csci 3411: Operating Systems

Deadlocks

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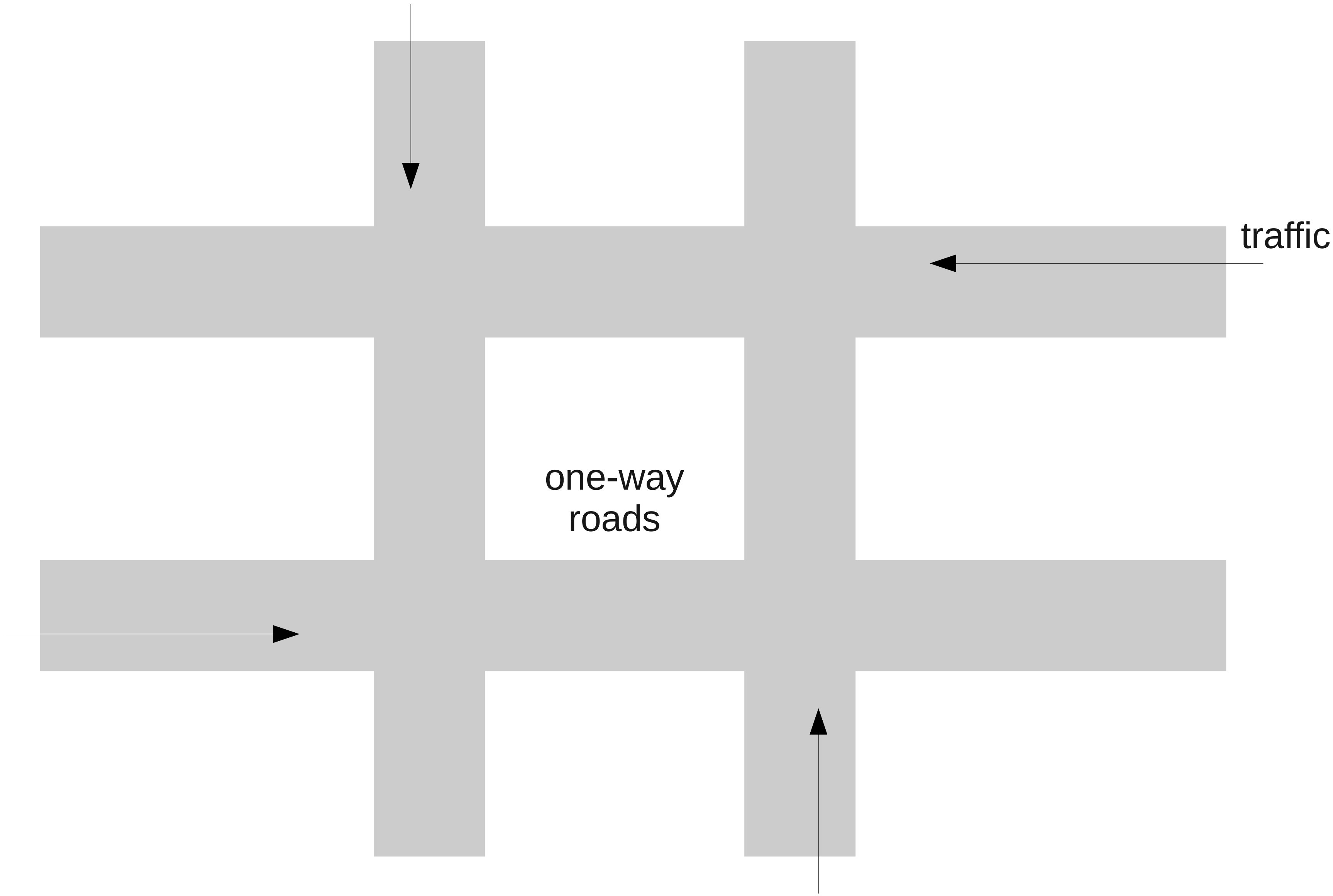
Slides evolved from Silberschatz and West

