Synchronization

Classical Synchronization Problems

Stefano Quer and Stefano Scanzio

Dipartimento di Automatica e Informatica

Politecnico di Torino
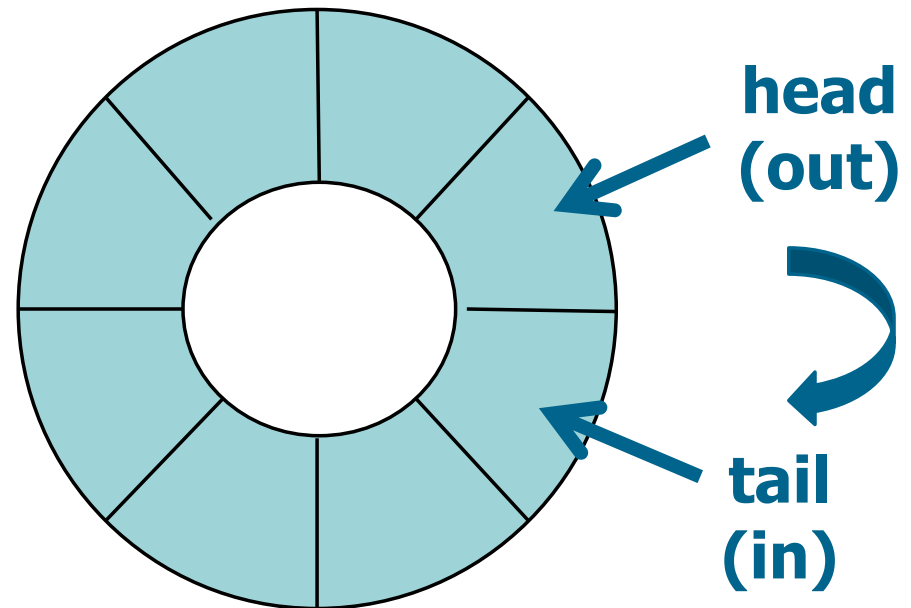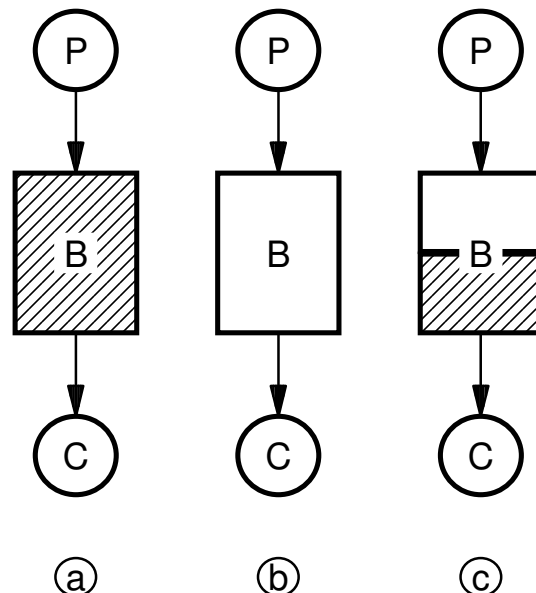
skenz.it/os   stefano.scanzio@polito.it

Producer-Consumer

❖ Producer and consumer with limited memory

➢ It uses a circular buffer of dimension **SIZE** to store the elements to be produced and consumed

➢ The circular buffer implements a FIFO queue (First-In First-Out)

full FIFO,
empty,
partially full

**head
(out)**

**tail
(in)**

ⓐ   ⓑ   ⓒ

Sequential access

```
#define SIZE ...
...
int queue[SIZE];
int tail, head;
...
void init () {
  tail = 0;
  head = 0;
  n = 0;
}
```

FIFO standard (non ADT)

```
void enqueue (int val) {
  if (n>SIZE) return;
  queue[tail] = val;
  tail=(tail+1)%SIZE;
  n++;
  return;
}
```

```
void dequeue (int *val) {
  if (n<=0) return;
  *val=queue[head];
  head=(head+1)%SIZE;
  n--;
  return;
}
```

Sequential vs parallel access

❖ In the sequential access enqueue and dequeue are concurrent

❖ In parallel access we can have two cases

  ➢ Only 1 producer and only 1 consumer

    ▪ The operations enqueue and dequeue act on different extremes of the queue, however the n variable is shared

