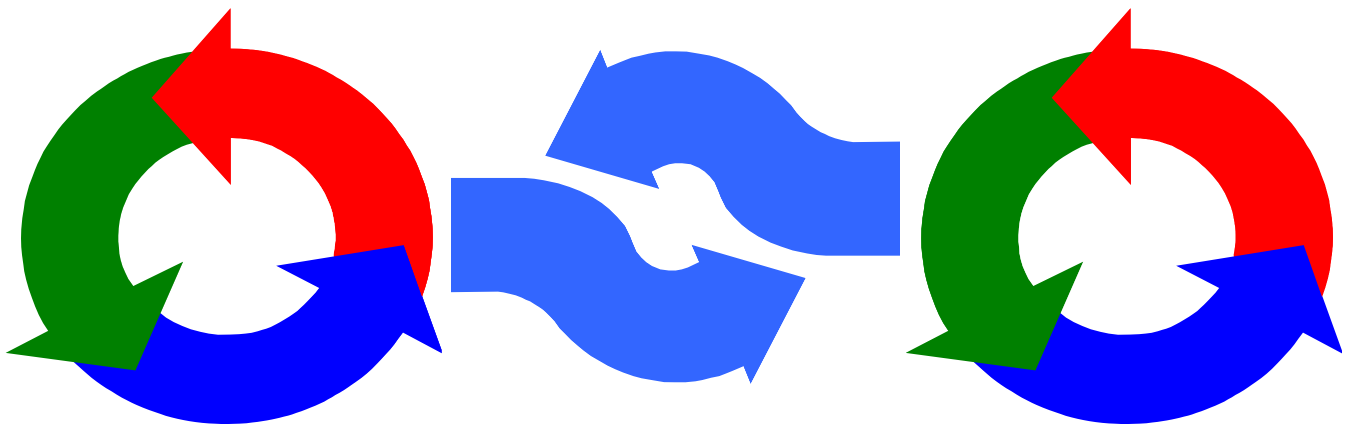
Chapter 6

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

- **Shared resources:**

the processes involved ***shared resources*** *which they use under mutual exclusion.*

