3. Monitors in general and in Java
Communication and synchronization of parallel processes

Communication between parallel processes: exchange of data by

- using a common, global variable,
  only in a programming model with **common storage**
- **messages** in programming model **distributed** or **common storage**
  synchronous messages: sender waits for the receiver (languages: CSP, Occam, Ada, SR)
  asynchronous messages: sender does not wait for the receiver (languages: SR)

Synchronization of parallel processes:

- **mutual exclusion (gegenseitiger Ausschluss):**
  certain statement sequences (critical regions) may not be executed by several processes at the same time
- **condition synchronization (Bedingungssynchronisation):**
  a process waits until a certain condition is satisfied by a different process

Language constructs for synchronization:
Semaphore, monitor, condition variable (programming model with common storage)
messages (see above)

Deadlock (Verklemmung):
Some processes are waiting cyclically for each other, and are thus blocked forever

Lecture Parallel Programming WS 2014/2015 / Slide 18

Objectives:

Fundamental notions for synchronization und communication

In the lecture:

Explain

- communication in common and in distributed storage,
- the difference of the two kinds of synchronization: mutual exclusion and condition synchronization,
- examples for them,
- language constructs for them.

Questions:

- Give examples where mutual exclusion or condition synchronization is needed.

Monitor - general concept

Monitor: high level synchronization concept introduced in [C.A.R. Hoare 1974, P. Brinch Hansen 1975]

Definition:

- A monitor is a **program module** for concurrent programming with **common storage**; it encapsulates data with its operations.
- A monitor has **entry procedures** (which operate on its data); they are **called by processes**; the monitor is **passive.**
- The monitor guarantees **mutual exclusion for calls of entry procedures:**
  at most one process executes an entry procedure at any time.
- **Condition variables** are defined in the monitor and are used within entry procedures for **condition synchronization**.

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Objectives:

Understand the fundamental concept of monitors

In the lecture:

Explain

- the properties of monitors,
- the 2 kinds of synchronization;
- condition variables are necessary for synchronization in monitors;
- examples for that

Questions:

- Are monitors usable without condition variables? for what applications?

Condition variables

A **condition variable** c is defined to have 2 operations to operate on it.
They are executed by processes when executing a call of an entry procedure.

- **wait (c)** The executing process **leaves the monitor** and waits in a set associated to c, until it is released by a subsequent call signal(c); then the process accesses the monitor again and continues.
- **signal (c):** The executing process releases **one arbitrary process** that waits for c.

  Which of the two processes immediately continues its execution in the monitor depends on the variant of the signal semantics (see PPJ-22).
  signal-and-continue:
  The signal executing process continues its execution in the monitor.

  A call signal (c) has **no effect, if no process is waiting** for c.

Condition synchronization usually has the form

```
if not B then wait (c);    or    while not B do wait (c);
```

The **condition variable c** is used to synchronize on the **condition B**.

Note the difference between condition variables and semaphores:
Semaphores are counters. The effect of a call V(s) on a semaphore is not lost if no process is waiting on s.

Lecture Parallel Programming WS 2014/2015 / Slide 19b

Objectives:

Understand condition variables

In the lecture:

Explain

- the 2 operations,
- distinction between B and c,
- comparison with semaphores.

Questions:

- Why has the wait operation to release the monitor?

Example: bounded buffer

```
monitor Buffer
   buf: Queue (k);
   notFull, notEmpty: Condition;      2 condition variables: state of the buffer

   entry put (d: Data)
      do length(buf) = k -> wait (notFull); od;
      enqueue (buf, d);
      signal (notEmpty);
   end;

   entry get (var d: Data)
      do length (buf) = 0 -> wait (notEmpty); od;
      d := front (buf); dequeue (buf);
      signal (notFull);
   end;
end;

process Producer (i: 1..n) d: Data;
   loop d := produce(); Buffer.put(d); end;
end;

process Consumer (i: 1..m) d: Data;
   loop Buffer.get(d); consume(d); end;
end;
```


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Objectives:

Recall the monitor notion using a simple example

In the lecture:

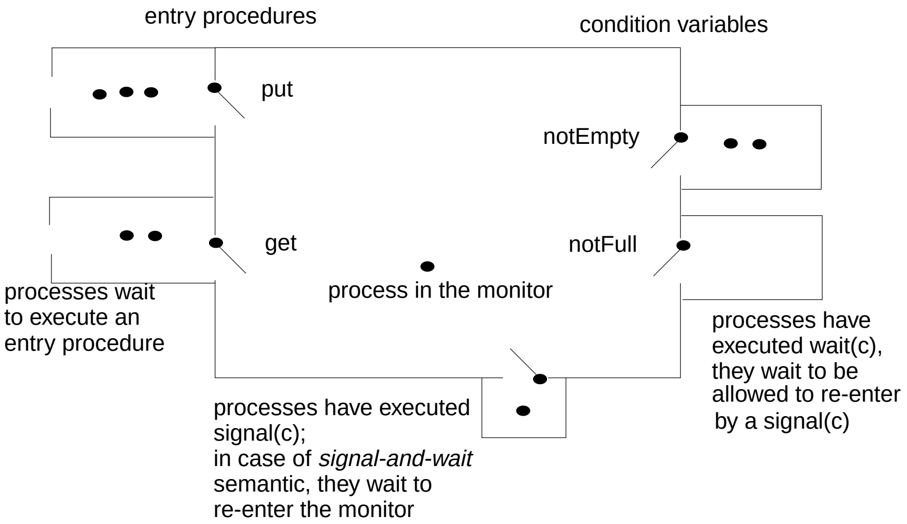
Explain

- 1 monitor, *n* producer processes, *m* consumer processes;
- monitor constructs: entry procedures, condition variable with wait and signal;
- usage of condition variables,
- notation: language SR, similar to Modula-2

Questions:

- What are the roles of the 2 condition variables?
- Explain the monitor using the notions of PPJ-19.

