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once acquired by a process, resources cannot be pre-empted (forcibly withdrawn) but are only released voluntarily.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

Has C awaits D

Has B awaits C
6.1 Deadlock analysis - primitive processes

♦ deadlocked state is one with **no outgoing transitions**

♦ in FSP: **STOP** process

\[
\text{MOVE} = (\text{north} \rightarrow (\text{south} \rightarrow \text{MOVE} | \text{north} \rightarrow \text{STOP})).
\]

MOVE

\[
\begin{array}{ccc}
0 & \rightarrow & 1 \\
\rightarrow & & \rightarrow \\
\text{north} & & \text{north} \\
\text{south} & & \\
1 & \rightarrow & 2 \\
\rightarrow & & \\
\text{north} & & \\
2 & & \\
\end{array}
\]

♦ animation to produce a trace.

♦ **analysis using LTSA:**

- Trace to DEADLOCK: north
- (shortest trace to STOP) north

Concurrency: Deadlock
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:

\[
P = (\text{printer.get} \rightarrow \text{GETSCANNER}),
\]
\[
\text{GETSCANNER} = (\text{scanner.get} \rightarrow \text{copy} \rightarrow \text{printer.put} \\
\rightarrow \text{scanner.put} \rightarrow P
\mid \text{timeout} \rightarrow \text{printer.put} \rightarrow P)
\]
\[
Q = (\text{scanner.get} \rightarrow \text{GETPRINTER}),
\]
\[
\text{GETPRINTER} = (\text{printer.get} \rightarrow \text{copy} \rightarrow \text{printer.put} \\
\rightarrow \text{scanner.put} \rightarrow Q
\mid \text{timeout} \rightarrow \text{scanner.put} \rightarrow Q)
\]

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

\[
\text{FORK} = (\text{get} \rightarrow \text{put} \rightarrow \text{FORK}). \\
\text{PHIL} = (\text{sitdown} \rightarrow \text{right.get} \rightarrow \text{left.get} \rightarrow \text{eat} \rightarrow \text{right.put} \rightarrow \text{left.put} \rightarrow \text{arise} \rightarrow \text{PHIL}).
\]

Table of philosophers:

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

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**
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);
    }
}
class Philosopher extends Thread {

  private int identity; // identity of philosopher

  public Philosopher {
    identity = 1; // initialize identity
  }

  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){}
  }

  /* other methods */
Dining Philosophers - implementation in Java

Code to create the philosopher threads and fork monitors:

```java
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?**

```plaintext
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”

\[ \text{||GETOUT} = \text{MAZE}(7). \]

Shortest path escape trace from position 7?

Trace to DEADLOCK:
- east
- north
- north
- west
- west
- north

Concurrency: Deadlock
Summary

◆ Concepts

  ● **deadlock**: no further progress
  
  ● **four necessary and sufficient conditions:**
    - serially reusable resources
    - incremental acquisition
    - no preemption
    - wait-for cycle

◆ Models

  ● no eligible actions (analysis gives shortest path trace)

◆ Practice

  ● **blocked threads**

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