Deadlocks

- What is deadlock & how it occurs
- Detecting potential deadlocks
  - – resource allocation graphs
- Recovery techniques
- Prevention techniques
- Livelock and starvation

Deadlocks

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

P0

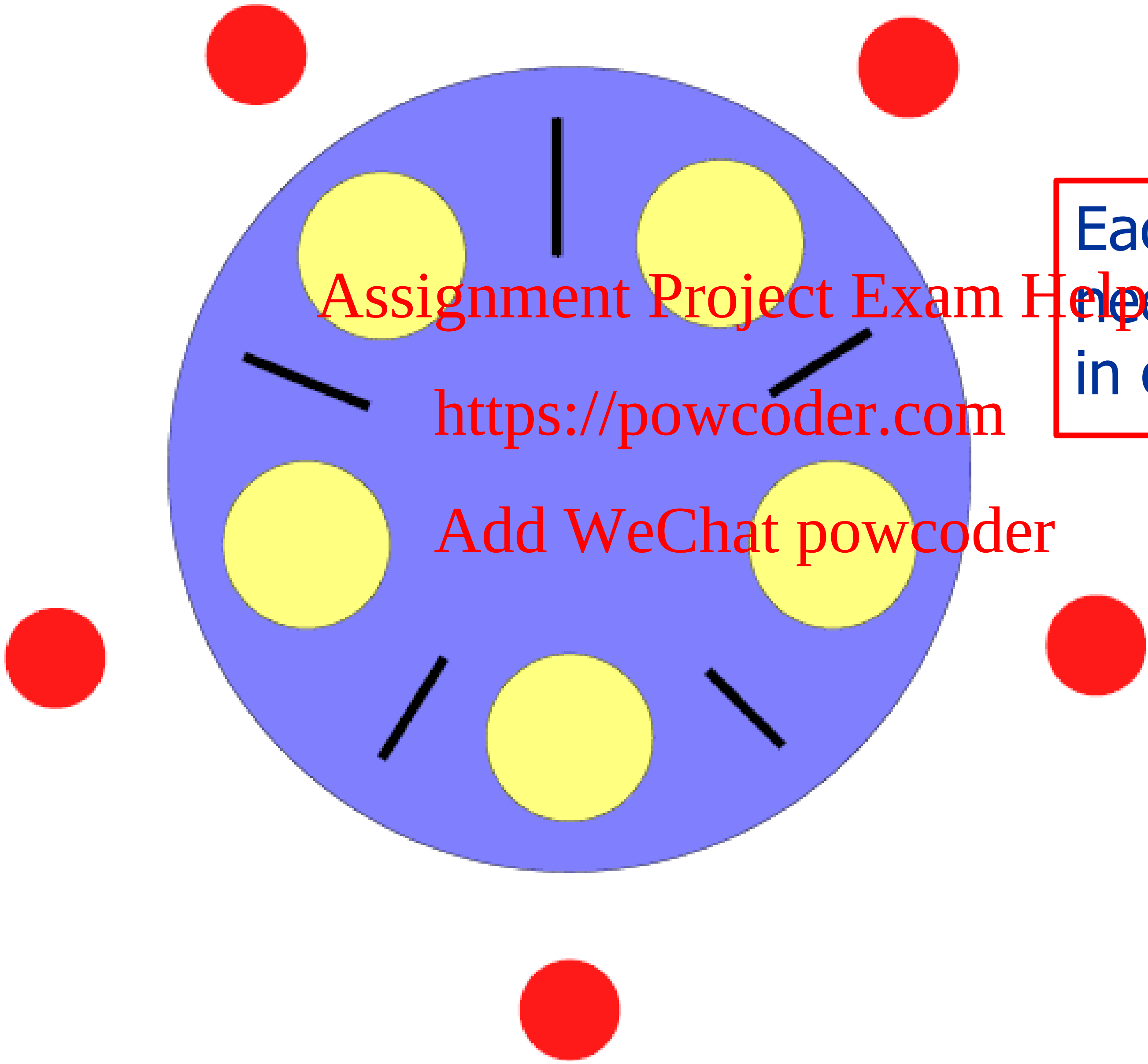
```
down(scanner);
down(cd_writer);
scan_and_record();
up(cd_writer);
up(scanner);
```

P1

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

Deadlock?