Synchronization in a monitor



Lecture Parallel Programming WS 2014/2015 / Slide 21

Objectives:

Visualization of monitor synchronization

In the lecture:

Explain

- waiting conditions using the example of PPJ-20;
- guaranteed: at most 1 process in the monitor;
- why waiting after a signal-operation

Questions:

- Explain the notions of PPJ-19 using this diagram.
- Can the example of a bounded buffer be implemented with only one condition variable? Explain.

Variants of signal-wait semantics

Processes compete for the monitor

- processes that are blocked by executing **`wait(c)`**,
- process that is in the monitor, may be executing **`signal(c)`**
- processes that wait to execute an entry procedure

signal-and-exit semantics:

The process that executes **`signal`** terminates the entry procedure call and leaves the monitor.
The released process enters the monitor **immediately** - without a state change in between

signal-and-wait semantics:

The process that executes **`signal`** leaves the monitor and waits to re-enter the monitor.
The released process enters the monitor **immediately** - without a state change in between
Variant **signal-and-urgent-wait**:

The process that has executed signal gets a higher priority than processes waiting for entry procedures

signal-and-continue semantics:

The process that executes signal continues execution in the monitor.
The released process has to wait until the monitor is free. The **state** that held at the **`signal`** call may be changed meanwhile; the waiting condition has to be checked again:

```
do length(buf) = k -> wait(notFull); od;
```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Objectives:

Understand the signal / wait semantics

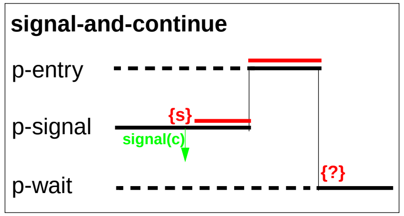
In the lecture:

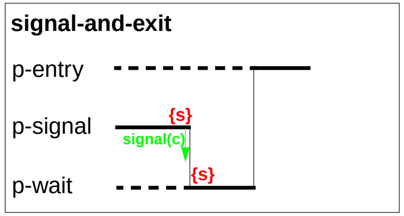
Explain the notions using slide PPJ-21

Questions:

- Consider the example of PPJ-20 and assume signal-and-continue semantics. The wait conditions have to be checked in loops, although all signal calls are placed immediately before ends of entry procedures. Why?

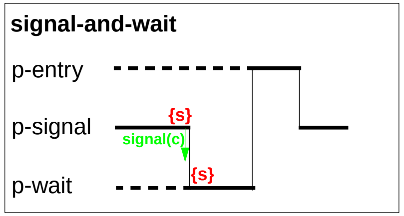
Variants of signal-wait semantics: examples of execution

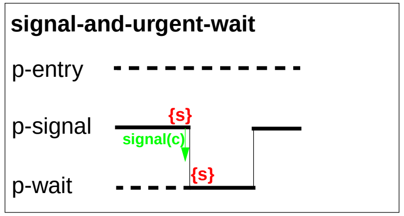




3 processes:
p-entry waits to enter an entry procedure
p-signal executes signal(c)
p-wait has executed wait(c)

{s} state when signal(c) is executed
{s} may be modified here:





Lecture Parallel Programming WS 2014/2015 / Slide 22a

Objectives:

Examples to understand the signal / wait semantics

In the lecture:

Explain the signal semantics of slide PPJ-22

Monitors in Java: mutual exclusion

Objects of any class can be used as **monitors**

Entry procedures:

Methods of a class, which implement critical operations on instance variables can be marked **`synchronized`:**

```
class Buffer
{  synchronized public void put (Data d) {...}
   synchronized public Data get () {...}
   ...
   private Queue buf;
}
```

If several processes **call `synchronized` methods** for the same object, they are executed under **mutual exclusion**.
They are synchronized by an internal synchronization variable of the object (lock).

Non-**`synchronized`** methods can be executed at any time concurrently.

There are also **`synchronized` class methods**: they are called under mutual exclusion with respect to the class.

`synchronized` blocks can be used to specify execution of a critical region with respect to an arbitrary object.

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Objectives:

Special properties of monitors in Java

In the lecture:

Explain

- objects being monitors;
- mutual exclusion for each object individually;
- synchronized methods are entry procedures;
- mutual exclusion only between calls of synchronized methods;

Questions:

Give examples for monitor methods that need *not* be executed under mutual exclusion.

Monitors in Java: condition synchronization

All processes that are blocked by **`wait`** are held in a single set;
condition variables can not be declared (there is only an implicit one)

Operations for condition synchronization:
are to be called from inside **`synchronized`** methods:

- **`wait()`** **blocks** the executing process; releases the monitor object, and waits in the unique set of blocked processes of the object
- **`notifyAll()`** releases **all** processes that are blocked by **`wait`** for this object; they then compete for the monitor; the executing process continues in the monitor (signal-and-continue semantics).
- **`notify()`** releases **an arbitrary** one of the processes that are blocked by **`wait`** for this object; the executing process continues in the monitor (signal-and-continue semantics); **only usable if all processes wait for the same condition**.