Deadlocks:Synchronization Gone Wild

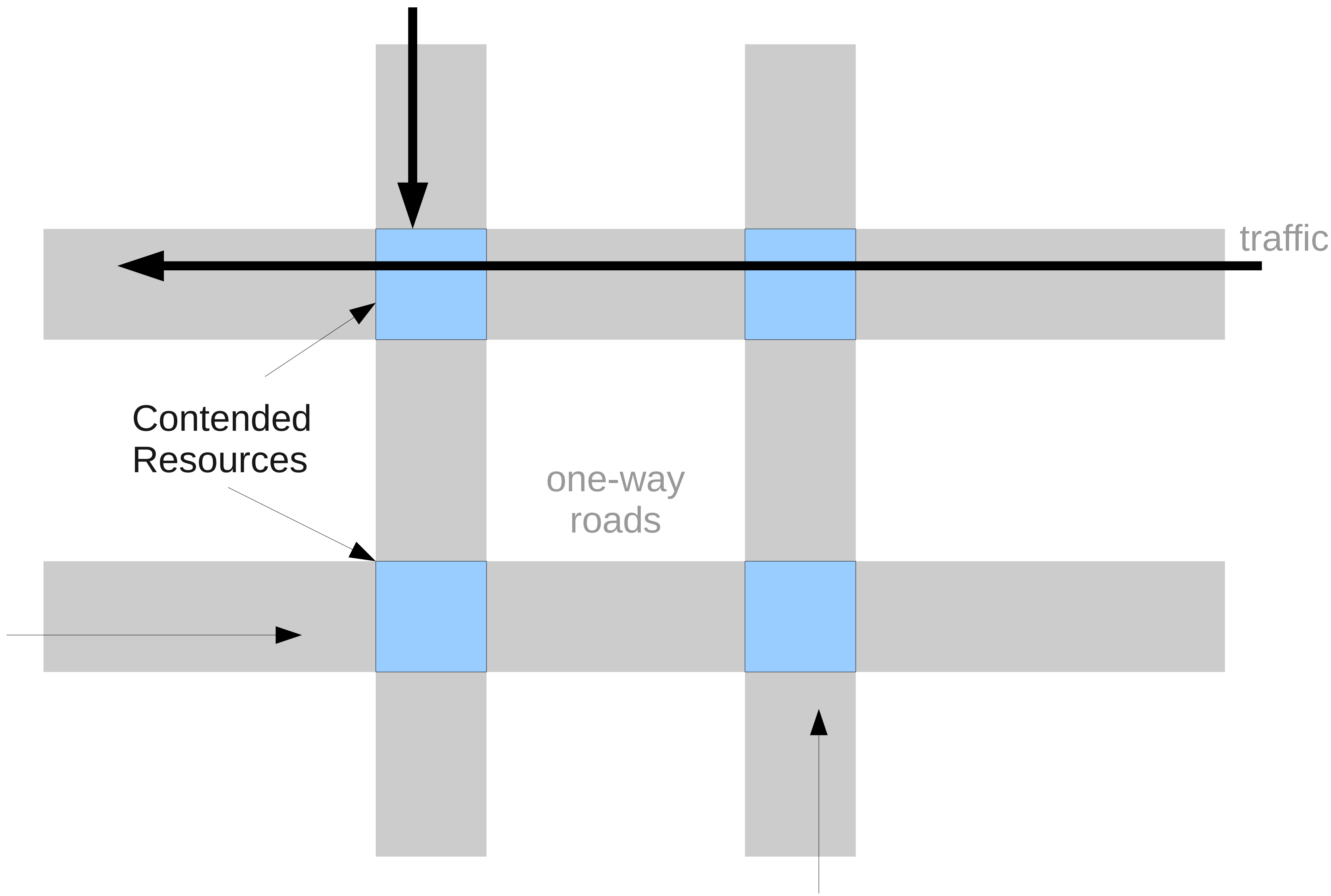
- A set of blocked processes each
  - Hold a *resource* (critical section, using device, mem)
  - Wait to acquire a resource held by another of the processes in the set
  - Can cause starvation
- An example:

<u>thread 1</u>	<u>thread 2</u>
wait(s1)	wait(s2)
wait(s2)	wait(s1)
process()	process()
signal(s2)	signal(s1)
signal(s1)	signal(s2)

