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Operating Systems

Deadlocks

Deadlocks

- Example: two processes want to scan a document, and then save it on a CD

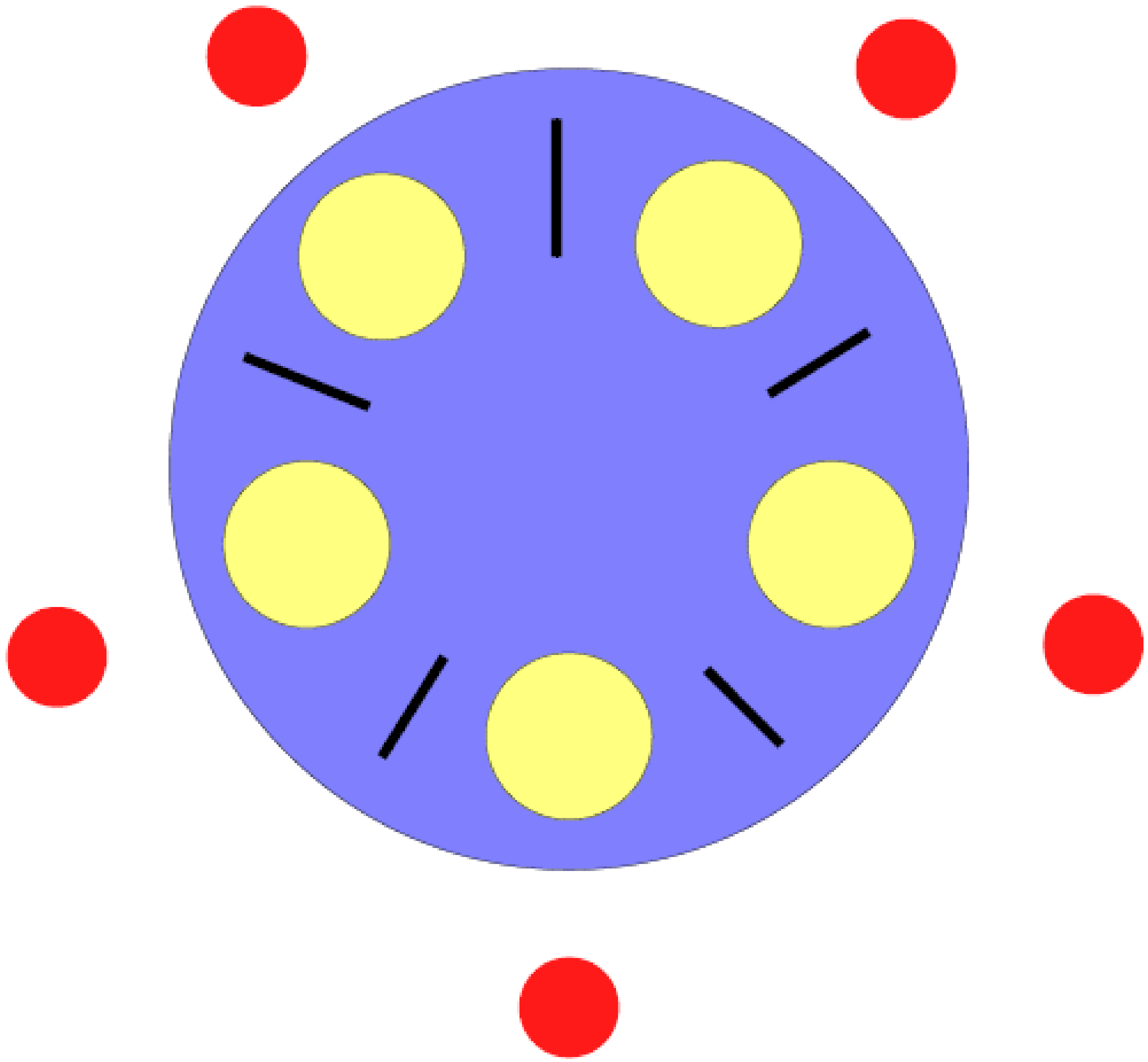
P0

```
down(scanner);
down(cd_writer);
scan_and_record();
up(cd_writer);
up(scanner);
```

P1

```
down(cd_writer);
down(scanner);
scan_and_record();
up(scanner);
up(cd_writer);
```

Dining Philosophers



Dining Philosophers

```
var chopstick:  array [0..4] of Semaphore

procedure philosopher(i:int)
  loop
    down(chopstick[i])
    down(chopstick[i+1 mod 5])
    eat
    up(chopstick[i])
    up(chopstick[i+1 mod 5])
    think
    end loop
  end philosopher
```

Does this work?

