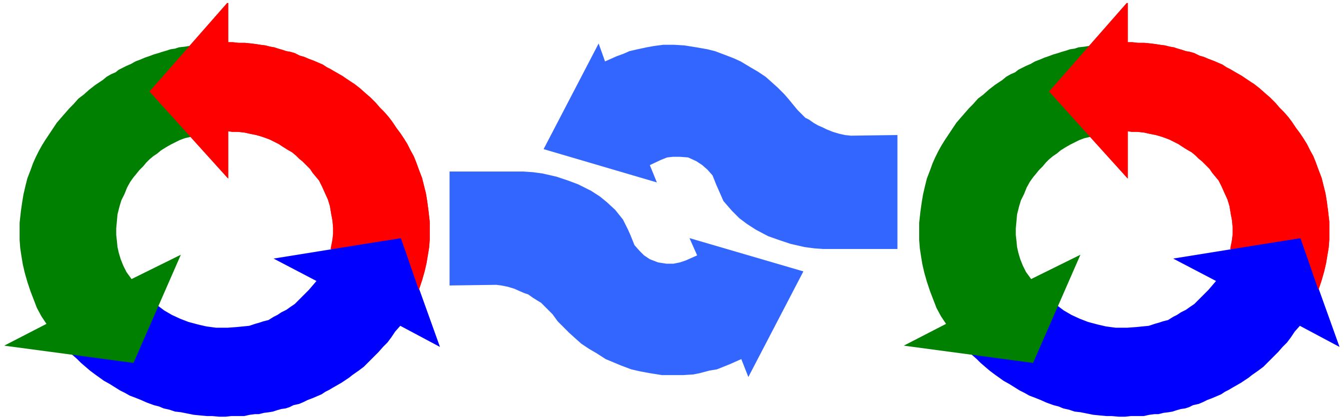
Chapter 6

Deadlock



Deadlock

Concepts:	system deadlock: no further progress four necessary & sufficient conditions
Models:	deadlock - no eligible actions
Practice:	blocked threads

Aim: deadlock avoidance - to design systems where deadlock cannot occur.

Deadlock: four necessary and sufficient conditions

- Serially reusable resources:

the processes involved share resources which they use under mutual exclusion.

- Incremental acquisition:

processes hold on to resources already allocated to them while waiting to acquire additional resources.

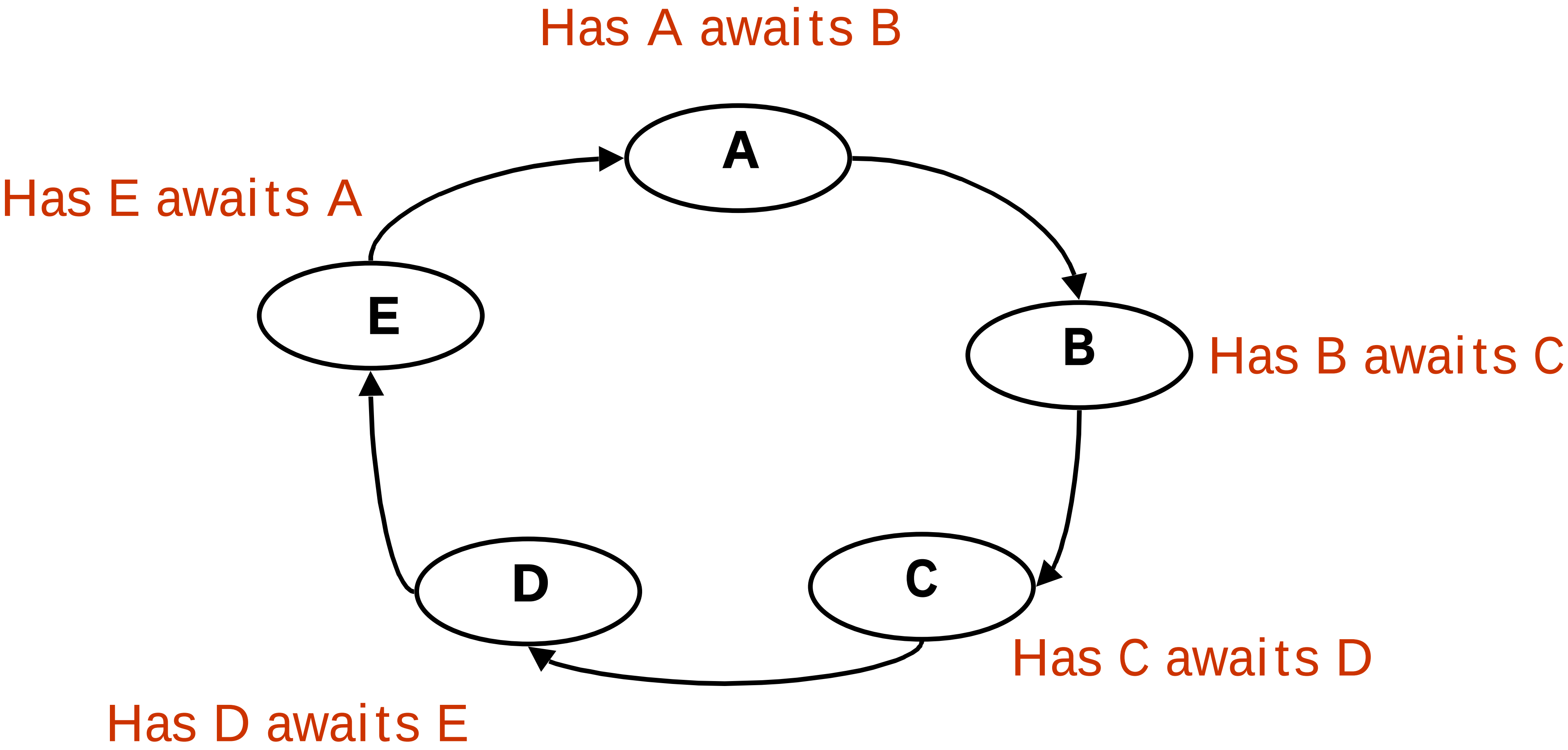
- No pre-emption:

