Operating Systems and Concurrency

Concurrency 6 + Revision
COMP2007

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University Of Nottingham
United Kingdom

2023

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Goals

Today

- Writers before readers.
- Beyond locks - alternative approaches to concurrency.

The Readers – Writers Problem (Last Time)

Solution 2: Readers First

- We implemented as solution to readers-writers that allowed concurrent reading when safe to do so.
- Recall the **room with a light switch analogy** - writers only enter a darkened room, readers happy to mix together.
- Unfortunately readers can overwhelm writers, and the **writers can starve**.
- Today - try to reverse the situation and **favour the writers**.

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The Readers – Writers Problem

Solution 3: Writers First

Solution 3 gives priority to **writers** and uses:

- Integers `iReadCount` and `iWriteCount` to keep track of the number of readers/writers.
- Mutexes `sRead` and `sWrite` to synchronise the **reader's/writer's critical section**.
- Semaphore `sReadTry` to stop readers when there is **a writer waiting**.
- Semaphore `sResource` to **synchronise** the resource for **reading/writing**.

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The Readers – Writers Problem

Solution 3: Writers First

```
void * reader(void * arg)
{
  while(1)
  {
    sem_wait(&sReadTry);
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    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```

```
void * writer(void * arg)
{
  while(1)
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    if(iWriteCount == 1)
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    sem_post(&sWrite);

    sem_wait(&sResource);
    printf("writing\n");
    sem_post(&sResource);