- **Incremental acquisition:**

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

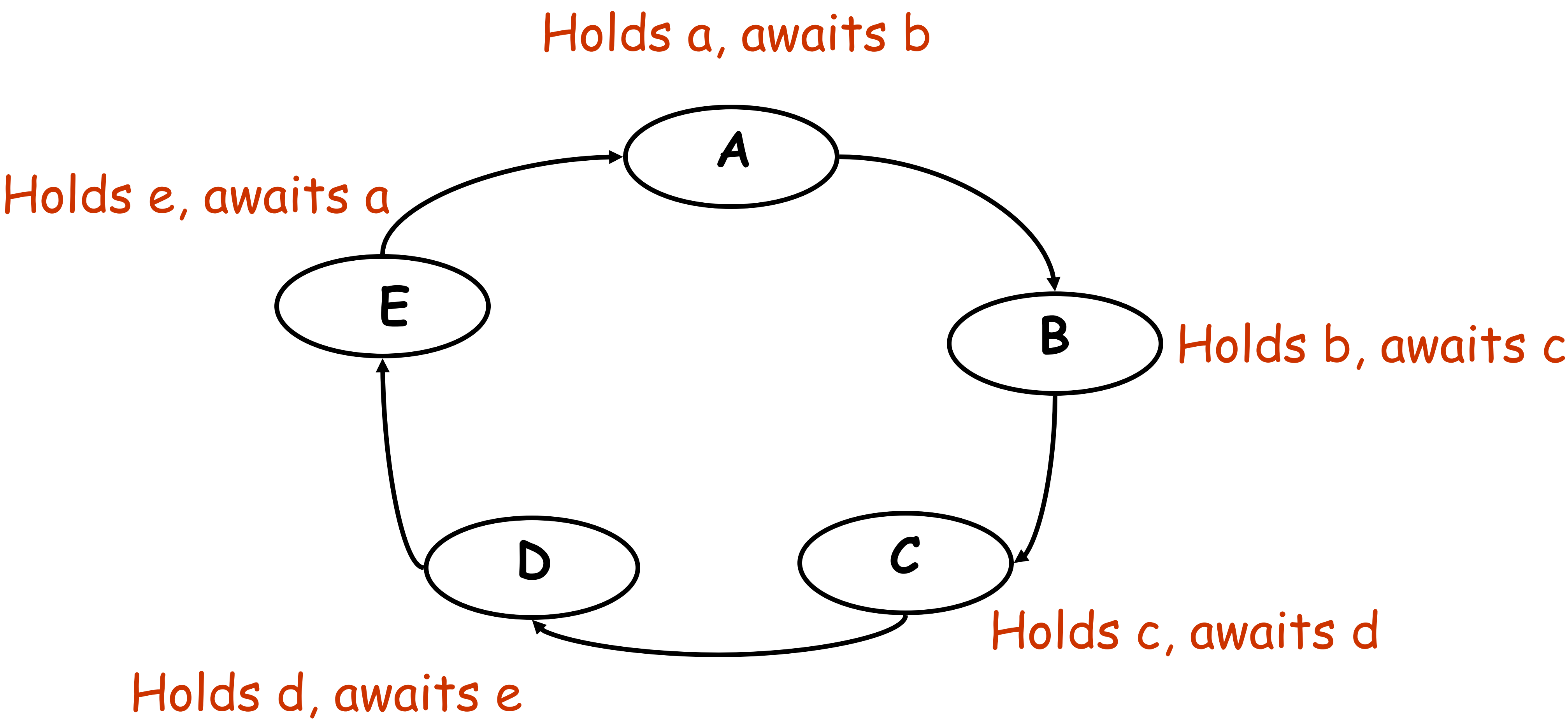
- **No pre-emption:**

once acquired by a process, ***resources cannot be pre-empted*** *(forcibly withdrawn) but are only released* ***voluntarily.***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

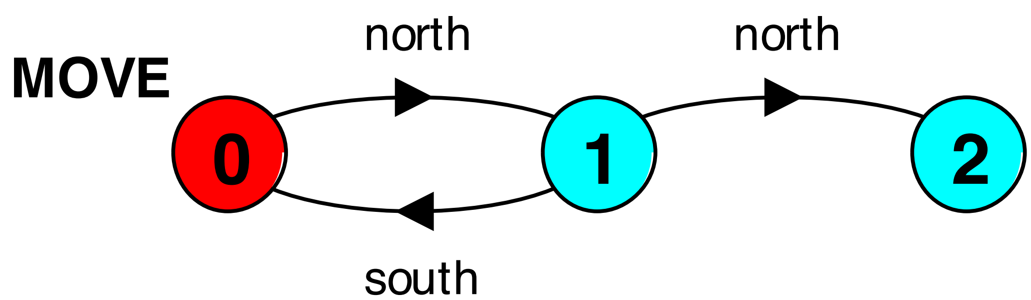
Wait-for Cycle



6.1 Deadlock Analysis – Primitive Processes

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

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



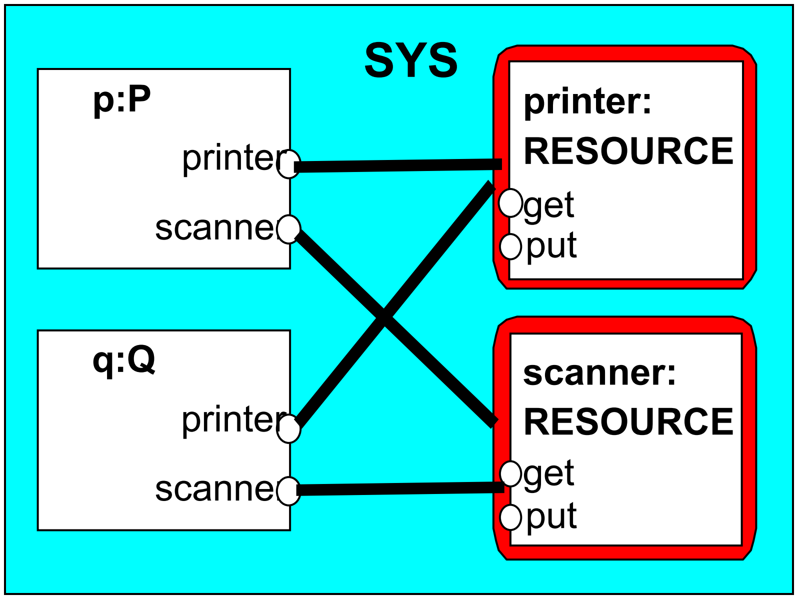
- animation to produce a trace.
- analysis using *LTSA*:

  (shortest trace to STOP)

