Concurrent Programming

Exercise Booklet 1: Paths

Note: For this booklet you must assume that assignment is atomic and that the scheduler is fair. Also, you may use "?" for the value of uninitialized variables. Solutions to selected exercises (◊) are provided at the end of this document. Important: You should first try solving them before looking at the solutions. You will otherwise learn **nothing**.

Exercise 1. (◊) Assume that the **print** command is atomic. Build the transition system and then exhibit all possible paths of execution of the following program:

```
Thread.start { //P   Thread.start { // Q
  print("Hi");         print("Hey");
  print("Alice");      print("Bob");
}                    }
```

Exercise 2. Draw the transition system for the following programs. What values can x take at the end of the execution?

1.

```
int x = 0;
Thread.start { //P     Thread.start { //Q
  int local = x;        int local = x;
  local = local + 1;    local = local + 1;
  x = local;            x = local;
}                     }
```

2.

```
int x = 0;
Thread.start { //P   Thread.start { //Q
  x = x + 1;          x = x + 1;
}                   }
```

Exercise 3. (◊) Given the following program:

```
int x = 0;
int y = 0;
Thread.start { //P2  Thread.start { //Q
  y = x + 1;          x = y + 1;
}                   }
```

1. Show an execution path such that at the end $x = 2$ and $y = 1$.
2. Is there a path s.t. $x = y = 1$? Justify your answer. What would happen if the assumption on atomicity of assignment is dropped?

Exercise 4. Given the following program:

```
int n = 0;
Thread.start { //P       Thread.start { //Q
  int local;              int local;
  5.times {               5.times {
    local = n;              local = n;
    n = local + 1;          n = local + 1;
} }                     } }
```

- Show an execution path in which the final value of n is 5.

Exercise 5. Assume that f has an integer root, i.e., $f(x) = 0$ for some integer. We now propose two different programs for finding this root. We consider a program to be *correct* if, in the case that f does have a root, both threads terminate and x holds the root. For each program indicate whether it is correct or not, justifying your answer by exhibiting appropriate paths.

- Program A:

```
boolean found = false;
Thread.start { //P
  int i = 0;
  while (!found) {
    i = i + 1;
    found = (f(i) == 0);
} }
```

```
Thread.start { //Q
  int j = 1;
  while (!found) {
    j = j - 1;
    found = (f(j) == 0)
} }
```

- Program B:

```
boolean found = false;
Thread.start { //P
  int i = 0;
  while (!found) {
    i = i + 1;
    if (f(i) == 0)
      found = true;
} }
```

```
Thread.start { //Q
  int j = 1;
  while (!found) {
    j = j - 1;
    if (f(j) == 0)
      found = true;
} }
```

Exercise 6. Consider the program:

```
int n = 0;
Thread.start { //P
  while (n < 2)
    print(n);
}
```

```
Thread.start { //Q
  n = n + 1;
  n = n + 1;
}
```

1. Supply the execution paths that print the following sequences: 012, 002, 02.
2. Should 2 necessarily appear in the output?
3. How many times can 2 appear in the output?
4. How many times can 1 appear in the output?
5. How many times can 0 appear in the output?
6. What is the length of the shortest sequence that can be exhibited?

Exercise 7. Consider the program:

```
int n = 0;
Thread.start { //P
  while (n < 1)
    n = n + 1;
```

```
Thread.start { //Q
  while (n >= 0)
    n = n - 1;
```

1. Provide an execution path in which the loop in the thread on the left is executed exactly once.
2. Provide a path in which the loop in the thread on the left is executed exactly three times.
3. Describe a path in which the loop in the thread on the left does not terminate.

Exercise 8. Consider the program:

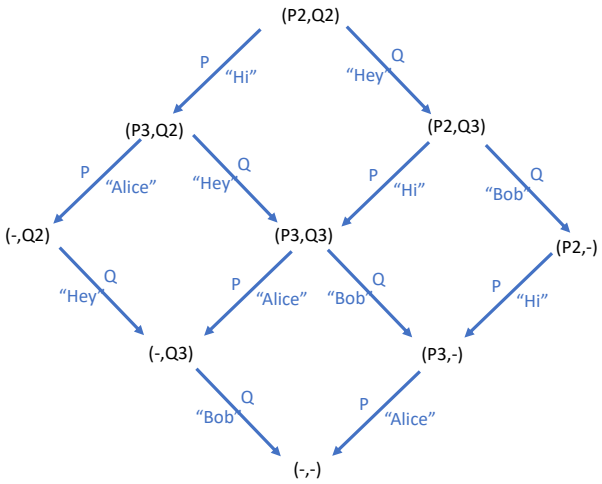
```
int n = 0;
boolean flag = false;
Thread.start { //P
  while (!flag)
    n = 1 - n;
}
```

```
Thread.start { //Q
  while (!flag)
    if (n == 0) { flag = true; }
}
```

1. Provide an execution path in which the program terminates.
2. What are the possible values of n when the program terminates.
3. Can the program not terminate?

1 Solutions to Selected Exercises

Answer to exercise 1



The execution paths are all the paths in the graph that start at the startstate $(P2, Q2)$ and end in the endstate $(-, -)$.

Answer to exercise 3

1. State format (IP_P, IP_Q, x, y). Path: $(P2, Q2, 0, 0) \rightarrow (-, Q2, 0, 1) \rightarrow (-, -, 2, 1)$
2. There are not paths that result in `x` and `y` both holding one. If the assumption on atomicity of assignment is dropped, then there would be such a path.