Starvation and Deadlock

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CIS520 – Operating Systems

Reader/Writer with Semaphores

```
SharedLock::AcquireRead() {
    rmx.P();
    if (first reader)
        wsem.P();
    rmx.V();
}
```

```
SharedLock::AcquireWrite() {
    wsem.P();
}
```

```
SharedLock::ReleaseRead() {
    rmx.P();
    if (last reader)
        wsem.V();
    rmx.V();
}
```

```
SharedLock::ReleaseWrite() {
    wsem.V();
}
```

Reader/Writer with Semaphores: Take 2

```
SharedLock::AcquireRead() {
        rblock.P();
        rmx.P();
        if (first reader)
                wsem.P();
        rmx.V();
        rblock.V();
}

SharedLock::ReleaseRead() {
        rmx.P();
        if (last reader)
                wsem.V();
       rmx.V();
}
```

```
SharedLock::AcquireWrite() {
        wmx.P();
        if (first writer)
                rblock.P();
        wmx.V();
        wsem.P();
}

SharedLock::ReleaseWrite() {
        wsem.V();
        wmx.P();
        if (last writer)
                rblock.V();
        wmx.V();
}
```

This is a bit difficult to read, so let's simplify it.

Reader/Writer with Semaphores: Take 2+

```
SharedLock::AcquireRead() {
    rblock.P();
    if (first reader)
        wsem.P();
    rblock.V();
}
```

```
SharedLock::AcquireWrite() {
    if (first writer)
        rblock.P();
    wsem.P();
}
```

```
SharedLock::ReleaseRead()  {
    if (last reader)
        wsem.V();
}
```

```
SharedLock::ReleaseWrite() {
    wsem.V();
    if (last writer)
        rblock.V();
}
```

The rblock prevents readers from entering while writers are waiting.

Starvation

The reader/writer lock example illustrates *starvation*: under load, a writer will be stalled forever by a stream of readers.

- **Example**: a **one-lane bridge or tunnel**.

  Wait for oncoming car to exit the bridge before entering.

  Repeat as necessary.

- **Problem**: a "writer" may never be able to cross if faced with a continuous stream of oncoming "readers".
- **Solution**: some reader must politely stop before entering, even though it is not forced to wait by oncoming traffic.

  Use extra synchronization to control the lock scheduling policy.

  Complicates the implementation: optimize only if necessary.

Deadlock

Deadlock is closely related to starvation.

- Processes wait forever for each other to wake up and/or release resources.
- *Example:* ***traffic gridlock***.

The difference between deadlock and starvation is subtle.

- With starvation, there always exists a schedule that feeds the starving party.

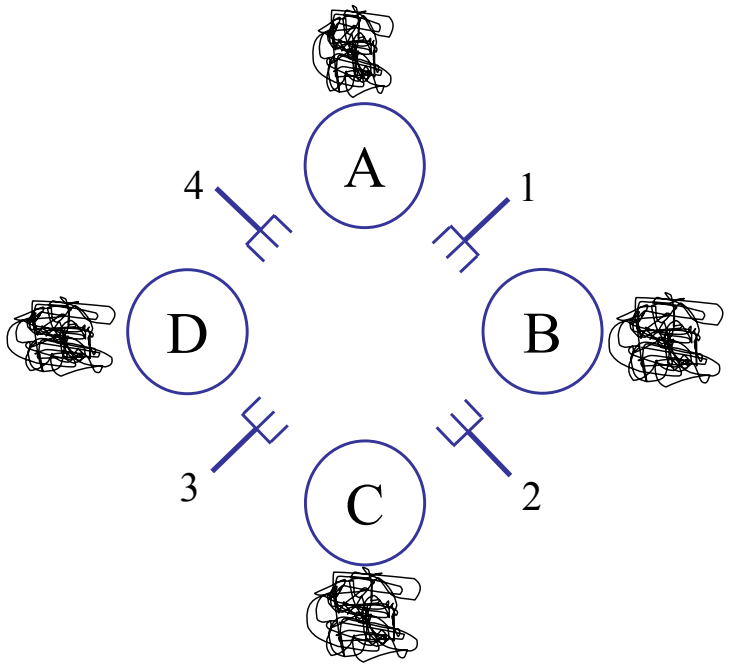
  The situation may resolve itself…if you're lucky.