What if everybody takes chopstick[i] at same time?

Deadlock

- Set of processes is deadlocked if each process is **waiting for an event** that only **another process** can cause

- Resource deadlock is most common, 4 conditions must hold:
  1. **Mutual exclusion:** each resource is either available or assigned to exactly one process
  2. **Hold and wait :** process can request resources while it holds other resources earlier
  3. **No preemption:** resources given to a process cannot be forcibly revoked
  4. **Circular wait:** two or more processes in a circular chain, each waiting for a resource held by the next process

Question

- Can the set of processes deadlocked include processes that are not in the circular chain in the corresponding resource allocation graph?

Question

- Can a single-processor system have no processes ready and no process running? Is this a deadlocked system?

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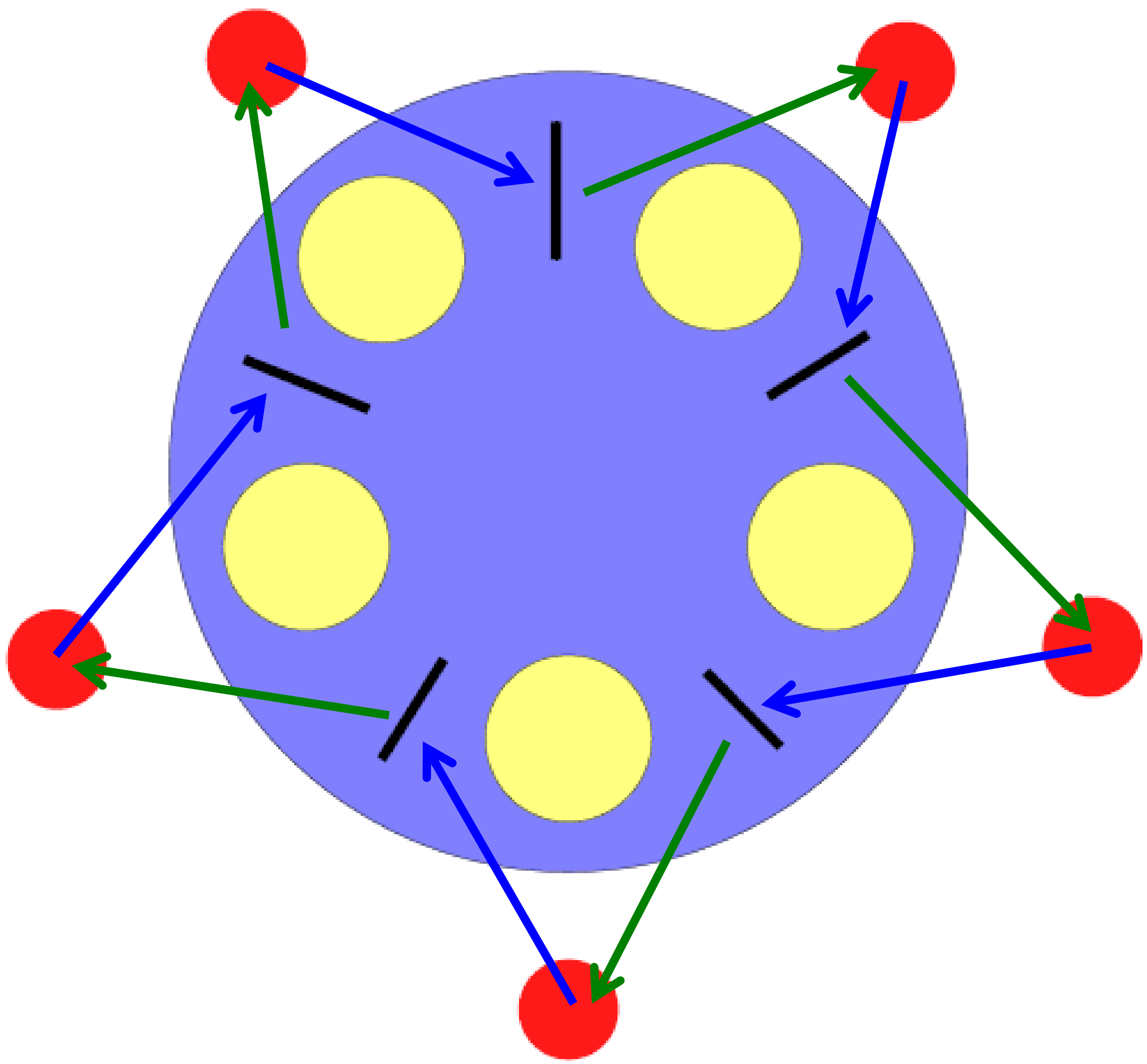
Resource Allocation Graphs