Dining Philosophers



Each philosopher needs 2 chopsticks in order to eat

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, requested 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

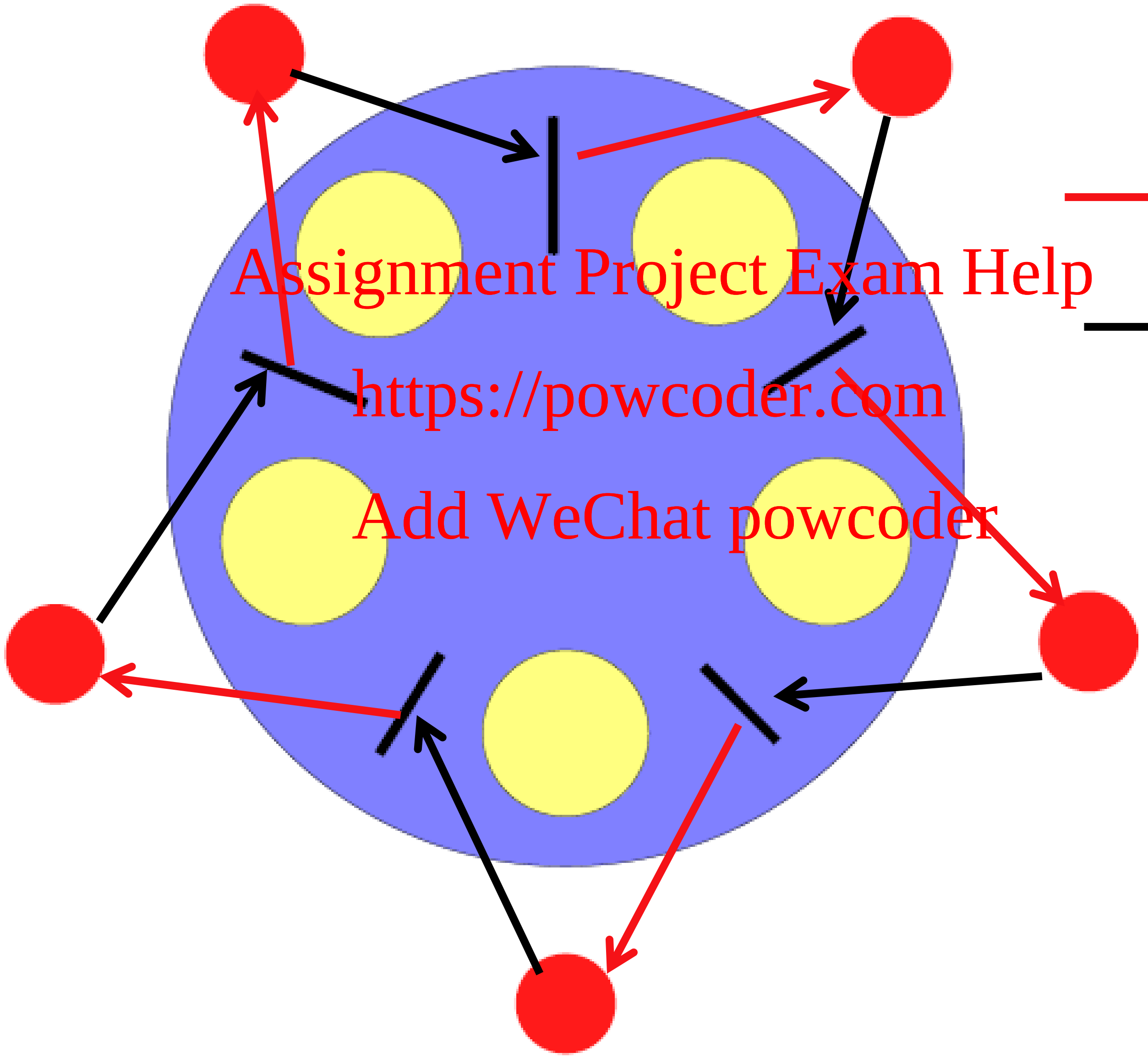
Resource Allocation Graphs

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



Owns chopstick

Waiting for chopstick

Strategies For Dealing With Deadlock

- Ignore it
  - "The Ostrich Algorithm"
  - Contention for resources is low → deadlocks infrequent
- Detection and recovery
- Dynamic avoidance by careful resource allocation
- Prevention by negating 1 of the 4 conditions