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    iWriteCount--;
    if(iWriteCount == 0)
      sem_post(&sReadTry);
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  }
}
```
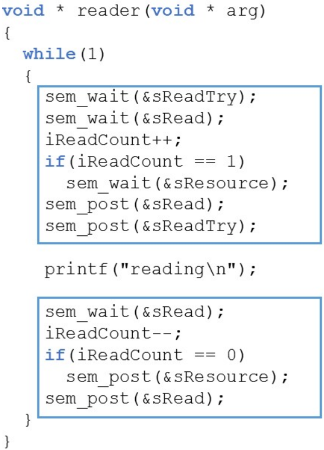

The Readers – Writers Problem

Solution 3: Writers First



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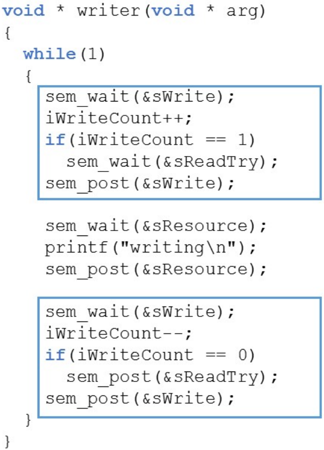

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The Readers – Writers Problem

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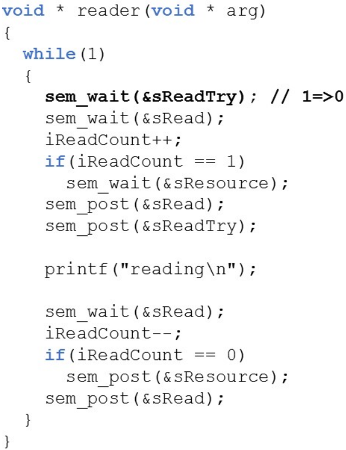

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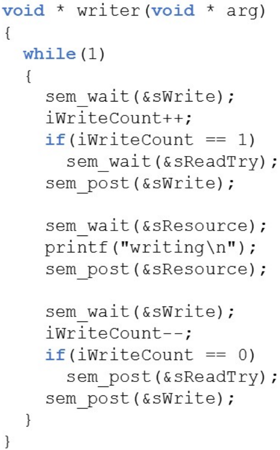

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      sem_wait(&sResource);
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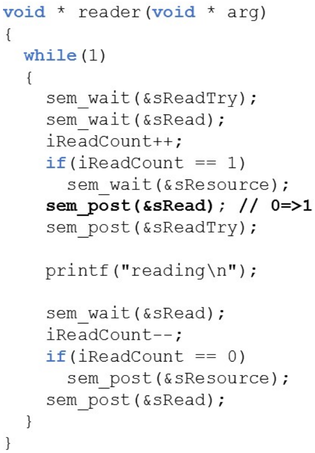
Solution 3: Writers First



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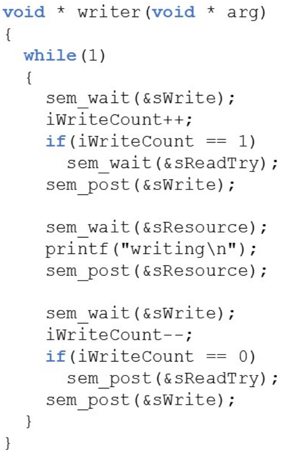

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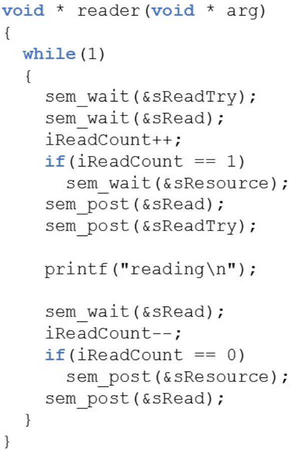

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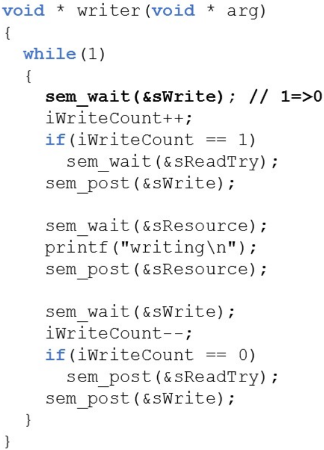

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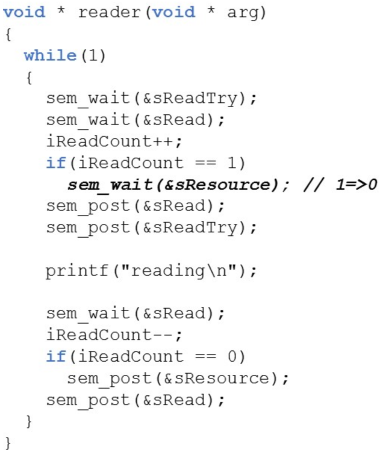

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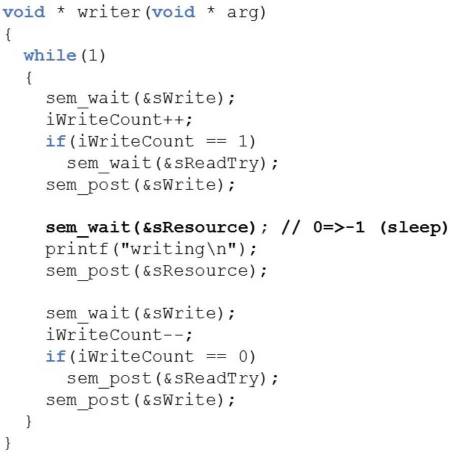

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    sem_post(&sWrite);

    sem_wait(&sResource); // 0=>-1 (sleep)
    printf("writing\n");
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    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource); // -1=>0
    sem_post(&sRead);
  }
}
```

```
void * writer(void * arg)
{
  while(1)
  {
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource); // wakeup
    printf("writing\n");
    sem_post(&sResource);

    sem_wait(&sWrite);
    iWriteCount--;
    if(iWriteCount == 0)
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    sem_post(&sRead); // 0=>1
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}
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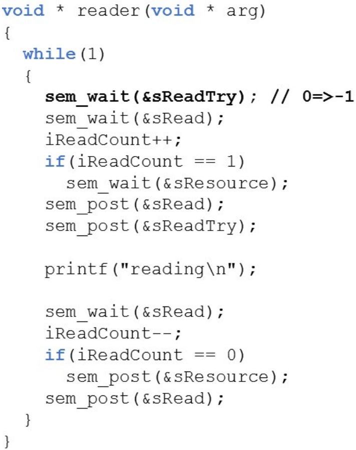

```c
void * reader(void * arg)
{
  while(1)
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    sem_wait(&sReadTry); // 0=>-1
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    if(iReadCount == 1)
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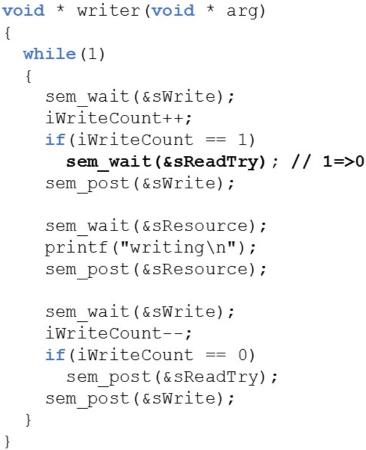

