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All of these must hold for it to be *possible* to deadlock

Deadlock

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4. **Circular Wait** There is a circular chain of processes where each holds a resource that is needed by the next in the circle

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This says that deadlock is happening as in the formal definition

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When it gets the new resource it will have to go back and pick up the other resources again

Which may require it to drop the new resource while waiting…

It is easy to get into a situation where the process never manages to get all the resources it needs: called *indefinite postponement*

Deadlock

Dining Philosophers

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Some Philosophers wish to share a plate of spaghetti, but they have only been provided with chopsticks

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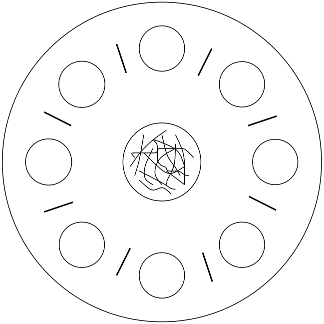
Some Philosophers wish to share a plate of spaghetti, but they have only been provided with chopsticks

Unfortunately, there is not quite enough chopsticks to go around

Deadlock

Dining Philosophers



Dining Philosophers

Deadlock

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Each Philosopher needs two chopsticks to eat, one from each side of their plate

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Deadlock

Dining Philosophers

Each Philosopher needs two chopsticks to eat, one from each side of their plate

We have

1. Mutual exclusion. Only one Philosopher can use a chopstick at a time
2. Hold-and-wait. Each Philosopher wants to eat and won't let go of a chopstick until they have eaten
3. No preemption. No-one is going to tell a Philosopher what to do!

Deadlock

Dining Philosophers

And if they all grab the left chopstick simultaneously

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4. Circular Wait. There is a circular chain of Philosophers where each holds a chopstick that is needed by the next in the circle

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Exercise Identify the conditions in the car gridlock scenarios

Deadlock

There are two approaches to the problem of deadlock

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1. Prevention. Stopping it happening ever by preventing one of the conditions occurring

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1. Prevention. Stopping it happening ever by preventing one of the conditions occurring
2. Detection and Breaking. Letting deadlock happen, but spotting when it does and then breaking it by destroying one of the conditions

Deadlock

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Avoidance is harder to manage as it needs to predict future requests for resources, but tends to be more efficient as it can allocate resources that prevention would disallow

Deadlock

Prevention

We can prevent deadlocks by disallowing any of the conditions

Breaking Mutual Exclusion

Deadlock

Prevention

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For example, trying to read a disk at the same time as another process is writing to it is a physical impossibility

A lot of hardware only works if there is exclusive access, e.g., printers, sound cards, etc.

Therefore we should take care to not hold on to such a resource for longer than is absolutely necessary

Breaking Hold-and-wait

Deadlock
Prevention

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We can require a process not to hold any resources if it ever gets blocked on another resource

Deadlock

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Breaking Hold-and-wait

We can require a process not to hold any resources if it ever gets blocked on another resource

This has the non-progress feature, as noted previously, and can be very inefficient with much grabbing and releasing to no avail

Deadlock

Prevention

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We might require a process to request all necessary resources simultaneously, blocking until all are available

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- Resources given to a process might be only needed much later, denying them to other processes in the meantime

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Breaking Hold-and-wait

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- This might prevent the process from doing useful other work while one of the resources is unavailable but not yet needed by the process
- Resources given to a process might be only needed much later, denying them to other processes in the meantime
- It may be that a process does not even know what resources it might need in advance, so this can be impossible to do anyway

Breaking Hold-and-wait

A variant of this was not even to admit a process to the scheduler until all resources are available: this is even worse

Deadlock

Prevention

Breaking Hold-and-wait

A variant of this was not even to admit a process to the scheduler until all resources are available: this is even worse

Perhaps a process only needs to write to disk at the end of a 2 hour compute session: do we really want to lock the disk for 2 hours?