Traffic and Resource Contention



Traffic and Resource Contention



Traffic and Resource Contention

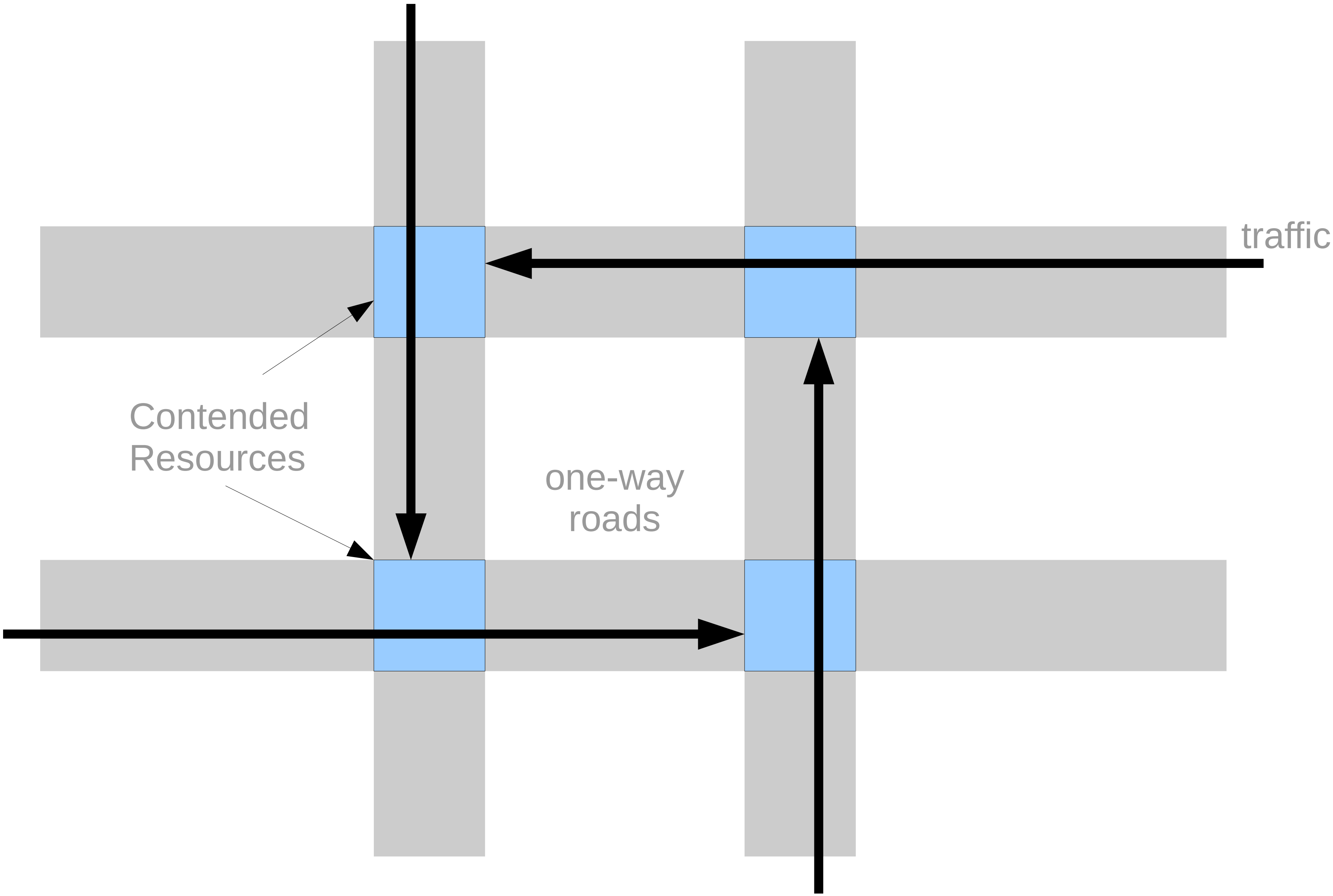


Image Source: http://www.glommer.net/blogs/?p=189

System Model

- Different resource types R_1, R_2, R_3, …
  - CPU, Devices, Memory, Data-structures
- Each resource type R_i has W_i instances
  - Amount of memory, multiple CPUs, counting semaphore
- Each process uses a resource as follows:

  request()

  use()

  release()

Deadlock Characterization

Deadlock *<u>can</u>* arise if 4 conditions hold simultaneously

1) *Mutual Exclusion*: single processes uses resource

2) *Hold and Wait:* process holding at least one resource is waiting to acquire additional resources held by other processes

3) *No Preemption*: a resource can be released only voluntarily by the process holding it after use

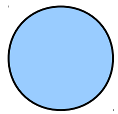
4) *Circular wait*: there exists a set $\{P_0, P_1, \ldots, P_n\}$ of waiting processes such that P_0 is waiting for a resource held by P_1, P_1 is waiting for a resource that is held by P_2, ..., and P_n is waiting for a resource that is held by P_0.

