INF4140 - Models of concurrency

RPC and Rendezvous

INF4140

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RPC and Rendezvous

Outline

- More on asynchronous message passing
  - interacting processes with different patterns of communication
  - summary
- remote procedure calls
  - concept, syntax, and meaning
  - examples: time server, merge filters, exchanging values
- Rendez-vous
  - concept, syntax, and meaning
  - examples: buffer, time server, exchanging values
- combinations of RPC, rendezvous and message passing
  - Examples: bounded buffer, readers/writers

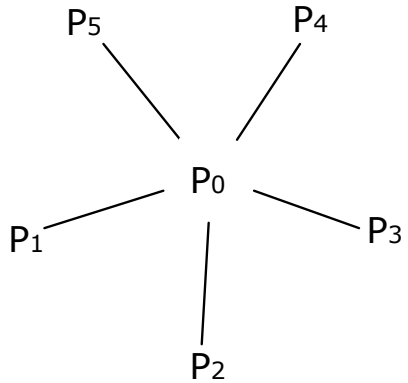
Interacting peers (processes): exchanging values example

Look at processes as peers.

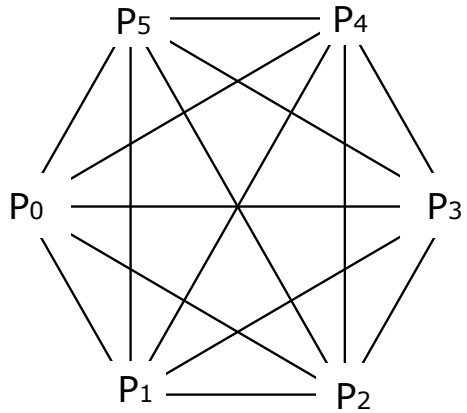
Example: Exchanging values

- Consider n processes P[0], ..., P[$n-1$], $n > 1$
- every process has a number, stored in local variable v
- Goal: all processes knows the largest and smallest number.
- simplistic problem, but "characteristic" of distributed computation and information distribution

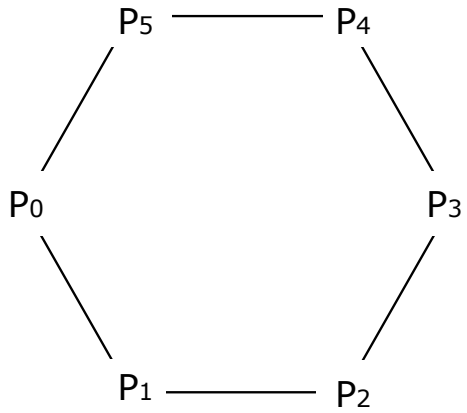
Different communication patters



centralized



symetrical

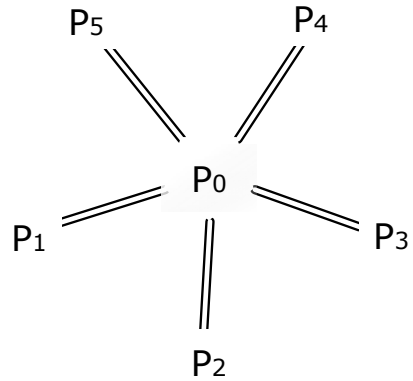


ring shaped

Centralized solution

Process P[0] is the coordinator process:

- P[0] does the calculation
- The other processes sends their values to P[0] and waits for a reply.



Number of *messages:*[1] (number of send:)

$$\begin{aligned} \text{P[0]}: &\quad n-1 \\ \text{P[1]}, \ldots, \text{P}[n-1]: &\quad (n-1) \end{aligned}$$

Total: $(n-1)+(n-1) = 2(n-1)$ messages

repeated "computation"

Number of *channels:* n

[1] For now in the pics: 1 line = 1 message (not 1 channel), but the notation in the pics is not 100% consistent.

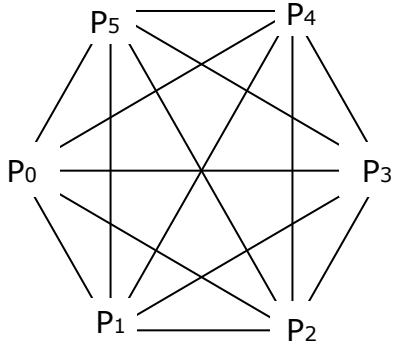
Centralized solution: code

```
chan values(int),
     results[1..n-1](int smallest, int largest);

process P[0] {  # coordinator process
  int v := ...;
  int new, smallest := v, largest := v; # initialization
  # get values and store the largest and smallest
  for [i = 1 to n-1] {
    receive values(new);
    if (new < smallest)      smallest := new;
    if (new > largest)       largest := new;
  }
  # send results
  for [i = 1 to n-1]
    send results[i](smallest, largest);
}
process P[i = 1 to n-1] {
  int v := ...;
  int smallest, largest;

  send values(v);
  receive results[i](smallest, largest);}
# Fig. 7.11 in Andrews (corrected a bug)
```

Symmetric solution



"Single-programme, multiple data (SPMD)"-solution:

Each process executes the same code
and shares the results with all other processes.