Breaking No Preemption

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Deadlock

Prevention

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The OS might choose to preempt the holding process and take the resource away from it, giving it back later when the process is scheduled again

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This would be confusing for the holding process as the resource might change while it was owned by another process

Deadlock

Prevention

Thus, the resource should be given back to the process in an equivalent state to it was in when it was preempted, so the process can continue from where it left off

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For others, not. For example, a printer

Breaking Circular Waits

Deadlock

Prevention

Breaking Circular Waits

One possible solution is to put an ordering on resources

$$R_1 < R_2 < R_3 < \dots$$

Deadlock

Prevention

Breaking Circular Waits

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E.g., (much simplified)

$$\text{disk 1} < \text{disk 2} < \text{printer} < \dots$$

Deadlock

Prevention

Then:

> *A process that holds resource R may then only request resources that are after R in the order*

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If a process makes such a request, the OS simply refuses to grant it

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In our example, if you have grabbed the printer, you cannot grab a disk

If a process makes such a request, the OS simply refuses to grant it

The process might choose to drop the printer and re-request the disk

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Now we cannot deadlock, as a deadlock would imply A has grabbed R_i and requested R_j; while B has grabbed R_j and requested R_i

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For this to happen we would have both

$$i < j \text{ and } j < i$$

and this is impossible

Deadlock

Prevention

Breaking Circular Waits

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This usually effectively reduces to the request-all-at-once scenario

Deadlock

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An unsafe request will not be granted by the OS

Deadlock

Avoidance

There are various algorithms that address the question of whether to grant a resource

Deadlock

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Exercise Dijkstra's Banker's Algorithm is one. Read about it and its limitations

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Detection and Breaking

Next: deadlock *detection* systems allow deadlocks to happen but rely on noticing and breaking them

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“The machine seems to have stopped. . . ”

Deadlock

Detection and Breaking

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Deadlock

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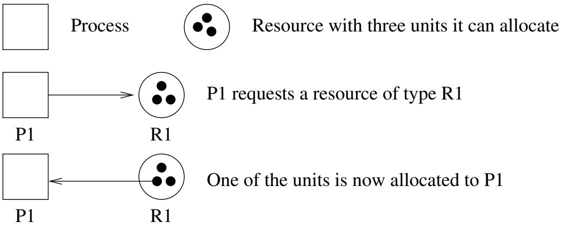
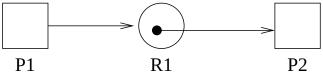
One method for deadlock detection uses *resource request and allocation graphs* (RRAG)



RRAGs

Deadlock

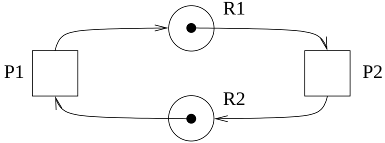
Detection and Breaking



P1 requests from R1, but it has no free units, so P1 will be blocked

Deadlock

Detection and Breaking



Circular Wait

P1 requests from R1, but it has been allocated to P2;
P2 requests from R2, but it has been allocated to R1:
this is deadlock

Deadlock

Detection and Breaking

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Exercise Read about this

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- Preempt the blocking resources: better, if possible. If there are multiple resources causing the deadlock we have to choose which, as preempting just a few might free things up enough

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- Preempt the blocking resources: better, if possible. If there are multiple resources causing the deadlock we have to choose which, as preempting just a few might free things up enough
- Add resources: rarely possible

Exercise Think about how you might apply deadlock prevention or breaking to (a) Dining Philosophers and (b) the car deadlock scenarios

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In a carefully written OS, you can eliminate many of the possible causes of deadlock, or, at least, reduce the chances of them happening

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We have already seen this for printers in the form of *spooling*

A process thinks it is writing to a printer, but it is actually writing to a tape, and the tape is later written to the printer

Deadlock

Similarly, for example, a process thinks it writes to a network card but the data is actually buffered by the OS somewhere in memory, to be sent later when the card is free

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Exercise Virtualisation allows the OS to prevent deadlocks. So which of the Coffman Conditions does it disallow?