Announcements

- Program #1
  - Is Friday at 6:00 PM

- Reading
  - Process Synchronization:
    - Chapter 6 (8^{th} Ed) or Chapter 7 (6^{th} Ed)

Cooperating Processes

- Often need to share information between processes
  - information: a shared file
  - computational speedup:
    - break the problem into several tasks that can be run on different processors
    - requires several processors to actually get speedup
  - modularity: separate processes for different functions
    - compiler driver, compiler, assembler, linker
  - convenience:
    - editing, printing, and compiling all at once

Interprocess Communication

- Communicating processes establish a link
  - can more than two processes use a link?
  - are links one way or two way?
  - how to establish a link
    - how do processes name other processes to talk to
      - use the process id (signals work this way)
      - use a name in the filesystem (UNIX domain sockets)
      - indirectly via mailboxes (a separate object)
- Use send/receive functions to communicate
  - send(dest, message)
  - receive(dest, message)

Producer-consumer pair

- producer creates data and sends it to the consumer
- consumer read the data and uses it
- examples: compiler and assembler can be used as a producer consumer pair
- Buffering
  - processes may not produce and consume items one by one
  - need a place to store produced items for the consumer
    - called a buffer
  - could be fixed size (bounded buffer) or unlimited (un-bounded buffer)

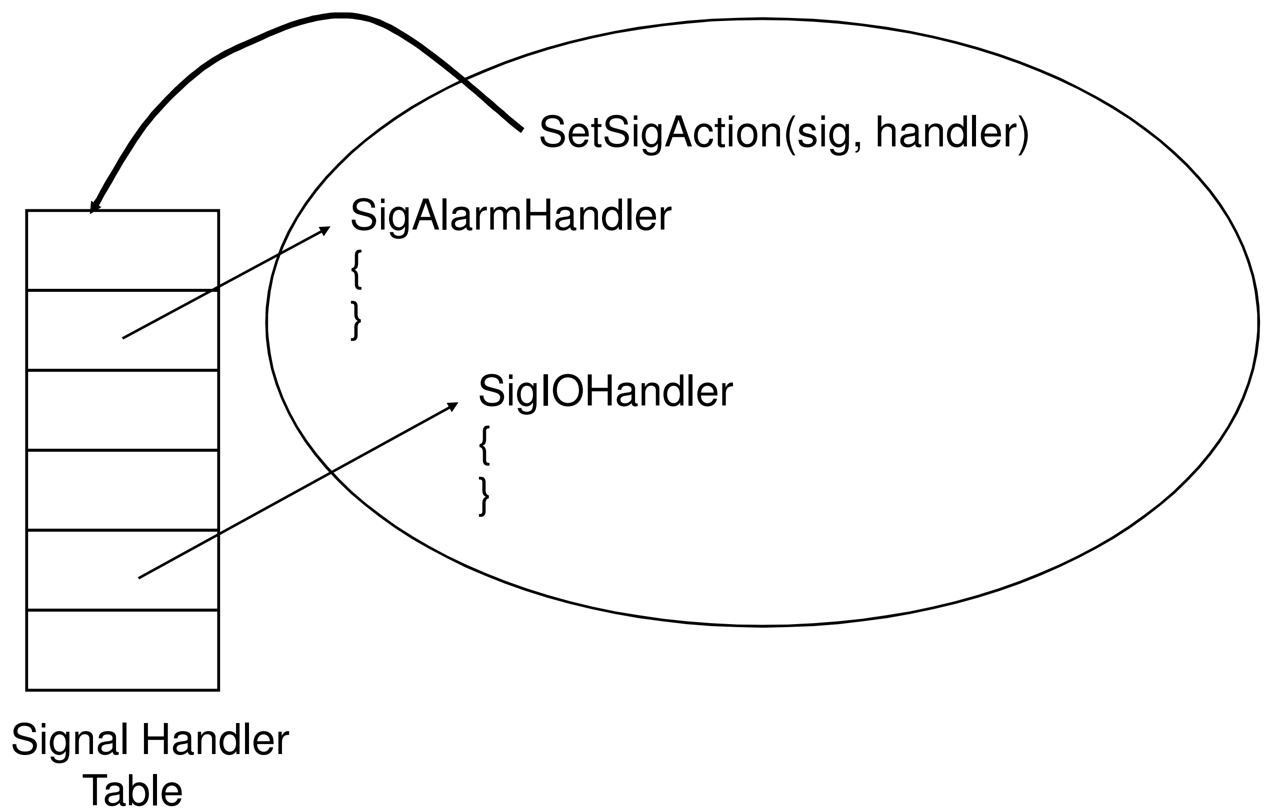
Message Passing

- What happens when a message is sent?
  - sender blocks waiting for receiver to receive
  - sender blocks until the message is on the wire
  - sender blocks until the OS has a copy of the message
  - sender blocks until the receiver responds to the message
    - sort of like a procedure call
    - could be expanded into a remote procedure call (RPC) system
- Error cases
  - a process terminates:
    - receiver could wait forever
    - sender could wait or continue (depending on semantics)
  - a message is lost in transit
    - who detects this? could be OS or the applications
- Special case: if 2 messages are buffered, drop the older one
  - useful for real-time info systems

Signals (UNIX)

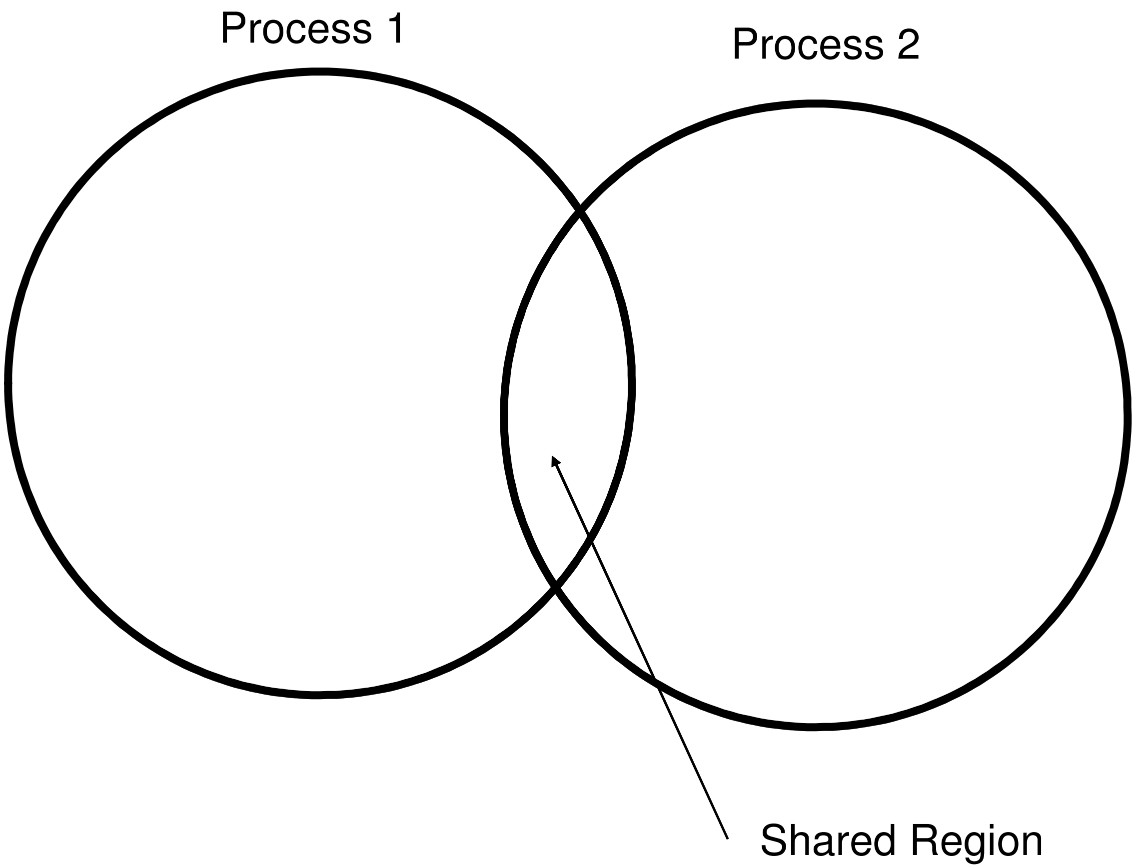
- provide a way to convey one bit of information between two processes (or OS and a process)
- types of signals:
  - change in the system: window size
  - time has elapsed: alarms
  - error events: segmentation fault
  - I/O events: data ready
- are like interrupts
  - a processes is stopped and a special handler function is called
- a fixed set of signals is normally available

