# Design and Analysis of Operating Systems
# CSCI 3753

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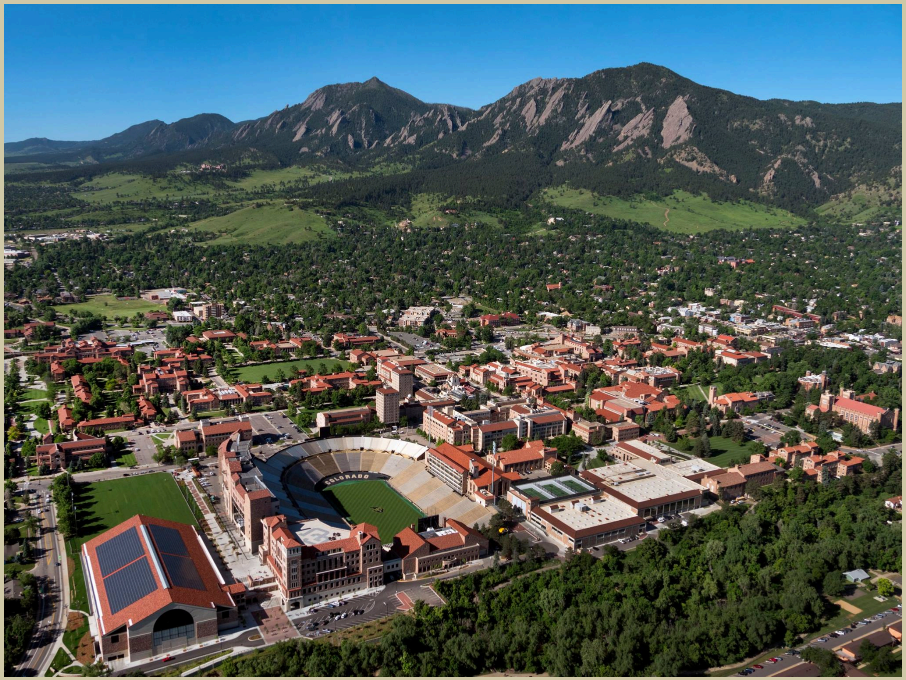
# Modeling Deadlock



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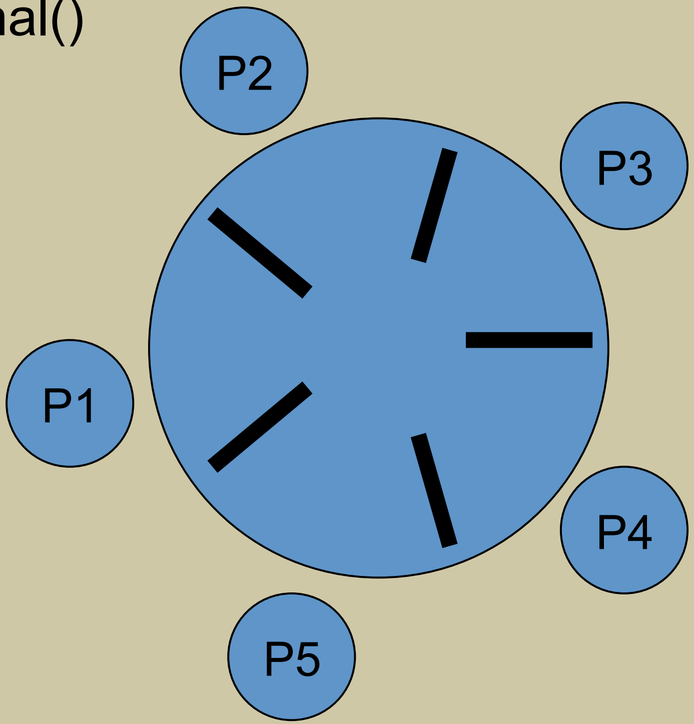
# Complete Monitor-based Solution to Dining Philosophers

```
monitor DP {
   status state[5];
   condition self[5];

   Pickup(int i) {
      state[i] = hungry;
      test(i);
      if(state[i]!=eating)
         self[i].wait;
   }

   test(int i) {
      if (state[(i+1)%5] != eating &&
         state[(i-1)%5] != eating &&
         state[i] == hungry) {

         state[i] = eating;
         self[i].signal();
      }
   }

   Putdown(int i) {
         state[i] = thinking;
         test((i+1)%5);
         test((i-1)%5);
   }

   init() {
      for i = 0 to 4
         state[i] = thinking;
   }
}  // end of monitor
```