once acquired by a process, resources cannot be pre-empted (forcibly withdrawn) but are only released voluntarily.

- Wait-for cycle:

a circular chain (or cycle) of processes exists such that each process holds a resource which its successor in the cycle is waiting to acquire.

Wait-for cycle



Has A awaits B

Has E awaits A

Has B awaits C

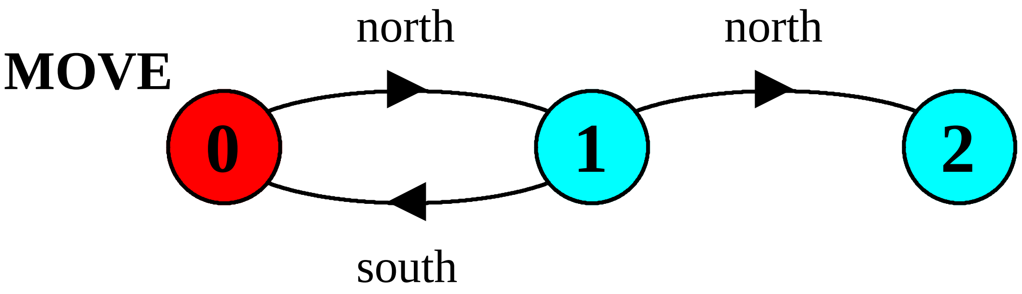
Has C awaits D

Has D awaits E

6.1 Deadlock analysis - primitive processes

- deadlocked state is one with no outgoing transitions
- in FSP: **STOP** process

```
MOVE = (north->(south->MOVE|north->STOP)).
```



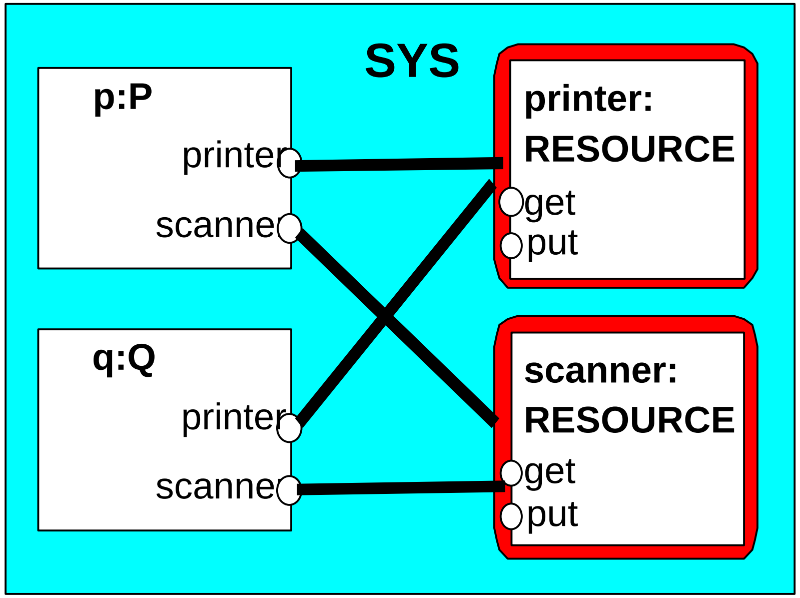
- animation to produce a trace.
- analysis using ***LTSA***:

