Announcements

- Reading chapter 6 (6.4 and 6.5)
- Midterm #1 is March 5 in class
- Late Policy for programs
  - no late work will be accepted
  - illness and family emergency will be considered on a case by case basis

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

```
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 highest 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.
  - 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 Test for Mutual Exclusion

```
repeat
        while test-and-set(lock);
        // critical section
        lock = false;
        // non-critical section
until false;
```

Note: no priority based on wait time

- bounded waiting time version

```
repeat
        waiting[i] = true;
        key = true;
        while waiting[i] and key
             key = test-and-set(lock);
        waiting[i] = false;
        // critical section
        j = (i + 1) % n
        while (j != i) and (!waiting[j])
             j = (j + 1) % n;
        if (j == i)
             lock = false;
        else
             waiting[j] = false;
        // non-critical section
until false;
```

wait until released or no one busy

look for a waiting process

no process waiting

release process j

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
```

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:

```
Process 2
    S1
    V(synch)
Process 1
    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