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    if(iWriteCount == 0)
      sem_post(&sReadTry);
    sem_post(&sWrite);
  }
}
```

The Readers – Writers Problem

Solution 3: Writers First

```
void * reader(void * arg)
{
  while(1)
  {
    sem_wait(&sReadTry);
    sem_wait(&sRead);
    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```

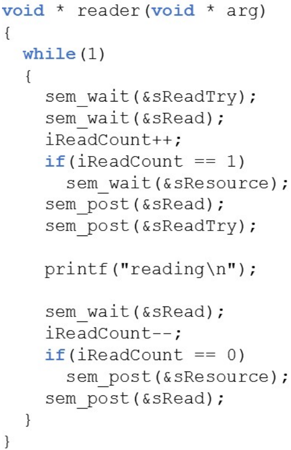
```
void * writer(void * arg)
{
  while(1)
  {
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource); // (woken up)
    printf("writing\n");
    sem_post(&sResource);

    sem_wait(&sWrite);
    iWriteCount--;
    if(iWriteCount == 0)
      sem_post(&sReadTry);
    sem_post(&sWrite);
  }
}
```

The Readers – Writers Problem

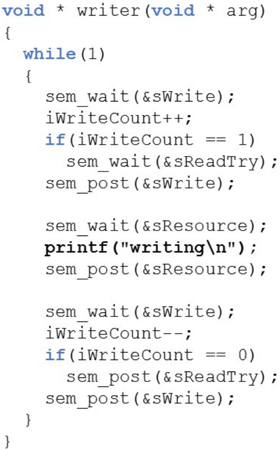
Solution 3: Writers First



```
void * reader(void * arg)
{
  while(1)
  {
    sem_wait(&sReadTry);
    sem_wait(&sRead);
    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```



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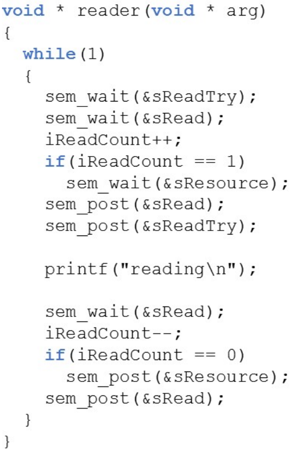
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource);
    printf("writing\n");
    sem_post(&sResource);

    sem_wait(&sWrite);
    iWriteCount--;
    if(iWriteCount == 0)
      sem_post(&sReadTry);
    sem_post(&sWrite);
  }
}
```

The Readers – Writers Problem

Solution 3: Writers First



```
void * reader(void * arg)
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  while(1)
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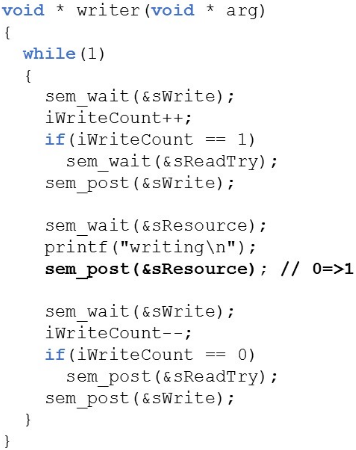
    sem_wait(&sRead);
    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```



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  {
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource);
    printf("writing\n");
    sem_post(&sResource); // 0=>1

    sem_wait(&sWrite);
    iWriteCount--;
    if(iWriteCount == 0)
      sem_post(&sReadTry);
    sem_post(&sWrite);
  }
}
```

The Readers – Writers Problem

Solution 3: Writers First

```
void * reader(void * arg)
{
  while(1)
  {
    sem_wait(&sReadTry);
    sem_wait(&sRead);
    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```

```
void * writer(void * arg)
{
  while(1)
  {
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource);
    printf("writing\n");
    sem_post(&sResource);

    sem_wait(&sWrite); // 1=>0
    iWriteCount--;
    if(iWriteCount == 0)
      sem_post(&sReadTry);
    sem_post(&sWrite);
  }
}
```

The Readers – Writers Problem

Solution 3: Writers First

```
void * reader(void * arg)
{
  while(1)
  {
    sem_wait(&sReadTry);
    sem_wait(&sRead);
    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```

```
void * writer(void * arg)
{
  while(1)
  {
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource);
    printf("writing\n");
    sem_post(&sResource);

    sem_wait(&sWrite);
    iWriteCount--; // 1=>0
    if(iWriteCount == 0)
      sem_post(&sReadTry);
    sem_post(&sWrite);
  }
}
```

