Operating Systems

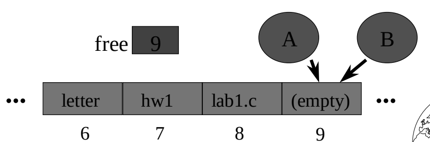
Process Synchronization
(Ch 7: 7.1 – 7.7, 7.10)

Too Much Pizza

	Person A	Person B
3:00	Look in fridge. Pizza!	
3:05	Leave for store.	Look in fridge. Pizza!
3:10	Arrive at store.	Leave for store.
3:15	Buy pizza.	Arrive at store.
3:20	Arrive home.	Buy pizza.
3:25	Put away pizza.	Arrive home.
3:30		Put pizza away.
		Oh no!

Cooperating Processes

- Consider: print spooler
  - Enter file name in spooler queue
  - Printer daemon checks queue and prints



- "Race conditions" (ugh!)
- (Hey, you! Show demo!)

Outline

- Need for synchronization
  - why?
- Solutions that require busy waiting
  - what?
- Semaphores
  - what are they?
- Classical problems
  - dining philosophers
  - reader/writers

Producer Consumer

- Model for cooperating processes
- Producer "produces" and item that consumer "consumes"
- Bounded buffer (shared memory)

```
item buffer[MAX]; /* queue */
int counter; /* num items */
```

Producer

```
item i; /* item produced */
int in; /* put next item */
while (1) {
  produce an item
  while (counter == MAX){/*no-op*/}
  buffer[in] = item;
  in = (in + 1) % MAX;
  counter = counter + 1;
}
```

Consumer

```
item i; /* item consumed */
int out; /* take next item */
while (1) {
  while (counter == 0) {/*no-op*/}
  item = buffer[out];
  out = (out + 1) % MAX;
  counter = counter - 1;
  consume the item
}
```

Trouble!

```
P:   R1 = counter     {R1 = 5}
P:   R1 = R1 + 1      {R1 = 6}
C:   R2 = counter     {R2 = 5}
C:   R2 = R2 -1       {R2 = 4}
C:   counter = R2     {counter = 4}
P:   counter = R1     {counter = 6}
```

Critical Section

- Mutual Exclusion
  - Only one process inside critical region
- Progress
  - No process outside critical region may block other processes wanting in
- Bounded Waiting
  - No process should have to wait forever (starvation)
- Note, no assumptions about speed!

First Try: Strict Alternation

```
int turn; /* shared, id of turn */

while(1) {
  while (turn <> my_pid) { /* no-op */}
  /* critical section */
  turn = your_pid
  /* remainder section */
}
```

Second Try

```
int flag[1]; /* boolean */

while(1) {
  flag[my_pid] = true;
  while (flag[your_pid]) { /* no-op */}
  /* critical section */
  flag[my_pid] = false;
  /* remainder section */
}
```

Third Try: Peterson’s Solution

```
int flag[1]; /* boolean */
int turn;
while(1) {
  flag[my_pid] = true;
  turn = your_pid;
  while (flag[your_pid] &&
          turn==your_pid){ /* noop */}
  /* critical section */
  flag[my_pid] = false;
  /* remainder section */
}
```

Multiple-Processes

- "Bakery Algorithm"
- Common data structures

```
boolean choosing[n];
int num[n];
```

- Ordering of processes
  - If same number, can decide "winner"

Multiple-Processes

```
choosing[my_pid] = true;
num[my_pid] = max(num[0],num[1] …)+1
choosing[my_pid] = false;
for (j=0; j<n; j++) {
  while(choosing[j]) { }
  while(num[j]!=0 &&
     (num[j],j)<(num[my_pid],my_pid)){}
}
/* critical section */
num[my_pid] = 0;
```

Synchronization Hardware

- Test-and-Set: returns and modifies atomically

```
int Test_and_Set(int &target) {
  int temp;
  temp = target;
  target = true;
  return temp;
}
```

Using Test_and_Set

```
while(1) {
  while (Test_and_Set(lock)) { }
  /* critical section */
  lock = false;
  /* remainder section */
}
```

- All the solutions so far have required "Busy Waiting" … what is that?

Outline

- Need for synchronization (done)
  - why?
- Solutions that require busy waiting (done)
  - what?
- Semaphores
  - what are they?
- Classical problems
  - dining philosophers
  - reader/writers

Semaphores

- Do not require "busy waiting"
- Semaphore S (shared, often initially =1)
  - integer variable
  - accessed via two (indivisible) atomic operations

```
wait(S): S = S - 1
  if S<0 then block(S)
signal(S): S = S + 1
  if S<=0 then wakeup(S)
```

Critical Section w/Semaphores

```
semaphore mutex; /* shared */

while(1) {
  wait(mutex);
  /* critical section */
  signal(mutex);
  /* remainder section */
}
```

(Hey, you! Show demo!)

