Concurrency

Kerrisk, Ch 29, 47, 48, 53, 54

Concurrency

- The two key concepts driving computer systems and applications are
  - communication: the conveying of information from one entity to another
  - concurrency: the sharing of resources in the same time frame
- Concurrency can exist in a single processor as well as in a multiprocessor system
- Managing concurrency is difficult, as execution behaviour is not always reproducible.

Concurrency Example

- Program a:

```
#!/usr/bin/sh
count=1
while [ $count -le 20 ]
do
   echo -n "a"
   count=`expr $count + 1`
done
```

- Program b

```
#!/usr/bin/sh
count=1
while [ $count -le 20 ]
do
   echo -n "b"
   count=`expr $count + 1`
done
```

- When run sequentially `(a; b)` output is sequential.
- When run concurrently `(a&; b&)` output is interspersed and different from run to run.

output different each time

Race conditions

- A race condition occurs when multiple processes are trying to do something with shared data and the final outcome depends on the order in which the processes run.
- E.g., If any code after a fork depends on whether the parent or child runs first.
- A parent process can call wait() to wait for termination (may block)
- A child process can wait for parent to terminate by polling (wasteful) (How would you do this?)
- One standard solution is to use signals.

Example 1

Process A

```
x = get(count)
write(x + 1)
```

Process B

```
y = get(count)
write(y + 1)
```

Count

1

`x = 1`

`write(2)`

2

`y = 2`

`write(3)`

3

The value of count is what we expect.

Example 2

Process A	Count	Process B
`x = get(count)` `write(x + 1)`		`y = get(count)` `write(y + 1)`
`x = 1` ←	1	→ `y = 1`
	2	← `write(2)`
		→ `y = 2`
	3	← `write(3)`
`write(2)` →	2	

Not what we wanted!

need atomic operation

Example: Race Conditions

Try running several instances of this

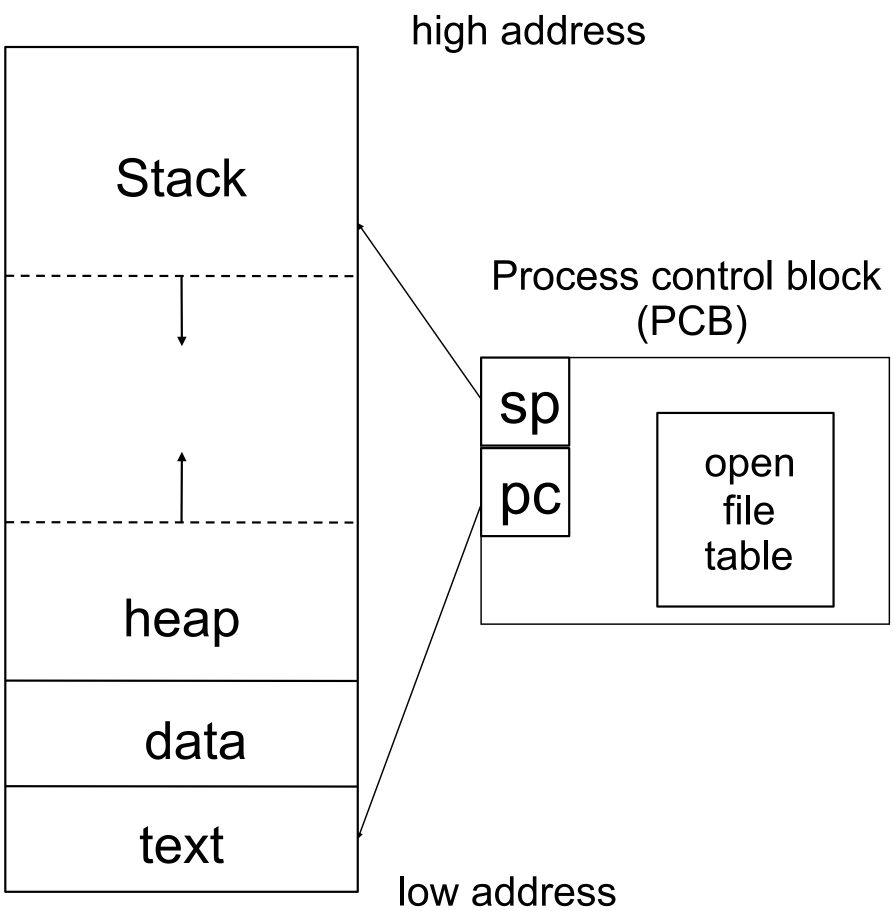
```
#!/bin/sh
c=1
while [ $c –le 10 ]
do
  sd=`cat sharedData`
  sd=`expr $sd + 1`
  echo $sd > sharedData
  c=`expr $c + 1`
  echo d = $sd
done
#file sharedData must exist and hold
#one integer
```

Threads

Motivation

- Processes are expensive to create.
- It takes quite a bit of time to switch between processes
- Communication between processes must be done through an external structure
  - files, pipes, shared memory
- Synchronizing between processes is cumbersome.
- *Is there another model that will solve these problems?*

Processes



- Each process has its own
  - program counter
  - stack
  - stack pointer
  - address space
- Processes may share
  - open files
  - pipes

What is a process?