Resource Allocation Graph

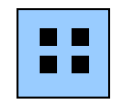
- $G = (V, E)$
- Two types of V:
  - $P = \{P_0, P_1, \ldots, P_n\}$, processes in the system
  - $R = \{R_1, R_2, \ldots, R_n\}$, resource types in the system
- Each edge in set E is either:
  - A directed *request edge*: $P_i \rightarrow R_j$
  - A directed *assignment edge*: $R_j \rightarrow P_i$

Resource Allocation Graph II

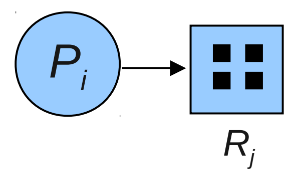
- Process:



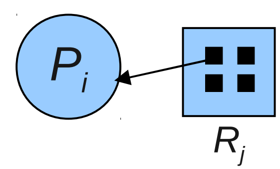
- Resource Type with 4 instances:



- P_i *requests* instance of R_j:

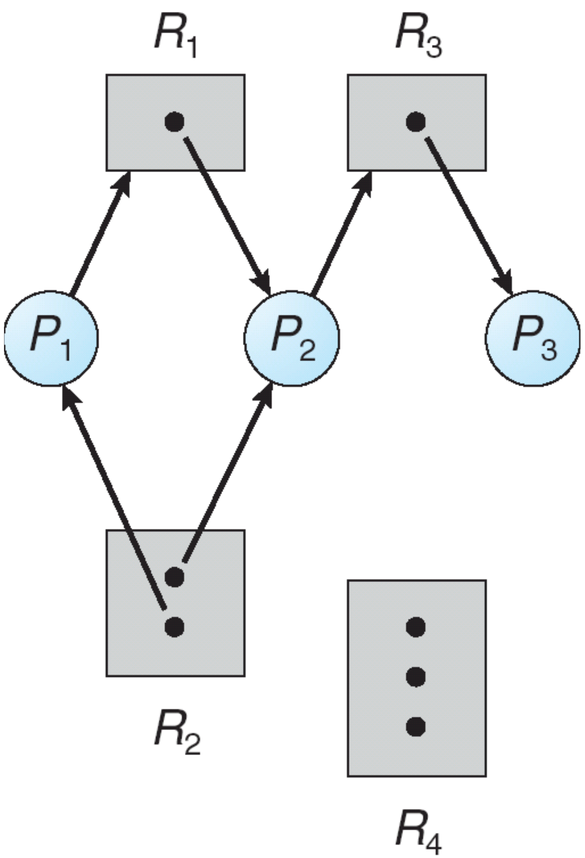


  - Call *wait*(semaphore)
  - Call *malloc*(10)
- P_i is *assigned* an instance of R_j:



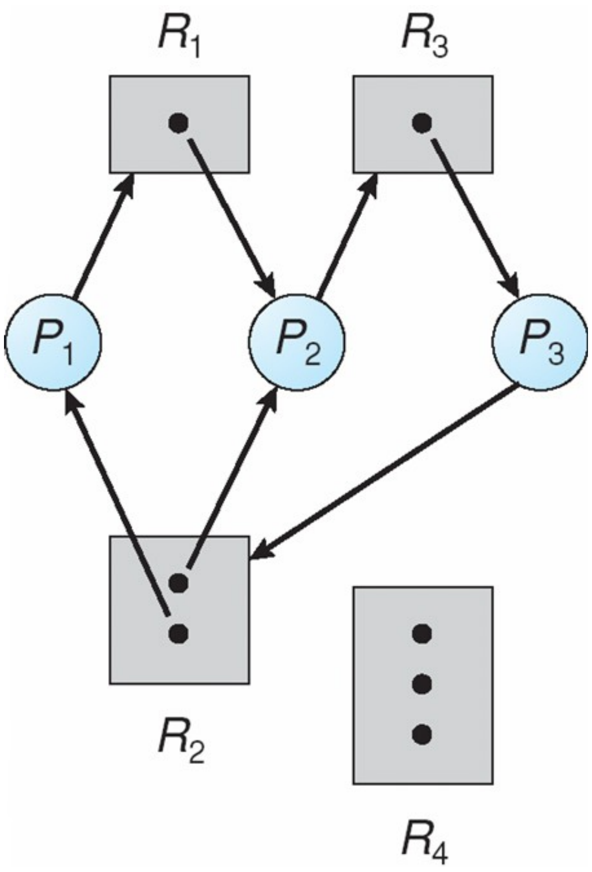
  - *wait*(semaphore) returns
  - *malloc*(10) returns a pointer