  (shortest trace to **STOP**)

```
Trace to DEADLOCK:
    north
    north
```

deadlock analysis - parallel composition

- in systems, deadlock may arise from the parallel composition of interacting processes.



```
RESOURCE = (get->put->RESOURCE).
P = (printer.get->scanner.get
     ->copy
     ->printer.put->scanner.put
     ->P).
Q = (scanner.get->printer.get
     ->copy
     ->scanner.put->printer.put
     ->Q).
||SYS = (p:P||q:Q
     ||{p,q}::printer:RESOURCE
     ||{p,q}::scanner:RESOURCE
     ).
```

Deadlock Trace?

Avoidance?

deadlock analysis - avoidance

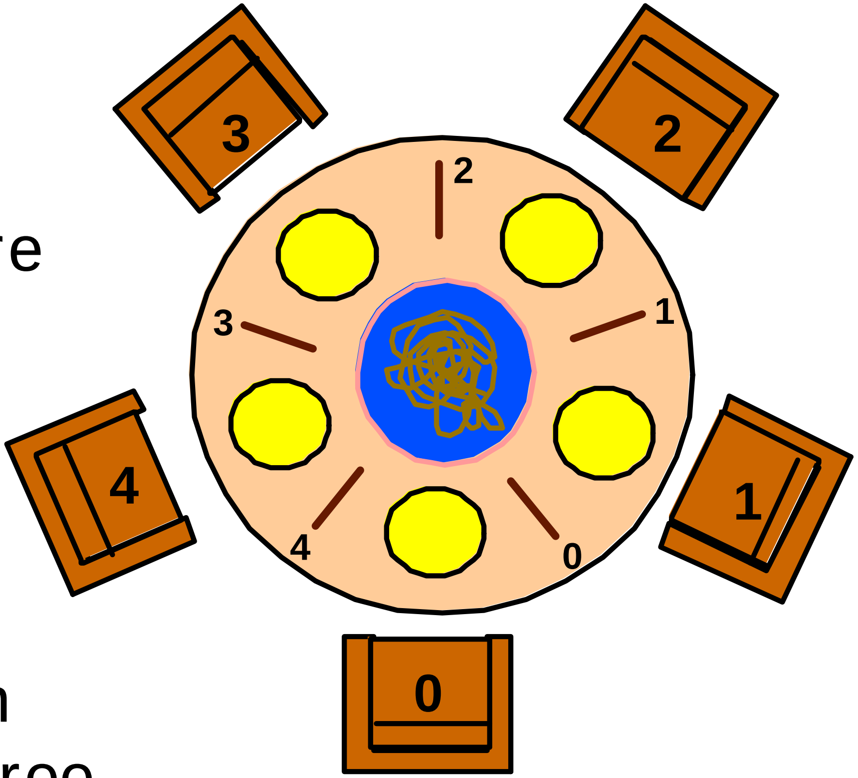
- acquire resources in the same order?
- Timeout:

```
P          = (printer.get-> GETSCANNER),
GETSCANNER = (scanner.get->copy->printer.put
                                 ->scanner.put->P
             |timeout -> printer.put->P
             ).
Q          = (scanner.get-> GETPRINTER),
GETPRINTER = (printer.get->copy->printer.put
                                 ->scanner.put->Q
             |timeout -> scanner.put->Q
             ).
```

Deadlock? ***Progress?***

6.2 Dining Philosophers

Five philosophers sit around a circular table. Each philosopher spends his life alternately thinking and eating. In the centre of the table is a large bowl of spaghetti. A philosopher needs two forks to eat a helping of spaghetti.