The Readers – Writers Problem

Solution 3: Writers First

```
void * reader(void * arg)
{
  while(1)
  {
    sem_wait(&sReadTry);  // wakeup
    sem_wait(&sRead);
    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```

```
void * writer(void * arg)
{
  while(1)
  {
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource);
    printf("writing\n");
    sem_post(&sResource);

    sem_wait(&sWrite);
    iWriteCount--;
    if(iWriteCount == 0)
      sem_post(&sReadTry); // -1=>0
    sem_post(&sWrite);
  }
}
```

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The Readers – Writers Problem

Solution 3: Writers First

```
void * reader(void * arg)
{
  while(1)
  {
    sem_wait(&sReadTry);
    sem_wait(&sRead);
    iReadCount++;
    if(iReadCount == 1)
      sem_wait(&sResource);
    sem_post(&sRead);
    sem_post(&sReadTry);

    printf("reading\n");

    sem_wait(&sRead);
    iReadCount--;
    if(iReadCount == 0)
      sem_post(&sResource);
    sem_post(&sRead);
  }
}
```

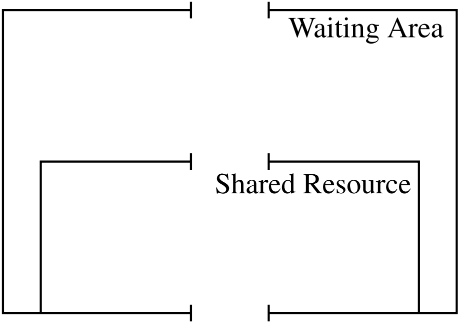
```
void * writer(void * arg)
{
  while(1)
  {
    sem_wait(&sWrite);
    iWriteCount++;
    if(iWriteCount == 1)
      sem_wait(&sReadTry);
    sem_post(&sWrite);

    sem_wait(&sResource);
    printf("writing\n");
    sem_post(&sResource);