- Once deadlock occurs, it cannot be resolved by any possible future schedule.

  …though there may exist schedules that *avoid* deadlock.

Dining Philosophers

- *N* processes share *N* resources
- resource requests occur in pairs
- random think times
- hungry philosopher grabs a fork
- ...and doesn't let go
- ...until the other fork is free
- ...and the linguine is eaten




```
while(true) {
        Think();
        AcquireForks();
        Eat();
        ReleaseForks();
}
```

Four Preconditions for Deadlock

Four conditions must be present for *deadlock* to occur:

1. *Non-preemptability*. Resource ownership (e.g., by threads) is *non-preemptable*.

   Resources are never taken away from the holder.

2. *Exclusion*. Some thread cannot acquire a resource that is held by another thread.

3. *Hold-and-wait*. Holder blocks awaiting another resource.

4. *Circular waiting*. Threads acquire resources out of order.

Resource Graphs

Given the four preconditions, some schedules may lead to *circular waits*.

- Deadlock is easily seen with a *resource graph* or *wait-for graph*.

  The graph has a vertex for each process and each resource.

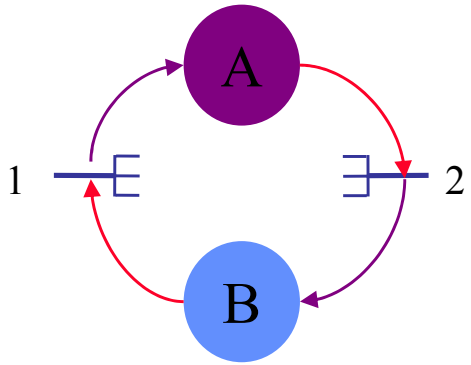
  If process ***A*** holds resource ***R***, add an arc from ***R*** to ***A***.

  If process ***A*** is waiting for resource ***R***, add an arc from ***A*** to ***R***.

The system is deadlocked iff the wait-for graph has at least one cycle.

Sn

A grabs fork ***1*** and waits for fork ***2***.



B grabs fork ***2*** and waits for fork ***1***.

assign request

Not All Schedules Lead to Collisions

The scheduler chooses a path of the executions of the threads/processes competing for resources.

Synchronization constrains the schedule to avoid illegal states.

Some paths "just happen" to dodge dangerous states as well.

What is the probability that philosophers will deadlock?

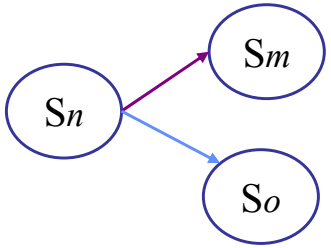
- How does the probability change as:

  think times increase?

  number of philosophers increases?

Resource Trajectory Graphs

Resource trajectory graphs (RTG) depict the scheduler's "random walk" through the space of possible system states.



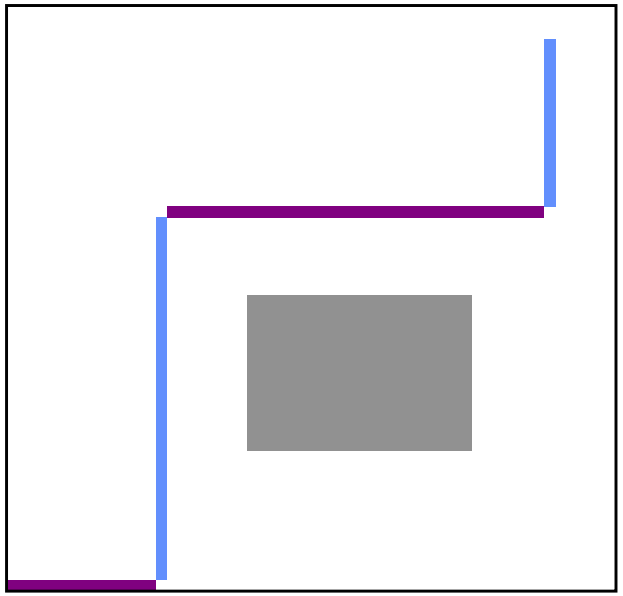
RTG for N processes is N-dimensional.

