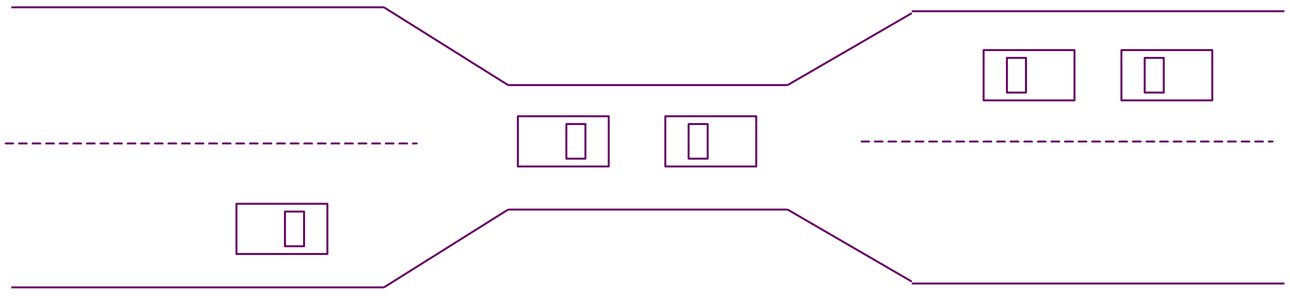
PROCESSES DEADLOCK (OR DEADLY EMBRACE)

- two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes.
  - Tape drives example
    - System has 2 tape drives.
    - P_1 and P_2 each hold one tape drive and each needs another one.
    - semaphores *A* and *B*, initialized to 1

P_0	P_1
wait (A);	*wait(B)*
wait (B);	*wait(A)*

  - **Bridge Crossing Example**



- Traffic only in one direction.
- Each section of a bridge can be viewed as a resource.
- If a deadlock occurs, it can be resolved if one car backs up (preempt resources and rollback).
- Several cars may have to be backed up if a deadlock occurs.
- Starvation is possible.

DEADLOCK SYSTEM MODEL

- Resource types R_1, R_2, . . ., R_m

  CPU cycles, memory space, I/O devices

- Each resource type R_i has W_i instances.

- Each process utilizes a resource as follows:
  - request
  - use
  - release

- Deadlock can arise if four conditions hold simultaneously (Coffman theorem)
  - **Mutual exclusion:** only one process at a time can use a resource.
  - **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes.
  - **No preemption:** a resource can be released only voluntarily by the process holding it, after that process has completed its task.
  - **Circular wait:** there exists a set $\{P_0, P_1, \ldots, P_0\}$ of waiting processes such that P_0 is waiting for a resource that is held by P_1, P_1 is waiting for a resource that is held by P_2, …, P_{n-1} is waiting for a resource that is held by P_n, and P_0 is waiting for a resource that is held by P_0.

METHODS FOR HANDLING DEADLOCKS

- Ensure that the system will *never* enter a deadlock state
  - **Prevention**
  - **Avoidance**

- Allow the system to enter a deadlock state and then recover
  - **Detect and Recover**

- Ignore the problem and pretend that deadlocks never occur in the system; used by most operating systems, including UNIX.

DEADLOCK PREVENTION

Resources must be claimed *a priori* in the system (resources pre-allocation)

or

Restrain the ways request can be made (Coffman condition denial).

- **Mutual Exclusion** – not required for sharable resources; must hold for nonsharable resources.

- **Hold and Wait** – must guarantee that whenever a process requests a resource, it does not hold any other resources.
  - Require process to request and be allocated all its resources before it begins execution, or allow process to request resources only when the process has none.
  - Low resource utilization; starvation possible.

- **No Preemption** –
  - If a process that is holding some resources requests another resource that cannot be immediately allocated to it, then all resources currently being held are released.
  - Preempted resources are added to the list of resources for which the process is waiting.
  - Process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting.

- **Circular Wait** – impose a total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration.