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

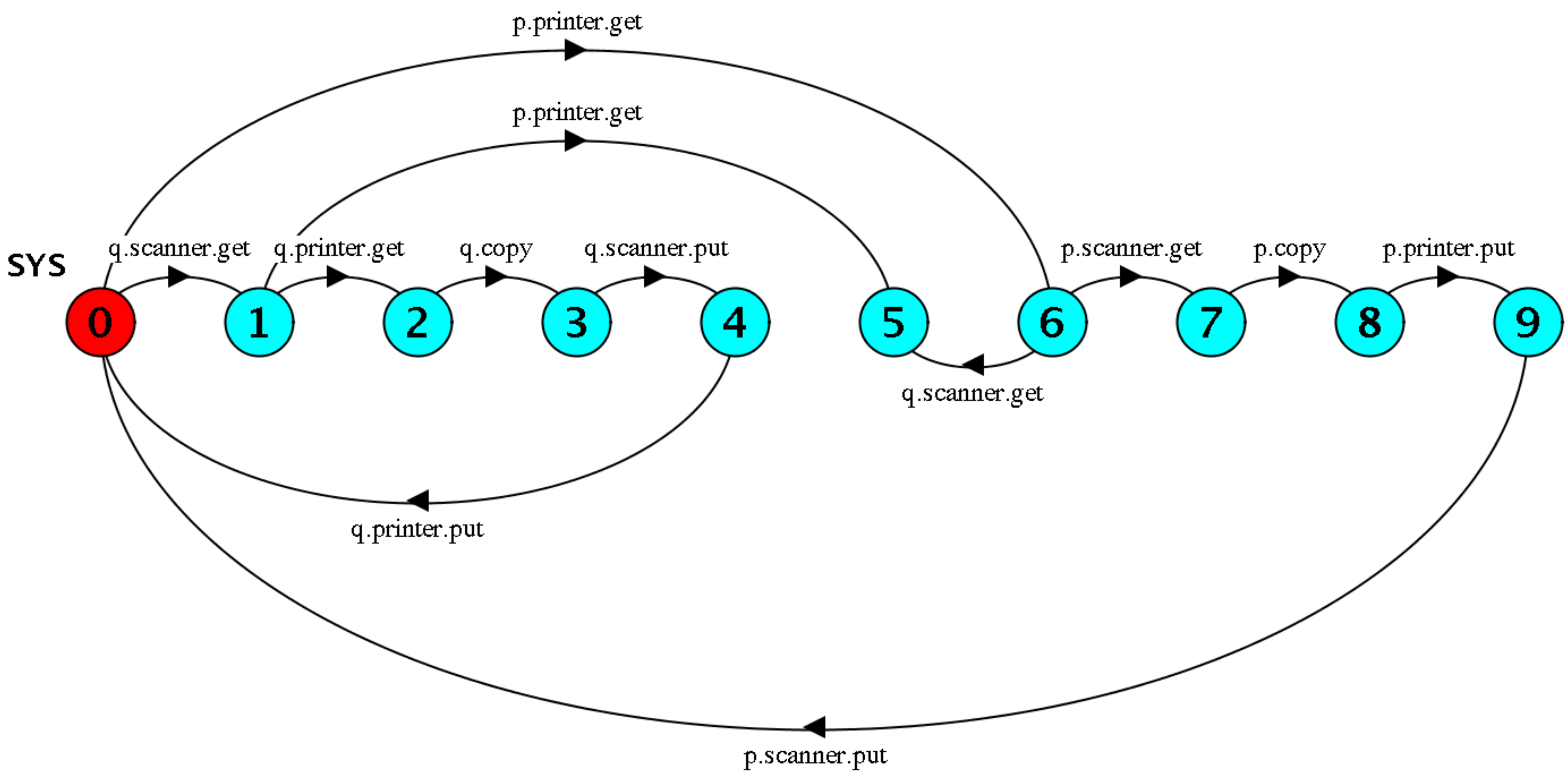
Deadlock Analysis – Parallel Composition

- 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 Analysis – Parallel Composition