  ➢ P producers and C consumers

    ▪ In addition to the previous case, concurrent access operations to the same extreme of the queue are possible

Concurrent access: Version 1

❖ For parallel access with 1 producer and 1 consumer

➢ You have to insert

▪ A semaphore "full" that counts the number of filled elements

▪ A semaphore "empty" that counts the number of empty elements

➢ The counter n can be removed

Concurrent access: Version 1

```
#define SIZE ...

...
int queue[SIZE];
int tail, head;
...
void init () {
    tail = 0;
    head = 0;
}
```

FIFO standard (non ADT) without the variable n

```
void enqueue (int val) {
    queue[tail] = val;
    tail=(tail+1)%SIZE;
    return;
}
```

```
void dequeue (int *val) {
    *val=queue[head];
    head=(head+1)%SIZE;
    return;
}
```

Concurrent access: Version 1

1 Producer
1 Consumer

Instead of n it uses
elements filled
elements empty

```
init (full, 0);
init (empty, SIZE);
```

```
Producer () {
  int val;
  while (TRUE) {
    produce (&val);
    wait (empty);
    enqueue (val);
    signal (full);
  }
}
```

```
Consumer () {
  int val;
  while (TRUE) {
    wait (full);
    dequeue (&val);
    signal (empty);
    consume (val);
  }
}
```

Concurrent access: Version 2

❖ Solution 1 is simmetric

- ➢ The producer produces filled positions
- ➢ The consumer produces empty positions

❖ It can be easily **extended** to the case where there are more producers and more consumers

- ➢ Producers and consumers operates on opposite extremes of the buffer
  - ▪ It can be done **concurrently**
  - ▪ As long as the queue is not completely full or completely empty
- ➢ Instead, two producers or two consumers must act in **mutual exclusion**

Concurrent access: Version 2

P Producers
C Consumers

It is necessary to force mutual exclusion between P and C

```
init (full, 0);
init (empty, SIZE);
init (MEp, 1);
init (MEc, 1);
```

```
Producer () {
  int val;
  while (TRUE) {
    produce (&val);
    wait (empty);
    wait (MEp);
    enqueue (val);
    signal (MEp);
    signal (full);
  }
}
```

```
Consumer () {
  int val;
  while (TRUE) {
    wait (full);
    wait (MEc);
    dequeue (&val);
    signal (MEc);
    signal (empty);
    consume (val);
  }
}
```

Readers & Writers

❖ **Classical problem**

➢ Courtois et al. [1971]

➢ Share data between two sets of concurrent processes

- A set of **Readers**, which can access **concurrently** to the data
- A set of **Writers**, which can access in **mutual exclusion**, both with other Writers and Readers processes, to the data

➢ Construct often used to create new synchronization primitives

Readers & Writers

❖ There are two versions of the problem

➢ Precedence to Readers

➢ Precedence to Writers

❖ Common goals

➢ Respect the precedence protocol

➢ Maximize concurrency

Precedence to Readers

❖ Giving precedence to Readers means

➢ Privileging Readers access over Writers access, i.e.

➢ Readers do not have to wait as long as a reader is in the CS

❖ Access protocol

➢ Readers can concurrently access to the data

➢ Until the Readers arrive, Writers have to wait

➢ When even the last Reader ends, then you can wake up a writer (or a reader … it depends on the scheduler)

Precedence to Readers: Version 1

```
nR = 0;
init (meR, 1);
init (w, 1);
```

Reader

```
wait (meR);
   nR++;
   if (nR==1)
     wait (w);
signal (meR);
...
reading
...
wait (meR);
   nR--;
   if (nR==0)
     signal (w);
signal (meR);
```

Writer

```
wait (w);
...
writing
...
signal (w);
```

Precedence to Readers: Version 2

```
nR = 0;
init (meR, 1);
init (meW, 1);
init (w, 1);
```

Reader

```
wait (meR);
  nR++;
  if (nR==1)
    wait (w);
signal (meR);
...
reading
...
wait (meR);
  nR--;
  if (nR==0)
    signal (w);
signal (meR);
```

To enforce the precedence to R
(the signal(w) unblocks an R)