# Deadlock Free Solution

- Monitors for implicit mutual exclusion
- Condition variables for ordering
  - cv.wait()
  - cv.signal() differs from semaphore's signal()

- Monitor-based solution to Dining Philosophers



# Deadlock: General Solution?

- Want a general solution to deadlock that is not restricted to the solutions for the 3 classic problems of DP, R/W, and BB P/C

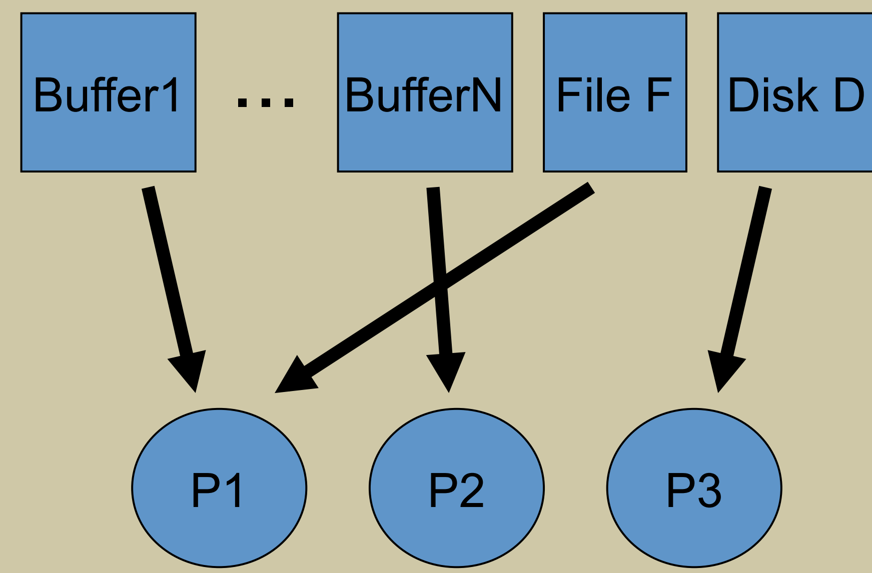
- A set of processes is in a deadlock state when every process in the set is waiting for an event (e.g. release of a resource) that can only be caused by another process in the set
  - You have a circular dependency

- multithreaded and multi-process applications are good candidates for deadlock
  - thread-thread deadlock within a process
  - process-process deadlock

# Modeling Deadlock

- Develop a model so we can see circular dependency
  - to use a resource, a process must
    1. request() a resource -- must *wait* until it's available
    2. use() or hold() a resource
    3. release() a resource
  - thus, we have resources and processes
  - Most of the following discussion will focus on reusable resources

Resources




Processes

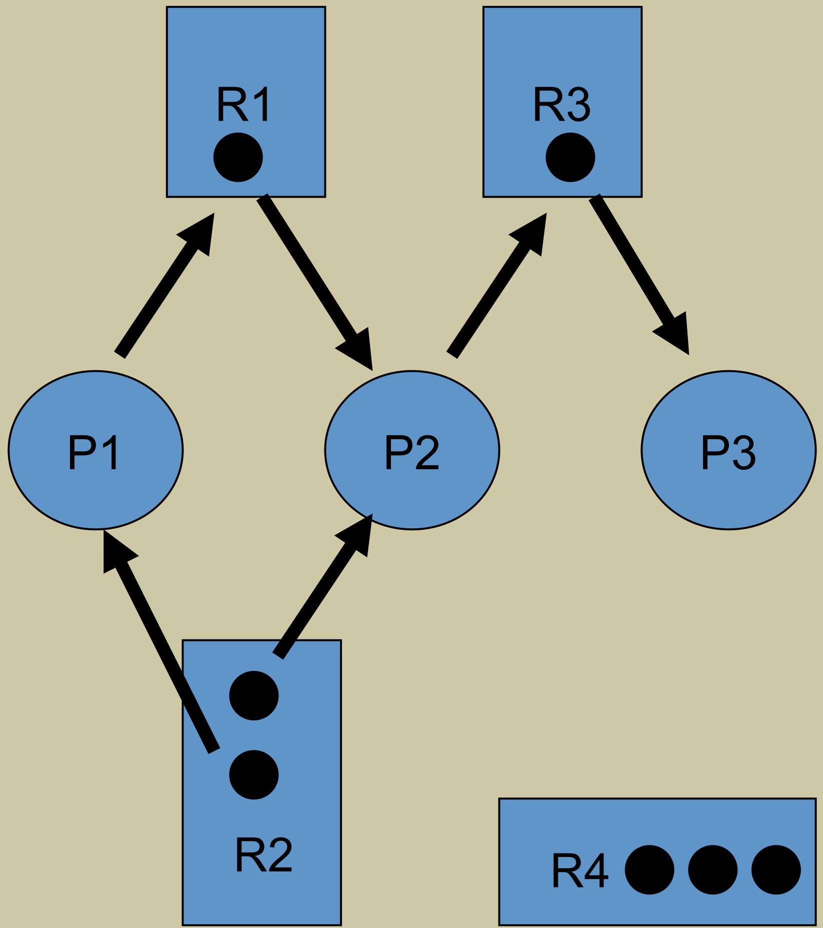
P1 holds Buffer 1 and File F
P2 holds Buffer N
P3 holds Disk D