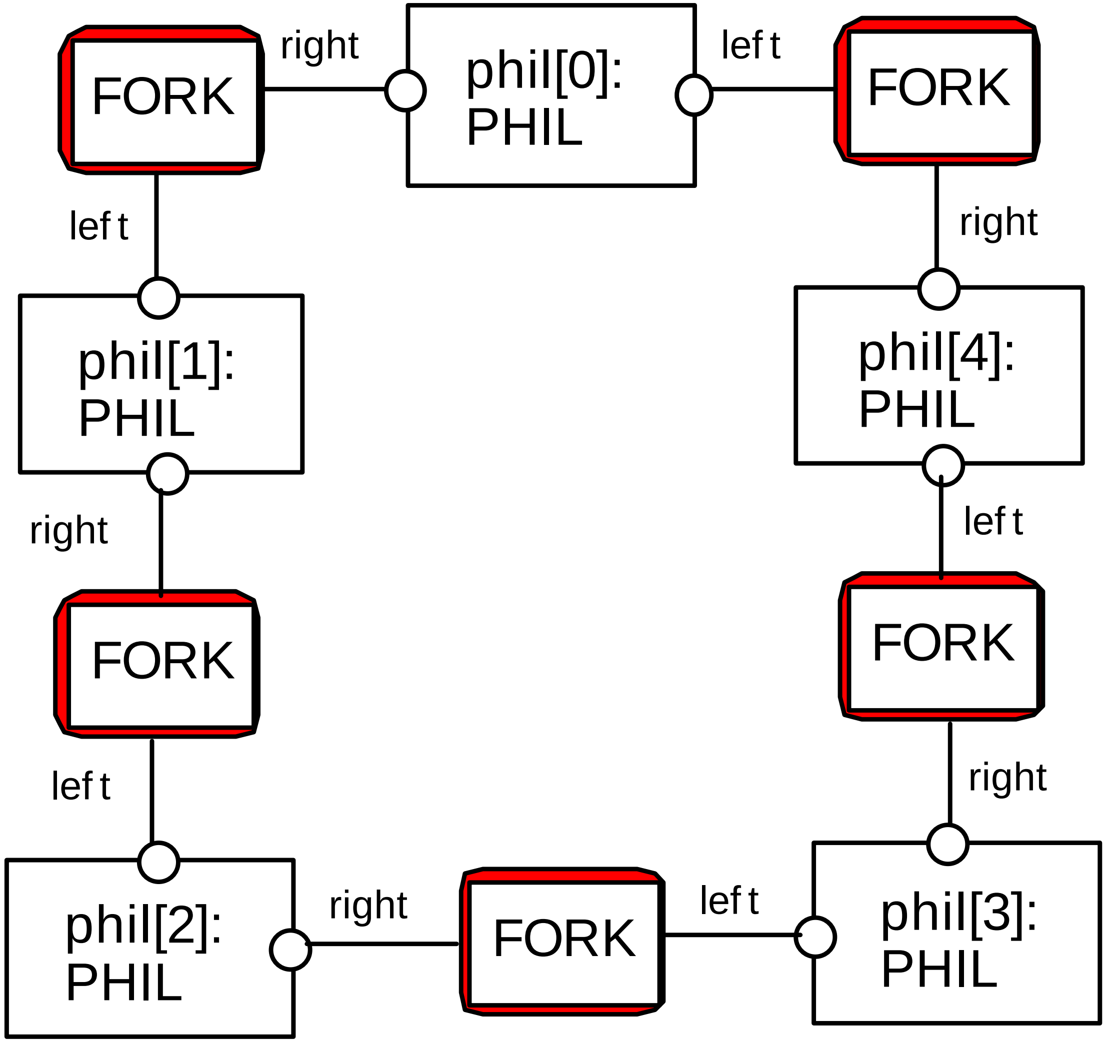


One fork is placed between each pair of philosophers and they agree that each will only use the fork to his immediate right and left.

Dining Philosophers - model structure diagram

Each FORK is a shared resource with actions **get** and **put**.

When hungry, each PHIL must first get his right and left forks before he can start eating.



Dining Philosophers - model

```
FORK = (get -> put -> FORK).
PHIL = (sitdown  ->right.get->left.get
          ->eat  ->right.put->left.put
          ->arise->PHIL).
```

Table of philosophers:

```
||DINERS(N=5)= forall [i:0..N-1]
    (phil[i]:PHIL ||
    {phil[i].left,phil[((i-1)+N)%N].right}::FORK
    ).
```

Can this system deadlock?

