CS 370: Operating Systems

[Atomic Transactions & Deadlocks]

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Topics covered in today's lecture

- Atomic Transactions
  - Locking protocols
  - Timestamp protocols
- Deadlocks
- Deadlock characterization

Locking Protocols

Locking protocol governs *how* locks are acquired and released

- There are different **modes** in which data can be locked
  - A transaction acquires a lock on a data item in different modes
- **Shared** mode locks
  - T_i can read, but not write, data item Q
- **Exclusive** mode locks
  - T_i can read and write data item Q

Transactions must request locks on data items in the right mode

- To **access** data item Q; T_i must first **lock** it
  - Wait if Q is locked in the exclusive mode
  - If T_i requests a shared-lock on Q
    - Obtain lock if Q is not locked in the *exclusive* mode

- T_i *must hold* lock on data item as long as it accesses it

Two-phase locking protocol: Locks and unlocks take place in two phases

- Transaction's **growing** phase:
  - Obtain locks
  - *Cannot release* any lock

- Transaction's **shrinking** phase
  - Can release locks
  - *Cannot obtain* any new locks

Two-phase locking protocol: Conflict serializability

- Conflicts occur when 2 transactions access same data item; and 1 of them is a write
- A transaction acquires locks serially; *without* releasing them during the acquire phase
  - Other transactions must wait for first transaction to start releasing locks.
- Deadlocks may occur

Order of conflicting transactions

- Two-phase locking
  - Determined at **execution** time

- How about selecting this order in *advance*?
  - **Timestamp based protocols**

Timestamp based protocols

- For each T_i there is a fixed timestamp
  - Denoted $TS(T_i)$
  - Assigned before T_i starts execution

- For a later T_j ; $TS(T_i) < TS(T_j)$

- Schedule must be equivalent to schedule in which T_i appears before T_j.

Timestamp based locking

- Protocol ensures there will be **no deadlock**
  - No transaction ever waits!

- Conflict serializabilty
  - Conflicting operations are processed *in timestamp order*

Each data item Q has two values

- `W-timestamp(Q)`
  - Largest timestamp of any transaction that successfully executed `write()`
- `R-timestamp(Q)`
  - Largest timestamp of any transaction that successfully executed `read()`

Transaction issues a `read(Q)`

- If $TS(T_i) <$ `W-timestamp(Q)`
  - Needs value that was already *overwritten*
  - The `read` is rejected and T_i is rolled back

- $TS(T_i) >=$ `W-timestamp(Q)`
  - Operation is executed
  - `R-timestamp(Q)` = **max**(`TS`(T_i), `R-timestamp(Q)`)

Transaction issues a `write(Q)`

- If `TS(`T_i`)` < `R-timestamp(Q)`
  - Value of Q produced by T_i needed *previously*
    - T_i assumed that this value would never be produced
  - The `write` is rejected and T_i is rolled back

- If `TS(`T_i`)` < `W-timestamp(Q)`
  - Trying to write an **obsolete** value of Q
  - The `write` is rejected and T_i is rolled back

What happens when a transaction is rolled back?