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 arc

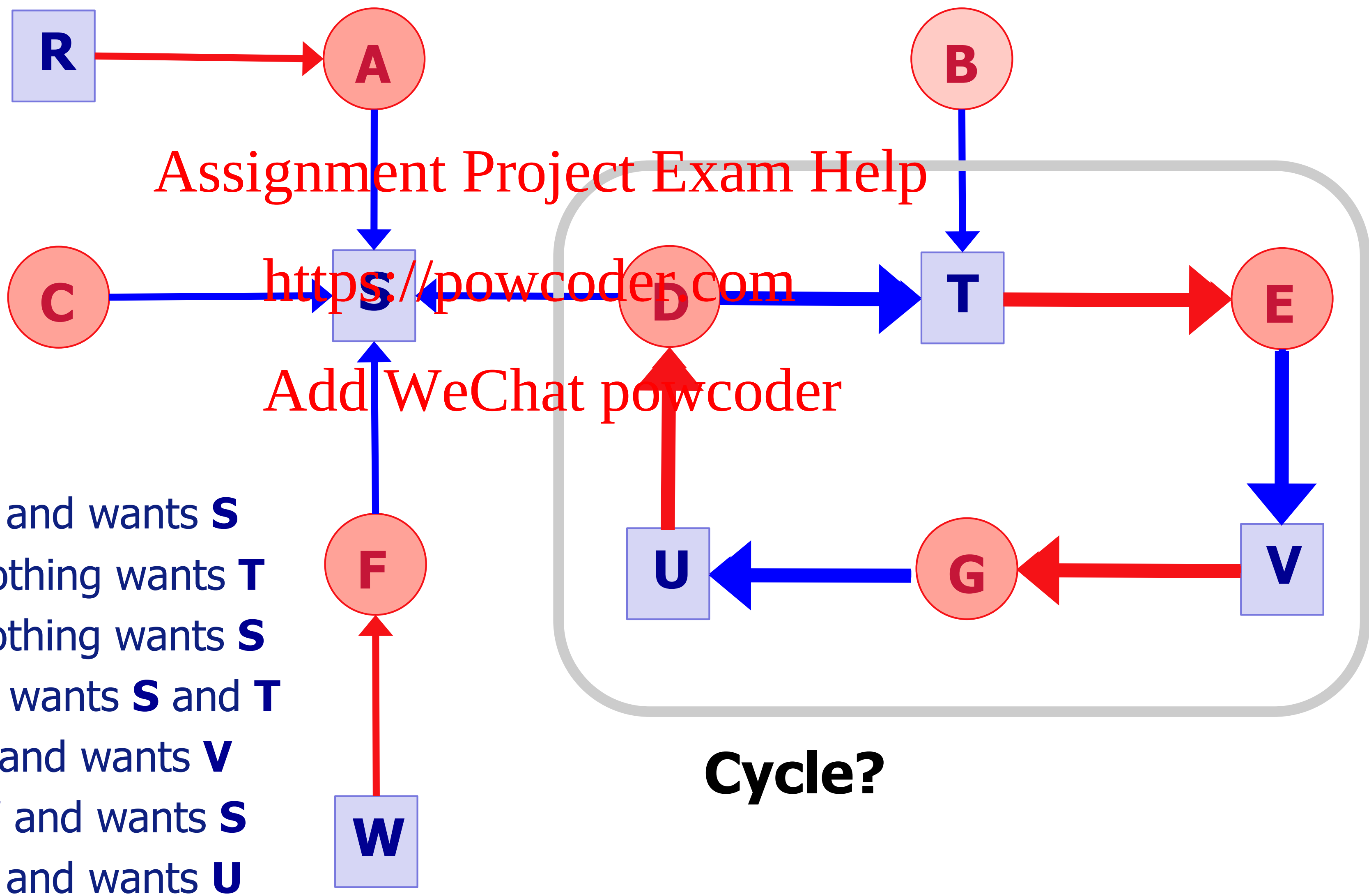
   Yes: goto **5**, No: goto **6**
5. Pick unmarked outgoing arc, mark it, follow it to new current node and goto **3**
6. If this is initial node then no cycles detected, terminate

   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.