Writer

```
wait (meW);
wait (w);
...
writing
...
signal (w);
signal (meW);
```

Conclusions

❖ The solution uses

➢ A global variable (nR) counts the number of Readers in the CS

➢ A semaphore for the mutual exclusion for the access to the variable nR (meR)

➢ A semaphore for the mutual exclusion of more Writers, or a Reader and the Writers (w)

➢ A semaphore for the mutual exclusion of writer (meW)

❖ Writers are subject to **starvation**, because they can wait (be blocked) forever

❖ More complex solutions without starvation of the Writers are possible

Precedence to Writers

- ❖ Giving priority to writers means
  - ➤ A Writer that is ready, must wait the smallest possible time
- ❖ Access protocol
  - ➤ Each Writer must wait that all Readers finish
  - ➤ Each Writer has a higher priority than every Reader

Precedence to Writers

```
nR = nW = 0;
init (w, 1); init (r, 1);
init (meR, 1); init (meW, 1);
```

Reader

```
wait (r);
  wait (meR);
    nR++;
    if (nR == 1)
      wait (w);
  signal (meR);
signal (r);
...
reading
...
wait (meR);
  nR--;
  if (nR == 0)
    signal (w);
signal (meR);
```
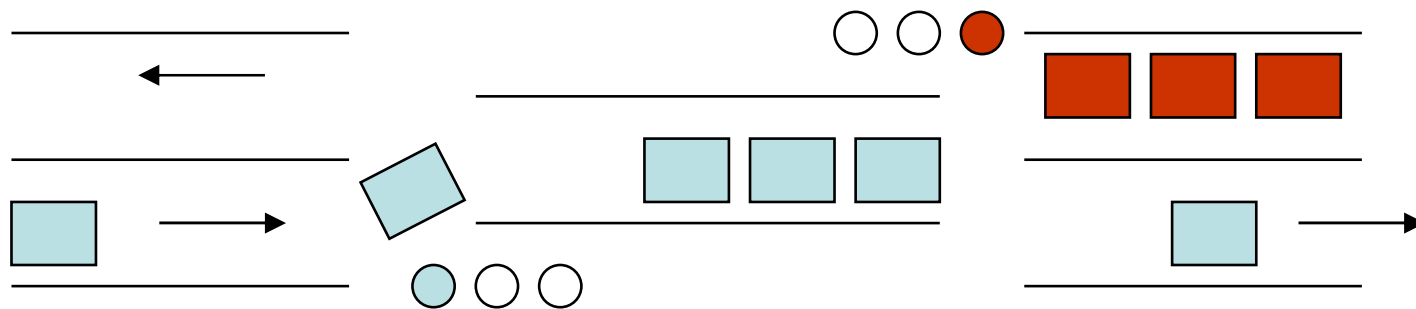
Writer

```
wait (meW);
  nW++;
  if (nW == 1)
    wait (r);
signal (meW);
wait (w);
  ...
  writing
  ...
signal (w)
wait (meW);
  nW--;
  if (nW == 0)
    signal (r);
signal (meW);
```

Conclusions

❖ The solution uses

- ➢ Two global variables (nR and nW) to count the number of Readers and Writers

- ➢ Two semaphores to guarantee mutual exclusion (meR and meW) for the access to the variables nR and nW

- ➢ Two semaphores to guarantee mutual exclusion between Readers/Writers (r and w)

❖ Reader are subject to **starvation**, because they can wait (be blocked) forever

❖ More complex solutions without starvation are possible

The "Alternate direction tunnel"

❖ In an alternate direction tunnel

➢ Allow any number of cars (processes) to proceed in the same direction

➢ If there is traffic in one direction, block traffic in the opposite direction

The "Alternate direction tunnel"

❖ Extension to the Readers-Writers problem, with two sets of Readers

❖ Data structure

  ➢ Two global counters (n1 and n2), one for each direction

  ➢ Two semaphores (s1 and s2), one for each direction

  ➢ A global semaphore for wait (busy)

❖ In its basic implementation, it can cause starvation of cars (in one direction with respect to the other)

Solution

```
n1 = n2 = 0;
init (s1, 1); init (s2, 1);
init (busy, 1);
```

left2right

```
wait (s1);
  n1++;
  if (n1 == 1)
    wait (busy);
signal (s1);
...
Run (left to right)
...
wait (s1);
  n1--;
  if (n1 == 0)
    signal (busy);
signal (s1);
```

right2left

```
wait (s2);
  n2++;
  if (n2 == 1)
    wait (busy);
signal (s2);
...
Run (left to right)
...
wait (s2);
  n2--;
  if (n2 == 0)
    signal (busy);
signal (s2);
```

