Deadlocks

Today

- Resources & deadlocks
- Dealing with deadlocks
- Other issues

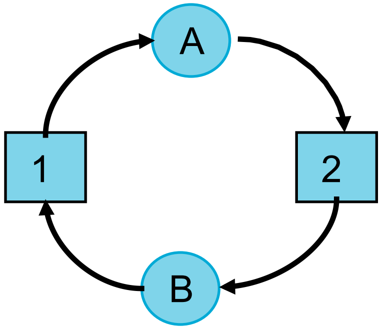
Next Time

- I/O and file systems

“That’s some catch, that Catch-22”

```
Thread A:
    lock(L1);
    lock(L2);
    ...
```

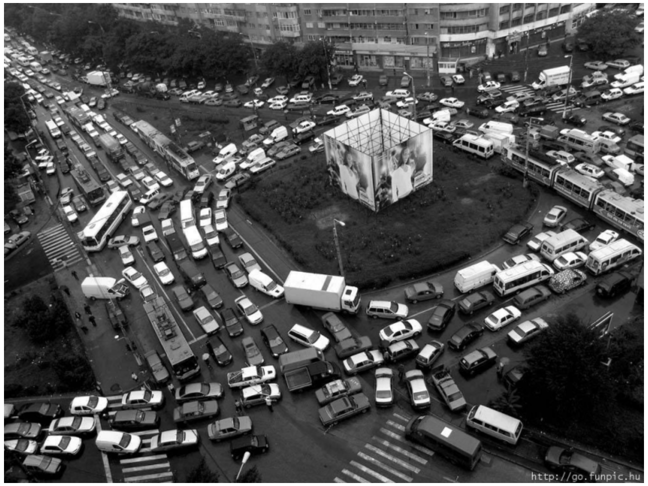
```
Thread B:
    lock(L2);
    lock(L1);
    ...
```



- *A set of threads is deadlocked if each thread in the set is waiting for an event that only another thread in the set can cause*
- None of the threads can …
  - run
  - release resources
  - be awakened

Introduction to deadlocks

- Assumptions
  - Threads or single-threaded processes
  - There are no interrupts possible to wake up a blocked thread



- Another “cute” example

  “When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up until the other has gone.” An actual law passed by the Kansas legislature …

Conditions for deadlock

1. Mutual exclusion - Each resource assigned to 1 thread or available
2. Hold and wait - A thread holding resources can request others resources
3. No preemption - Previously granted resources cannot forcibly be taken away
4. Circular wait – A circular chain of 2+ threads, each waiting for resource held by the next thread

All conditions must hold for a deadlock to occur.

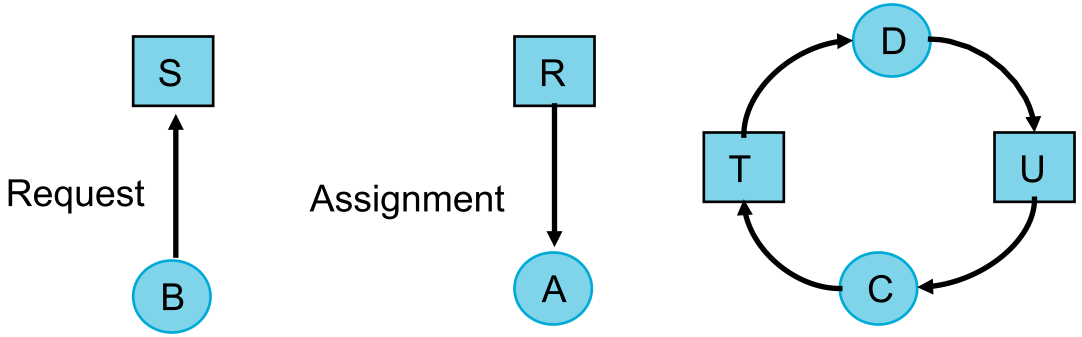
Each of the 1-3 conditions is associated with a policy the system can or not have; break one condition → no deadlock

System model

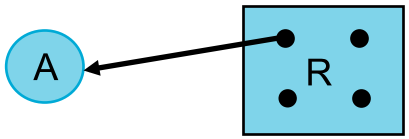
- System – a collection of resources to be shared
- Resources, in types with multiple instances each (printers, files, memory,…)
- Resources can be
  – Preemptable - can be taken away w/o ill effects (e.g. memory)
  – Nonpreemptable - process will fail if resource were taken away (e.g. CD recorder)
- A thread must request a resource before using it & release it once done (`open/close`, `malloc/free`, …)
  – Sequence of events to use a resource: request/use/release

Deadlock modeling

- Modeled with directed graphs
  - Process B is requesting/waiting for resource S
  - Resource R assigned to process A
  - Process C & D in deadlock over resources T & U

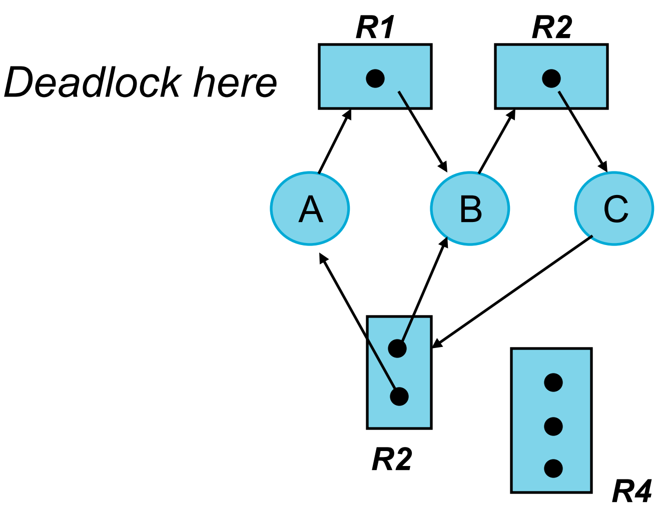


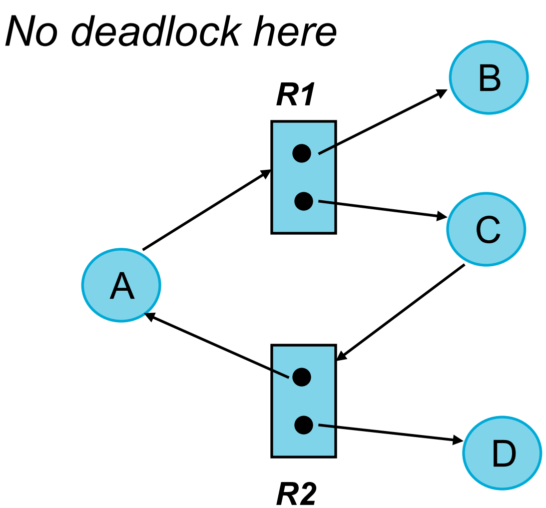
- Generalizing to multiple resource instances per class



Basic facts

- If graph contains no cycles $\Rightarrow$ no deadlock.
- If graph contains a cycle $\Rightarrow$
  - if only one instance per resource type, then deadlock.
  - if several instances per resource type, maybe a deadlock.





Deadlock modeling

Clearly, the ordering of operations plays a role

Requests and releases of each process

A	B	C
Request R	Request S	Request T
Request S	Request T	Request R
Release R	Release S	Release T
Release S	Release T	Release R

… and one particular ordering

1. A requests R
2. B requests S
3. C requests T
4. A requests S
5. B requests T
6. C requests R

….

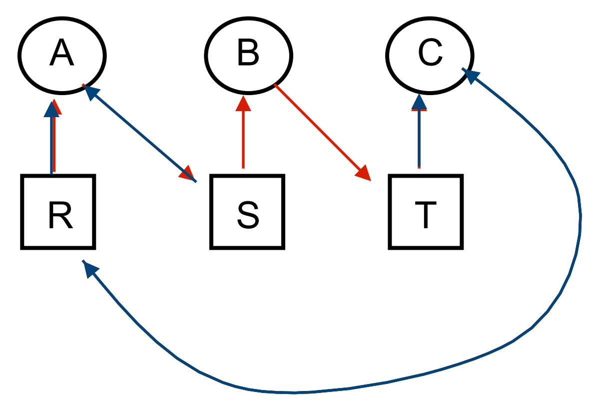
deadlock

But with an alternative

1. A requests R
2. C requests T
3. A requests S
4. C requests R
5. A releases R
6. A releases S

….

no deadlock



Dealing with deadlocks

Possible strategies

- Ignore the problem altogether – ostrich "algorithm"
- Detection and recovery – do not stop it; let it happen, detect it and recover from it
- Dynamic avoidance – careful resource allocation
- Prevention – negating one of the four necessary conditions

The ostrich algorithm

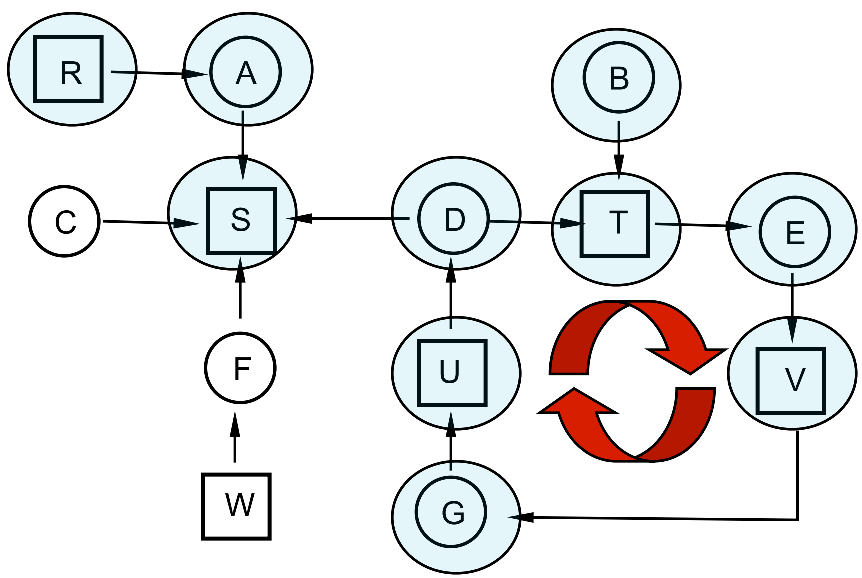
- Pretend there is no problem
- Reasonable if
  - deadlocks occur very rarely
  - cost of prevention is high
- UNIX's & Windows' approach
- A clear trade off between
  - Convenience
  - Correctness
- Not quite an option for your code

Deadlock detection – single instance

- Detect a cycle in the directed graph
  - Simplest case
- *How,* when & what

A linked list of nodes

```
1.L ← empty
  all arcs set as unmarked
2.For each node N
   /* depth-first search */
   2.1.Add N to L & check
       if N in L twice there's a
       deadlock; exit
   2.2.Pick one arc at random,
       mark it & follow it to next
       current node
3.At end, if no arc no deadlock
```



Arcs:

A→S, A←R, B→T, C→S
D→S, D←T, E→V, E←T
F→S, F←W, G→V, G←V

L:[R], L:[R,A], L:[R,A,S]
L:[B], L:[B,T], L:[B,T,E], …

Detection - multiple instances

n processes, *m* classes of resources

E – vector of existing resources

A – vector of available resources

C – matrix of currently allocated resources

R – request matrix

C_{ij} – P_i holds C_{ij} instances of resource class *j*

R_{ij} – P_i wants C_{ij} instances of resource class *j*

Invariant – $\Sigma_i C_{ij} + A_j = E_j$

(Currently allocated + available = existing)

i.e. all resources are either allocated or available

Algorithm:

Idea: See if there's any process that can be run to completion with available resources, mark it and free its resources …

```
All processes unmarked
1.Look for unmarked process
   Pi for which    Ri ≤ A
2.If found, add Ci. to A,
   mark the process and go
   to 1
3.If not, exit
All unmarked processes, if
   any, are deadlock
```

Detection

(existing) (available)

E = (4 2 3 1) A = (2 1 0 0)

What process 1 needs

C =	0	0	1	0		R =	2	0	0	1
	2	0	0	1			1	0	1	0
	0	1	2	0			2	1	0	0

What process 1 has

Three processes and 4 resource types

After running process 3

A = (2 2 2 0)

Now you can run process 2

A = (4 2 2 1)

…

Algorithm:

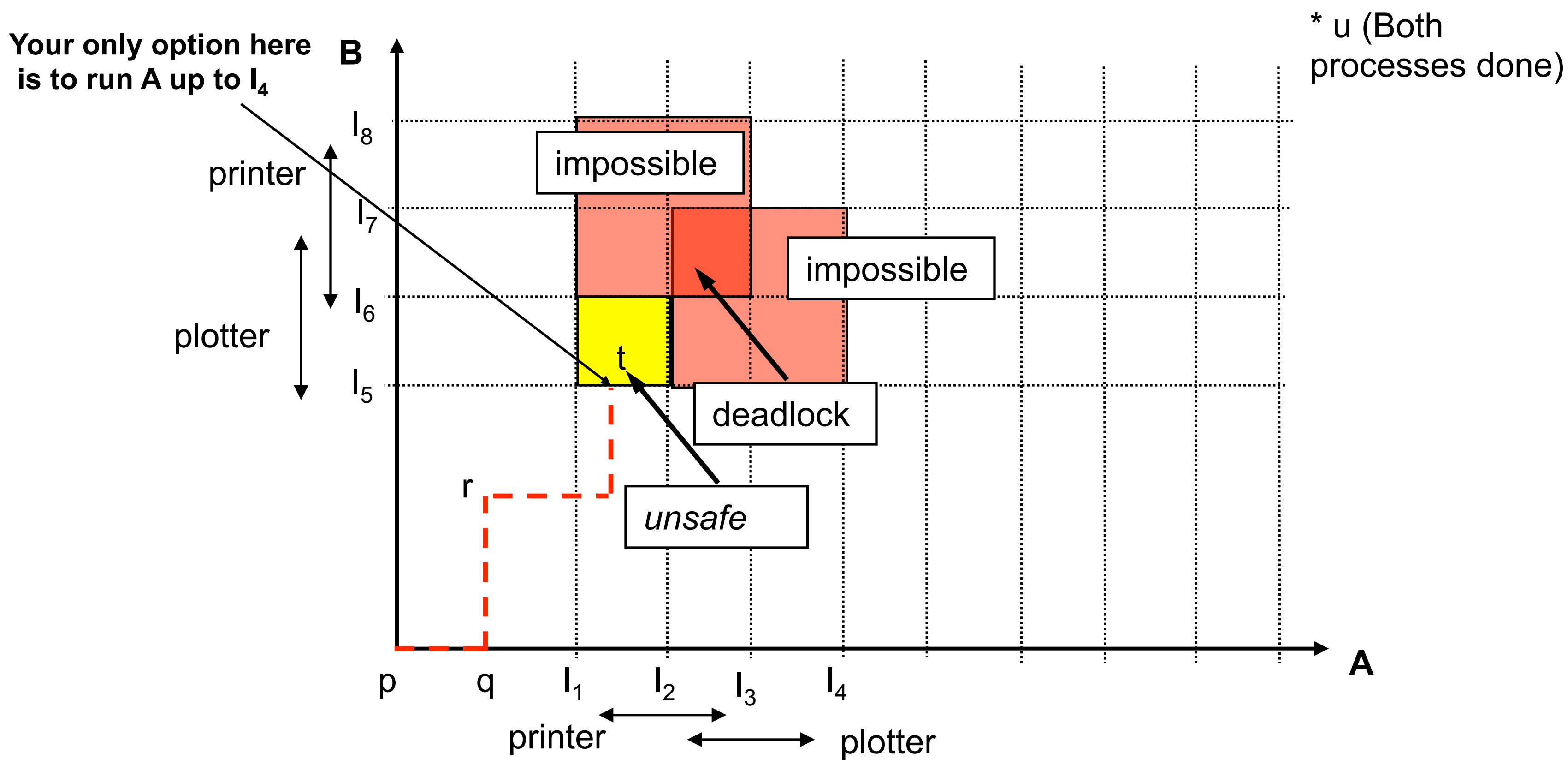
```
All processes unmarked
1.Look for unmarked
   process Pi for which
   Ri ≤ A
2.If found, add Ci. to A,
   mark the process and go
   to 1
3.If not, exit
All unmarked processes, if
   any, are deadlock
```

When to check & *what* to do

- *When* to try
  - Every time a resource is requested
  - Every fixed period of times or when CPU utilization drops
- *What* to do then - recovery
  - Through preemption
    - depends on nature of the resource
  - Through rollback
    - Need to checkpoint processes periodically
  - By killing a process
    - Crudest but simplest way to break a deadlock
    - Kill one in or not in the deadlock cycle

Deadlock avoidance

- Dynamically make sure not to get into a deadlock
- Two process resource trajectories
- Every point in the graph, a joint state of the processes



Safe and unsafe states

- Safe if
  - There is no deadlock
  - There is a scheduling order by which all processes can finish
- Un-safe is not deadlock – just no guarantee

Example with one resource (10 instances of it)

Safe

Free: 3

	Has	Needs
A	3	9
B	2	4
C	2	7

	Has	Needs
A	3	9
B	4	4
C	2	7

Free: 1

	Has	Needs
A	3	9
B	0	-
C	2	7

Free: 5

	Has	Needs
A	3	9
B	0	-
C	7	7

Free: 0

	Has	Needs
A	3	9
B	0	-
C	0	-

Free: 7

Unsafe

Free: 3

	Has	Needs
A	3	9
B	2	4
C	2	7

	Has	Needs
A	4	9
B	2	4
C	2	7

Free: 2

	Has	Needs
A	4	9
B	4	4
C	2	7

Free: 0

	Has	Needs
A	4	9
B	0	-
C	2	7

Free: 4

A requests and is granted another instance

In retrospect, A's request should not have been granted

Banker's algorithm *(Dijkstra, again)*

- Considers
  – Each request as it occurs
  – Sees if granting it leads to a safe state i.e. there are enough resources to satisfy one customer
- With multiple resources

```
1.Look for a row Ri ≤ A, if none the system will
  eventually deadlock
2.If found, mark Pi and add Ci to A
3.Repeat until processes are terminated or a deadlock
  occurs
```

- Very cute, but mostly useless
  – Most processes don't know in advance what they need
  – The lists of processes and resources are not static
  – Processes may depend on each other

Deadlock prevention

- Avoidance is pretty hard or impossible
- Can we break one of the condition?
  - Mutual exclusion
  - Hold & wait
  - No preemption
    - Not a viable option
    - How can you preempt a printer?
  - Circular wait

Attacking mutual exclusion

- Some devices can be spooled (printer)
  - Only the printer daemon uses printer resource
  - Thus deadlock for printer eliminated
- But not all devices can be spooled – process table?
- Principle:
  - Assigning resource only when absolutely necessary
  - Reduce number of processes that may claim the resource

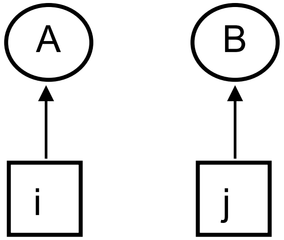
Attacking hold & wait

- Processes request all resources at start (hold & ~~wait~~)
  - Process never has to wait for what it needs
- But
  - May not know required resources at start
  - It ties up resources others could be using
- Variation (~~hold~~ & wait)
  - Process must release all resources to request a new one

Attacking circular wait

- Impose total order on resources
- Processes request resources in order
- If all processes follow order, no circular wait occurs

Deadlock if i → A → j & j → B → i
If i < j then A → j …



- Process cannot request resource lower than what it’s holding
- Advantage - Simple
- Disadvantage - Arbitrary ordering

Related issues

- Two-phase locking – gather all locks, work & free all
  - If you cannot get all, drop all you have and start again
- Non-resource deadlocks
  - Each is waiting for the other to do some task
  - E.g. communication deadlocks:
    - A sends a request and blocks until B replies, message gets lost!
    - Timeout!
- Livelocks – try, sleep and try again
  - There’s some action, just not progress
- Starvation
  - SJF to allocate resources – consider allocation of a printer
    - May cause long job to be postponed indefinitely
      - even though not blocked
  - FIFO?

Next time

- I/O devices, file abstraction and file systems …