Dining Philosophers - model analysis

```
Trace to DEADLOCK:
   phil.0.sitdown
   phil.0.right.get
   phil.1.sitdown
   phil.1.right.get
   phil.2.sitdown
   phil.2.right.get
   phil.3.sitdown
   phil.3.right.get
   phil.4.sitdown
   phil.4.right.get
```

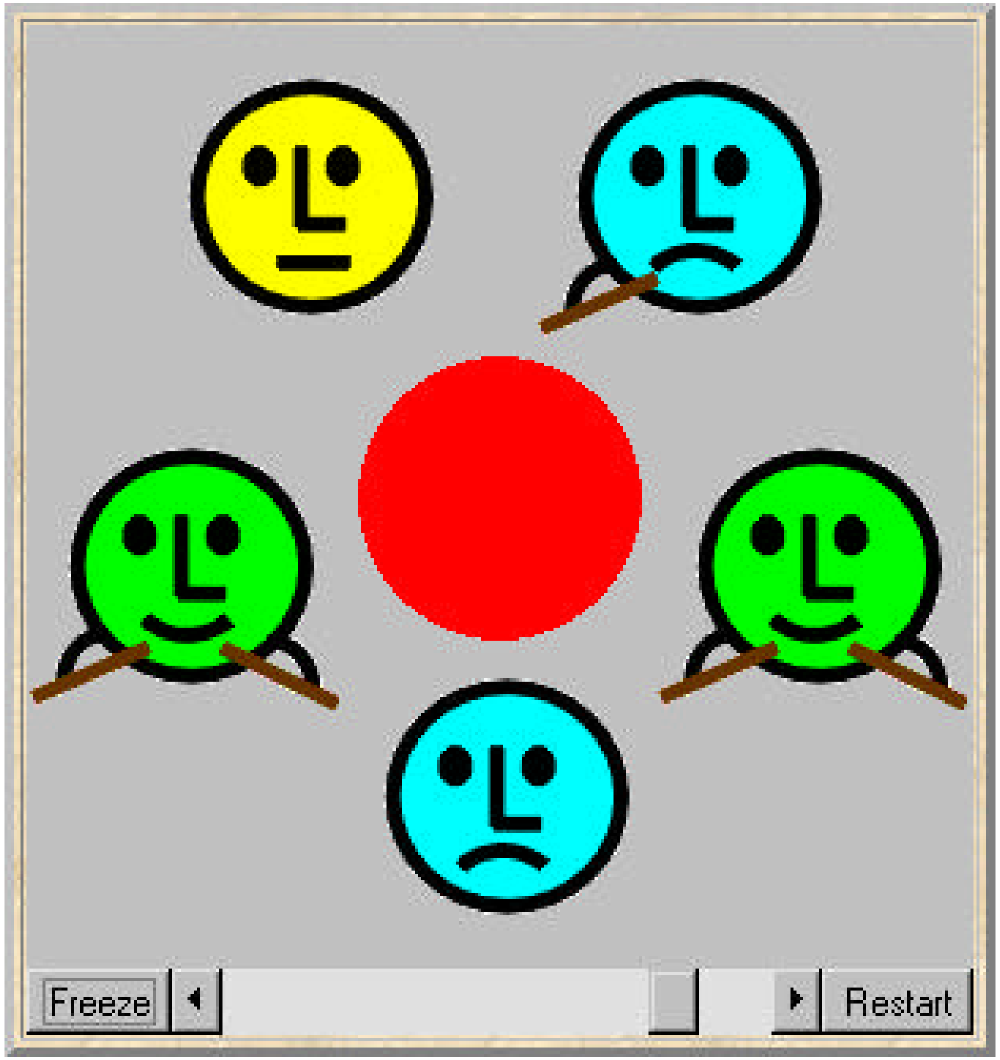
This is the situation where all the philosophers become hungry at the same time, sit down at the table and each philosopher picks up the fork to his right.

The system can make no further progress since each philosopher is waiting for a fork held by his neighbor i.e. a ***wait-for cycle*** exists!

