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The Condor Programmer's Manual - Version II

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Abstract: This is the *CONDOR* programmer's manual, that describes the hardware and software that form the basis of the real-time computational architecture built originally for the Utah-MIT hand. The architecture has been used successfully to control the hand and the MIT-Serial Link Direct Drive Arm in the past. A number of such systems are being built to address the computational needs of other robotics research efforts in and around the lab. This manual, which is intended primarily for programmers/users of the *CONDOR* system, represents our effort at documenting the system so that it can be a generally useful research tool.

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Contents

The Utah-MIT Hand project was started in the fall of 1983 to build a high performance dexterous robotic end-effector, capable of human-like performance. The hand itself was built by the fall of 1985. The first version of the hand was controlled by an earlier incarnation of the hardware and software presented in this document. (This earlier version was based on Motorola 68000 single-board computers on the Intel Multibus. This version will be referred to as *CONDOR* -Version I in this document.)

A redesign of the actuators was completed in the fall of 1986. Coupled with this was a redesign of the computational architecture, both hardware and software. It is this second version (known as *CONDOR* -Version II) that this document describes.

Although the computational architecture was developed originally to control the Utah-MIT hand, the architecture that has resulted is a powerful, multi-micro-processor system that is fairly general in its scope, and is oriented specifically towards real-time computation. The architecture has been used to control other robotic devices besides the Utah-MIT hand, notably the MIT serial link direct-drive ARM. There are a number of these systems in the process of being built at MIT to address the real time needs of other research groups at MIT's Artificial Intelligence Laboratory. Besides this, a number of research efforts around the nation (in particular Stanford's NYMPH architecture and a research architecture being built at IBM) have acknowledged our system's influence on their design.

2.1 The Hand Project

The Utah-MIT hand is a pneumatically powered four-fingered hand, built to investigate issues related to machine dexterity, as part of an ongoing project at the University of Utah's Center for Engineering Design and M.I.T's Artificial Intelligence Laboratory. Each finger of the hand has four joints. Each joint is driven by a pair of pneumatic actuators operating at around 70 psi. The actuator used is an extremely fast, single stage, pressure servo controlling the position of a graphite piston encased in a glass cylinder. The movement of a piston is transmitted to the actual joint by tendons routed over pulleys. The hand is approximately anthropomorphic in size and shape. A more detailed discussion of the design issues involved can be found in Jacobsen et al. [1985, 1986].

The hand has thus sixteen degrees of freedom in itself (four fingers each with four degrees of freedom) (see Fig. 2.1). It also has two wrist degrees of freedom to some extent, but these are not presently actuated. The hand is mounted physically on the arm subsystem, which comprises of four cartesian degrees of freedom. The hand can be moved up and down in a vertical direction (the z axis), and horizontally, (the y axis) using this arm. In addition to these two degrees of freedom, a two degree of freedom x-y table is positioned beneath the arm bringing the total degrees of freedom of the wrist relative to a fixed absolute reference frame to four. The actuator assembly (known as the actuator pack) is mounted separately from the arm subassembly. The tendons from the actuator pack are routed to the hand via a mechanism known as the *remotizer* which is essentially a mechanism for mounting the hand separately from the actuator pack while keeping constant the lengths of all the tendons even while the hand is moving.

The manual is organised into the following sections.

1. A section on hardware. This section describes briefly, the different components that comprise the hardware configuration of the *CONDOR* system.

2. System and application level software support needed for the *CONDOR* system. Since this manual is a *programmer's* manual, we provide explanations at two levels; one aimed mainly at a user of the system, and another for a prospective maintainer or implementor of system software. Some sections intended for the latter group assume a fairly detailed knowledge of Unix and the C programming language.

   Users whose main interest in the computational architecture is to use it to control the hand ought to read Section 4.3. This section documents the external interface that the software presents to the application programmer and provides a description of all the utility libraries.

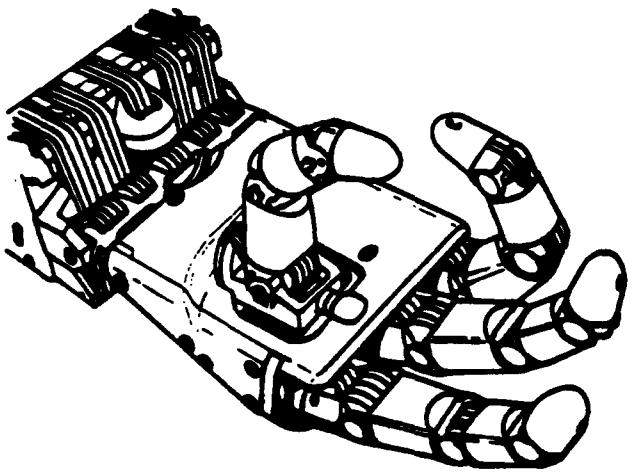


Figure 2.1: The Utah-MIT dexterous hand

3. Manual pages for the various programs that go into making up the development and run-time environment that is the *CONDOR* system.

The version of the system described in this document pertains mostly to the development environment that runs on the Sun-3 workstations in the Lab.[1], and the runtime environment that runs on Motorola 68020 based single board computers on the VME-Bus.

[1]The Sun-3 is a trademark of Sun Microsystems, Inc.

This section discusses the hardware architecture of the *CONDOR* hand control system. The purpose of this section is to provide the motivation for some of the design decisions that were made during the development of the *CONDOR* system, and to provide some guidance for installing and maintaining such a system.

3.1 Design Considerations

An early decision was made to use off-the-shelf hardware whenever possible. This decision was motivated by the observation that computations needed to control a general purpose robotic hand are suitable for general purpose computer architectures, and custom-made computer hardware is rarely cost effective when only few systems are to be built. In addition, keeping a custom built system at the state of the art requires constant improvements in the hardware, and is a never ending proposition. Such a task is best left to commercial companies that specialize at this.

An initial examination of the types of computations that were expected to be performed indicated that a multiprocessor based hardware solution would work well. Using multiple processors is advantageous for several reasons. Most importantly, additional computer power can be obtained by adding more processors to the system. In addition, alternate control strategies can be tested simply by partitioning them in different ways. For example, reprogramming a uniprocessor that controls multiple robots would require much more work, since many time critical events need to be serviced in a complex fashion.

Once the decision to use multi-micro-processors had been made, the individual processor on which the system would be based had to be chosen. Table. 3.1 compares the price to performance ratio of some of the CPU's available then that were considered. (See also Table. 3.2 which gives benchmark timings for some of the operations on the current configuration).

Table 3.1: Comparisons of processing power available from different hardware configurations.

Processor Type	Speed	Cost	Comments
Microvax II	1 MIP	mod	interconnect problems
Vax 11/750	1 MIP	high	interconnect problems
Symbolics 3600	1 MIPS	high	lacks real time support
National 32032	1 MIPS	low	
Motorola 68000	1 MIPS	low	lacks floating point
Motorola 68020	2.5 MIPS	low	

In some robotics controllers, the enormous attention paid to efficiency and performance has often resulted in cryptic, unmaintainable and inextensible systems. Since our system is to be used primarily as a research tool, it was desirable that it be highly flexible, extensible and portable to other hardware architectures as well. However, at the same time, performance goals had to be met. These goals were often conflicting, but we felt that by appropriately organizing the computational hierarchy we would be able to strike the right balance between them. For a more detailed discussion of the pertinent issues involved see Siegel et al., [1985] and Narasimhan et al., [1986].

The important features of the *CONDOR* hardware that are expected to persist across multiple system configurations are therefore (see Table. 3.3):

1. **Powerful multi-micro-processor system.** (the individual CPU that the system is based on may change although at present we strongly rely on the Motorola 680xx line).

2. **Standard interconnect scheme.** The present version of the system (i.e. *CONDOR* -Version II), is based on the industry standard VME-bus. An earlier version was based on the Intel Multibus. These high-speed busses form the basis for our inter-processor communication scheme. Using an industry-standard bus to form the backplane of our system has the added advantage in that peripherals like A-D/D-A boards, and digital I/O boards are readily available for such busses as are powerful single-board computers.

3. **Tightly-coupled multi-processor interconnect.** The present version of the system and quite a few in the future will be based on the shared dual-port memory paradigm for interprocessor communication. Although support may be added for network interfaces, parallel ports etc., these are not expected to be fast enough to satisfy our real-time constraints which are typical of high-performance robotic controllers.

3.2 Components

The hardware architecture of the *CONDOR* system consists of the following components (see Fig. 3.1);

1. The analog controller subsystem. This subsystem can be used to bring up the hand in a turn-key mode which is extremely useful in running certain diagnostic tests and quick demonstrations. It requires very little else to operate and is described in the document *The Utah-MIT dexterous hand - Electronics*, and will not be described further in this document. Users of the *CONDOR* will rarely use the system in this mode. This system essentially consists of the box with flashing lights next to the hand. The more important function played by this box is that it houses and powers the analog drivers needed to power the hand's electronics. This forms the lowest level of the hand control system.

2. The *CONDOR* processors. In addition to the analog controller at the lowest level, a bunch of four *MOTOROLA 68020* processors are used to control the hand when it is running under digital control. These are housed in a VME-Bus cardcage. The analog-to-digital and digital-to-analog boards, are presently housed on the Multibus, but they will be moved to the VME-bus shortly. The processor boards are plugged into the VME-Bus across which data is transferred for interprocessor communication. A-D/D-A transfers occur across the VME-Bus to Multibus adaptor.

3. The Sun-3. The *CONDOR* microprocessors are interfaced to a Sun-3 via a bus-to-bus adaptor link. The adaptor basically extends the bus on the development machine to include the bus on which the control processors reside. In addition to this extremely fast connection that can transfer data at rates comparable to a standard VME-Bus, there also exists a slower connection between the Sun and the microprocessor subsystem via a 9600 baud serial line. The Sun is used mainly for program development. The user interface for most control programs also presently resides on this machine.

4. The Arm control hardware. The Arm subsystem is controlled by Slo syn stepper motors which are controlled by a controller card that also plugs into the Multibus.

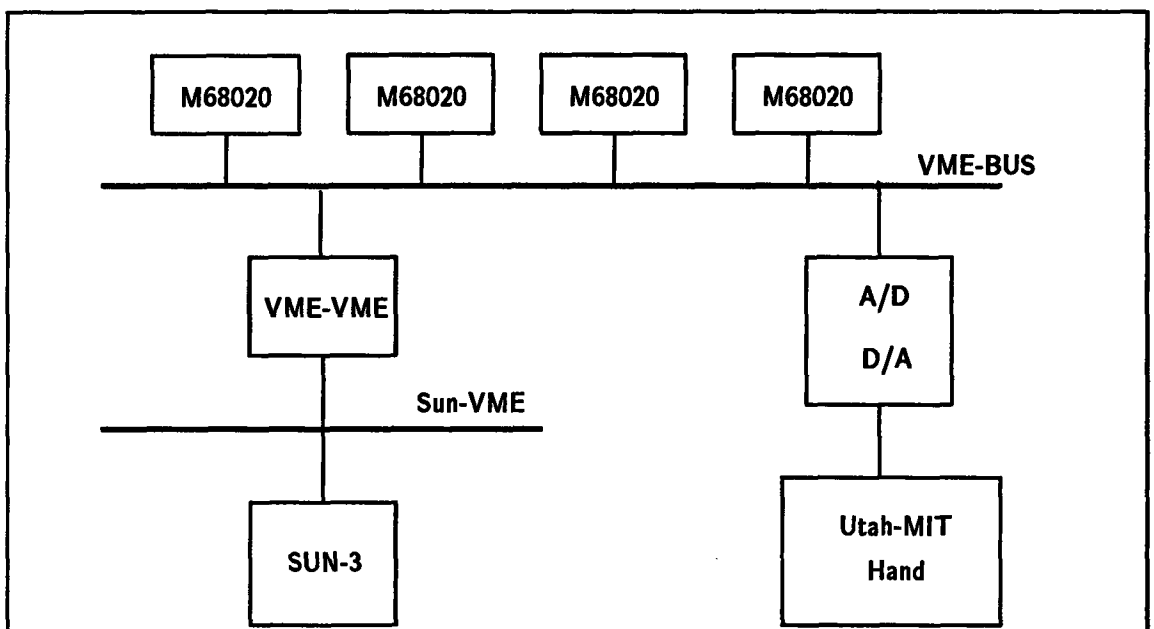


Figure 3.1: Hardware block diagram for the Utah-MIT hand controller.

In this document, we do not discuss either the arm control hardware or the analog controller hardware designed for the Utah-MIT hand. Our emphasis will primarily be on the Motorola 68020 system designed to run control software and the development software that presently runs on the Sun.

3.3 The VME-Bus system

3.3.1 The Ironics IV-3201 Single Board Computer

This processor board forms the main workhorse of the multi-micro-processor controller hardware. The Ironics IV-3201 Processor board is a powerful single-board computer based on the Motorola 68020 microprocessor, coupled with the fast 68881 floating-point unit. In addition to the microprocessor, many other functions are provided on-board as described below.

An industry-standard 28-pin byte-wide memory socket is provided to hold a PROM which contains up to 32 Kbytes. This prom is used to provide the monitor which bootstraps user programs.

The board contains one megabyte of RAM, which may be expanded to a total of four megabytes if desired. This no wait-state, dead-lock protected RAM is dual-ported; i.e it may be accessed either locally by the processor, or as a VME-Bus Slave by another device.

Memory base addresses may be jumpered to start at any of a set of predefined locations. It is necessary that the dual port address of every board in a system be configured correctly for the software to operate correctly (see Appendix B, for this configuration information).

The Ironics single board computer is adequately described in the document titled *IV-3201 68020 CPU Board – User's Guide*, which is available from Ironics, Inc. Please refer to this document for further information regarding the features it has, and for board-specific configuration information.

3.3.2 VME-Bus

The individual ironics cpu boards are all plugged into the industry standard VME-Bus backplane. More documentation on the VME-Bus can be found in the document titled *The VME-Bus specification manual* which is available from a number of manufacturers. This document is also known as the *IEC 821 Bus* and the *IEEE P1014/D1.0*.

The VME-bus specification provides for a variety of options. The version of the backplane we use in our system is based on the J1-J2 two-high connectors each of which are 96 pins.

The bus specification includes provisions for data transfer, interrupts and bus arbitration. It specifies a bus that has 32 bits of address and data and 5 bits (or 32 values) for address modifier codes. This enables address cycles on the bus to be further distinguishable by the code that is passed on the modifier lines, and obviates the need for specialized i/o spaces.

The VME-Bus'es different address spaces are mapped into separate blocks of the full 32 bit address space on the Ironics 3201 processor board. Please see the document titled *IV-3201 68020 CPU Board* available from Ironics, for the particular mapping that is currently available from them.

The VME-Bus provides for 4 different levels of bus requests and grants. We have chosen to put all the Ironics cpu boards at bus request level 3 (BR3). The `synergist-3` type of bus-to-bus adaptor is configured to run at level 2 (BR2) while the `hve-2000` type of adaptor is configured to run at level 3 (BR3).

Please see the section below, for information pertaining to VME-Bus interrupts.

The bus arbitration on the VME-Bus we presently rely on the system controller functions performed by the IV-3273 system controller available from Ironics. We do not use the system controller available on the HVE bus to bus adaptor which must be disabled on the slave VME-Bus, for proper operation on the *CONDOR* system.

3.3.3 Interrupts

The VME-Bus supports vectored interrupts. The basic idea is that an interrupting device raises an appropriate interrupt request line to indicate that it wishes to interrupt a processor. The VME-Bus supports eight levels of interrupt priority. The device that wishes to service the interrupt is known as the ***interrupt handler***. When this device senses that a peripheral wants to interrupt the processor, it acknowledges the interrupt, starting an *IACK* cycle. The peripheral is supposed to place a vector number on the data bus when it receives the interrupt acknowledge signal. The vector number indicates to the processor the routine that it must execute in response to the requested interrupt. For a detailed explanation of the signal transitions during this entire process, see the *VMEBus Specification Manual.* For an explanation of how processor vectors work, see the *Motorola 68020 User's Manual.* Please see Section 4.3.17.1 for programming information regarding interrupt vectors.

Each of the Ironics 3201 boards has an interrupt handler chip that can be programmed to respond to any of the eight VME-Bus interrupt levels, or any of eight local onboard interrupt sources. Please refer to the *Ironics 3201 User's Manual* and the *Motorola 68155 Interrupt Handler - Data sheets* for further information on this interrupt handler chip.

3.3.4 Ironics IV-3273 system controller

The Ironics IV-3273 system controller board performs the important function of arbitrating bus requests on the slave VME-Bus. This board also has a number of devices like a serial io device, a parallel port device etc., on it, that can be used by the 3201 processor boards. For further information on this controller board, please refer to *The Ironics IV-3273 System Controller - User's Guide* available from Ironics.

This board's serial io chip (the Motorola M68681) forms the terminal driver of our system. Please see Page 23 for programming details concerning hardware devices, and Appendix A for details on how to write a device driver for a new device that is to be incorporated into the system. This serial driver is needed only for initial bootstrapping and debugging operations. Since the serial chip on the ironics system controller card can be controlled only by one processor at a time, forcing all processors' terminal i/o through this single serial chip is hopelessly cumbersome. To overcome this problem we have designed a pseudo terminal emulator which the processors can use to communicate with the Sun over the bus-to-bus adaptor. This psedo terminal emulator or pty is designed as a service to work on top of the message passing system which will be described later.

3.3.5 HVE Bus to Bus adaptor

The Hal Versa Engineering board connects the slave VME-Bus on which the Ironics single board computers are mounted to the VME-Bus that houses the Sun-3. Physically this subsystem consists of two boards connected together by two cables. While one board is plugged into the Sun-VME backplane the other is designed to plug into the slave VME system.

There are two versions of the hve adaptor that are currently in use. The first version, called the `synergist-3` is a 16-bit device while the second called the `hve-2000` is a full-fledged 32 bit device that connects up the two vme-busses in a completely transparent fashion.

The synergist-3 version of the adaptor provides i/o locations that the users can write to on either side of the bus. These i/o locations when written to, cause dynamic connection or disconnection of the bus-to-bus adaptor. For the *CONDOR* software system to function correctly, these i/o locations must be configured correctly. (Please see Section B for details).

For programming details on how to use the bus-to-bus adaptor system from the Sun please see Section 4.3.8. For programming details on how to use the mailbox communication mechanism to communicate to the Sun from the microprocessors see Section 4.4.1.1.

The bus-to-bus adaptor in addition to providing a fast and transparent memory-to-memory link also provides a way of mapping interrupts from the Ironics processors to the Sun CPU. To accomplish this purpose we have left ONE interrupt level (level one) connected between the two busses. The other interrupt levels are disconnected to prevent unwanted interaction between the Sun's Operating system and interrupting devices on the slave vme bus. The sun initiates communication with the ironics processors by using the mailbox interrupt present on the processor boards while the ironics processors use this single interrupt level to interrupt the sun across the bus-to-bus adaptor in order to communicate with it.

3.3.6 Memory Board on the VME

The message passing system requires each processor to have a section of memory devoted primarily for message passing. While it is easy to get such memory on the *CONDOR* processors, getting such memory from the Sun end may not be such an easy task. Rather than use Sun's DVMA space or other solutions that were not very appealing, we chose to augment the slave VME-Bus with an extra 1Megabyte memory board intended solely for use by the Sun.

Any commercially available memory board will do the task. We recommend the *MVME-204* board made by Motorola. This board is available in two flavors – the *MVME-204-1* is a one megabyte board, while the *MVME-204-2* is a 2 megabyte memory board.

If adding such a board would not be possible owing to other constraints, the software can be reconfigured and recompiled so that a small portion of memory from an Ironics processor board can be used by the sun for this purpose.