Number of messages:

n processes sending $n-1$ messages each,
Total: $n(n-1)$ messages.

Number of (bi-directional) channels: $n(n-1)$

Symmetric solution: code

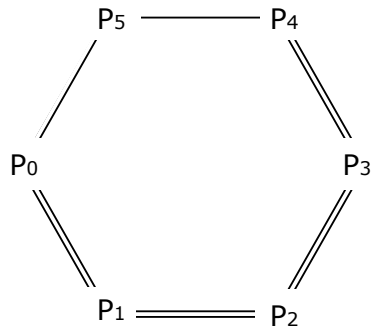
```
chan values[n](int);

process P[i = 0 to n-1] {
  int v := ...;
  int new, smallest := v, largest := v;

  # send v to all n-1 other processes
  for [j = 0 to n-1 st j ≠ i]
    send values[j](v);

  # get n-1 values
  # and store the smallest and largest.
  for [j = 1 to n-1] { # j not used in the loop
    receive values[i](new);
    if (new < smallest)     smallest := new;
    if (new > largest)      largest := new;
  }
} # Fig. 7.12 from Andrews
```

Ring solution



Almost symmetrical, except P[0], P[$n-2$] and P[$n-1$].

Each process executes the same code and sends the results to the *next* process (if necessary).

Number of messages:

P[0]:	2
P[1], ..., P[$n-3$]:	$(n-3)\times 2$
P[$n-2$]:	1
P[$n-1$]:	1

$2+2(n-3)+1+1=2(n-1)$ messages sent.

Number of channels: n .

Ring solution: code (1)

```
chan values[n](int smallest, int largest);

process P[0] { # starts the exchange
  int v := ...;
  int smallest := v, largest := v;
  # send v to the next process, P[1]
  send values[1](smallest, largest);
  # get the global smallest and largest from P[n-1]
  #    and send them to P[1]
  receive values[0](smallest, largest);
  send values[1](smallest, largest);
}
```

Ring solution: code (2)

```
process P[i = 1 to n-1] {
  int v := ...;
  int smallest, largest;
  # get smallest and largest so far,
  #    and update them by comparing them to v
  receive values[i](smallest, largest)
  if (v < smallest) smallest := v;
  if (v > largest)   largest := v;
  # forward the result, and wait for the global result
  send values[(i+1) mod n](smallest, largest);
  if (i < n-1)
    receive values[i](smallest, largest);
  # forward the global result, but not from P[n-1] to P[0]
  if (i < n-2)
    send values[i+1](smallest, largest);
} # Fig. 7.13 from Andrews (modified)
```

Message passing: Summary

Message passing: well suited to programming filters and interacting peers (where processes communicates one way by one or more channels).
May be used for client/server applications, but:

- Each client must have its own reply channel
- In general: two way communication needs two channels

$\Rightarrow$ many channels

RPC and rendezvous are better suited for client/server applications.

Remote Procedure Call: main idea

CALLER

```
at computer A


...
call foo(ARGS);          ----->

                         <-----
...
```

CALLEE

```
at computer B


op foo(FORMALS); # declaration


proc foo(FORMALS)  # new process
  ...
end;
```

RPC (cont.)

RPC: combines elements from monitors and message passing

- As ordinary procedure call, but caller and callee may be on different machines.[2]
- Caller: blocked until called procedure is done, as with monitor calls and synchronous message passing.
- Asynchronous programming: not supported directly
- A new process handles each call.
- Potentially two way communication: caller sends arguments and receives return values.

