received attention in numerous papers over the past twenty years. Amdahl's Law is due to Gene Amdahl, a parallel processing pioneer [9].

1.8 Exercises

Exercise 1. The dining philosophers problem was invented by E. W. Dijkstra, a concurrency pioneer, to clarify the notions of *deadlock* and *starvation* freedom. Imagine five philosophers who spend their lives just thinking and feasting. They sit around a circular table with five chairs. The table has a big plate of rice. However, there are only five chopsticks (in the original formulation forks) available, as shown in Fig. 1.5. Each philosopher thinks. When he gets hungry, he sits down and picks up the two chopsticks that are closest to him. If a philosopher can pick up both chopsticks, he can eat for a while. After a philosopher finishes eating, he puts down the chopsticks and again starts to think.

1. Write a program to simulate the behavior of the philosophers, where each philosopher is a thread and the chopsticks are shared objects. Notice that you must prevent a situation where two philosophers hold the same chopstick at the same time.
2. Amend your program so that it never reaches a state where philosophers are deadlocked, that is, it is never the case that each philosopher holds one chopstick and is stuck waiting for another to get the second chopstick.
3. Amend your program so that no philosopher ever starves.
4. Write a program to provide a starvation-free solution for any number of philosophers n.

Exercise 2. For each of the following, state whether it is a safety or liveness property. Identify the bad or good thing of interest.

1. Patrons are served in the order they arrive.
2. What goes up must come down.

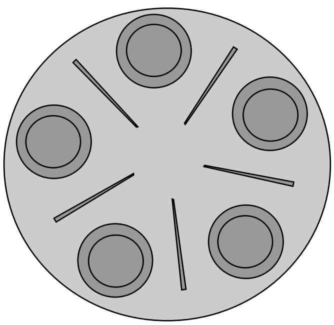

Figure 1.5 Traditional dining table arrangement according to Dijkstra.

3. If two or more processes are waiting to enter their critical sections, at least one succeeds.
4. If an interrupt occurs, then a message is printed within one second.
5. If an interrupt occurs, then a message is printed.
6. The cost of living never decreases.
7. Two things are certain: death and taxes.
8. You can always tell a Harvard man.

Exercise 3. In the producer–consumer fable, we assumed that Bob can see whether the can on Alice's windowsill is up or down. Design a producer–consumer protocol using cans and strings that works even if Bob cannot see the state of Alice's can (this is how real-world interrupt bits work).

Exercise 4. You are one of P recently arrested prisoners. The warden, a deranged computer scientist, makes the following announcement:

> You may meet together today and plan a strategy, but after today you will be in isolated cells and have no communication with one another.
>
> I have set up a "switch room" which contains a light switch, which is either *on* or *off*. The switch is not connected to anything.
>
> Every now and then, I will select one prisoner at random to enter the "switch room." This prisoner may throw the switch (from *on* to *off*, or vice-versa), or may leave the switch unchanged. Nobody else will ever enter this room.
>
> Each prisoner will visit the switch room arbitrarily often. More precisely, for any N, eventually each of you will visit the switch room at least N times.
>
> At any time, any of you may declare: "we have all visited the switch room at least once." If the claim is correct, I will set you free. If the claim is incorrect, I will feed all of you to the crocodiles. Choose wisely!

- Devise a winning strategy when you know that the initial state of the switch is *off*.
- Devise a winning strategy when you do not know whether the initial state of the switch is *on* or *off*.

Hint: not all prisoners need to do the same thing.

Exercise 5. The same warden has a different idea. He orders the prisoners to stand in line, and places red and blue hats on each of their heads. No prisoner knows the color of his own hat, or the color of any hat behind him, but he can see the hats of the prisoners in front. The warden starts at the back of the line and asks each prisoner to guess the color of his own hat. The prisoner can answer only "red" or "blue." If he gives the wrong answer, he is fed to the crocodiles. If he answers correctly, he is freed. Each prisoner can hear the answer of the prisoners behind him, but cannot tell whether that prisoner was correct.