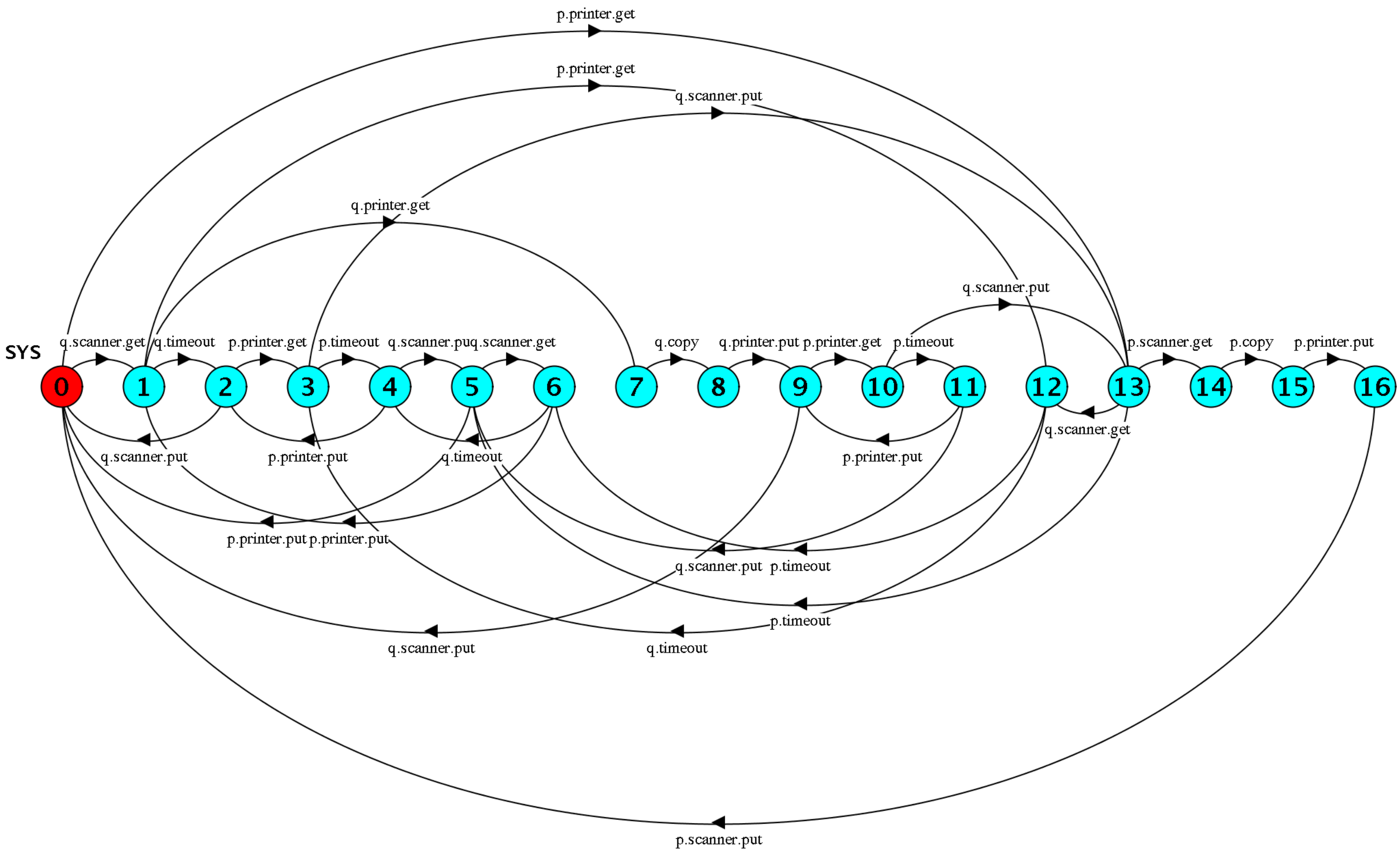
Deadlock Analysis - Avoidance

♦ adding Timeout:

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

Deadlock?

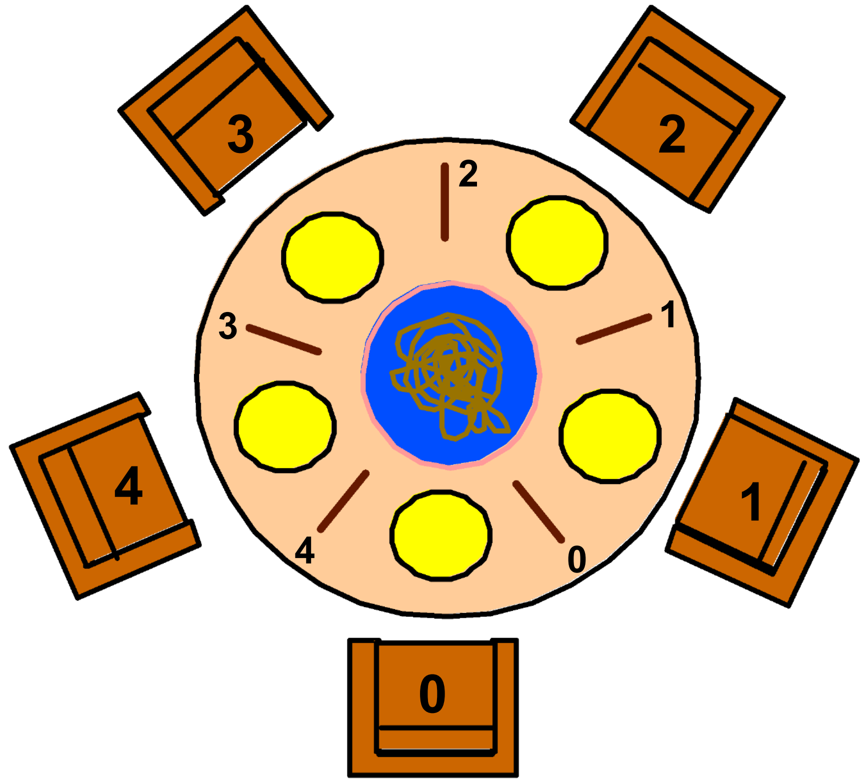
Deadlock Analysis – Parallel Composition