[Tanenbaum, MOS 6.4.1]

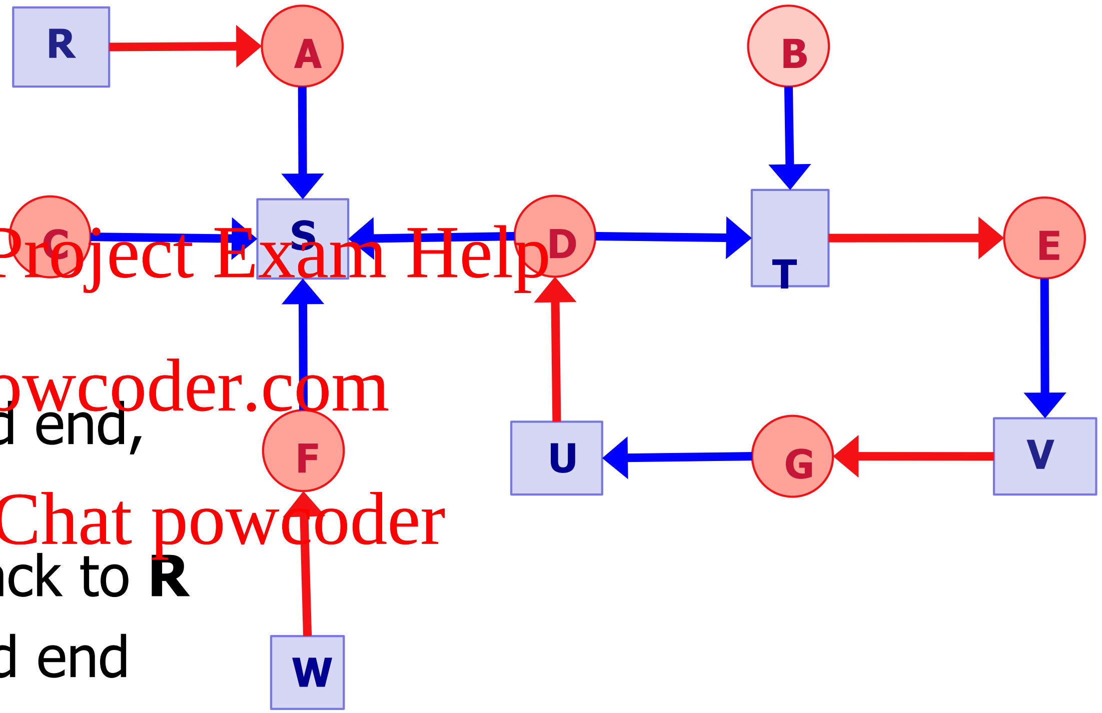
Detection – Example



- **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 (2)

- 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



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

Killing processes:

- Select random process in cycle and kill it!
    - OK for compile jobs, not so good for database, why?

Circular Chain Deadlock Question

Suppose that there is a resource deadlock in a system. Can the set of processes deadlocked include processes that are not in the circular chain in the corresponding resource allocation graph?

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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)

	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 knows that all customers don’t need max credit
  - So reserves only 10 (instead of 22) units
- Each customer randomly asks for credit
- For each process A-D,
  - Has = number of resource items allocated
  - Max = number of items required.

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

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

	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

SAFE

	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 – 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

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

Bankers Algorithm Question

A system has 12 magnetic tape drives and 3 processes : P0, P1, and P2.

Process	Has	Max Need
P0	5	10
P1	2	4
P2	2	9

What is a safe sequence for running the processes?

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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*