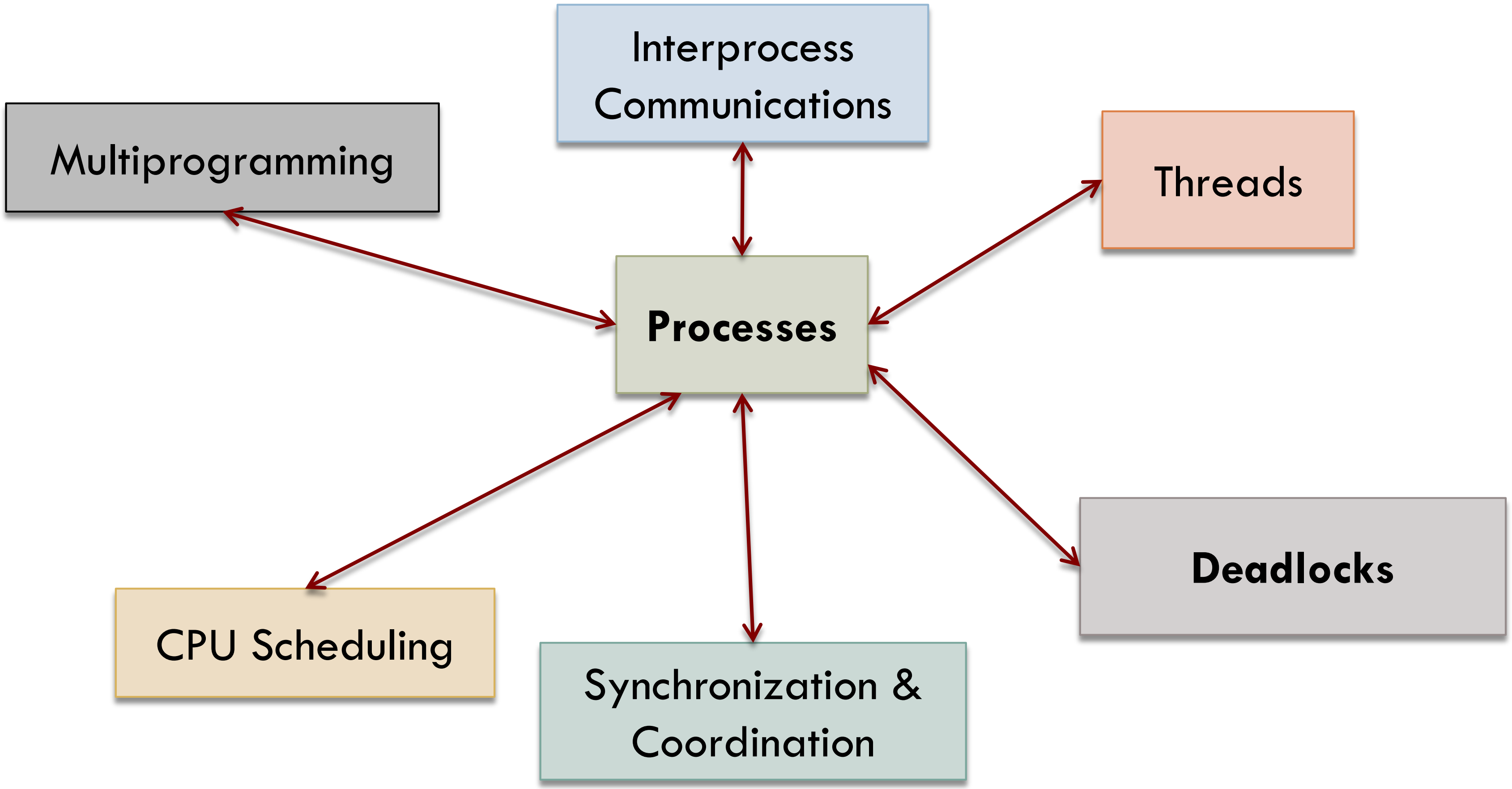
- Transactions T_i is assigned a new timestamp
  - Restart

Schedule using the timestamp protocol:

T2	T3
`read(B)`	
	`read(B)`
	`write(B)`
`read(A)`	
	`read(A)`
	`write(A)`

Timestamps are assigned to transactions before the start of the first instruction `TS(T2) < TS(T3)`