3.3.7 A/D and D/A converter boards

A variety of analog-to-digital and digital-to-analog converter boards are available off-the-shelf for the VMEBus. In this section we describe the boards made by Data Translation, that are the ones currently being used by the *CONDOR* controller for its data acquisition operations. (Users intending to use the system present in MIT's AI Laboratory should refer to Section 4.6.1).

There are a number of features that one ought to watch out for in picking data acquisition hardware. Primary considerations are speed, number of channels and number of bits of resolution provided by the board. Other factors that merit evaluation are programmable gain, interrupt capability and protection circuitry.

1. *Data Translation A/D Boards:* The A/D board that we recommend for the *CONDOR* system is a device that has 32 single ended channels each at 12-bits of resolution. The board is made by Data Translation and its product number is DT-1401. It has a programmable gain option and provides interrupting capability. For programming details on data acquisition hardware see Section 4.3.6.

2. *Data Translation D/A Boards:* The DT1406 D/A board made by Data Translation complements the A/D board effectively. It provides 8, 12 bit channels, intended for voltage output. Besides multiplying DAC's the board also has a DC/DC converter for noise reduction.

3.3.8 The Arm Controller Hardware

The arm controller hardware is based on the Magnon stepper-motor controller on the Multibus. Since this is also a feature peculiar to our local environment, documentation on this is deferred to a later section. Programmers interested in using this system should refer to Section 4.6.1 for details.

3.3.9 The Motorola parallel-port board

In our system the capability for parallel i/o is provided by the Motorola MVME-340 parallel port board. This board is based on the Motorola 68230 Programmable parallel port and Timer chip.

The versatility of this chip, and consequently that of the board makes it impossible to describe it adequately in this document. For further documentation on the chip and the board please see the document titled *MVME-340 - User's manual* available from Motorola.

Table 3.2: Timing Information (in microseconds)

Explanation	Add	Sub	Multiply	Divide	Fadd	Fsub	Fmul	Fdiv
Motorola 68000	5.2	6.0	8.2	57.0	170.1	190.0	275.7	642.2
68020/no cache	6.2	5.6	6.3	41.0	32.4	32.4	40.8	42.3
68020/cache	4.0	2.9	4.0	26.7	24.7	24.8	31.5	35.0

Table 3.3: Computational components of the hand controller.

Processor type:	Motorola 68020
Clock rate:	16-25 megahertz
Instruction rate:	$\approx$ 2.5 MIP
Processor on board memory:	1 Megabyte
Total processors:	4
Total memory:	4 megabytes
Bus Architecture:	VME-bus
Analog to digital converters:	128
Digital to analog converters:	32
Connection to Sun:	Bus-to-Bus adaptor

This section will describe the software that has been developed for the *CONDOR* system. The version of the software described here runs on the *MOTOROLA 68020* version of the system. Future ports to other architectures will adhere to the protocols described herein to a very large extent.

This section is intended primarily for other programmers of the *CONDOR* system for control applications; It presumes prior knowledge of the "C" Programming Language [1] and of the 4.2 BSD Unix environment; The subsections have been organized roughly in increasing order of detail and complexity.

4.1 Introduction and Motivation

The software system was designed to achieve the following goals:

(a) Provide a flexible environment to aid the development of real-time control programs.

(b) Provide efficient, low-overhead support for commonly performed operations.

(c) Provide an extensible and portable basis for subsequent software development.

These goals were often conflicting, but we hope that the system that we have developed strikes a reasonable balance between flexibility and efficiency. The goal of flexibility and portability at the software level partially dictated our choice of C and Unix as the basis of our development environment, and also led to a conscious effort to minimize machine specific assembly language coding. We have ported the system onto two different machines and each port has contributed to streamlining our design.

In this document we describe the modules and the programmer's interface to the real time development system. In a sense, this document specifies the interface or architecture for real-time program development on the *CONDOR* . By separating these modules and specifying exactly what this interface looks like, we hope to make the development environment into one that the control programmer can rely on.

Separating the control programs from the underlying system support required for them is also beneficial in another respect. By writing emulation libraries for the architecture, it will be possible to run the same higher level control programs on different architectures. This will make possible a degree of sharing and building on previous work that has been noticeably absent in robotics efforts in the past.

The system comprises of a large number of software libraries and a set of stand-alone programs. The development software is to a large extent independent of the hand control programs we have written.

The programmer's model we have been using relies on the following assumptions:

[1] see Kernighan B., and Ritchie, D., *The C Programming Language - Reference Manual*

- All control programs will be written in C on the development machine.
- These programs are intended to be run on one or more processors comprising the *CONDOR* hardware.
- The programs are compiled and downloaded to the individual microprocessors to be actually run.
- The programs are then run and debugged on the slave microprocessors.

The software system has therefore been designed to provide support for the following:

(a) Provide C startup and runtime support on the bare machine.

(b) Provide facilities for interprocessor communication.

(c) Provide support for debugging in this environment.

Besides the above, the system provides support for adding new hardware devices into the base sytem, for user level scheduling of real-time tasks and managing timers, for file system operations on the slave microprocessors and a host of other often needed system functions.

4.2 Roadmap

The following section is intended to provide a brief overview of what the various facilities are, and where the source for them can be located.

1. `./condor` – The top level source directory.
2. `./bin` – Directory for binary executables, utilities etc.
3. `./include` – Directory for include files.
4. `./include/vme` – Directory for include files specific to the VME port.
5. `./hand` – Hand control programs.
6. `./lib` – Directory where libraries are kept.

The source directory has the following subdirectories.

1. `./condor/boot` – Source for creating boot proms. Not needed for Version II of the hardware.
2. `./condor/cmd` – Source for standalone utilities.
3. `./condor/ddt` – Source for the obsolete Stanford debugger system.
4. `./condor/diag` – Various diagnostic programs.

5. `./condor/doc` – Documentation.
6. `./condor/libc/crt` – C runtime support routines.
7. `./condor/libc/csu` – C startup support.
8. `./condor/libc/dev` – Device independent file descriptor routines.
9. `./condor/libc/ironics` – Ironics port code.
10. `./condor/libc/libsun` – Support code that runs on the Suns.
11. `./condor/libc/microbar` – Microbar port code.
12. `./condor/libc/stdio` – Stdio support code.
13. `./condor/libc/strings` – Strings library.
14. `./condor/libc/sun` – 020 specific code that is different from the sun supported library code.
15. `./condor/libc/test` – Testing and validation programs.
16. `./condor/libc/unix` – Miscellaneous Unix support routines.
17. `./condor/libc/vmedev` – Device drivers for various VME boards.
18. `./condor/libutils/math` – Utility math library source.
19. `./condor/libutils/parser` – Command parser library source.
20. `./condor/libutils/xwindows` – X window system support library.

Individual files, will be mentioned by name later on in the document, as and when required.

4.3 Level Zero software for the *CONDOR*

This section will summarize briefly, what software is currently available for doing real-time programming, on the *CONDOR* system, at the uni-processor level. In particular, this section covers information on the math, stdio and interrupt management library routines. These sections cover programmer libraries that are used often. The more complex facilities for message-passing based inter processor communication and the *MOS* (the Minimal Operating System) are deferred to the section which follows. Documentation is provided only for those functions that are completely new in our system or whose semantics deviate sufficiently from their normal interpretation in the Unix Programmer's manual. (For example, no documentation is provided here, on standard functions like `printf`, `sin` or `malloc`, besides mentioning their names to indicate that they are supported). This section, along with the standard I/O documentation commonly found in the Unix Programmer's manual, should provide the user with the capability of writing simple control programs that run on one processor of the *CONDOR* system.

The functions are documented in terms of the modules they appear in, in no particular order. A fully alphabetical index for all the functions appears at the end of this document to enable users to locate the documentation associated with a particular function more readily.

It should be also mentioned that in this document we do not provide any documentation on how to write hand control programs, or documentation on the hand control programs that are currently available. Such documentation will be deferred to another document that will be published in the future.

4.3.1 A primer on interaction

In this section, we describe, how a simple program can be downloaded and run on the micros. It is provided primarily for illustration. The example does not use the sophisticated window based user interface program and hence will be quite easy to understand. By following the example, one can get a feel for what is involved in actually running a simple program on the slave microprocessor. We hope that the example helps a prospective user get on and use the system in an extremely short period of time.

1. Make sure that the hardware is plugged in, and everything is configured correctly. (Refer to Section B for details on configuration, if you haven't already).

2. Power the slave VME first before powering up the sun. This should cause the green led on the front panel of the Ironics processors to light up. Now power up and boot the Sun to run Unix as usual.

3. The program `raw` can be used to connect up directly to the Ironics's serial line, using the Serial port on the Sun. When you execute this program, with the serial line connecting the serial port on your sun to the ironics serial port, the Ironics boot prom monitor (called IMON) should appear on your terminal.

4. Prepare a file called `test.c` and include the following example program in it. (Of course you can replace it with the first program of your choice).

```
main()
{
    int i;
    for(;;) {
        printf(''Type in a number: '');
        scanf(''%d'', &i);
        printf(''%d's factorial is %d\n'', i, factorial(i));
    }
}

factorial(i)
int i;
{
    if(i < 0) {
       printf(''Can't take factorial of a negative number!\n'');
       exit(0);
    }
    if(i == 0) return(1);
    else return(i * factorial(i-1));
}
```

5. Now cross-compile it for the slave microprocessor system using the `icc program` as given below.

   ```
   icc -o test.68 test.c
   ```

   Notice that this command takes arguments exactly like the `cc` command.

6. Download the program to the ironics processor. You can do this by typing

   ```
   dl68 -p 0 test.68
   ```

   if you have the VME-VME connection in place. If you dont have such a connection in place yet, you can type

   ```
   dl68 -p - -sd /dev/ttyb test.68
   ```

   For this to work, you must have the serial port 'B' on your Sun connected to the alternate serial port on the Ironics 3273 system controller board. Now if you type

   ```
   LO ;=''Downloading: ''
   ```

   at IMON the downloading will begin. Obviously, if you have two windows, one connected up to the processor via `raw` and the other running a simple shell the above procedure is quite simple to do, and its results will be easier to observe. Make sure that the alternate serial port is set up correctly before doing this. (Please see the IMON documentation on the IO command on how to do this).

7. After the downloading is done, you are ready to execute the program. The `icc` program links programs to start at 0x10000 by default. Hence if one types

   ```
   GO 10000
   ```

   at IMON after the downloading is complete the program will begin executing, and you will be prompted with:

   ```
   Type in a number:
   ```

   After satisfying yourself that your program indeed is working, you can type "~" followed by `'q'` (that is the tilde character followed by the `'q'` character) to return from the `raw` program.

That concludes our first simple example. As an exercise, figure out how many bits are there in an integer as compiled by `icc` (Hint: Use the program that you just downloaded and ran).

The program `mraw` and the shell script `mrun` can be used to run the above program on any other processor besides processor 0. Notice that the same program runs identically over the bus to bus adaptor using pty's and `mraw` as it does over the serial line using the `tty` driver and the `raw` program.

4.3.2 Memory management routines

The memory management routines implemented provide standard Unix semantics for the functions given below. They provide the programmer with a way to do dynamic memory management according to conventional C programming practice. The stack for a running program is allocated to grow downwards from a previously decided point (defined in `storage.h`) offset from the end of the program and data. The stacksize for a running program is a compiled in constant, but can be changed if one needs to do so, by changing the constant and recompiling the system. The heap is implemented to grow upwards from the address in memory where the stack grows downward from. It is defined to grow until the end of local memory, but not anywhere beyond. Local memory size is computed when programs begin to execute. Although bounds checking is done while allocating storage dynamically, no such checking is done for stack allocation. This of course means, that stack overruns can mean global disaster. The current maximum size of the stack is set to be 0x20000 bytes.

malloc(*bytes*) *Function*
unsigned bytes;
Standard Unix semantics.[2]

free(*ptr*) *Function*
*char *ptr;*
Standard Unix semantics.

sbrk(*incr*) *Function*
int incr;
Gets a chunk of memory of size *incr* from the system. Returns nil if currently allocated memory size plus the increment asked for exceeds the maximum memory present on the machine. This function is used internally by `malloc()`.

realloc(*ptr, bytes*) *Function*
*char *ptr;*
unsigned bytes;
Standard Unix semantics.

Examining memory:
The following routines that deal with memory are specific to the slave microprocessors (i.e. these cannot be used on the Sun).

memory_peekc(*address*) *Function*

[2] In all of the documentation, whenever we refer to *standard* Unix semantics, we are referring to 4.2BSD Unix as implemented by Sun's O.S. In particular, we mean that the `man` program on the Sun can be used to find out the exact documentation on the functions, which we omit repeating here.

unsigned int address;
This routine tries reading a byte from the given argument, ***address***. It returns nil if it was able to read the address (which will probably mean that the address references a valid location), and one if it cannot read a byte from the address. This can be used to detect the presence of hardware devices in the system that respond to byte reads, in a reliable fashion.

memory_peekw(*address*) *Function*
unsigned int address;
This routine tries reading a short from the given argument, ***address***. It returns nil if it was able to read the address and one if it cannot.

memory_peekl(*address*) *Function*
unsigned int address;
This routine tries reading a long (32 bits on the 020) from the given argument, ***address***. It returns nil if it was able to read the address and one if it cannot.

memory_size() *Function*
This routine tries to compute what the size of memory is. This is used internally by the system upon startup. It returns the size of local memory on the slave processors.

print_memory_size() *Function*
This routine prints out a line indicating how much memory the system is operating with currently.

4.3.3 Math routines

The math library for the 68000 resembles closely the standard math library under Unix (see Unix Programmer's Manuals volume 3m).

There are many versions of the math library. The first version is the one that uses VAX-G floating point format which was used in the *CONDOR* - Version I system. Since the Microbar board had no extra hardware for floating point, all floating point operations were performed entirely in software and was miserably slow. Most control programs that have been written thus far, therefore did their calculations with scaled integer arithmetic, and used table lookup for transcendental functions.

The second version of the library was designed to be used with the Sun-C compiler, and uses the now popular IEEE-standard format [3] for floating point numbers. This is the version used in *CONDOR* - Version II.

There is also a library of functions available for the programmer who desires to use vectors and matrices a lot in his code. These specialized libraries however, are considered part of the hand control libraries and documentation on these functions will be forthcoming shortly along with the rest of the documentation on how to write hand control programs.

When using functions in the floating point library:

- Always remember to include a line in your source file that says:

```
#include <math.h>
```

  to get the appropriate type declarations for the various routines in the library, and

- Link your programs with the *-lm* option as follows:

```
cc -o foo foo.c -lm
```

Note:
There exists a fast version of the floating point library that uses the advanced capabilities of the *Motorola 68881* floating point chip that is available on the IRONICS board.
End Note.

The following functions are available only on the floating point library on the Suns; They make use of the Motorola 68881 floating point chip and are faster than the versions supplied by Sun along with their current version of the "C" compiler.

sincos(*theta, ptrcos, ptrsin*) *Function*
double theta;
*double *ptrcos;*
*double *ptrsin;*
This routine takes an angle *theta*, which is a double precision floating point number and uses the fast `Fsincos` instruction, to calculate both the sine and cosine of the angle in a single instruction. The resulting values are stored through the pointers supplied by the

[3] Draft 796 IEEE Floating Point Standard

second and third arguments *ptrcos* and *ptrsin*. The argument convention is retained only for historical reasons.

Ssincos(*theta, ptrcos, ptrsin*) *Function*
float theta;
*float *ptrcos;*
*float *ptrsin;*
This routine is very much like the one above, only that it is highly optimized for single precision floating point numbers. If you do not deal with double precision numbers, this function is the one you should be using. In fact, using **Ssincos** is faster than calling the single precision versions of **sin** or **cos** separately.

In addition to the usual math library routines of **sin**, **cos**, **tan**, and **sqrt** the following additional routines are provided.

asin(*theta*) *Function*
float theta;
Returns the arc sine of its argument *theta*.

acos(*theta*) *Function*
float theta;
Returns the arc cosine of its argument *theta*.

atan(*theta*) *Function*
float theta;
Returns the arc tangent of its argument *theta*.

4.3.4 The I/O Package

The I/O package and the basic support provided for devices forms the glue between the programmer and the lower level device drivers in the system. All communication is done via the so-called file descriptors.

File descriptors are typically integer objects that one gets as a result of opening a device. In our system we have redefined the semantics of Unix file descriptors somewhat, and hence the system calls that have Unix-sounding names behave in a fashion almost like their counterparts in a standard Unix system.

The differences between standard Unix semantics and our calls are mentioned below.

open(*name, flags, mode*) *Function*
*char *name;*
int flags;
int mode;
This function opens a file named by *name* and returns an integer `file descriptor` object that can be used by the user later on in his program to refer to the opened device or file. All hardware devices' names begin with a ':' character. So, to open the terminal device connected to the Ironics 3273 system controller, one would need to do:

```
open(''':tty'', 0, 2);
```

The devices configured into a system, that a user can open and use, are given in

`./condor/libc/ironics/conf.c`.

Currently we support:

1. `:tty` – The Motorola 68681 serial chip on the Ironics 3273 system controller.
2. `:pty` – Pseudo terminal drivers. The flag argument to this device indicates which processor a pty should be opened to.
3. `:ptysun` – Pseudo terminal driver to the sun. Opening this device results in an `fd` that is connected to a terminal window on the Sun. Reading and writing from this fd, will correspond to doing i/o with the corresponding window on the sun. Notice that for this to work, an appropriate program that provides the pty service must be running on the Sun end.
4. `:magnon` – The magnon stepper motor controller boards.
5. `:mpp` – The motorola parallel port boards. (MVME304).
6. `:dt1401` – The data translation data acquisition boards.
7. `:adc` – The multibus a-d, d-a boards.
8. `:dt1406` – The data translation a-d boards for the vme.

All other names are used to indicate files that the user wants opened on the Sun system. Such open calls will be mapped to their corresponding equivalents on the Server using the message passing system, transparent to the user (see Section 4.4.1.1 for details on the message passing system).

File descriptors 0, 1, and 2 are bound by default to the serial device (controlled by a Motorola 68681 chip) on the Ironics 3273 system controller. One can change this, so that these descriptors are opened to the pseudo terminal on the sun. On processors numbered 1 and above this is in fact what is done, even upon startup. This means that programs that interact with the terminal to do i/o will use the serial port on processor 0 but the memory mapped bus-to-bus adaptor when running on any other processor.

The *mode* argument is used to indicate the mode in which the file or device should be opened. (0 indicates that the device should be opened for reading, 1 for writing and 2 for both reading and writing).

The *flags* argument is device specific. For normal files, this argument has the standard 4.2 BSD Unix semantics. But for special devices this argument is used to indicate a variety of device specific information, (for example, in the case of the `:pty` device this argument is used to indicate the processor number to which the pty device must be opened, in the case of the `:magnon` device this argument is used to indicate the board number of the stepper motor controller).

The `file descriptor` object that is returned is to be used as the first argument to certain device specific functions. The alternative was to use a whole series of `ioctl()`'s to do the different operations and we think that our approach is cleaner than the normal Unix way of overloading the `ioctl` call. (Since there are a number of these devices that are presently supported, we do not document all the calls written for the various devices here. By convention we have placed the driver for a device called `mpp` in a file called `mpp.c` in the device directory. An examination of the device driver file should be sufficient for a programmer to find out about the functions that it makes available – please see also Appendix A for details on writing and using device drivers under the *CONDOR* system.)

dup(*oldd*) *Function*
int oldd;
This has the standard 4.2 Unix semantics of duplicating a `file descriptor` object.

creat(*name, mode*) *Function*
*char *name;*
int mode;
Creat internally is implemented by open with the appropriate bits set for the flags argument. It does not make any sense to creat a device that already exists in the `devsw` or configuration table.

read(*dev, buf, count*) *Function*
int dev;
*char *buf;*

int count;

write(*dev, buf, count*) *Function*
int dev;
*char *buf;*
int count;
Both the `read`, and `write` calls have semantics similar to 4.2 BSD. However, notice that since we do not support multitasking on the Ironics processors, the processes block while doing i/o. This does not mean however that all computation comes to a standstill. Device specific read and write operations must be written so that they are interruptible. It is not unreasonable to be writing a block of collected data to a file, when a timer interrupt has to be serviced as part of the next servo cycle.

