## Deadlocks

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### Topics covered in today’s lecture

- Deadlocks  
- Deadlock characterization  
- Deadlock vs Starvation  
- Resource allocation graph

### Frequently asked questions from the previous class survey

- Exponential Moving Average  
- Is the α adjusted? How is the first estimate (i.e. τ₀) chosen?  
- MFQ  
  - Any user-level control over setting the quanta? No  
  - Must there be a quanta for every priority level? Yes  
  - Is the quanta in milliseconds or nanoseconds? Milliseconds  
  - At a given priority level what is the order of processes being scheduled?  
  - When does a process get off the MFQ?  
- HLT on x86 halts the CPU until the next external interrupt  
- How does a thread first get assigned to a core?

### What we will look at ...

- **Prevention**  
- **Avoidance**  
- **System Model**  
- **Characterization**  
- **Requirements**  
- **Detection & Recovery**

### Deadlocks

A waiting process is never again able to change state  
It is waiting for resources held by other processes

### For many applications, processes need exclusive accesses to multiple resources

- Process A: Asks for scanner and is granted it  
- Process B: Asks CD recorder first and is granted it.  
- Process A: Now asks for CD recorder  
- Process B: Now asks for Scanner  
- Both processes are blocked and will remain so forever!  
  - **Deadlock**
Other deadlock situations

- Distributed systems involving multiple machines
- Database systems
  - Process 1 locks record R1
  - Process 2 locks record R2
  - Then, processes 1 and 2 try to lock each other’s record
- Deadlocks can occur in hardware or software resources

Resource Deadlocks

- Major class of deadlocks involves resources
  - Can occur when processes have been granted access to devices, data records, files, etc.
  - Other classes of deadlocks: communication deadlocks, two-phase locking
- Related concepts
  - Deadlocks and starvation

Preemptable resources

- Can be taken away from process owning it with no ill effects
- Example: Memory
  - Process B’s memory can be taken away and given to process A.
    - Swap B from memory, write contents to backing store, swap A in and let it use the memory

Non-preemptable resources

- Cannot be taken away from a process without causing the process to fail
- If a process has started to burn a CD
  - Taking the CD-recorder away from it and giving it to another process?
    - Garbled CD
    - CD recorders are not preemptable at an arbitrary moment
- In general, deadlocks involve non-preemptable resources

Some notes on deadlocks

- The OS typically does not provide deadlock prevention facilities
- Programmers are responsible for designing deadlock free programs

System model

- Finite number of resources
  - Distributed among competing processes
- Resources are partitioned into different types
  - Each type has a number of identical instances
  - Resource type examples:
    - Memory space, files, I/O devices
A process must utilize resources in a sequence

- **Request**
  - Requesting resource must wait until it can acquire resource
  - `request()`, `open()`, `allocate()`

- **Use**
  - Operate on the resource

- **Release**
  - `release()`, `close()`, `free()`

For kernel managed resources, the OS maintains a system resource table

- **Is the resource free?**
  - Record process that the resource is allocated to

- **Is the resource allocated?**
  - Add to queue of processes waiting for resource

- For resources not managed by the OS
  - Use `wait()` and `signal()` on semaphores

Deadlock: Formal Definition

- A set of processes is deadlocked if each process in the set is waiting for an event that only another process in the set can cause.

  - Because all processes are waiting, none of them can cause events to wake any other member of the set
  - Processes continue to wait forever

Deadlocks:

**Necessary Conditions (I)**

- **Mutual Exclusion**
  - At least one resource held in nonsharable mode
  - When a resource is being used
  - Another requesting process must wait for its release

- **Hold-and-wait**
  - A process must hold one resource
  - Wait to acquire additional resources
  - Which are currently held by other processes

**Necessary Conditions (II)**

- **No preemption**
  - Resources cannot be preempted
  - Only voluntary release by process holding it

- **Circular wait**
  - A set of `{P_0, P_1, ..., P_n}` waiting processes must exist
  - \( P_0 \rightarrow P_1 \rightarrow P_2 \rightarrow ... \rightarrow P_n \rightarrow P_0 \)
  - Implies hold-and-wait
Deadlocks vs. Starvation

- Deadlocks and starvation are both liveness concerns.
- Starvation: Task fails to make progress for an indefinite period of time.
- Deadlock is a form of starvation, but with a stronger condition:
  - A group of tasks forms a cycle where none of the tasks makes progress because each task is waiting for some other task in the cycle to take action.

Starvation does not imply deadlock.

Also...

- Just because a system can suffer deadlock or starvation does not mean that it always will:
  - A system is subject to starvation if a task could starve in some circumstances.
  - A system is subject to deadlock if a group of tasks could deadlock in some circumstances.
- Circumstances impact whether a deadlock or starvation may occur:
  - Choices made by scheduler, number of tasks, workload or sequence of requests, which tasks win races to acquire locks, order of task activations, etc.

Circumstances impact whether a deadlock or starvation may occur.