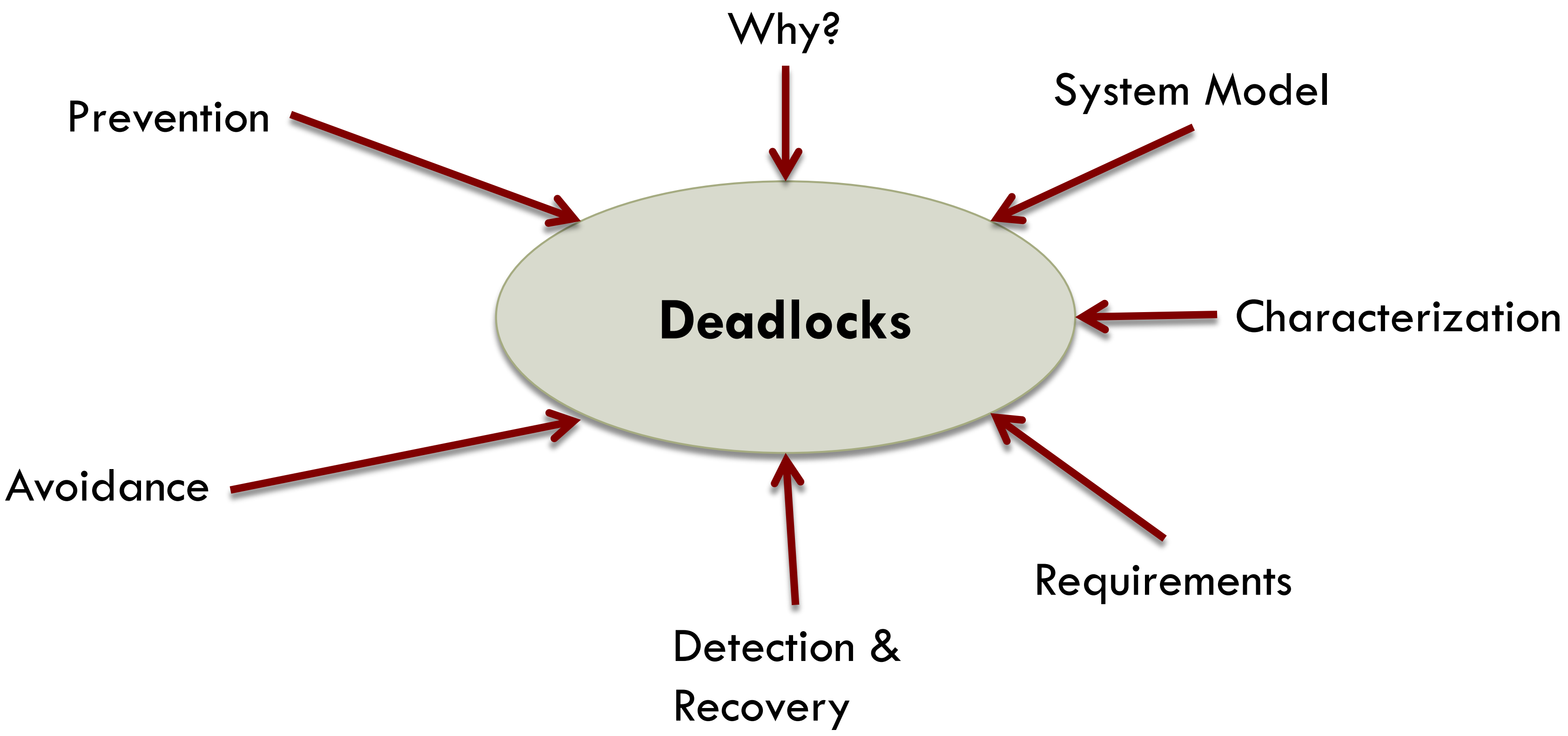
The Journey So Far …



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

DEADLOCKS

What we will look at …



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
    - Deadlock
- **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
  - Livelocks 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**

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
    - $P_0 \rightarrow P_1$; $P_1 \rightarrow P_2$, …, $P_n \rightarrow P_0$
  - Implies hold-and-wait

Resource allocation graph

- Used to describe deadlocks precisely

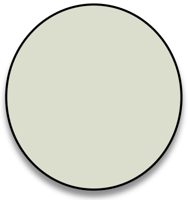
- Consists of a set of vertices and edges

- Two different sets of nodes
  - `P`: the set of all **active processes** in system
  - `R`: the set of all **resource types** in the system

