The Dining Philosophers

Operating Systems
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We are going to discuss two problems

These are classic thread synchronization problems

They are examples to show how semaphores and monitors can be used to achieve synchronization —

- The Dining Philosophers Problem (Textbook 31.6)
- The Sleeping Barber Problem (not in the textbook, but in Lab 3)

The Dining Philosophers

The Dining Philosophers Problem

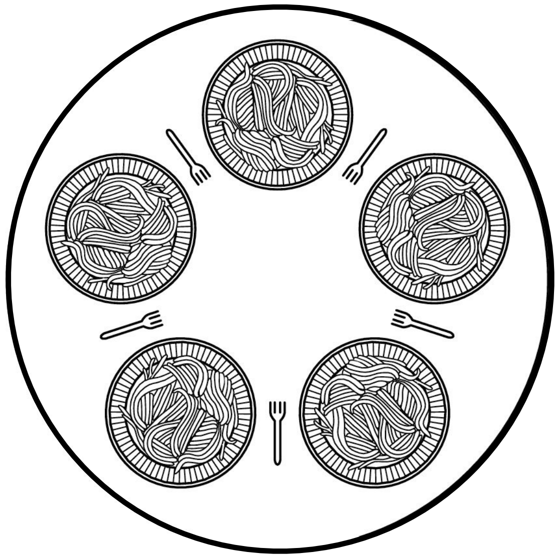
Five philosophers sit at a table

One fork between two neighbouring philosophers

Philosophers think, grab both forks, eat, put down both forks

Models exclusive access to a limited number of resources (such as I/O devices)

Each philosopher is modelled as a thread



```
while true do
  think()
  Pickup left fork
  Pickup right fork
  eat()
  Put down left fork
  Put down right fork
```

Is this a valid solution?

```
philosopher(int i)
  while true do
    think()
    pickup_forks(i)
    eat()
    putdown_forks(i)
pickup_forks(int i)
    pickup_fork(i)
    pickup_fork((i+1) modulo 5)
putdown_forks(int i)
    putdown_fork(i)
    putdown_fork((i+1) modulo 5)
```

The Problem

It may happen that all five philosophers take their left fork at the same time, and then try to take their right fork, which is taken by a neighbouring philosopher!

No one is able to progress — a deadlock

How do we solve this problem?

Intuition: taking the left and right forks needs to be made into one **atomic action**

Second Try: the Dining Philosophers Problem

```
semaphore mutex = 1 // binary semaphore
philosopher(int i)
  while true do
    think()
    mutex.down()
    pickup_forks(i)
    eat()
    putdown_forks(i)
    mutex.up()
```

The Problem Now

Only one philosopher can be eating at a given time

But we should be able to allow two philosophers eating at the same time!

How do we solve this problem?

First intuition: define a smaller critical section by moving the binary semaphore operations into **pickup_forks()** and **putdown_forks()**

Now the solution looks like this — correct?

```
philosopher(int i)
  while true do
    think()
    pickup_forks(i)
    eat()
    putdown_forks(i)
pickup_forks(int i)
    mutex.down()
    pickup_fork(i)
    pickup_fork((i+1) modulo 5)
    mutex.up()
putdown_forks(int i)
    mutex.down()
    putdown_fork(i)
    putdown_fork((i+1) modulo 5)
    mutex.up()
```

Looks fine so far—but what about pickup_fork()?

The solution looks fine for now, but we haven't implemented pickup_fork() and putdown_fork() yet!

How do we implement pickup_fork() and putdown_fork()?

- We do not need to maintain any additional states to know if a fork is available
- Just look at the status of two adjacent philosophers

The status of two adjacent philosophers

They can be in one of the three states: eating, thinking, or “hungry” (waiting for forks to become available)

A philosopher may only eat if both of his neighbours are not eating

What if a philosopher tries to pickup a fork, but it is not available?

- It needs to wait for it to become available — **thread synchronization**
- His neighbour, once finished eating, will have to wake him up

First try: synchronization with semaphores

```
semaphore sem[5]= {5 of 0}
int status[5] = {5 of THINKING}
pickup_forks(int i)
   mutex.down()
   status[i] = HUNGRY
   int left = (i+4) modulo 5, right = (i+1) modulo 5
   if status[left] == EATING or
      status[right] == EATING then
     sem[i].down()
   status[i] = EATING
   mutex.up()
```

First try: synchronization with semaphores

```
putdown_forks(int i)
  mutex.down()
  status[i] = THINKING
  int left = (i+4) modulo 5, right = (i+1) modulo 5
  if status[left] == HUNGRY then
    sem[left].up()
  if status[right] == HUNGRY then
    sem[right].up()
  mutex.up()
```

Problem with the first try

In pickup_forks(), if a philosopher i has failed to pick up both forks, it calls sem[i].down(), which blocks itself, before calling mutex.up() to leave the critical section

No other thread is able to enter the critical section — deadlock!