Process *i* advances along axis *I*.

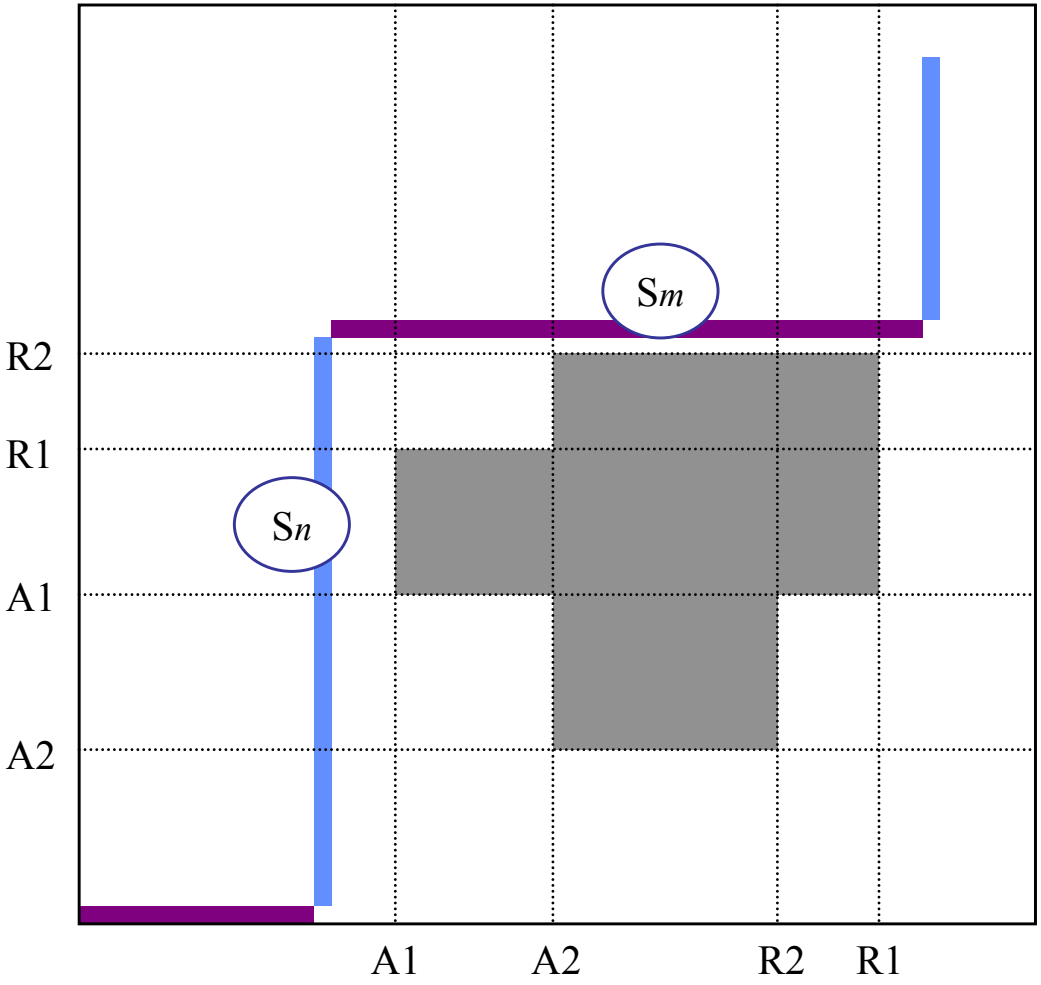
Each point represents one state in the set of all possible system states.