Example Resource Allocation Graph



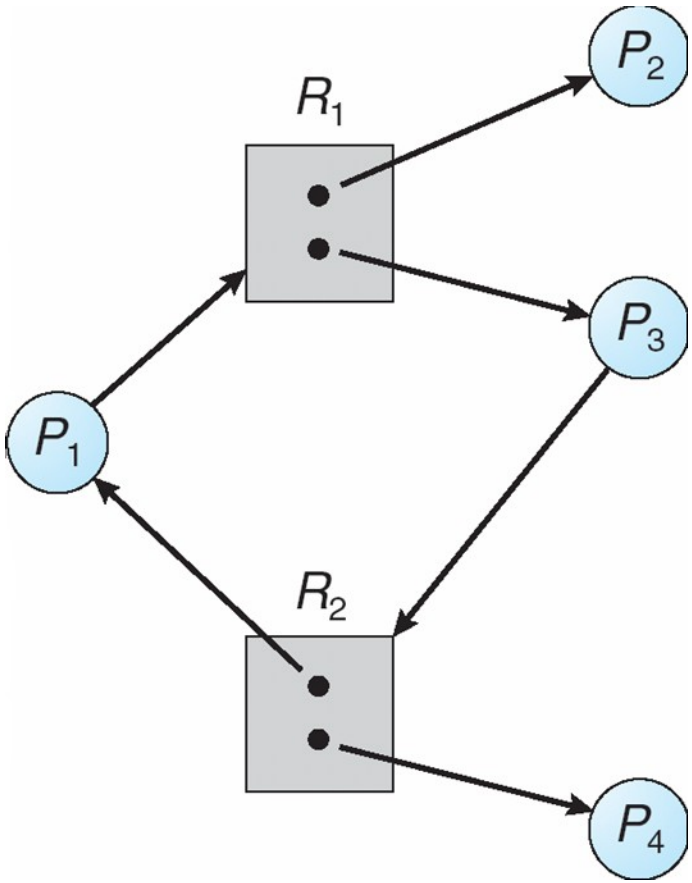
Is there a deadlock?

Example Resource Alloc. Graph II



Is there a deadlock?

Example Resource Alloc. Graph III



Is there a deadlock?

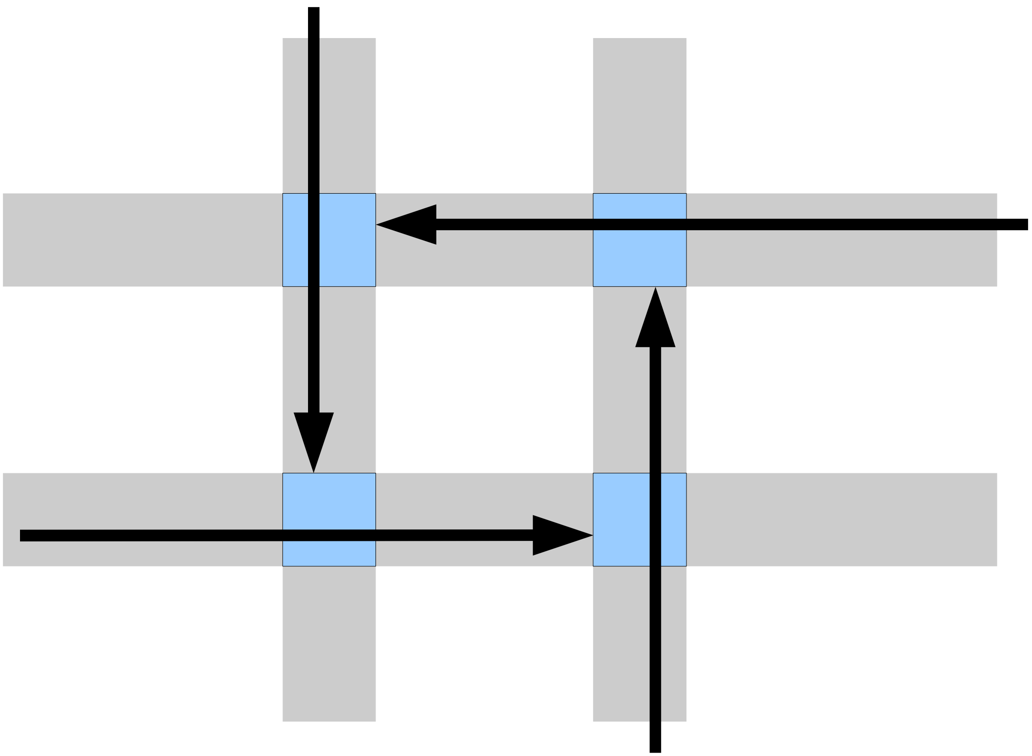
Conditions for Deadlock

- If a graph contains no cycles, no deadlock!