n

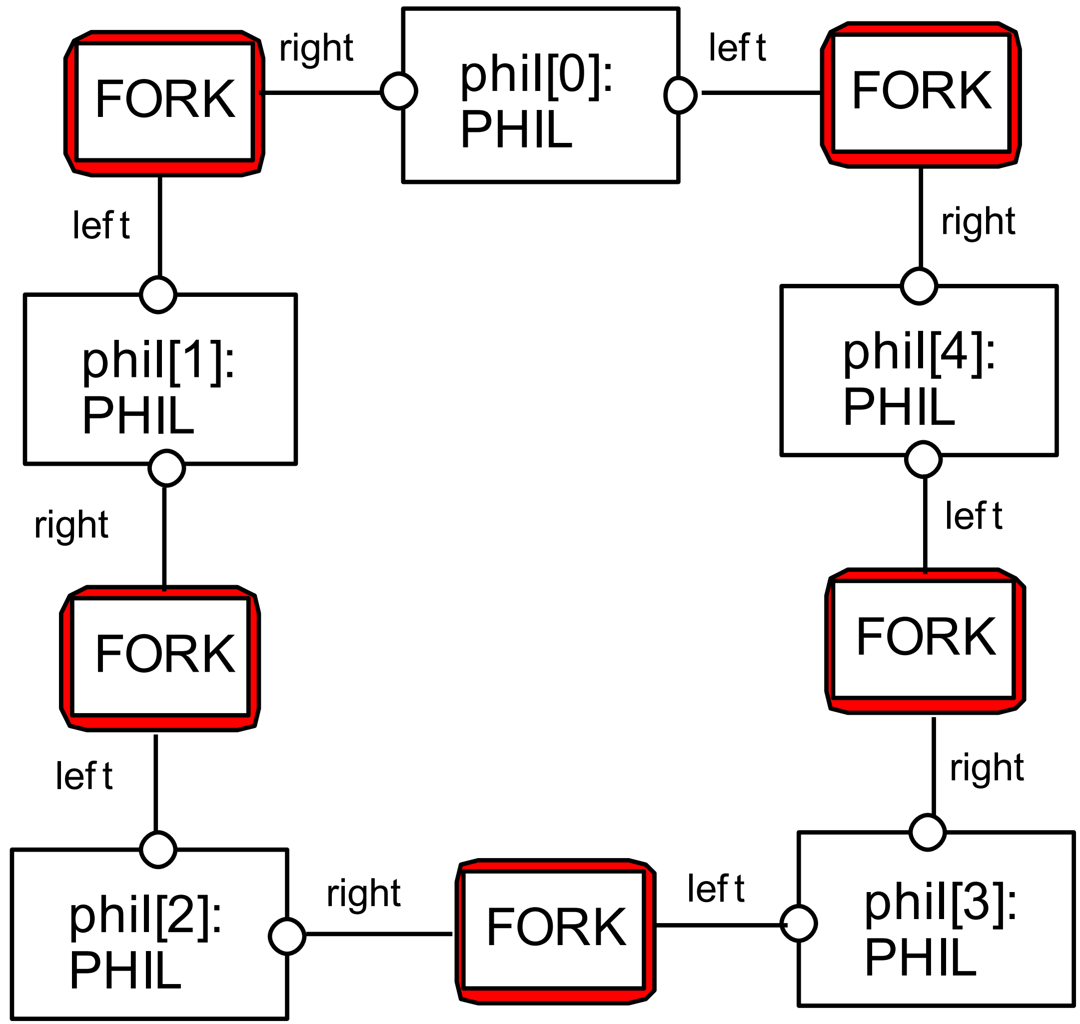
6.2 Dining Philosophers

- 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
- 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

