CS 370: OPERATING SYSTEMS
[DEADLOCKS]

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Frequently asked questions from the previous class survey

- How is sched_latency chosen?
- Are there cases where processes don't need as much of the time slice that they are assigned? Downsides if this is the case?
- How does a scheduler assign a process to the same core to avoid cache?

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Topics covered in this lecture

- Dealing with Deadlocks
- Deadlock Prevention
- Deadlock Avoidance

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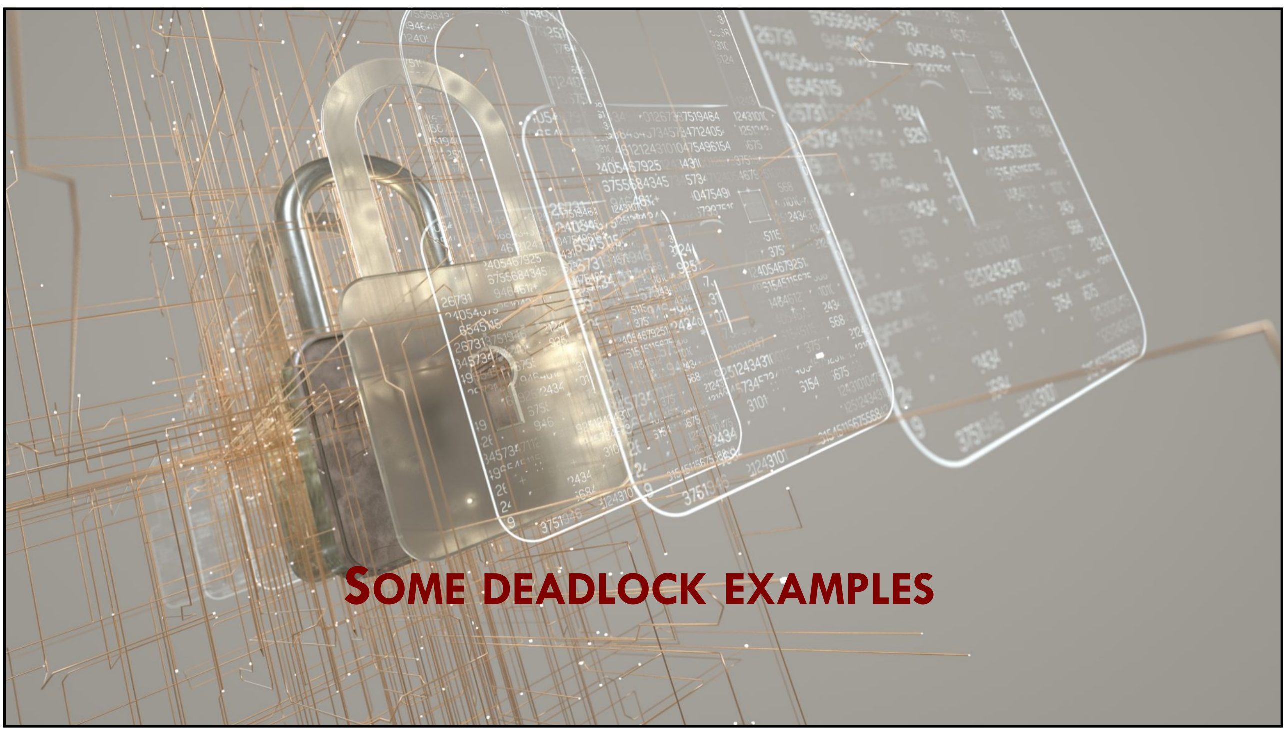

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Law passed by Kansas Legislature … early 20th Century

"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"