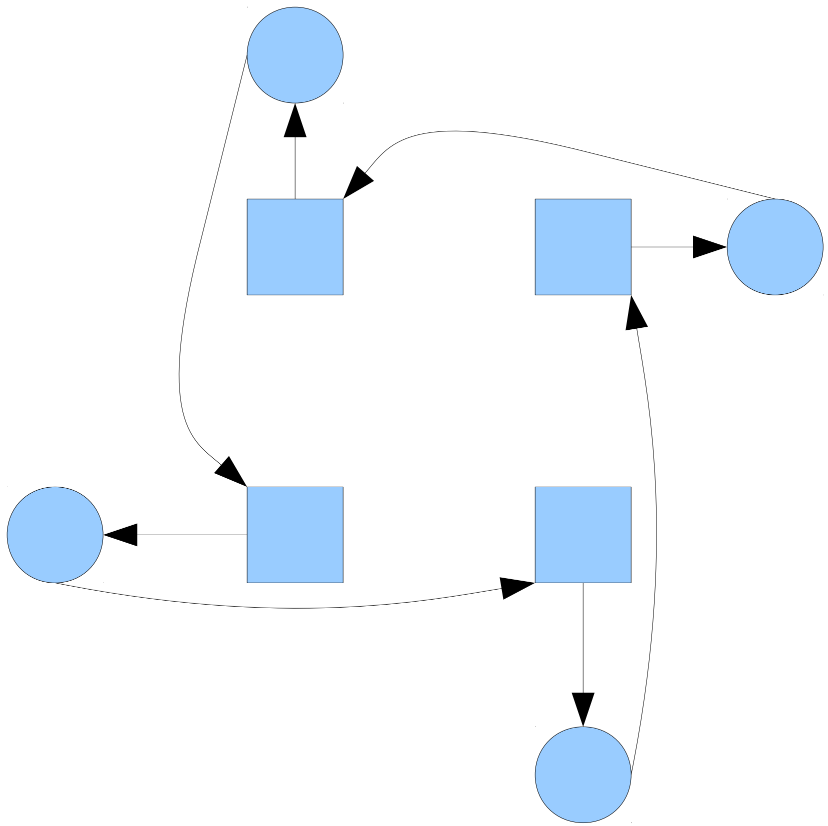
- If graph contains cycle:
  - If one instance per resource type → deadlock
  - If several instances per resource type, deadlock is *possible* but not certain

Traffic Resource Allocation Graph

System



Model



Methods for Handling Deadlocks

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

- Allow deadlocks to happen, then recover
  - *Detection* and *Recovery*

- Ignorance, luck, and crossed fingers
  - Most systems take this approach

Deadlock Prevention

Prevent any of the 4 conditions for deadlock

- *Mutual Exclusion*: can't compromise here
- *Hold and Wait*: guarantee that when process requests a resource, it holds no others
  - Processes allocated all its resources before it begins execution and requests resources only when it has none

    → low resource utilization and starvation possible

Deadlock Prevention II

- *No Preemption*: If a process holds a resource, and makes a request for another that cannot be satisfied, release all currently held resources
  - Resources added list of resources process is waiting for
  - Process restarted when it can acquire *all* these resources
- *Circular Wait*: Impose a total ordering on resources
  - Ensure that processes request resources in increasing order
  - *Informally, this is a pervasively used technique*

Deadlock Avoidance

- Dynamically observe pattern of resource allocation given system state and decide if its safe to allocate resources
  - Each process declares *maximum number* of resources of each type it will need (a-priori)
  - Deadlock avoidance algorithm dynamically examines resource allocation state; ensure no circular wait condition
  - Resource allocation *state* defined by the number of available and allocated resources *and* the maximum demands of processes

