Interprocess Synchronization and Communication

Remote Procedure Calls (RPC)

- Higher-level, procedural interface to IPC
- To the programmer: looks like a regular procedure call
  - Procedure is in a separate address space, does not share global variables
- Each RPC needs separate process
  - Reads parameters, runs remote procedure, returns result
  - Done using send and receive primitives . . .

Implementation

caller process		*RP_guard process*
send(RP_guard, parameters)	→	receive(caller, parameters)
		↓
		RP parameters)
		↓
receive(RP_guard, results)	←	send(caller, results)

Example: Producer Consumer Problem

```
procedure producer;
begin
	while true do begin
		// produce a nextp
		send(“RP_guard”, nextp);
	end;
end;
procedure consumer;
begin
	while true do begin
		receive(“RP_guard”, nextc);
		// consume nextc
	end;
end;
```

Common Concurrency Problems

- Atomicity violation bugs
- Order violation. bugs
- Livelock
- Deadlock

Atomicity Violation Problems

- When an operation that is supposed to be indivisible is not
- Simple example: checking permission to access file, then accessing it

```
if (access(file1, W_OK) < 0 ||
        (fd = open(file1, O_WRONLY)) < 0){
    perror(file1);
    exit(1);
}
```

Atomicity Violation Problems

```
if (access(file1, W_OK) < 0 ||
          (fd = open(file1, O_WRONLY)) < 0){
     perror(file1);
     exit(1);
}
```

Attacker executes:

```
     rm file1
     ln /etc/passwd logfile
```

Example from MySQL

- Thread 1

```
if (thd->proc_info){
      fputs(thd->proc_info,  …);
```

- Thread 2

```
thd->proc_info = NULL;
```

Order Violation Bug

- Two operations should be done in pone order, but instead are done in another order
- First order works
- Second order causes problems

Order Violation Bug

- Thread 1

```
void init() {
    mThread =
            PR_CreateThread(mMain, …);
```

- Thread 2

```
void mMain(…) {
    mState = mThread->State;
```

The Fix

- When available. use locks (semaphores, etc.) to create a critical section among the statements to ensure indivisibility or specific order

Livelock

- Processes loop, neither advancing until the other does
- “Livelock” as processes are active
- Example: proposed software solution #3 for concurrency

```
var interested: array[0..1] of boolean = false;
                // who wants to enter critical section
interested[i] = true;  // … entry section
while interested[j] do
     /* nothing */
. . .                          // … critical section
interested[i] = false;         // … exit section
```

Deadlock

- Resource manager: the part of the kernel responsible for managing resources
  - *request*: asks the resource manager to give the process a resource
  - *release*: informs resource manager that process no longer needs a resource that it has been given

Example

- A system has 2 devices, *a* and *b*
- A system has 2 processes *p* and *q*
- The following occurs
  - *p* requests device *a*, and resource manager allocates it to *p*
  - *q* requests device *b*, and resource manager allocates it to *q*
  - *p* requests device *b*, but resource manager cannot allocate it, so *p* blocks until *b* becomes free
  - *q* requests device *a*, but resource manager cannot allocate it, so *q* blocks until *a* becomes free
- Processes *p* and *q* are now deadlocked

Deadlock vs. Starvation

- Deadlock occurs when a needed resource is *never* available for reallocation
- Starvation occurs when a needed resource is available for reallocation but never assigned to the process requesting it
  - *Example*: the dining philosopher's problem, where everyone picks up left fork, and puts it down, and picks it up again . . .

