COS 140: Foundations of Computer Science

Handling Deadlocks: Banker's Algorithm

Fall 2018

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Homework, reminder

- Chapter 22 (online)
- Homework at the end of chapter
- Homework due 11/16 (later than usual!)
- Prelim II: Wednesday, 11/14

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Operating systems as resource managers

- Example of resources
- Sharable vs non-sharable resources
- *Preemptible* vs non-preemptible resources
- Potential problem: deadlocks

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What are deadlocks?

- A deadlock occurs when each process in a set of processes is waiting for some event that only another process in the set can cause. [after Tannenbaum]
- Example:

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  - P1: needs CD-ROM and sound card

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- Example:
  - P1: needs CD-ROM and sound card
  - P1: asks for CD-ROM and receives it

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- Example:
  - P1: needs CD-ROM and sound card
  - P1: asks for CD-ROM and receives it
  - P2: needs CD-ROM and sound card

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- Example:
  - P1: needs CD-ROM and sound card
  - P1: asks for CD-ROM and receives it
  - P2: needs CD-ROM and sound card
  - P2: asks for sound card and gets it

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- Example:
  - P1: needs CD-ROM and sound card
  - P1: asks for CD-ROM and receives it
  - P2: needs CD-ROM and sound card
  - P2: asks for sound card and gets it
  - P1: asks for sound card $\Rightarrow$ blocks

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- Example:
  - P1: needs CD-ROM and sound card
  - P1: asks for CD-ROM and receives it
  - P2: needs CD-ROM and sound card
  - P2: asks for sound card and gets it
  - P1: asks for sound card $\Rightarrow$ blocks
  - P2: asks for CD-ROM $\Rightarrow$ blocks

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Conditions for deadlocks

Mutual exclusion: Resource is either available or assigned to at most one process

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Hold-and-wait: Process can hold one resource and then ask for others

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No preemption: Can't take a resource away from a process once assigned

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Mutual exclusion: Resource is either available or assigned to at most one process

Hold-and-wait: Process can hold one resource and then ask for others

No preemption: Can't take a resource away from a process once assigned

Circular wait: $\geq$ 2 processes in circle in which each is waiting for resource held by next in circle

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Digression: Directed graphs

- Many areas of CS require us to think of objects and relationships between them; e.g., paths between locations, data dependencies, constraints in logic puzzles

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- Can represent this formally as a *graph*:
  - *Vertices* (or nodes) represent the objects
  - *Edges* (or arcs, or links) represent the relationships

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Digression: Directed graphs

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- Can represent this formally as a *graph*:
  - *Vertices* (or nodes) represent the objects
  - *Edges* (or arcs, or links) represent the relationships
- Sometimes, relationship is directional
  - Think “one-way streets”
  - Now the edges have direction, and the graph is called a *directed graph* or *digraph*

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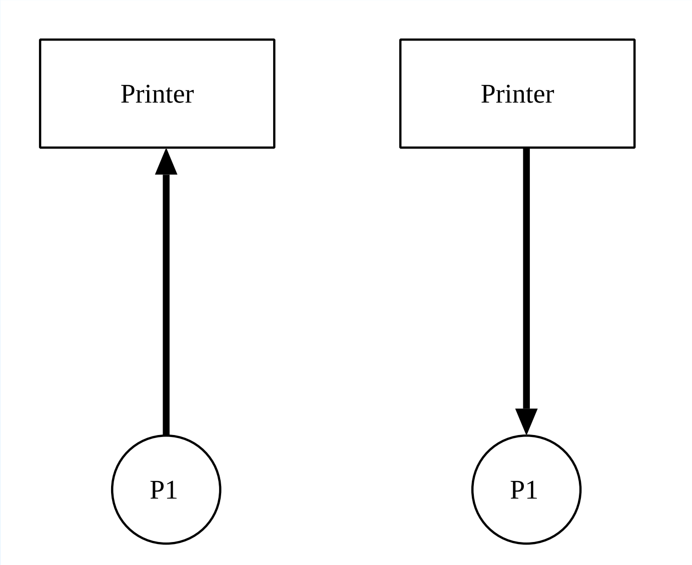
Modeling deadlocks as digraphs

- Circles: processes
- Squares: resources
- Link from process $\longrightarrow$ resource: process requests resource
- Link from resource $\longrightarrow$ process: process has control of resource



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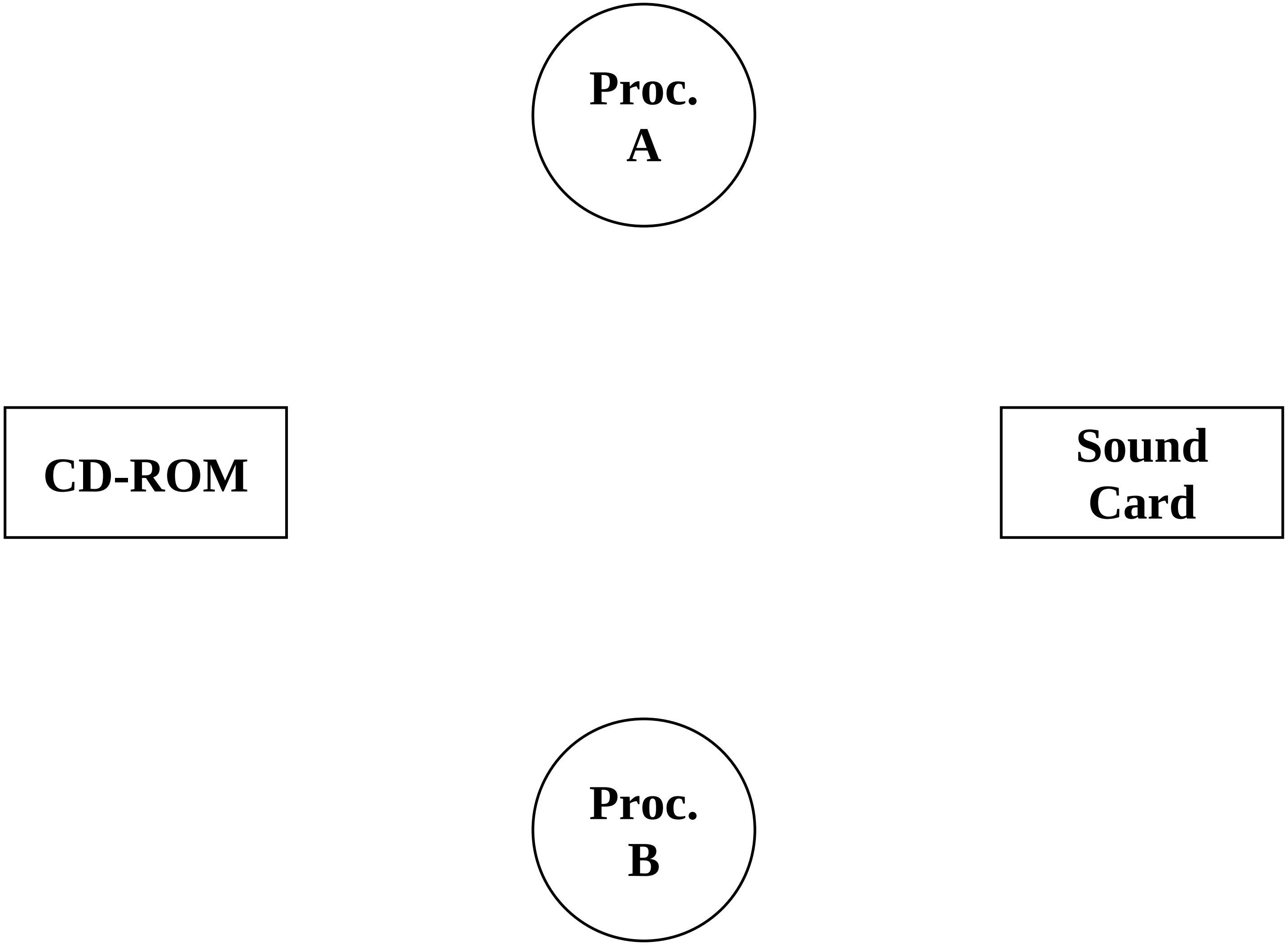
Modeling deadlocks as digraphs



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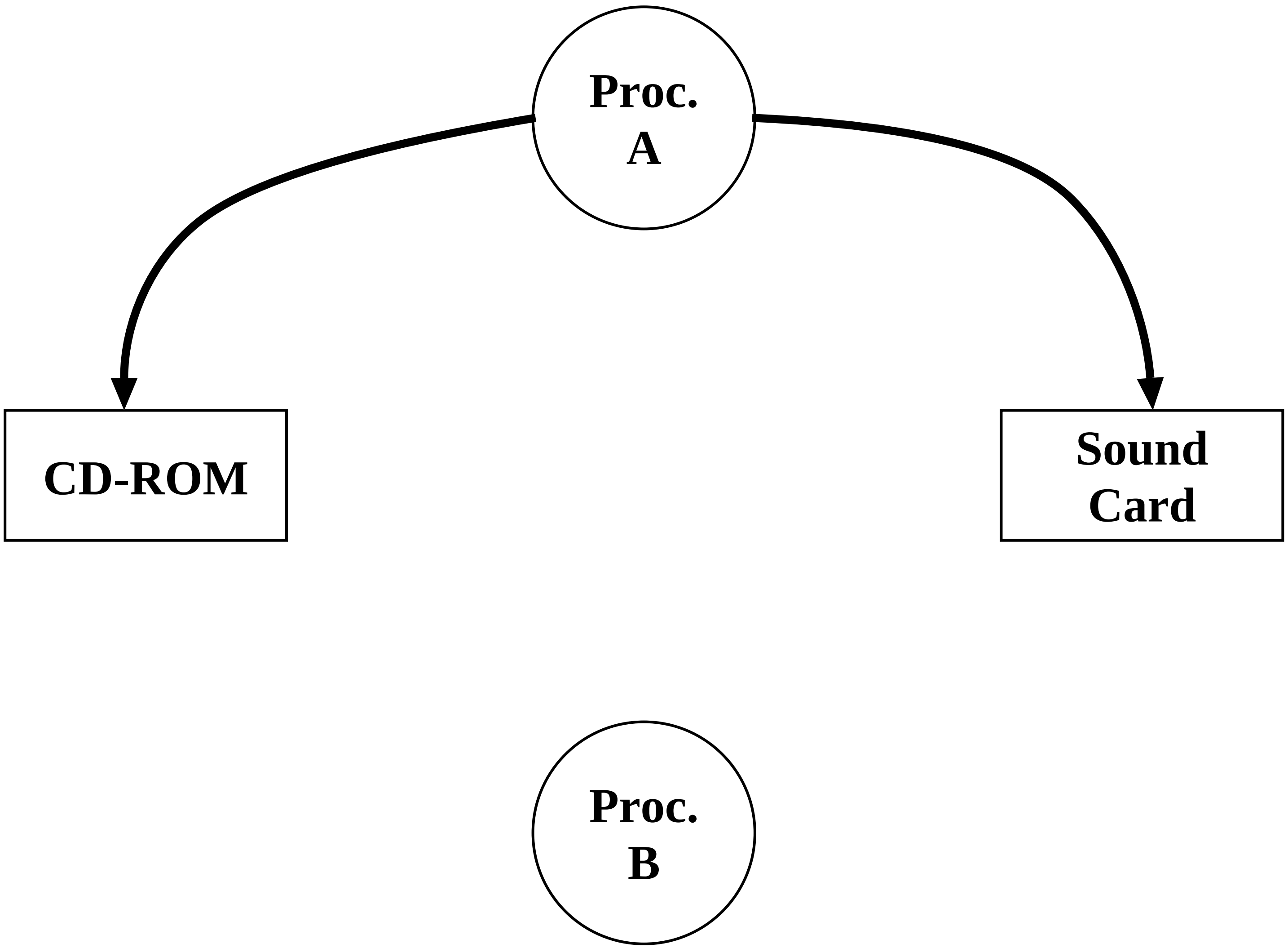