Always call `wait` in loops, because with **signal-and-continue** semantics
after **`notify`, `notifyAll`** the **waiting condition may be changed:**

```
while (!Condition) try { wait(); } catch (InterruptedException e) {}
```


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Objectives:

Understand condition synchronization in Java

In the lecture:

Explain

- meaning of `wait`, `notifyAll`; and `notify`;
- more than one waiting condition;
- when to use `notify` or `notifyAll`;
- consequences of signal-and-continue semantics.

Questions:

- Construct a situation where a condition *C* holds before a call of `notifyAll`, but does not hold after the wait operation that is executed in the released process. Use interleaved execution to demonstrate the effects.

A Monitor class for bounded buffers

```
class Buffer
{  private Queue buf;                 // Queue of length n to store the elements
   public Buffer (int n) {buf = new Queue(n); }

   synchronized public void put (Object elem)
   {                                  // a producer process tries to store an element
      while (buf.isFull())            // waits while the buffer is full
         try {wait();} catch (InterruptedException e) {}
      buf.enqueue (elem);     // changes the waiting condition of the get method
      notifyAll();            // every blocked process checks its waiting condition
   }
   synchronized public Object get ()
   {                                  // a consumer process tries to take an element
      while (buf.isEmpty())           // waits while the buffer is empty
         try {wait();} catch (InterruptedException e) {}
      Object elem = buf.first();
      buf.dequeue();          // changes the waiting condition of the put method
      notifyAll();            // every blocked process checks its waiting condition
      return elem;
   }
}
```


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Objectives:

Example for a monitor class in Java

In the lecture:

Explain

- changes of the waiting condition;
- why using `notifyAll`;
- the state transitions of `notifyAll` in the `get`-Operation;

Questions:

- In which states can a buffer be with respect to the two waiting conditions?
- What can one conclude if several processes are waiting?
- Explain in detail what happens if `notifyAll()` is executed when several processes are waiting.

Concurrency Utilities in Java 2

The **Java 2 platform** includes a package of *concurrency utilities*. These are classes which are designed to be used as building blocks in building concurrent classes or applications. ...

...

Locks - While locking is built into the Java language via the synchronized keyword, there are a number of **inconvenient limitations to built-in monitor locks**. The **`java.util.concurrent.locks`** package provides a high-performance lock implementation with **the same memory semantics as synchronization**, but which also supports specifying a timeout when attempting to acquire a lock, multiple condition variables per lock, non-lexically scoped locks, and support for interrupting threads which are waiting to acquire a lock.

http://java.sun.com/j2se/1.5.0/docs/guide/concurrency/index.html

http://java.sun.com/j2se/1.5.0/docs/api/java/util/concurrent/locks/Condition.html

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Objectives:

Recognize improvements in Java 2 Concurrency Package

In the lecture:

The topics on the slide are explained.

Concurrency Utilities in Java 2 (example)

```
class BoundedBuffer {
   final Lock lock = new ReentrantLock();                          explicit lock
   final Condition notFull  = lock.newCondition();            condition variables
   final Condition notEmpty = lock.newCondition();

   final Object[] items = new Object[100];
   int putptr, takeptr, count;

   public void put (Object x) throws InterruptedException {
      lock.lock();                                       explicit mutual exclusion
      try {  while (count == items.length) notFull.await();          specific wait
             items[putptr] = x;
             if (++putptr == items.length) putptr = 0;
             ++count;
             notEmpty.signal();                                    specific signal
      } finally { lock.unlock();}                        explicit mutual exclusion
   }

   public Object get () throws InterruptedException {
      lock.lock();                                       explicit mutual exclusion
      try {  while (count == 0) notEmpty.await();                   specific wait
             Object x = items[takeptr];
             if (++takeptr == items.length) takeptr = 0;
             --count;
             notFull.signal();                                     specific signal
             return x;
      } finally { lock.unlock();}                        explicit mutual exclusion
   }
}
```


Lecture Parallel Programming WS 2014/2015 / Slide 25k

Objectives:

Recognize improvements in Java 2 Concurrency Package

In the lecture:

The topics on the slide are explained.

3. Systematic Development of monitors
Monitor invariant

A **monitor invariant (MI)** specifies **acceptable states of a monitor**

MI has to be true whenever a process may leave or (re-)enter the monitor:

- after the **initialization**,
- at the **beginning** and at the **end of each entry procedure**,
- before and after each call of **wait**,
- before and after each call of **signal** with **signal-and-wait** semantics (*),
- before each call of **signal** with **signal-and-exit** semantics (*).

Example of a monitor invariant for the bounded buffer:
MI: 0 <= buf.length() <= n

The **monitor invariant has to be proven** for the program positions
after the initialization, at the end of entry procedures, before calls of wait (and signal if (*)).

One can **assume that the monitor invariant holds** at the other positions
at the beginning of entry procedures, after calls of wait (and signal if (*)).

Lecture Parallel Programming WS 2014/2015 / Slide 26

Objectives:
Understand monitor invariants

In the lecture:
Explain

- An invariant is a property to be guaranteed.
- MI for the example.

Suggested reading:
Andrews: 6.1, 6.2

Questions:

- Why can MI be assumed at the begin of entry procedures and after calls of wait?