For devices like the parallel port, it is wiser to use the device specific functions rather than these generic read and write routines since they often provide a finer granularity of control.

lseek(*dev, count, whence*) *Function*
int dev;
long count;
int whence;
This routine is applicable only to files open on the sun, and resembles the standard Unix `lseek`.

ioctl(*dev, code, arg*) *Function*
int dev;
int code;
*int *arg;*
A variety of device specific operations are implemented with ioctl's. The arguments have the same meaning as they do under 4.2 BSD Unix.

Built on top of the underlying device mechanism is the stdio package. The stdio package provides the primary method of interaction between user programs and terminals (be they the serial tty line or the pty line associated with a window on the Sun). See Unix Programmers Manuals, Volume 3s, for details on the `stdio` library.

The differences from the 4.2 BSD version of `stdio` library functions are enumerated below:

- `printf` does not take the `%lf` option for double precision floating point numbers.
- `scanf` however needs a `%lf` option to read in double precision floating point numbers.
- `stdin` and `stdout` default to Serial Port B, on processor 0. This means that printouts programmed with `printf` will occur on the terminal connected to the bottom-most of the two serial ports on the serial pack associated with the Ironics system controller board.

- The symbols `porta`, `portb` are reserved, and refer to predefined buffers. i.e. writing

```
fprintf(portb, "Hello World.\n");
```

  is equivalent to

```
printf("Hello World.\n");
```

  `porta`, of course refers to the other serial port. This applies only to programs running on processor number 0.

The stdio calls supported in our system are mentioned below.

fopen(*name, mode*) *Function*
*char *mode;*
*char *name;*
Open a buffered file with name *name* and mode *mode*, and returns a pointer to a `FILE`.

fclose(*fp*) *Function*
*FILE *fp;*
Close a buffered file.

fprintf(*fp, fmt, args*) *Function*
*FILE *fp;*
*char *fmt;*
vararg args;
Prints out to a buffered stream given by *fp* instead of `stdout`.

fscanf(*fp, fmt, args*) *Function*
*FILE *fp;*
*char *fmt;*
vararg args;
Reads from a buffered stream given by *fp* instead of `stdin`.

fseek(*fp, offset, whence*) *Function*
*FILE *fp;*
long offset;
int whence;
Seek to the specified location in the specified buffered file.

rewind(*fp*) *Function*
*FILE *fp;*
Set the file pointer for the specified buffered file given by *fp* to the beginning of the file.

getc(*fp*) *Function*
*FILE *fp;*
Reads and returns a character from the file given by *fp*;

putc(*c, fp*) *Function*
char c;
*FILE *fp;*
Write a character given by *c* to the file specified by *fp*.

fflush(*fp*) *Function*
*FILE *fp;*
Flushes the buffers on the buffered file specified by *fp*.

fgets(*buf, count, fp*) *Function*
*char *buf;*
int count;
*FILE *fp;*
Read a line from the specified buffered file.

fputs(*buf,fp*) *Function*
*char *buf;*
*FILE *fp;*
Write a null terminated string given by *buf* to a buffered file specified by *fp*;

fdopen(*fd, mode*) *Function*
int fd;
*char *mode;*
Creates a buffered file and returns a pointer to it, from the unbuffered descriptor given by *fd*.

ungetc(*c, fp*) *Function*
char c;
*FILE *fp;*
Push a character given by *c* back onto the buffered input stream specified by *fp*.

The following functions are specialized versions of the functions given above, wherein the pointer to the buffered file, has been replaced by `stdin` and `stdout` which are globally defined to refer to the standard input and standard output streams.

getchar() *Function*
Reads and returns a character from `stdin`.

putchar(*c*) *Function*
char c;

Puts the character *c* onto stdout.

gets(*buf*) *Function*
*char *buf;*
Gets a null terminated string into the character buffer specified by *buf*, from stdin.

puts(*buf*) *Function*
*char *buf;*
This function prints out on stdout the character buffer specified by *buf*.

printf(*fmt, args*) *Function*
*char *fmt;*
vararg args;
Except for the differences from the standard printf documented above, this function provides all the functionality to do the conventional stream oriented print out that is commonly used by C programmers to interact with stdout.

scanf(*fmt, args*) *Function*
*char *fmt;*
vararg args;
Except for the differences from the standard scanf documented above, this function provides all the functionality to do the conventional stream oriented input from stdin that is commonly used by C programmers.

4.3.5 Strings Library

A large number of functions are available for operating on conventional C ascii strings. These will not be detailed here, since their semantics are exactly the same as that of their Unix counterparts (do a man string for details). The functions that we support are strcpy, strcpyn, strncpy, strlen, strcat, strncat, strcatn, strcmp, strncmp, strcmpn, strchr, strrchr, strpbrk, index, rindex. In addition to these bzero, bcopy and bcmp are also supported, as are atof, atoi, atol, atov, ecvt, fcvt, gcvt, modf and ldexp. The standard man page documentation available for these functions applies for their *CONDOR* versions too.

4.3.6 Data Transfer routines

There are different versions of routines to manage different data transfer mechanisms, depending on the hardware device. The serial device, for example, relies on the normal read and write calls to provide buffered or non-buffered i/o operation. Devices like A/D and D/A converters and parallel ports however, require more flexible ways of operation. These operations are done by device specific routines, defined in the file corresponding to that device. All these routines must take as the first argument, an integer object that corresponds to the file descriptor object which is got by opening the device.

For example, here is a piece of code, that illustrates the usage:

```
int
parallel_port_startup(board_number)
int board_number;
{
    int fd;
    if((fd = open('':mpp'', board_number, 2)) < 0){
        printf(''Couldn't open device?\r\n'');
        exit(0);
    }

    /* Reset the board */
    mpp_reset(fd);

    /* Configure the board to be in raw 16-bit mode */
    mpp_config_16bit_raw(fd);

    /* return the fd, so that the user can use it later */
    return(fd);
}
```

A/D and D/A converter routines

The following functions are provided for the converters that are supported in the system in addition to the standard i/o routines like `open()`.

adc_set_gain(*fd, gain*) *Function*
int fd;
int gain;
This routine takes an integer *gain* value and sets up the board, previously opened, to operate with that gain. This routine works only on those controllers that have a programmable gain option.

adc_read_channel(*fd, channelnumber*) *Function*
int fd;
int channelnumber;

This routines converts, reads and returns an int from an analog to digital converter's channel given by *channelnumber*.

adc_convert(*fd, start, count, buf*) *Function*
int fd;
int start;
int count;
*unsigned short *buf;*
This routine takes the starting channel number *start*, a channel count *count* and a pointer to a buffer *buf*. It converts the analog to digital channels starting from channel number *start* to *start + count* and stores the resulting values in successive locations pointed to by *buf*.

adc_fill_convert(*fd, channelno, count, buf*) *Function*
int fd;
int channelno;
int count;
*unsigned short *buf;*
Sometimes it is necessary to convert a single channel repeatedly. This routine provides the capability for converting a single channel repeatedly, and storing the consecutively converted values in successive locations pointed to by *buf*. The channel number is given by the second argument *channelno* and the number of times the conversion process is to be repeated is given by the third argument *count*.

adc_repeat_convert(*fd, channelno, count, buf*) *Function*
int fd;
int channelno;
int count;
*unsigned short *buf;*
This routine takes a channel number, a repeat count and a pointer to a short. It converts the channel repeatedly count times and stores the converted value in the short pointed to by the last argument.

adc_poll_convert(*fd, start, count, buf*) *Function*
int fd;
int start;
int count;
*unsigned short *buf;* This routine is identical in functionality to `adc_convert`, but uses polling instead of vectored interrupts to perform its task.

adc_poll_read_channel(*fd, channel*) *Function*
int fd;
int channel;

This converts a single channel given by *channel* using polling, and returns the resulting short.

dac_write(*fd, start, no, buf*) *Function*
int fd;
int start;
int no;
*short *buf;*
This routine writes to the digital to analog converters starting from channel *start*, upto channel *start + no*, the values found from successive shorts pointed to by *buf*.

4.3.7 Simple Real Time Tasking

The *CONDOR* is a system that was explicitly designed for real time control. The *MOS* (or the Minimal Operating System) enables the user to have many real-time tasks running concurrently. Sometimes, however, it is desirable to have only a single real time task running on a processor. This is often the case, when data has to be collected during a movement of a robot or when no useful partitioning of the control loop into many concurrent loops can be made. For these situations, a simple set of routines that avoid the overhead of the *MOS* is provided (this overhead has been measured to be approximately sixty microseconds per servo invocation). For details on the more complex interface see Section 4.5.1 on Page 77.

The following set of functions are available both on the *CONDOR* slave microprocessors as well as the sun. (On the sun, real time interrupts are not guaranteed to be real time, since the routines mentioned below use the standard Unix interval timer routines).

start_servo(*loop, rate*) *Function*
*int (*loop)();*
int rate;
This function takes a pointer to a function *loop* and an integer value *rate* as arguments and sets up the timer to invoke the function *loop* with a frequency of *rate* cycles per second. No interrupts will actually occur until the servo is explicitly enabled.

enable_servo() *Function*
This function enables a servo, if one had been set up using the previous function. This will cause timer interrupts to occur at the rate desired and the function that the user has designated to be the servo loop function, will be executed at that rate.

disable_servo() *Function*
This function disables a running servo.

servo_status() *Function*
This function prints out information about a servo.

servo_ramp(*start*) *Function*
int rate;
This routine is available to the user if the `servo.c` library is compiled with the `BENCHMARK` option. The function provides a very simplistic way in which the user can determine how fast a servo loop can be run. This function can be made use of only *after* a call to `start_servo` has been made. The function starts from a specified rate and ramps up the servo rate in steps of ten hertz upto the maximum possible. At each servo rate, it executes the specified servo loop for some time (approximately 6 seconds). It continues to do this until the servo loop overruns because an extremely fast rate has been set. The function then reports this rate as the maximum attainable, for that particular servo routine.

It is an error to call `enable_servo` if a servo loop has not been set up yet, or when a servo loop has already been enabled. Likewise, `disable_servo` must be invoked only when

a servo has been previously enabled.

stop_servo() *Function*
This function stops a running servo as well. However, this has the side-effect of undoing the effects of `start_servo`. If you want to start up the servo again after this function has been invoked, you have to set things up using `start_servo` again.

set_servorate(*rate*) *Function*
int rate;
This function sets the rate for the servo designated by `start_servo` to be its integer argument *rate*. The function has the side-effect of disabling a running servo. So, in order to start the servo running again, one needs to call `enable_servo` again.

Two functions are provided to enable the user to write programs that may require modification of complex data structures while the servo is executing. (These functions are also available on the sun, where the processor level returned is really meaningless. The functions on the sun merely serve to block out the real-time timer interrupts and re-enable them).

protect_servo() *Function*
Returns a short integer on the Ironics end which indicates the current processor level. All interrupts are masked out after this function has executed.

unprotect_servo(*level*) *Function*
short level;
Sets the processor priority level to the specified argument *level*. The above two routines can be used together as illustrated by the following piece of code:

```
short level;
level = protect_servo();
<uninterruptible code ... >
unprotect_servo(level);
```

If the servo cannot execute at the rate desired, there are two ways the error can be handled. The first, which is the default, is that the an overrun counter is incremented. Once the overrun counter exceeds a specific threshold the servo is disabled and a diagnostic error message is reported at the console. The status routine prints the value of the overrun counter and can be used to determine if the servo is repeatedly overrunning itself.

4.3.8 HVE Libarary - The memory mapped connection

The HVE library functions are available to enable a user process running on the sun to use the VME-to-VME adaptor in a flexible fashion. The library functions have been designed to operate with two kinds of bus-to-bus adaptors in use at the lab. The first is the SYNERGIST-III/IV kind of system which was an older and 16-bit version of the HVE-2000 which supports full 32 bit transfers across the adaptor.

hve_init() *Function*
This function must be called before any other function in this library. It ensures that the data space (A24D16 in the case of the synergist-3 and A24D32 in case of the hve-2000) and short i/o space (A16D16) are both mapped into the user space. While the synergist-3 needs to be enabled for operation by a memory write to a specific memory location, the hve-2000 is always connected. The initialization routine tries to determine which kind of board it is dealing with and enables it for operation if the board requires it.

hve_initialize_data() *Function*
This function is called internally by hve_init, to initialize the data space.

hve_initialize_io() *Function*
This function is called internally by hve_init to initialize the io space.

After the initialization has been done, the programmer can use the following routines to get a pointer into the address space that has been mapped into his process.

hve_get_datapointer() *Function*
This routine returns a pointer to the beginning of the data space mapped into the user process that executed the hve_init call. For example, this routine can be used as follows to read the memory on an Ironics board whose dual-port address has been set to start at 0xb00000.

```
read_ram(start, end)
int start, end;
{
        register int i;
        unsigned char *beginning_of_slave_ram;
        unsigned char value;
        int  slave_ram_offset = 0xb00000;

        beginning_of_slave_ram = hve_get_datapointer() + slave_ram_offset;
        /* Now read the ram starting at start */

        for(i=start;i < end; i++) {
            value = *(unsigned char *)(beginning_of_slave_ram + i);
            printf(''Ram address: %lx, Value %x\n'',
```

```
                    beginning_of_slave_ram + i, value);
        }
}
```

Notice that this enables one to read and write the memory across the adaptor just as if it were a huge array mapped into the user process.

hve_get_iopointer() *Function*
This returns a pointer to the io space on the VME-Bus that is mapped into a running user process. This will enable one to control devices (normally a-d, d-a and other io devices) whose device registers are normally located in A16D16 space, directly from a user process on the Sun.

hve_enable() *Function*
This routine, called internally by `hve_init` enables the VME-to-VME connection. It can be used by users who wish to be dynamically making and breaking the connection. This routine works only on the `synergist-3`. On the `hve-2000` it does not do anything.

hve_disable() *Function*
This routine disables the VME-to-VME connection. After this routine has been executed, `hve_get_datapointer` and `hve_get_iopointer` will not work until the connection is enabled once again with an explicit call to `hve_enable`. This routine also works only on the `synergist-3` adaptor and not on the `hve-2000`.

4.3.9 Dealing with multiple processors

This section documents routines that are available to the user to provide a more convenient interface to interact across the bus to bus adaptor. Some of these routines are also available on the Ironics end. These routines are mainly intended as utility functions.

The following routines are available both on the Ironics and on the Sun.

proc_presentp(*processor*) *Function*
int processor;
Takes a *processor* number as an argument. Returns one if the processor is present in the system.

proc_runningp(*processor*) *Function*
int processor;
Takes a *processor* number as an argument and returns one if the processor is running a user program. Returns zero if either the processor is halted or is running the boot rom monitor.

proc_any_runningp() *Function*
Returns one if any processor in the system is running a user program. Returns zero otherwise.

proc_print_status() *Function*
Prints the status of the various processors present in the system.

The following routine is provided for one program to control the execution of programs on other microprocessors:

imon_go(*processor, address*) *Function*
int processor, address;
This starts execution of a program on *processor* at *address*. The routine is available both on the Ironics and on the suns. Once a program is running on a particular processor, it cannot restart itself.

The following functions are available on the sun, to deal with downloading large blocks of data, and to download executable code to the control microprocessors. These are intended mainly for programs on the suns. The file server can be used for sending data up from the ironics and provides a far more flexible buffered interface for doing i/o than these functions:

download_a_file(*filename, processor, offset*) *Function*
*char *filename;*
int processor;
int offset;
This function downloads an executable found in file *filename*, onto processor given by the second argument *processor* at the offset given by *offset*. Since the function uses the entry point commonly defined in object files usually the third argument `offset` can be defaulted

to zero, without any trouble. The function takes care to see that the file will be downloaded to the correct processor (using the correct dual-port address for that processor).

download_do_clear(*processor, start, no*) *Function*
int processor;
int start;
int no;
This function is provided so that a large area of memory on the slave microprocessors can be cleared (set to zero) extremely quickly from the sun. The area that is zeroed out, will be on processor specified by *processor*, and will start at the local address specified by the second argument *start* and extend upto *start + no*;

For transfers down to the slave microprocessors the following function can be used:

download_a_block(*buf, processor, addr, count*) *Function*
*unsigned char *buf;*
int processor;
int addr;
int count;
This function downloads into the specified address, *count* bytes of the data block beginning at the address specified by *buf*. The third argument *addr* specifies where the data is downloaded to, and specifies the local ram address relative to the processor specified by the second argument *processor*.

For data transfers in the other direction, the following function can be used on the sun:

upload_into_file(*filename, proc, start, bytecount*) *Function*
*char *filename;*
int proc;
int start;
int bytecount;
This function causes a file named *filename* to be created which will contain the data starting from the address specified by *start* and will contain *bytecount* bytes. The second argument *proc* specifies the processor number from whose local memory the data will be copied.

upload(*buf, proc, start, bytecount*) *Function*
*char *buf;*
int proc;
int start;
int bytecount;
This function performs much the same job as the previous one, only it puts the data it gets into a buffer *buf* which is passed in as the first argument, instead of into a file.

4.3.10 Command Parser Library - Input routines

User level programs often consists of a simple command loop, involving the following actions:

1. Querying the user, regarding what command needs to be executed.
2. Providing help and documentation when the user requests them.
3. Parsing arguments to the required commands.
4. Executing the commands as requested by the user.

Most control programs may wish to provide such a simple query-processing loop as well. The following functions are designed to provide the user with a flexible interface for doing this. The command parser library is NOT part of the standard C library; It is a part of a utility library that needs to be linked in (with `-lutils` on the Sun and with `-lutils68` for the Ironics) separately as part of the linking process. The command parser library is based on an underlying emacs-like line editor that is operational at all times. This means that the user can, at any point in time, use characters like control-A, control-B etc., to edit his input. The library also provides partial completions, and help to a novice user, which will be described below.

It must be mentioned that the command loop processing can happen while a servo is executing in the background. One can use this feature to tune parameters like gains, and damping co-efficients of a running system. It is this feature that enables the tuning of control parameters on line to achieve better performance.

exec_command(*parameter_list*) *Function*

This is the most often used entry point into the command parser library. This routine provides the most often used functionality desired by most command processing functions. However it does not provide for argument parsing (see below for another function that does this as well).

The *parameter_list* is assumed to have the following syntax; Any number of parameters can be given for a given command processing loop.

The parameter list must be terminated by a `NULL`.

```
exec_command(''Command: '',
             ''test-1'', test_function, ''Execute test 1'',
             ''set-gain'', set_gains, ''Set the gain'',
             ''set-damp'', set_damping, ''Set the damping'',
             NULL);
```

The first argument specifies the prompt for a command loop. The prompt is followed by one or more comand specifiers, each of which starts with a string representation of a command, followed by a function that will be executed when that command is typed at the terminal. This function is assumed to be a simple one, that does not take any arguments. The third part of a comand specifier list is a string that will be typed out at the user if he types a '?'.

The routine defines three commands as built in, and these must not be defined by the user. The first is a command called ``help'', which can be executed by the user just as any other command. What this function does is it types out the command names followed by their documentation strings given as part of their command specifiers. The second is the command ``quit'' which quits the exec_command routine. This enables one to build different levels of command loop processing. (for example, the set_gains routine could itself have an exec_command specification – when this routine is executed the new command loop will be the one that takes effect. When the user quits out of this loop, he will be returned to the old command loop).