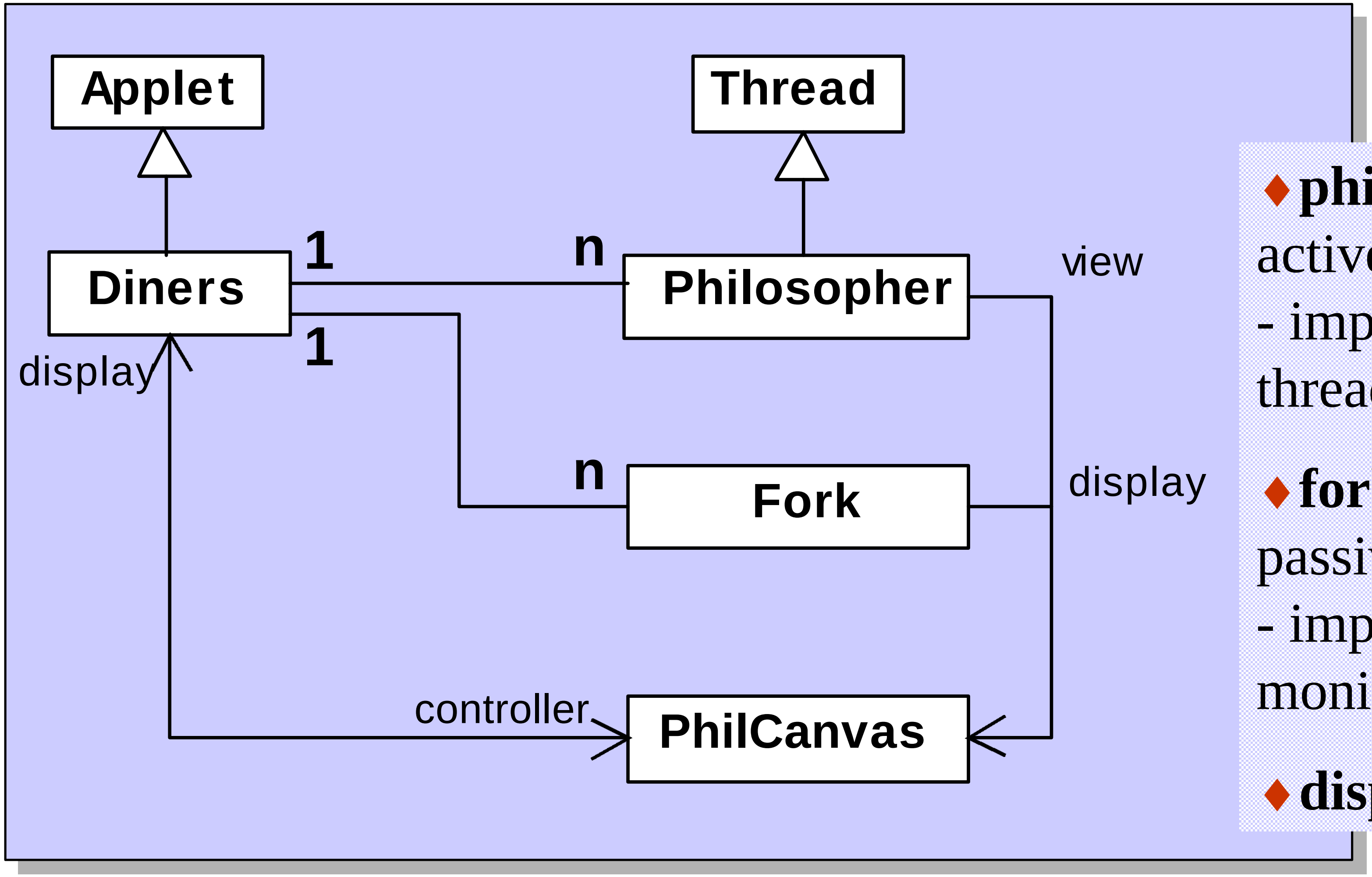
Dining Philosophers

Deadlock is easily detected in our model.

How easy is it to detect a potential deadlock in an implementation?



Dining Philosophers - implementation in Java



- **philosophers**: active entities - implement as threads
- **forks**: shared passive entities - implement as monitors
- **display**

Dining Philosophers - Fork monitor

```
class Fork {
  private boolean taken=false;
  private PhilCanvas display;
  private int identity;

  Fork(PhilCanvas disp, int id)
    { display = disp; identity = id;}

  synchronized void put() {
    taken=false;
    display.setFork(identity,taken);
    notify();
  }

  synchronized void get()
     throws java.lang.InterruptedException {
    while (taken) wait();
    taken=true;
    display.setFork(identity,taken);
  }
}
```

`taken` encodes the state of the fork

Dining Philosophers - Philosopher implementation

```
class Philosopher extends Thread {
  ...
  public void run() {
    try {
      while (true) {                            // thinking
        view.setPhil(identity,view.THINKING);
        sleep(controller.sleepTime());          // hungry
        view.setPhil(identity,view.HUNGRY);
        right.get();                            // gotright chopstick
        view.setPhil(identity,view.GOTRIGHT);
        sleep(500);
        left.get();                             // eating
        view.setPhil(identity,view.EATING);
        sleep(controller.eatTime());
        right.put();
        left.put();
      }
    } catch (java.lang.InterruptedException e){}
  }
}
```

Follows from the model (sitting down and leaving the table have been omitted).