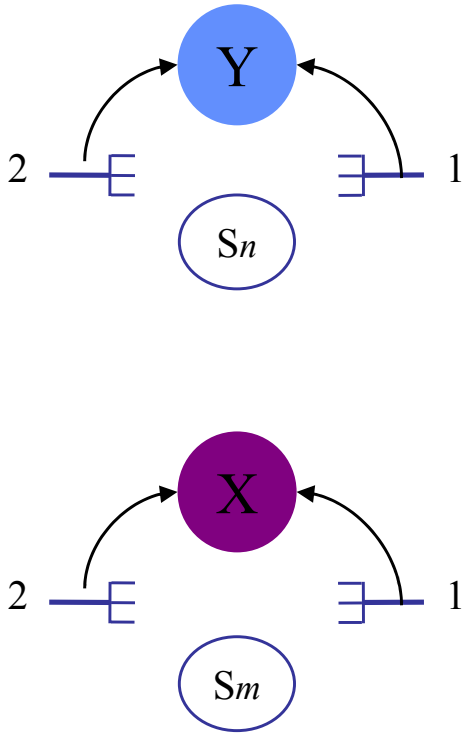
cross-product of the possible states of all processes in the system

(But not all states in the cross-product are legally reachable.)



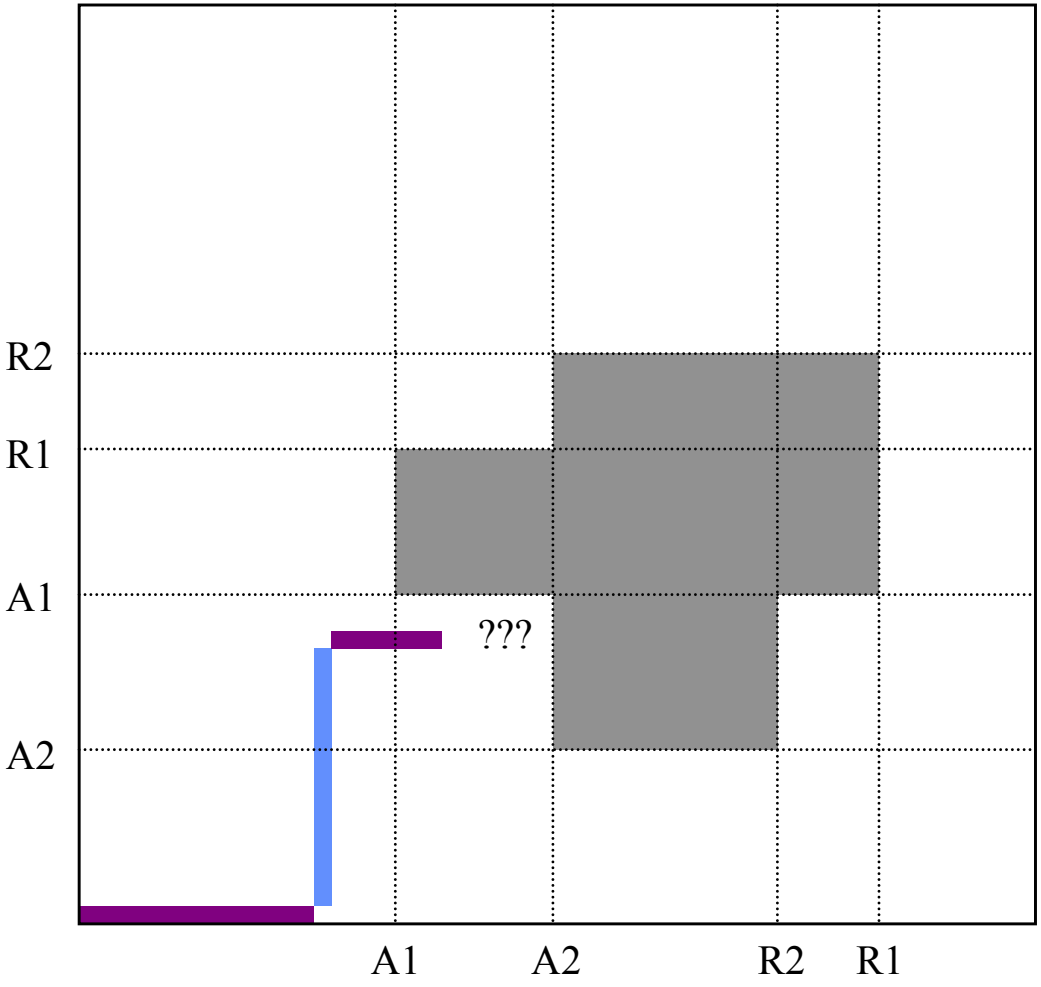