- **Directed graph** models resource allocation
  - Directed arc from resource to process means that the process is currently owning that resource
  - Directed arc from process to resource means that the process is currently blocked waiting for that resource
- **Cycle = deadlock**

Dining Philosophers – Deadlock Cycle



Strategies For Dealing With Deadlock

- Ignore it
  - "The Ostrich Algorithm"
  - Contention for resources is low → deadlocks infrequent
- Detection and recovery
  - After system is deadlocked (1) detect the deadlock and (2) recover from it
- Dynamic avoidance
  - Dynamically consider every request and decide whether it is safe to grant it; needs some information regarding potential resource use
- Prevention
  - Prevent deadlocks by ensuring at least one of the four deadlock conditions can never hold

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Detection and Recovery

- Detects deadlock and recovers ***after the fact***
- Dynamically builds resource ownership graph and looks for cycles
- When an ***arc*** has been inspected it is marked and not visited again

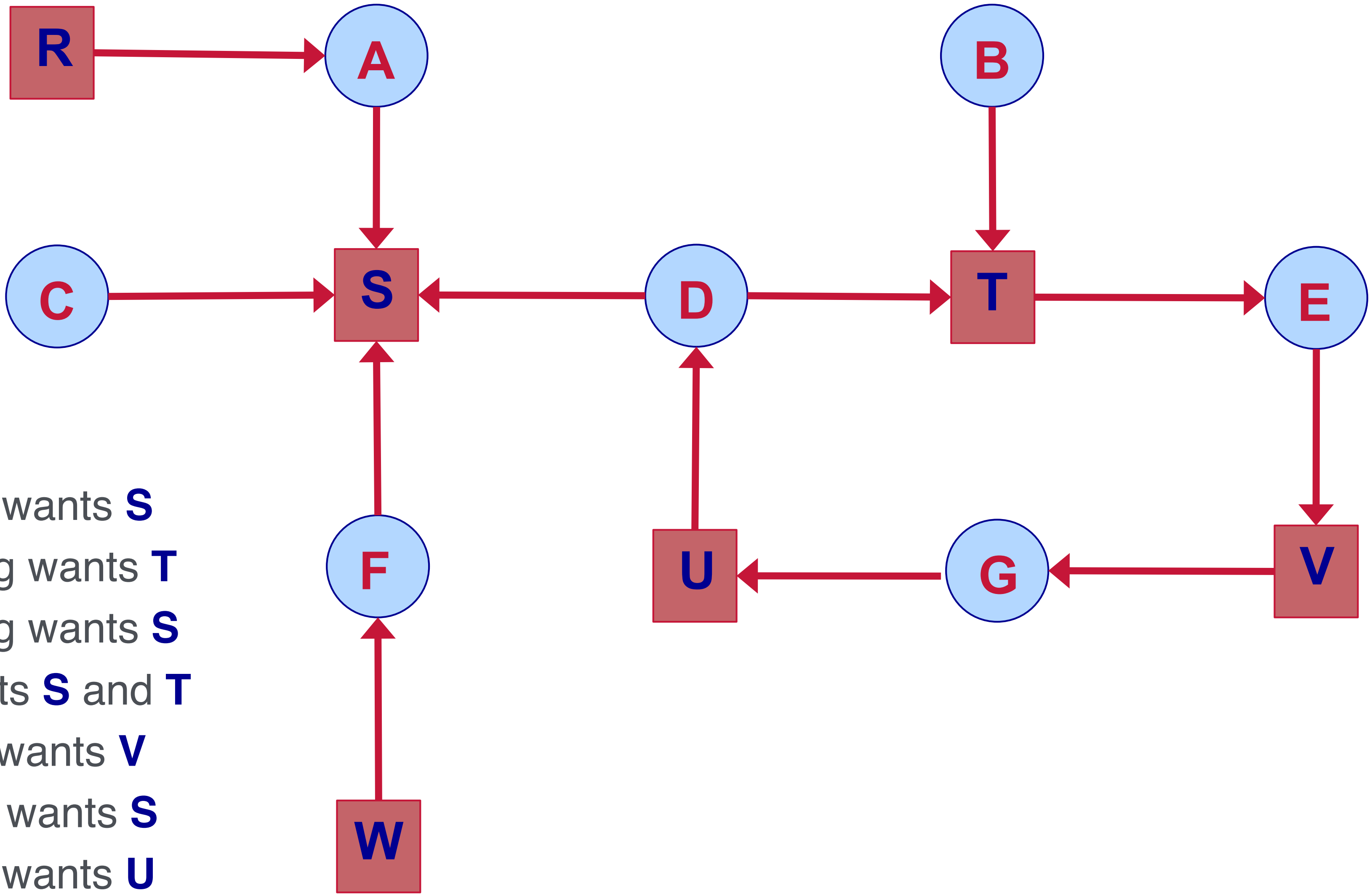
1. For each node do:
2. Initialise **L** to the empty list
3. Add the current node to **L** and check if it appears in **L** two times. Yes: cycle!
4. From current node check if any unmarked outgoing arch

   Yes: goto **5**, No: goto **6**
5. Pick unmarked outgoing arc, mark it, follow it to new current node and goto **3**
6. If this is initial node then no cycles detected, terminate

   else reached dead end, remove it, go back to previous node and make it current and goto **3**

We are doing a depth-first search from each node in the graph, checking for cycles.