SOS: Semaphore Implementation

- Note: key and int are different
  - Like critical.c sample
- How do you make sure the *signal* and the *wait* operations are atomic?

Semaphore Implementation

- Disable interrupts
  - Why is this not evil?
  - Multi-processors?
- Use correct software solution
- Use special hardware, i.e.- Test-and-Set

Design Technique: Reducing a Problem to a Special Case

- Simple solution not adequate
  - ex: disabling interrupts
- Problem solution requires special case solution
  - ex: protecting *S* for semaphores
- Simple solution adequate for special case
- Other examples:
  - name servers, on-line help

Trouble!

```
signal(S)
/* cr */
wait(S)
```

```
wait(S)
/* cr */
wait(S)
```

```
/* cr */
```

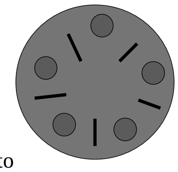
Process A	*Process B*
wait(S)	wait(Q)
wait(Q)	wait(S)
…	…

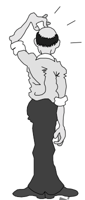
Classical Synchronization Problems

- Bounded Buffer
- Readers Writers
- Dining Philosophers

Dining Philosophers

- Philosophers
  - Think
  - Sit
  - Eat
  - Think
- Need 2 chopsticks to eat





Dining Philosophers

Philosopher i:

```
while (1) {
  /* think… */
  wait(chopstick[i]);
  wait(chopstick[i+1 % 5]);
  /* eat */
  signal(chopstick[i]);
  signal(chopstick[i+1 % 5]);
}
```

(Other solutions?)

Other Solutions

- Allow at most N-1 to sit at a time
- Allow to pick up chopsticks only if both are available
- Asymmetric solution (odd L-R, even R-L)

Readers-Writers

- *Readers* only read the content of object
- *Writers* read and write the object
- Critical region:
  - No processes
  - One or more readers (no writers)
  - One writer (nothing else)
- Solutions favor Reader *or* Writer

Readers-Writers

Shared:

```
semaphore mutex, wrt;
int readcount;
```

Writer:

```
wait(wrt)
/* write stuff */
signal(wrt);
```

Readers-Writers

Reader:

```
wait(mutex);
readcount = readcount + 1;
if (readcount==1) wait(wrt);
signal(mutex);
/* read stuff */
wait(mutex);
readcount = readcount - 1;
if (readcount==0) signal(wrt);
signal(mutex);
```

Monitors

- High-level construct
- Collection of:
  - variables
  - data structures
  - functions
  - Like C++ class
- One process active inside
- "Condition" variable
  - not counters like semaphores

Monitor Producer-Consumer

```
monitor ProducerConsumer {
   condition full, empty;
   integer count;

   /* function prototypes */
   void enter(item i);
   item remove();
}
void producer();
void consumer();
```

Monitor Producer-Consumer

```
void producer() {
  item i;
  while (1) {
     /* produce item i */
     ProducerConsumer.enter(i);
  }
}
void consumer() {
  item i;
  while (1) {
     i = ProducerConsumer.remove();
     /* consume item i */
  }
}
```

Monitor Producer-Consumer

```
void enter (item i) {
   if (count == N) sleep(full);
   /* add item i */
   count = count + 1;
   if (count == 1) then wakeup(empty);
}
item remove () {
  if (count == 0) then wakeup(empty);
  /* remove item into i */
  count = count - 1;
  if (count == N-1) then sleep(full);
  return i;
}
```

Other Process Synchronization Methods

- Critical Regions
- Conditional Critical Regions
- Sequencers
- Path Expressions
- Serializers
- ...
- All essentially equivalent in terms of semantics. Can build each other!

Ex: Cond. Crit. Region w/Sem

```
region X when B do S {
 wait(x-mutex);
 if (!B) {
    x-count = x-count + 1;
    signal(x-mutex);
    wait(x-delay);
    /* wakeup loop */
    x-count = x-count -1
}
/* remainder */
```

Ex: Wakeup Loop

```
while (!B) {
  x-temp = x-temp + 1;
  if (x-temp < x-count)
     signal(x-delay);
  else
     signal(x-mutex);
  wait(x-delay);
}
```

Ex: Remainder

```
S;
if (x-count > 0) {
  x-temp = 0;
  signal(x-delay);
} else
  signal(x-mutex);
```

Trouble?