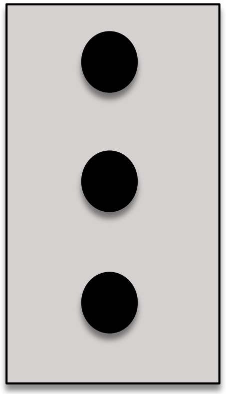
Directed edges

- **Request** edge
  - 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



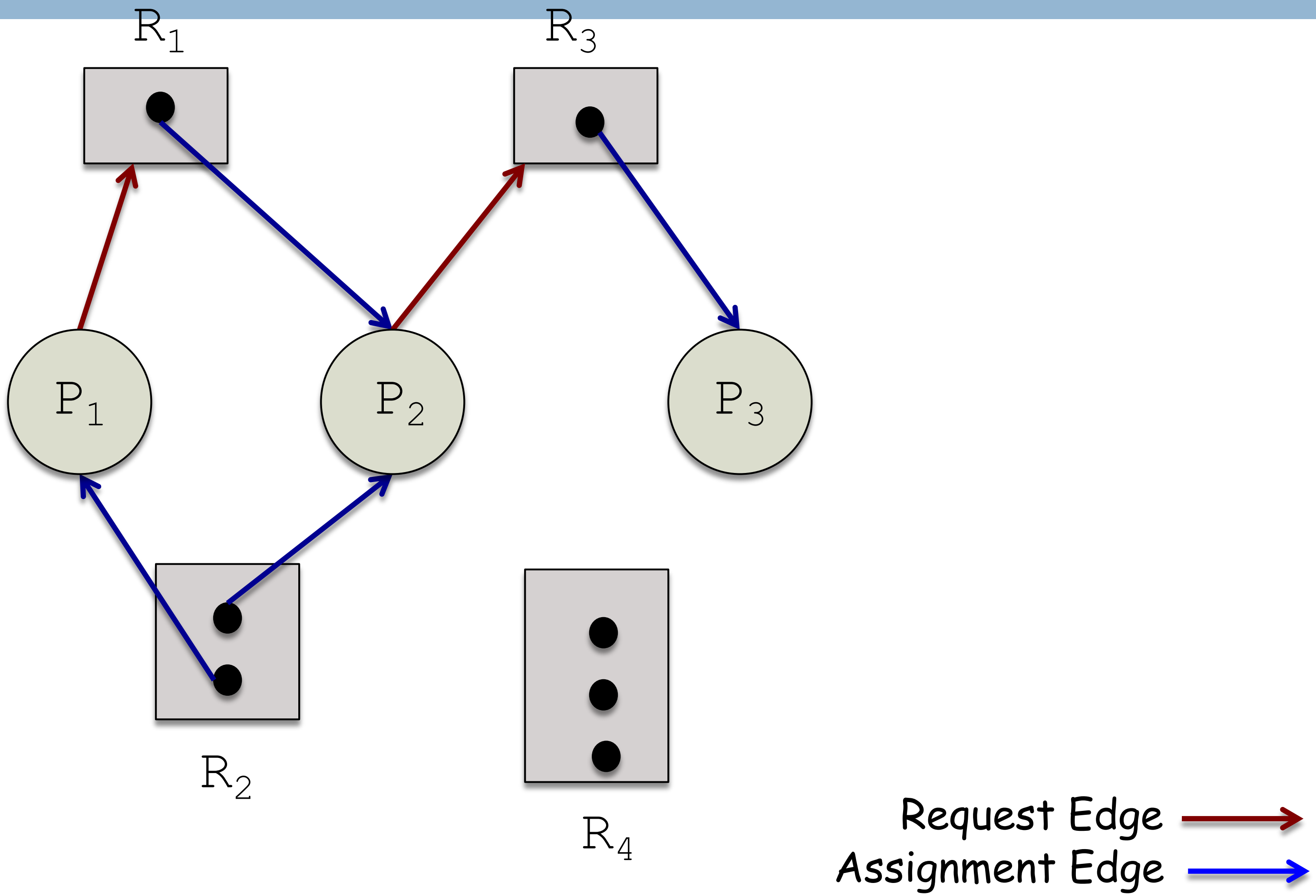
Processes



Resources

A resource type may have multiple instances

Resource Allocation Graph example

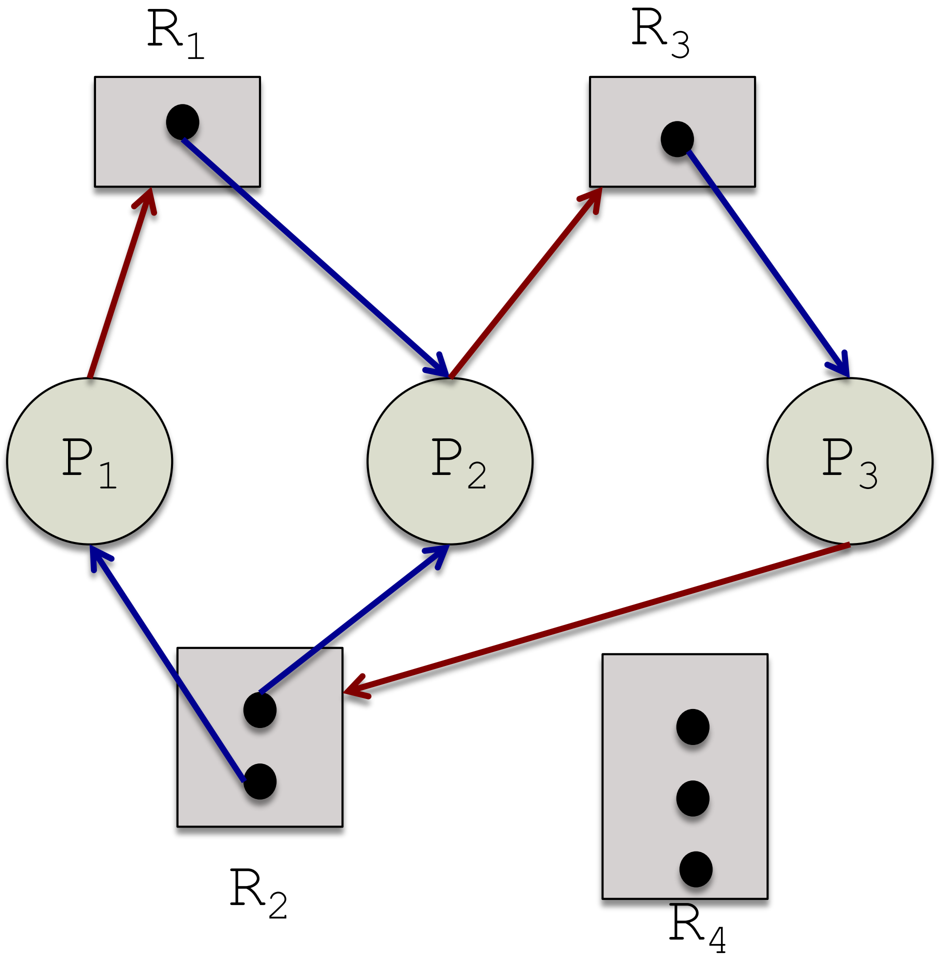


