CS 332/532 Systems Programming

Lecture 24

Signals / 2

Parallel Computing

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Agenda

- Signals
- Signal Handling
- Parallel Processing/Computing
  - MPI
  - OpenMP

signal()

- signal - ANSI C signal handling
-
```
typedef void (*sighandler_t)(int);
```
- `sighandler_t signal(int signum, sighandler_t handler);`

- **signal**() sets the disposition of the signal *signum* to *handler*, which is either **SIG_IGN**, **SIG_DFL**, or the address of a programmer-defined function (a "signal handler").

Linux signal handling

- Perform the default action. Most signals have a default action associated with them, if the process does not change the default behavior then the default action specific to that particular signal will occur.
  - The predefined default signal is specified as SIG_DFL.
- Ignore the signal. If a signal is ignored, then the default action is performed.
  - The predefined ignore signal handler is specified as SIG_IGN.
- Catch and Handle the signal. It is also possible to override the default action and invoke a specific user-defined task when a signal is received.
  - This is usually performed by invoking a signal handler using signal() or sigaction() system calls.
- However, the signals SIGKILL and SIGSTOP cannot be caught, blocked, or ignored.

Default Action Of Signals

- Each signal has a default action, one of the following:
  - **Term:** The process will terminate.
    Core: The process will terminate and produce a core dump file.
    Ign: The process will ignore the signal.
    Stop: The process will stop.
    Cont: The process will continue from being stopped.
- Default action may be changed using handler function. Some signal's default action cannot be changed. **SIGKILL** and **SIGABRT** signal's default action cannot be changed or ignored
- https://linuxhint.com/signal_handlers_c_programming_language/

Basic Signal handler examples

```c
#include<stdio.h>
#include<signal.h>
#include<unistd.h>
void sig_handler(int signum){

  //Return type of the handler function should be void
  printf("\nInside handler function\n");
}

int main(){
  signal(SIGINT,sig_handler); // Register signal handler
  for(int i=1;;i++){    //Infinite loop
    printf("%d : Inside main function\n",i);
    sleep(1);  // Delay for 1 second
  }
  return 0;
}
```

```
tump@tump:~/Desktop/c_prog/signal$ gcc Example1.c -o Example1
tump@tump:~/Desktop/c_prog/signal$ ./Example1
1 : Inside main function
2 : Inside main function
^C
Inside handler function
3 : Inside main function
4 : Inside main function
^\Quit (core dumped)
tump@tump:~/Desktop/c_prog/signal$
```

```c
#include<stdio.h>
#include<unistd.h>
#include<signal.h>
int main(){
  signal(SIGINT,SIG_IGN); // Register signal handler for ignoring the signal

  for(int i=1;;i++){    //Infinite loop
    printf("%d : Inside main function\n",i);
    sleep(1);  // Delay for 1 second
  }
  return 0;
}
```

```
tump@tump:~/Desktop/c_prog/signal$ gcc Example2.c -o Example2
tump@tump:~/Desktop/c_prog/signal$ ./Example2
1 : Inside main function
2 : Inside main function
^C3 : Inside main function
4 : Inside main function
^C5 : Inside main function
^\Quit (core dumped)
tump@tump:~/Desktop/c_prog/signal$
```

```c
#include<stdio.h>
#include<unistd.h>
#include<signal.h>

void sig_handler(int signum){
  printf("\nInside handler function\n");
  signal(SIGINT,SIG_DFL);   // Re Register signal handler for default action
}

int main(){
  signal(SIGINT,sig_handler); // Register signal handler
  for(int i=1;;i++){    //Infinite loop
    printf("%d : Inside main function\n",i);
    sleep(1);  // Delay for 1 second
  }
  return 0;
}
```

```
tump@tump:~/Desktop/c_prog/signal$ gcc Example3.c -o Example3
tump@tump:~/Desktop/c_prog/signal$ ./Example3
1 : Inside main function
2 : Inside main function
3 : Inside main function
^C
Inside handler function
4 : Inside main function
^C
tump@tump:~/Desktop/c_prog/signal$
```

```c
#include<stdio.h>
#include <unistd.h>
#include <stdlib.h>
#include<signal.h>
void sig_handler_parent(int signum){
  printf("Parent : Received a response signal from child \n");
}

void sig_handler_child(int signum){
  printf("Child : Received a signal from parent \n");
  sleep(1);
  kill(getppid(),SIGUSR1);
}

int main(){
  pid_t pid;
  if((pid=fork())<0){
    printf("Fork Failed\n");
    exit(1);
  }
  /* Child Process */
  else if(pid==0){
    signal(SIGUSR1,sig_handler_child); // Register signal handler
    printf("Child: waiting for signal\n");
    pause();
  }
  /* Parent Process */
  else{
    signal(SIGUSR1,sig_handler_parent); // Register signal handler
    sleep(1);
    printf("Parent: sending signal to Child\n");
    kill(pid,SIGUSR1);
    printf("Parent: waiting for response\n");
    pause();
  }
  return 0;
}
```

```c
#include<stdio.h>
#include <unistd.h>
#include <stdlib.h>
#include<signal.h>
void sig_handler_parent(int signum){
  printf("Parent : Received a response signal from child \n");
}

void sig_handler_child(int signum){
  printf("Child : Received a signal from parent \n");
  sleep(1);
  kill(getppid(),SIGUSR1);
}

int main(){
  pi
  if
  }
  /*
  el
  }
  /*
  el
    signal(SIGUSR1,sig_handler_parent); // Register signal handler
    sleep(1);
    printf("Parent: sending signal to Child\n");
    kill(pid,SIGUSR1);
    printf("Parent: waiting for response\n");
    pause();
  }
  return 0;
}
```

```
tump@tump:~/Desktop/c_prog/signal$ gcc Example6.c -o Example6
tump@tump:~/Desktop/c_prog/signal$ ./Example6
Child: waiting for signal
Parent: sending signal to Child
Parent: waiting for response
Child : Received a signal from parent
Parent : Received a response signal from child
tump@tump:~/Desktop/c_prog/signal$
```