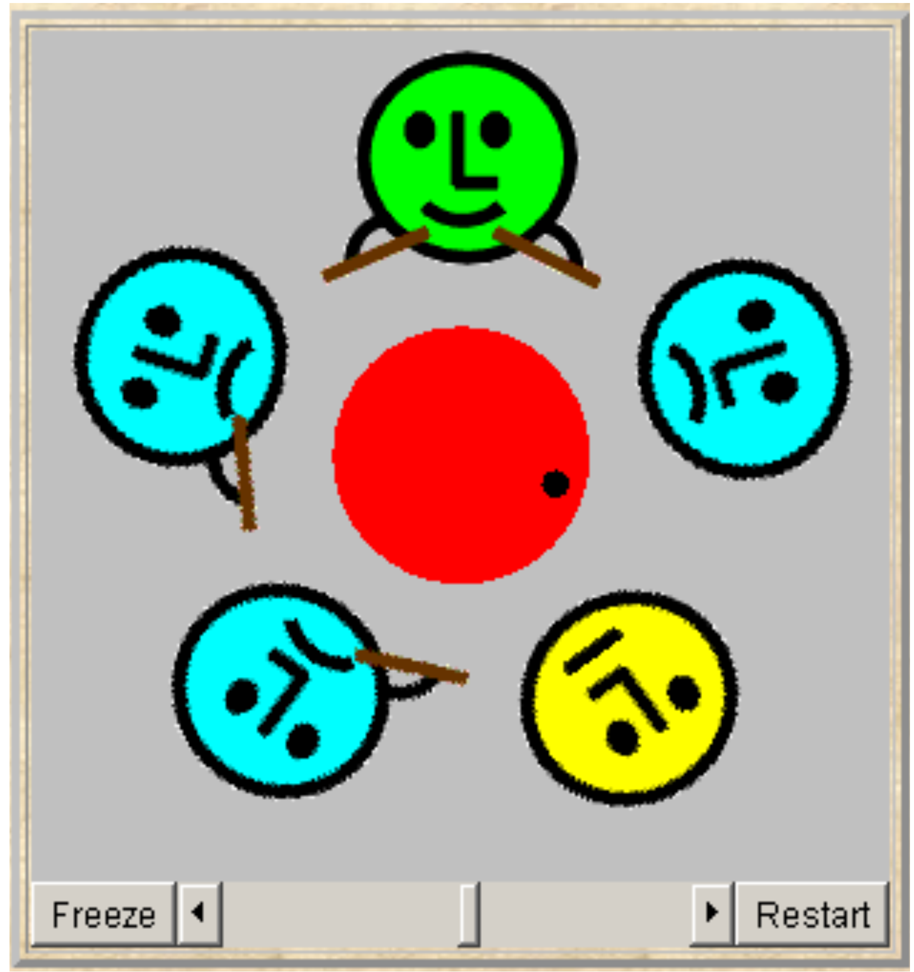
```
Trace to DEADLOCK:
     phil.0.sitdown
     phil.0.right.get
     phil.1.sitdown
     phil.1.right.get
     phil.2.sitdown
     phil.2.right.get
     phil.3.sitdown
     phil.3.right.get
     phil.4.sitdown
     phil.4.right.get
```

- 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 neighbour i.e. a ***wait-for cycle*** exists!