There is nothing unusual about the command loop processing itself. What makes it unique and useful is its interactive nature. If the user types `set-` and then a special completion character (which is presently set to `tab`, the system will automatically search the current command table and respond with:

```
Partial completions:
 set-gain - Set the gain
 set-damp - Set the damping
```

If only a single match was found, the routine will complete the partially typed input automatically.

Typing '?' at any time (or any other assigned help character) will cause the help routine to be executed. Typing carriage return or newline at any time is equivalent to signalling that the user is done with his input. The routine tries completing his partially typed in input – if a valid match is found, the full completion is printed out before the command is executed.

While typing input, a subset of emacs-like editing commands can be used to alter the input buffer.

get_keyword(*prompt, keyword_list*) *Function*
*char *prompt;*
The exec_command routine is built on top of a facility that can be used in a very general manner. Another routine that uses the basic facility is a facility to read keywords from the terminal while providing input editing, completions, and partial matches. The get_keyword routine takes a keyword list which is basically a sequence of character string arguments terminated by a NULL argument. It prompts the user with a *prompt* argument and returns the string keyword typed at the terminal, or minus one if the user aborts with an abort character, which is presently set to control-g.

get_keyword_value(*prompt, keyword_value_list*) *Function*
*char *prompt;*
This routine is very much like the routine above. The difference is, that here instead of specifying a string of keyword values all of which are strings, the user specifies keyword-value pairs. The routine returns the value associated with a particular keyword when that keyword is typed at the terminal.

For example:

```
int base = get_keyword_value(''Type in a base: '',
                             ''decimal'', 1,
                             ''hex'', 2,
                             ''octal'', 3,
                             NULL);
```

This will set the variable base to be equal to 1 if the string ''decimal'' (or a recognizable partial string that complets to it) is typed at the terminal.

The returned value can be anything that can fit into a valid integer object.

execute_command(*prompt, commandlist*) *Function*
*char *prompt;*
The most generic form of command parsing function is provided by this function. Like exec_command it provides the basic facility to parse and execute commands. In addition, it provides programs with the ability to parse for arguments from a predetermined set of types. This routine is very much in the experimental stages. Full documentation on how to use this facility will be forthcoming shortly.

4.3.10.1 Miscellaneous input routines

Besides the above routines, the following routines provide the user with the capability of getting input from the user. They can be used anywhere in a user program intermixed with command parser library calls.

• Strings and characters:

tty_gets(*buffer, prompt, redisplayflag, complete*) *Function*
*char *buffer;*
*char *prompt;*
int redisplayflag;
*char *complete;*
This routine displays the prompt and gets a string from the user, with input-editing a-la emacs. Returns when the user types one of the completion-characters given in the string *complete*. If *redisplayflag* is zero nothing is done. If it is one, then the buffer passed in as argument is put into the edit buffer first, displaying it for the user to edit. If the flag is equal to two, then the buffer passed in as argument is put into the edit buffer but no display is done, of this string.

The following routines are part of the same utility library to read integer values from the terminal, using a flexible syntax which is explained below.

tty_read_immediate() *Function*
This routine returns the next character typed at the terminal by the user. Returns negative one if the user types an abort character (presently set to control-g.

• Numbers:

A number is specified by #<radix-value>r<number>. This syntax is borrowed from Lisp-Machine usage. The following synonyms are predefined.

```
#16r  can be written as #x.
#8r   can be written as #o.
#2r   can be written as #b.
#10r  can be written as #d.
```

If radix is not explicitly specified with a #, it defaults to 10, or the last set radix.

For example:

```
#xa   - stands for number 10 decimal.
#b101 - stands for 5 decimal.
#o10  - stands for 8 decimal.
#8r10 - #o10
```

Any valid radix from 2 to 36 can be specified. The function complains if you type a character that it is not able to recognize in the current radix. (for example: 'f' is not a valid character in base 15).

If one specifies 's' instead of the 'r' then all future reads will use the specified base for input. The default base on startup is 10. So, to set the default base for reading in numbers to be hex, one can type

```
#16sa1000 or #xsa1000
```

when prompted for the first time.

read_int(*prompt*) *Function*
*char *prompt;*

read_valid_int(*prompt*) *Function*
*char *prompt;*
Both the above routines prompt the user with the given argument *prompt* and attempt to parse for an integer. The latter routine will handle user errors, and will continue to reprompt the user until a valid integer is typed.

read_int_in_range(*prompt, begin, end*) *Function*
*char *prompt;*
int begin;
int end;
Reads and returns an integer greater than or equal to *begin* and less than or equal to *end.*

4.3.11 Window system functions

Most system programs written to control the hand, rely on using the X-Window system and the Sx-Library for the Toolkit functions provided on top of the X-Window system. We document here, our extensions to the X library which we have found useful, and other programmers may wish to use. It must be said that this version is based on Version 10 of the X window system, and parts of the library may change with Version 11.

The library is written so that it will provide a simple, easy to understand, interface for programmers who wish to deal with the window system. In most cases, it chooses a reasonable set of defaults which helps to standardize the interface across most programs, and frees the programmer from worrying about them.

All functions in our extension library begin with the characters `xw_`. The library predefines certain fonts for the convenience for the user as well.

The fonts are:

xw_textfont *Variable*

xw_textfont_name *Variable*
This is the default font for text. The variable with `_name` appended to it describes the character string representation of the name of the font, while the former refers to a data structure of type `FontInfo *`.

xw_bigfont *Variable*
This refers to a larger text font.

xw_italicfont *Variable*
This is the default font used for italic text.

xw_boldfont *Variable*
This is the default bold faced font.

xw_smallfont *Variable*
The default small text font.

xw_startup(*host, name, x, y, width, height*) *Function*
*char *host;*
*char *name;*
*int *x, *y, *width, *height;*
This function initializes the X library, the Sx library and Xw libraries. The first argument *host* refers to the display on which the program is to be run on. The second argument *name* refers to the program name as it should appear on the title bar window. This routine provides an initialization interface such that the size of the initial program window created are returned in the next four arguments. If a default value for these values is not provided

the program will attempt to get the user to use the mouse to locate the left top and right bottom corners of the window in which the program should run.

An alternate startup interface is provided by the following function.

xw_create_root(*x, y, width, height, host, name*) *Function*
int x,y,width,height;
*char *name;*
*char *host;*
The *name*, and the *host* arguments have the same meaning as in the function above. The first four arguments specify where the root window of the program is to be created.

xw_get_point_from_mouse(*window, x, y*) *Function*
Window window;
*int *x, *y;*
This routine uses a cross cursor to obtain a position from the user. It grabs the mouse until it is clicked and returns the location where it was clicked in the variables x and y.

xw_tracking_mouse(*window, function*) *Function*
Window window;
*int (*function)();*
This routine grabs the mouse in the window specified by *window*. As the mouse is moved in the window, it calls the function specified by *function* repeatedly with two arguments x and y which are set to be the current co-ordinates of the mouse within the window. The tracking is stopped when the user clicks any of the mouse buttons.

xw_get_rect_from_mouse(*x, y, width, height*) *Function*
*int *x, *y, *width, *height;*
This function grabs the mouse and reads two points from it, which are set to be the left-top and right-bottom of a rectangle on the screen. The function returns the rectangle in the variables pointers to which are passed to it as arguments.

xw_get_window_from_mouse() *Function*
This function grabs the mouse and returns the `Window` in which the mouse is subsequently clicked. This can be used in choosing a window.

xw_listener_create(*window, label, width, height, font, xorigin, yorigin*) *Function*
Window window;
*char *label, *font;*
This function creates and returns a pointer to a window that has an xterm process associated with it. Such a window provides the terminal emulator functions that are required by programs doing text output. Such a listener window, once created can have a command parser loop running inside it. The precise manner in which this can be done, is explained below.

4.3.11.1 The command parser and X Windows

The command parser that runs on the Ironics slave microprocessors and the Sun also runs under the Xwindow system. The following section will describe very briefly how to use the command parser from within user programs to get a relatively powerful interface running on the X window sytem.

As mentioned earlier, the command parser provides a flexible way of specifying a top user level command loop interface. Under X things are a lot more complicated since X responds with *events* when the user types at his keyboard or moves the mouse, and programs that expect input from *stdin* have to be modified to understand this. When one creates an X window moreover, one does not get a powerful object, but a rather primitive one. Although toolkits are supposed to provide the added functionality of utilities like scroll bars, they are not available at this time.

The **xw** functions provide a programmer with a way of creating a powerful interface with very little work. The following example will illustrate how the user can create a window under the X window system and associate a command parser with it.

The first function that must be called as mentioned before, is:

```
Window root;
root=xw_startup(displayname, programname, &x, &y, &width, &height);
```

This function will startup the xw library on the display provided by *display*, and give it a title *programname*. The next four arguments to it are pointers to integer variables. The initialization code looks in the user's .Xdefaults file for these variables. If they have been specified there, the program is initialized with those desired choices (the four variables specify the x-origin, the y-origin, the width and height of the program's window respectively). If the user has not specified them in his defaults file, the routine prompts him for the values with the mouse for the left top and bottom right corners of the program window.

After the root window has been set up, a number of *listener* windows can be setup to run under it, as follows:

```
TTYWindow *window1;
window1 = xw_listener_create(root, "Command1", 40, 20,
                    "9x15", x, y);
```

This creates a listener window in which a command loop will be run. The listener window is really an xterm window, that the user program communicates over a *pty* [4], but this is totally hidden from the user, as we will see below. The first argument is the window as whose subwindow the listener window will be created. The second argument forms the label for the window, which is presently ignored. The third and fourth argument specify the width and height (in terms of characters of the specified font) of the window. The fifth specifies the font to be used, while the last two arguments specify the left top corner of the listener window relative to the parent window in which it will be created.

After a listener window has been created, a command loop is usually associated with the following routine:

[4] *pty* is the Unix abbreviation for pseudo terminals

```
Xexec_command(window1, "Command: ",
              "foo", foo, "A foo Command",
              "bar", bar, "A bar command",
              "baz", baz, "A baz command",
              0);
```

The first argument is a pointer to a TTYWindow created by a call to `xw_listener_create`. The second argument is the prompt, that must be used each time during the command loop. We recommend that a non-null prompt be used always, since things can get confusing if you do not know where your input buffer begins in an X window. Notice that this function takes arguments in a manner that is similar to the `exec_command` routine – the only difference is in the first argument, which is a pointer to a TTYWindow created by a call to `xw_listener_create`. The other difference is that while the former never returns until the user executes the builtin command `quit` from the command loop, the `Xexec_command` routine returns immediately.

After a number of such listeners have been created, the user then calls

```
xw_handle_events(handlerroutine);
```

What this routine does is it provides support for the command loop processing. Whenever there is X activity that this routine does not understand, it calls the user specified `handlerroutine` which must be a function that expects no arguments.

This function does not interpret other X events that happen in any fashion, nor does it modify the X event queue. Thus one can use this routine in conjunction with other Toolkit libraries; For example if handlerroutine was declared to be

```
handlerroutine()
{
        while(XPending()) {
                XEvent event;
                XNextEvent(&event);
                Sx_HandleEvent(&event);
        }
}
```

one gets a set of listener windows that works with the Sx library.

All this is very straightforward. Now let us briefly mention a few features of the system not found in conventional toolkits.

1. The command loop dispatching provides for completion. In the above example, if the user types `f` and then hits any of the completion keys (these are presently set to `TAB` and `?`) the function will look up the command table and complete the rest of his input to

   ```
   Command: f<tab>
   Command: foo        (in the same line)
   ```

2. The command loop editor provides a line editor a-la emacs. Characters like control-a, control-e, control-f, control-b, delete, control-e etc., work with their emacs like behaviour in the input buffer.

3. Partial matches are also recognized. In the above example if the user types a completion character after typing the character b the system will respond with

```
Command: b<tab>
Partial Completions:
    bar - A bar command
    baz - A baz command
```

4. A few commands are built in. These are `help`, `alias` and `quit`. The first provides help if the user types `?` or `help`. The second allows aliasing one command to another, and the third enables one to quit one command processing loop. (This is needed because the user can call the `Xexec_command` from within one of his functions. This makes the command loop processing stack oriented. At any time one command loop is active in each TTYWindow. When you quit out of it, it is popped of its stack and a previous command loop is made the current one. For example if you had written inside of `foo()`

```
Xexec_command(window, "Command-level-1: ",
              "apples", apple, "Eat an apple",
              "oranges", orange, "Guess what",
              0);
```

After `foo` finishes executing, you will be prompted, not with

```
"Command: "
```

as before, but with

```
"Command-level-1: "
```

and the new command table will be in effect.

5. Commands are invoked with two arguments, and while they execute, stdout will be bound to the window in which the command loop will be running. (Using `printf` from inside a command function will therefore work, and the output will appear in the designated window). The first argument passed to the executing function will be a pointer to a string starting from after a recognizable command in the input buffer. The second argument will be the TTYWindow in which the command was executed from. For example, if you had written `foo()` to be

```
foo(buffer, window)
   char *buffer;
   TTYWindow *window;
{
        printf("Rest of the string %s\n", buffer);
}
```

You will be able to type "foo is foo" at the command prompt and get the response "Rest of the string is foo". Notice that completion and partial matches all work on the first word alone. It is upto the user program to interpret the rest of the buffer as it pleases. This provides a simple mechanism for providing arguments to the functions in the command table, which is described later.

Note:
Command functions must be written in a fashion so as to be quick and do no reading from stdin. If they do, these functions could hang awaiting input, and all window system activity would freeze.
End Note.

4.3.11.2 Parsing for arguments in the command parser

Often routines that one wishes to write, expect arguments. These arguments in some cases are merely strings, or numbers. In other cases they are complex like pathnames or filename components. To parse for all combinations of these arguments is certainly a complex task. What the command parser library provides is a simple way for doing this.

The main routine that parses for arguments is the Xparse_argument routine. This function can be invoked both inside the X version of the command parser and the non-X version of the command parser.

The user can invoke this function as illustrated in the following example:

```
foo(arg, window)
char *arg;
TTYWindow *window;
{
        char buf[80];
        if(Xparse_argument(&arg, STRING, buf, "Type in a string",
                        "error in parsing string arg?") < 0)
           return -1;
        printf("Got argument: %s\n", buf);
}
```

The first argument MUST be always the address of the rest of the input string, that the user defined routine is invoked with. The second argument is a type indicator. A number of predefined types and routines that parse for them have been already written, and there is a flexible way that the user can define his own types too, as will be described

later. The third argument is usually a pointer to a variable which will hold the parsed argument. In the case of a string variable or a filename argument this will point to a char buffer, but in the case of an integer this will be a pointer to that integer variable. The third argument is a help string that will be typed at the user if he does not specify that argument. In the above example, if the routine `foo` was invoked by the user typing "foo" at the command parser, the `Xparse_argument` routine will try parsing for a string argument that comes immediately after the command (separated by a `space` or a `tab`). If it finds no such argument it will type the help string at the user and return to the top level with his input still in the visible input buffer for him to edit or add to. The following will illustrate what happens in the above example

```
Command: foo<RET>
Type in a string
Command: foob<RET> No matches.
Command: foo b<RET>
Got argument: b
Command: foo bar<RET>
Got argument: bar
```

The predefined types are: `STRING`, `FILENAME`, `INTEGER`, `CHAR`, `FLOAT`. There is a mechanism for the user to define his own types in addition to those mentioned above. An example of how this is done will illustrate the generality of the mechanism:

First, the user ought to choose a type code dispatcher (usually this is a small integer greater than 20);

```
#define KEYWORD  20
```

Then a parsing function is associated with the type code as illustrated below:

```
char *mykeyword();
define_type(KEYWORD, mykeyword);
```

All user defined types are defined as shown above, by specifying a type code followed by a routine that is to parse for arguments with that type. All type parsing routines must be written so as to return a pointer to a string value. They must all take 3 arguments as shown below:

```
char *
mykeyword(buf, valid, retval)
int *retval;
char *buf;
int *valid;
{
    *valid = -1;
    if (buf == NULL) return(buf);
    if (*buf == NULL) return(buf);
```

```
    if(strncmp(buf, "yes",3) == 0) {
        *valid = 1;
        *retval = 1;
        return((char *)(buf+3));
    }
    if(strncmp(buf, "no",2) == 0) {
        *valid = 1;
        *retval = 0;
        return((char *)(buf+2));
    }
    return(buf);
}
```

That is all one need to do, in order to define a user-defined type. Once the parsing function has been associated with the type code, one can use the `Xparse_argument` routine as illustrated below, in any one of the command functions.

```
if(Xparse_argument(&arg, KEYWORD, &val, "boolean test value",
                   "only yes or no please?") < 0) return -1;
```

The type parsing routine will be invoked with the *REST of the input buffer* as the first argument. What this means is that if you define a function called `foo` and invoke it by typing `foo bar baz`, the first argument to the first argument parser routine will be the string `bar baz`. This routine can therefore look at however much of the input it wants to look at – but it must return a pointer to the *REST of the buffer* after it has done so. So, in the above example, if the first argument was supposed to be a string delimited by spaces, the first routine will parse upto the space following the bar, and therefore return a pointer to the string `baz`. This means that the contract of each argument parsing function is fairly simple – It is always invoked with the rest of the input buffer. It can look at however much of the input buffer as it wants to, but it must always return the rest of the input buffer so that routines that parse for arguments coming after this one will be invoked correctly.

The command parser routine's second argument will be a pointer to an integer. This variable must be set to -1 at the beginning of your parsing routine, and set to a non-negative value to indicate a successful parse. This enables the `Xparse_argument` routine to recognize if a user defined argument parsing function has detected an error. The third argument to the command parser routine is a pointer to a pointer to an int. The user defined routine can set this variable to anything that it parses for – this is how it communicates the value that it parsed back to `Xparse_argument` routine. In the above example, the user defined keyword parser, sets the retval variable to be 0 or 1 depending on whethere the user typed a `yes` or a `no`.

An example of a program that uses the command parser, X windows and the xw functions extensively is the default user interface program `condor`. Users who expect to be writing a lot of user interface code, are advised to look at this program's source for examples of all the functions that we have described above; The compactness of this program is a prime example of the usefulness of the user interface library.

4.3.11.3 Window Geometry

There are functions that provide an interface for managing the geometry of window layouts as well, in addition to those provided by X and Sx.

Included in the utilities is a package for window configuration. This package permits the creation and management of subwindows. The basic concept is that a window may be split into many subwindows along either the horizontal or the vertical. The size of each subwindow can be specified as a percentage of the total window. These subwindows can in turn be split into subwindows of their own.

The geometry management package is divided up into two main layers; the lower level structure management and a higher layer of user structures and routines. The higher level will be described first since that is the level that programmers should use. This level depends on the lower level and the one structure that needs to be described before hand is the wr structure:

```
struct wr {
    Window wr_id;        /* window */
    RECTANGLE wr_rect;   /* rectangle it is associated with */
};                       /* RECTANGE consists of x,y,width and
                            height */
```

The user layer of structures and routines is meant to simplify the construction and maintenance of complex displays. It is based on a tree structure with each node being a division of the previous node. The top of the tree represents the window and the leaves of the tree represent the subwindows. The user first creates a tree, then splits each layer as they desire. The tree stores only the percentages of the splits and no calculation of actual coordinates is done until the user specifies. Sub-trees may be resized, or even hidden (by setting the sizes to 0). Once the tree has been set up appropriately, the user can make windows or terminals from the tree. This creates windows for only the leaves of the tree. If the root window of the tree is later resized, the user only needs to change the size of the root node, call for recalculation, and ask to change the size of the windows from the tree. To facilitate easy access to the leaves of a tree, they can be counted and collected into an array.