Exercise Sigint

- Till now we used the kill command and the keyboard to generate the signals.
- Now we will generate the signal in a program using the C API for *kill* or *raise* system call.
- In this example, we replace the SIGINT signal handler with our own and in the signal handler asks the user if the process should be terminated and then based on the response continue with either terminating the process or let it continue to run.
- We use read function instead of scanf to emphasize that scanf is not a reentrant function

sigint

```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <signal.h>

static void sig_int(int signo) {
    ssize_t n;
    char buf[2];

    signal(signo, SIG_IGN); /* ignore signal first */
    printf("Do you really want to do this: [Y/N]? ");
    fflush(stdout);
    n = read(STDIN_FILENO, buf, 2);
    if ( buf[0] == 'Y' ) {
        raise(SIGTERM); // or kill(0, SIGTERM); // or exit (-1);
    } else {
        printf("Ignoring signal, be careful next time!\n");
        fflush(stdout);
    }
    signal(signo, sig_int); /* reinstall the signal handler */
}
```

```c
int main(void) {
    if (signal(SIGINT, sig_int) == SIG_ERR) {
        printf("Unable to catch SIGINT\n");
        exit(-1);
    }
    for ( ; ; )
        pause();

    return 0;
}

```

```
(base) mahmutunan@MacBook-Pro lecture23 % gcc -Wall sigint.c -o sigint
(base) mahmutunan@MacBook-Pro lecture23 % ./sigint
^CDo you really want to do this: [Y/N]? N
Ignoring signal, be careful next time!
^CDo you really want to do this: [Y/N]?
Ignoring signal, be careful next time!
^CDo you really want to do this: [Y/N]? Y
zsh: terminated  ./sigint
(base) mahmutunan@MacBook-Pro lecture23 %
```