Design steps using monitor invariant

1. Define the **monitor state,** and design the **entry procedures without synchronization**
   e. g. bounded buffer: element count; entry procedures put and get
2. Specify a **monitor invariant**
   e. g.: **MI**: **`0 <= length(buf) <= N`**
3. Insert **conditional waits**:
   Consider every operation that may violate **MI**, e. g. **`enqueue(buf)`**;
   find a condition **Cond** such that the operation may be executed safely if **Cond && MI** holds,
   e. g. **`{ length(buf)<N && MI } enqueue(buf);`**
   define one condition variable **c** for each condition Cond
   insert a conditional wait in front of the operation:
   `do !(length(buf)<N) -> wait(c); od`
   Loop is necessary in case of signal-and-continue or the may in step 4!
4. **Insert notification of processes:**
   after every state change that may make a waiting condition **Cond** true insert
   `signal(c)` for the condition variable **c** of Cond
   e. g. **`dequeue(buf); signal (c);`**
   Too many signal calls do not influence correctness - they only cause inefficiency.
5. **Eliminate unnecessary calls of `signal`** (see PPJ-28)
   Caution: Missing signal calls may cause deadlocks!
   Caution: signal-and-continue semantics lacks control of state changes

Lecture Parallel Programming WS 2014/2015 / Slide 27

Objectives:
Learn a design method

In the lecture:
Explain the single steps using the buffer example.

Questions:

- Explain step (5).

Bounded buffers
Derivation step 1: monitor state and entry procedures

```
monitor Buffer
   buf: Queue;                               // state: buf, length(buf)

   init buf = new Queue(n); end
   entry put (d: Data)             // a producer process tries to store an element


      enqueue (buf, d);

   end;
   entry get (var d: Data)         // a consumer process tries to take an element


      d := front(buf);
      dequeue(buf);

   end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 27a

Objectives:

Stepwise monitor design

In the lecture:

Explain step 1 for the buffer example

Bounded buffers
Derivation step 2: monitor invariant MI

```
monitor Buffer
   buf: Queue;                               // state: buf, length(buf)

   init buf = new Queue(n); end                   // MI: 0 <= length(buf) <= N
   entry put (d: Data)             // a producer process tries to store an element


      enqueue (buf, d);

   end;
   entry get (var d: Data)         // a consumer process tries to take an element


      d := front(buf);
      dequeue(buf);

   end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 27b

Objectives:

Stepwise monitor design

In the lecture:

Explain step 2 for the buffer example

PPJ-27c

Bounded buffers
Derivation step 3: insert conditional waits

```
monitor Buffer
   buf: Queue;                          // state: buf, length(buf)
   notFull, notEmpty: Condition;
   init buf = new Queue(n); end         // MI: 0 <= length(buf) <= N
   entry put (d: Data)          // a producer process tries to store an element

      /* length(buf) < N && MI */
      enqueue (buf, d);

   end;
   entry get (var d: Data)      // a consumer process tries to take an element

      /* length(buf) > 0 && MI */
      d := front(buf);
      dequeue(buf);

   end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 27c

Objectives:

Stepwise monitor design

In the lecture:

Explain step 3 for the buffer example.
Loop is needed for signal-and-continue and harmless for other semantics.

PPJ-27ca

Bounded buffers
Derivation step 3: insert conditional waits

```
monitor Buffer
   buf: Queue;                          // state: buf, length(buf)
   notFull, notEmpty: Condition;
   init buf = new Queue(n); end         // MI: 0 <= length(buf) <= N
   entry put (d: Data)          // a producer process tries to store an element
      do length(buf) >= N -> wait(notFull); od;
      /* length(buf) < N && MI */
      enqueue (buf, d);

   end;
   entry get (var d: Data)      // a consumer process tries to take an element
      do length(buf) <= 0 -> wait(notEmpty); od;
      /* length(buf) > 0 && MI */
      d := front(buf);
      dequeue(buf);

   end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 27ca

Objectives:

Stepwise monitor design

In the lecture:

Explain step 3 for the buffer example.
Loop is needed for signal-and-continue and harmless for other semantics.

Bounded buffers
Derivation step 4: insert notifications

```
monitor Buffer
   buf: Queue;                              // state: buf, length(buf)
   notFull, notEmpty: Condition;
   init buf = new Queue(n); end             // MI: 0 <= length(buf) <= N
   entry put (d: Data)          // a producer process tries to store an element
      do length(buf) >= N -> wait(notFull); od;
      /* length(buf) < N && MI */
      enqueue (buf, d);
      /* length(buf)>0 */
   end;
   entry get (var d: Data)      // a consumer process tries to take an element
      do length(buf) <= 0 -> wait(notEmpty); od;
      /* length(buf) > 0 && MI */
      d := front(buf);
      dequeue(buf);
      /* length(buf)<N */
   end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 27d

Objectives:

Stepwise monitor design

In the lecture:

Explain step 4 for the buffer example.
Here the signal-calls are inserted at positions where the release-condition is guaranteed to hold - not only may hold. (So the loops around wait are in this case only needed if we have signal-and-continue semantics.)

Bounded buffers
Derivation step 4: insert notifications

```
monitor Buffer
   buf: Queue;                              // state: buf, length(buf)
   notFull, notEmpty: Condition;
   init buf = new Queue(n); end             // MI: 0 <= length(buf) <= N
   entry put (d: Data)          // a producer process tries to store an element
      do length(buf) >= N -> wait(notFull); od;
      /* length(buf) < N && MI */
      enqueue (buf, d);
      /* length(buf)>0 */ signal(notEmpty);
   end;
   entry get (var d: Data)      // a consumer process tries to take an element
      do length(buf) <= 0 -> wait(notEmpty); od;
      /* length(buf) > 0 && MI */
      d := front(buf);
      dequeue(buf);
      /* length(buf)<N */ signal(notFull);
   end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 27da

Objectives:

Stepwise monitor design

In the lecture:

Explain step 4 for the buffer example.
Here the signal-calls are inserted at positions where the release-condition is guaranteed to hold - not only may hold. (So the loops around wait are in this case only needed if we have signal-and-continue semantics.)