    sem_wait(&sWrite);
    iWriteCount--;
    if(iWriteCount == 0)
      sem_post(&sReadTry);
    sem_post(&sWrite); // 0=>1
  }
}
```

The Readers – Writers Problem

Solution 3: Writers First - Intuitions



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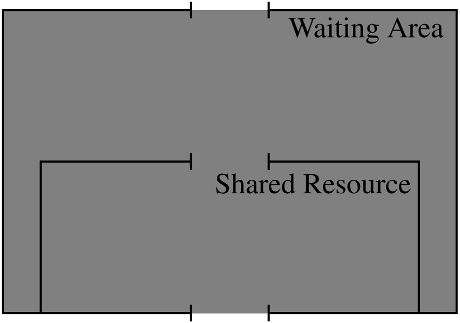
The Readers – Writers Problem

Solution 3: Writers First - Intuitions



Constraints:

- Everyone happy to go into a room with the light off.
- Readers and writers don't like each other.
- Readers happy to enter a room with a green light on, but not a yellow one.
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- Only readers are allowed to use the bottom exit.

The Readers – Writers Problem

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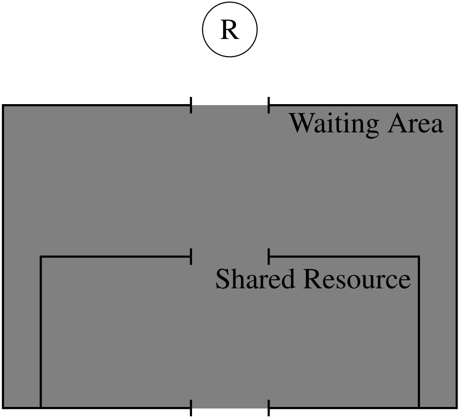

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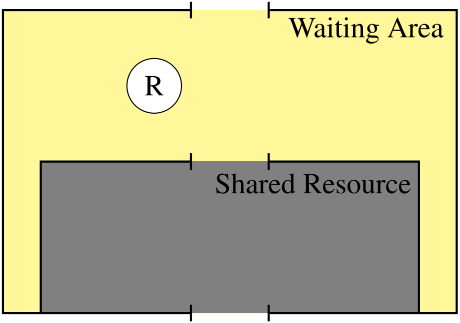

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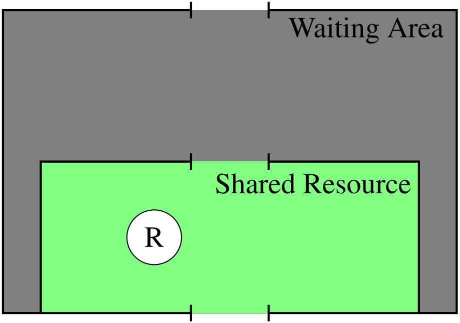

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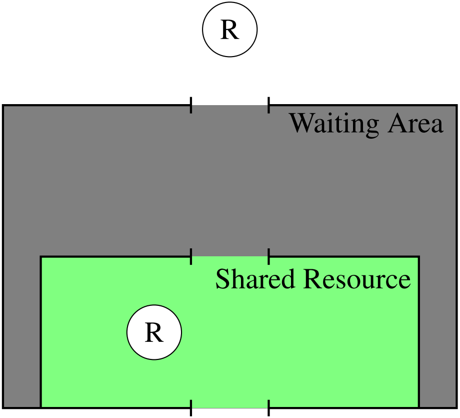

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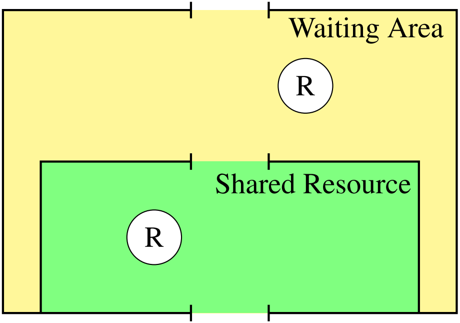

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The Readers – Writers Problem

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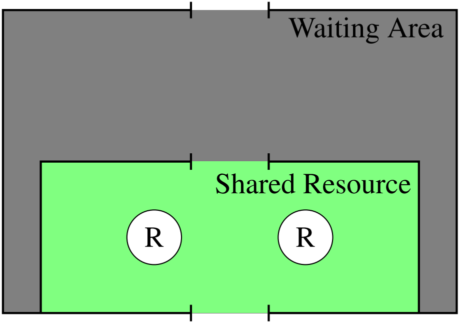

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The Readers – Writers Problem

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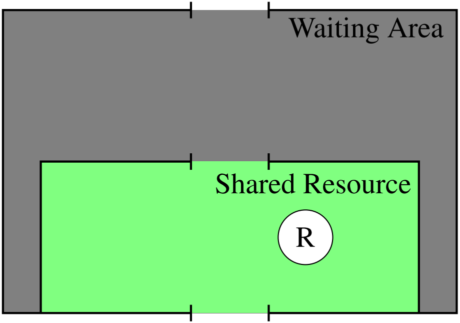

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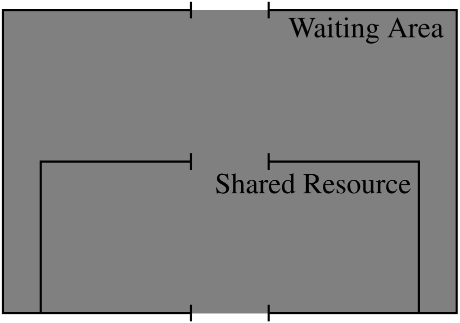

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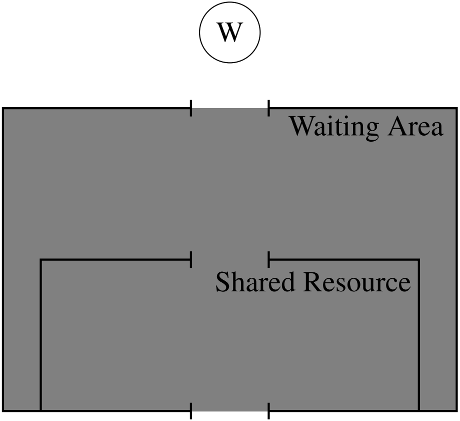

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The Readers – Writers Problem

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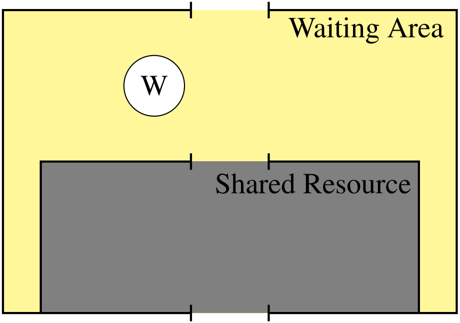