Deadlock Avoidance Algorithms

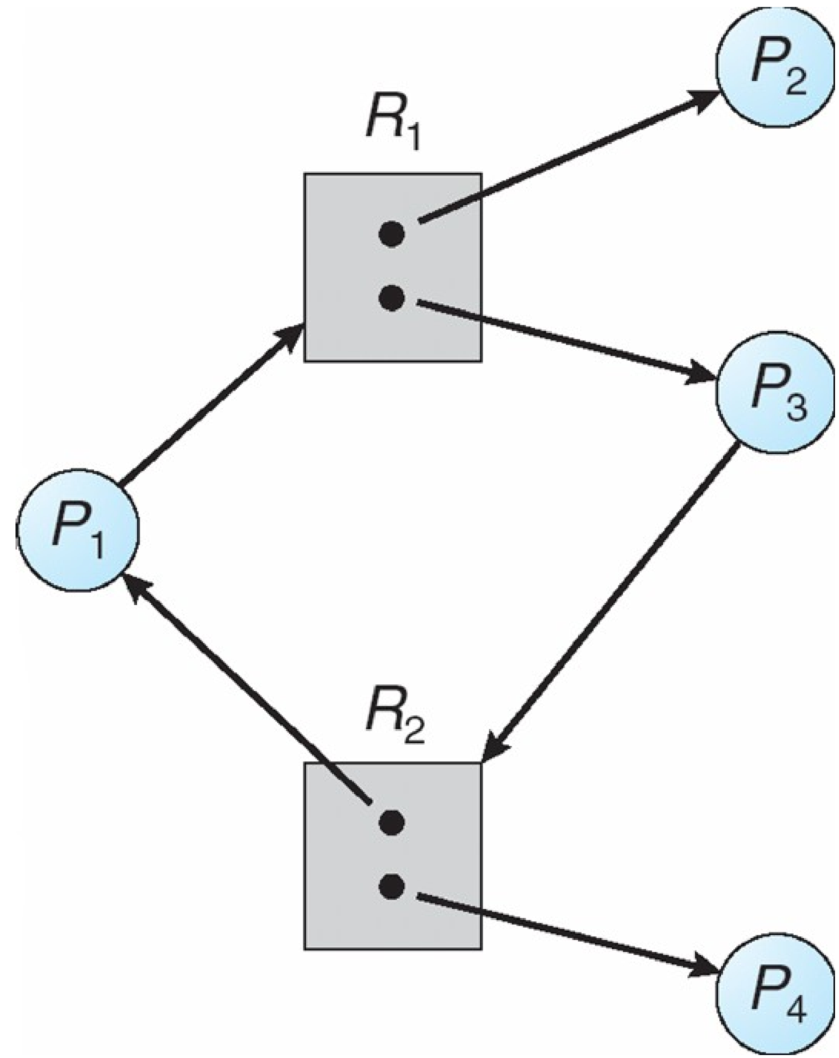
- Single instance of all system resource types
  - Avoid cycles in resource-allocation graph
- Multiple instances of resource types
  - Dijkstra's Banker's Algorithm

Required Notion: Safe State

- System in *Safe State* if there exists a sequence <P_1, P_2, ..., P_n> *of all* processes such that for each P_i, the resources that P_i can still request can be satisfied by currently available resources and resources held by all P_k, k < i
- Thus:
  - If P_i can't currently access all its resources, it can wait for all P_k to complete
  - When P_i terminates, we know that P_{i+1} can run
- Safe state sufficient condition to avoid deadlock!

Safe State?

- Assume in *this* case that
  - Maximum resources required = all held and requested resources



Banker's Algorithm

- High level:
  - When a resource request is made, ensure that the allocation will result in a safe state, or
  - Wait for resources until a safe state is possible
  - While other processes compute and eventually release their resources
- Good resource utilization
  - Processes concurrently execute that use “complementary” resources
  - Considers *both* worst case, and *actual* allocations

Banker's Algorithm II

- System has *n* processes, *m* resource types
- *available*[*j*] = *k*, there are *k* instances of resource *j* available
  - vector of length *m*
- *max*[*i, j*] = *k*, P_i will request at most *k* instances of R_j
  - *n x m* matrix
- *allocation*[*i, j*] = *k*, P_i is currently allocated *k* instances of R_j
  - *n* x *m* matrix
- *need*[*i, j*] = *k, * P_i may require *k* more instances of R_j to complete its task
  - *n* x *m* matrix
  - *need*[i,j] = *max*[i,j] - *allocation*[i,j]

Safety Algorithm

```
finished[n] = {false, …}  // is a process finished executing?
track_avail[m] = available  // copy allocation vector

while (1) {
      next = i where
            finished[i] = false && (need[i, j]  <= track_avail[j] forall j)
      if (next doesn't exist) {
            if (finished[i] == true forall i) {
                  return system is in safe state
            } else {
                  return system is NOT in a safe state
            }
      }
      /* Process "next" ran successfully.
       * Return its resources to the system */
      finished[next] = true
      track_avail[j] += allocation[next, j] forall j
}
```

Resource Request Algorithm

request[i,j] = k // *P_i is requesting k instances of R_j*

if (request[i,j] > *need*[i, j] *forall* j) {

    Error! P_i requested more than it said it would!