Bounded buffers
Derivation step 5: eliminate unnecessary notifications

```
monitor Buffer
   buf: Queue;                              // state: buf, length(buf)
   notFull, notEmpty: Condition;
   init buf = new Queue(n); end             // MI: 0 <= length(buf) <= N
   entry put (d: Data)            // a producer process tries to store an element
      do length(buf) >= N -> wait(notFull); od;
      /* length(buf) < N && MI */
      enqueue (buf, d);
      if (length(buf) == 1) signal(notEmpty);              // see PPJ-28
                                     // not correct under signal-and-continue
   end;
   entry get (var d: Data)        // a consumer process tries to take an element
      do length(buf) <= 0 -> wait(notEmpty); od;
      /* length(buf) > 0 && MI */
      d := front(buf);
      dequeue(buf);
      if length(buf) == (N-1) -> signal(notFull);          // see PPJ-28
                                     // not correct under signal-and-continue
   end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 27e

Objectives:

Stepwise monitor design

In the lecture:

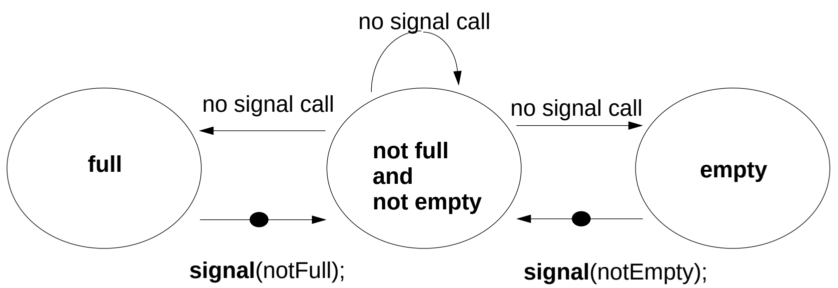
Explain step 5 for the buffer example

Relevant state changes

Processes need only be awakened when the state change is relevant:
when the waiting condition Cond changes from false to true,
i.e. when a waiting process can be released.

These arguments do **not** apply for **signal-and-continue** semantics; there **Cond** may be changed between the signal call and the resume of the released process.

E. g. for the bounded buffer states w.r.t signalling are considered:



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Objectives:

Improve efficiency

In the lecture:

Explain

- state variables and waiting conditions;
- deadlock problem.

Suggested reading:

Lea: 4.3.2

Questions:

- What happens with processes that are awakened unnecessarily?

Pattern: Allocating counted resources

A **monitor** grants access to a set of k ≥ 1 resources of the **same kind**.
Processes request n resources, 1≤ n ≤ k, and return them after having used them.
Examples:
Lending bikes in groups (n ≥ 1), allocating blocks of storage (n ≥ 1),
Taxicab provider (n=1), drive with a weight of n ≥ 1 tons on a bridge

Monitor invariant	**requestRes(1)**	**returnRes(1)**
0 ≤ avail don't give a non-ex. resource	if/do (!(1≤avail)) wait(av); avail--;	avail++; /* no wait! */ signal(av);
stronger invariant:		

0 ≤ avail && 0 ≤ inUse
... and don't take back more than have been given
	if/do (!(1≤avail)) wait(av);
	avail--; inUse++;
	signal(iu);
		if/do (!(1≤inUse)) wait(iu);
		avail++; inUse--;
		signal(av);

Monitor invariant	**requestRes(n)**	**returnRes(n)**
0 ≤ avail don't give a non-ex. resource	do (!(n≤avail)) wait(av[n]); avail = avail - n;	avail = avail + n; /* no wait! */ signal(av[1]); ... signal(av[avail]);

The **identity** of the resources may be relevant: use a boolean array avail[1] ... avail[k]

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Objectives:
Allocation of equal resources

In the lecture:
Explain
- the task,
- the monitor invariant and the waiting conditions,
- variants of the pattern.

Questions:
- Elaborate the examples.
- Describe further examples.

Monitor for resource allocation

A **monitor** grants access to a set of k >= 1 resources of the **same kind**.
Processes request n resources, 1<=n<=k, and return them after having used them.

Assumption: Process does not return more than it has received => simpler invariant:

```
class Resources
{  private int avail;                                  // invariant: avail >= 0

   public Resources (int k) { avail = k; }

   synchronized public void getElems (int n)           // request n elements
   {  while (avail<n)                                  // negated waiting condition
        try { wait(); } catch (InterruptedException e) {}
      avail -= n;
   }

   synchronized public void putElems (int n)           // return n elements
   {  avail += n;                   // waiting is not needed because of assumption
      notifyAll();                                     // notify() would be wrong!
   }
}
```


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Objectives:
Java monitor for resource allocation

In the lecture:
Explain
- the program structure,
- the consequence of the assumption.

Questions:
- Why do we need `notifyAll()`?

Processes and main program for resource monitor

```
import java.util.Random;

class Client extends Thread
{  private Resources mon; private Random rand;
   private int ident, rounds, maximum;

   public Client (Resources m, int id, int rd, int max)
   {  mon = m; ident = id; rounds = rd; maximum = max;
      rand = new Random();            // a number generator determines how many
   }                                  // elements are requested in each round,

   public void run ()                 // and when they are returned
   {  while (rounds > 0)
      {  int m = Math.abs(rand.nextInt()) % maximum + 1;
         mon.getElems (m);
         try { sleep (Math.abs(rand.nextInt()) % 1000 + 1); }
            catch (InterruptedException e) {}
         mon.putElems (m);
         rounds--;
      }
   }
}
```

```
public class TestResource
{ public static void main (String[] args)
  { int avail = 20;
    Resources mon = new Resources (avail);
    for (int i=0; i<5; i++)
      new Client (mon, i, 4, avail).start();
  }
}
```


Lecture Parallel Programming WS 2014/2015 / Slide 31

Objectives:

Use the monitor class of PPJ-30

In the lecture:

Explain the classes

Assignments:

Implement the program, add control output, and test it.

Readers-Writers problem (Step 1)

A monitor grants reading and writing access to a data base:
readers shared, **writers exclusive**.