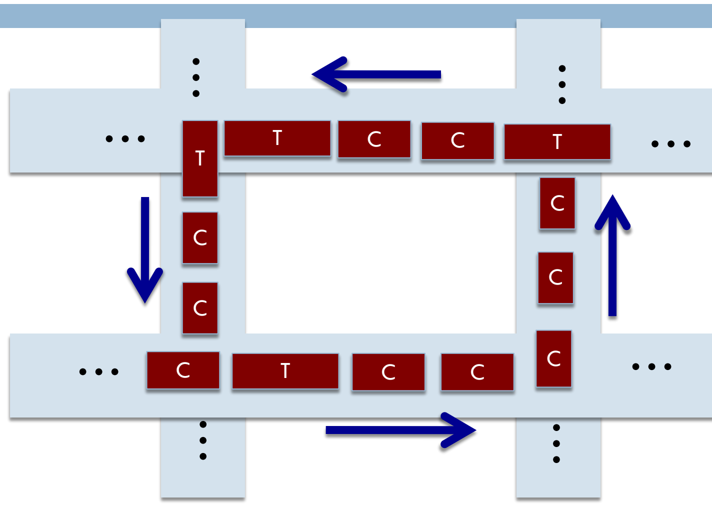
Dining philosophers problem: Necessary conditions for deadlock (1)

- 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

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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

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DEALING WITH DEADLOCKS

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Four strategies for dealing with deadlocks

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

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Ostrich Algorithm

- Stick your head in the sand; pretend there is no problem at all
- Reactions
  - Mathematician: Unacceptable; prevent at all costs
  - Engineers: How often? Costs? Etc.

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OS suffer from deadlocks that are not even detected [1/3]

- 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 [2/3]

- Every OS table represents a **finite** resource
- Should we abolish all of these because collection of n processes
  1. Might claim $1/n$ th of the total AND
  2. 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

OS suffer from deadlocks that are not even detected [3/3]

- If deadlock elimination is free
  - No discussions
- But the price is often high
  - Inconvenient restrictions on processes
- Tradeoff
  - Between **convenience** and **correctness**

DEADLOCK CHARACTERIZATION

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

Deadlocks: Necessary Conditions (II)

- **No preemption**
  - Resources cannot be preempted
  - Only voluntary release by process holding it
- **Circular wait**
  - A set of $\{P_0, P_1, \ldots, P_n\}$ waiting processes must exist
    - $P_0 \rightarrow P_1; P_1 \rightarrow P_2, \ldots, P_n \rightarrow P_0$
  - Implies hold-and-wait

Hanging on
You're all that's left to hold on to
I'm still waiting
I'm hanging on
You're all that's left to hold on to

Red Hill Mining Town, The Joshua Tree, U2

DEADLOCK PREVENTION

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Deadlock Prevention

- Ensure that **one** of the necessary conditions for deadlocks *cannot* occur
  1. Mutual exclusion
  2. Hold and wait
  3. No preemption
  4. Circular wait

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Mutual exclusion must hold for non-sharable resources, but …

- Sharable resources do not require mutually exclusive access
  - *Cannot be involved* in a deadlock
- A process never needs to wait for sharable resource
  - Read-only files
- Some resources are *intrinsically nonsharable*
  - So, denying mutual exclusion often not possible

Deadlock Prevention: Ensure hold-and-wait never occurs in the system [Strategy 1]

- Process must request and be allocated all its resources **before** execution
  - Resource requests must precede other system calls
- E.g., copy data from DVD drive, sort file, & print
  - Printer needed only at the end
  - BUT process will hold printer for the *entire* execution

Deadlock Prevention: Ensure hold-and-wait never occurs in the system [Strategy 2]

- Allow a process to request resources *only when it has none*
  - *Release* all resources, *before requesting* additional ones
- E.g., copy data from DVD drive, store file, & print
  - First request DVD and disk file
    - Copy and release resources
  - Then request file and printer

Disadvantages of protocols targeting hold-and-wait

- **Low resource utilization**
  - Resources are allocated but unused for long durations
- **Starvation**
  - If a process needs several popular resources
    - Popular resource might always be *allocated to some other* process

Deadlock Prevention: Eliminate the preemption constraint [1/2]

- {C1} If a process is holding some resources
- {C2} Process requests another resource
  - Cannot be immediately allocated
- All resources currently held by process is **preempted**
  - Preempted resources added to list of resources process is waiting for

Deadlock Prevention: Eliminate the preemption constraint [2/2]

- Process requests resources that are not currently available
  - If resources are allocated to another waiting process?
    - Preempt resources from the second process and assign it to the first one
- Often applied when resource state can be ***saved and restored***
  - CPU registers and memory space
  - Unsuitable for tape drives