The main tree structure is as follows:

```
typedef struct WINDOW_TREE {
    int number_of_children;
    int direction;
    struct wr *wrec;
    int *percentages;
    struct WINDOW_TREE *children[MAX_CHILDREN];
    TTYWindow *proc_tty;
} window_tree;
```

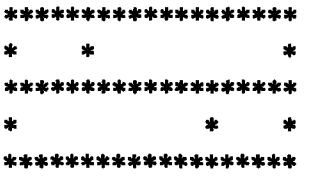
The routines are:

geom_tree_new_node(*x,y,width,height*) *Function*
int x,y,width,height;
Creates a new tree whose root has the specified coordinates. This should be the first routine used to create a tree. The routine returns a pointer to a `struct window_tree` when it is done.

geom_tree_split(*parent, direction, number_of_children, list*) *Function*
*window_tree *parent;*
int direction; / ROWWISE or COLUMNWISE */*
int number_of_children;
vararg list;
This will split a node of a tree into the specified number of subnodes. Each of these subnodes can be accessed as a tree itself. The list is a list of percentages to be used for the size of each child. If the first element in the list is -1, then all the children are equal, otherwise there should be a value for each child. This can be called on any node of the tree. An example of the several calls to split follows:

```
my_tree = (window_tree *)new_node(x,y,width,height);
split(my_tree, ROWWISE, 2, -1)
split(my_tree->children[0],COLUMNWISE, 2, 30, 70);
split(my_tree->children[1],COLUMNWISE, 2, 70, 30);
```

This will create a structure that would look as follows:



geom_tree_resize_parent(*parent,x,y,width,height*) *Function*
*window_tree *parent;*
int x,y,width,height;
Change the size of a parent in the tree. This will cause all the subtrees to change size when they are recalculated. It should only be called on the root of the tree. Since the sizes for all the subtrees are calculated in recalculate.

geom_tree_recalculate(*parent*) *Function*
*window_tree *parent;*
Recursively recalculate the actual sizes (in pixels) of every node in a tree. It uses the x,y, width and height of the root node, and the percentages of all the subnodes to set the x,y, width and height of every node in the tree. This routine must be called before all operations that attempt to display the tree, and should usually be called only on the root of a tree.

geom_tree_change_direction(*parent,direction*) *Function*
*window_tree *parent;*
int direction;
Change the direction that children are split from in any node of a tree. The direction may be either ROWWISE or COLUMNWISE. This can be called on any node of the tree.

geom_tree_resize_children(*parent, number_of_children, list*) *Function*
*window_tree *parent;*
int number_of_children;
vararg list;
This will resize the children of any node in the tree only up to the number of children that originally exist for that node. List is a list of percentages that can be used for the size of each child. If the first element of the list is -1, then every child of the node is given the same size. It is acceptable for a child to have 0 percent size, in this case that child (and all its subchildren will still exist but have no size and hence not be displayed).

geom_tree_make_windows_from_tree(*parent, root_window*) *Function*
*window_tree *parent;*
Window root_window;
This routine will use the tree given (it should be the root of a tree) to create subwindows in the given window. It will recursively step down the tree and create a subwindow only for each leaf of the tree.

geom_tree_make_terminals_from_tree(*parent,root_window*) *Function*
*window_tree *parent;*
Window root_window;
This routine will use the tree given (it should be the root of a tree) to create subwindows with terminals in each subwindow in the given window. It will recursively step down the tree and create a subwindow only for each leaf of the tree.

geom_tree_change_windows_from_tree(*parent, root_window*) *Function*
*window_tree *parent;*
Window root_window;
This routine will resize the windows in *root_window* using the given tree. Care must be taken that this window corresponds to the given tree or errors will occur since the program will attempt to resize windows that may not exist. If a node is encountered that has a width or height of 0 then that subwindow is unmapped. If a node that used to be unmapped (because its width or height was previously 0) and now has a width or height, then it is mapped. If the user resized the root window, all one needs to do to keep the subwindows at their appropriate size is shown in the following example:

```
XQueryWindow(ROOT, &winfo); /* get the new size */
                            /* resize the parent */
resize_parent(my_tree,winfo.x, winfo.y, winfo.width, winfo.height);
```

```
recalculate(my_tree);   /* recalculate the tree */
change_windows_from_tree(my_tree, ROOT); /* change the
                                            subwindows */
```

geom_tree_count_leaves(*parent*) *Function*
*window_tree *parent;*
Returns the number of leaves in a given tree (or number of children that a given node contains).

geom_tree_get_leaves(*parent, leaf_array*) *Function*
*window_tree *parent;*
*window_tree **leaf_array;*
Does not allocate storage, but fills leaf_array with the leaves of the specified tree. An example of the way to get an array that contains the leaves of a tree follows:

```
num_leaves = count_leaves_in_tree(my_tree);
leaf_array = (window_tree **)malloc(sizeof(window_tree) * num_leaves);
get_leaves(my_tree,leaf_array);
```

The basic data structure for this layer is the wr which was specified before. It consists of a rectangle `x,y,width,height` and a `window id`.

Routines are provided for:
Setting this structure:

geom_setstruct(*wr,x,y,width,height*) *Function*
*struct wr *wr;*
int x,y,width,height;

geom_setfrom_winfo(*wr,info,id*) *Function*
*struct wr *wr;*
*Winfo *info;*
Window id;

Creating this structure:

geometry_init(*id*) *Function*
Window id;
Takes a window id and returns a pointer to the wr structure that is associated with that Window.

geometry_init_from_size(*x,y,width,height*) *Function*
int x,y,width,height;

Does the same thing as the routine above only instead of taking a window Id it does this from the rectangle parameters provided.

Creating a window using this structure:

geometry_create(*wr*) *Function*
*struct wr *wr;*

Mapping an associated window:

geometry_map(*wr*) *Function*
*struct wr *wr;*

And most importantly splitting the structure:

geometry_split(*wr, direction, number, percent_list*) *Function*
*struct wr *wr;*
int direction, number;
int percent_list[];

geometry_split_from_window(*id, direction, number, percent_list*) *Function*
Window id;
int direction,number;
vararg percent_list;

This routine is the basis of the entire geometry package and is called from the higher level split routines. Using the wr structure, it splits the structure and returns the specified number of subwindows (though the window ids are not filled in at this point) in an array of wrs. The percent list is used to specify the size of each window that is split or if it is NULL, each subwindow is sized equally.

For further documentation on the X window system see the document "Xlib - C library interface to the X Window system", and for documentation on Sx please see the document "Sx Overview".

4.3.12 Hash Tables

The utility library also includes a fast hash table library for looking up data associated with keywords. The functions provided by this library are described below. The file `vme/hash.h` needs to be included by any file that needs to use these functions.

htinit(*size*) *Function*
size;
This function initializes the hash table modules and returns a pointer to a hash table object, which is `typedef`'ed to be `hashtable`. Therefore, to use this, one would do

```
hashtable ht;
ht = htinit(HASHTABSIZE);
```

The size of the hashtable depends on the application.

htinstall(*key, table, data*) *Function*
*char *key;*
hashtable table;
*char *data;*
This routines associates the given *data* item with the specified *key*, in the given hashtable. The data item can be a pointer to a user specified data structure if need be. The install routine returns negative one if it fails for some reason. If the key already exists in the table, the old association is forgotten.

htlookup(*key, table*) *Function*
*char *key;*
hashtable table;
This takes a *key* and looks it up in *table*. If the entry is not found it returns null. Otherwise, it returns a pointer to a structure of type *htentry* which is declared in file `hash.h` to be:

```
struct ht_entry {
    char *ht_key;
    char *ht_data;
    struct ht_entry *ht_next;
};
```

Users normally will not need to use this function, but instead can use the following function, if they need to retrieve the value associated with a particular key.

htgetdata(*key, table*) *Function*
*char *key;*
hashtable table;
This function takes a *key* and a hashtable *table*; it returns the value associated with the key if found in the given table or null if not.

htmap(*table, function*) *Function*
hashtable table;
int (*function)();
This calls the specified ***function*** successively with every element in the hash table. The two arguments passed to the function are a pointer to the data associated with a particular key, and the key itself.

htstat() *Function*
Prints out various statistics concerning the usage of a hashtable if it contains any entries.

htdelete(*key, table*) *Function*
char *key;
hashtable table;
This function deletes the entry associated with the specified ***key*** if it is found in the table specified by ***table***. If the item is not found in the table, it returns negative one.

hthash(*s, table*) *Function*
char *s;
hashtable table;
This routine takes a key value and a hashtable, and returns an offset number into the table of entries. Since the hash table internally uses linear chaining to handle collisions, using the offset directly will yield a list of entries all of which hashed to that same value as the specified argument ***s***.

htclobber(*table*) *Function*
hashtable table;
This function deletes all the elements and deallocates a hash table. Consequently, this must be used only with great care. If the hash table datum are pointers to dynamically allocated objects, the user must free the data objects individually before deallocating the table. Usually this can be done with:

```
htmap(table, free);
```

4.3.13 Buffer routines

The buffer manipulation routines provide a low overhead way of managing data that needs to behave like a FIFO queue. It is extremely easy to write a set of linked list manipulation routines that do what the functions documented below do. However, the routines below, require the user to specify what the size of the buffer pool ought to be in advance. This provides a way of controlling memory usage, which could get to be expensive in certain kinds of computation.

To use the routines in this library you must have `cbuf.h` included in your source file with a line that says,

```
#include <cbuf.h>
```

The functions that are user visible in this module are:

buffer_create(*no_elements, size*) *Function*
int no_elements;
int size;
This function takes in two arguments, and returns a pointer to an element of type `struct circular_buffer`. The first argument *no_elements* is the number of elements that the queue is designed to hold and the second argument *size* indicates the size of each element. For example, to create a buffer to hold ten file structures one can write

```
struct circular_buffer *cb;
cb = buffer_create(10, sizeof(struct file));
```

Once the buffer has been created, the user can use the following functions to add and delete elements from the queue.

buffer_put(*queue, object, dontwait*) *Function*
*struct circular_buffer *queue;*
*char *object;*
int dontwait;
The first argument is a pointer to a queue to which the second argument *object* must be added. If the third argument *dontwait* is set to one, then the routine will return immediately if it does not find any space in the queue to hold the new object, returning minus one to indicate failure. If the third argument is set to nil, then the routine will wait until space becomes available in the buffer. Notice that it makes sense to do this only if the queue is being emptied by some other process. The element is added to the queue by the `bcopy()` routine, and is assumed to be of the same size as the elements for which the queue was created in the first place.

buffer_get(*queue, dontwait*) *Function*
*struct circular_buffer *queue;*
int dontwait;

This routine takes a queue as the first argument and returns a pointer to an element popped off it. Notice that this routine just returns a pointer to an element – If the user needs to use the returned object later on in his computation, he had better copy it into his own locally allocated variables. If the second argument *dontwait* is one, then the routine returns nil immediately, if the queue is empty. If *dontwait* is nil however, it waits until an element appears in the queue.

4.3.14 Tree library

The command parser and other such system libraries use a set of functions that operate on binary trees. The functions in this library are documented briefly in the following section.

tree_create(*elementsize, predicate*) *Function*
int elementsize;
int predicate;
This routine creates and returns a pointer to a `struct btree`. Each element of the tree is set to be of size *elementsize* and *predicate* is a function that imposes an ordering relation between the elements of the tree. This function must be written so that it can take two nodes as arguments and return a value that is less than, equal to or greater than zero depending on whether the first node is less then, equal to or greater than the second node. The function should return zero only if the two nodes are identical.

tree_free(*root*) *Function*
*struct btree *root*;
This routine frees all elements and the memory associated with a particular tree. All other calls made to the tree package with a tree that has been previously freed will fail, after this call.

tree_insert(*root, elt*) *Function*
*struct btree *root;*
*char *elt;*
This routine inserts element specified by *elt* into the binary tree specified by *root*. The routine returns a pointer to the modified tree data structure. Note that the size of the element to be added to the tree must be equal to the size of the elements for which the tree was created to handle. The insertion of the element will happen at the right place in the tree as specified by the ordering function.

tree_lookup(*root, elt*) *Function*
*struct btree *root;*
*char *elt;*
This routine will search for *elt* in the tree specified by *root*. If a match is found (as indicated by a returned value of zero by the user supplied comparison predicate function) then that element will be returned. If no match is found then the routine returns `NULL`.

tree_delete(*root, elt*) *Function*
*struct btree *root;*
*char *elt;*
This function deletes element specified by *elt* from the tree specified by *root*. It returns a pointer to the modified tree.

tree_traverse(*root, way, function*) *Function*
*struct btree *root;*
int way;
*int (*function)();*
This function traverses a specified tree in a manner specified by *way*, which can be one of `POSTORDER`, `PREORDER`, `INORDER`. If specified the *function* is invoked once with every element as its single argument.

4.3.15 Small set package

This package comprises of a set of routines to manipulate small sets of integers (typically between the integers 1 to 32). In the Utah-MIT hand which has sixteen joints, such a package comes in handy at the level of joint control.

The set is based on bit vectors and can be easily extended to larger set sizes, should that be required. All the functions given below require one to include the file `<set.h>`.

set_emptyset() *Function*
This creates and returns an object of type SET, that is empty.

set_singleton(*i*) *Function*
int i;
This routine creates and returns an object of type SET that contains a single member, indicated by *i*.

set_add_element(*set, elt*) *Function*
SET set;
int elt;
This adds the specified integer *elt* to the set specified by *SET*. The routine returns the modified set.

set_delete_element(*set, elt*) *Function*
SET set;
int elt;
This routine deletes *elt* from the specified set.

set_memberp(*set, elt*) *Function*
SET set;
int elt;
This function is a predicate that returns one if the given element *elt* is a member of the given set and zero if it is not.

set_intersect(*set1, set2*) *Function*
SET set1;
SET set1;
This function returns the set intersection of the two specifed sets.

set_union(*set1, set2*) *Function*
SET set1;
SET set1;
This function returns the set union of the two specified sets.

set_difference(*set1, set2*) *Function*
SET set1;
SET set1;
This function returns the set difference *set1 - set2.*

In addition to this routine a *forall* macro is available that can be used as follows:

```
int joint;
forall(joint, currently_selected_joints) {
    printf(''Joint %d, Gain %d, Damping %d\n'',
         joint, Joint[joint]->gain,
         Joint[joint]->dampint);
}
```

where `currently_selected_joints` is a SET that has been appropriately initialized.

4.3.16 Miscellaneous routines

These routines are included here, since they do not fall into any of the above mentioned categories.

abort() *Function*
This is different from the Unix `abort()` that is defined to produce a coredump of a running process. Our version merely exits a running program, and returns control to the Boot Prom monitor.

exit(*status*) *Function*
int status;
Returns from a running C program to the Boot Prom monitor. Exit code *status* is presently ignored.

_ccleanup() *Function*
Function that waits until all the terminal queues have been flushed before returning. This is called internally by `exit` but users may find it useful on occasion too.

_panic(*string*) *Function*
*char *string;*
Function that prints out the *string* at the terminal and then causes the program to terminate. Used to indicate that an abnormal and non-recoverable error occured.

isatty(*fd*) *Function*
int fd;
Returns one if argument *fd* is less than three. This function can be used to find out if a given file descriptor is attached to a tty.

_setprocid(*id*) *Function*
int id;
Sets the current processor id to be that of the argument *id*. Use this function with care.

_getprocid() *Function*
Returns the processor id of the processor on which the program is currently running.

rand() *Function*

srand() *Function*
Standard Berkeley Unix semantics.

syserr(*no*) *Function*

int no;
Prints out the error message corresponding to system error number *no*. This routine also sets the global variable errno to be the given error number.

errno *Variable*
Global variable that can be examined to find out the cause of certain system error codes.

4.3.17 Internals

In this section we document those few functions that are either internal to the implementation or on the way to becoming obsolete. We provide this information for users who need to delve into the internal implementation.

4.3.17.1 Interrupts and Vectors

The following functions allow the user to manipulate interrupt vectors on the slave microprocessors. These routines affect the system at the lowest levels and hence we do not recommend they be used by the casual user. There are many more functions that make up the internals than are documented here – we have chosen to document below only those functions that we felt needed documentation. The normal user is advised to stay with the higher level interfaces meant for handling terminal i/o, timer interrupts, mailboxes and so on, so that his code will port easily and be immensely more readable and maintainable.

splx(*level*) *Function*
int level;
This routine turns off interrupt processing at levels below the specified by *level*. Internally it calls routines spl0 through spl7 on the Ironics board that has seven interrupt levels since is is based on the Motorola 68020 processor. Doing a splx(7) is equivalent to doint a spl7(), and turns off all interrupts below level 7, which basically turns off all interrupts. Correspondingly doing a spl0() enables all levels of interrupt on the processor.

The vector library provides a mapping between vector numbers and routines that these vector numbers should invoke. The Motorola 68020 defines a number of system vectors and leaves a number of vectors unspecified so that a user can assign devices that provide support for vectored interrupts can use them. (Please see the document on how to write device drivers for documentation on how to choose a vector number when you are configuring a new piece of hardware into the system).

The following functions provide a flexible interface to the programmer who needs to deal with vectors:

vector_init() *Function*
Initializes the vector system. This is done automatically upon system initialization so the normal user would not need to call this.

vector_print(*vectornumber*) *Function*

int vectornumber;
This routine prints out a short description of the routine assigned to the vector number specified by *vectornumber.*

vector_print_all() *Function*
This routine prints out the entire mapping in place, that maps vector numbers to routines.

vector_set(*num, routine, name*) *Function*
int num;
*int (*routine)();*
*char *name;*
This function takes a vector number given by *num* and a routine given by *routine* and sets up the mapping so that that function will be invoked when an interrupting device supplies the designated vector. The third argument *name* is a string describing the use of the vector and is purely for descriptive purposes.

The routines designated to be interrupt vectors should all be off the following form;

```
int
bus_error_handler(num, registers)
int num;
char *registers;
```

These functions will be invoked by the system. The first argument passed to them will be the vector number that caused the invocation, and the second argument will be a pointer to the registers saved at the time of the call.

(Please see the Motorola 68020 User's Manual for descriptions of system defined vectors, and stack frames relating to those vectors).

with_handler_do(*num, routine, replacement*) *Function*
int num;
*int (*routine)();*
*int (*replacement)();*
This routine takes a vector number and pointers to two functions given by *routine* and *replacement.* It replaces the presently assigned handler for the vector by *replacement* and then invokes *routine* with no arguments. This routine is provided for users who wish to temporarily override the system default routines with their own. One obvious application for such a functionality arises when the user wishes to reassign the bus error handler.

with_handler_extended(*num, routine, replacement, arg*) *Function*
int num;
*int (*routine)();*
*int (*replacement)();*
int arg;
This routine is exactly like the one above, except it invokes the routine with the specified argument *arg.*

4.3.17.2 The interrupt generator

The following routines provide a way to use the interrupt generator chip on the Ironics. They are internal to the implementation.

igen_interrupt(*vector*) *Function*
int vector;
This function gets the onboard interrupt generator chip to generate an interrupt with the specified vector. The level at which the interrupt is generated is got by stripping the lowest three bits of the specified vector.

igen_reset() *Function*
This resets the onboard interrupt generating device.

4.3.17.3 The interrupt handler

The following functions provide an interface to the interrupt handler chip on the Ironics 3201 board. Again, these functions are internal to the present implementation.