Detection – Example



A holds **R** and wants **S**

B holds nothing wants **T**

C holds nothing wants **S**

D holds **U** wants **S** and **T**

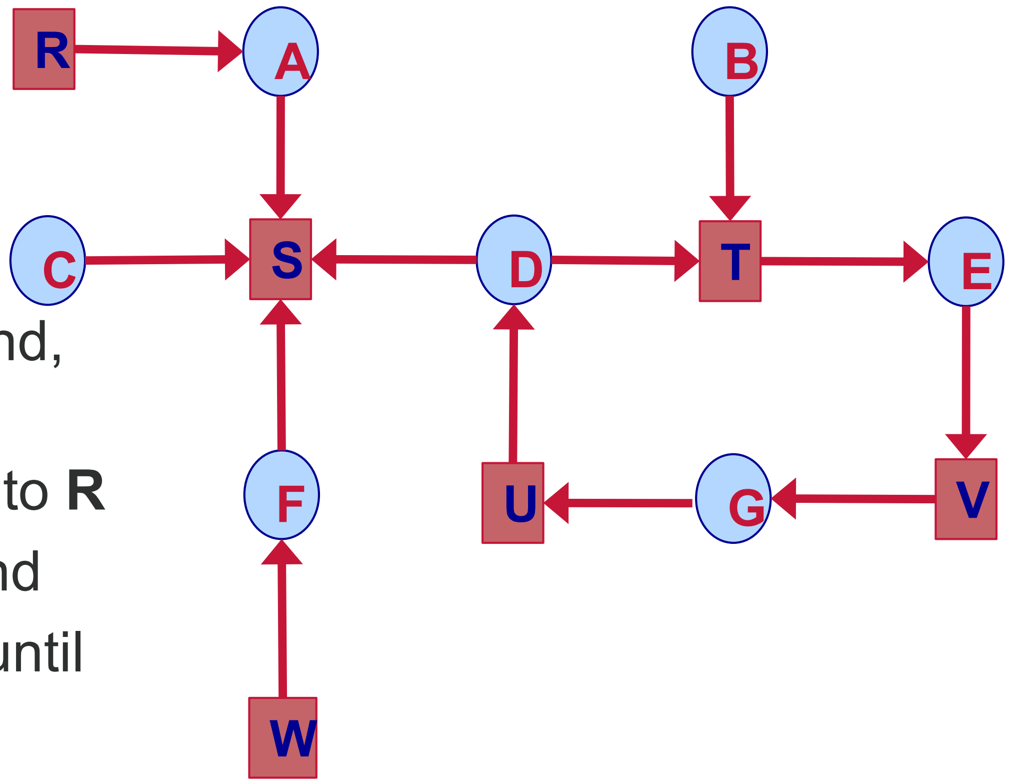
E holds **T** and wants **V**

F holds **W** and wants **S**

G holds **V** and wants **U**

Detection – Example

- Starting at **R**, initialise **L** = [ ]
- Add **R** to list and move to **A** (only possibility)
- Add A giving **L = [R,A]**
- Go to S so **L = [R,A,S]**
- **S** has not outgoing arcs → dead end, backtrack to **A**
- **A** has no outgoing arcs, backtrack to **R**
- Restart at **A**, add A to ***L*** → dead end
- Restart at **B**, follow outgoing arcs until **D**, now **L = [B,T,E,V,G,U,D]**
- Make random choice:
  - **S** → dead end and backtrack to **D**
  - Pick T update **L = [B,T,E,V,G,U,D,T]**
- Cycle: Deadlock found, STOP



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Recovery

- Pre-emption:
  - Temporarily take resource from owner and give to another

- Rollback:
  - Processes are periodically **checkpointed** (memory image, state)
  - On a deadlock, **roll back** to previous state
    - When is it going to resolve the deadlock?

- Killing processes:
  - Select random process in cycle and kill it!
    - E.g., Might work for compile jobs, but not for DB systems

Strategies For Dealing With Deadlock

- Ignore it
- Detection and recovery
- Dynamic avoidance
  - System grants resources when it knows that it is safe to do so
- Prevention

Banker's Algorithm (Dijkstra 1965)

- Setup with a single type of resource
- N customers have a maximum credit limit expressed in number of credit units
  - E.g., 1 credit unit = £1K
- Each customer may ask for its maximum credit at some point, use it, and then repay it
- Banker knows that all customers don't need max credit at the same time
  - So it reserves less than the sum of all credit limits

Banker's Algorithm (Dijkstra 1965)

	Has	Max
A	0	6
B	0	5
C	0	4
D	0	7

Free: 10

- Four customers A, B, C and D
  - Credit unit = £1K
- Banker reserves only 10 (instead of 22) units

Banker's Algorithm – Safe vs. Unsafe States

SAFE

	Has	Max
A	1	6
B	1	5
C	2	4
D	4	7

Free: 2

UNSAFE

	Has	Max
A	1	6
B	2	5
C	2	4
D	4	7

Free: 1

- Safe state:
  - Are there enough resources to satisfy ***any*** (maximum) request from some customer?
  - Assume that customer repays loan, and then check next customer closest to the limit, etc.
- A state is **safe** iff there exists a sequence of allocations that *guarantees* that all customers can be satisfied