recall -forkexecvp.c

```c
int main(int argc, char **argv) {
    pid_t pid;
    int status;

    if (argc < 2) {
        printf("Usage: %s <command> [args]\n", argv[0]);
        exit(-1);
    }

    pid = fork();
    if (pid == 0) { /* this is child process */
        execvp(argv[1], &argv[1]);
        printf("If you see this statement then execl failed ;-(\n");
    perror("execvp");
    exit(-1);
    } else if (pid > 0) { /* this is the parent process */
        printf("Wait for the child process to terminate\n");
        wait(&status); /* wait for the child process to terminate */
        if (WIFEXITED(status)) { /* child process terminated normally */
            printf("Child process exited with status = %d\n", WEXITSTATUS(status));
        } else { /* child process did not terminate normally */
            printf("Child process did not terminate normally!\n");
            /* look at the man page for wait (man 2 wait) to determine
               how the child process was terminated */
        }
    } else { /* we have an error */
        perror("fork"); /* use perror to print the system error message */
        exit(EXIT_FAILURE);
    }

    printf("[%ld]: Exiting program .....\n", (long)getpid());

    return 0;
}
```

- Let us now consider how signals impact child processes created using fork/exec. We will be running a c program that consist of fork and execvp system calls (hw1.c)
- This code illustrates the use of dynamic memory allocation to create contiguous 2D-matrices and use traditional array indexing. It also illustrate the use of gettime to measure wall clock time.

```
$ ./a.out /home/UAB/puri/CS332/shared/hw1 1000
Wait for the child process to terminate
^C
$ ps -u
USER       PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
puri     19202  0.3  0.1 125440  3912 pts/0    Ss   10:05   0:00 -bash
puri     19320  0.0  0.0 161588  1868 pts/0    R+   10:06   0:00 ps -u
$
```

```
$ ./a.out /home/UAB/puri/CS332/shared/hw1 1000
Wait for the child process to terminate
^Z
[1]+  Stopped                 ./a.out /home/UAB/puri/CS332/shared/hw1 1000
$
$ jobs
[1]+  Stopped                 ./a.out /home/UAB/puri/CS332/shared/hw1 1000
$ ps -u
USER       PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
puri     19202  0.1  0.1 125440  3912 pts/0    Ss   10:05   0:00 -bash
puri     19351  0.0  0.0   4220   352 pts/0    T    10:08   0:00 ./a.out /home/U
puri     19352 29.0  0.6  27800 23844 pts/0    T    10:08   0:01 /home/UAB/puri/
puri     19353  0.0  0.0 161588  1864 pts/0    R+   10:08   0:00 ps -u
$ kill -CONT 19352
$
$ ps -u
USER       PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
puri     19202  0.0  0.1 125440  3912 pts/0    Ss   10:05   0:00 -bash
puri     19351  0.0  0.0   4220   352 pts/0    T    10:08   0:00 ./a.out /home/U
puri     19352 17.9  0.6  27800 23844 pts/0    R    10:08   0:04 /home/UAB/puri/
puri     19355  0.0  0.0 161588  1872 pts/0    R+   10:08   0:00 ps -u
$ Time taken for size 1000 = 32.274239 seconds
$ jobs
[1]+  Stopped                 ./a.out /home/UAB/puri/CS332/shared/hw1 1000
$ kill -CONT 19351
$ Child process exited with status = 0
[19351]: Exiting program .....
[1]+  Done                    ./a.out /home/UAB/puri/CS332/shared/hw1 1000
$ jobs
$
```

signal(7) — Linux manual page

- A process can change the disposition of a signal using

  sigaction () or signal().

- Sending a signal
  - raise()
  - kill()
  - pidfd_send_signal()
  - killpg()
  - pthread_kill()
  - tgkill()
  - sigqueue()

Parallel Processing (computing)

- A serial process is simply a process that is run entirely by one core of one processor.
- A parallel process is a process that is divided among multiple cores in a processor or set of processors. Each sub process can have its own set of memory as well as share memory with other processes.
- This is analogous to doing the puzzle with the help of friends. Because a supercomputer has a large network of nodes with many cores, we must implement parallelization strategies with our applications to fully utilize a supercomputing resource.

https://curc.readthedocs.io/en/latest/programming/parallel-programming-fundamentals.html