Determining deadlocks

- If the graph contains **no cycles**?
  - <u>No process</u> 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

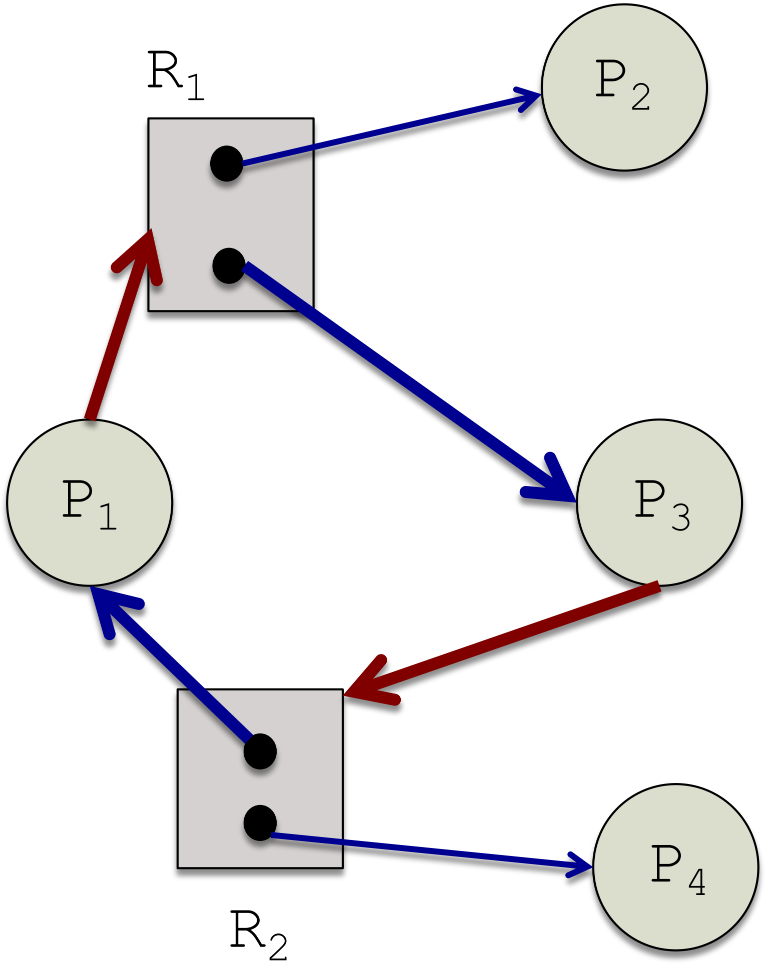


Two cycles

$P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_3 \rightarrow P_3 \rightarrow R_2 \rightarrow P_1$