_init_i68155() *Function*
Initialize the interrupt handler chip. This routine is invoked automatically upon program initialization.

int_stat() *Function*
This routine prints out the status of the interrupt handler chip.

int_enable_vmebus(*level*) *Function*
int level;
Enable the vmebus interrupt level specified by *level* on the processor.

int_disable_vmebus(*level*) *Function*
int level;
Disable the vmebus interrupt level specified by *level* on the processor.

int_enable_local(*level*) *Function*
int level;
Enable the local interrupt level specified by *level* on the processor.

int_disable_local(*level*) *Function*
int level;
Enable the vmebus interrupt level specified by *level* on the processor.

int_enable_mailbox() *Function*
Enable mailbox interrupts.

int_disable_mailbox() *Function*
Disable mailbox interrupts.

int_enable_timer() *Function*
Enable timer interrupts.

int_disable_timer() *Function*
Disable timer interrupts.

_typec(*character,port*) *Function*
Types out a given *character* at the serial port *port*. The difference between this and using `putchar` or `printf` is that this function operates completely asynchronously, i.e. does NOT obey the usual UNIX line-buffering scheme. The effect of this function is immediate;

_typec_b(*character*) *Function*

_typec_a(*character*) *Function*
Same functionality as the function mentioned above, but these two routines operate on the specified port (these are retained for historical reasons only).

The printouts caused by these routines are interrupt-driven.

_typec_nointer(*character*) *Function*
however, is a function that prints out a character given to it without using interrupts.

Symmetric to these interrupt driven routines for doing output, is a set of routines for doint asynchronous input.

readc(*port*) *Function*
Reads, and returns a character from port *port* as soon as it is made available from the keyboard.

_readc_b() *Function*
and

_readc_a() *Function*
on the other hand read and return a character from the designated port.

_kbhit() *Function*
This function returns NULL if the keyboard has been idle and no key has been struck for some time. It returns NON-NULL if the keyboard has been active, and there are characters waiting to be read from the input queue.

4.4 Level One Software for the *CONDOR*

Besides the commonly used, level zero application software, there are three large systems that we haven't described yet. These systems provide the user program with:

1. a simple scheme of *Message-Passing* based on shared-memory on the micro-processors to achieve interprocessor communication,
2. a low overhead scheduler known as the MOS (for the Minimal Operating System) that schedules different computational tasks on the microprocessors and
3. a debugging system based on the message passing library.

4.4.1 Message Passing Support

This section provides, a description of the *Message-Passing* system and the primitives that it provides.

The explanation provided here, is intended mainly for those that are interested in using the **CONDOR** system for real time control. The purpose of this section is to provide the reader with a basic understanding of how to write simple programs that use the *MPS* successfully to communicate between processors.

4.4.1.1 Introduction

The message passing system provides a simple, low-overhead manner in which communication of data can occur between processors that comprise the *CONDOR* controller. A typical application running on the *CONDOR* controller comprises of a set of processes running on the microprocessors. These processes can communicate with one another using the *MPS*. Since the servos are always compute bound tasks, any system for communication between such tasks has to be extremely time-efficient in order not to impair the real time performance of the system noticeably. The primary design goal of the *MPS* was therefore efficiency.

The present system is to a large extent, a redesign of the system described in Narasimhan et al. [1986]. Although the functionality provided by that system was far greater than that provided by the present version, we feel that this second attempt has been made substantially more efficient. Since the previous implementation was based on C it should be relatively easy to port that to the present system as well, for users who feel that they need the added levels of functionality.

4.4.1.2 Messages

In any multiprocessing environment interprocessor communication is a necessity. Since the Ironics processors and the Sun host computer are all bus masters on a common VME bus, each machine has access to each other's dual ported memory. Interprocessor communication occurs over the bus and directly uses shared memory. This allows, for example, any processor to directly access data in another processor's memory. The most basic form

of interprocessor communication possible would be direct memory reads and writes from another processor storage. Unfortunaly, this unrestricted access, though highly efficient, is hard to control.

To overcome the problems of unrestricted memory access, a mailbox-based message passing system is supported. Mailbox interrupts can be thought of as a software extension to the processor's hardware level interrupts. Another way of thinking about them conceptually is to regard mailbox numbers as port numbers that map to specific remote procedure calls.

A mailbox interrupt has a vector number and a handler routine. When a particular mailbox vector arrives its appropriate handler is invoked. The handler is passed the processor number that initiated the mailbox interrupt and a one integer data value. This integer data value is the message's data. To summarize, there are two pieces of data that get transmitted for every message – viz., a message handler number and a piece of integer data that can be used as the user sees fit.

Let us say, for example that the user wants to write an address handler that will receive a message composed of a memory address, and will respond with the value found at that particular memory address.

This simple example will illustrate not only how messages are received, but also how messages are sent and how certain messages can be replied to.

The conceptual design for such a user level message passing system is simple. Each mailbox handler is invoked with the first argument being the processor number that sent the message and the second argument being a piece of data that is wide enough to fit into a 32 bit quantity. We can therefore design the message handler such that when invoked, the memory address it needs to look at will be passed to it as the data associated with the message (since we do not expect our addresses to be longer than this). The message handler will essentially decode the message to find out what this address is, and return it.

The handler can therefore be written thus:

```
simple_decoder(proc, data)
int proc;
int data;
{
    return(*(unsigned int *)data);
}
```

After writing the handler one has to associate this handler with a vector number so that when other processors request this service, it will be performed correctly.

This is done by the following piece of code.

```
int simple_decoder();
mbox_set_vector(12, simple_decoder, ''A test handler'');
```

Once this call has been executed messages that arrive for vector numbered 12 will cause the simple decoder routine to be invoked automatically.

But how does another processor invoke this routine? This is done by the `mbox_send` routine. If the `simple_decoder` routine is available on processor 0 one can execute the following piece of code on any of the processors (including 0) to invoke the service.

```
value = mbox_send_with_reply(0, 12, address);
```

This will cause the handler that corresponds to the number 12 to be invoked on processor 0 with the second argument being `address`. The call will not return until the other processor has responded with the value found at the given address. This call can therefore be used to provide synchronization.

There does exist another version of this sending that does not require the sender to wait until the handler for the message has completed executing on the recipient processor (see the routine `mbox_send` for details).

There are several important points to be noted about using the mailbox handler for communication:

(a) Since message sending happens asynchronously, the execution of a handler resembles an interrupt. All caveats that apply to interrupts and interrupt handlers therefore apply to message handlers too.

(b) The base system is extensible in the sense that more complicated protocols can be built on top of it. For example, the underlying system does not provide any support for queueing, although one can very easily build one for mailboxes that require this.

(c) On the sun, message handling is arranged to always happen on the process that sets up the handler using the Unix `select` system call.

(d) Since the message system is based on shared memory, sending long messages is usually handled by sending a pointer to the beginning of a long piece of data. If the communication mechanism is serial, wherein a stream of data needs to be sent, sending a large number of messages may cause unwanted system overhead (although message sending is usually a single subroutine call). This can be avoided via a packet based interface to the message passing system which is not documented in this version of the document. It is our opinion, that such links will be of such low bandwidth that they will rarely be used, if ever at all.

(e) Most often, one may need a variety of functions that need to be performed in response to a message. Instead of defining ONE message handler for each such function, it may be helpful to collect related groups of handlers into a single handler, that dispatches to separate routines based on the data item sent along with the message.

(f) We have thus far used the convention that related messages thus grouped will be found in a single file, and that the vector numbers that correspond to message handlers be localized to a single `.h` file. This allows the symbolic use of handler names rather than numbers.

(g) Where efficiency is important, the message handling system can be used just to set up pointers from one processor into another's memory. After such a set up is complete, the processors can read and write this shared memory as they please. This removes the burning of addresses in programs, but maintaining the integrity of shared data structures will entirely be the programmer's reponsibility.

4.4.2 The Sun end

An examination of the dual ported memory configuration is useful for guiding multiprocessor programming. An Ironics processor's memory is entirely dual ported, and hence totally accessable over the bus. The Sun has a region of memory called DVMA space (for Direct Virtual Memory Access). The DVMA area occupies the lowest megabyte of the VME 24D16 and 24D32 address space of the VME bus. However, it is not convienent for an Ironics processor to communicate with the Sun using this space, since Unix memory management issues become complex.

Instead, an extra 1 megabyte dual ported ram board is installed in the VME bus for uses primarly by the Sun. This board can be thought of as the local memory that the Sun has control over. Ironics processors can directly communicate with this storage, instead of using the DVMA space on the Sun. If need be, this area of memory that the Sun uses for receiving messages intended for it, can be allocated on any of the Ironics single board computers' onboard dual-ported memory.

From the Sun, the Condor system maps the entire VME 24D16 space (or VME 24D32 space if the adaptor used is the hve-2000) into the user address space of the control process. Memory references to any of the Ironics or the Sun's 1 megabyte board on the VME bus become simple array references from a user's program. The PROC_RAM(processor) macro returns the pointer to the bottom of memory for the particular processor.[5] For example, to write a value to location 100 in processor 3's memory one could use the following code:

```
int *processor3_ram = (int *)(PROC_RAM(3));
processor3_ram[100] = value;
```

(Please see also the description of `hve_get_pointer` in Section 4.3.8.)

The PROC_RAM macro is also used for programs running on Ironics processors to access memory of other Ironics processors. The code above would work, in fact, on any processor in the Condor system.

Even though the mailbox routines in the Condor system are highly efficient, it is sometimes desirable to directly use the VME bus shared memory for interprocessor communications. For example, consider a data structure on processor A:

```
struct data {
    int a;
    int b;
} data_A;
```

Consider the following mailbox handler also present on processor A:

```
get_data_pointer(proc, data)
int processor;
int data;
{
```

[5]This macro requires that the file `vme/memloc.h` be included in the code that uses it.

```
    return ((PROC_RAM(PROC_A) + (int)(&data_A));
}
```

Processor B could define a pointer to such a structure, and initialize it's value using the mailbox handler made available on processor A:

```
struct data {
    int a;
    int b;
} *data_A = (struct data *)
            mbox_send_with_reply(PROC_A,GET_A_DATA_PTR, 0);
```

The mailbox handler on A will pass the VME bus address of its data structure back to processor B.

The Sun processor is actually considered to be more than one virtual processors. That is, while each Ironics processor can receive messages just for that processor, the Sun can have more than one message destination. The function `muse_init` is called by a program running on the Sun to initialize the message passing system. This routine takes an argument which is used to assign the virtual Sun processor number that Ironics processors can send messages to. The include file <vme/mbox.h> defines the processor numbers available for the Sun. Typically, PROC_SUN_0 is used by user programs. A second Sun destination, for example PROC_SUN_1 can be defined by forking a new process on the Sun and invoking muse_init(PROC_SUN_1).

muse_init(*proc, mode*) *Function*
int proc;
int mode;
This routine initializes the message passing system on the Sun end. It is passed a number which forms the processor number which the system will use for responding to and sending messages. These numbers should be allocated on a per-process basis. The second argument indicates the mode in which the application program intends to use the mailbox system on the sun end. Currently three such modes are defined. It is essential the programmer understands the consequences of the three different modes.

1. `muse_init` can be invoked with the mode argument set to `LISTEN_WITH_CHILD`. This will cause a second process to be forked, which will go into an infinite loop listening for messages from the *CONDOR* slave processors. Whenever it receives a message, it will signal the application process using the `SIGUSR1` signal. [6]

2. The programmer can also use the mode `LISTEN_RETURN_FD`. In this case, no alternate process is forked. The file descriptor corresponding to the mailbox device is merely returned. The programmer can then use this fd in any fashion he chooses. In particular, he can use the `select()` system call to listen for urgent conditions on this descriptor.

[6] In Unix the term "signal" denotes a programmable software interrupt.

3. The third and the most often used mode in which the mailbox system can be used at the sun end, is done by setting the mode argument to the `muse_init` call to be `LISTEN_WITH_SIGNAL`. Under this mode of operation, the mailbox interrupts on the Sun end are handled via a system defined handler for the `SIGURG` signal. Once this mode has been selected the user must not redefine the `SIGURG` handler in his application program, if he wishes to continue to receive mailbox interrupts.

On the Sun end the EVH library is used by the programmer to receive and service mailbox interrupts. The mechanism by which this is done requires modification to the Sun 4.2 BSD kernel. (This is described in detail below and is intended only for those that are familiar with Unix – Others can skip to the section that summarizes the mailbox functions. These functions provide the same interface on a user process running on the sun as they do on the micros, and are written on top of the EVH handler. Understanding how the latter works is not a prerequisite for using the former.)

4.4.2.1 EVH Handler - Mailbox handler on the Sun end

When an Ironics processor wants to interrupt the Sun it uses the single interrupt level that is left connected across the bus-to-bus adaptor. Each Sun virtual processor number is associated with a particular interrupting vector number, but all the vectors are on the same interrupt level. Thus, when the Ironics processor wants to interrupt the sun, it uses an on-board interrrupt generator chip to cause an interrupt on the Sun across the bus-to-bus adaptor. When the Sun operating system receives this interrupt it uses the EVH device which is described below to handle it.

4.4.2.2 How the EVH handler works

The EVH handler is a kernel configurable option which can be turned on using the standard Unix system configuration files; The option `EVH` (exception vector handler), turns this feature in the kernel on. The exception vector handler or `EVH` is really a *pseudo-device* which allows a user to catch and handle any unconfigured exception vectors. This is done through `select` and `ioctl` on a character special file – an `evh` device file.

The minor number of an EVH device file specifies which exception vector the device is for. This means that if you wish to receive interrupts on a specific vector numbered A on the sun, you have to create an EVH device whose minor number is A. Currently on the machine used in the Hand project we have the following devices available:

```
/dev/evh_201 - corresponds to vector number 201
/dev/evh_209 - corresponds to vector number 209
/dev/evh_217 - corresponds to vector number 217
/dev/evh_225 - corresponds to vector number 225
/dev/evh_233 - corresponds to vector number 233
/dev/evh_241 - corresponds to vector number 241
/dev/evh_249 - corresponds to vector number 249
```

Since we use the interrupt generator chip on the Ironics card, to generate the interrupts on the sun end, and since we map only ONE interrupt level across the two busses, the number of interrupt vectors that we can use on the Sun is only seven. Since we do not have any application that requires seven processes operating simulataneously on the sun listening to the *CONDOR* microprocessors, we feel that this is a justifiable limitation. If more vectors are desired than this number, either another interrupt generator can be used [7] or another level can also be left connected between the two busses.

With an EVH device, it is possible to be notified asynchronously whenever the specified exception occurs. Alternatively, you can use polling (either blocking or non-blocking) to find out whether or not a particular interrupt has occurred.

The EVH pseudo-device is most useful when there is unconfigured hardware present in the system. The EVH option makes it possible for a user's program to handle interrupts from the unconfigured hardware.

4.4.2.3 How to use the EVH handler

The following section provides detailed information on how the EVH device can be used. This is not intended for application programmers for whom the mailbox and hve library functions provide a higher level interface. As far as they are concerned, when an interrupt happens, the mailbox associated with the Sun is examined and the incoming message is handled by the routine specified in the vector, automatically by the sytem. Instead, it is intended for those that need to debug the lower level system when it is not functioning and for those that intend writing their own interfaces similar to the mailbox system.

To use an EVH device, the user typically, opens the device whose minor number corresponds to the vector number he intends to use. The user can optionally also tell the system the process or process group to send `SIGURG` signals to. You can then use the `mmap` call to map address space across the bus adaptor or other pieces of hardware that you want to control.

Everything done with the EVH is done with `selects` and with `ioctls`. The only selection option available is that of exceptional condition. (For a list of the `ioctls` available, see the man page associated with EVH.)

An interrupt will cause all current and subsequent `selects` (for exceptional condition) to succeed until the (exceptional) condition is cleared via the `EIOCSUC` ('set urgent condition') `ioctl`. Further, if, at the time of the interrupt, an fcntl `F_SETOWN` has been done on the device, then the designated process or process group will receive a `SIGURG` signal. The program can then check via a `select` call to find out which device has the urgent condition pending.

When an interrupt occurs that is not otherwise handled by SUN's kernel, `trap()` is called and the `T_M_ERRORVEC` (or `T_M_ERRORVEC + USER` if called from user mode) case is executed. The default action within this case is to panic the kernel. However, if, via the EVH pseudo-device, the user has indicated that the kernel should not panic, but instead handle the interrupt, then the EVH device will awaken any processes currently `selecting`

[7] The Ironics system controller card, and the Motorola parallel port card, can both generate interrupts at specified vectors and levels too.

for the device; will send a SIGURG signal, if appropriate, to a designated process or process group; and will mark the 'device' as having an exceptional condition pending.
Note:
It is not necessary for some process to be currently handling interrupts for the 'device' in order to avoid the panic. All that is necessary is that the interrupt vector is marked as one that is to be handled. This marking is done via the EIOCSUH `ioctl`. Once marked as a 'to-be-handled' vector, a vector remains so marked until it is explicitly unmarked or the system is rebooted. Closing the device does not unmark it. Thus an unexpected process exit will *NOT* cause the system to panic the next time that the hardware interrupts.
End Note.

The following is a list of the existing kernel files which need to be modified for the EVH option:

```
conf/files.sun3
sun3/scb.s
conf/makefile.sun3
sun3/trap.c
sun/conf.c
sys/kern_descrip.c
sun3/locore.s
sys/tty.c
```

The following is a list of the new kernel files (which implement the bulk of the EVH option):

```
conf/EVH
sundev/evh.c
h/evh_ioctl.h
sundev/evh_debug.c
```

For a description of what changes were made to each file, consult the file `README.EVH` in the kernel source directory.

4.4.2.4 List of functions used for message passing

To summarize, the functions provided by the message passing system are given below. To use these, the user must include the file `vme/mbox.h` in his source file.

mbox_vector_print(*vector*) *Function*
int vector;
Print the handler for a specified mailbox vector. This routine is useful for debugging purposes.

mbox_vectors_print() *Function*
Print all currently assigned mailbox vector handlers. This routine is useful for debugging purposes. Both user assigned and system assigned vectors are listed.

mbox_vector_set(*vector, routine, name*) *Function*
int vector;
*int (*routine)();*
*char *name;*
Set the handler for a mailbox vector. The *vector* is a vector number from 0 to 255. Typically vectors from 0 to 127 are reserved for system purposes and vectors 128 to 255 are available for user handlers. This routine, however, can set any of the 256 vectors. Be careful not to redefine a handler already in use. The include file `<vme/sysports.h>` lists system vectors in use. The *routine* is the handler procedure to be invoked when an interrupt arrives. The routine is passed two integer arguements: the processor number that generated the interrupt and a data value passed by the processor. The *name* is a character string used for pretty printing the vector handler name. (There is a third argument that the routine is invoked with on the Ironics, which is a pointer to a saved set of registers that represent the machine's state when the mailbox interrupt corresponding to the interrupt happened. This can be used by routines that need to switch context in response to an incoming message).

mbox_vector_delete(*vector*) *Function*
int vector;
This routine deletes the handler for vector *vector*. Subsequent `mbox_send()` calls to that vector will result in an error.

mbox_send(*processor, vector, data*) *Function*
int processor;
int vector;
int data;
This routine is used to send a message to a processor. The `mbox_send` routine will return as soon as the accepting processor's handler has been invoked. No reply value from the handler will be returned. Note that since the `mbox_send` returns before the handler completes execution, no syncronization is performed. If a subsequent call to a `mbox_send` is made, it will cause execution of a new copy of the handler on the recipient processor. The currently executing handler will be interrupted and the new message will be handled.

mbox_send_with_reply(*processor, vector, data*) *Function*
int processor;
int vector;
int data;
Send a message to the specified *processor* and wait for the handler to return with a reply. The return value from the invoked handler is passed back to the sending processor. This is the value that `mbox_send_with_reply` returns.