Resource allocation graph

- Used to describe deadlocks precisely.
- Consists of a set of vertices and edges.
- Two different sets of nodes:
  - \( P \): the set of all active processes in system.
  - \( R \): the set of all resource types in the system.
Directed edges

- **Request edge**
  - Process $P_i$ has requested an instance of resource type $R_j$
  - Directed edge from process $P_i$ to resource $R_j$
  - Denoted $P_i \rightarrow R_j$
  - Currently waiting for that resource

- **Assignment edge**
  - Instance of resource $R_j$ assigned to process $P_i$
  - Directed edge from resource $R_j$ to process $P_i$
  - Denoted $R_j \rightarrow P_i$

Representation of Processes and Resources

- Processes
- Resources
  - A resource type may have multiple instances

Resource Allocation Graph example

- Directed edges:
  - Request edge:
    - $P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_3 \rightarrow P_3 \rightarrow R_2 \rightarrow P_1$
  - Assignment edge:
    - $P_2 \rightarrow R_3 \rightarrow P_3 \rightarrow R_2 \rightarrow P_2$

Determining deadlocks

- If the graph contains **no cycles**?
  - No process in the system is deadlocked
- If there is a **cycle** in the graph?
  - If each resource type has exactly one instance:
    - Deadlock **has** occurred
  - If each resource type has multiple instances:
    - A deadlock **may have** occurred

Resource Allocation Graph:

- Deadlock example
  - Two cycles:
    - $P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_2 \rightarrow P_1$
    - $P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_2 \rightarrow P_2$

- Cycle but not a deadlock
  - $P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_2 \rightarrow P_3$
  - $P_1$ may release instance of $R_2$ to $P_3$ and break cycle
Resource Allocation Graphs and Deadlocks

- If the graph does not have a cycle
  - No deadlock
- If the graph does have a cycle
  - System may or may not be deadlocked

Methods for handling deadlocks

- Use protocol to prevent or avoid deadlocks
  - Ensure system never enters a deadlocked state
- Allow system to enter deadlocked state; BUT
  - Detect it and recover
- Ignore problem, pretend that deadlocks never occur

Problems with undetected deadlocks

- Resources held by processes that cannot run
- More and more processes enter deadlocked state
  - When they request more resources
- Deterioration in system performance
  - Requires restart

When is ignoring the problem viable?

- When they occur infrequently (once per year)
  - Ignoring is the cheaper solution
  - Prevention, avoidance, detection and recovery
    - Need to run constantly

Law passed by Kansas Legislature ... early 20th Century

“When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up again until the other has gone”

Some deadlock examples

- Law passed by Kansas Legislature ... early 20th Century
  - “When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up again until the other has gone”
Dining philosophers problem:
Necessary conditions for deadlock (1)
- Mutual exclusion
  - 2 philosophers cannot share the same chopstick
- Hold-and-wait
  - A philosopher picks up one chopstick at a time
  - Will not let go of the first while it waits for the second one

Dining philosophers problem:
Necessary conditions for deadlock (2)
- No preemption
  - A philosopher does not snatch chopsticks held by some other philosopher
- Circular wait
  - Could happen if each philosopher picks chopstick with the same hand first

Is there a traffic deadlock here?

The traffic scenario:
Necessary Conditions (1)
- Mutual Exclusion
  - A vehicle needs its own space
  - We can’t stack automobiles on top of each other
- Hold-and-wait
  - A vehicle does not move and stays in place if it cannot advance

The traffic scenario:
Necessary Conditions (2)
- No preemption
  - We cannot move an automobile to the side
- Circular-wait
  - Each vehicle is waiting for the one in front of it to advance

DEALING WITH DEADLOCKS
Four strategies for dealing with deadlocks

- Ignore the problem
  - May be if you ignore it, it will ignore you
- Detection and Recovery
  - Let deadlocks occur, detect them, and take action
- Deadlock avoidance
  - By careful resource allocation
- Deadlock prevention
  - By structurally negating one of the four required conditions

OS suffer from deadlocks that are not even detected

- Every OS table represents a finite resource
- Should we abolish all of these because collection of $n$ processes
  - Might claim $1/n$ th of the total AND
  - Then try to claim another one
- Most users prefer occasional deadlock to a restrictive policy
  - E.g. All users: 1 process, 1 open file … one everything is far too restrictive

THE OSTRICH ALGORITHM

- Stick your head in the sand; pretend there is no problem at all

Reactions

- Mathematician: Unacceptable; prevent at all costs

OS suffer from deadlocks that are not even detected

- Number of processes in the system
  - Total determined by slots in the process table
  - Slots are a finite resource
- Maximum number of open files
  - Restricted by size of the inode table
- Swap space on the disk

OS suffer from deadlocks that are not even detected

- If deadlock elimination is free
  - No discussions
- But the price is often high
  - Inconvenient restrictions on processes
  - Tradeoff
  - Between convenience and correctness
The contents of this slide-set are based on the following references: