Deadlocks

Today

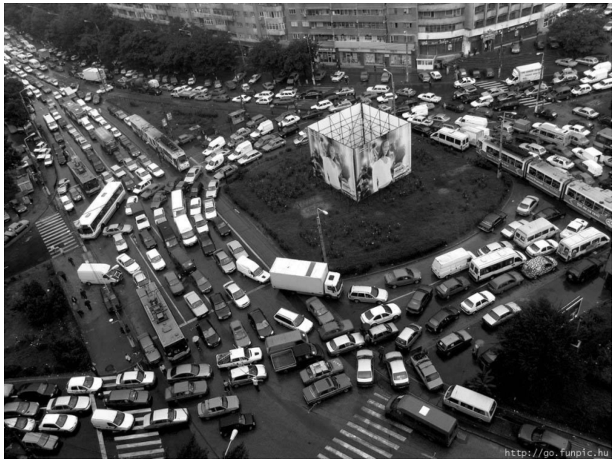
- Resources & deadlocks
- Dealing with deadlocks
- Other issues

Next Time

- Memory management

Introduction to deadlocks

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
- 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
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 next one

All conditions must hold for a deadlock to occur.

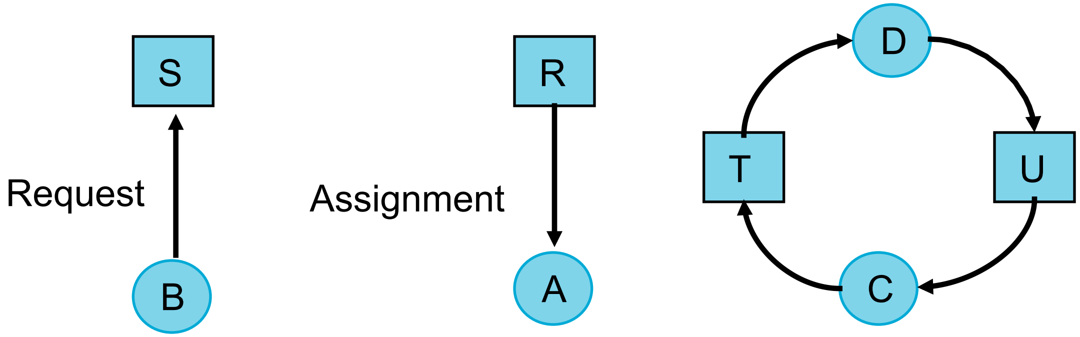
Each of the 1-3 conditions is associated with a policy the system can or not have; break one condition → no deadlock

System model

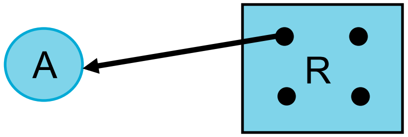
- System – a collection of resources to be shared
- Resources partitioned in types, each with multiple instances (printers, files, memory,…)
  - A request for resource type R can be satisfied by any instance of the type
- Resources can be
  - Preemptable - can be taken away from process w/o ill effects
    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



