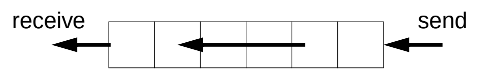
7. Asynchronous Message Passing

Processes send and receive messages via channels

Message: value of a composed data type or object of a class

Channel: **queue** of arbitrary length, containing messages



operations on a channel:

- **send (b)**: adds the message b to the end of the queue of the channel;
  does **not block** the executing process (in contrast to synchronous send)
- **receive()**: yields the oldest message and deletes it from the channel;
  blocks the executing process as long as the channel is empty.
- **empty()**: yields true, if the channel is empty; the result is **not necessarily up-to-date.**

send and **receive** are executed under mutual exclusion.

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Objectives:
Understand channels

In the lecture:
Explain:

- non-blocking send requires a channel;
- non-blocking send is the important difference between asynchronous and synchronous message passing;
- how to use results of empty();
- for tight synchronization of processes several channels are needed.

Questions:

- Why does a channel need a queue?
- Why may the result of empty() be not upto date?

Channels implemented in Java

```
public class Channel
{                            // implementation of a channel using a queue of messages
   private Queue msgQueue;

   public Channel ()
      { msgQueue = new Queue (); }

   public synchronized void send (Object msg)
      { msgQueue.enqueue (msg); notify(); }      // wake a receiving process

   public synchronized Object receive ()
      {  while (msgQueue.empty())
            try { wait(); } catch (InterruptedException e) {}
         Object result = msgQueue.front();          // the queue is not empty
         msgQueue.dequeue();
         return result;
      }

   public boolean empty ()
      { return msgQueue.empty (); }
}
```

All waiting processes wait for the same condition => notify() is sufficient.
After a notify-call a new receive-call may have stolen the only message => wait loop is needed

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Objectives:
Understand the channel implementation

In the lecture:

- explain the mutual exclusion;
- explain why the result of need not be up to date - even if Channel.empty would be synchronized;
- argue why notify() is sufficient, but a wait loop is needed.

Questions:

- Where do you know this synchronization pattern from?

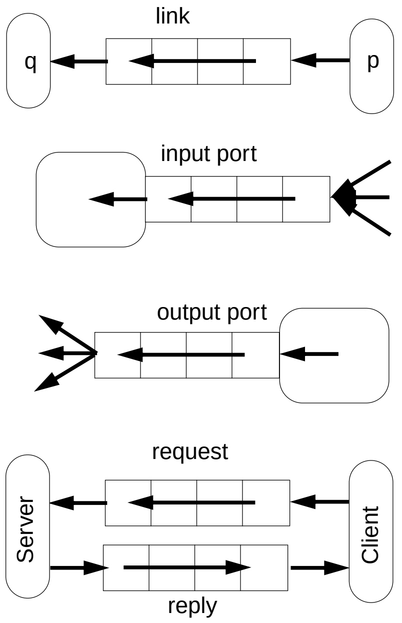
Processes and channels

link:
one **sender** is connected to **one receiver**;
e. g. processes form chains of transformation steps (pipeline)

input port of a process:
many senders - one receiver;
channel belongs to the receiving process;
e. g. a server process receives tasks from several client processes

output port of a process:
one sender - many receivers;
channel belongs to the sending process;
e. g. a process distributes tasks to many servers (unusual structure)

pair of **request and reply channels;**
one process requests - the others replies;
tight synchronization,
e. g. between client and server



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Objectives:
Identify channel structures

In the lecture:
Explain applications of the structures

Termination conditions

When system of processes terminates the following **conditions** must hold:

1. **All channels are empty.**
2. **No** processes are **blocked on a receive** operation.
3. **All** processes are **terminated**.

Otherwise the **system state is not well-defined**, e.g. task is not completed, some operations are pending.

Problem:
In general, the processes **do not know the global system state**.

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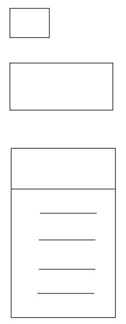
Objectives:
Final clean-up

In the lecture:
The conditions are explained.