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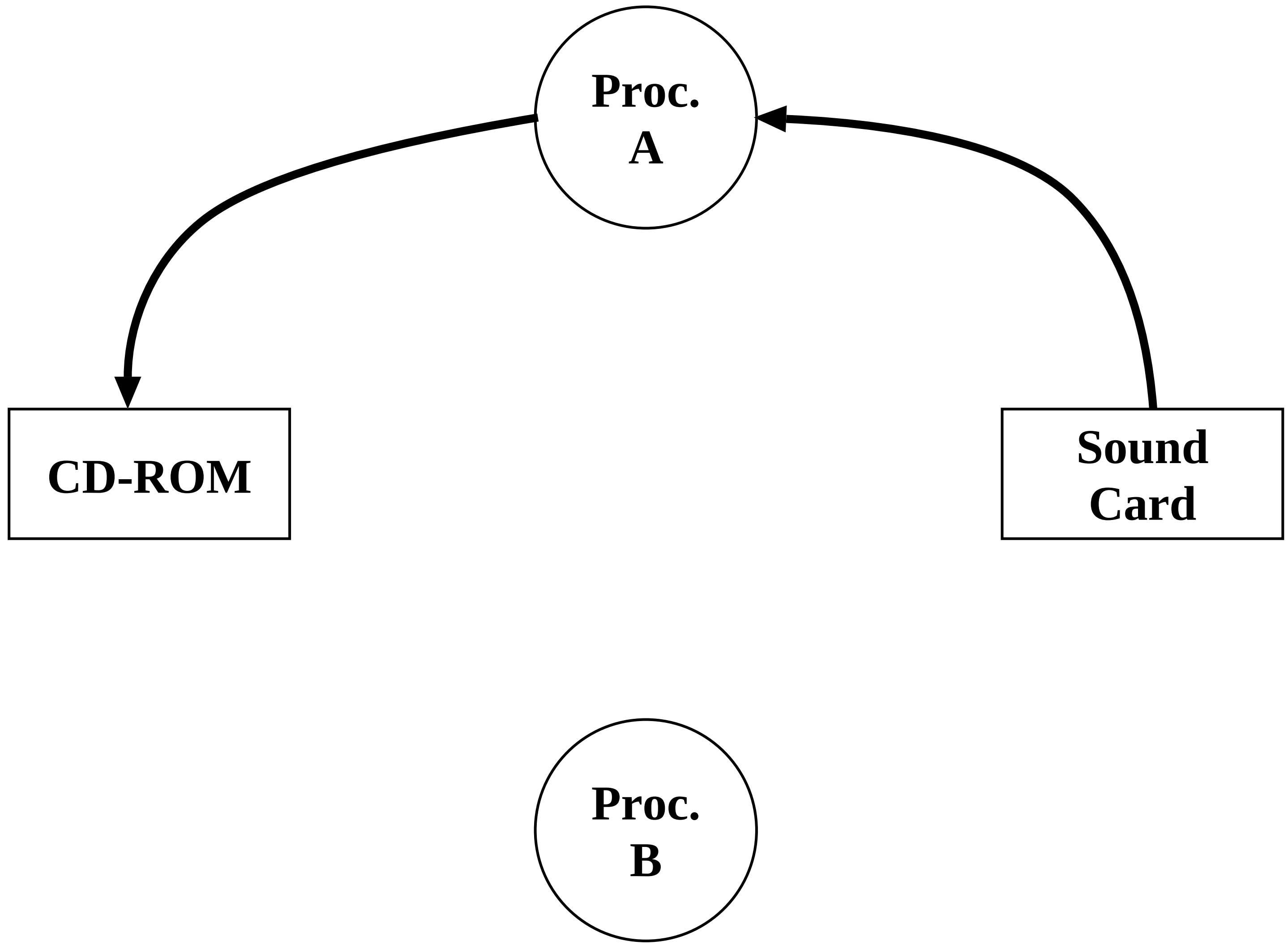