- You can generalize it to multiple resource instances per class



Deadlock modeling

Clearly, the ordering of operations plays a role

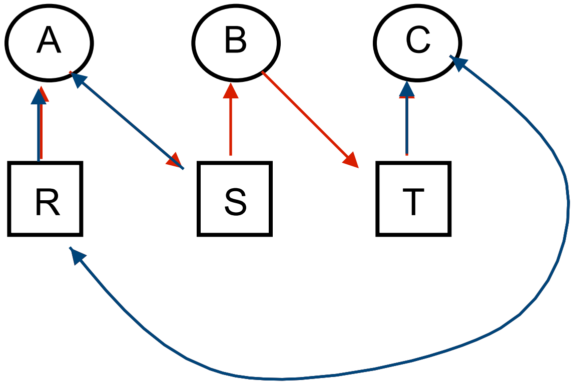
Requests and releases of each process

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

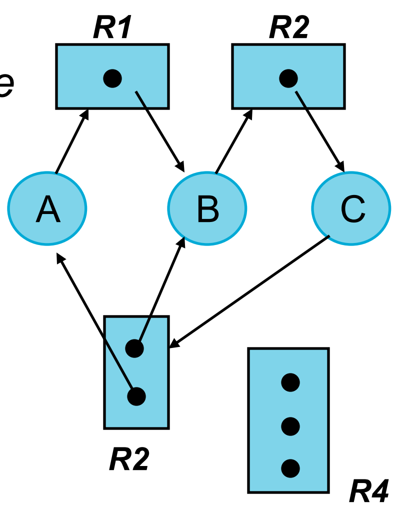
The ostrich algorithm

- 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

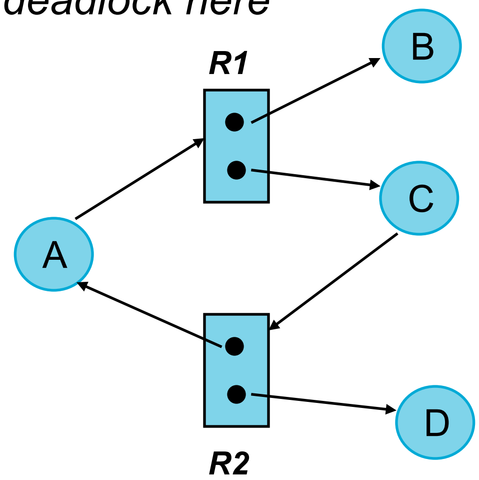
Basic facts

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

Deadlock here



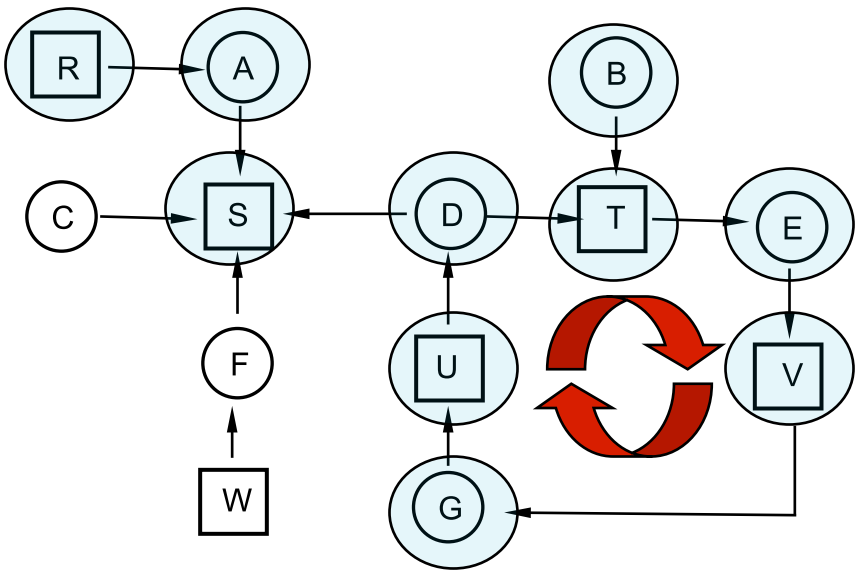
No deadlock here



Deadlock detection – single instance

- *How,* when & what
- Simplest case

```
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:

```
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
```

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

Detection

(existing) E = (4 2 3 1)

(available) A = (2 1 0 0)

What process 1 needs

C =

0	0	1	0
2	0	0	1
0	1	2	0

What process 1 has

R =

2	0	0	1
1	0	1	0
2	1	0	0

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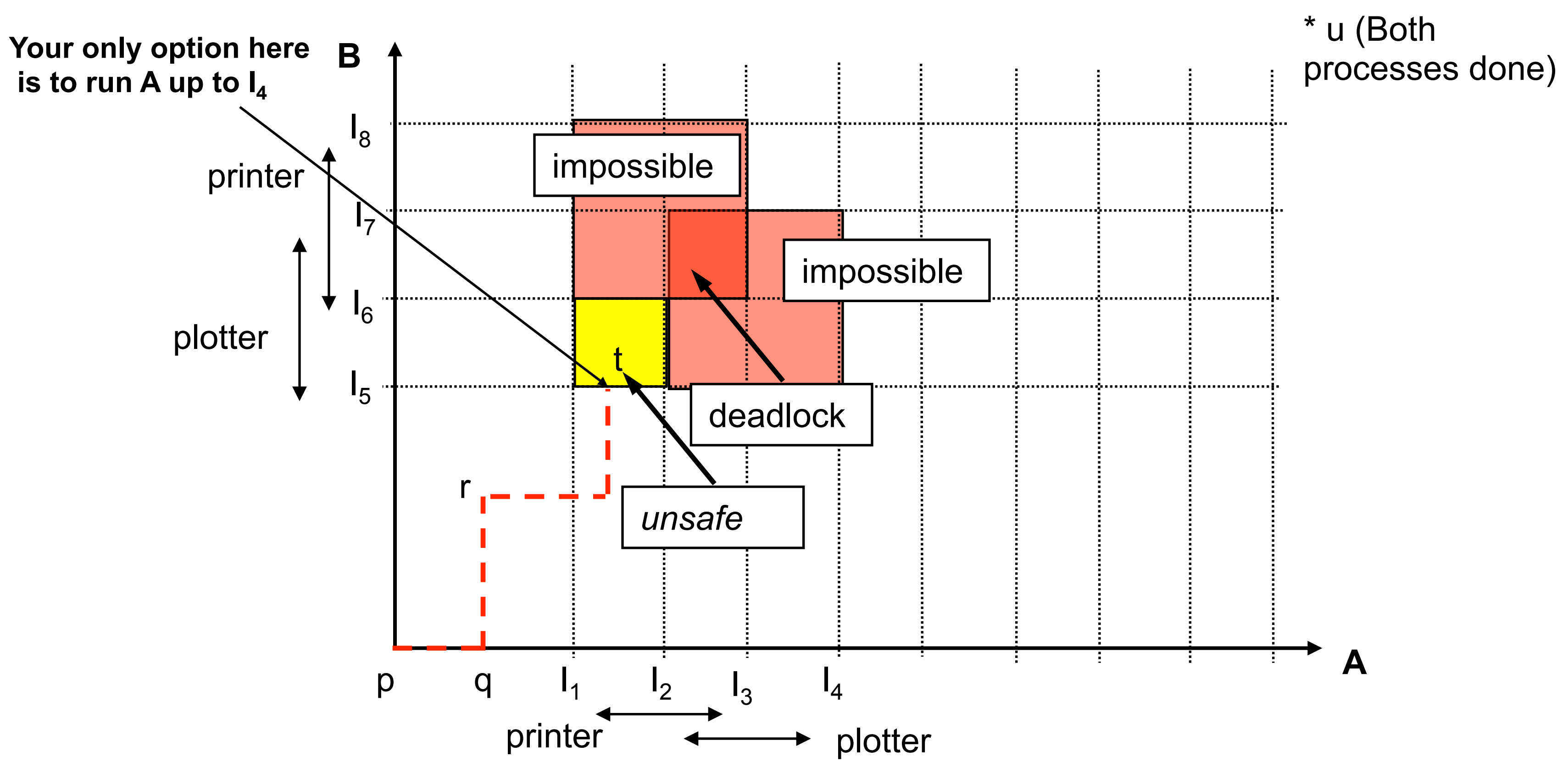
Idea: See if there's any process that can be run to completion with available resources, mark it and free its resources …

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 some scheduling order by which all processes can run to completion
- 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

- 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 $R_{i.} \leq A$, if none the system will eventually deadlock
  2. If found, mark P_i and add $C_{i.}$ 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

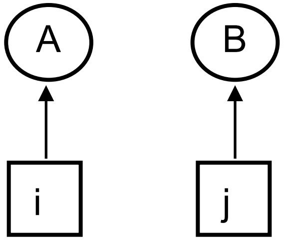
Attacking hold & wait

- Processes request all resources at start (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)
  - 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

Next time

- We have discussed sharing CPU to improve utilization and turnaround time
- For that to happen we also need to share memory
- We'll start with memory organization and basic management techniques (e.g. paging)
- Before moving to memory virtualization …

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!
- Starvation
  - Algorithm to allocate a resource
  - SJF – consider allocation of a printer
    - Great for multiple short jobs in a system
    - May cause long job to be postponed indefinitely
      - even though not blocked
  - Solution: FIFO