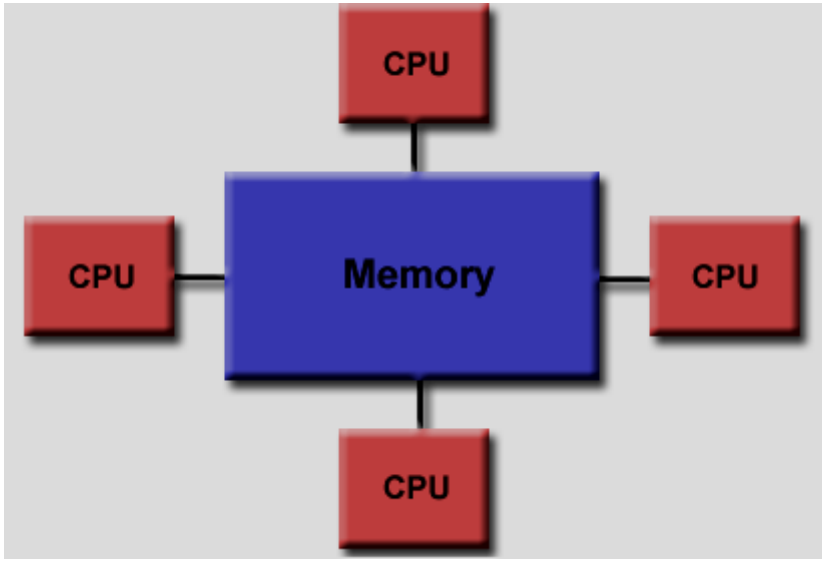
Parallel processing versus Parallel computing

- Parallel processing and parallel computing are very similar terms, but some differences are worth noting. Parallel processing, or parallelism, separates a runtime task into smaller parts to be performed independently and simultaneously using more than one processor. A computer network or computer with more than one processor is typically required to reassemble the data once the equations have been solved on multiple processors.
- While parallel processing and parallel computing are sometimes used interchangeably, parallel processing refers to the number of cores and CPUs running alongside a computer, while parallel computing refers to what the software does to facilitate the process.

https://www.ibm.com/think/topics/parallel-computing

Parallel computation

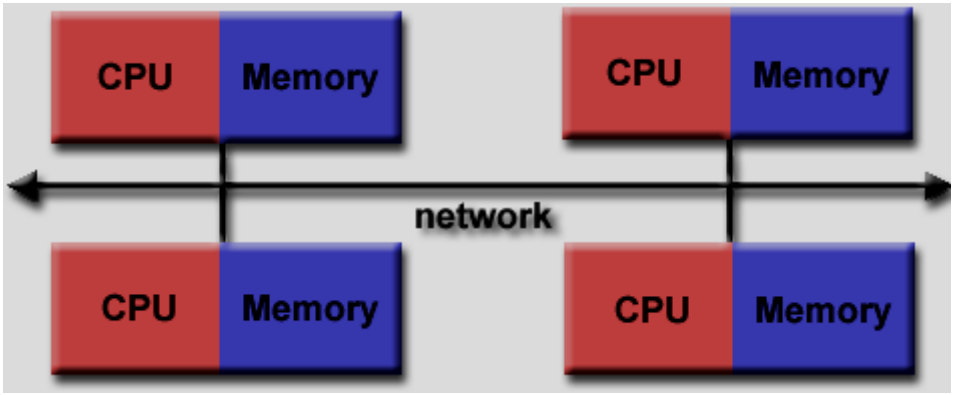
- Shared Memory Model:



https://curc.readthedocs.io/en/latest/programming/parallel-programming-fundamentals.html