RTG for Two Philosophers

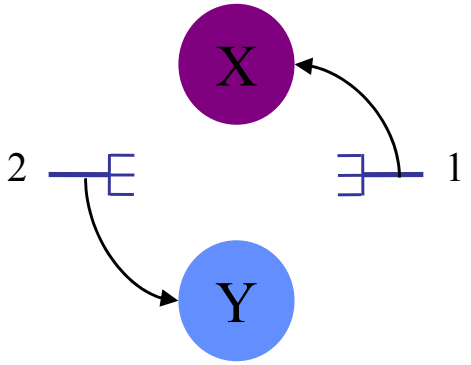




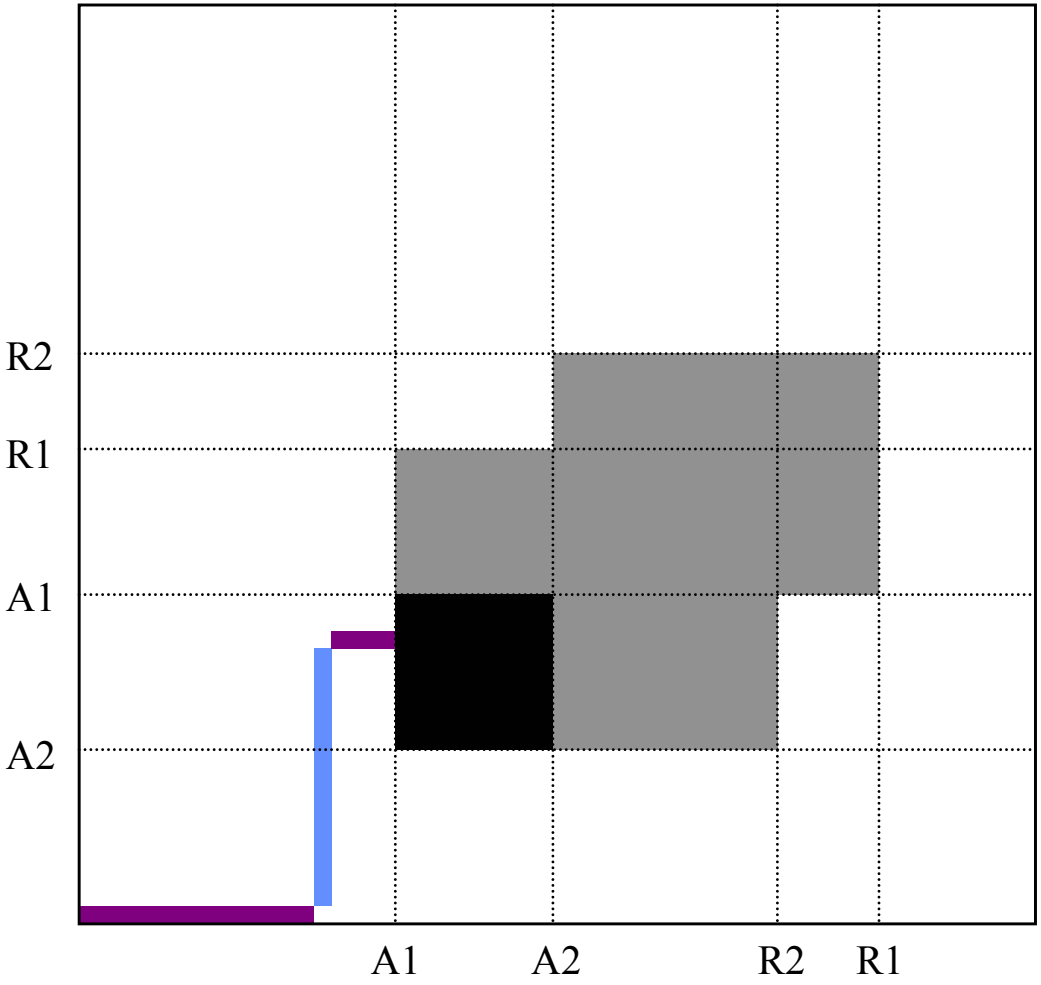
(There are really only 9 states we care about: the important transitions are allocate and release events.)