Message structures

A **message object** may have arbitrary structure suitable for the **particular purpose**:



empty	**synchronization** only
kind	different **kinds** of messages, without data e. g. signal different kinds of events
kind argument vector	different kinds of messages with **data** e. g. number and or identities of resources special case: a channel on which the sender expects a reply

Operations on messages:
constructors

setKind (k), getKind ()

setArg (ind, val), getArg (ind), getArgList ()

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Objectives:

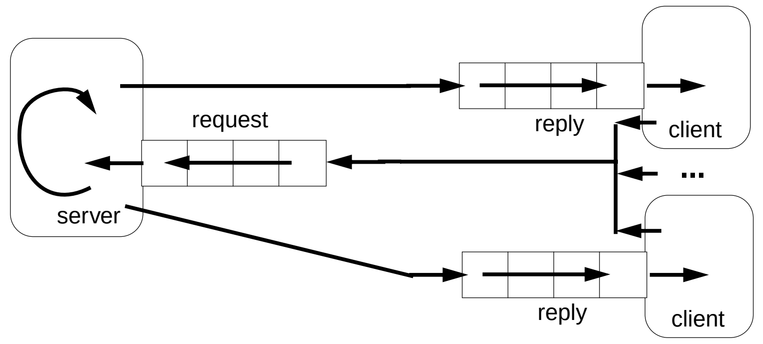
Message structures for different purposes

In the lecture:

Explain the use of different message structures

Client / server: basic channel structure

One **server process responds to requests of several client processes**



request channel:
input port of the server

reply channel:
one for each client (input port),
may be sent to the server included in the request message

Application: server distributes data or work packages on requests

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Objectives:

Understand the channel structure

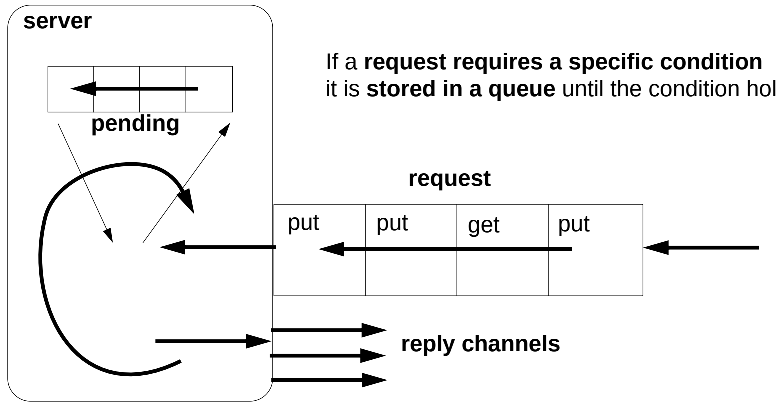
In the lecture:

Explain how

- the channels are used,
- channels are communicated,
- such a system is terminated: stop sending requests; let first the server and then the clients empty their channels.

Server processes: different kinds of operations

Different requests (operations) are represented by different **kinds of messages**.



If a **request requires a specific condition** it is **stored in a queue** until the condition holds.

The server processes the requests **strictly sequentially**;
thus, it is guaranteed that critical sections are **not executed interleaved**.

Termination: terminate clients, empty channel, empty queue.

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Objectives:

Understand the structure of a server process

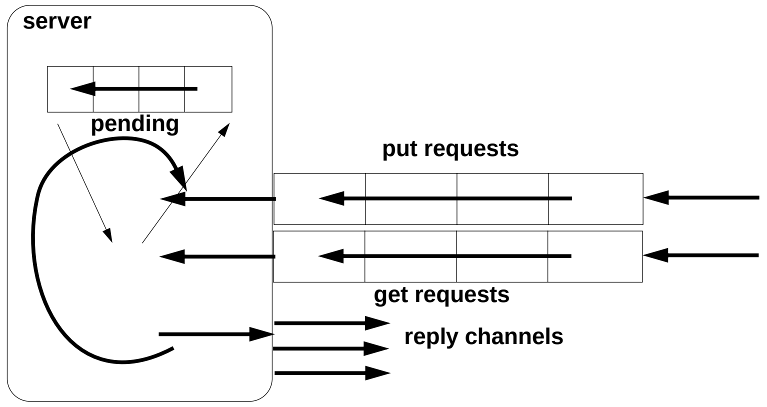
In the lecture:

- Explain the loop for execution of operations.
- Explain why requests are stored.
- Explain why operations are executed under mutual exclusion.

Questions:

- Design a server that implements a counting semaphore, which can be used to synchonize many processes.
- How can the monitors of PPJ-19 and following, be transformed into such a server?

