstruction, dozens of full farm tests of algorithms for actual charm yield were run, each test for a few days. The charm yield tripled. X Window operator control displays written in Tcl/Tk aided bookkeeping. Tape reading was multiply buffered, so that events were almost always available immediately when a client asked for them. During smooth running, timing CPUs showed that at least 97% of client processing cycles were used. Overall efficiency, considering cycles lost for any reason, exceeded 90% over a 2\frac{1}{2} year period.

Efficient management of multiple processors has led to the reconstruction of 200,000 charm particles, the world’s largest sample. Results\textsuperscript{n} include DPF’96 papers by N. Copty, L. Cremaldi, K. Gounder, M. Purohit, K.C. Peng, A. Tripathi, R. Zaliznyak, and C. Zhang. We especially thank Lucien Cremaldi and Breese Quinn for their contributions to building and running the UMiss farm. This work was supported in part by U.S. DOE DE-FG05-91ER40622.

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