Introduction to Operating Systems

CPSC/ECE 3220 Summer 2018

Lecture Notes
OSPP Chapter 6 – Part B

(adapted by Mark Smotherman from Tom Anderson's slides on OSPP web site)

Deadlock Definition

- Resource: a physical or virtual entity that can be assigned to a user or application
  - Anything needed by a thread to do its job (CPU, disk space, memory, lock)
  - Preemptable: can be taken away by OS
  - Non-preemptable: must leave with thread
- Starvation: thread waits indefinitely
- Deadlock: circular waiting for resources
  - Deadlock => starvation, but not vice versa

Example: two locks

Thread A	Thread B
lock1.acquire();	lock2.acquire();
lock2.acquire();	lock1.acquire();
// critical section	// critical section
lock2.release();	lock1.release();
lock1.release();	lock2.release();

Bidirectional Bounded Buffer

Thread A	Thread B
buffer1.put(data);	
buffer1.put(data);	buffer2.put(data);
	buffer2.put(data);
buffer2.get();	
buffer2.get();	buffer1.get();
	buffer1.get();

Suppose buffer1 and buffer2 both start almost full.

Two locks and a condition variable

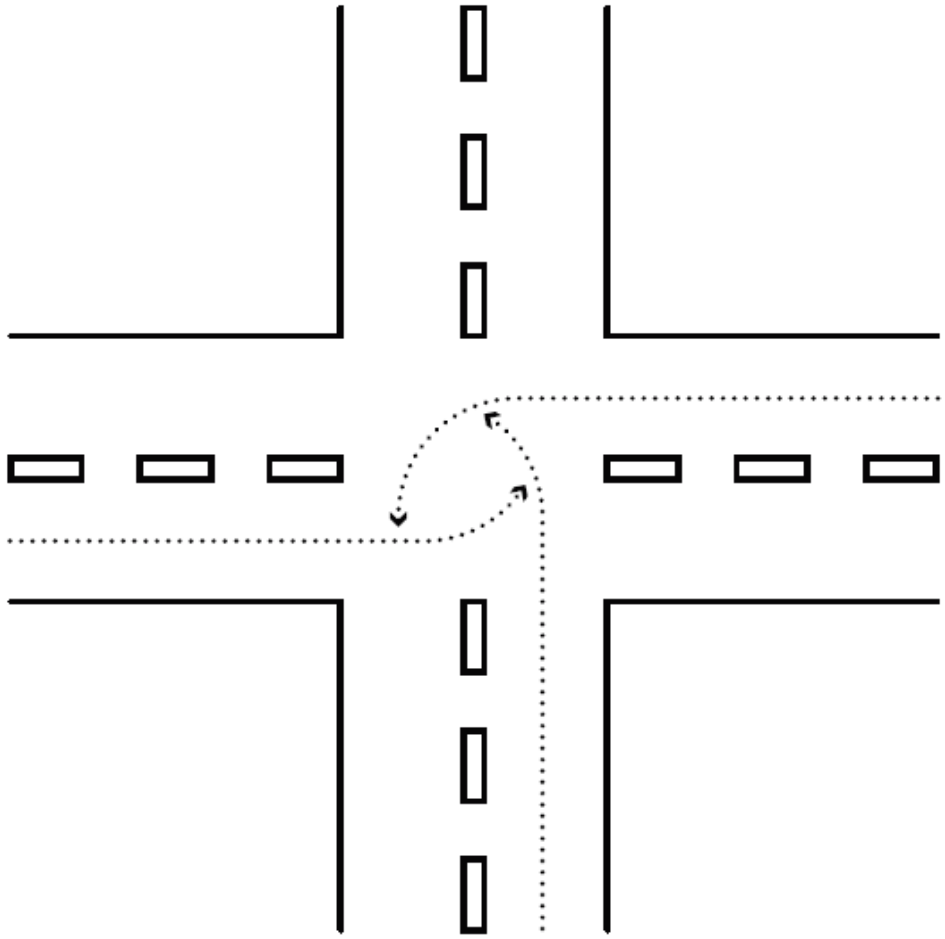
Thread A

```
lock1.acquire();
...
lock2.acquire();
while (need to wait) {
    condition.wait(lock2);
}
lock2.release();
...
lock1.release();
```