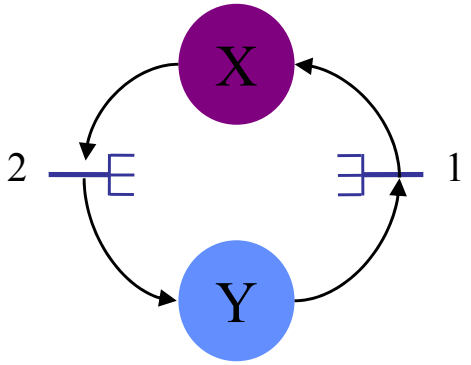
Two Philosophers Living Dangerously





The Inevitable Result





no legal transitions out
of this *deadlock state*

Dealing with Deadlock

1. *Ignore it*. "How big can those black boxes be anyway?"
2. *Detect it and recover*. Traverse the resource graph looking for cycles before blocking any customer.
   - If a cycle is found, **preempt**: force one party to release and restart.
3. *Prevent it* statically by breaking one of the preconditions.
   - Assign a fixed *partial ordering* to resources; acquire in order.
   - Use locks to reduce multiple resources to a single resource.
   - Acquire resources in advance of need; release all to retry.
4. *Avoid it* dynamically by denying some resource requests.

   Banker's algorithm

Deadlock prevention – attacking the cause

Look at the deadlock conditions listed above.

- *Mutual Exclusion* - To eliminate mutual exclusion, allow everybody to use the resource immediately if they want to. Unrealistic in general - do you want your printer output interleaved with someone elses?
- *Hold and Wait*. Ensure that when a process requests resources, does not hold any other resources. Either
    - asks for all resources before executes, or
    - dynamically asks for resources in chunks as needed, then releases all resources before asking for more.
    - Two problems –
        - Processes may hold but not use resources for a long time because they will eventually hold them, and
        - Starvation. If a process asks for lots of resources, may never run because other processes always hold some subset of the resources.
- *Circular Wait*. To prevent circular wait, order resources and require processes to request resources in that order. (resource ordering)

Extending the Resource Graph Model

Reasoning about deadlock in real systems is more complex than the simple resource graph model allows.

- Resources may have multiple instances (e.g., memory).

  Cycles are necessary but not sufficient for deadlock.

  For deadlock, each resource node with a request arc in the cycle must be fully allocated and unavailable.

- Processes may block to await *events* as well as resources.

  E.g., ***A*** and ***B*** each rely on the other to wake them up for class.

  These "logical" producer/consumer resources can be considered to be available as long as the producer is still active.

  Of course, the producer may not produce as expected.

Banker's Algorithm

The *Banker's Algorithm* is the classic approach to deadlock *avoidance* (choice 4) for resources with multiple units.

1. Assign a **credit limit** to each customer.

   "maximum claim" must be stated/negotiated in advance

2. Reject any request that leads to a **dangerous state**.

   A dangerous state is one in which a sudden request by any customer(s) for the full credit limit could lead to deadlock.

   A recursive reduction procedure recognizes dangerous states.

3. In practice, this means the system must keep resource usage well below capacity to maintain a **reserve surplus**.

   Rarely used in practice due to low resource utilization.

Deadlock detection revisited…

- **When to run deadlock detection algorithm?** Obvious time: whenever a process requests more resources and suspends. If deadlock detection takes too much time, maybe run it less frequently.
- **What do you do**? Must free up some resources so that some processes can run. So, preempt resources - take them away from processes. Several different preemption cases:
  - **preempt some resources** without killing job - for example, main memory. Can just swap out to disk and resume job later.
  - **roll job back** to point before acquired resources. At a later time, restart job from rollback point.
  - **kill job.** All resources are then free. Can either
    - kill processes one by one until system is no longer deadlocked. Or,
    - just go ahead and kill all deadlocked processes.
- How come these topics never seem to arise in modern Unix systems?