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

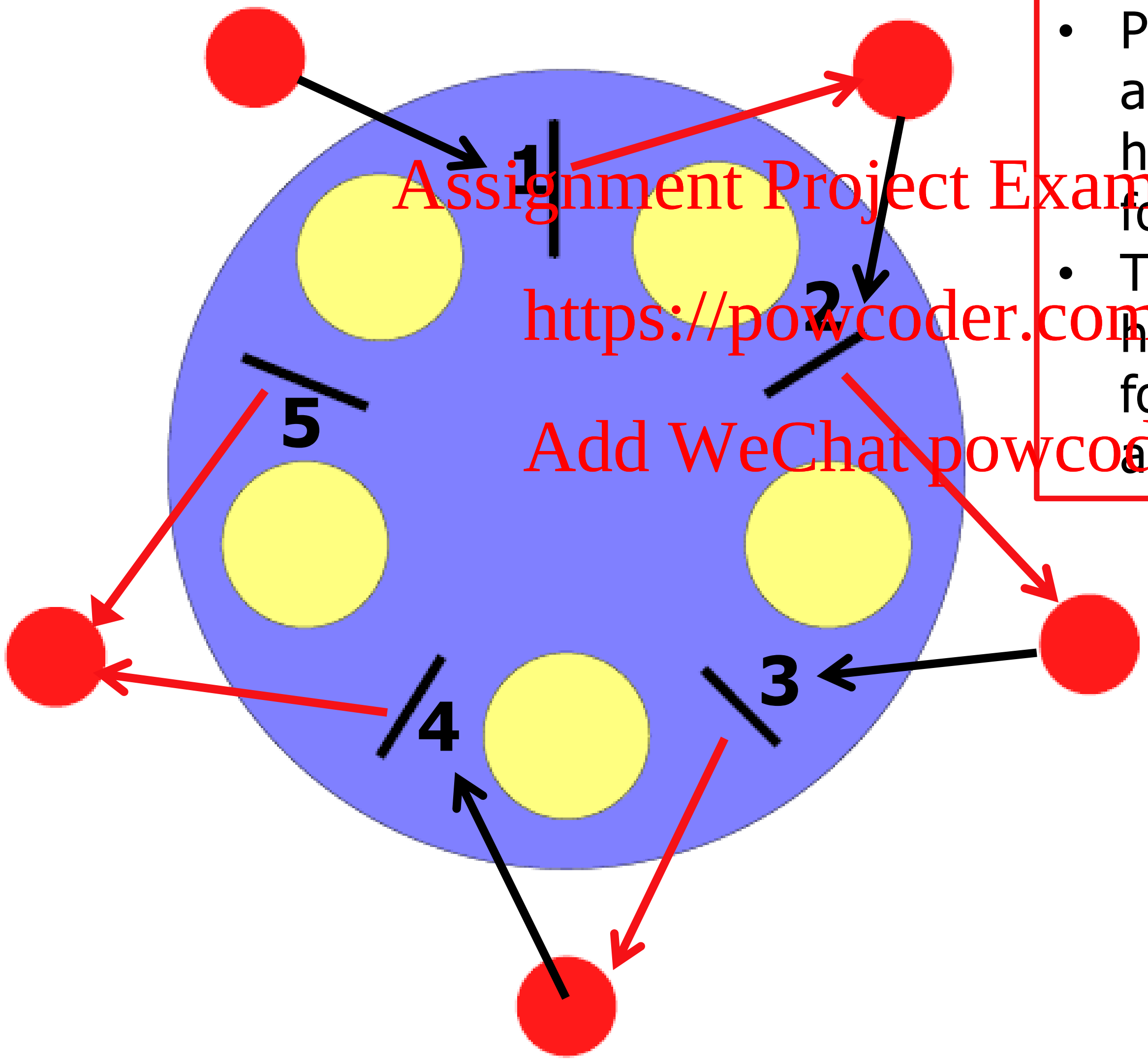
Attacking the No-Preemption condition

- E.g., forcing a process to give up printer half way through. Usually not good

Attacking Circular Wait Problem

- Force single resource per process, if needs second, must release first.
  - 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



- Request resources in specific order
- Philosopher gets chopstick 4 and can then ask for 5, but if he gets 5 first he cannot ask for chopstick 4.
- 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 does not make progress

- Example 1: `Enter_region()` tests mutex then either grabs resource or reports failure. If attempt fails, it tries again. Processes loop after gaining first resource but failing second.


```
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

Single Processor Deadlock?

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

Deadlock 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?

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Deadlock Summary

Deadlocks occur from:

- Accessing limited resources – not enough to go round
- Incorrect programming of synchronisation

Resource allocation graphs can detect potential cyclic deadlock

Recovery: pre-emption, rollback, kill process

Prevention

- Use safe resource allocation strategy
- Avoid unnecessary mutual exclusion – share instead
- Ordered resource allocation

Livelock: no progress – incorrect programming?

Starvation: often due to priority