Dining Philosophers - implementation in Java

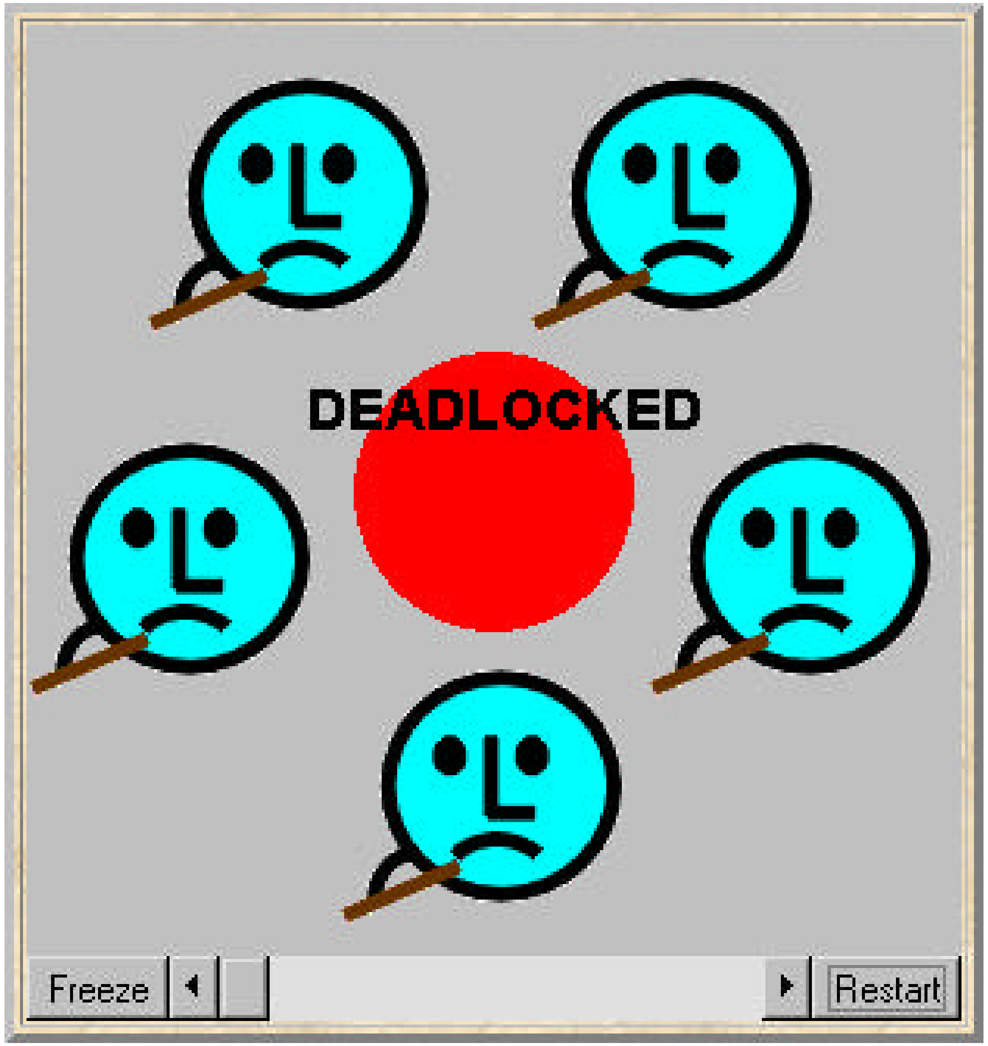
Code to create the philosopher threads and fork monitors:

```
for (int i =0; i<N; ++i)
  fork[i] = new Fork(display,i);
for (int i =0; i<N; ++i){
  phil[i] =
    new Philosopher
        (this,i,fork[(i-1+N)%N],fork[i]);
  phil[i].start();
}
```

Dining Philosophers

To ensure deadlock occurs eventually, the slider control may be moved to the left. This reduces the time each philosopher spends thinking and eating.

This "speedup" increases the probability of deadlock occurring.



Deadlock-free Philosophers

Deadlock can be avoided by ensuring that a wait-for cycle cannot exist. ***How?***

Introduce an *asymmetry* into our definition of philosophers.