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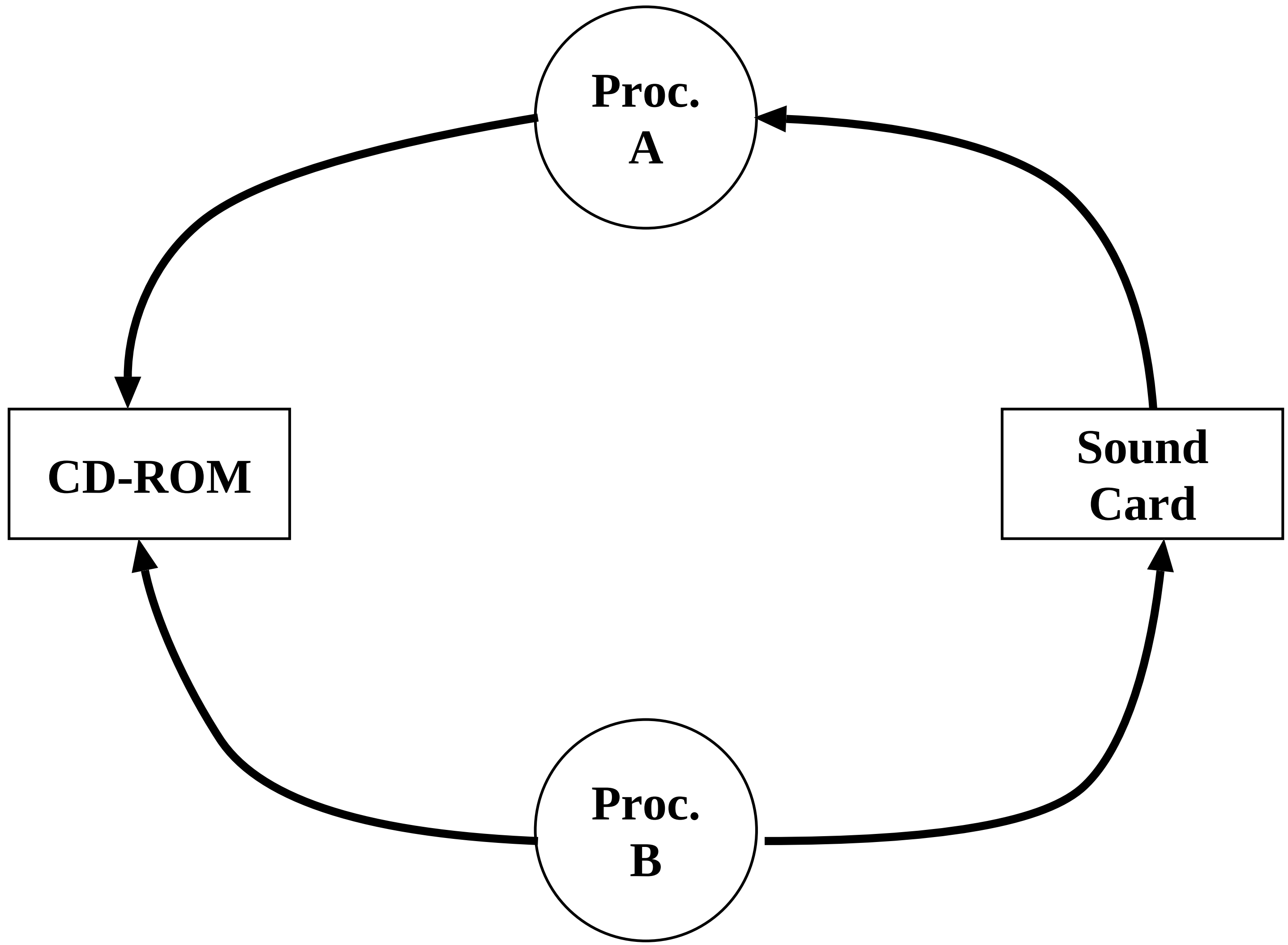