Signals


SetSigAction(sig, handler)
SigAlarmHandler
{
}
SigIOHandler
{
}
Signal Handler
Table

Shared Memory

- Like Threads, but only part of memory shared
- Allows communication without needing kernel action
  - Kernel calls setup shared region



Producer-consumer: shared memory

- Consider the following code for a producer

```
repeat
    ….
    produce an item into nextp
    …
    while counter == n;
    buffer[in] = nextp;
    in = (in+1) % n;
    counter++;
until false;
```

- Now consider the consumer

```
repeat
    while counter == 0;
    nextc = buffer[out];
    out = (out + 1) % n;
    counter--;
    consume the item in nextc
until false;
```

- Does it work?
    - NO!

Problems with the Producer-Consumer Shared Memory Solution

- Consider the three address code for the counter

Counter Increment	Counter Decrement
reg_1 = counter	reg_2 = counter
$reg_1 = reg_1 + 1$	$reg_2 = reg_2 - 1$
counter = reg_1	counter = reg_2

- Now consider an ordering of these instructions

T_0	producer	reg_1 = counter	{ $reg_1 = 5$ }
T_1	producer	$reg_1 = reg_1 + 1$	{ $reg_1 = 6$ }
T_2	consumer	reg_2 = counter	{ $reg_2 = 5$ }
T_3	consumer	$reg_2 = reg_2 - 1$	{ $reg_2 = 4$ }
T_4	producer	counter = reg_1	{ counter = 6 }
T_5	consumer	counter = reg_2	{ counter = 4 }

← This should be 5!

Definition of terms

- *Race Condition*
  - Where the order of execution of instructions influences the result produced
  - Important cases for race detection are shared objects
    - counters: in the last example
- *Mutual exclusion*
  - only one process at a time can be updating shared objects
- *Critical section*
  - region of code that updates or **uses** shared data
    - to provide a consistent view of objects need to make sure an update is not in progress when reading the data
  - need to provide mutual exclusion for a critical section

Critical Section Problem

- processes must
  - request permission to enter the region
  - notify when leaving the region
- protocol needs to
  - provide mutual exclusion
    - only one process at a time in the critical section
  - ensure progress
    - no process outside a critical section may block another process
  - guarantee bounded waiting time
    - limited number of times other processes can enter the critical section while another process is waiting
  - not depend on number or speed of CPUs
    - or other hardware resources

Critical Section (cont)

- May assume that some instructions are atomic
  - typically load, store, and test word instructions
- Algorithm #1 for two processes
  - use a shared variable that is either 0 or 1
  - when $P_k = k$ a process may enter the region

```
repeat
    (while turn != 0);
    // critical section
    turn = 1;
    // non-critical section
until false;
```

```
repeat
    (while turn != 1);
    // critical section
    turn = 0;
    // non-critical section
until false;
```

- this fails the progress requirement since process 0 not being in the critical section stops process 1.