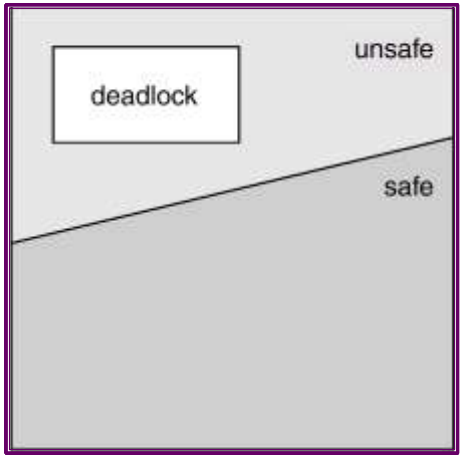
DEADLOCK AVOIDANCE

- Requires that the system has some additional *a priori* information available.
- Simplest and most useful model requires that each process declare the *maximum number* of resources of each type that it may need.
- The deadlock-avoidance algorithm dynamically examines the resource-allocation state to ensure that there can never be a circular-wait condition.
- Resource-allocation ***state*** is defined by the number of available and allocated resources, and the maximum demands of the processes.

SAFE STATE – SAFE SEQUENCE

- ☞ When a process requests an available resource, system must decide if immediate allocation leaves the system in a *safe state*.
- ☞ System is in safe state if there exists a safe sequence of all processes - Banker's Algorithm (Habermann theorem).
- ☞ Sequence $<P_1, P_2, \ldots, P_n>$ is safe if for each P_{i}, the resources that Pi can still request can be satisfied by currently available resources + resources held by all the P_j, with $j<I$.
  - If $\mathrm{P_i}$ resource needs are not immediately available, then P_i can wait until all P_j have finished.
  - When P_j is finished, P_{i} can obtain needed resources, execute, return allocated resources, and terminate.
  - When P_i terminates, P_{i+1} can obtain its needed resources, and so on.
- ☞ If a system is in safe state $\Rightarrow$ no deadlocks.
- ☞ If a system is in unsafe state $\Rightarrow$ possibility of deadlock.

Avoidance $\Rightarrow$ ensure that a system will never enter an unsafe state.



THE BANKER'S ALGORITHM

Example

5 processes P_1 through P_5; 3 resource types:
A (10 instances), B (5 instances), and C (7 instances).
Snapshot at time T_0:

	Allocation	Max	Available
	A B C	A B C	A B C
P_1	0 1 0	7 5 3	3 3 2
P_2	2 0 0	3 2 2	
P_3	3 0 2	9 0 2	
P_4	2 1 1	2 2 2	
P_5	0 0 2	4 3 3	

	Need
	A B C
P_1	7 4 3
P_2	1 2 2
P_3	6 0 0
P_4	0 1 1
P_5	4 3 1

The system is in a safe state since the sequence $< P_2, P_4, P_5, P_3, P_1 >$ satisfies safety criteria.

THE BANKER'S ALGORITHM

Example

P_2 makes a $\text{Request}_1 = (1,0,2) \leq \text{Available} = (3,3,2) \Rightarrow$ *true*.

	Allocation	Need	Available
	A B C	*A B C*	*A B C*
P_1	0 1 0	7 4 3	2 3 0
P_2	3 0 2	0 2 0	
P_3	3 0 2	6 0 0	
P_4	2 1 1	0 1 1	
P_5	0 0 2	4 3 1	

Executing safety algorithm shows that sequence $\langle P_2, P_4, P_5, P_3, P_1 \rangle$ satisfies safety requirement.

Can request for (3,3,0) by P_5 be granted?

Can request for (0,2,0) by P_1 be granted?

DEADLOCK DETECTION

- Allow system to enter deadlock state

- Recovery scheme
  - **Process termination**
  - **Resource Preemption**

RECOVERY FROM DEADLOCK

Process Termination

- Abort all deadlocked processes.
- Abort one process at a time until the deadlock cycle is eliminated.

In which order should we choose to abort?

- Priority of the process.
- How long process has computed, and how much longer to completion.
- Resources the process has used.
- Resources process needs to complete.
- How many processes will need to be terminated.
- Is process interactive or batch?

Resource Preemption

- Selecting a victim – minimize cost.
- Rollback – return to some safe state, restart process for that state.
- Starvation – same process may always be picked as victim, include number of rollback in cost factor.