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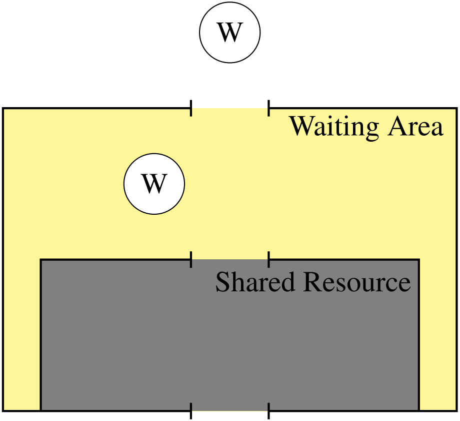

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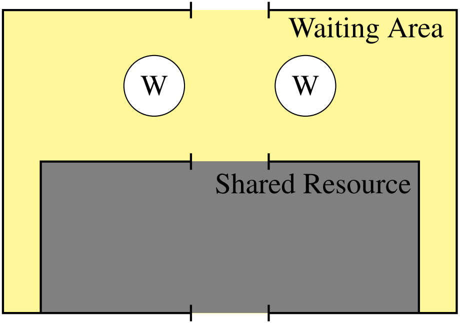

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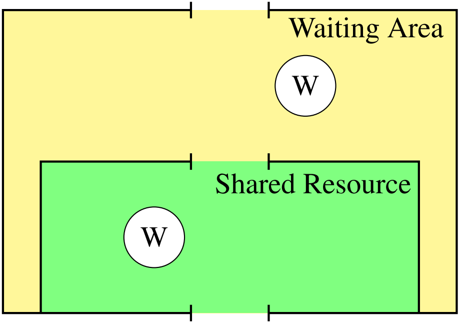

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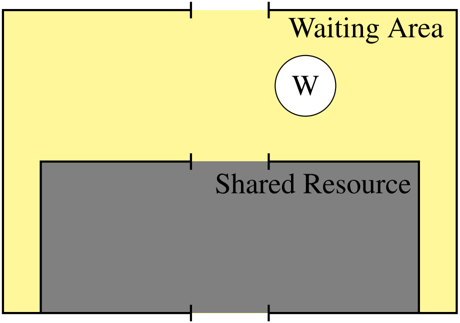

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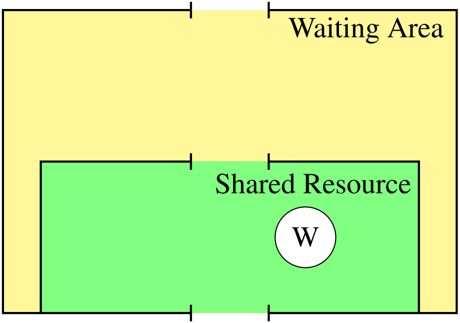

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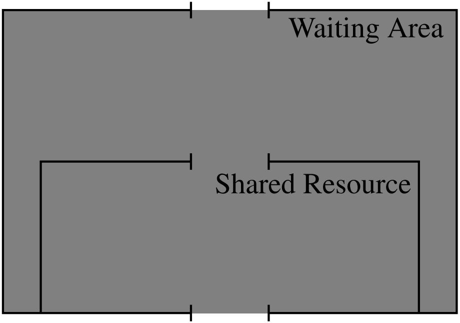

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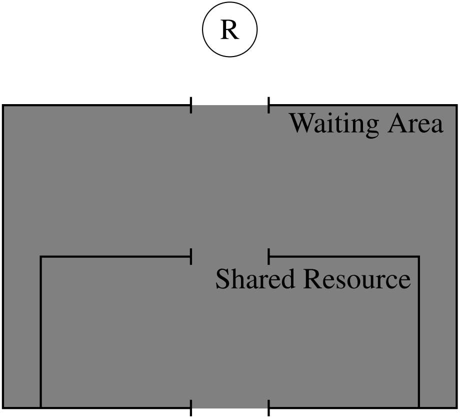

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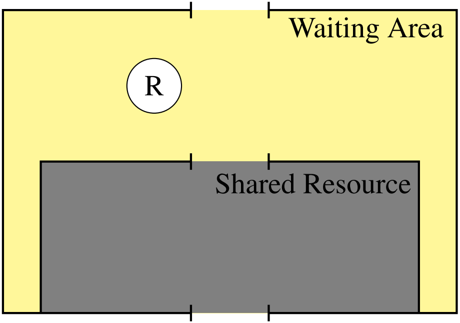

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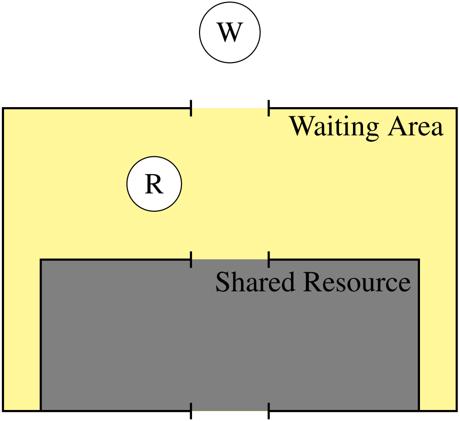

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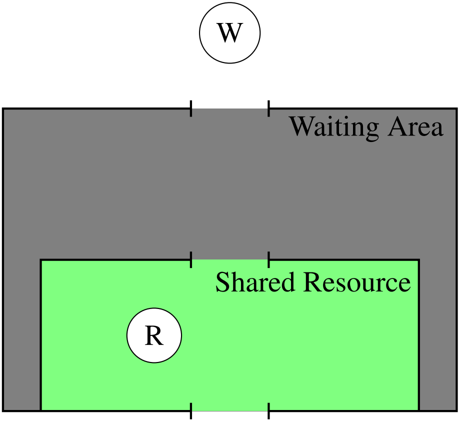

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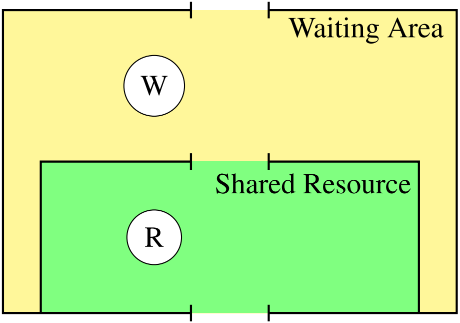

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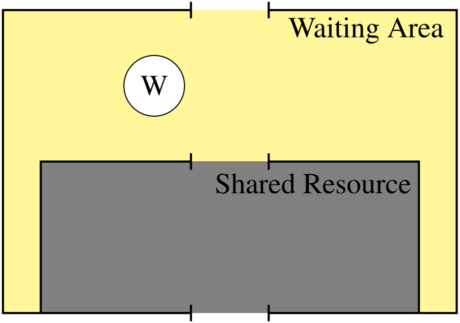

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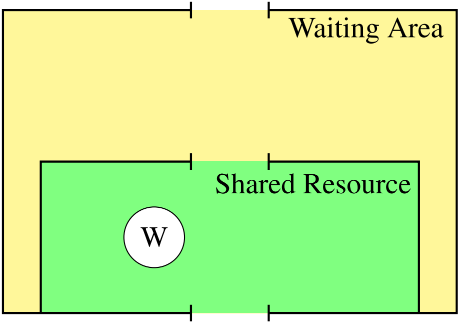

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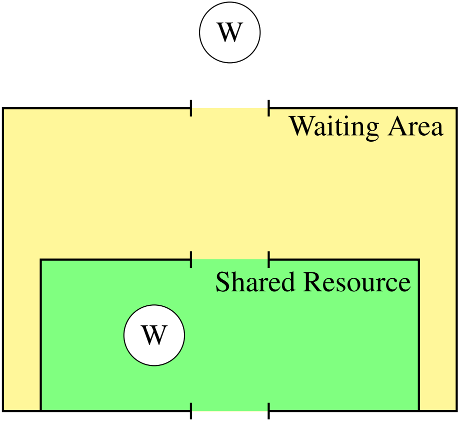

Constraints:

- Everyone happy to go into a room with the light off.
- Readers and writers don't like each other.
- Readers happy to enter a room with a green light on, but not a yellow one.
- Writers happy to enter a room with a yellow light on, but not a green one.
- Only readers are allowed to use the bottom exit.

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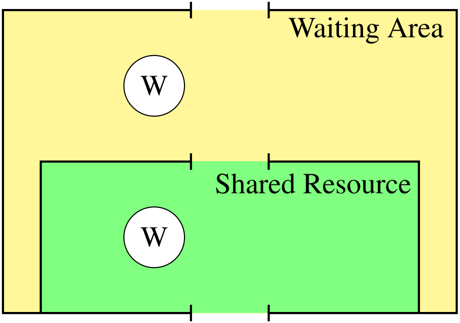

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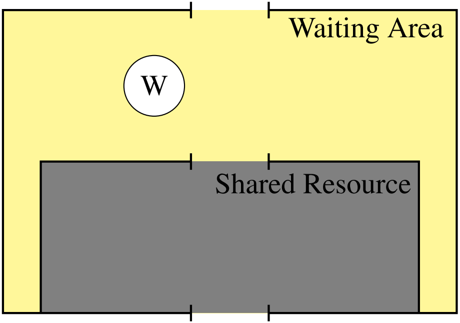

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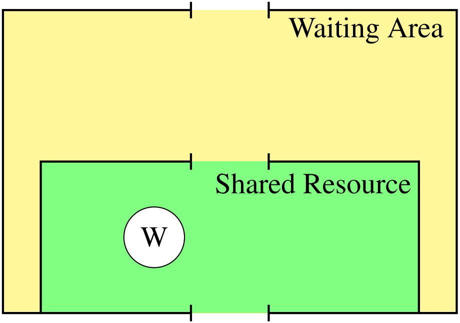