Critical Section (Algorithm 2)

- Keep an array of flags indicating which processes want to enter the section

Both processes could be here at the same time → (points to `flag[i] = true;`)

```
bool flag[2];

repeat
    flag[i] = true;
    while (flag[j]);

    // critical section

    flag[i] = false;

    // non-critical section
until false;
```

- This does NOT work either!
  - possible to have both flags set to 1

Critical Section (Algorithm 3)

- Combine 1 & 2

```
bool flag[2];
int turn;

repeat
    flag[i] = true;
    turn = j;
    while (flag[j]&& turn ==j);

    // critical section

    flag[i] = false;

    // non-critical section
until false;
```

- This one does work! Why?

Critical Section (many processes)

- What if we have several processes?
- One option is the Bakery algorithm

```
bool choosing[n];
integer number[n];

choosing[i] = true;
number[i] = max(number[0],..number[n-1])+1;
choosing[i] = false;
for j = 0 to n-1
        while choosing[j];
        while number[j] != 0 and ((number[j], j) < number[i],i);
end
// critical section
number[i] = 0
```

Bakery Algorithm - explained

- When a process wants to enter critical section, it takes a number
  - however, assigning a unique number to each process is not possible
    - it requires a critical section!
  - however, to break ties we can used the lowest numbered process id
- Each process waits until its number is the lowest one
  - it can then enter the critical section
- provides fairness since each process is served in the order they requested the critical section

Synchronization Hardware

- If it's hard to do synchronization in software, why not do it in hardware?
- Disable Interrupts
  - works, but is not a great idea since important events may be lost (depending on HW)
  - doesn't generalize to multi-processors
- test-and-set instruction
  - one atomic operation
    - executes without being interrupted
  - operates on one bit of memory
  - returns the previous value and sets the bit to one
- swap instruction
  - one atomic operation
  - swap(a,b) puts the old value of b into a and of a into b

Using Test and Set for Mutual Exclusion

```
repeat
        while test-and-set(lock);          <-- Note: no priority based on wait time
        // critical section
        lock = false;
        // non-critical section
until false;
```

- bounded waiting time version

```
repeat
        waiting[i] = true;
        key = true;
        while waiting[i] and key           <-- wait until released or no one busy
             key = test-and-set(lock);
        waiting[i] = false;
        // critical section
        j = (i + 1) % n
        while (j != i) and (!waiting[j])   <-- look for a waiting process
             j = (j + 1) % n;
        if (j == i)
             lock = false;                 <-- no process waiting
        else
             waiting[j] = false;           <-- release process j
        // non-critical section
until false;
```

Semaphores

- getting critical section problem correct is difficult
  - harder to generalize to other synchronization problems
  - Alternative is semaphores
- semaphores
  - integer variable
  - only access is through atomic operations
- P (or wait)

  ```
  while s <= 0;
  s = s - 1;
  ```
- V (or signal)

  ```
  s = s + 1
  ```
- Two types of Semaphores
  - Counting (values range from 0 to n)
  - Binary (values range from 0 to 1)

Using Semaphores

- critical section

```
repeat
        P(mutex);
        // critical section
        V(mutex);
        // non-critical section
until false;
```

- Require that Process 2 begin statement S2 after Process 1 has completed statement S1:

```
semaphore synch = 0;
Process 1
    S1
    V(synch)
Process 2
    P(synch)
    S2
```

Implementing semaphores

- Busy waiting implementations
- Instead of busy waiting, process can block itself
  - place process into queue associated with semaphore
  - state of process switched to waiting state
  - transfer control to CPU scheduler
  - process gets restarted when some other process executes a signal operations

Implementing Semaphores

- declaration

```
type semaphore = record
    value: integer = 1;
    L: FIFO list of process;
end;
```

- P(S):

```
S.value = S.value -1
if S.value < 0 then {
        add this process to S.L
        block;
};
```

Can be neg, if so, indicates how many waiting

- V(S):

```
S.value = S.value+1
if S.value <= 0 then {
        remove process P from S.L
        wakeup(P);
}
```

Bounded waiting!!