4.5 Support for Real Time tasks

There are two levels of support provided for scheduling and running real time tasks on the *CONDOR* hardware. First, there are the bunch of routines that can be invoked by any user program that schedule one C routine to execute at a specified rate. For more complex applications that require more than one real time task to be executing at a time, a low-overhead scheduler has been implemented. In the following section we describe the functions that make up the more complex interface (for details on the simpler interface see Section 4.3.7 on 32).

4.5.1 MOS – A Minimal Operating System

Another important component of the low level system software that goes into controlling the Utah-MIT hand is the *MOS*, short for the Minimal Operating System. The following paragraphs detail the facilities provided by this component of the software and how a user program can use them effectively. Actual implementation details are deferred to the section on implementation details.

The servo loop scheduling system allows a processor to run various control loops at different rates, in a highly efficient manner. Since a typical hand control program will have several servo loops running at rates in excess of 500 hertz, it is important for each scheduler invocation to be fast. To achieve this, scheduling flexibility has been limited to minimize the execution overhead that it requires. In fact, it is a gross overstatement to call this an operating system. It is, in fact, just an efficient utility for programming a system timer and for starting procedures based on precomputed rate information.

To minimize execution overhead, the *MOS* is table driven. An *event table* is automatically generated by the system when the `mos-start` command is issued. This table lists the elapsed time between invocations of the scheduled servo loops. For example, the event table for two servo loops, one running every ten seconds and the other running every five seconds, has two entries. The first entry indicates that both loops are to start, and five seconds elapse until the next event. The second entry indicates that the five second loop should start, and another five seconds are to elapse before the next event. After this, the cycle repeats, and the first entry of the event table is reused.

With the system outlined so far, it is possible for more than one loop to be runnable at the same time. The system must have an orderly method for selecting the actual loop that will be run from the set of runnable loops. A *process table* is maintained for this purpose. All the tasks in the system are arranged, in order of decreasing servo rate, in this table. When the event table indicates a loop is ready to run, it is marked runnable in the process table. The system then searches down the process table, and starts the fastest rate loop that is marked runnable.

The time to the next event stored in the event table is loaded into a timer on the processor. When the time has elapsed, the running task is interrupted, and the scheduler is reinvoked. The next tasks in the event table that are scheduled to start are marked runnable in the process table. If a loop with a speed slower than the interrupted loop is made runnable, the interrupted loop will be resumed. If a higher speed servo loop is made

runnable the slower loop that was interrupted will be temporarily suspended, until higher speed loops that are runnable complete.

An implication of assigning a priority to a process based on its rate is that a loop can only be interrupted by a higher speed loop, and hence, no coprocessing can take place. This is not considered to be a problem. The rate specified for a servo loop is a request that the loop be run that number of times a second. The exact time that a loop is invoked is not important, as long as it runs within its specified time slice. In other words, a loop scheduled to run every second is only a guarantee that the loop will run *sometime* within a second. A finer precision in selecting the time at which a procedure will run is not needed within our control programming scenario.

Eliminating coprocessing results in a convenient simplification to the system; only one stack need be maintained for all the servo processes running on a processor. Stack pointers are not changed when a new process is invoked, or a suspended process is resumed.

When a loop terminates, the scheduler is also invoked. The terminating loop is marked idle in the process table, and a new loop is selected to run. If no servo loops in the process table are runnable, the background job is activated.

To summarize, the functions that can be invoked are:

mos_init() *Function*
This function must be invoked before you can make use of any of the functions described below.

mos_schedule(*name,servoloop,rate*) *Function*
This routine schedules the routine named *name* at a rate given by the third argument. A pointer to the routine should be passed as the second argument as *servoloop*. You can schedule more than one loop on one processor, besides having a background command loop.

mos_reschedule(*name, servoloop*) *Function*
This command sets the process named by its first argument *name* to be the loop which forms its second argument. This can be done for example, even if *servoloop* had been previously scheduled, and by this a change in the servo rate can be obtained with very little overhead.

mos_enable_loop(*name*) *Function*
This enables the servo loop named by its first argument.

mos_disable_loop(*name*) *Function*
This routine disables the loop named by its first argument.

mos_start() *Function*
This routine does most of the work of building the event table; This routine starts up the timer, and the various routines that have been scheduled via mos_schedule become active once this routine has been invoked. The background task is usually whatever code that

follows a call to this routine.

mos_stop() *Function*
Stops the scheduled servo loops from executing.

mos_show_status() *Function*
Prints out the status of the loops that are currently being scheduled.

mos_show_full_status() *Function*
A more verbose form of the previous function.

4.6 Debugging Support

All the debugging support is based on an emulation library that emulates the `ptrace` call. Recompiling any standard debugger that uses this call should be all that is required to make that debugger work along with our system.

We use a debugger called `GDB` internally. The following documentation describes the changes to this debugger that we found necessary – one can expect that similar changes have to be made to other debuggers if one wishes to use them instead.

Some relatively minor changes were made to the source to GDB to allow a user to use it on the sun to debug programs running on the ironics board. These changes allow a user using GDB on the Sun to set breakpoints, single step, examine and set variables, and so on.

4.6..1 Commands added to GDB

Two commands were added to GDB to facilitate its use in debugging programs running on the ironics board. These commands are `attach` and `detach`.

attach(*pid*) *Function*
Stops the specified process and places it under control of the debugger. That is, the process is `attached` to the debugger.

detach(*signal*) *Function*
Removes the specified process from under the control of the debugger. That is, the process is `detached` from the debugger. If the signal is not specified, it defaults to 0 (i.e., no signal).

4.6..2 Ptrace, Wait, and friends

The following section describes the debugging support currently available for the *CONDOR* system. Since the bulk of a programmer's time is spent debugging, the quality of support provided for debugging can drastically affect programmer productivity. The *CONDOR* system solves the debugging problem in a rather unique way. To understand how this works, it is important to first understand how debugging works under Unix.

Unix debuggers currently rely on using two system calls, `ptrace` and `wait` to debug other processes. Normally a parent process runs another process which is to be debugged and uses the `ptrace` system call, to examine the child's registers, single step it and so on. By using the message passing system, we have written a collection of routines that emulate the `ptrace` and `wait` system calls. Basically there are two sets of routines, one set that runs on the Sun and another that is linked into programs intended to run on the *CONDOR* microprocessors.

Since the libraries are relatively independent, they can linked in with ANY STANDARD Unix debugger of your choice on the Sun end. This means that after the linking is done, one essentially has a debugger that instead of debugging another process on the sun, debugs another program running on one of the *CONDOR* slave microprocessors.

Note:
The debugger on the SUN and program running on the ironics board do not, really, have a parent and child relationship in the unix sense. However, this terminology is fairly deeply ingrained into the unix documentation for `wait`, for `ptrace`, and for the various debuggers. And, in fact, most unix systems do not allow a process to debug any processes except immediate children.
End Note.

Emulations for `ptrace` and `wait` have been written so as to make as much as possible of the debugger interface be 'debugger independent' as possible. Different people have different ideas as to what a good debugger interface really should be like. Ideally, it should be possible to accommodate all of these people by having a library of routines which they simply link in ahead of the standard C library.

Since we tend to use the debugger known as 'gdb' currently we have linked and tested the `ptrace` emulation libraries with this debugger only. However it should be possible to do the same to any other debugger such as dbx, sdb or adb.

4.6..3 How to use the debugger

There are versions of the debugger, (`gdb`) that have been linked with the emulation libraries instead of the standard system call library. Once this program has been started up, one can use the `attach` command to connect up to a slave process on the *CONDOR* microprocessor. The documentation on `gdb` is pretty comprehensive and should be sufficient for most debugging purposes. (To use the debugger, the memory mapped hve connection must be turned on and enabled).

In the child program, the message passing system is typically initialized by crt0.o and the code needed for the support of `ptrace` and `wait` is already present if the the correct crt0.o has been used. That is, nothing is required on the user's part other than to make sure that the correct crt0.o is used and that the library containing the `ptrace` and `wait` emulations (libcemul.a), is searched prior to the standard C library.

In unix, debuggers use `ptrace` and `wait` to interact with the child that they are debugging. `Wait` is used to inform the parent when the child exits, when the child stops for tracing, and (under Berkeley Unix) when the child stops as a result of a `SIGTTIN`, `SIGTTOU`, `SIGTSTP`, or `SIGSTOP` signal.

With the exception of a ptrace request of 0 (PTRACE_TRACEME), all ptrace requests are executed by the parent and the parent is only allowed to issue a ptrace request when the child in question is stopped waiting to receive a ptrace request from its parent.

In Sun's OS,the 'parent' can trace a process which is not it's immediate child if the uid's are 'right'.

The manner in which the emulation of the ptrace call works, is described below.

When the parent issues a ptrace call, the emulation routine sends a message to the child asking it to carry out the requested operation. The child, if stopped waiting for such a request, will attempt to carry it out and will send back to the parent a reply giving the completion status of the request (successful or unsuccessful) and, if applicable, any ancilliary requested information.

In the ptrace emulation routines, the parent always sends messages expecting a reply; the child only replies to ptrace messages, the child never initiates a ptrace message.

In the wait emulation routines, the parent sends a message asking the child if it is sleeping and telling it whether it intends to wait for the child to go to sleep. The child responds by telling its parent whether it is sleeping or not. Additionally, if the parent is going to wait for the child to go to sleep, then the child records this fact. And whenever the child goes to sleep, it checks to see if its parent is waiting for it to go to sleep. If it is, then it informs its parent that it is now going to go to sleep.

Nothing bad happens if the parent is no longer waiting when the child informs it that it is now sleeping. The parent is not normally notified when the child sleeps because of the assumption that we may someday have the child sleep for something other than ptrace and we don't want to generate a lot of unnecessary 'sleep' and 'wakeup' messages from the child to the parent. If the parent does not ask the child what it's current state is, but rather expects the child to always keep the parent up to date on the child's status, then the child must inform the parent whenever it *changes* state – running to sleeping and sleeping to running both – not just when it goes to sleep.

Since the *CONDOR* microprocessors do not run a real operating system, there arose the question of what it should do when it is waiting for a message from the Sun telling it what to do. It was felt that it whould be best if it 'gave up the bus' and thereby minimized its impact upon other processors wishing to use the bus. Thus, whenever a program being debugged needs to wait for a message from the Sun telling it what to do, it goes to sleep. The best way of 'putting it to sleep' seemed to be to change the single process system into a dual process system where the second process is not a real process but rather a fake process that just executes an 'idle loop'; where the idle loop is just a loop with a 'stop' instruction in it. This is what was in fact done.

4.6.1 Local Differences

This last section is only intended for users of the *CONDOR* system present at the MIT's Artificial Intelligence Laboratory. It describes very briefly the differences between the standard *CONDOR* controller hardware and the one presently being used to control the Utah MIT Hand.

The present system at the Laboratory, still relies on stepper motor controllers on the

Multibus to control the arm positioning hardware and older models of the A/D and D/A converter boards to control the hand. This hardware is housed in a Multibus cardcage connected up to the standard *CONDOR* controller's VME-Bus backplane via a VME-Bus to Multi-BUS adaptor.

There are two implications that programmer's must be aware of, if they intend using this hardware. The first has to do with the fact that since some of the Multibus devices do not decode all the address lines the sixteen bit I/O space is drastically reduced due to a wrap around problem. Choosing where to place a new board in A16D16 space therefore, has to be done carefully, to avoid possible clashes with devices that already exist in that address space. The second implication has to do with the mapping of interrupts. The VME-bus expects vectored interrupts even when a device on the Multibus may not be capable of generating any vectors. In such a case, it may not be possible to use such a device in a mode that requires it to interrupt a *CONDOR* processor at all.

Following is the list of hardware that is peculiar to our local environment:

1. *Data Translation DT1742 A/D Board*
   The model DT1742-64SE-PG-C uses a multiplexer front-end to select one of 64 single-ended input channels for conversion by the 12-bit A/D converter. Software programmable gains of 1, 2, 4, or 8 may be selected. Data is read as signed 12-bit quantities with the high order two bits giving the gain code. All accesses to the board are byte wide, and the primitive address decoding scheme requires the board to be installed in I/O space. When power to the board is off, input voltages must not exceed + or - 1 volt.

2. *Data Translation DT728 D/A Board*
   This board, model DT728-8-10V contains eight 12-bit digital-to-analog converters, each of which produces an output in the range -10 to +10 Volts. Data is written to the boards as signed RIGHT-justified 12-bit quantities. Since only a maximum of 20 bits of address are recognized by the board selection circuitry, it is necessary for this board to be in I/O space. The board generates XACK acknowledgement only in response to IOWC write commands.

3. *The Magnon Stepper Control Boards*
   These boards are again Multibus based stepper motor controllers. They have a number of features that make them relatively unique. The controllers control the position of the motors by sensing the back e.m.f generated from the motor and inferring the relative position between the stator and the rotor from this. While this enables highly accurate control of the motor's position it also enables one to do away with all the sensing hardware needed. Each controller board controls two stepper motors rated upto 5 amps each. The boards also come with the drivers making them a compact unit.

4.6.2 Conclusion

We hope that what we have presented in the sections above is enough documentation for a prospective user of a real time system to get started in using the system. For a system

that is as complicated and composed of so many pieces as this, expertise only comes with experience and practice. Good Luck!

4.7 Acknowledgements

First and foremost, our acknowledgements go to the engineers at the University of Utah's Center for Engineering Design, whose marvelous device even today asks for more powerful controllers. Version I of the *CONDOR* was only the beginning of an answer, and we hope that Version II is a better one. A number of other people have contributed significantly to the system presented herein. Our thanks go mainly to Prof. John Hollerbach, who guided us with enthusiasm throughout the project from its inception and inspired us to combine experimental with theoretical work. Also to George Gerpheide and David Kreigman who shared our work in building Version I of the *CONDOR* system. To David Taylor, who contributed the signal handling code and the debugging system built on top of the message passing system and to Steve Drucker who did some of the user-interface code and has always been willing to share our work.

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This section, describes utility programs that have been developed to aid in the development of real-time programs. Some of these programs are essential utilities, while others are programs which could be substituted or replaced with better tools.

There are a number of programs in addition to those that are documented here. Most of these are meant for diagnostic purposes and are fairly easy to use. Others, meant for controlling the hand will be described in a later document.

In addition to these programs are those that are available along with the standard C compiler supplied by sun, to work on object files. These include programs like `ranlib`, `nm`, `size`, `file`. Documentation on programs like these can be obtained from Sun Microsystems.

5.1 CONF

conf show the configuration of a system

Conf is a program that can be used to verify a *CONDOR* system that has been set up for running. Currently, this program knows to check for the presence of the various *CONDOR* processors and to test if the HVE bus to bus adaptor has been configured correctly. This program runs on the suns. The program can be extended to verify the state of other hardware devices in the system as well.

This program derives most of its information from the configuration information found in the `conf.c` file.

5.2 DL68

dl68 downloader to the local hand and arm microprocessors.

OPTIONS: [-p processor -n -d -sd serialline] filenames
DESCRIPTION

DL68 is a downloader for the Microbar 68020 boards using the VME-VME connection or a serial device.

The -d switch specifies a dma device and the -s switch can be used to specify a serial line.

The options are:

- *-p processor-list* specifies on what processors the given file is to be loaded. Processor-list is a string of ascii-characters that indicate the numbers of the processors onto which the given object file is to be loaded. This switch makes the program download to a vmebus address. Since the address mapping for each processor is different as seen across the VME-Bus, the program adds the appropriate offset so that the object file is loaded into the different processors at the correct locations. This switch must be used always while downloading across the bus to bus adaptor.

  eg: *dl68 -p 01234 servo.68*
  will load onto processors 0 through 4 the object file servo.68.

  Note that an address offset will be added if you use this option to specify a processor number. To prevent any address offset from being added (this may be required if you are downloading via a serial line, for example) use *-p* , i.e. a minus sign to indicate the absence of a processor number.

- *-n* tells the program to go about its job quietly. The printouts that appear by default are suppressed.

- *-s serial-tty-line* specifies the line (eg. /dev/tty00) that you will be using.

- *-sd serial-line* specifies the serial line to use for the downloading. (This switch is the default to be used for the "ironics". It stands essentially for `-s serial-line -x ''ironics''`.

- *-d dma-link* specifies the dma link (eg. /dev/dr0) to use while downloading. This is only to be used on the VAX.

- *-D* a debug switch that enables printing of the sizes of the various segments got from the header of the file to be downloaded.

- *-S* This switch has to be used to download files compiled with the -r option. This enables downloading of the symbol table, so that the debugger can use it.

- *-m hexaddress* Specifies the offset address in the specified processor's memory where the program will be loaded.
- *-x machine* where machine is one of "motorola" or "ironics". This option is for the fast blast protocol downloading instead of the usual S-record format over a serial line.

FILES

- `/usr/projects/condor/cmd/dl68.c`
- `/usr/projects/condor/cmd/dl68utils.c`
- `/usr/projects/bin/dl68`

5.3 ICC

ICC - compile and link top level program for the *CONDOR* .

OPTIONS: [-L libpath -M machine] filenames
DESCRIPTION

This program essentially forms the top level driver loop for the compile and linkedit phases for programs written for the *CONDOR* real time system. It should normally be configured for a site. Once configured, the `icc` command can be used just like the `cc` command, since basically the program invokes `cc` and `ld` with the appropriate arguments passed to it.

The options that the program understands are:

- *-M machine* – where machine can be one of "microbar" or "ironics". By convention the libraries for these different machines are stored in the files `libc-ironics.a` and `libc-microbar.a`. This option enables the program to search the correct library.
- *-L libpath* – This option provides a way of maintaining multiple versions of the system at the same time. Since the version of the system that is currently under development may differ from the working version, one can keep the library files of different versions in different directories. Using this switch the libpath option can be used to specify the prefix string that is to be taken as the root of the directories where the libraries and crt0.o files are found.

5.4 BURN68

BURN68 - program to burn boot proms.

OPTIONS: [-owprfniblPB] filename
DESCRIPTION

BURN68 is a program used to burn the boot proms for the *CONDOR* system. It understands a variety of options, which are outlined below. The program is written to send data over the serial line connected to the DATA I/O Universal System programmer. The input file given to the program can be a .68 file as produced by ld68 or an IMAGE format file.

The options that the program understands are:

- *-b* Turn on debugging. (prints out a lot of diagnostic messages).
- *-o "offset"* Default is 0.
- *-w "num"* specifies how many bytes wide the proms are. "num" defaults to 2.
- *-p "device"* Sets the serial line device over which the data is to be sent to "device".
- *-r "rate"* Sets the device's baud rate to "rate".
- *-f "family-pinout code"* Sets the family and pin out codes for the Unipak.
- *-n* If the unipak is not in place.
- *-i* Treats the input file as an IMAGE file, instead of a .68 file.
- *-l* For producing only a listing.
- *-P "num"* Prom number to start burning at.
- *-B "num"* Byte offset to start burning at.

The family and pinout codes are:

- 27128 - family code: 79 and pinout code: 51.
- 2764 - family code: 35 and pinout code: 33.

To use the burner, start up the program, and then press

SEL F1 START

on the programmer. The programmer should display just a bunch of horizontal lines at this stage. Once this has been done, burning of the proms can begin, as per instructions given by the program.

5.5 RAW

raw - raw connection to the *CONDOR* system.

OPTIONS: ttyline
DESCRIPTION

The RAW program takes one argument, a terminal line device, and connects up in raw mode to that serial line. This program can be used for example to directly connect up to one of the *CONDOR* processors, by taking a serial line and connecting it to *Port B* of the Ironics system controller board's serial io connection.

Once the connection has been made, whatever is typed at the keboard is sent down the serial line, and whatever is output over the serial line is sent to your terminal. RAW does this by using two processes, one a reader and the other a writer. Typing ~ at the reader will make it prompt you for quitting the connection. At this stage, if one types q the connection is closed and the two processes are terminated.