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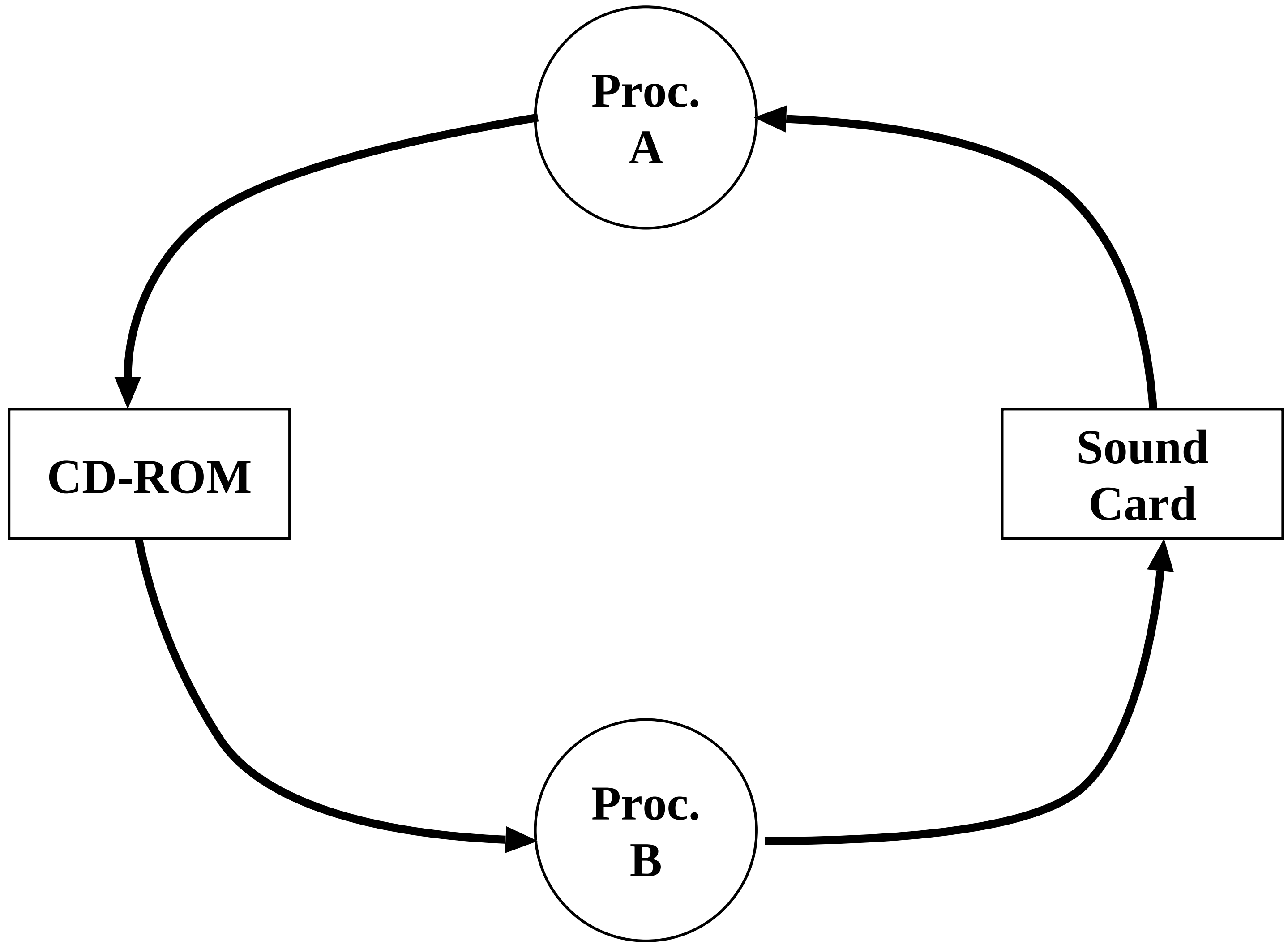

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What do we do about deadlocks?