[2] cf. RMI

RPC: module, procedure, process

Module: new program component – contains both

- procedures and processes.

```
module M
   headers of exported operations;
body
   variable declarations;
   initialization code;
   procedures for exported operations;
   local procedures and processes;
end M
```

Modules may be executed on different machines

M has: *procedures* and *processes*

- may share variables
- execute concurrently $\Rightarrow$ *must be synchronized to achieve mutex*
- May only communicate with processes in M' by procedures exported by M'

RPC: operations

Declaration of operation O:

op O(*formal parameters*.) [returns *result*] ;

Implementation of operation O:

proc O(*formal identifiers*.) [returns *result identifier*]{
declaration of local variables;
statements
}

Call of operation O in module M:[3]

call M.O(*arguments*)

Processes: as before.

[3] Cf. static/class methods

Synchronization in modules

- RPC: primarily a *communication* mechanism
- within the module: in principle allowed:
  - more than one process
  - shared data

$\Rightarrow$ need for synchronization

- two approaches
  1. "implicit":
     - as in monitors: mutex built-in
     - additionally condition variables (or semaphores)
  2. "explicit":[4]
     - user-programmed mutex and synchronization (like semaphorse, local monitors etc)

[4] assumed in the following

Example: Time server (RPC)

- module providing timing services to processes in other modules.
- interface: two visible operations:
  - get_time() returns int – returns time of day
  - delay(int interval) – let the caller sleep a given number of time units
- multiple clients: may call get_time and delay at the same time

$\Rightarrow$ Need to protect the variables.

- internal process that gets interrupts from machine clock and updates tod

Time server code (rpc)

```
module TimeServer
  op get_time() returns int;
  op delay(int interval);
body
  int  tod := 0;          # time of day
  sem    m := 1;          # for mutex
  sem d[n] := ([n] 0);    # for delayed processes
  queue of (int waketime, int process_id) napQ;
  ## when m = 1, tod < waketime for delayed processes
  proc get_time() returns time { time := tod; }

  proc delay(int interval) {
    P(m);          # assume unique myid and i [0,n-1]
    int waketime := tod + interval;
      insert  (waketime, myid) at appropriate place in napQ;
    V(m);
    P(d[myid]);  # Wait to be awoken
  }
  process Clock ...

  :
  :
end TimeServer
```

Time server code: clock process

```
process Clock {
    int id; start hardware timer;
    while (true) {
      wait for interrupt, then restart hardware timer
      tod := tod + 1;
      P(m);                                              # mutex
      while (tod ≥ smallest waketime on napQ) {
        remove (waketime, id) from napQ;                 # book-keeping
        V(d[id]);                                        # awake process
      }
      V(m);                                              # mutex
  } }
end TimeServer # Fig. 8.1 of Andrews
```

Rendezvous

RPC:

- offers inter-module communication
- synchronization (often): must be programmed explicitly

Rendezvous:

- Known from the language Ada (US DoD)
- Combines communication and synchronization between processes
- *No* new process created for each call
- instead: perform 'rendezvous' with existing process
- Operations are executed one at the time

synch_send and receive may be considered as primitive rendezvous.
cf. also join-synchronization

Rendezvous: main idea

CALLER

```
at computer A


...
call foo(ARGS);          ----->

                         <-----

...
```

CALLEE

```
at computer B


op foo(FORMALS); # declaration

... # existing process
in foo(FORMALS)  ->
  BODY;
ni
```

Rendezvous: module declaration

```
module M
   op O1(types);
   ...
   op On(types);
body

   process P1 {
      variable declarations;
      while (true)                                  # standard pattern
         in O1(formals) and B1 -> S1;
         ...
         [] On (formals) and Bn -> Sn;
         ni
   }
   ... other processes
end M
```

Calls and input statements

Call:

call O_i ($expr_1, \ldots, expr_m$);

Input statement, multiple guarded expressions:

in $O_1(v_1, \ldots v_{m_1})$ and B_1 -> S_1;
...
[] $O_n(v_1, \ldots v_{m_n})$ and B_n -> S_n;
ni

The guard consists of:

- and B_i – synchronization expression (optional)
- S_i – statements (one or more)

The variables $v_1, \ldots, v_{m_i}$ may be referred by B_i and S_i may read/write to them.[5]

[5] once again: no side-effects in B!!!

Semantics of input statement

Consider the following:

```
in ...
[] O_i(v_i, ..., v_{m_i}) and B_i -> S_i ;
...
ni
```

The guard *succeeds* when O_i is called and B_i is true (or omitted).

Execution of the in statement:

- Delays until a guard succeeds
- If more than one guard succeed, the oldest call is served[6]
- Values are returned to the caller
- The the call- and in-statements terminates

[6] this may be changed using additional syntax (by), see [Andrews, 2000].