# Modeling Deadlock using Directed Graph

- a ***resource allocation graph*** can be used to model deadlock
  - try to represent deadlock by a *directed graph* D(V,E), consisting of
    - vertices V: namely processes and resources
    - and edges E:
      - a request() for a resource $R_j$ by a process $P_i$ is signified by a directed arrow from process $P_i \rightarrow R_j$
      - a process $P_i$ will hold() a resource $R_j$ via a directed arrow $R_j \rightarrow P_i$

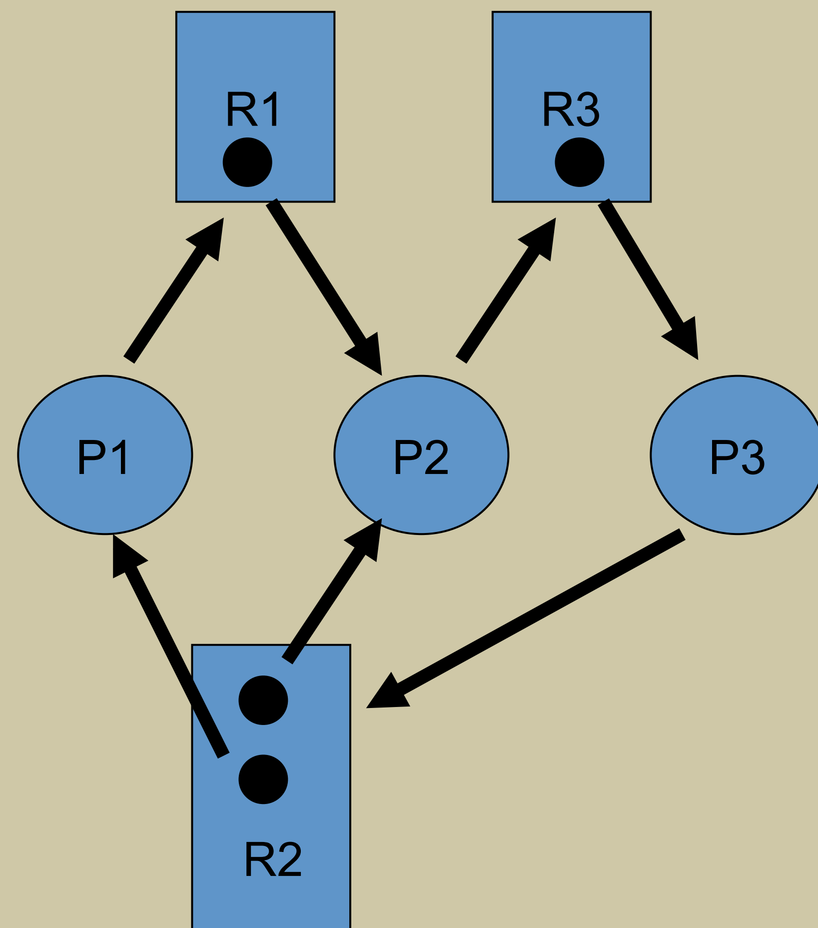
# Modeling Deadlock

- Example 1:
  - P1 wants resource R1 but that is held by P2
  - P2 wants resource R3 but that is held by P3
  - Also, P1 holds an *instance* of resource R2, and
  - P2 holds an instance of R2
  - There is no deadlock
    - if the graph contains no cycles or loops, then there is no deadlock



