INF4140 - Models of concurrency

Fall 2016

November 4, 2016

Abstract

This is the "handout" version of the slides for the lecture (i.e., it's a rendering of the content of the slides in a way that does not waste so much paper when printing out). The material is found in [Andrews, 2000]. Being a handout-version of the slides, some figures and graph overlays may not be rendered in full detail, I remove most of the overlays, especially the long ones, because they don't make sense much on a handout/paper. Scroll through the real slides instead, if one needs the overlays.

This handout version also contains more remarks and footnotes, which would clutter the slides, and which typically contains remarks and elaborations, which may be given orally in the lecture.

INF4140 7 Nov. 2016

1 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

Remark 1 (Join)**.** *RPC and rendezvous is good for client-server patterns, Andrews claims. What is new here is that it's* two-way *communication (but in the previous chapter, when we "simulated" a monitor via channel communication, we already used basically to chanels, for the synchronous entering to the monitor) Both have a "call-notation". The difference between rendez-vous and rpc is on the server side:*

1. *for RPC, on the server, each call is served by a "new process" (at least conceptually).*
2. *For the rendezvous, there is already an existing process. Then caller and callee perform a rendez-vouz.*

Therefore there will be an extra syntax for the receiving *side of the rendez-vouz.*

1.1 Message passing (cont'd)

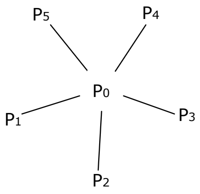
Interacting peers (processes): exchanging values example

Look at processes as peers.

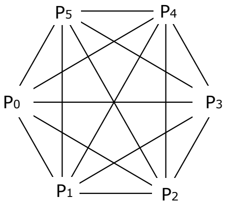
Example: Exchanging values

- 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

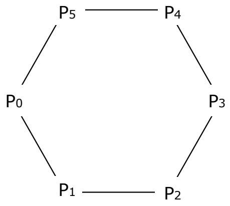
Different communication patterns



centralized

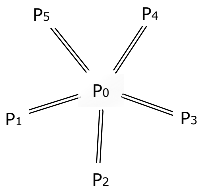


symetrical



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 sends:)
P[0]: $n-1$
P[1], …, P[$n-1$]: $(n-1)$
Total: $(n-1)+(n-1) = 2(n-1) \sim 2n$ messages
repeated "computation"

Number of *channels:* $\sim n$

Remark 2 (Join)**.** *P[0] receives $n-1$ messages and, sequentially afterwards, sends $n-1$ messages.*

Now: one single line means: 1 message, also for the following slides. That has actually changed from the earlier picture.

---

[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)
```

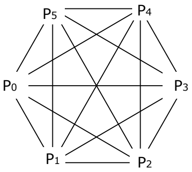
```

        for i:=0; i<m; i++        {
                go P (i,values, results[i],r)
        }

        for i:=0; i<m; i++        {
                v = <- values
                if v > largest   { largest = v}

        }
        fmt.Printf("largest␣%v\n",largest)
        for i := range results  {
                results[i] <- largest
        }
}
```

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

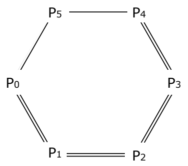
```
chan values[n](int);

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: $\begin{array}{rl} \text{P}[0]: & 2 \\ \text{P}[1], \ldots, \text{P}[n-3]: & (n-3)\times 2 \\ \text{P}[n-2]: & 1 \\ \text{P}[n-1]: & 1 \end{array}$ $2+2(n-3)+1+1=2(n-1)$ messages sent.

Number of channels: n .

Remark 3 (Join)**.** *That every process does the same code, that's of course not really true: P_0 is different, and then there's a conditional in the others, which checks on the process id.*

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

⇒ many channels

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

1.2 RPC

Remote Procedure Call: main idea

```
CALLER                                   CALLEE

at computer A                            at computer B
```

```
                                      op foo(FORMALS); # declaration

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

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 ⇒ *must be synchronized to achieve mutex*
- May only communicate with processes in M' by procedures *exported* by M'

RPC: operations

Declaration of operation O:

$$\text{op O}(\mathit{formal\ parameters.})\ [\ \text{returns}\ \mathit{result}]\ ;$$

Implementation of operation O:

$$\text{proc O}(\mathit{formal\ identifiers.})\ [\ \text{returns}\ \mathit{result\ identifier}]\{\quad \mathit{declaration\ of\ local\ variables;}\ \mathit{statements}\quad \}$$

Call of operation O in module M:[3]

$$\text{call M.O}(\mathit{arguments})$$

Processes: as before.

---

[2] cf. RMI
[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

⇒ 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.)

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

⇒ 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
```

---

[4] assumed in the following

1.3 Rendez-vouz

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                                  CALLEE

at computer A                           at computer B
```

```
                                       op foo(FORMALS); # declaration

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

Rendezvous: module declaration

```
module M
  op $O_1$(types);
  ...
  op $O_n$(types);
body

  process $P_1$ {
    variable declarations;
    while (true)                            # standard pattern
      in $O_1$(formals) and $B_1$ -> $S_1$;
      ...
      [] $O_n$ (formals) and $B_n$ -> $S_n$;
      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]

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

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
```

---

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

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

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
```

RPC, rendezvous and message passing

We do now have several combinations:

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

in addition (not in Andrews)

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

Rendezvous, message passing and semaphores

Comparing input statements and receive:

$$\text{in O}(a_1, \ldots, a_n) \text{ ->} v_1{=}a_1, \ldots, v_n{=}a_n \text{ ni} \quad \Longleftrightarrow \quad \text{receive O}(v_1, \ldots, v_n)$$

Comparing message passing and semaphores:

$$\text{send O() and receive O()} \quad \Longleftrightarrow \quad \text{V(O) and P(O)}$$

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
```

References

[Andrews, 2000] Andrews, G. R. (2000). *Foundations of Multithreaded, Parallel, and Distributed Programming*. Addison-Wesley.