Different variants

- different versions of rendezvous, depending on the language
- origin: ADA (`accept`-statement) (see [Andrews, 2000, Section 8.6])
- design variation points
  - synchronization expressions or not?
  - scheduling expressions or not?
  - can the guard inspect the *values* for input variables or not?
  - non-determinism
  - checking for *absence* of messages? priority
  - checking in more than one operation?

Bounded buffer with rendezvous

```
module BoundedBuffer
  op deposit(TypeT), fetch(result TypeT);
body
  process Buffer {
    elem buf[n];
    int front := 0, rear := 0, count := 0;
    while (true)
      in deposit(item) and count < n ->
            buf[rear] := item; count++;
                 rear := (rear+1) mod n;
      [] fetch(item) and count > 0 ->
                  item := buf[front]; count--;
                 front := (front+1) mod n;
      ni
  }
end BoundedBuffer  # Fig. 8.5 of Andrews
```

Example: time server (rendezvous)

```
module TimeServer
  op get_time() returns int;
  op delay(int);    # absolute waketime as argument
  op tick();        # called by the clock interrupt handler
body
  process Timer {
    int tod = 0;
    start timer;
    while (true)
      in get_time() returns time -> time := tod;
      [] delay(waketime) and waketime <= tod -> skip;
      [] tick() -> { tod++; restart timer; }
      ni
  }
end TimeServer  # Fig. 8.7 of Andrews
```

We do now have several combinations:

invocation	*service*	*effect*
call	*proc*	*procedure call (RPC)*
call	*in*	*rendezvous*
send	*proc*	*dynamic process creation*
send	*in*	*asynchronous message passing*

We do now have several combinations:

invocation	*service*	*effect*
call	*proc*	*procedure call (RPC)*
call	*in*	*rendezvous*
send	*proc*	*dynamic process creation*
send	*in*	*asynchronous message passing*

in addition (not in Andrews)

- asynchronous procedure call, wait-by-necessity, futures

Comparing input statements and receive:

in O(a_1, ...,a_n) ->v_1=a_1,...,v_n=a_n ni $\iff$ receive O(v_1, ..., v_n)

Comparing message passing and semaphores:

send O() and receive O() $\iff$ V(O) and P(O)

Bounded buffer: procedures and "semaphores (simulated by channels)"

```
module BoundedBuffer
  op deposit(typeT), fetch(result typeT);
body
  elem buf[n];
  int front = 0, rear = 0;
  # local operation to simulate semaphores
  op empty(), full(), mutexD(), mutexF();          // operations
  send mutexD(); send mutexF();  # init. "semaphores" to 1
  for [i = 1 to n]             # init. empty-"semaphore" to n
    send empty();

  proc deposit(item) {
    receive empty(); receive mutexD();
    buf[rear] = item; rear = (rear+1) mod n;
    send mutexD(); send full();
  }
  proc fetch(item) {
    receive full(); receive mutexF();
    item = buf[front] ; front = (front+1) mod n;
    send mutexF(); send empty();
  }
end BoundedBuffer  # Fig. 8.12 of Andrews
```

The primitive $?O$ in rendezvous

New primitive on operations, similar to empty(...) for condition variables and channels.

$?O$ means number of pending invocations of operation O.

Useful in the input statement to give priority:

```
in
        O1  ...                    -> S1 ;
[ ]
        O2  ...  and  (?O1 = 0)  -> S2 ;
ni
```

Here O_1 has a higher priority than O_2.

Readers and writers

```
module ReadersWriters
  op read(result types);   # uses RPC
  op write(types);         # uses rendezvous
body
  op startread(), endread();  # local ops.
  ... database (DB)...;

  proc read(vars) {
    call startread();      # get read access
    ... read vars from DB ...;
    send endread();        # free DB
  }
  process Writer {
    int nr := 0;
    while (true)
      in startread() -> nr++;
      [] endread()   -> nr--;
      [] write(vars) and nr = 0 ->
           ... write vars to DB ... ;
      ni
  }
end ReadersWriters
```

Readers and writers: prioritize writers

```
module ReadersWriters
  op read(result typeT);   # uses RPC
  op write(typeT);         # uses rendezvous
body
  op startread(), endread();  # local ops.
  ... database (DB)...;

  proc read(vars) {
    call startread();      # get read access
    ... read vars from DB ...;
    send endread();        # free DB
  }
  process Writer {
    int nr := 0;
    while (true)
    in startread() and ?write = 0 -> nr++;
      [] endread()    -> nr--;
      [] write(vars) and nr = 0 ->
           ... write vars to DB ... ;
      ni
  }
end ReadersWriters
```

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