Different kinds of operations on different channels



Server must not block on an empty input port while another port may be non-empty:

```
while (running) {
   if (!putPort.empty()) {  msg = putPort.receive(); ... }
   if (!getPort.empty()) {  msg = getPort.receive(); ... }
   if (!pending.empty()) {  msg = pending.dequeue(); ... }
}
```

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Objectives:

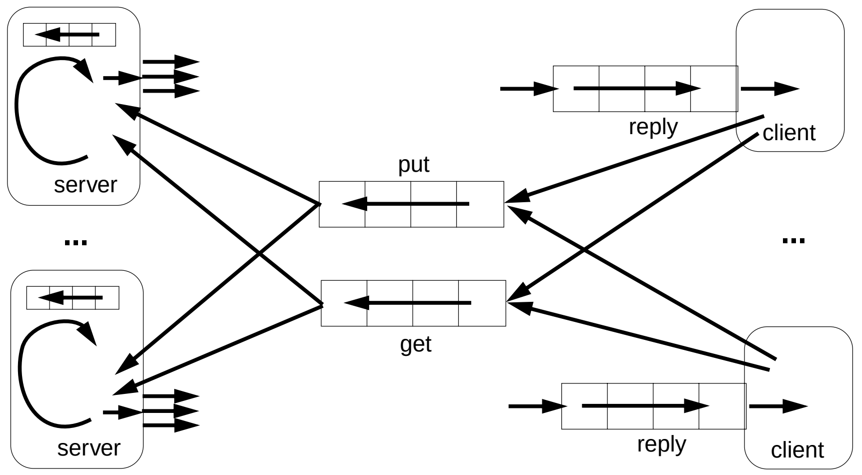
Compare to the one-channel structure

In the lecture:

Explain how channels are checked.

Several servers

Several server processes, several client processes**, several request channels**



Termination: empty request channels, empty queues, empty reply channels

Caution: a **receive** on a channel **may block** a server!

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Objectives:

Multi server structure

In the lecture:

- Parallelism is increased by several servers.
- Messages contain their reply channels.
- Explain termination.

Receive without blocking

If several processes receive from a channel **ch**, then the check

```
     if (!ch.empty()) msg = ch.receive();
```

may block.
That is not acceptable when several channels have to be checked in turn.
Hence, a new non-blocking channel method is introduced:

```
public class Channel
{  ...
   public synchronized Object receiveMsgOrNull ()
   {  if (msgQueue.empty()) return null;
      Object result = msgQueue.front();
      msgQueue.dequeue();
      return result;
}  }
```

Checking several channels:

```
while (msg == null)
{  if ((msg = ch1.receiveMsgOrNull()) == null)
   if ((msg = ch2.receiveMsgOrNull()) == null)
      Thread.sleep (500);
}
```

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Objectives:

Avoid receive on empty channel

In the lecture:

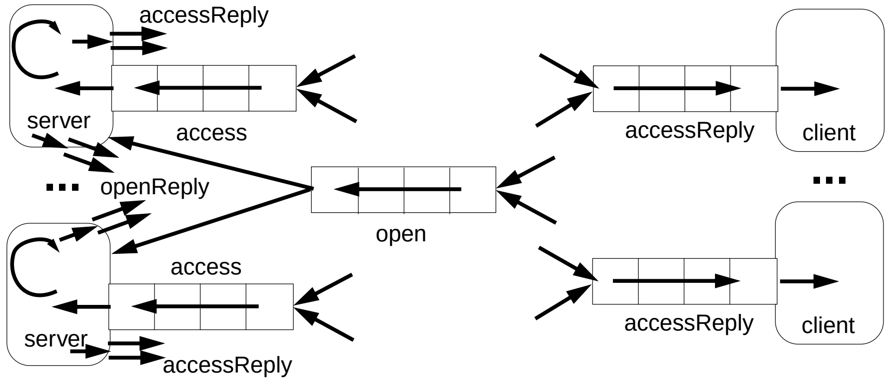
Explain:

- Multi servers check common channels.
- A false result of empty() may not be up to date when the receive() is executed.
- Hence, an atomic operation is needed.

Conversation sequences between client and server

Example for an **application pattern** is „file servers“:

- **several equivalent servers** respond to requests of **several clients**
- a client sends an **opening request** on a **channel common** for all servers (**open**)
- one server commits to the task; it then leads a conversation with the client according to a **specific protocol**, e. g.
  (open openReply) ((read readReply) | (write writeReply))* (close closeReply)
- **reply channels** are contained in the **open** and **openReply** messages.



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Objectives:

Typical client / server paradigm

In the lecture:

- Explain the channel structure.
- The server sends its reply channel to the client, too.
- Explain the central server loop.

Active monitor (server) vs. passive monitor

active monitor		passive monitor
active process	**1. program structure**	passive program module
request - reply via channels	**2. client communication**	calls of entry procedures
kinds of messages and/or different channels	**3. server operations**	entry procedures
requests are handled sequentially	**4. mutual exclusion**	guaranteed for entry procedure calls
queue of pending requests replies are delayed	**5. delayed service**	client processes are blocked condition variables, wait - signal
may cooperate on the same request channels	**6. multiple servers**	multiple monitors are not related

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Objectives:

Compare monitor structures

In the lecture:

Explain the differences