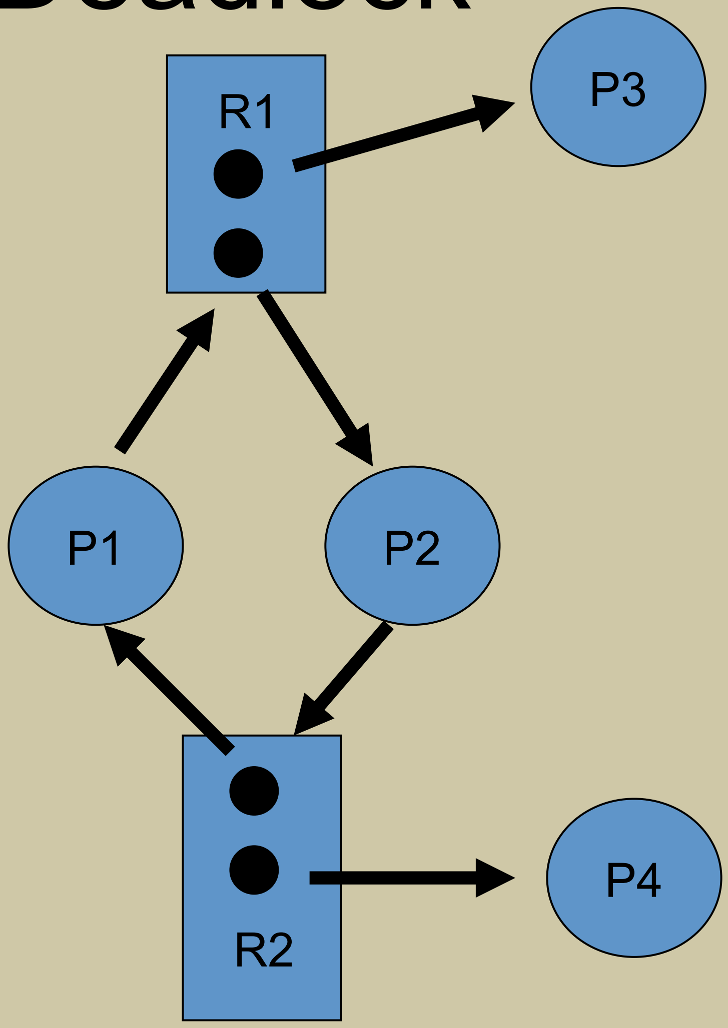
# Modeling Deadlock

- Example 2:
  - same graph as before, except now P3 requests instance of R2
  - Deadlock occurs!
    - P3 requests R2, which is held by P2, which requests R3, which is held by P3 - this is a loop
      - $P_3 \rightarrow R_2 \rightarrow P_2 \rightarrow R_3 \rightarrow P_3$
      - If P1 could somehow release an instance of R2, then we could break the deadlock
    - But P1 is part of a second loop:
      - $P_3 \rightarrow R_2 \rightarrow P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_3 \rightarrow P_3$
      - So P1 can't release its instance of R2
  - if the graph contains cycles or loops, then there *may be the possibility* of deadlock
    - but does a loop guarantee that there is deadlock?



# Modeling Deadlock

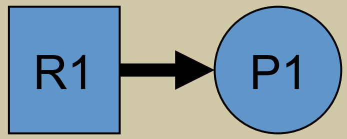
- Example 3:
  - there is a loop:
    - $P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_2 \rightarrow P_1$
  - In this case, there is no deadlock
    - either P3 can release an instance of R1, or P4 can release an instance of R2
      - this breaks any possible deadlock cycle
  - if the graph contains cycles or loops, then there *may be the possibility* of deadlock, but this is not a guarantee of deadlock



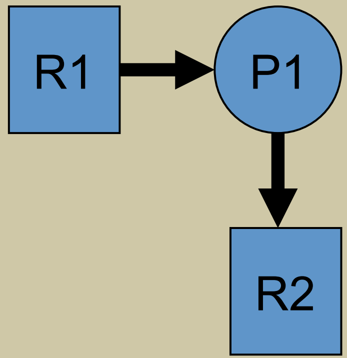
# Necessary Conditions for Deadlock

- The following 4 conditions must hold simultaneously for deadlock to arise:

1. Mutual exclusion
   - at least 1 resource is held in a non-sharable mode. Other requesting processes must wait until the resource is released

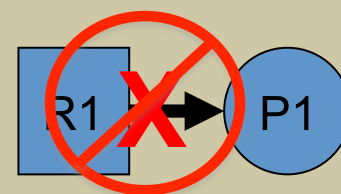



2. Hold and wait
   - a process holds a resource while requesting (and waiting for) another one

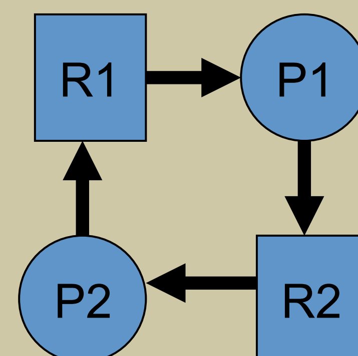


# Necessary Conditions for Deadlock

- The following 4 conditions must hold simultaneously for deadlock to arise: (continued)




3. No preemption:
   - resources cannot be preempted and can only be released voluntarily by the process holding them, after the process is finished.  No OS intervention is allowed.  A process cannot withdraw its request.