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- Lack of **compositionality** - you cannot compose small correct concurrent programs to form large correct concurrent programs.
- We could try to grab locks and back-off if we cannot acquire them all - we risk another problem - **livelock**.
- **Access to shared state is implicit** - it can be hard to tell who's modifying what, and if suitable locks are held at the time.
- **Lock convoying** - threads end up queuing up behind a thread holding a lock - linearizes behaviour and can take a long time to clear.

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1. Message passing - **synchronous** or **asynchronous**.
2. **Transactional memory**.

Message Passing

Synchronous Message Passing

- We avoid sharing memory, and instead have have channels $c, d, \ldots$
- There are two operations on channel c:
  1. $c(x)$ sends message x over the channel.
  2. $\overline{c}(x)$ receives a value over the channel into x.
- Communication is **synchronous** - a send must wait for a corresponding receive and vice-versa. **Think phone calls**.

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blocked	$\overline{c}(x)$
$\ldots$	$\ldots \quad (x = data)$

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Pros and cons of synchronous message passing:

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- Can implement mutexes and semaphores using synchronous message passing - **deadlocks, starvation etc. all still possible**.

Message Passing

Asynchronous Message Passing

In an attempt to mitigate the issues of synchronous message passing, **senders do not block** waiting for an available receiver. **Think sending an email**. Often use what is known as an **Actor** based model.

[1] Example adapted from notes of Ian Stark

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For example, to specify a simple counter [1]:

```
class Counter extends Actor {
  var counter = 0

  def receive = {
    case Zero => counter = 0
    case Inc => counter = counter + 1
  }
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```

Then to increment a `Counter` object, you just send it a message:

```
mycounter ! Inc // Send Inc message - don't wait for receiver
mycounter ! Inc // Send another - queued up until dealt with
```

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Message Passing

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- Can implement mutexes using asynchronous message passing - **deadlocks, starvation etc. all still possible**.

Transactional Memory

A Database Analogy

Imagine I owe Geert £10.

- Inside the bank, our account balances might be stored in a database table:

Holder	**Balance**
Geert	10000000
Dan	15

- Transferring the money to Geert requires two steps:
  1. Deduct £10 from the Dan account.
  2. Add £10 to the Geert account.

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Transactional Memory

A Database Analogy

Requirements for the bank transfer

- We would like the transfer to be **atomic** - In particular it either completely succeeds or totally fails.
- If other (atomic) changes are being made to the database, we would like them to be **serializable** - as if they don't overlap in time.

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Transactional Memory

Database Transactions

To satisfy our requirements, we wrap our changes in a **transaction**:

```
begin transaction;
update accounts set balance = balance + 10 where holder = 'Geert';
update accounts set balance = balance - 10 where holder = 'Dan';
commit;
```

Either both updates take place, or neither.

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Rollback

Realistic transactions may be more complex, and can encounter reasons they cannot succeed. Instead of `commit` they explicitly call `rollback` to fail the whole transaction.

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Transactional Memory

Transactions for thread coordination

The idea of transactional memory is to have the memory shared between threads behave transactionally, just like a database does.

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do {
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- A form of **livelock** still possible - as we back-off and try again after rollbacks.
- **Starvation** still possible - smaller transactions may cause repeated rollbacks of longer ones.

Thanks!

Change of lecturer back to Geert and a new topic on Wednesday!

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