$P_2 \rightarrow R_3 \rightarrow P_3 \rightarrow R_2 \rightarrow P_2$

Resource Allocation Graph: Cycle but not a deadlock



$P_1 \rightarrow R_1 \rightarrow P_3 \rightarrow R_2 \rightarrow P_1$

P_4 may release instance of R_2 allocate 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

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)

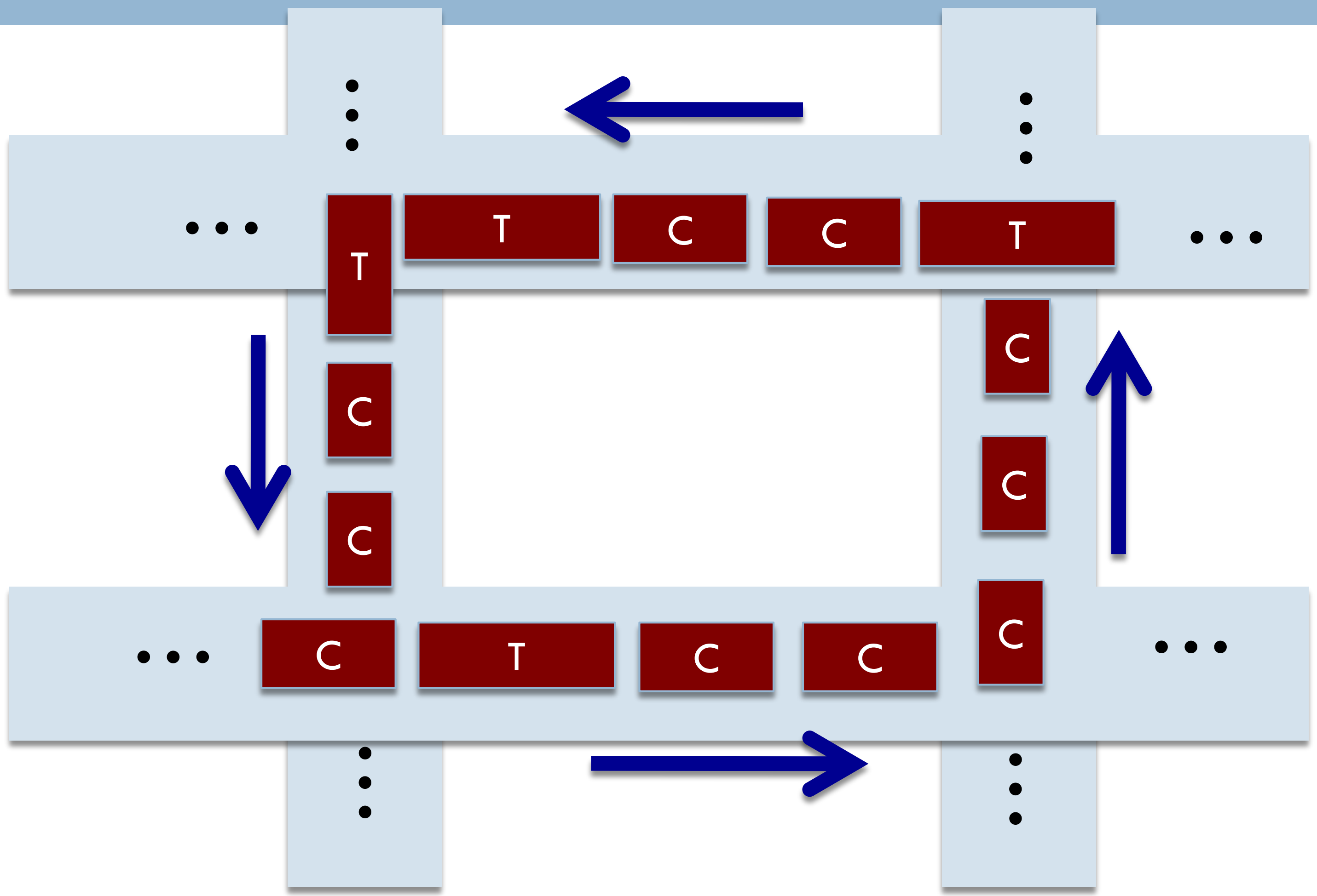
- Mutual exclusion
  - 2 philosophers *cannot share* the same chopstick
- Hold-and-wait
  - A philosopher *picks up one* chopstick at a time
  - Will not let go of the first while it *waits for the second* one

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

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 5, 7]
- *Andrew S Tanenbaum. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 7]