```
monitor ReadersWriters
   nr: int;   // number readers
   nw: int;   // number writers
init nr=0; nw=0; end

entry requestRead()



   nr++;

end;

entry releaseRead()
   nr--;



end;
```

```
entry requestWrite()



   nw++;

end;

entry releaseWrite()
   nw--;



end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 32a

Objectives:

Understand synchronization of readers and writers

In the lecture:

Explain

- important class of synchronization: shared reading and exclusive writing,
- the readers / writers problem,
- the monitor invariant,
- the design steps,
- different overlapping waiting conditions,
- consequences: several signals in releaseWrite.

Assignments:

- Implement the monitor.
- Implement processes for readers and writers. Delay the processes using `sleep` with random numbers as parameters. Produce output using the observer module.
- To avoid starvation of writers apply the following strategy: New readers have to wait until no writer is waiting. Introduce a new counter for that purpose. What do you observe?

Questions:

The following problem is similar - but symmetric: Control bi-directional traffic over a bridge that has only one lane. Explain the design!

Readers-Writers problem (Step 2)

A monitor grants reading and writing access to a data base:
readers shared, **writers exclusive**.

Monitor invariant RW:

(nr == 0 || nw == 0) && nw <= 1

```
monitor ReadersWriters
   nr: int;   // number readers
   nw: int;   // number writers
init nr=0; nw=0; end

entry requestRead()




   nr++;

end;

entry releaseRead()
   nr--;




end;
```

```
entry requestWrite()




   nw++;

end;

entry releaseWrite()
   nw--;




end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 32b

Objectives:

Understand synchronization of readers and writers

In the lecture:

Explain

- important class of synchronization: shared reading and exclusive writing,
- the readers / writers problem,
- the monitor invariant,
- the design steps,
- different overlapping waiting conditions,
- consequences: several signals in releaseWrite.

Assignments:

- Implement the monitor.
- Implement processes for readers and writers. Delay the processes using `sleep` with random numbers as parameters. Produce output using the observer module.
- To avoid starvation of writers apply the following strategy: New readers have to wait until no writer is waiting. Introduce a new counter for that purpose. What do you observe?

Questions:

The following problem is similar - but symmetric: Control bi-directional traffic over a bridge that has only one lane. Explain the design!

Readers-Writers problem (Step3)

A monitor grants reading and writing access to a data base:
readers shared, **writers exclusive**.

Monitor invariant RW:

(nr == 0 || nw == 0) && nw <= 1

```
monitor ReadersWriters
   nr: int;   // number readers
   nw: int;   // number writers
init nr=0; nw=0; end

entry requestRead()
   do !(nw==0)
      -> wait(okToRead);
   od;
   { nw==0 && RW }
   nr++;
   { RW }
end;

entry releaseRead()
   { RW && nr>0} nr--;



end;
```

```
entry requestWrite()
   do !(nr==0 && nw<1)
      -> wait(okToWrite);
   od;
   { nr==0 && nw<1 && RW }
   nw++;
   { RW }
end;

entry releaseWrite()
   { RW && nw==1} nw--;



end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 32c

Objectives:

Understand synchronization of readers and writers

In the lecture:

Explain

- important class of synchronization: shared reading and exclusive writing,
- the readers / writers problem,
- the monitor invariant,
- the design steps,
- different overlapping waiting conditions,
- consequences: several signals in releaseWrite.

Assignments:

- Implement the monitor.
- Implement processes for readers and writers. Delay the processes using `sleep` with random numbers as parameters. Produce output using the observer module.
- To avoid starvation of writers apply the following strategy: New readers have to wait until no writer is waiting. Introduce a new counter for that purpose. What do you observe?

Questions:

The following problem is similar - but symmetric: Control bi-directional traffic over a bridge that has only one lane. Explain the design!

PPJ-32d

Readers-Writers problem (Step 4)

A monitor grants reading and writing access to a data base:
readers shared, **writers exclusive**.

Monitor invariant RW:

(nr == 0 || nw == 0) && nw <= 1

```
monitor ReadersWriters
   nr: int;   // number readers
   nw: int;   // number writers
init nr=0; nw=0; end

entry requestRead()
   do !(nw==0)
      -> wait(okToRead);
   od;
   { nw==0 && RW }
   nr++;
   { RW }
end;

entry releaseRead()
   { RW && nr>0} nr--;
   { RW && nr>=0}
   { may be nr==0}

   signal(okToWrite);
end;

entry requestWrite()
   do !(nr==0 && nw<1)
      -> wait(okToWrite);
   od;
   { nr==0 && nw<1 && RW }
   nw++;
   { RW }
end;

entry releaseWrite()
   { RW && nw==1} nw--;
   { nr==0 && nw==0}
   signal(okToWrite);
   signal_all(okToRead);
end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 32d

Objectives:

Understand synchronization of readers and writers

In the lecture:

Explain

- important class of synchronization: shared reading and exclusive writing,
- the readers / writers problem,
- the monitor invariant,
- the design steps,
- different overlapping waiting conditions,
- consequences: several signals in releaseWrite.

Assignments:

- Implement the monitor.
- Implement processes for readers and writers. Delay the processes using `sleep` with random numbers as parameters. Produce output using the observer module.
- To avoid starvation of writers apply the following strategy: New readers have to wait until no writer is waiting. Introduce a new counter for that purpose. What do you observe?

Questions:

The following problem is similar - but symmetric: Control bi-directional traffic over a bridge that has only one lane. Explain the design!

PPJ-32e

Readers-Writers problem (Step 5)

A monitor grants reading and writing access to a data base:
readers shared, **writers exclusive**.

Monitor invariant RW:

(nr == 0 || nw == 0) && nw <= 1

```
monitor ReadersWriters
   nr: int;   // number readers
   nw: int;   // number writers
init nr=0; nw=0; end

entry requestRead()
   do !(nw==0)
      -> wait(okToRead);
   od;
   { nw==0 && RW }
   nr++;
   { RW }
end;

entry releaseRead()
   { RW && nr>0} nr--;
   { RW && nr>=0}
   { may be nr==0}
   if nr==0
   -> signal(okToWrite);
end;

entry requestWrite()
   do !(nr==0 && nw<1)
      -> wait(okToWrite);
   od;
   { nr==0 && nw<1 && RW }
   nw++;
   { RW }
end;

entry releaseWrite()
   { RW && nw==1} nw--;
   { nr==0 && nw==0}
   signal(okToWrite);
   signal_all(okToRead);
end;
end;
```


Lecture Parallel Programming WS 2014/2015 / Slide 32e

Objectives:

Understand synchronization of readers and writers

In the lecture:

Explain

- important class of synchronization: shared reading and exclusive writing,
- the readers / writers problem,
- the monitor invariant,
- the design steps,
- different overlapping waiting conditions,
- consequences: several signals in releaseWrite.

Assignments:

- Implement the monitor.
- Implement processes for readers and writers. Delay the processes using `sleep` with random numbers as parameters. Produce output using the observer module.
- To avoid starvation of writers apply the following strategy: New readers have to wait until no writer is waiting. Introduce a new counter for that purpose. What do you observe?

Questions:

The following problem is similar - but symmetric: Control bi-directional traffic over a bridge that has only one lane. Explain the design!

Readers/writers monitor in Java

```
class ReaderWriter
{  private int nr = 0, nw = 0;
                  // monitor invariant RW: (nr == 0 || nw == 0) && nw <= 1
   synchronized public void requestRead ()
   {  while (nw > 0)                          // negated waiting condition
         try { wait(); } catch (InterruptedException e) {}
      nr++;
   }
   synchronized public void releaseRead ()
   {  nr--;
      if (nr == 0) notify ();                 // awaken one writer is sufficient
   }