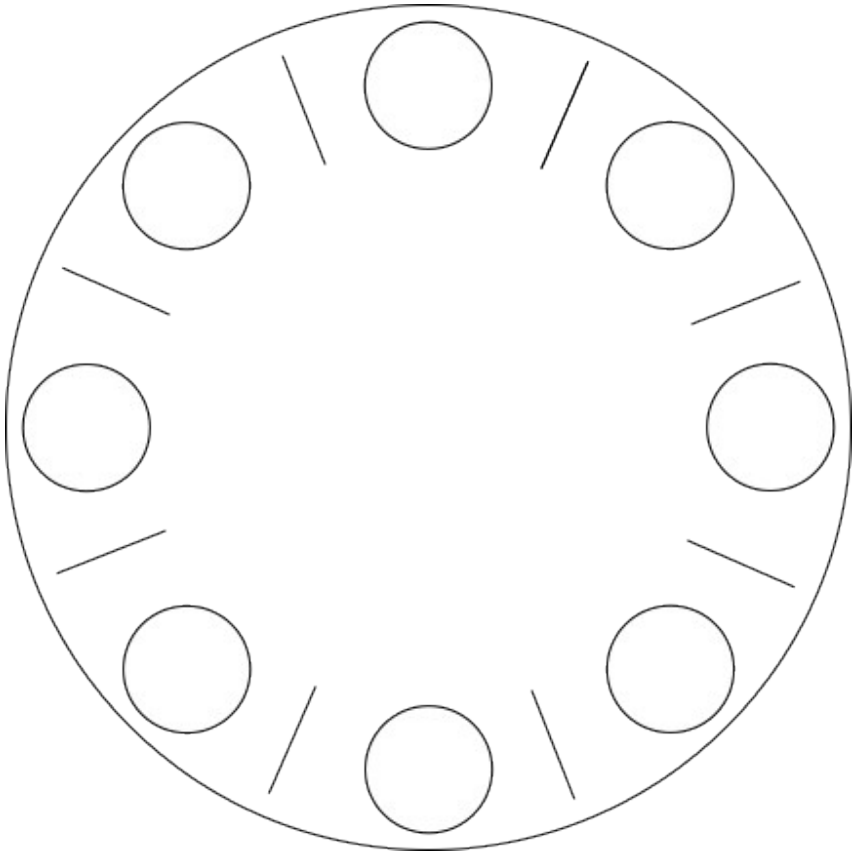
Thread B

```
lock1.acquire();
...
lock2.acquire();
...
condition.signal(lock2);
...
lock2.release();
...
lock1.release();
```

Yet another Example



Dining Philosophers



Each philosopher needs two chopsticks to eat.
Each grabs chopstick on the right first.

Necessary Conditions for Deadlock

- Limited access to resources
  - If infinite resources, no deadlock!
- No preemption
  - If resources are virtual, can break deadlock
- Multiple independent requests
  - “wait while holding”
- Circular chain of requests

Question

- How does Dining Philosophers meet the necessary conditions for deadlock?
  - Limited access to resources
  - No preemption
  - Multiple independent requests (wait while holding)
  - Circular chain of requests
- How can we modify Dining Philosophers to prevent deadlock?

Approaches to Handling Deadlock

- Prevent by limiting program behavior
  - Limit program from doing anything that might lead to deadlock
- Avoid by predicting the future
  - If we know what program will do, we can tell if granting a resource might lead to deadlock
- Detect and recover
  - If we can rollback a thread, we can fix a deadlock once it occurs

Exploit or Limit Behavior

- Provide enough resources
  - How many chopsticks are enough?
- Eliminate wait while holding
  - Release lock when calling out of module
  - Telephone circuit setup
- Eliminate circular waiting
  - Lock ordering: always acquire locks in a fixed order
  - Example: move file from one directory to another