- Monitors and Regions attractive, but ...
  - Not supported by C, C++, Pascal ...
    - semaphores easy to add
- Monitors, Semaphores, Regions ...
  - require shared memory
  - break on multiple CPU (w/own mem)
  - break distributed systems
- In general, Inter-Process Communication (IPC)
  - Move towards *Message Passing*

Inter Process Communication

- How does one process communicate with another process? Some of the ways:
  - *shared memory* – read/write to shared region
    - `shmget()`, `shmctl()` in Unix
    - Memory mapped files in WinNT/2000
  - *semaphores* - signal notifies waiting process
  - *software interrupts* - process notified asynchronously
  - *pipes* - unidirectional stream communication
  - *message passing* - processes send and receive messages.

Software Interrupts

- Similar to hardware interrupt.
- Processes interrupt each other (often for system call)
- Asynchronous! Stops execution then restarts
  - cntl-C
  - child process completes
  - alarm scheduled by the process expires
    - Unix: SIGALRM from `alarm()` or `setitimer()`
  - resource limit exceeded (disk quota, CPU time...)
  - programming errors: invalid data, divide by zero

Software Interrupts

- `SendInterrupt(pid, num)`
  - type `num` to process `pid`,
  - `kill()` in Unix
  - (NT doesn't allow signals to processes)
- `HandleInterrupt(num, handler)`
  - type `num`, use function `handler`
  - `signal()` in Unix
  - Use exception handler in WinNT/2000
- Typical handlers:
  - ignore
  - terminate (maybe w/core dump)
  - user-defined
- (Hey, show demos!)

Unreliable Signals

- Before POSIX.1 standard:

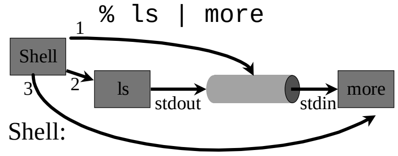
```
signal(SIGINT, sig_int);
...
sig_int() {
  /* re-establish handler */
  signal(SIGINT, sig_int);
}
```

- Another signal could come before handler re-established!

Pipes

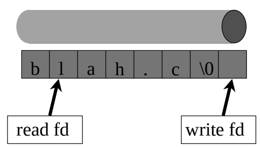
- One process writes, 2nd process reads

`% ls | more`



- Shell:
  1 create a pipe
  2 create a process for `ls` command, setting `stdout` to write side of pipe
  3 create a process for `more` command, setting `stdin` to read side of pipe

The Pipe



- Bounded Buffer
  - shared buffer (Unix 4096K)
  - block writes to full pipe
  - block reads to empty pipe

The Pipe

- Process inherits file descriptors from parent
  - file descriptor 0 stdin, 1 stdout, 2 stderr
- Process doesn't know (or care!) when reading from keyboard, file, or process or writing to terminal, file, or process
- System calls:
  - read(fd, buffer, nbytes) (`scanf()` built on top)
  - write(fd, buffer, nbytes) (`printf()` built on top)
  - pipe(rgfd) creates a pipe
    - rgfd array of 2 fd. Read from rgfd[0], write to rgfd[1]
- (Hey, show sample code!)

Message Passing

- Communicate information from one process to another via primitives:
  `send(dest, &message)`
  `receive(source, &message)`
- Receiver can specify *ANY*
- Receiver can block (or not)

Producer-Consumer

```
void Producer() {
  while (TRUE) {
     /* produce item */
     build_message(&m, item);
     send(consumer, &m);
     receive(consumer, &m); /* wait for ack */
  }}
void Consumer {
  while(1) {
     receive(producer, &m);
     extract_item(&m, &item); [redacted]
     send(producer, &m); /* ack */
     /* consume item */
  }}
```

Consumer Mailbox

```
void Consumer {
  for (i=0; i<N; i++)
     send(producer, &m); /* N empties */
  while(1) {
     receive(producer, &m);
     extract_item(&m, &item);
     send(producer, &m); /* ack */
     /* consume item */
  }
}
```

New Troubles with Messages?

New Troubles with Message Passing

- Scrambled messages (*checksum*)
- Lost messages (*acknowledgements*)
- Lost acknowledgements (*sequence no.*)
- Process unreachable (down, terminates)
- Naming
- Authentication
- Performance (from copying, message building)
- (Take cs4513!)