Dining (5) philosophers problem

❖ Model in which different resources are common to different concurrent processes

❖ Due to Dijkstra [1965]

❖ Definition of the problem

➢ A table is set with

  ▪ 5 rice dishes

  ▪ 5 (Chinese) chopsticks each between two plates

➢ Around the table sit 5 philosophers

➢ Philosophers **think** or **eat**

  ▪ To eat each philosopher needs two chopsticks

  ▪ Chopsticks can be obtained one at a time
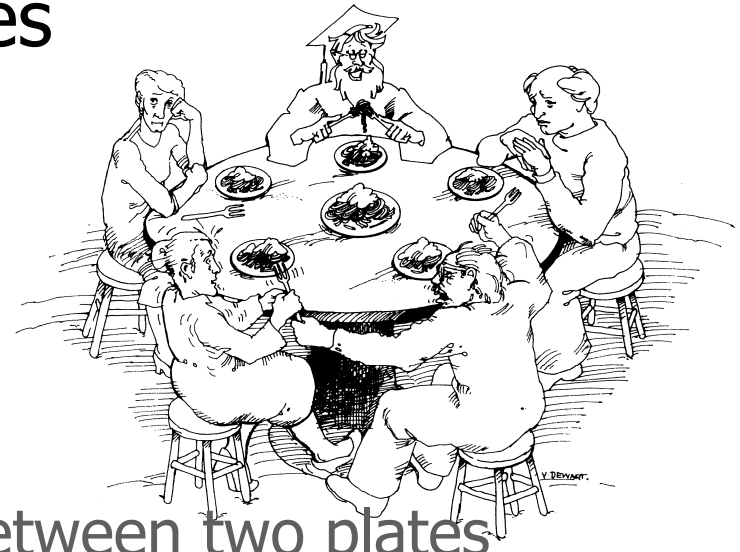
Model 0

❖ "Philosophical" solutions (not correct)

➢ Teach philosophers to eat with only 1 chopstick

➢ Provide more than 5 chopsticks

➢ Allow only at most to 4 philosophers to sit at the table

➢ Force asymmetry

- Even position philosophers take the left fork first
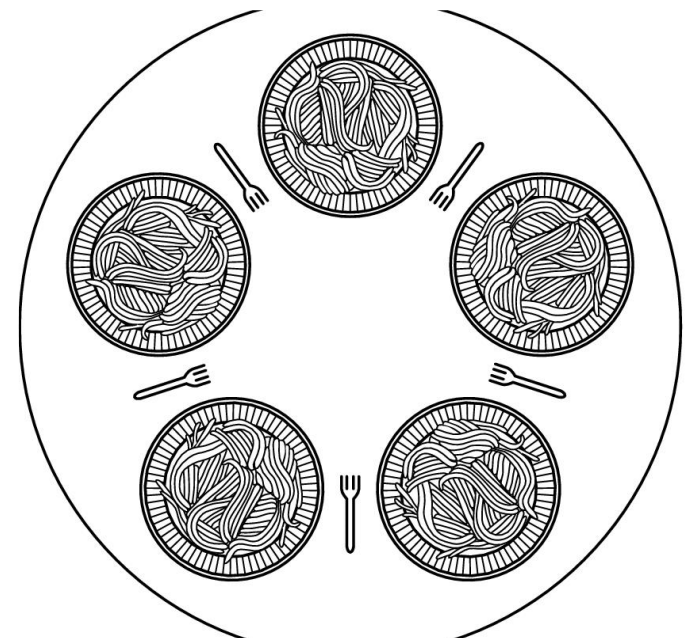- Odd position philosophers take the right fork first
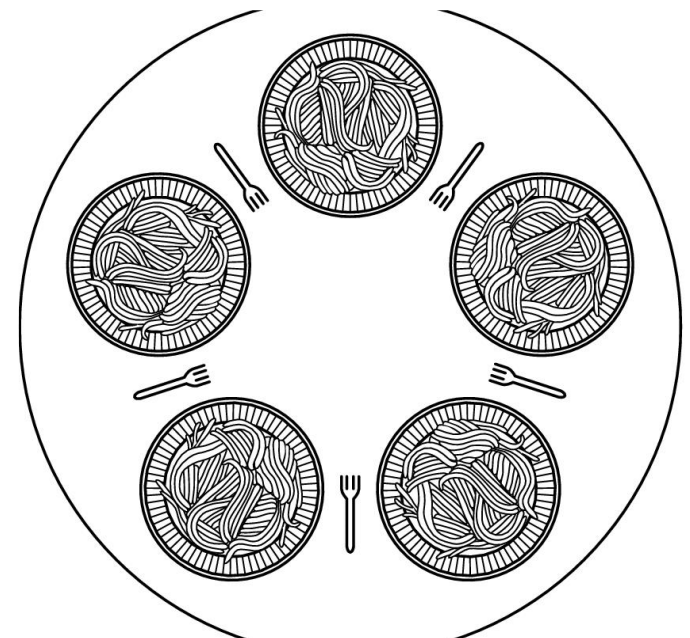
Model 1