4. Circular wait
   - A set of n waiting processes $\{P_0, ..., P_{n-1}\}$ must exist such that Pi waits for a resource held by $P_{(i+1)\%n}$

# Solutions to Handling Deadlocks

1. Prevention by OS
   – provide methods to guarantee that at least 1 of the 4 necessary conditions for deadlock does not hold
2. Avoidance by OS
   – the OS is given advanced information about process requests for various resources
   – this is used to determine whether there is a way for the OS to satisfy the resource requests and avoid deadlock

# Solutions to Handling Deadlocks (2)

3. Detection and Recovery by OS
   - Analyze existing system resource allocation, and see if there is a sequence of releases that satisifies every process' needs.
   - If not, then deadlock is detected, so must recover – drastic action needed, like killing the affected processes!

# Solutions to Handling Deadlocks (3)

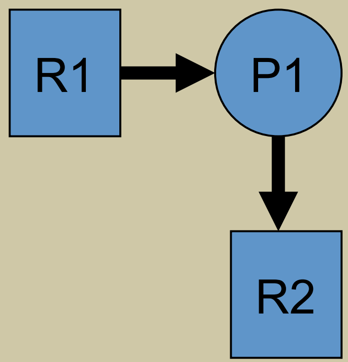
4. Application-level solutions (OS Ignores and Pretends)
   - the most common approach, e.g. UNIX and Windows, based on the assumption that deadlock is relatively infrequent
   - it's up to the application programmer to implement mechanisms that prevent, avoid, detect and deal with application-level deadlock
   - Map your problem to known deadlock-free solutions: e.g. Bounded Buffer P/C, Readers/Writers problems, Dining Philosophers, …

# Deadlock Prevention: Mutual Exclusion

- Prevent the *mutual exclusion* condition #1 from coming true
  - This is opposite of our original goal, which was to provide mutual exclusion.
  - Also, many resources are non-sharable and must be accessed in a mutually exclusive way
    - example: a printer should print a file X to completion before printing a file Y. a printer should not print half of file X, and then print the first half of file Y on the same paper
  - thus, it is unrealistic to prevent mutual exclusion

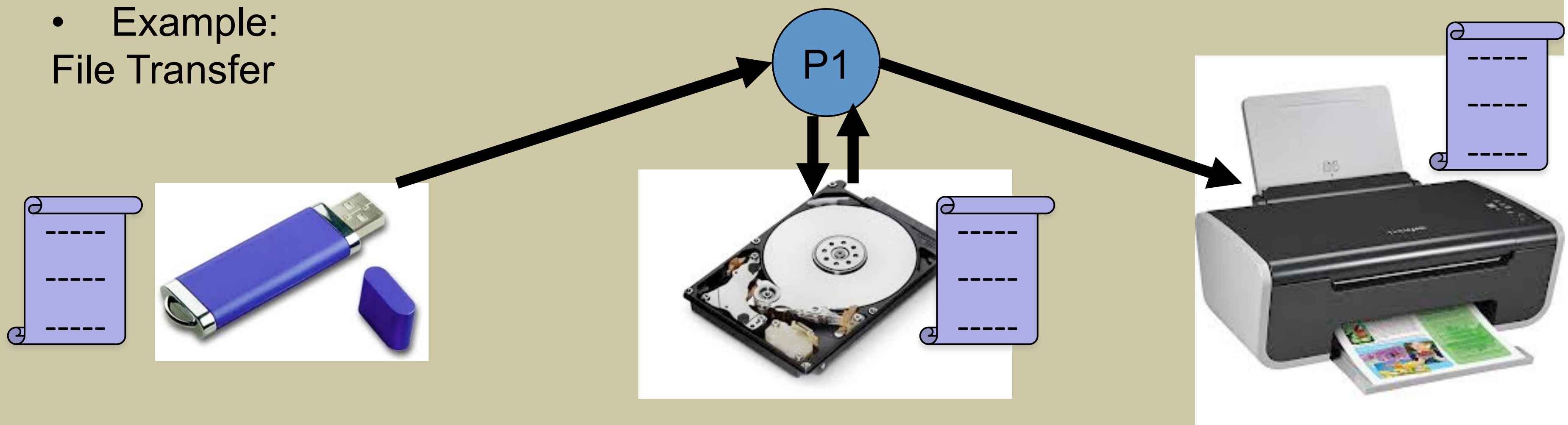
# Deadlock Prevention: Hold and Wait

- Prevent the hold and wait condition #2 from coming true
  - prevent a process from holding resources and requesting others
  - Solution I: request all resources at process creation
  - Solution II: release all held resources before requesting a set of new ones simultaneously
  - Solution III: only allow a process to hold one resource at a time