Parallel computation

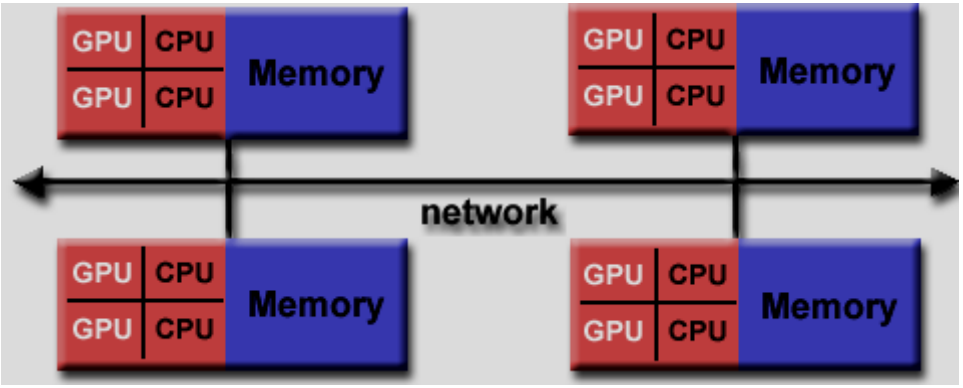
- Distributed Memory Model:



https://curc.readthedocs.io/en/latest/programming/parallel-programming-fundamentals.html

Parallel computation

- Distributed/Shared Model::



https://curc.readthedocs.io/en/latest/programming/parallel-programming-fundamentals.html

Tools for Parallel Programming

- OpenMP
- MPI

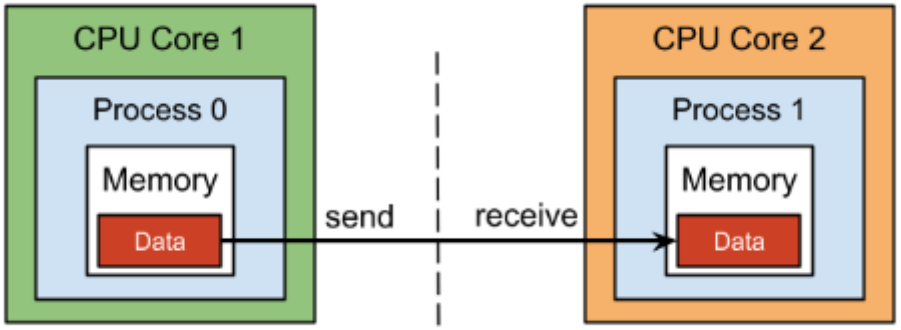
Message Passing Interface (MPI)

- It is a standardized and portable message-passing system to program parallel computers. in distributed-memory systems.
- It's a library of functions that programmers can call from C, C++, or Fortran code to write parallel programs. With MPI, an MPI communicator can be dynamically created and have multiple processes concurrently running on separate nodes of clusters
- Processes communicate with each other by passing messages to exchange data. Parallelism occurs when a program task gets partitioned into small chunks and distributes those chunks among the processes, in which such each process processes its part.

https://hpc.nmsu.edu/discovery/mpi/introduction/#:~:text=MPI%20Communication%20Methods,-MPI%20provides%20three&text=It%20involves%20the%20transfer%20of,Point%2Dto%2DPoint%20communication

MPI Communication Methods

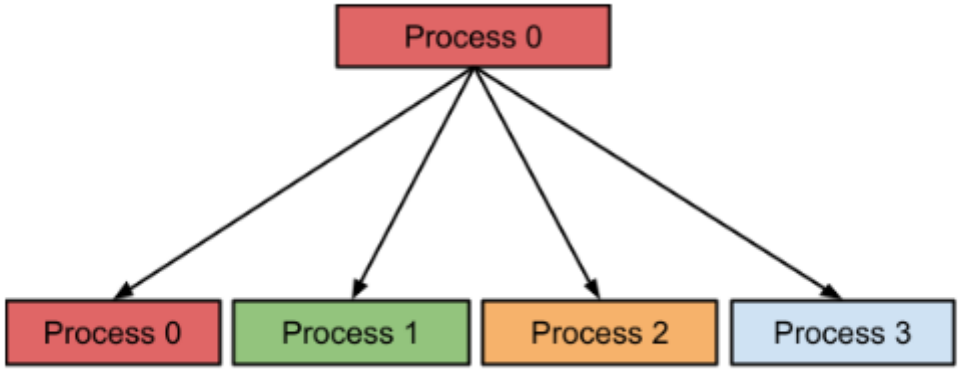
- Point-to-Point Communication



https://hpc.nmsu.edu/discovery/mpi/introduction/#:~:text=MPI%20Communication%20Methods,-MPI%20provides%20three&text=It%20involves%20the%20transfer%20of,Point%2Dto%2DPoint%20communication