}

while (request[i,j] < *available*[j] *forall* j) {

    P_i must block and wait until more resources become available

}

available[j] -= request[i,j] *forall* j

allocation[i,j] += request[i,j] *forall* j

need[i,j] -= request[i,j] *forall j*

if (*system is safe*) {

    Resources allocated to P_i

} else {

    Undo changes to available, allocation, and need, and P_i waits

}

Banker's Algorithm Example

- Processes P_0 through P_4 and 3 resource types: *A(10), B(5), C(7)*
- System state at time t_0

	Allocation	Max	Need	Available
	A B C	*A B C*	*A B C*	*A B C*
P0	0 1 0	7 5 3	7 4 3	3 3 2
P1	2 0 0	3 2 2	1 2 2	
P2	3 0 2	9 0 2	6 0 0	
P3	2 1 1	2 2 2	0 1 1	
P4	0 0 2	4 3 3	4 3 1	

Safe State: <P_1, P_3, P_4, P_2, P_0>

Other Safe States???

Example: P_1 Requests (1, 0, 2)

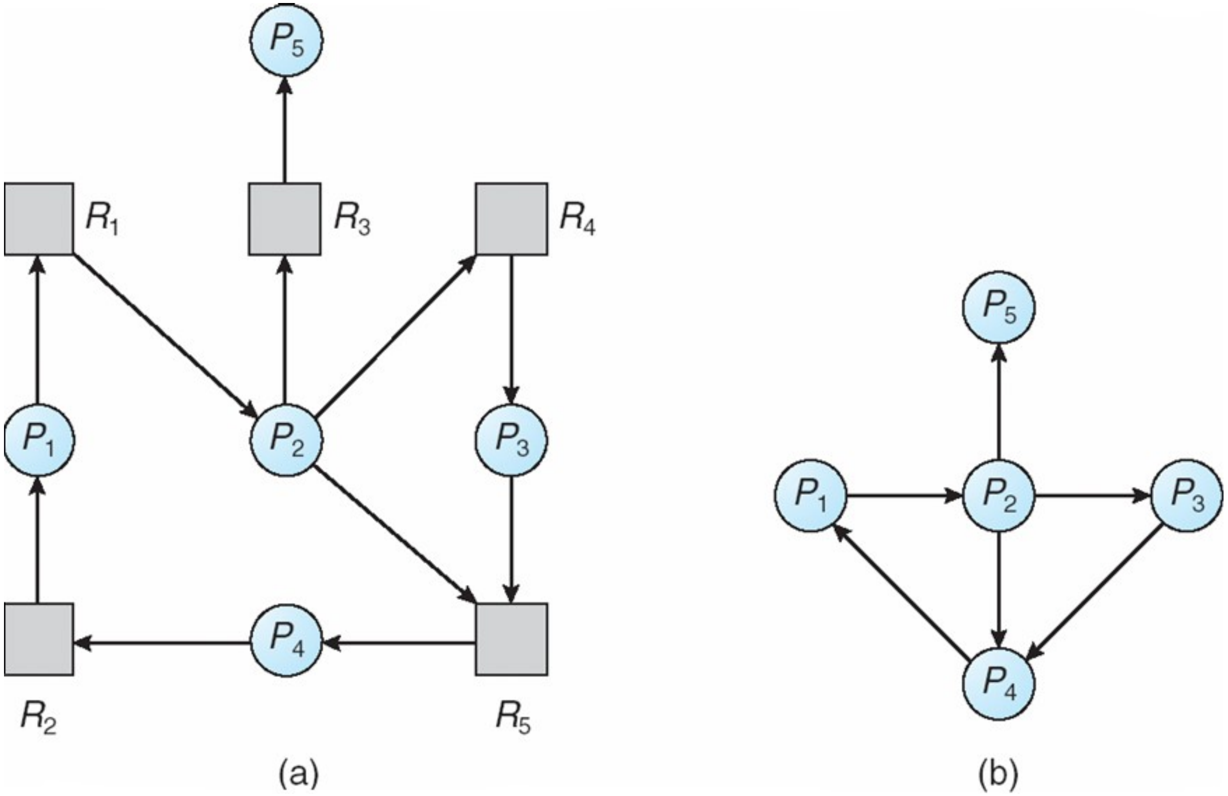
- Check that Request ≤ Available (i.e. (1,0,2) ≤ (3,3,2) ⇒ true)

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	2 3 0
P_1	3 0 2	0 2 0	
P_2	3 0 2	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence < P_1, P_3, P_4, P_0, P_2> is a Safe State
- Can request for (3,3,0) by P_4 be granted?
- Can request for (0,2,0) by P_0 be granted?

Deadlock Detection

- Periodically check to see if system is deadlocked
- Doesn't consider *maximum* resources required: practical
- Single instance resources:



Resource-Allocation Graph   Corresponding wait-for graph

Deadlock Recovery

- Process Termination
  - Abort all deadlocked processes
  - Abort deadlocked processes one at time, till resolved
  - In which order???
  - OOM killer in Linux