Banker's Algorithm – Safe vs. Unsafe States

	Has	Max
A	3	9
B	2	4
C	2	7

Free: 3

SAFE

	Has	Max
A	3	9
B	4	4
C	2	7

Free: 1

	Has	Max
A	3	9
B	0	–
C	2	7

Free: 5

	Has	Max
A	3	9
B	0	–
C	7	7

Free: 0

	Has	Max
A	3	9
B	0	–
C	0	–

Free: 7

	Has	Max
A	4	9
B	2	4
C	2	7

Free: 2

UNSAFE

	Has	Max
A	4	9
B	4	4
C	2	7

Free: 0

	Has	Max
A	4	9
B	—	—
C	2	7

Free: 4

A state is **safe** iff there exists a sequence of allocations that *guarantees* all customers can be satisfied

Banker's Algorithm – Save vs. Unsafe States

SAFE

	Has	Max
A	1	6
B	1	5
C	2	4
D	4	7

Free: 2

UNSAFE

	Has	Max
A	1	6
B	2	5
C	2	4
D	4	7

Free: 1

- Request granted only if it leads to a safe state
- Unsafe state does not have to lead to deadlock, but banker cannot rely on this behaviour

- Algorithm can be generalized to handle multiple resource types

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Strategies For Dealing With Deadlock

- Ignore it
- Detection and recovery
- Dynamic avoidance
- Prevention
  - *Attack one of the four deadlock conditions:*
    - *Mutual exclusion,*
    - *Hold and wait*
    - *No preemption*
    - *Circular wait*

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Deadlock : 4 conditions

1. **Mutual exclusion:** each resource is either available or assigned to exactly one process

2. **Hold and wait :** process can request resources while it holds other resources earlier

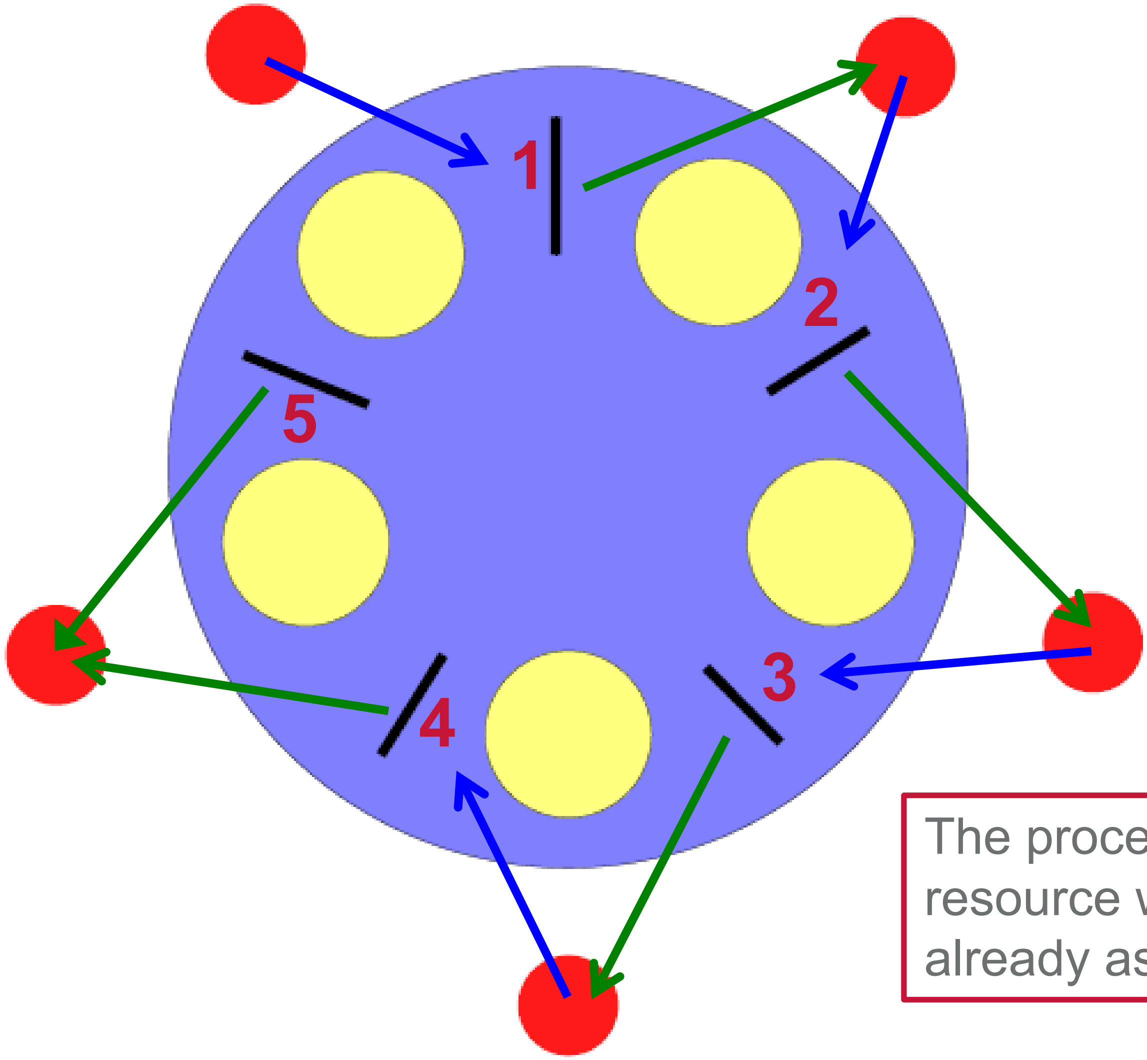
3. **No preemption:** resources given to a process cannot be forcibly revoked