Approaches to Allocation

- *Liberal*: whenever a request can be granted, do so; if not, block process until request an be granted
- Conservative: be willing to deny a request on occasion to prevent deadlock
- Serialization: processes cannot hold resources concurrently, so if one process requests and is granted a resource, no other process can acquire another resource
  - *Example*: in 2 device example, once *p* acquires *a*, *q*'s request for *b* would be denied

Resource Types

- *Reusable resources*: these have a fixed total inventory: none are created, and none destroyed.
  - Units are requested and acquired from a pool of available units and after use are returned to the pool where other processes can get them.
  - *Examples*: processors, memory, tape drives, *etc*.
- *Consumable resources*: have no fixed number of units; created (produced) or acquired (consumed) as needed
  - Unblocked producer may release any number of units which become immediately available; once acquired, units cease to exist.
  - *Examples*: messages, information in I/O buffers, *etc*.
- **We will not discuss deadlock analysis of consumable resources.**

Policies to Handle Deadlock

- *Ignore it*: okay if deadlocks are rare and users know how to recover
- *Prevention*: ensure deadlock can never occur
  - If granting request could cause deadlock, deny request
  - 4 conditions must hold for deadlock to occur
- *Avoidance*: use knowledge of the process' future behavior to constrain the pattern of resource allocation
- *Detection and recovery*: determine when a system, processes are deadlocked and recover from it
  - Most useful when deadlocks infrequent and cost of recovery is low

Deadlock Prevention

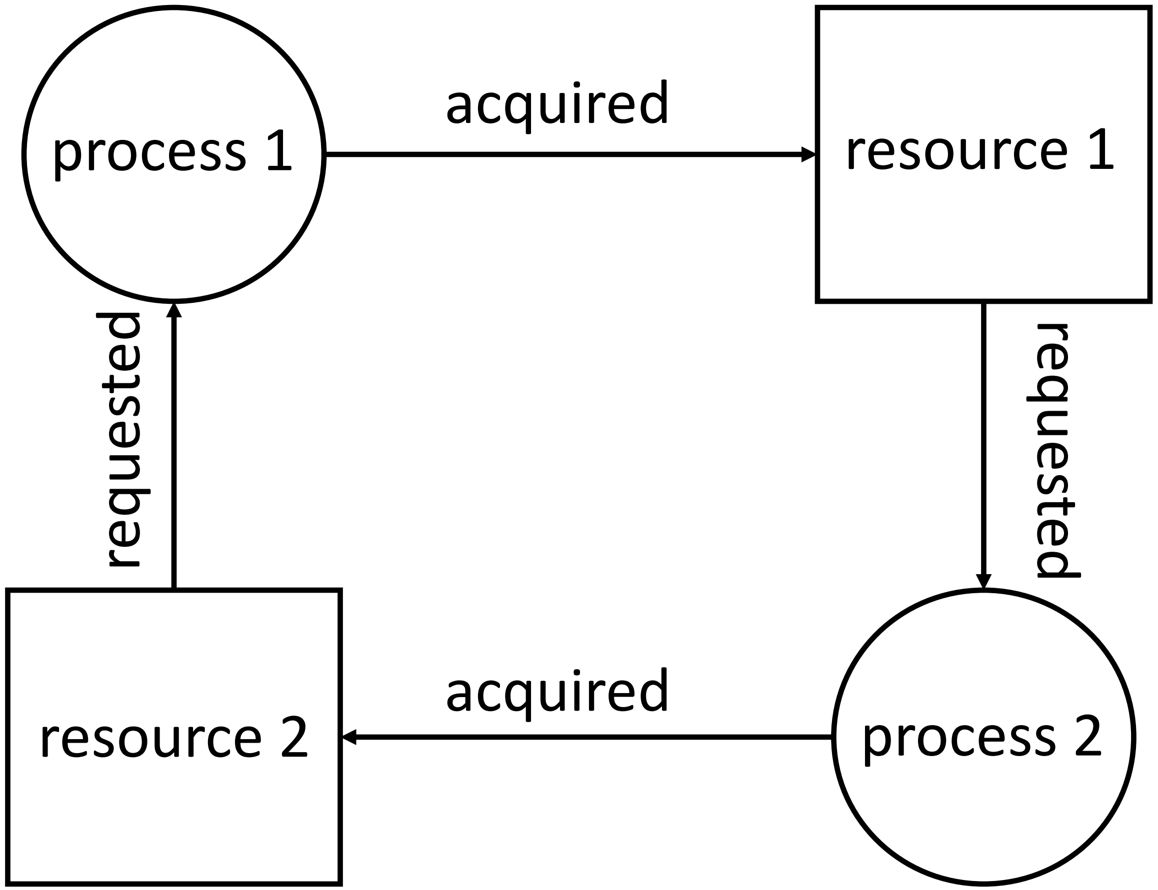
- A *safe state* is one that can never lead to deadlock
- So restrict the system so all states are safe
- Several designs for this, all based on breaking 1 of 4 conditions all of which must hold for deadlock to be possible

