9. Synchronous message passing

Processes communicate and synchronize directly,
space is provided for **only one message** (instead of a channel).

Operations:

- **send (b):** **blocks** until the partner process is ready to receive the message
- **receive (v)**: blocks until the partner process is ready to send a message.

When both sender and receiver processes are ready for the communication,
the message is transferred, like an assignment v := b;

A send-receive-pair is both **data transfer and synchronization point**

Origin: Communicating Sequential Processes (CSP) [C.A.R. Hoare, CACM 21, 8, 1978]

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Objectives:

Notions of synchronous message passing

In the lecture:

- Explain the operations.
- Compare with asynchronous messages.

Questions:

- Compare the notions of synchronous and asynchronous messages.

Notations for synchronous message passing

Notation in CSP und Occam:

`p:   ...  q ! ex ...` **send** the value of the expression **ex** to process **q**

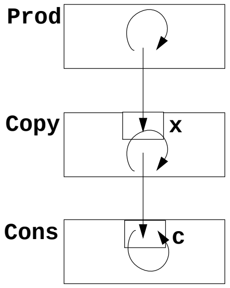
`q:   ...  p ? v  ...` **receive** a value from process **p** and assign it to variable **v**

multiple ports and **composed messages** may be used:

```
p:   ...  q ! Port1 (a1,..,an) ...

q:   ...  p ? Port1 (v1,..,vn) ...
```

Example: copy data from a producer to a consumer:

```
Prod:   var p: int;
        do true -> p :=...; Copy ! p od

Copy:   var x: int;
        do true -> Prod ? x; Cons ! x od

Cons:   var c: int;
        do true -> Copy ? c; ... od
```



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Objectives:

Notations of synchronous message passing

In the lecture:

- Explain the notations.
- Synchronization without a reply channel.
- Example: copy process.

Selective wait

Guarded command: (invented by E. W. Dijkstra)

a branch may be taken, if a **condition** is true and a **communication** is enabled (**guard**)

```
if Condition1; p ! x -> Statement1
[] Condition2; q ? y -> Statement2
[] Condition3; r ? z -> Statement3
fi
```

A communication statement in a guard yields

true, if the partner process is ready to communicate

false, if the partner process is terminated,

open otherwise (process is not ready, not terminated)

Execution of a guarded command depends on the guards:

- If **some guards are true**, one of them is chosen, the communication and the branch statement are executed.
- If **all guards are false** the guarded command is completed without executing anything.
- **Otherwise** the process is blocked until one of the above cases holds.

Notation of an **indexed selection**:

```
if (i: 1..n) Condition; p[i] ? v -> Statements fi
```

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Objectives:

Understand guards

In the lecture:

- Guarded commands are needed to check whether a message is available without blocking the process.
- Explain the 3 states of a guard.
- Conditions are evaluated only once.

Questions:

- Compare selective wait with the operations empty and receive-if-not-empty of asynchronous messages.

Guarded loops

A **guarded loop** repeats the execution of its guarded command **until all guards yield false:**

```
do
   Condition1; p ! x-> Statement1
[] Condition2; r ? z-> Statement2
od
```

Example: bounded buffer:

```
process Buffer
   do
      cnt < N; Prod ? buf[rear]  -> cnt++; rear := rear % N + 1;
   [] cnt > 0; Cons ! buf[front] -> cnt--; front := front % N + 1;
   od
end
```

```
process Prod
   var p:=0: int;
   do p<42; Buffer ! p -> p:=p+1;
   od
end
```

```
process Cons
   var c: int;
   do Buffer ? c -> print c;
   od
end
```

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Objectives:

Understand guarded loops

In the lecture:

Explain

- the example,
- mutual exclusion: process with synchronization points,
- condition synchronization: condition in a guard.