4. **Circular wait:** two or more processes in a circular chain, each waiting for a resource held by the next process

Deadlock Prevention

- Attacking the Mutual Exclusion condition
  - E.g., share the resource
- Attacking the Hold and Wait condition
  - Require all processes to request resources before start
    - If not all available then wait
  - Issue: need to know what you need in advance
- Attacking the No-Preemption condition
  - E.g., forcing a process to give up printer half way through not good
- Attacking Circular Wait condition
  - Force single resource per process?
    - Optimality issues
  - Number resources, processes must ask for resources in this order
    - Issue: large number of resources…can be difficult to organise

Dining Philosophers – Ordering Resources



The process holding the highest resource will never ask for a resource already assigned.

Communication Deadlock

- E.g., process **A** sends message to **B** and blocks waiting on **B**’s reply

- **B** didn’t get **A**’s message then **A** is blocked and **B** is blocked waiting on message → ***deadlock***!

- Ordering resources, careful scheduling not useful here

- What should we use?
  - Communication protocol based on timeouts

Livelock

- **Livelock**: Processes/threads are not blocked, but they or the system as a whole not making progress
- Example 1: `Enter_region()` tests mutex then either grabs resource or reports failure. If attempt fails, it tries again.

```
process_A
{
   Enter_region (resource1)
   Enter_region (resource2)
   Use(resource1, resource2)
   Leave_region (resource2)
   Leave_region (resource1)
}
```

```
process_B
{
   Enter_region (resource2)
   Enter_region (resource1)
   Use(resource1, resource2)
   Leave_region (resource1)
   Leave_region (resource2)
}
```

- Example 2: System receiving and processing incoming messages. processing thread has lower priority and never gets a chance to run under high load (**receive livelock**)

Starvation

- Concerns policy
- Who gets what resource when
- Many jobs want printer, who gets it?
  - Smallest file? Suits majority, fast turnaround, but what about occasional large job?
  - FCFS is more fair in this case

Deadlocks: summary

- Resource deadlock: set of processes each waiting for a resource another one holds
  - Four conditions required for deadlock
  - Resource allocation graphs can be used to reason about deadlocks
- Strategies for avoiding deadlock
  - Ignoring
  - Detection and recovery
  - Dynamic avoidance
  - Prevention
- Communication deadlock: concerns policy
- Livelock: overall system makes no progress

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Question

- Two processes, A and B, each need three records, 1, 2, and 3, in a database. If A asks for them in the order 1, 2, 3, and B asks for them in the same order, deadlock is not possible. However, if B asks for them in the order 3, 2, 1, then deadlock is possible. With three resources, there are 3! = 6 possible combinations each process can request resources. What fraction of all combinations is guaranteed to be deadlock free?