- Ignore them
- Detect them and (try to) recover
- Prevent them altogether
- Predict and avoid them

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Ignoring deadlocks: The Ostrich Algorithm

- Sounds stupid, but...
- Consider:
  - How often will a deadlock happen?
  - How severe will it be if it does happen?
  - How hard would it be to avoid/prevent/detect?

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Deadlock detection/recovery

- Detection:
  - Monitor resource allocation using (e.g.) a digraph
  - If detect a cycle $\Rightarrow$ deadlock has occurred
- Recovery:
  - Kill one of the processes
  - If that doesn't work: kill another, etc.
- Another alternative: just look for processes that have been idle for a long time and kill them
- May be okay when aborting and restarting is okay (e.g., batch jobs)

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Deadlock prevention

- Set things up so that deadlocks cannot occur at all
- Done by attacking one of the deadlock conditions
- Attacking mutual exclusion condition:
  - Don't let non-sharable resources be assigned to anyone
  - E.g., spooling

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Deadlock prevention

- Attacking hold-and-wait condition:
  - Process can't request a resource if holding any
  - One way: processes request all resources up front
  - Problem: may not know ahead of time what you need!
  - Problem: hold resources too long in general
  - Another approach: release all you're holding momentarily to request another
- Attacking no preemption condition: not realistic

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Deadlock prevention

- Attacking the circular wait condition:
  - Stupid way: processes can only hold a single resource at a time

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Deadlock prevention

- Attacking the circular wait condition:
  - Stupid way: processes can only hold a single resource at a time
  - Better way:
    - Number the resources
    - Process can request whatever it wants, whenever it wants...as long as the requests are in numerical order

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Deadlock prevention

- Attacking the circular wait condition (cont'd):
  - Resource allocation graph can't have cycles in this scheme – why not?

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Deadlock prevention

- Attacking the circular wait condition (cont'd):
  - Resource allocation graph can't have cycles in this scheme – why not?
    - Consider the case where process A holds resource i and B holds j – deadlock only possible if A requests j and B requests i

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    - If $i > j$, then A can't request j
    - If $j > i$, then B can't request i

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Deadlock prevention

- Attacking the circular wait condition (cont'd):
  - Resource allocation graph can't have cycles in this scheme – why not?
    - Consider the case where process A holds resource i and B holds j – deadlock only possible if A requests j and B requests i
    - If $i > j$, then A can't request j
    - If $j > i$, then B can't request i
  - Problem – may not be able to find an ordering that satisfies everyone!

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Deadlock avoidance

- Idea: predict when some action $\longrightarrow$ deadlock, avoid it
- Dijkstra's Banker's Algorithm (single resource version)
  - Modeled on the way a banker might deal with lines of credit to customers
  - Deadlock if there is no way to guarantee that all customers can borrow up to their maximum resource limit at some point in time

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Dijkstra's Banker's Algorithm

- Safety:

  A state is *safe* if some sequence of other possible states exists that allows all customers (processes) to get up to their maximum resource limit at some time

- Keep track of maxmimum and current allocation for each customer
- Start in a safe state
- When process requests additional amount of resource, make sure that next state will also be safe
- If so, allow request, else disallow it

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Banker's Algorithm Example

- Initial state:

Process	Current	Maximum
A	0	7
B	0	3
C	0	2
D	0	4

Remaining: 8

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	2	3
C	0	2
D	2	4

Remaining: 1

- Safe or not?