Deadlock Prevention: Eliminating Circular wait

- Impose **total ordering** of all resource types
  - Assign each resource type a unique number
  - One-to-one function `F:R→N`

```
F(tape drive) = 1;
F(printer) = 12
```

1. Request resources in ***increasing* order**
2. If several instances of a resource type needed?
   - Single request for all them must be issued

Requesting resources in an increasing order of enumeration

- Process initially requested R_i
- This process can now request R_j ONLY IF

  $F(R_j) > F(R_i)$
- Alternatively, process requesting R_j must have released resources R_i such that

  $F(R_i) >= F(R_j)$
- Eliminates circular wait

Hierarchy of resources and deadlock prevention

- Hierarchy by itself does not prevent deadlocks
  - Developed programs **must follow ordering**
- **F** *based on* ***order*** *of usage* of resources
  - Tape drive needed before printing
    - `F(tape drive) < F(printer)`

Deadlock Prevention: **Summary**

- Prevent deadlocks by **restraining** how requests are made
  - Ensure at least 1 of the 4 conditions *cannot* occur
- Side effects:
  - Low device utilization
  - Reduced system throughput

Dining Philosophers: Deadlock prevention strategies [1/2]

- Mutual exclusion
  - Philosophers can *share* a chopstick
- Hold-and-wait
  - Philosopher should release the first chopstick if it cannot obtain the second one

Dining Philosophers: Deadlock prevention strategies [2/2]

- Preemption
  - Philosophers can *forcibly take* each other's chopstick
- Circular-wait
  - Number the chopsticks
  - Pick up chopsticks in ascending order
    - Pick the lower numbered one before the higher numbered one

DEADLOCK AVOIDANCE

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Deadlock avoidance

- Require *additional* information about **how** resources are to be requested
- Knowledge about sequence of requests and releases for processes
  - Allows us to decide if resource allocation *could cause a future deadlock*
  - Process P: Tape drive, then printer
  - Process Q: Printer, then tape drive

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Deadlock avoidance: Handling resource requests

- For each resource request:
  - Decide whether or not process should wait
    - To avoid possible **future** deadlock
- Predicated on:
  1. Currently available resources
  2. Currently allocated resources
  3. Future requests and releases of each process

Avoidance algorithms differ in the amount and type of information needed

- **Resource allocation state**
  - Number of available and allocated resources
  - Maximum demands of processes
- Dynamically **examine** resource allocation state
  - Ensure circular-wait cannot exist
- Simplest model:
  - Declare maximum number of resources for each type
  - Use information to avoid deadlock

Safe sequence

- **Sequence** of processes $<P_1, P_2, \ldots, P_n>$ for the current allocation state
- Resource requests made by P_i can be satisfied by:
  - Currently available resources
  - Resources held by P_j where $j < i$
    - If needed resources not available, P_i can wait
  - In general, when P_i terminates, P_{i+1} can obtain its needed resources
- If no such sequence exists: system state is **unsafe**

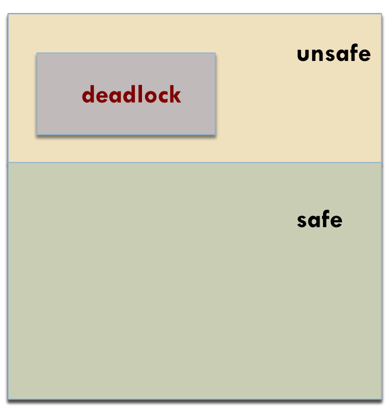
Deadlock avoidance: Safe states

- If the system can:
  1. Allocate resources to each process in **some order**
     - Up to the *maximum* for the process
  2. Still avoid deadlock

Safe states and deadlocks

- A system is safe ONLY IF there is a **safe sequence**
- A safe state is not a deadlocked state
  - Deadlocked state is an unsafe state
  - Not all unsafe states are deadlocks

State spaces



Unsafe states

- An unsafe state *may lead* to deadlock
- **Behavior** of processes controls unsafe states
- Cannot prevent processes from requesting resources such that deadlocks occur