MPI Communication Methods

- Collective Communication



https://hpc.nmsu.edu/discovery/mpi/introduction/#:~:text=MPI%20Communication%20Methods,-MPI%20provides%20three&text=It%20involves%20the%20transfer%20of,Point%2Dto%2DPoint%20communication

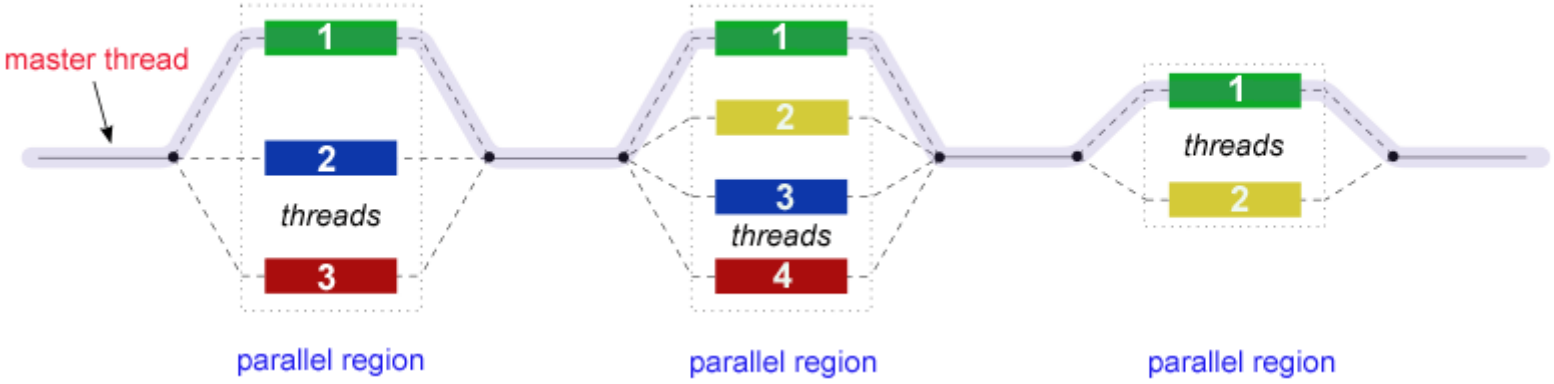
OpenMP

- OpenMP is an acronym for Open Multi-Processing
- An Application Programming Interface (API) for developing parallel programs in shared-memory architectures
- It may be used to explicitly direct multi-threaded, shared memory parallelism.
- It is supported in C, C++, and Fortran
- OpenMP provides a standard among a variety of shared memory architectures/platforms.
- It is based upon the existence of multiple threads in the shared memory programming paradigm

https://people.cs.rutgers.edu/~venugopa/parallel_summer2012/openMP.html

OpenMP Execution Model

- Thread Based Parallelism
- Explicit Parallelism
- Fork - Join Model



https://hpc-tutorials.llnl.gov/openmp/programming_model/

Goals of OpenMP

- **Standardization**:
  - Provide a standard among a variety of shared memory architectures/platforms
  - Jointly defined and endorsed by a group of major computer hardware and software vendors
- **Lean and Mean**:
  - Establish a simple and limited set of directives for programming shared memory machines.
  - Significant parallelism can be implemented by using just 3 or 4 directives.
  - This goal is becoming less meaningful with each new release, apparently.
- **Ease of Use**:
  - Provide capability to incrementally parallelize a serial program, unlike message-passing libraries which typically require an all or nothing approach
  - Provide the capability to implement both coarse-grain and fine-grain parallelism
- **Portability**:
  - The API is specified for C/C++ and Fortran
  - Public forum for API and membership
  - Most major platforms have been implemented including Unix/Linux platforms and Windows

https://hpc-tutorials.llnl.gov/openmp/introduction/