# Deadlock Prevention: Hold and Wait

- Example:
File Transfer

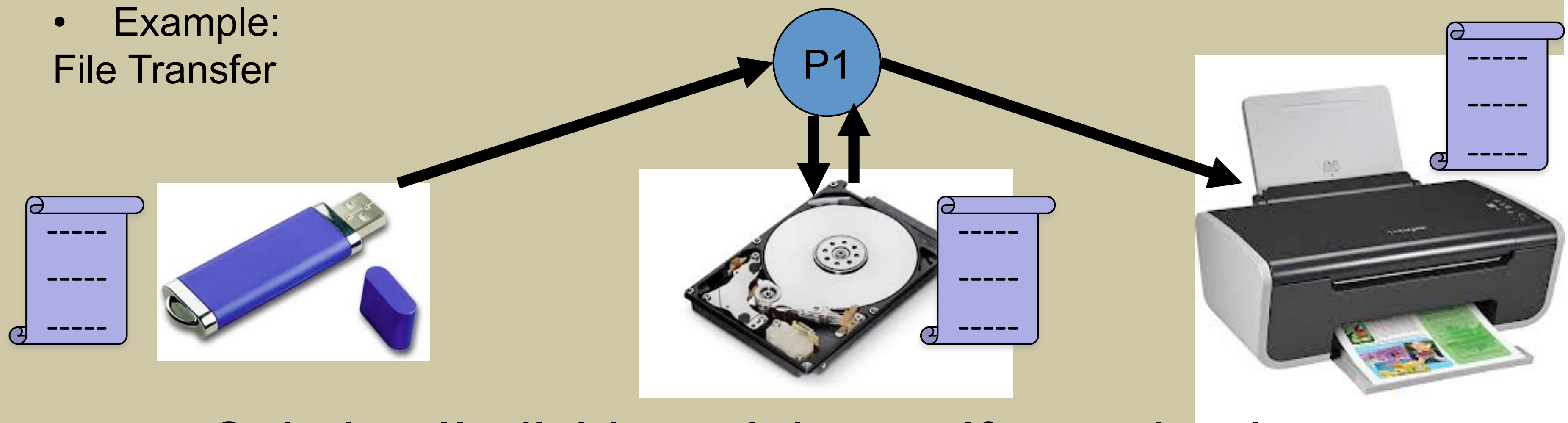



- a process reads file from USB drive and writes it to hard drive, retrieves the file, then sends the file to the printer
- Solution I: request the USB drive, hard drive, and printer at process creation

# Deadlock Prevention: Hold and Wait

- Example:

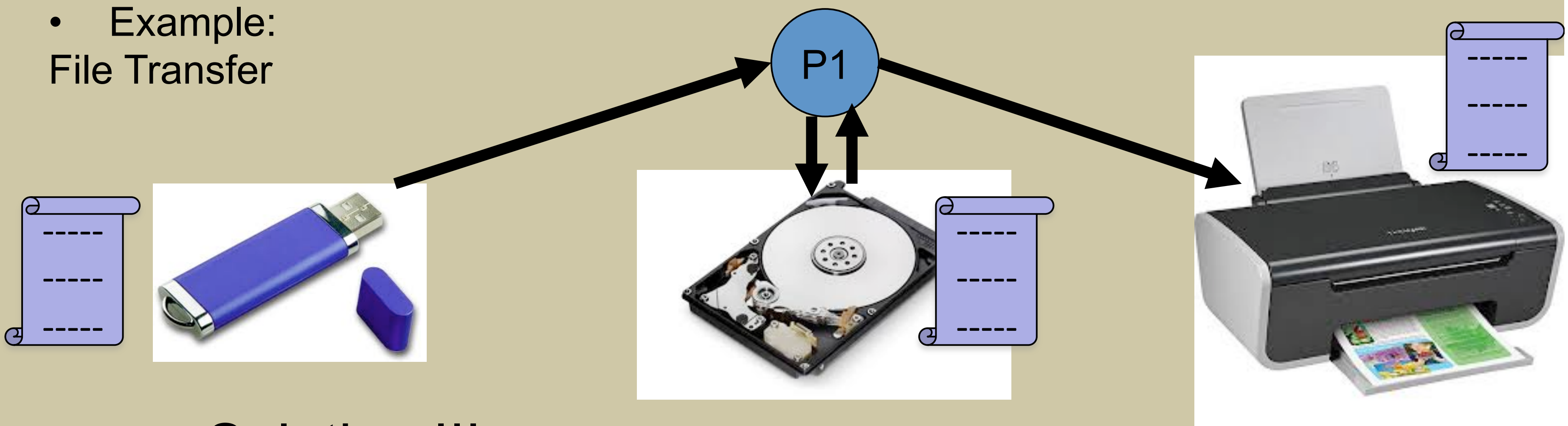
File Transfer




– Solution II: divide task into self-contained stages that release all & then request all resources
  - obtain the USB and hard drive together for the file transfer, then release both together
  - next obtain the hard drive and printer together for the printing operation, then release both together

# Deadlock Prevention: Hold and Wait

- Example: File Transfer




– Solution III:
  - Request the USB drive then release
  - Request the hard drive then release
  - Request the hard drive again then release
  - Request the printer then release

# Deadlock Prevention: Hold and Wait

- Disadvantages of Hold-and-wait solutions
  - Solution I: don't know in advance all resources needed
  - Solutions I & II: poor resource utilization
    - a process that is holding multiple resources for a long time may only need each resource for a short time during execution
  - Solution II: possible starvation
    - a process that needs several popular resources simultaneously may have to wait a very long time

# Deadlock Prevention: Hold and Wait

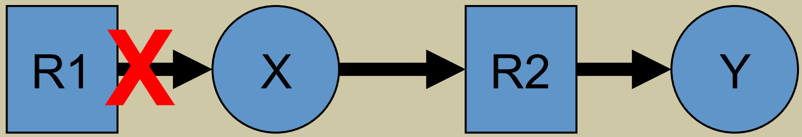
- Disadvantages of Hold-and-wait solutions
  - Solution III: Some processing may require holding more than one resource at a time
    - e.g. writing a file to a printer may require locking both the file and the printer
    - Reading a file from a drive may require locking both the file and the drive

# Deadlock Prevention: Hold and Wait

- Example: Dining Philosophers Problem prevented hold-and-wait – How?
  - Enforced a rule that either a philosopher picked up both chopsticks or none at all, i.e. all-or-nothing
  - Hence no holding one chopstick while waiting on the other chopstick

# Deadlock Prevention: No Preemption

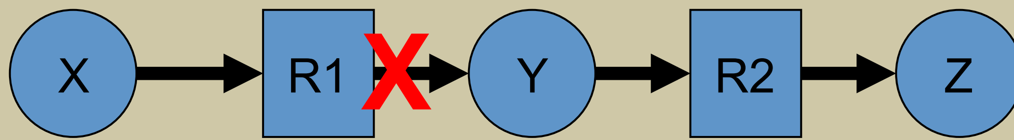
- Prevent the “No Preemption” condition #3 from coming true
  - allow resources to be preempted




  - Policy I:
    - If a Process X requests a held resource, then all resources currently held by X are released.
    - X is restarted only when it can regain all needed resources

# Deadlock Prevention: No Preemption

– Policy II:




- If a process X requests a resource held by process Y, then preempt the resource from process Y, but only if Y is waiting on another resource
- Otherwise, X must wait.
- the idea is if Y is holding some resources but is waiting on another resource, then Y has no need to keep holding its resources since Y is suspended

# Deadlock Prevention: No Preemption

- Disadvantages:
  - these policies don't apply to all resources, e.g. printers should not be prempted while in the middle of printing, disks should not be preempted while in the middle of writing a block of data
  - can result in unexpected behavior of processes, since an application developer may not know a priori which policy is being used