Example: 12 Tape drives available in the system

	Maximum Needs	Current Allocation
P_0	10	5
P_1	4	2
P_2	9	2

Before T0:
3 drives available

Safe sequence
<P_1, P_0 , P_2>

- At time **T0** the system is in a safe state
- P_1 can be given 2 tape drives
- When P_1 releases its resources; there are 5 drives
- P_0 uses 5 and subsequently releases them (# 10 now)
- P_2 can then proceed

Example: 12 Tape drives available in the system

	Maximum Needs	Current Allocation
P_0	10	5
P_1	4	2
P_2	9	2

Before T1:
3 drives available

- At time **T1**, P_2 is allocated 1 tape drive

Example: 12 Tape drives available in the system

	Maximum Needs	Current Allocation
P_0	10	5
P_1	4	2
P_2	9	3

After T1:
2 drives available

- At time **T1**, P_2 is allocated 1 tape drive
- Only P_1 can proceed.
- When P_1 releases its resources; there are 4 drives
  - P_0 needs 5 and P_2 needs 6
- **Mistake** in granting P_2 additional tape drive

Crux of deadlock avoidance algorithms

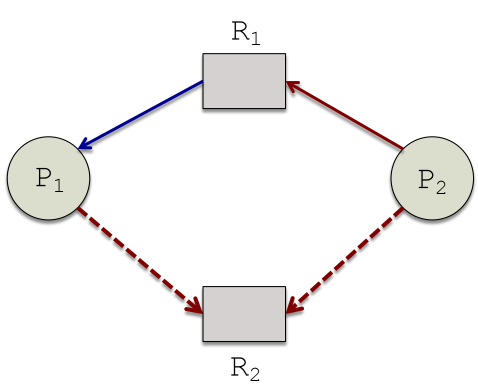
- **Ensure** that the system will always remain in a safe state
- Resource allocation request **granted** only if it will leave the system in a safe state

RESOURCE ALLOCATION GRAPH ALGORITHM

Claim edges

- Indicates that a process P_i may request a resource R_j at some time in the future
- Representation:
  - Same direction as request
  - Dotted line

Resource allocation graph with a claim edge



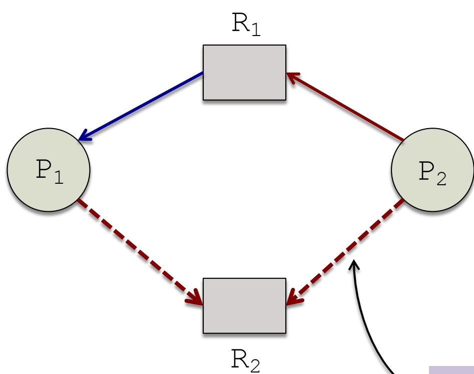
Conversion of claim edges

- When process P_i requests resource R_j
  - Claim edge converted to a request edge
- When resource R_j released by P_i
  - The assignment edge $R_j \rightarrow P_i$ is **reconverted** to a claim edge $P_i \rightarrow R_j$

Allocating resources

- When process P_i requests resource R_j
- Request granted only if
  - Converting claim edge to $P_i \rightarrow R_j$ to an assignment edge $R_j \rightarrow P_i$ *does not result* in a **cycle**

Using the allocation graph to allocate resources safely



P_2 has requested R_2

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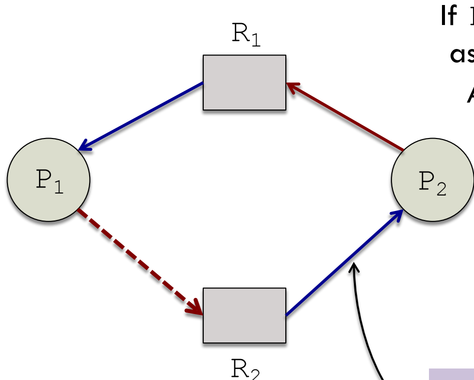
Using the allocation graph to allocate resources safely

If P_1 requests R_2 after it's assigned to P_2?
A deadlock will occur



Assignment leads to a cycle

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Resource allocation graph algorithm

- Not applicable in systems with multiple resource instances

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 7]
- *Andrew S Tanenbaum. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620. [Chapter 6]*