Prefix sums computed with synchronous messages

Synchronous communication provides both **transfer of data and synchronization.**

Necessary synchronization only (cf. synchronous barriers, PPJ-48)

```
const N := 6; var a [0:N-1] : int;

process Worker (i := 0 to N-1)                    a process for each element
   var d := 1, sum, new: int

   sum := a[i];

                        {Invariant SUM: sum = a[i-d+1] + ... + a[i]}
   do d < N-1 ->

      if (i+d) < N -> Worker(i+d) ! sum fi        shift old value to the right

      if (i-d) >= 0-> Worker(i-d) ? new; sum := sum + new fi
                                                  get new value from the left
      d := 2*d                                    double the distance
   od                                             {SUM and d >= N-1}
end
```

Why can deadlocks not occur?

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Objectives:

See an application of synchronous messages

In the lecture:

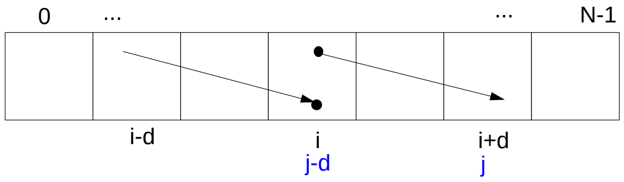
- Explain the communication graphically.
- Compare with asynchronous messages

Questions:

- Why are programs based on synchronous messages more compact and less redundant than those with aynchronous messages?

No deadlocks in synchronous prefix sums

sychronization pattern



- **! and ?** operations occur always **in pairs**:

  if i+d < N and i>=0 process i executes `Worker(i+d)!sum`
  let j = i+d, i.e. j-d = i >= 0, hence process j executes `Worker(j-d)?new`

- There is always a process that does **not send but receives**:

  Choose i such that i<N and i+d >= N, then process i only receives:
  Prove by induction.

- As **no process first receives and then sends**, there is **no deadlock**

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Objectives:

Deadlock proof for PPJ-91

In the lecture:

Explain

- why absence of deadlocks is crucial,
- the steps of the proof.

Client/Server scheme with synchronous messages

Technique:
for each **kind of operation** that the server offers, a communication via **2 ports**:

- `oprReq` for transfer of the parameters
- `oprRepl` for transfer of the reply

Scheme of the **client processes**:

```
process Client (I := 1 to N)
   ...
   Server ! oprReq (myArgs)
   Server ? oprRepl (myRes)
   ...
end
```

Scheme of the **server process**:

```
process Server ()
   ...
   do (c: 1..N) ConditionOpr1; Client[c] ? oprReq(oprArgs)
                      -> process the request ...
                         Client[c] ! oprRepl(oprResults)
   [] correspondingly for other operations ...
   od
end
```

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Objectives:

Understand the scheme

In the lecture:

Explain the communication structure

Questions:

- Describe a server for resource allocation in this scheme.

Synchronous Client/Server: variants and comparison

Synchronous servers have the
same characteristics as asynchronous servers,
i. e. active monitors (PPJ-70).

Variants of synchronous servers:

1. Extension to **multiple instances of servers**:
   use **guarded command loops** to check
   whether a communication is enabled
2. If an operation can **not be executed immediately**,
   it has to be delayed, and
   its arguments have to be stored in a pending queue
3. The **reply port can be omitted** if
   - there is no result returned, and
   - the request is never delayed
4. Special case: resource allocation with request and release.
5. **Conversation sequences** are executed in the part „process the request“.
   Conversation protocols are implemented by a
   sequence of send, receive, and guarded commands.

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Objectives:

Understand the variants

In the lecture:

Explain

- how pending requests are handled,
- when a channel can be omitted,
- how conversation sequences are handled,

Campare to active monitors.