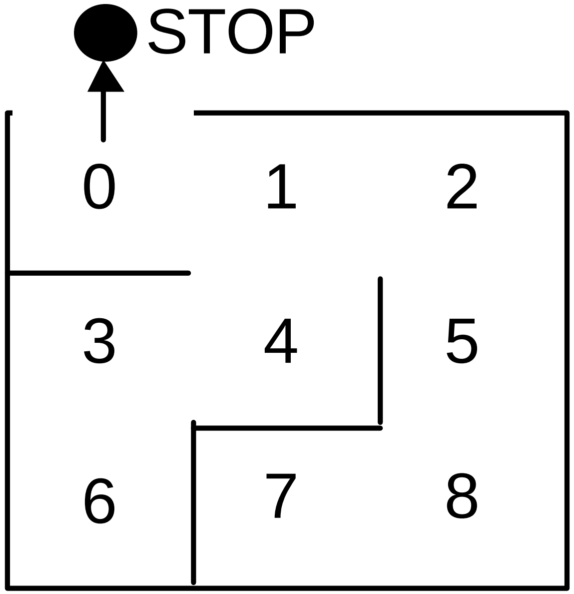
Use the identity I of a philosopher to make even numbered philosophers get their left forks first, odd their right first.

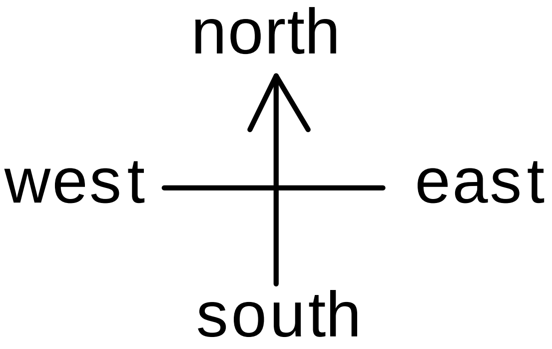
Other strategies?

```
PHIL(I=0)
   = (when (I%2==0) sitdown
           ->left.get->right.get
           ->eat
           ->left.put->right.put
           ->arise->PHIL
     |when (I%2==1) sitdown
          ->right.get->left.get
          ->eat
           ->left.put->right.put
           ->arise->PHIL
     ).
```

Maze example - shortest path to “deadlock”

We can exploit the shortest path trace produced by the deadlock detection mechanism of ***LTSA*** to find the shortest path out of a maze to the **STOP** process!





We must first model the **MAZE**.

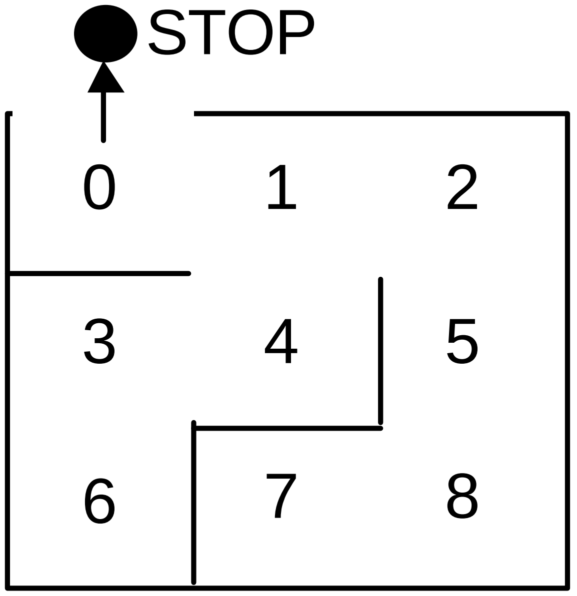
Each position can be modelled by the moves that it permits. The **MAZE** parameter gives the starting position.

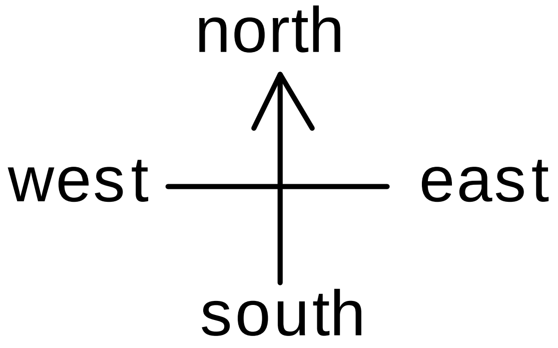
```
eg. MAZE(Start=8) = P[Start],
    P[0] = (north->STOP|east->P[1]),...
```

Maze example - shortest path to “deadlock”

```
||GETOUT = MAZE(7).
```

Shortest path escape trace from position 7 ?





```
Trace to
DEADLOCK:
      east
      north
      north
      west
      west
      north
```

Summary

- Concepts
    - **deadlock**: no futher progress
    - four necessary and sufficient conditions:
        - serially reusable resources
        - incremental acquisition
        - no preemption
        - wait-for cycle
- Models
    - no eligable actions (analysis gives shortest path trace)
- Practice
    - blocked threads

Aim: deadlock avoidance - to design systems where deadlock cannot occur.