So how do we solve this problem?

How about this solution?

```
pickup_forks(int i)
   mutex.down()
   status[i] = HUNGRY
   int left = (i+4) modulo 5, right = (i+1) modulo 5
   if status[left] == EATING or
      status[right] == EATING then
     mutex.up()
     sem[i].down()
     status[i] = EATING
   else
     status[i] = EATING
     mutex.up()
```

Still another problem

Philosopher 1 and 4 were both eating at this time

They finish eating at the same time

Philosopher 1 wakes up 2, and 4 wakes up 3, since both 2 and 3 are hungry at the time (2 waiting on sem[2], 3 on sem[3])

Both sem[2].down() and sem[3].down() are allowed to proceed!

Changing if to while?

Can we solve the problem by changing if to while in pickup_forks()?

```
while status[left] == EATING or
   status[right] == EATING do
  mutex.up()
  sem[i].down()

status[i] = EATING
```

Changing if to while?

Can we solve the problem by changing if to while in pickup_forks()?

```
while status[left] == EATING or
    status[right] == EATING do
  mutex.up()
  sem[i].down()

status[i] = EATING
```

No — we are testing status[left] and status[right] without acquiring mutual exclusion locks!

Correct implementation of pickup_forks()

```
pickup_forks(int i)
    mutex.down()
    status[i] = HUNGRY
    int left = (i+4) modulo 5, right = (i+1) modulo 5
    while status[left] == EATING or
          status[right] == EATING do
      mutex.up()
      sem[i].down()
      mutex.down()
    status[i] = EATING
    mutex.up()
```

Alternative solution: revise putdown_forks()

Alternatively, we can leave pickup_forks() as it was

Instead, we revise putdown_forks() —

- When a philosopher finishes eating, it **only** wakes up a neighbouring philosopher if it is sure that its other neighbour is not eating!
- If it does wake up a neighbour, it sets its status to EATING

Alternative solution: revise putdown_forks()

```
pickup_forks(int i)
    mutex.down()
    status[i] = HUNGRY
    int left = (i+4) modulo 5, right = (i+1) modulo 5

    if status[left] == EATING or
       status[right] == EATING then
      mutex.up()
      sem[i].down()
    else
      status[i] = EATING
      mutex.up()
```

Alternative solution: revise putdown_forks()

```
putdown_forks(int i)
    mutex.down()
    status[i] = THINKING
    int left = (i+4) modulo 5, right = (i+1) modulo 5

    if status[left] == HUNGRY and
       status[(left+4) modulo 5] != EATING then
      status[left] = EATING
      sem[left].up()
    if status[right] == HUNGRY and
       status[(right+1) modulo 5] != EATING then
      status[right] = EATING
      sem[right].up()
    mutex.up()
```

Now you see why we need monitors!

Using semaphores, even when solving a simple synchronization problem, is a bit too tricky

Task 1 in Lab 3 asks you to implement the Dining Philosophers problem using monitors and condition variables

- The monitor implementation in BLITZ follows MESA semantics
- Keep this in mind when designing your solution

But semaphores are more **powerful** primitives — it allows us to design a simpler solution

Revisiting our initial solution

```
philosopher(int i)
 while true do
   think()
   pickup_forks(i)
   eat()
   putdown_forks(i)
pickup_forks(int i)
   pickup_fork(i)
   pickup_fork((i+1) modulo 5)
putdown_forks(int i)
   putdown_fork(i)
   putdown_fork((i+1) modulo 5)
```

Towards designing a simpler solution

```
semaphore forks[5]= {5 of 1}
pickup_fork(int i)
  forks[i].down()
putdown_fork(int i)
  forks[i].up()
```

But what about the deadlock?

Making the solution deadlock-free

```
pickup_forks(int i)
  if i == 4 then
    pickup_fork((i+1) modulo 5)
    pickup_fork(i)
  else
    pickup_fork(i)
    pickup_fork((i+1) modulo 5)

putdown_forks(int i)
   putdown_fork(i)
   putdown_fork((i+1) modulo 5)
```

What we’ve covered so far

Three Easy Pieces: Chapter 31.6