❖ Use one binary semaphore (mutex) to protect the access to the only resource "the food"

  ➢ Cancel concurrency

  ➢ Only one philosopher eats at the same time (in two could eat)

```
init (mutex, 1);
```

```
while (true) {
   Think ();
   wait (mutex);
   Eat ();
   signal (mutex);
}
```
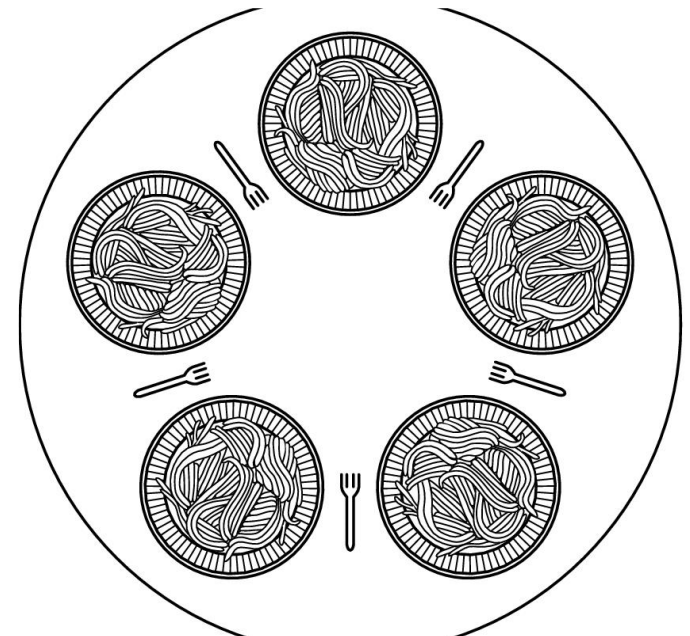
Model 2

❖ A semaphore for each chopstick

➢ It can cause deadlock

```
init (chopstick[0], 1);
...
init (chopstick[4], 1);
```

i∈ [0, 4]

```
while (true) {
   Think ();
   wait (chopstick[i]);
   wait (chopstick[(i+1)mod5]);
   Eat ();
   signal (chopstick[i]);
   signal (chopstick[(i+1)mod5]);
}
```

Solution

❖ **Data structures**

➢ A state for each philosopher (THINKING, HUNGRY, EATING)

➢ A semaphore for each philosopher (for access to food)

➢ Another semaphore to manage the access in mutual exclusion to the philosopher state variable

```
while (TRUE) {
   Think ();
   takeForks (i);
   Eat ();
   putForks (i);
}
```

Solution

```
int state[N]
init (mutex, 1);
init (sem[0], 0); ...; init (sem[4], 0);
```

```
takeForks (int i) {
   wait (mutex);
   state[i] = HUNGRY;
   test (i);
   signal (mutex);
   wait (sem[i]);
}
```

```
putForks (int i) {
   wait (mutex);
   state[i] = THINKING;
   test (LEFT);
   test (RIGHT);
   signal (mutex);
}
```

```
test (int i) {
   if (state[i]==HUNGRY && state[LEFT]!=EATING &&
       state[RIGHT]!=EATING) {
     state[i] = EATING;
     signal (sem[i]);
   }
}
```