Deadlock Prevention

Deadlock requires 4 conditions to hold simultaneously:

- *Mutual exclusion*: when a process has acquired a resource, no other process can acquire it
- *No preemption*: when a process has acquired a resource, it cannot be reallocated until the process releases it
- *Circular wait*, *resource waiting*: blocked processes form a circular chain, with each holding a resource requested by another member of the chain and holding a resource held by another member of the chain
- *Hold and wait*, *partial allocation*: a process may request resources while holding other resources

Circular Wait



Deadlock Prevention

- Only 1 process at a time may hold resources
  - Breaks circular wait as process 2 can never acquire resources while process 1 has any resources
  - Effectively eliminates multiprogramming
- Processes must request, *and acquire*, all resources it might need at one time
  - Breaks circular wait as no process can wait on a resource allocated to another process
  - Resources may be requested but never used
  - Resources may be allocated *long* before use

Deadlock Prevention

- Classes of resources are ordered, and constraints placed upon ordering resources in different classes
  - Called *hierarchical ordering policy* or *ordered resource policy*
- How: divide resources into *n* classes
  - Process can request allocations from class c_i if and only if it has no allocation from classes $c_{i+1}, \ldots, c_n$
  - If it needs to get such a resource, it must release all resources it has and request them too
  - Breaks hold and wait as processes do not hold resources when blocked awaiting another resource assignment
- Some resources must be allocated before a process needs it

Deadlock Avoidance

- Use Banker's Algorithm, which determines if system is in a safe or unsafe state by trying to finish
- Example: if a request is granted, then *after* that:

  process p_1 has 4 resource units, needs 4 more

  process p_2 has 2 resource units, needs 1 more

  process p_3 has 2 resource units, needs 7 more

  2 resource units are available

Deadlock Avoidance

1. Satisfy p_2; then
   process p_1 has 4 resource units, needs 4 more
   process p_3 has 2 resource units, needs 7 more
   4 resource units are available
2. Satisfy p_1; then
   process p_3 has 2 resource units, needs 7 more
   8 resource units are available
3. Satisfy p_3; all processes finished

So this is a safe state and the request is granted

Deadlock Avoidance

- Example: if a request is granted, then *after* that:

  process p_1 has 4 resource units, needs 4 more

  process p_2 has 2 resource units, needs 1 more

  process p_3 has 3 resource units, needs 6 more

  1 resource unit are available

Deadlock Avoidance

1. Satisfy p_2; then

    process p_1 has 4 resource units, needs 4 more
    process p_3 has 3 resource units, needs 6 more
    3 resource units are available

p_1, p_3 cannot finish

So this is an unsafe state and the request is denied

Problems with Banker’s Algorithm

1. Banker’s algorithm requires a fixed number of resources
   - If something goes off line for repair or maintenance, the system may be put into an unsafe state without any action by the processes;
2. Banker’s algorithm requires a fixed number of processes
   - This is unreasonable, especially in time sharing systems.
3. Banker's algorithm guarantees all requests will be granted in a finite time
   - But printing your program (due today) next year grants your request in a finite time. You need a better guarantee than that!

Problems with Banker’s Algorithm

4. Banker's algorithm requires jobs to release their resources in a finite time
    - Suppose a process grabs a resource and then blocks indefinitely, waiting for an external event to occur. Again, you need a better guarantee that that!
5. Banker's algorithm requires users to know and state process needs in advance.
    - Infeasible in many cases (especially in time-sharing)

Deadlock Detection and Recovery

- System generates a resource graph
- It looks for loops
- If it finds one, it breaks it
  - It can reallocate resources
  - It can terminate processes