# Deadlock Prevention: Circular Wait

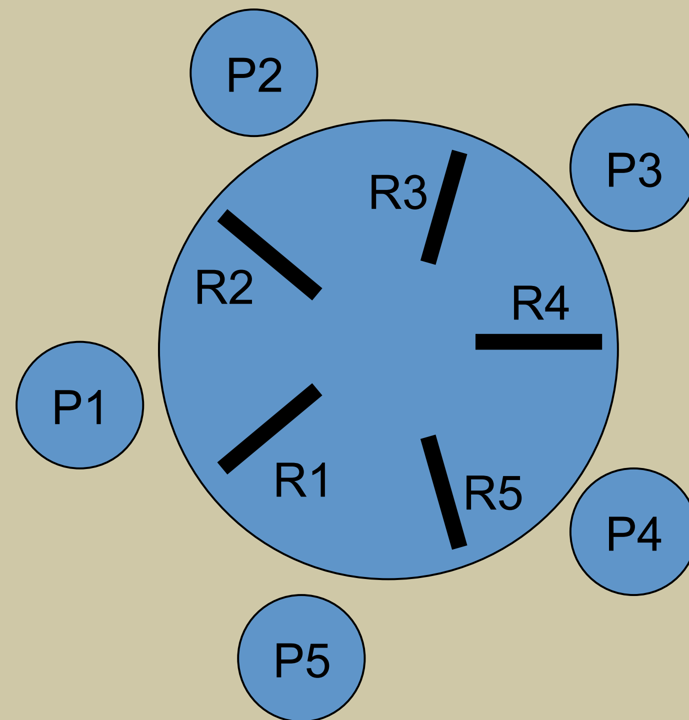
- Prevent the *circular wait* condition #4 from coming true
  - Solution I: a process can only hold 1 resource at a time
    - disadvantage: in some cases, a process needs to hold multiple resources to accomplish a task
  - Solution II: impose a total ordering of all resource types and require each process to request resources in increasing order
    - this prevents a circular wait - see next slide

# Deadlock Prevention: Circular Wait

- Solution II example:
  - Order all resources into a list: R1, R2, ..., Rm, where R1 < R2 < ... < Rm
    - tape drive = R1, disk drive = R2, printer = R10, temporary buffer = R22
  - Impose the rule that a process holding $R_i$ can only request $R_j$ if $R_j > R_i$
  - If a process P holds some $R_k$ and requests $R_j$ such that $R_j < R_k$, then the process must release all such $R_k$, acquire $R_j$, then reacquire $R_k$

# Deadlock Prevention: Circular Wait

- Applying ordering of resources to break circular waiting in the Dining Philosophers Problem
  - R1 < R2 < R3 < R4 < R5
  - Deadlock happened when all processes first requested their right chopsticks, then requested their left chopsticks
  - Here, P1 to P4 can all request their right then left chopsticks
  - *But Process P5 requests its left (R1) then right (R5) chopstick due to ordering*
    - thus, P5 blocks on R1, not R5, which breaks any possibility of a circular deadlock - why?



# Deadlock Prevention: Circular Wait

- Disadvantages of ordering resources:
  - can lead to poor performance, due to releasing and then reacquiring resources
  - Difficult to implement in a dynamic resource environment
    - Coming up with a global scheme for numbering resources

# Solutions to Handling Deadlocks

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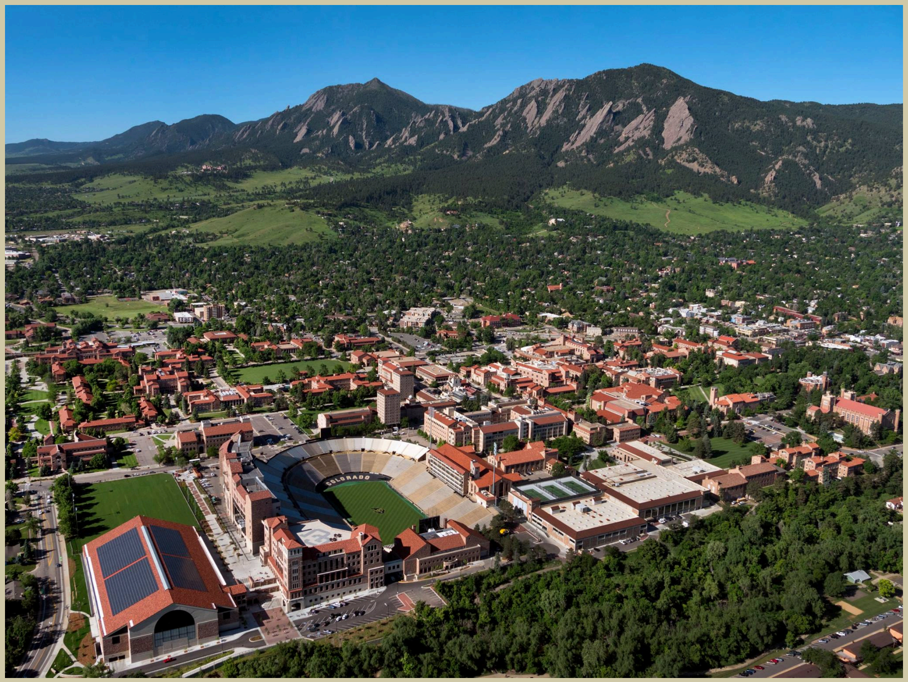


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