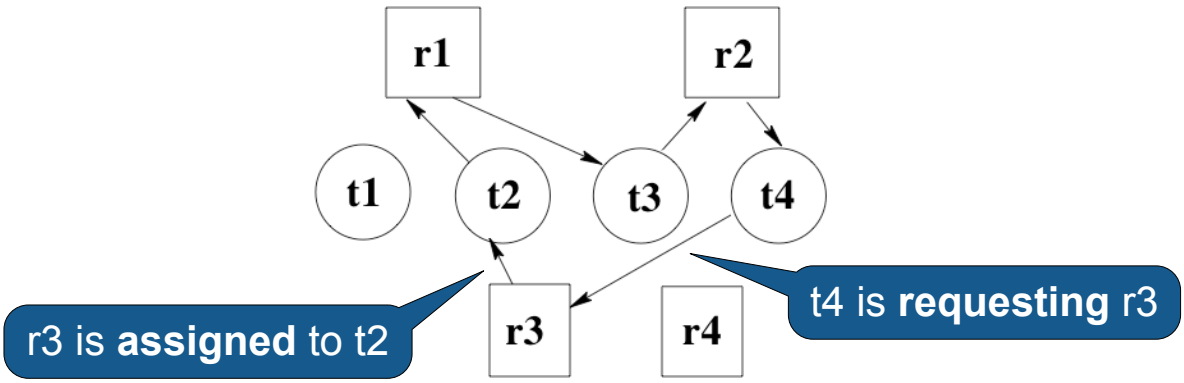
Recap: Deadlocks

- Necessary conditions
  - Mutual exclusion
  - Hold and Wait
  - No Preemption
  - Circular Wait

- Deadlock prevention
- Deadlock detection
- Deadlock avoidance

Resource Allocation Graph



Allocation Example

3 threads sharing 12 disks (11 currently used)

	maximum	current	could request
t_1	4	3	1
t_2	8	4	4
t_3	12	4	8

Safe state?

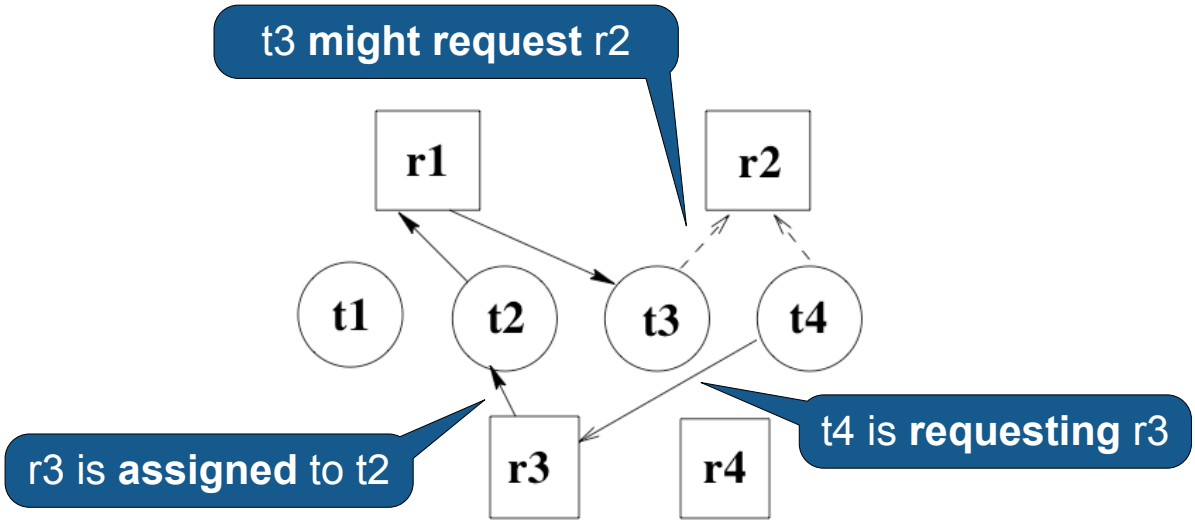
Allocation Example (cont)

t_3 requests last disk (now all 12 used)

	maximum	current	could request
t_1	4	3	1
t_2	8	4	4
t_3	12	**5**	**7**

Safe state?

Deadlock Avoidance with RA Graph



Banker's Algorithm

Banker's Algorithm: Data

```
class ResourceManager {
  int n;         // # threads 0 to n
  int m;         // # resources 0 to m
  avail[m],      // # of available resources of each type
  max[n,m],      // # of resources that each thread may need
  alloc[n,m],    // # of each resource that each thread is using
  need[n,m],     // # of resources that each thread might still
                 // request (i.e., max - alloc)
```


Banker's Algorithm: Allocation

```
public void synchronized allocate(int request[m], int i) {
    // thread i wants request[m] new resources
    if (request > need[i])  // vector comparison
      error();  // Can't request more than you declared
    else while (request[i] > avail)
      wait();   // Insufficient resources available

    // enough resources exist, see if would lead to unsafe state
    avail = avail - request;  // vector operations
    alloc[i] = alloc[i] + request;
    need[i] = need[i] - request;

    while (!safeState()) {
      // if this is an unsafe state, undo the allocation and wait
      <undo the changes to avail, alloc[i], and need[i]>
      wait();
      <redo the changes to avail, alloc[i], and need[i]>
  }
}
```

Banker's Algorithm: Safety Check

```
private boolean safeState() {
  boolean work[m] = avail[m];  // accommodate all resources
  boolean finish[n] = false;   // none finished yet

  // find a process that can complete its work now
  while (find i such that !finish[i]
          and need[i] <= work) { // vector operations
    work = work + alloc[i];
    finish[i] = true;
  }

  return (finish[i] for all i);
}
```


Banker's Algorithm: Example

	Max	Allocation	Available
	A B C	A B C	A B C
P_0	0 0 1	0 0 1	–
P_1	1 7 5	1 0 0	–
P_2	2 3 5	1 3 5	–
P_3	0 6 5	0 6 3	–
Total		**2 9 9**	**1 5 2**

Banker's Algorithm: Example 2

	Max	Allocation	Available
	A B C	A B C	A B C
P_0	0 0 1	0 0 1	–
P_1	1 7 5	**1 5 2**	–
P_2	2 3 5	1 3 5	–
P_3	0 6 5	0 6 3	–
Total		**2 14 11**	**1 0 0**