Example

Thread 1

1. Acquire A
2.
3. Acquire C
4.
5. If (maybe) Wait for B

Thread 2

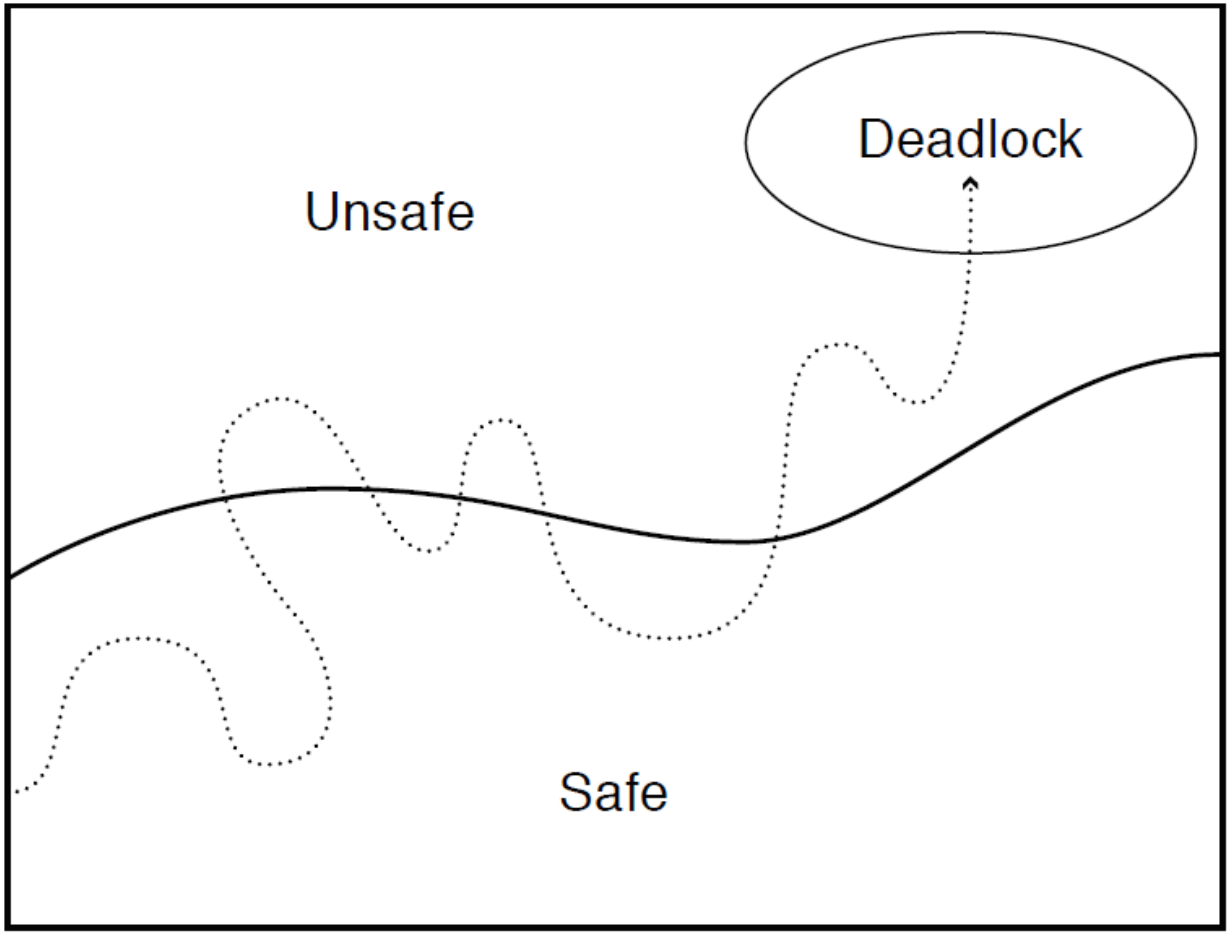
1.
2. Acquire B
3.
4. Wait for A

How can we make sure to avoid deadlock?

Deadlock Dynamics

- Safe state:
  - For any possible sequence of future resource requests, it is possible to eventually grant all requests
  - May require waiting even when resources are available!
- Unsafe state:
  - Some sequence of resource requests can result in deadlock
- Doomed state:
  - All possible computations lead to deadlock

Possible System States



Predict the Future

- Banker's algorithm (Dijkstra)
  - State maximum resource needs in advance
  - Allocate resources dynamically when resource is needed -- wait if granting request would lead to deadlock
  - Request can be granted if some sequential ordering of threads is deadlock free
  - Extends to multiple resource types

Banker’s Algorithm

- Grant request iff result is a safe state
- Sum of maximum resource needs of current threads can be greater than the total resources
  - Provided there is some way for all the threads to finish without getting into deadlock
- Example: proceed iff
  - total available resources - # allocated >= max remaining that might be needed by this thread in order to finish
  - Guarantees this thread can finish

Banker's Algorithm Example (1a)

example using total units = 10

thread	max need	allocated	remaining need	able to finish?
A	8	2	6	?
B	6	3	3	?
C	4	2	2	?

available units = 3

Banker's Algorithm Example (1b)

example using total units = 10

thread	max need	allocated	remaining need	able to finish?
A	8	2	6	?
B	6	3	3	?
C	4	2	2	?