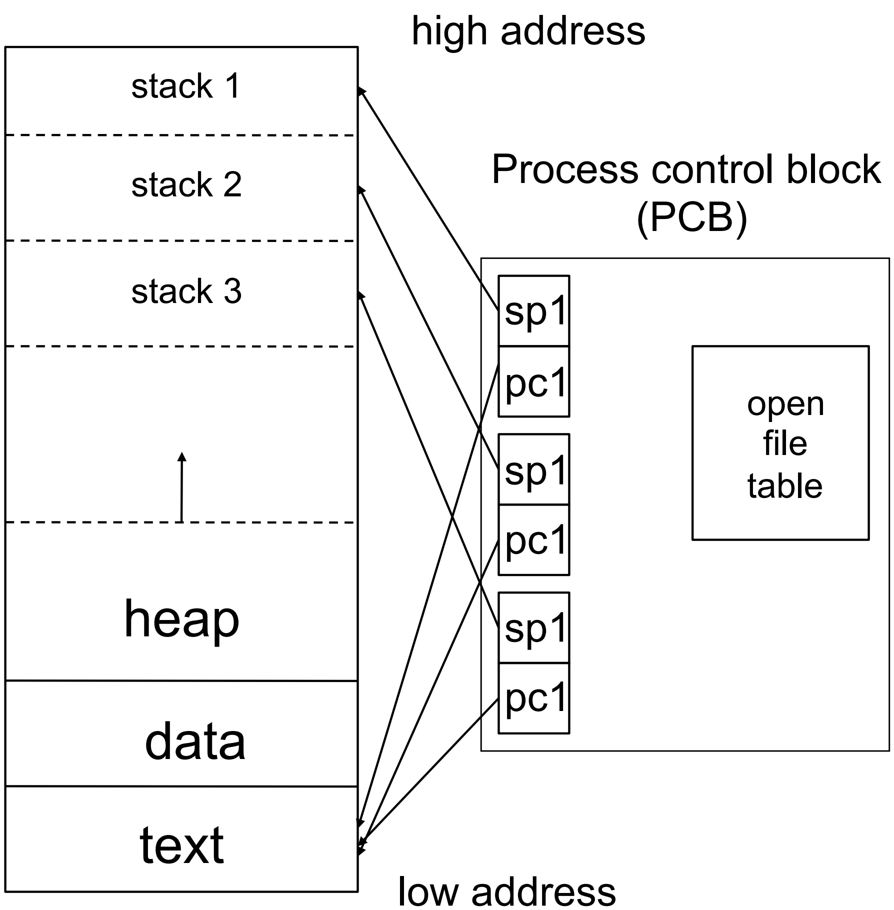
- OS abstraction for execution
- Running instance of a program

- Components of a process:
  - Address space
  - Code and data
  - Stack
  - Program Counter (PC)
  - Set of registers
  - Set of OS resources: open files, network connections…

Rethinking Processes

- What is similar in cooperating processes?
  - They all share the same code and data (address space)
  - They all share the same privileges
  - They all share the same resources (files, sockets, etc.)
- What don't they share?
  - Each has its own execution state: PC, SP, and registers
- Key idea: Why don't we separate the concept of a process from its execution state?
  - Process: address space, privileges, resources, etc.
  - Execution state: PC, SP, registers
- Exec state also called thread of control, or thread

Threads



- Each thread has its own
  - program counter
  - stack
  - stack pointer
- Threads share
  - address space
    - variables
    - code
  - open files

What is a Thread?

- A thread is a single control flow through a program
  - What is a “control flow”?
  - How is control flow represented?
- A program with multiple control flows is multithreaded

Control Flow

- Control includes all of the values that select which instructions in a program are executed.
- Control flow, then, is the sequence of instructions being executed.
- The hardware uses the program counter (PC) and stack to make control flow decisions.

Advantages

- Communication between threads is cheap
  - they can share variables!
- Threads are “lightweight”
  - faster to create
  - faster to switch between

Producer/Consumer Problem

- Simple example: `who | wc -l`
- Both the writing process (`who`) and the reading process (`wc`) of a pipeline execute concurrently.
- A pipe is usually implemented as an internal OS buffer.
- It is a resource that is concurrently accessed by the reader and the writer, so it must be managed carefully.