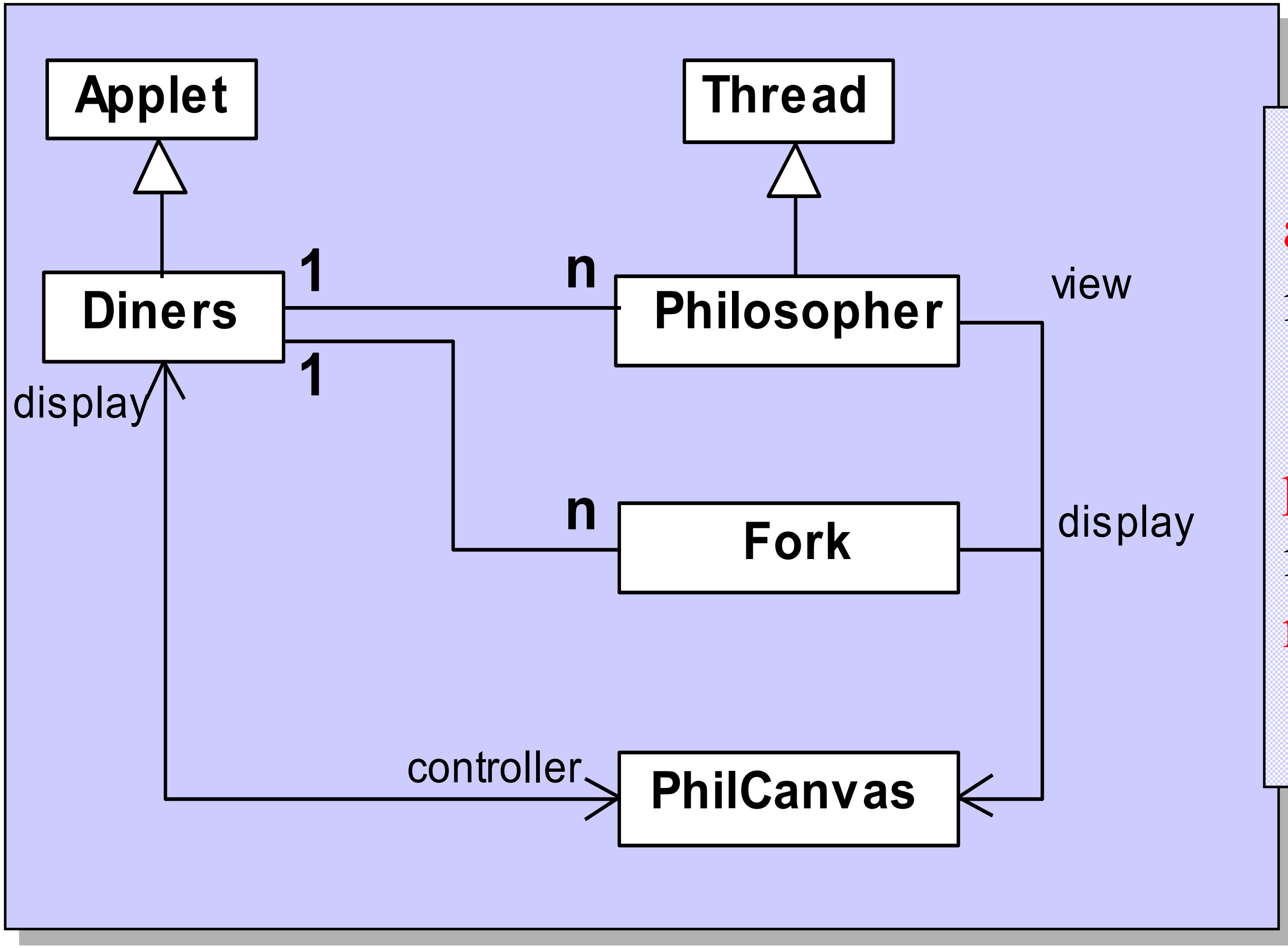
Dining Philosophers

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();                              // got right 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){}
  }
}
```

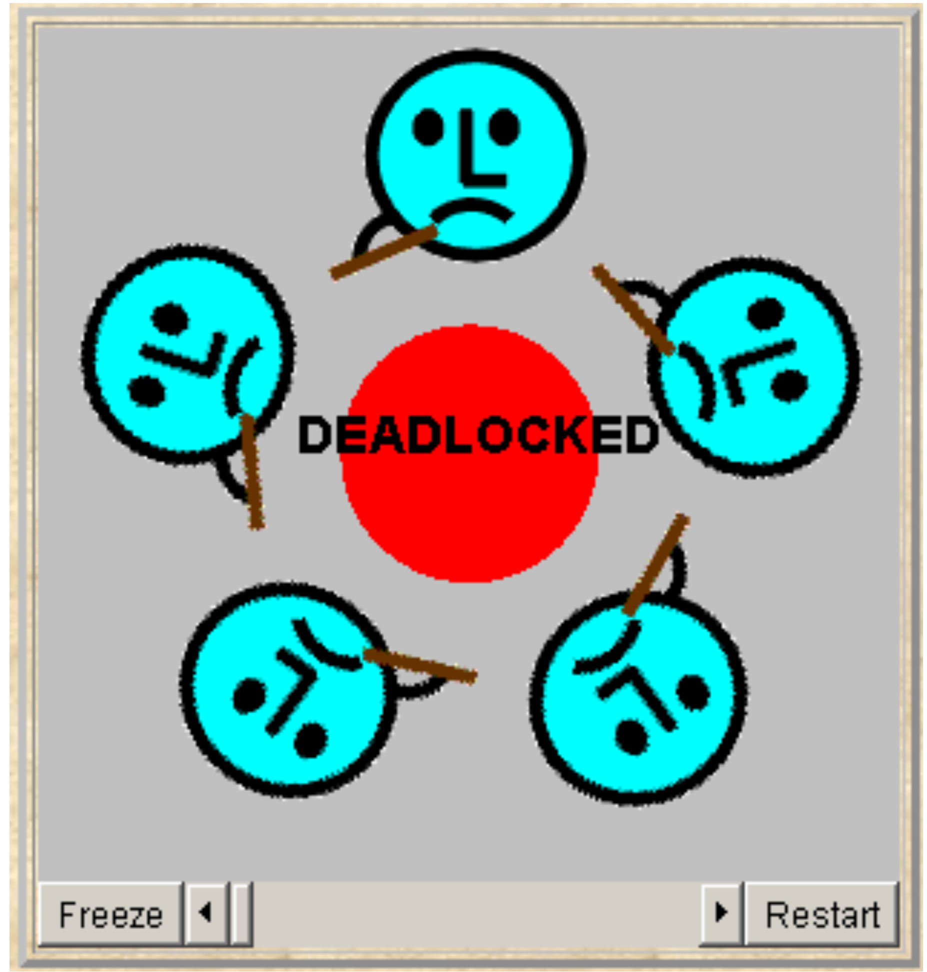
Dining Philosophers - Implementation in Java

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

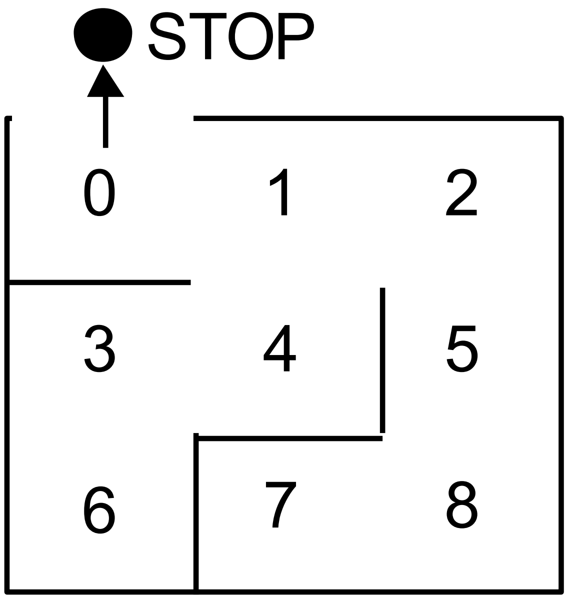
- Deadlock can be **avoided** by ensuring that a wait-for cycle cannot exist.
- Introduce an *asymmetry* into our definition of philosophers.
- Use the identity I of a philosopher to make even numbered philosophers get their left forks first, odd their right first.

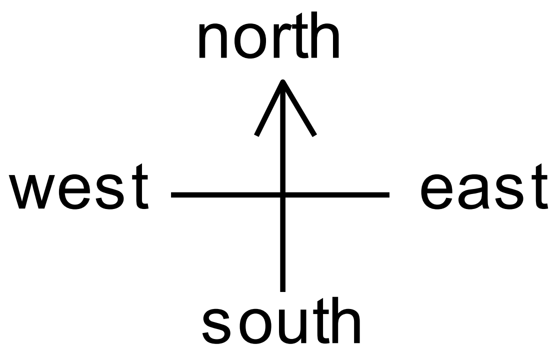