available units = 3

Show that this is a safe state since there is a sequence of thread executions that allows each thread to obtain its maximum resource need, complete its work, and release its resources:

thread		allocation in steps
A	2	
B	3	
C	2	
allocated	7	
available	3	

Banker's Algorithm Example (1c)

example using total units = 10

thread	max need	allocated	remaining need	able to finish?
A	8	2	6	?
B	6	3	3	?
C	4	2	2	true

available units = 3

Show that this is a safe state since there is a sequence of thread executions that allows each thread to obtain its maximum resource need, complete its work, and release its resources:

thread		allocation in steps
A	2	2
B	3	3
C	2 grant 2=>4	
allocated	7	9
available	3	1

Banker's Algorithm Example (1d)

example using total units = 10

thread	max need	allocated	remaining need	able to finish?
A	8	2	6	?
B	6	3	3	?
C	4	2	2	?

available units = 3

Show that this is a safe state since there is a sequence of thread executions that allows each thread to obtain its maximum resource need, complete its work, and release its resources:

thread			allocation in steps
A	2	2	2
B	3	3	3
C	2 grant 2=>4 release=>0		
allocated	7	9	5
available	3	1	5

Banker's Algorithm Example (1e)

example using total units = 10

thread	max need	allocated	remaining need	able to finish?
A	8	2	6	?
B	6	3	3	true
C	4	2	2	true

available units = 3

Show that this is a safe state since there is a sequence of thread executions that allows each thread to obtain its maximum resource need, complete its work, and release its resources:

thread			allocation in steps		
A	2	2	2	2	2
B	3	3	3 grant3=>6 release=>0		
C	2 grant 2=>4 release=>0		0	0	
allocated	7	9	5	8	2
available	3	1	5	2	8

Banker's Algorithm Example (1f)

example using total units = 10

thread	max need	allocated	remaining need	able to finish?
A	8	2	6	true
B	6	3	3	true
C	4	2	2	true

available units = 3

Show that this is a safe state since there is a sequence of thread executions that allows each thread to obtain its maximum resource need, complete its work, and release its resources:

thread	allocation in steps						
A	2	2	2	2	2 grant 6=>8 release=>0		
B	3	3	3 grant3=>6 release=>0		0	0	
C	2 grant 2=>4 release=>0		0	0	0	0	
allocated	7	9	5	8	2	8	0
available	3	1	5	2	8	2	10

Banker's Algorithm Example (1g)

example using total units = 10

thread	max need	allocated	remaining need	able to finish?
A	8	2	6	?
B	6	3	3	?
C	4	2	2	?

available units = 3

This is a safe state since there is a sequence of thread executions that allows each thread to obtain its maximum resource need, complete its work, and release its resources:

thread		allocation in steps
A	2	
B	3	
C	2	
allocated	7	
available	3	

Can you show a second sequence that leads to the recovery of all 10 resources?

Banker's Algorithm Example (2)

example using total units = 10

thread	max need	allocated	remaining need
A	8	2	6	true
B	6	3	3	true
C	4	2	2	true

available units = 3

Initial state

thread A requests 2 units (of the three unallocated)

thread	max need	allocated	remaining need
A	8	**4**	**4**	**false**
B	6	3	3	**false**
C	4	2	2	**false**

available units = **1**

Unsafe state if request is granted

Cannot grant this request since there would not be enough unallocated units to satisfy the remaining need for any thread!

Banker's Algorithm Example (3)

Example using total units = 10

thread	max need	allocated	remaining need	finish?
A	8	2	6	true
B	6	3	3	true
C	4	2	2	true

available units = 3

Initial state

thread C requests 1 units (of the three unallocated)

thread	max need	allocated	remaining need	finish?
A	8	2	6	**true**
B	6	3	3	**true**
C	4	**3**	**1**	**true**

available units = **2**

Safe state if request is granted

Can grant this request!

Banker’s Algorithm Example (4)

Algorithm extends to vectors of resources.

	max need			allocated			remaining			available		
	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
A	4	1	2	3	0	0	1	1	2	5	1	1
B	7	4	4	2	4	3	5	0	1			
C	3	3	3	0	2	1	3	1	2			

This is a safe state since the unused units (5,1,1) can satisfy B's remaining claim of (5,0,1); when B ends it will release its resources and thus increase the unused units to (7,5,4). This can satisfy both A and C's remaining need.

Detect and Repair

- Algorithm
  - Scan wait for graph
  - Detect cycles
  - Fix cycles
- Proceed without the resource
  - Requires robust exception handling code
- Roll back and retry
  - Transaction: all operations are provisional until have all required resources to complete operation

Detecting Deadlock