Producer/Consumer

- consumer should be blocked when buffer is empty
- producer should be blocked when buffer is full
- producer and consumer should run independently as far as buffer capacity and contents permit
- producer and consumer should never be updating the buffer at the same instant (otherwise data integrity cannot be guaranteed)
- producer/consumer is a harder problem if there are more than one consumer and/or more than one producer.

Pthreads

- POSIX threads (pthreads) is the most commonly used thread package on Unix/Linux

pthread_create

```
int pthread_create(pthread_t *tid,
         pthread_attr_t *attr,
         void *(*func)(void*), void *arg);
```

- `tid` uniquely identifies a thread within a process and is returned by the function
- `attr` sets attributes such as priority, initial stack size
  - can be specified as NULL to get defaults
- `func` - the function to call to start the thread
  - accepts one void *argument, returns void *
- `arg` is the argument to func
- returns 0 if successful, a positive error code if not
- does not set `errno` but returns compatible error codes
- can use `strerror()` to print error messages

pthread_join

```
int pthread_join(pthread_t tid,
                 void **status)
```

- `tid` - the tid of the thread to wait for
  - cannot wait for any thread (as in `wait()`)
- `status`, if not NULL returns the `void *` returned by the thread when it terminates.
- a thread can terminate by
  - returning from `func`
  - the `main()` function exiting
  - `pthread_exit()`

More functions

- `void pthread_exit(void *status)`
  - a second way to exit, returns `status` explicitly
  - `status` must not point to an object local to the thread, as these disappear when the thread terminates.
- `int pthread_detach(pthread_tid);`
  - if a thread is detached its termination cannot be tracked with `pthread_join()`
  - it becomes a daemon thread
- `pthread_t pthread_self(void)`
  - returns the thread ID of the thread which called it
  - often see `pthread_detach(pthread_self())`

Passing Arguments to Threads

```
pthread_t thread_ID;  int fd, result;
fd = open("afile", "r");
result = pthread_create(&thread_ID, NULL,
                myThreadFcn, (void *)&fd);
if(result != 0)
  printf("Error: %s\n", strerror(result));
```

- We can pass any variable (including a structure or array) to our thread function.
- It assumes the thread function knows what type it is.
- This example is **bad** if the main thread alters fd later.

Solution

- Use malloc() to create memory for the variable
  - initialize variable's value
  - pass pointer to new memory via pthread_create()
  - thread function releases memory when done.
- Example:

```
typedef struct myArg {
  int fd;
  char name[25];
} MyArg;

int result;
pthread_t thread_ID;
```

Example (cont'd)

```
MyArg *p = (MyArg *)malloc(sizeof(MyArg));
p->fd = fd;  /* assumes fd is defined */
strncpy(p->name, "CSC209", 7);
result = pthread_create(&threadID, NULL,
                  myThreadFcn, (void *)p);
void *myThreadFcn(void *p) {
   MyArg *theArg = (MyArg *) p;
   write(theArg->fd, theArg->name, 7);
   close(theArg->fd);
   free(theArg);
   return NULL;
```

Thread-safe functions

- Not all functions can be called from threads
  - many use global/static variables
  - new versions of UNIX have thread-safe replacements like strtok_r()
- Safe:
  - `ctime_r(), gmtime_r(), localtime_r(), rand_r(), strtok_r()`
- Not Safe:
  - `ctime(), gmtime(), localtime(), rand(), strtok(), gethostxxx()`
- Could use semaphores to protect access but will generally result in poor performance.

Pthread Mutexes

```
int pthread_mutex_init(pthread_mutex_t *mp,
      const pthread_mutexattr_t *attr);

int pthread_mutex_lock(pthread_mutex_t *mp);
int pthread_mutex_trylock(pthread_mutex_t *mp);
int pthread_mutex_unlock(pthread_mutex_t *mp);
int pthread_mutex_destroy(pthread_mutex_t *mp);
```

- easier to use than `semget()` and `semop()`
- only the thread that locks a mutex can unlock it
- mutexes often declared as globals

Example

```
pthread_mutex_t myMutex;
int status;

status = pthread_mutex_init(&myMutex, NULL);
if(status != 0)
   printf("Error: %s \n", strerror(status));
pthread_mutex_lock(&myMutex);
/* critical section here */
pthread_mutex_unlock(&myMutex);
status = pthread_mutex_destroy(&myMutex);
if(status != 0)
  printf("Error: %s\n", strerror(status));
```