Raw traps control-c and control-z, as well.

5.6 MRAW

mraw - connection to the *CONDOR* system over the memory mapped connection

OPTIONS: [-d] [-n] [-e] processor [address]
DESCRIPTION

The MRAW program takes two arguments, the second of which is optional and defaults to 0x10000 if unspecified. The first argument specifies a processor number to connect up to. This program starts execution at the specified address on the processor and then connects up to it, using the memory mapped connection. This is intended to provide much the same functionality as is provided by the `raw` program over the serial line.

The program presently understands the following switches:

- *-d* This sets the debugging switch to be on. This means that the program will try to begin execution not at the default address of 0x10000 but at address 0x10002. Starting execution at this address starts up and initializes the program but stops just before execution begins at `main`. This enables one to then start up a debugger like `gdb` and `attach` to the processor in order to debug it.
- *-n* This option disables the starting of the program. This option is needed so that users can terminate a session with `mraw` and restart it to connect to a previously running program on one of the *CONDOR* processors.
- *-e* If this option is specified then the program will cause any currently executing program on the *CONDOR* microprocessor to exit, before beginning execution again. This may be used to exit out of an errant program and restart it.

This program allows different users to be using the different microprocessors at the same time, which may be necessary if more than one person is involved in doing develepment at the same time.

There are a number of window system based programs as well that can be used along with the system. Since most of these use a programmatic user interface and the command parser interface, they are pretty much self-documenting. (To find out about the capabilities of the programs, just execute them, and type 'help' at the command window that pops up).

5.7 CONDOR

OPTIONS: [-t display]
DESCRIPTION

CONDOR - default top level user interface program.

This program forms the top level user interface to interact with the microprocessors. It has menus to do the most often performed tasks like downloading, executing programs, debugging etc.

The `-t` option to the condor program specifies that it use a tiled form of window management. This means that the program will open up windows to the individual microprocessors all of which will be visible at once on the screen.

The program uses the X window system. Hence, setting the environment variable `DISPLAY` or specifying the second argument of the form `machine:0` will cause the program to run with its windows being popped up on the host specified by `machine`. For this to work correctly, the user must use the `xhost` command to allow the program access to the X server from the host on which the `condor` program will be running.

This program opens up a slave pty window for every processor in the system and provides a command window running on the Sun. From this command window, users can download programs into the slave processors, start execution, run other programs on the Sun that are designed to communicate with the slave processors and perform a number of other functions. Menu accelerators are provided for the commands that are used most often. There is also a command to execute other commands out of a file to save time spent in repeated typing.

5.8 XPLOT

XPLOT - plotting package for the system.

The plotting package is meant more for looking at collected data sets (over different trial runs for example), than for plotting functions. Data can be plotted from files that contain data in ascii, plot or raw binary form. The plotting package currently supports two modes. The first allows the user to look at just about any form of collected data. The second

however is specialized for examining control variables collected over a run while the hand is operating.

This section is intended only for those that intend adding a new hardware device to the *CONDOR* system. Hardware devices addressed by this section include

(a) Analog-to-digital and Digital-to-analog converter boards.

(b) Serial I/O boards.

(c) Parallel I/O boards.

In short, device drivers can be written for any piece of hardware that requires initialization, involves interaction with onboard device registers and may involve transfer of data to and from the device.

We do not intend for this mechanism to be used for devices that require extremely complicated control. (There is no equivalent of the standard Unix `strategy` routine). In particular, the mechanisms provided may not be enough for devices like ethernet or disk controllers.

The *CONDOR* system's device mechanisms have been designed to be extremely fast and portable. The functions that these mechanisms provide are as follows:

1. Provide for automatic device initialization.
2. Provide capabilities to handle interrupting devices.
3. Provide capabilities to handle shared interrupt vectors.
4. Provide standard calls like open, `read` and `write`, where appropriate.
5. Provide extensibility to handle devices that may require more than the standard capabilities to be controlled.

A.1 Configuration parameters

The first step in adding a new hardware device to the system is to decide where its device registers are to be located on the VME bus. The VME bus has different address spaces, and depending on the capability of the particular board you are trying to configure into the

system this space may vary. We have tried to keep all our devices restricted to the A24D32 or A16D16 spaces.

The include file `../condor/libc/ironics/vmebus.h` contains definitions for all devices present in the system. You can scan this file to determine where your new device should be placed. A define for the starting address of the device should then be added to this file.

Once you have decided where to place the hardware device you must configure it so that it responds correctly – this usually involves changing jumpers on the board, and can be done after consulting its documentation usually supplied along with the device by the board's manufacturer.

Configuration may also involve choosing a hardware vector and an interrupting level. Since the IRONICS board uses level 2 and since the VME-VME adaptor maps level 1 interrupts across the bus to the SUN (for use by the message passing system), these levels should not be used. Choosing any other level (from 3 to 7) is acceptable. Note that you can have more than one device interrupting on the same level. However, only one processor can respond to one VME bus interrupt level. This limitation is neccessitated by the VME bus handshaking interrupt protocol. The processor that responds to an interrupt level must inform the interrupting device that it received the interrupt. Thus, only one processor can respond to one interrupt level. Choosing an interrupt vector is somewhat more involved and is explained below (Many devices have a register where you can write this information, and hence this may not involve making jumper changes to the board).

Once you have configured the board, according to the manufacturer's documentation, plug it into the slave end of the VME bus. To verify that your configuration is correct, you can use the standard IMON commands to see if the addresses where the board is supposed to respond are valid. (Please see the "Imon - User Guide" available from IRONICS, for information on how to do this).

We recommend that if the device can be tested at this level, that is if you can write values into the registers and observe the effects of your actions, you should certainly do so. Playing with the device at the lowest level will familiarize you with its quirks and save you much time later on when writing the higher levels of software.

Once you are reasonably certain that the device works and is indeed responding to addresses which it ought to be responding to, you are ready to write its device driver.

A.2 The devsw structure and the devtab table

The way device drivers work in the system is extremely simple conceptually. There is a table called `devtab` which is essentially an array of `devsw` structures each of which pertains to a particular kind of hardware device in the system. In addition to hardware devices certain software devices are also present in this table, which require the standard Unix

device operations. (You can take a look at the file `conf.c` to see an example of the table and the individual entries in it).

This table essentially maps device independent calls (like open()) etc., to device specific open() routines.

The devsw entry for a particular device looks as follows

```
struct devsw {
    char *dvname;              /* name of the device */
    int (*dvopen)();           /* open routine */
    int (*dvclose)();          /* close */
    int (*dvread)();           /* read */
    int (*dvwrite)();          /* write */
    int (*dvcntl)();           /* ioctl */
    int (*dvinit)();           /* init - probe */
    int (*dvputc)();           /* put a char */
    int (*dvgetc)();           /* get a char */
    int (*dvseek)();           /* seek */
    int (*dviint)();           /* input interrupt routine */
    int (*dvoint)();           /* output interrupt routine */
    char *dvdata;              /* device specific data */
    char *dvbuf;               /* device's buffer */
    int dvno;                  /* device's no */
    int *dvcsrs;               /* device csr array */
    int *dvvectors;            /* device's vector array */
};
```

The structure should be fairly straightforward to understand. The manner in which the individual fields are used is explained later in this document.

Every device must provide support for the following two routines which are absolutely essential to the system:

1. `init` – There must be a device specific `init` routine present for every device. This may be an empty routine for some devices, but it must be present nevertheless. This is a requirement, because the system calls every device's init routine automatically upon startup.
2. open – This routine also must be present for every device in the system. If it is not, an open() call performed with that device name will fail.

Aside from these routines, all others are optional. In many cases, as will be discussed below, device specific routines that do not get mapped by the `devsw` are used. A unmapped device

specific routine has two advantages. The first is that it has slightly lower overhead, since the extra address indirection that the device switch adds is not present. Second, the procedure arguments for the general devsw supported routines are not flexible enough for all device operations.

A.3 Explanation of the internals

In what follows we provide an explanation of what a user needs to do to add a new device into the system.

Convention note:

> *We have thus far assumed that every device is given a unique name, and the device specific routines for a device will be found in a file with that same name (i.e routines for the* `mpp` *device will be found in the file* `mpp.c`*). The device specific routines are also named by concatenating the routine name to the device name. For example, the device specific init routine for the* `mpp` *device is* `mpp_init` *and the device specific open routine for the* `mpp` *device is* `mpp_open`*. In the discussion below, we refer to the device specific routine as* `device_routine` *where* `device` *is to be replaced by the device's name (such as* `mpp`*) and* `routine` *is replaced with the device specific routine's name.*

A.3.1 Init routine

The `init` routine is the first routine that the user should write when adding a new device into the system. The `init` routine is called by the system at initialization time (that is, before the `main()` routine is first invoked). It allows the system to initialize the hardware, and perhaps to count the number of such devices that are found in the system.

Each device may require device specific data to be maintained internally in a device specific data structure. There may only be one such data structure for all such devices in the system, or there may be one such data structure for every such device (or every board) in the system. If there is to be one device specific data structure for each device, the `init` routine can `malloc()` the storage for it. Alternatively, if a device specific data structure is required for each opened instance of the device, the device specific open routine would be the proper place to allocate this data structure.

The device specific init routines is defined as follows:

device_init(*ptr, csr*) *Function*
struct devsw *ptr;
unsigned int *csr;

The init routine will be automatically invoked for every device in the system with the above two arguments. The first argument is a pointer to the devsw structure that corresponds to that device, while the second of the arguments is a pointer to an integer array that contains the control register addresses for the different instances of that device in the system. This second argument is essentially the devswentry->dvcsrs field. In making up the conf.c table entry, if you have more than once instance of a device to be configured into the system, make sure that the dvcsrs field points to an integer array that contains an entry for every such instance.

For an example, let's examine the device initialization routine for the an analog to digital converter board:

```
adc_init(ptr, csr)
struct devsw *ptr;
u_int *csr;
{
    struct adc *adc;
    int boards;
    int i;

    /* first find out how many devices we have */
    for (boards = 0; csr[boards] != 0; boards++) ;

    /* malloc storage for the data */
    if ((ptr->dvdata = (char *)
        malloc(sizeof (struct adc) * boards)) == 0)
      return (-1);
    max_adc_boards = boards;

    /* probe to see which boards really exist */
    for (i = 0; i < boards; i++) {
        adc = &((struct adc *)(ptr->dvdata))[i];
        if (memory_peekc(csr[i]) == 0) {
            /* board is responding */

            adc->adc_port = (struct adc_port *)csr[i];
            adc->adc_gain = 0;
        } else {
            /* board not found */
```

```
            adc->adc_port = 0;
        }
    }
}
```

The first function this routine does is to count the number of boards that are configured into the system in `conf.c`. Next, the routine `malloc()`'s storage for the device specific data structures, and sets a local static variable that tell's the driver the size of the structure. Finally, the routine actually probes at each configured board's csr to determine if the board is actually present in the system. If the board is found, it's address is added to the device specific data structure. The device specific open routine checks to see if this address if found before it allows the board to be opened, preventing a program from trying to access non-existent hardware.

A.3.2 Open routine

The device open routine is invoked each time the open call is made for that device. In many cases, the device specific open does not perform much work, and might do little more than reset the hardware into a known condition.

The device specific routine takes the following arguments:

device_open(*ptr, name, flags, mode, fd, data*) *Function*
*struct devsw *ptr;*
*char *name;*
int flags;
int mode;
int fd;
int data;

The routine is called with a pointer, *ptr*, to the *devsw* entry for the particular device being opened, the character string *name* used for the name of the device, the *flags* field used in the initial open call, the *mode* field used in the initial open call, the *fd* that was allocated by the system for that particular invocation of open, and a *data* argument that was defined by the device name to device switch mapping table. These arguments will be described in more detail below.

To better understand how the open routine is invoked let's trace the chain of routines between an actual call to open and the ultimate invocation of the device specific open routine. A typical call to open could be `open(''mpp'', flags, mode)`. The first argument

is the logical device name. All devices are named beginning with a ":" to help distinguish them from filenames. Any filename that is opened that does not contain the leading ":" is assumed to be a file, and the open call is passed on to the *CONDOR* fileserver for proper handling. The next two arguments, *flags*, and *mode*, are passed directly to the device specific open routine, as described above.

When the system open call is made, a file descriptor, *fd*, is allocated. The *fd* is returned by open, and is used to access all the data structures that are associated with the device. Next, the system sets up a mapping from the allocated *fd* to the actual device specific routines. This mapping is used to get pointers to the actual device routines needed for subsequent operations. In addition, the mapping allows a routine to get device specific data directly from an *fd*.

Next, open calls a device setup routine. This routine is used to map the devices interrupt vectors to its interrupt handlers. The general idea is this: When an interrupt occurs, the *CONDOR* system only knows the vector that generated that interrupt. Given that vector, a particular device specific interrupt handler must be invoked. In addition, the device specific interrupt handler must be passed the proper data structures that were allocated by the device open call. Finally, it should be possible to overload interrupt vectors. That is, two different devices may generate the same vector, and polling must be used to determine that actual device that was requesting services.

The device setup routine maps vector numbers to *fd's*. When an interrupt vector is trapped by the system, all the device specific interrupt routines that correspond to that vector are invoked, and the interrupt routines are passed the *fd's* that could possibly correspond to the devices requesting service. In general, all the device driver programmer needs to know about this mechanism is that in the vectors that the device generates must be listed in the devsw entry for the device.

Finally, the system open routine invokes the device specific routine, passing in the arguments as listed above. Often, the *flags* field in the system open call are used to specify the board number of the device being opened. Thus, the device specific open routine should check to make sure the board being opened actually exists. In addition, the device specific open routine often calls the `setdevdata` routine. This routine maps a device specific data structure (often there is one device specific data structure per physical hardware device, but sometimes there is one structure per open invocation of that device) the *fd*. The corresponding routine `getdevdata` is used to get back the device specific data struture from an *fd*.

For a simple example, let's examine the open routine for the analog to digital converter device:

```
adc_open(ptr, name, board, mode, fd, data)
struct devsw *ptr;
char *name;
```

```
int board;
int mode;
int fd;
int data;
{
    register struct adc *adc;
    register struct adc_port *port;

    /* if we are trying to open a existent board, reject */
    if (board >= max_adc_boards)
      return (-1);

    /* get a point to the board's device specific data structure */
    adc = &((struct adc *)(ptr->dvdata))[board];
    port = adc->adc_port;

    /* if the board didn't respond during init, reject */
    if (adc->adc_port == 0)
      return (-1);

    /* map the device specific data to allocated fd for open call */
    setdevdata(fd, (char *)(adc));
    return (0);
}
```

In this example, the device specific data structure has already been allocated by the device's init routine. All this routine does is insure that the device being opened is actually present and responding, and then it maps the device specific data to the system allocated `fd`. If it was desired for this device to be exclusive open, a flag in the device specific data would be checked in open, and if it indicated the device was not already in use, the open would be allowed.

A.3.3 Close routine

The device close routine is defined as follows:

device_close(*fd*) *Function*
int fd;

The device close routine is called by the system close routine. Often this routine does

nothing more than NULL out the device specific data field by calling `setdevdata(fd, 0)`, where the *fd* is passed in by `close`.

The system close routine deallocated the associated fd, and informs the system interrupt handler routines that the device is no longer open. For an exclusive open device, the close routine should set a flag in the device specific data structure that would allow other devices to perform an open.

Here is the close routine for the analog to digital converter device:

```
adc_close(fd)
int fd;
{
    /* un-map the device specific data from the fd */
    setdevdata(fd, 0);
}
```

If this were an exclusive open device, close should reset the device open flag in the device's specific data.

A.3.4 Other standard routines

The routines `read`, `write`, `lseek`, and tt ioctl are all supported by the basic device system. The routines are defined as follows:

device_read(*ptr, buf, count, fd*) *Function*

```
struct devsw *ptr;
char *buf;
int count;
int fd;
```

device_write(*ptr, buf, count, fd*) *Function*

```
struct devsw *ptr;
char *buf;
int count;
int fd;
```

device_lseek(*ptr, count, whence, fd*) *Function*
*struct devsw *ptr;*
long count;
int whence;
int fd;

device_ioctl(*ptr, code, arg, fd*) *Function*
*struct devsw *ptr;*
int code;
*int *arg;*
int fd;

In the above example, the value of *ptr* is the address of the device switch entry for the associated device. The variable *fd* is the file descriptor. Often, *fd* is used in a call to `getdevdata(fd)` to extract the device specific data.

A.3.5 Support for non-standard routines

Routines such as `read` and `write` are mapped to device specific read and write routines by the device switch. In some cases however, there is a need to perform operations on devices that do not fit into the framework of the standard system calls. In Unix, `ioctl` calls would be made to handle these situations. The *CONDOR* device switch also supports this convention, though in some cases it is not convenient to use.

Instead, it is possible to write a device specific operation routine that is called from a user program directly. These routines take an *fd*, but they take arguments in a more flexible manner.

For example, the analog to digital converter device driver has a command to set an output amplifier's gain. The follow code performs the operation:

```
adc_set_gain(fd, gain)
int fd;
int gain;
{
    /* get a pointer to the devices's specific data */
    register struct adc *adc = (struct adc *)getdevdata(fd);

    adc->adc_gain = gain;
}
```

This routine is called directly from a user program, and does not incur the overhead of an indirect call through the **devsw** table.

The device driver framework provided in the *CONDOR* system gives the users a certain level of abstraction from the actual hardware without added high overhead. Unlike higher level device drivers, these routines do little more than provide a uniform framework for accessing hardware.

In this section we detail the modifications that we have found necessary to make to the basic hardware as received from the different vendors. This section is NOT intended to be a complete manual on how to configure the various boards – the vendors' application notes and reference manuals are the best source for such information. This section is only intended to document differences and local changes that we have had to make in order to fix and in some cases augment the hardware so that it works correctly in our system.

Most of the configuration information is online and is described in the file `vmebus.h` in the directory `/usr/projects/include/vme`. This file is the final arbiter on all hardware address assignments and must be maintained uptodate. The interrupt vector and level assignments are somewhat more flexible and are described in the file `conf.h` in the same directory.

B.1 The Ironics boards

Almost no local modification of these boards ought to be necessary if the rev level of the board is greater than 1.3. The vmebus dual port addresses of the processors needs to be configured as follows:

```
Processor 0 - 0xb00000
Processor 1 - 0xc00000
Processor 2 - 0xd00000
Processor 3 - 0xe00000
Processor 4 - 0xf00000
Processor 5 - 0xa00000
```

The necessary information for configuring the boards to these addresses can both be found online and in the 3201 User's Manuals.

The processor I.D. of each board needs to be burned into a specific location in its boot prom monitor. This i.d. number needs to be burnt into the longword beginning at 0x7ffc of boot prom space, on the Ironics 27C256 proms. The family and pinout code for this prom is 45/32.

On the 3273 system controller besides the usual configuration jumpers we have found it necessary to lift pin 7 of u19 which disables the IRQ7 generated on RESET.,

B.2 The HVE Adaptor

On the hve-2000 and on the synergist-3 the default is to leave all interrupt levels connected between the sun host and the slave system. In our local configuration however, we have disabled all but one level of interrupt between the two systems. This can be done by cutting the traces under the jumpers provided for this purpose. Level 1 interrupts are the only ones that need to be connected through between the slave vme and the sun host. On the hve-2000 it is also necessary to disable the arbiter on the slave end of the vme and the system clock. This can also be done by cutting the appropriate traces provided for the purpose. (We are told that in future revisions of this board, this will be a jumper option, and will not necessitate cutting a trace).

Another change (which is a configuration option on the hve-2000) is to disable the sysreset line between the two systems. This is done so that a reset performed on the slave end (often necessitated owing to errant programs) does not reset the development host running Unix.

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