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	2	3
C	0	2
D	2	4

Remaining: 1

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\rightarrow$ D $\rightarrow$ C $\rightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	3	3
C	0	2
D	2	4

Remaining: 0

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\longrightarrow$ D $\longrightarrow$ C $\longrightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	–	–
C	0	2
D	2	4

Remaining: 3

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\longrightarrow$ D $\longrightarrow$ C $\longrightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	–	–
C	0	2
D	4	4

Remaining: 1

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\longrightarrow$ D $\longrightarrow$ C $\longrightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	–	–
C	0	2
D	–	–

Remaining: 5

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\longrightarrow$ D $\longrightarrow$ C $\longrightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	–	–
C	2	2
D	–	–

Remaining: 3

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\rightarrow$ D $\rightarrow$ C $\rightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	3	7
B	–	–
C	–	–
D	–	–

Remaining: 5

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\longrightarrow$ D $\longrightarrow$ C $\longrightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	7	7
B	–	–
C	–	–
D	–	–

Remaining: 1

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\rightarrow$ D $\rightarrow$ C $\rightarrow$ A

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Banker's Algorithm Example 2

- Initial state:

Process	Current	Maximum
A	–	–
B	–	–
C	–	–
D	–	–

Remaining: 8

- Safe or not?
  - Safe
  - Possible sequence of processes running to completion: B $\rightarrow$ D $\rightarrow$ C $\rightarrow$ A

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Banker's Algorithm Example 3

Proc	Curr	Max
A	3	7
B	2	3
C	0	2
D	2	4

Remaining: 1

$\overset{B \text{ wants } 1}{\Longrightarrow}$

Proc	Curr	Max
A	3	7
B	3	3
C	0	2
D	2	4

Remaining: 0

- Allow the request?

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Banker's Algorithm Example 3

Proc	Curr	Max
A	3	7
B	2	3
C	0	2
D	2	4

Remaining: 1

$\stackrel{B \text{ wants } 1}{\Longrightarrow}$

Proc	Curr	Max
A	3	7
B	3	3
C	0	2
D	2	4

Remaining: 0

- Allow the request?
  - Yes.
  - Possible sequence of processes running to completion: B $\rightarrow$ D $\rightarrow$ C $\rightarrow$ A

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Banker's Algorithm Example 4

Proc	Curr	Max
A	6	7
B	0	3
C	0	2
D	1	4

Remaining: 1

$\xrightarrow{A \text{ wants } 1}$

Proc	Curr	Max
A	7	7
B	0	3
C	0	2
D	1	4

Remaining: 0

- Allow the request?

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Banker's Algorithm Example 4

Proc	Curr	Max
A	6	7
B	0	3
C	0	2
D	1	4

Remaining: 1

$\xrightarrow{A \text{ wants } 1}$

Proc	Curr	Max
A	7	7
B	0	3
C	0	2
D	1	4

Remaining: 0

- Allow the request?
  - Yes.
  - Possible sequence of processes running to completion: A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ D

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Banker's Algorithm Example 5

Proc	Curr	Max
A	4	7
B	1	3
C	0	2
D	1	4

Remaining: 2

$\xrightarrow{D \text{ wants } 1}$

Proc	Curr	Max
A	4	7
B	1	3
C	0	2
D	2	4

Remaining: 1

- Allow the request?

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Banker's Algorithm Example 5

Proc	Curr	Max
A	4	7
B	1	3
C	0	2
D	1	4

Remaining: 2

$\xrightarrow{D \text{ wants } 1}$

Proc	Curr	Max
A	4	7
B	1	3
C	0	2
D	2	4

Remaining: 1

- Allow the request?
  - NO!
  - No sequence possible where they all can finish

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Banker's Algorithm: Critique

- Is it too strong?
- After all – no guarantee that in the previous example:

Proc	Curr	Max
A	4	7
B	1	3
C	0	2
D	1	4

Remaining: 2

$\overset{D \text{ wants } 1}{\Longrightarrow}$

Proc	Curr	Max
A	4	7
B	1	3
C	0	2
D	2	4

Remaining: 1

D might not give back 1 immediately, moving back into safe state

- But we're interested in *guarantee* that there will be no deadlock, so this is what we need.

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Banker's Algorithm: Critique

- Scales to multiple processes/resources
- Problems:
  - Need to know maximum resources needed per process – often (usually?) impossible for multiprocess system
  - Number of processes constantly changes
  - Resources can disappear
- But: Really no better general-purpose algorithm exists for this

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Summary

- Handling deadlocks is difficult
- No best general solution
- How you choose to handle it depends on your situation: *trade-offs*

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