Synchronous messages in Occam

Occam:

- concurrent programming language, based on **CSP**
- initially developed in 1983 at INMOS Ltd. as native language for **INMOS Transputer** systems
- a program is a nested structure of parallel processes (**PAR**), sequential code blocks (**SEQ**), guarded commands (**ALT**), synchronous send (**!**) and receive (**?**) operations, procedures, imperative statement forms;
- communication via **1:1 channels**
- fundamental data types, arrays, records
- extended 2006 to **Occam-pi**, University of Kent, GB
  pi-calculus (Milner et. al, 1999):
  formal process calculus where names of channels can be communicated via channels
  Kent Retargetable occam Compiler (**KRoC**)
  (open source)

```
CHAN OF INT chn:
PAR
   SEQ
      INT a:
      a := 42
      chn ! a

   SEQ
      INT b:
      chn ? b
      b := b + 1
```

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Objectives:

A brief introduction to Occam

In the lecture:

- Occam: CSP-based language, standard language of Inmos Transputers
- parallel processes are program constructs (PAR)
- ? and !: send and receive as in CSP
- ALT: guarded command; (! not allowed in a guard)
- channels are here 1:1-links between processes for synchronous message passing
- indexed processes: PAR i=1 FOR n ...
- very restricted data types
- program structure by indentation

Bounded Buffer in Occam

```
CHAN OF Data in, out:
   PAR
      SEQ -- process buffer
         Queue (k) buf:
         Data d:
         WHILE TRUE
            ALT
               in ? d & length(buf) < k
                  enqueue(buf, d)
               out ! front(buf) & length(buf) > 0
                     ! not allowed in a guard
                  dequeue(buf)
```

```
SEQ
   -- only one producer process
   Data d:
   WHILE TRUE
      SEQ
         d = produce ()
         in ! d
```

```
SEQ
   -- only one consumer process
   Data d:
   WHILE TRUE
      SEQ
         out ? d
         consume (d)
```

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Objectives:

Bounded buffer in Occam

In the lecture:

Explain

- program structure: 3 processes
- ALT: guarded command; (! not allowed in a guard)
- ? and !: send and receive as in CSP
- 2 channels between producer, consumer, and buffer

Synchronous rendezvous in Ada

Ada:

- **general purpose** programming language dedicated for **embedded systems**
- 1979: Jean Ichbiah at CII-Honeywell-Bull (Paris) wins a **competition** of language proposals initiated by the **US DoD**
- **Ada 83 reference manual**
- **Ada 95 ISO Standard**, including oo constructs
- **Ada 2005**, extensions
- **concurrency notions**: processes (`task`, `task type`), shared data, synchronous communication (**rendezvous**), entry operations pass data in both directions, guarded commands (`select`, `accept`)

```
task type Producer;

task body Producer is
    d: Data;
begin
    loop
        d := produce ();
        Buffer.Put (d);
    end loop;
end Producer;

task type Consumer;

task body Consumer is
    d: Data;
begin
    loop
        Buffer.Get (d);
        consume (d);
    end loop;
end Consumer;
```

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Objectives:

Brief introduction to Ada

In the lecture:

Explain

- Ada: general purpose language, in particular suitable for embedded systems
- processes are defined as tasks; task types for several processes of the same type
- communicate synchronously by rendezvous: bi-directional communication operation
- parameters may be passed in either direction (call-by-value-and-result)

Ada: Synchronous rendezvous

```
task type Buffer is      -- interface
    entry Put (d: in  Data); -- input port
    entry Get (d: out Data); --  output port
end Buffer;

task body Buffer is
    buf: Queue (k);
    d:   Data;
begin
    loop
        select         -- guarded command
            when length(buf) < k =>
                accept Put (d: in Data) do
                    enqueue(buf, d);
                end Put;
            or
            when length(buf) > 0 =>
                accept Get (d: out Data) do
                    d := front(buf);
                end Get;
                dequeue(buf);
        end select;
    end loop;
end Buffer;
```

```
task type Producer;

task body Producer is
    d: Data;
begin
    loop
        d := produce ();
        Buffer.Put (d);
    end loop;
end Producer;

task type Consumer;

task body Consumer is
    d: Data;
begin
    loop
        Buffer.Get (d);
        consume (d);
    end loop;
end Consumer;
```

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Objectives:

Bounded buffer using Ada rendezvous

In the lecture:

Explain

- task declares communication interface: entries
- entries are called by other tasks
- parameters may be passed in either direction (call-by-value-and-result)
- each entry has several accept-statements (communication operation) in the task body
- select is a guarded command
- one-sided anonymous: the task does not know who calls its entry