```
PHIL(I=0)
  = (when (I%2==0) sitdown
        ->left.get->right.get
        ->eat
        ->left.put->right.put
        ->arise->PHIL
    |when (I%2==1) sitdown
        ->right.get->left.get
        ->eat
        ->left.put->right.put
        ->arise->PHIL
    ).
```

Other strategies?

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 first model the **MAZE**.

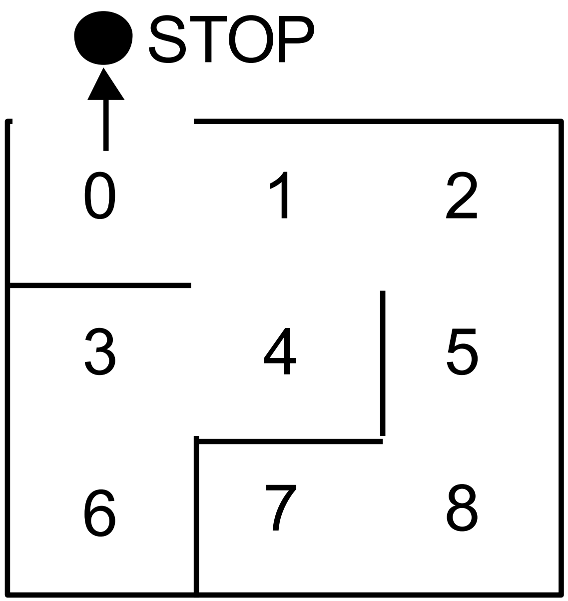
Each position is modelled by the moves that it permits. The **MAZE** parameter gives the starting position.

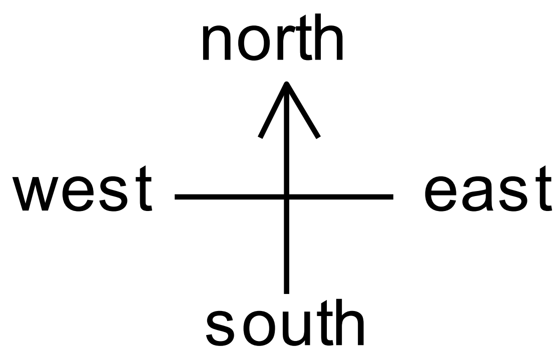
```
eg. MAZE(Start=8) = P[Start],
    P[0] = (north->STOP|east->P[1]),...
```

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.