   synchronized public void requestWrite ()
   {  while (nr > 0 || nw > 0)                // negated waiting condition
         try { wait(); } catch (InterruptedException e) {}
      nw++;
   }
   synchronized public void releaseWrite ()
   {  nw--;
      notifyAll ();          // notify 1 writer and all readers would be sufficient!
   }
}
```


Lecture Parallel Programming WS 2014/2015 / Slide 33

Objectives:

Readers / writers monitor in Java

In the lecture:

Explain the methods.

Assignments:

Use the monitor in a complete program as described for PPJ-32.

Questions:

- How would you program the monitor if you could use condition variables? Write it in the notation of slide PPJ-20.

Method: rendezvous of processes

Processes pass through a **sequence of states** and **interact** with each other.
A monitor coordinates the **rendezvous in the required order**.

Design method:

Specify states by counters;
characterize **allowed states by invariants** over counters;
derive waiting conditions of monitor operations from the invariants;
substitute counters by binary variables.

Example: Sleeping Barber:

In a sleepy village close to Paderborn a barber is sleeping while waiting for customers to enter his shop. When a customer arrives and finds the barber sleeping, he awakens him, sits in the barber‘s chair, and sleeps while he gets his hair cut. If the barber is busy when a customer arrives, the customer sleeps in one of the other chairs. After finishing the haircut, the barber gets paid, lets the customer exit, and awakens a waiting customer, if any.

2 kinds of processes: barber (1 instance), customer (many instances)

2 rendezvous: haircut and customer leaves

The task is also an example for the Client/Server pattern.

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Objectives:

Overview over the method.

In the lecture:

Explain the steps of the method and the example.

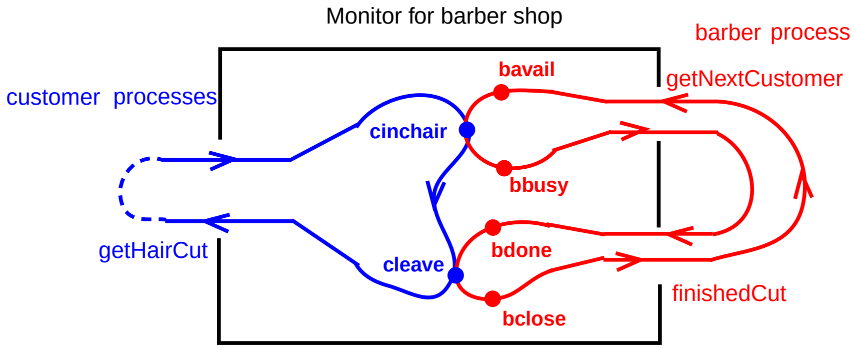
Assignments:

Solve the task "Roller Coaster (Achterbahn)" correspondingly.

Questions:

- Describe similar tasks.

Monitor design for the Sleeping Barber problem (step 1)



Counters represent states, incremented in entry procedures:

entry proc getHairCut:

cinchair++;
cleave++;

entry proc getNextCustomer:

bavail++;
bbusy++;

entry proc finishedCut:

bdone++;
bclose++;

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Objectives:

Characterize rendezvous by counters

In the lecture:

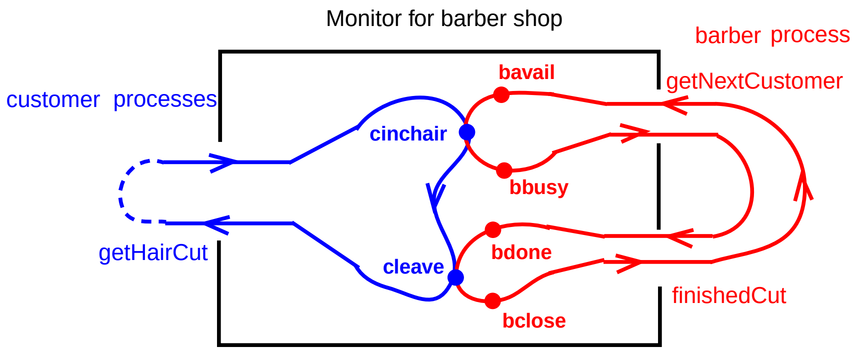
Explain

- the role of the counters,

Questions:

- How are the values of the counters related?

Monitor invariant for the Sleeping Barber problem (step 2)



Invariants over counters:

C1: cinchair >= cleave and
bavail >= bbusy >= bdone >= bclose

C2: bavail >= cinchair >= bbusy

C3: bdone >= cleave >= bclose

Monitor invariant: BARBER: C1 and C2 and C3

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Objectives:

Monitor invariant over counters

In the lecture:

Explain

- the meaning of the inequalities

Questions:

- What must the processes do to guarantee *C2*?
- What must the processes do to guarantee *C1*?

Waiting conditions for the Sleeping Barber problem (step 3)

Monitor invariant: BARBER: C1 and C2 and C3:

C1: cinchair >= cleave and
bavail >= bbusy >= bdone >= bclose — guaranteed by execution order

C2: bavail >= cinchair >= bbusy — leads to 2 waiting conditions

C3: bdone >= cleave >= bclose — leads to 2 waiting conditions

entry proc getHairCut:

do not (bavail > cinchair) -> wait (b); done;
cinchair++;

do not (bdone > cleave) -> wait (o); done;
cleave++;

entry proc getNextCustomer:

bavail++;

do not (cinchair > bbusy) -> wait (c); done;
bbusy++;

entry proc finishedCut:

bdone++;

do not (cleave > bclose) -> wait (e); done;
bclose++;

Lecture Parallel Programming WS 2014/2015 / Slide 36

Objectives:

First phase of monitor design

In the lecture:

- Explain the waiting conditions.

Questions:

- Why need some incrementations a waiting condition, and others don't?

Substitute counters (step 3a)

new binary variables:
- barber = bavail - cinchair
- chair = cinchair - bbusy
- open = bdone - cleave
- exit = cleave - bclose

value ranges: {0, 1}

Old invariants:
- C2: bavail >= cinchair >= bbusy
- C3: bdone >= cleave >= bclose

New invariants:
- C2: barber >= 0 && chair >= 0
- C3: open >= 0 && exit >= 0

increment operations and conditions are substituted:

entry proc getHairCut:

do not (barber > 0) -> wait (b); done;
barber--; chair++;

do not (open > 0) -> wait (o); done;
open--; exit++;

entry proc getNextCustomer:

barber++;

do not (chair > 0) -> wait (c); done;
chair--;

entry proc finishedCut:

open++;

do not (exit > 0) -> wait (e); done;
exit--;

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Objectives:

Understand substitution of variables

In the lecture:

- Show substitution in comparison to PPJ-36.
- All state variables have the value range {0, 1}.

Questions:

- Explain how the general condition variables are used.

Signal operations for the Sleeping Barber problem (step 4)

new binary variables:

barber = bavail - cinchair
chair = cinchair - bbusy
open = bdone - cleave
exit = cleave - bclose

value ranges: {0, 1}

Old invariants:

C2: bavail >= cinchair >= bbusy
C3: bdone >= cleave >= bclose

New invariants:

C2: barber >= 0 && chair >= 0
C3: open >= 0 && exit >= 0

insert call signal (x) call where a condition of x may become true:

entry proc getHairCut:

```
do not (barber > 0) -> wait (b); done;
barber--; chair++; signal (c);

do not (open > 0) -> wait (o); done;
open--; exit++; signal (e);
```

entry proc getNextCustomer:

```
barber++; signal (b);

do not (chair > 0) -> wait (c); done;
chair--;
```

entry proc finishedCut:

```
open++; signal (o);

do not (exit > 0) -> wait (e); done;
exit--;
```


Lecture Parallel Programming WS 2014/2015 / Slide 37a

Objectives:

Understand substitution of variables

In the lecture:

- Explain how to use general condition variables for the implementation of the monitor.

Assignments:

- Implement the monitor in Java according to this plan and test it.

Questions:

- Explain insertion of the awaken operations.