Lesson 9

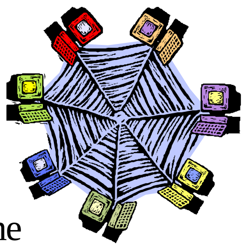
Concurrency Control in Distributed Environment

Ch 8 [BenA 06]

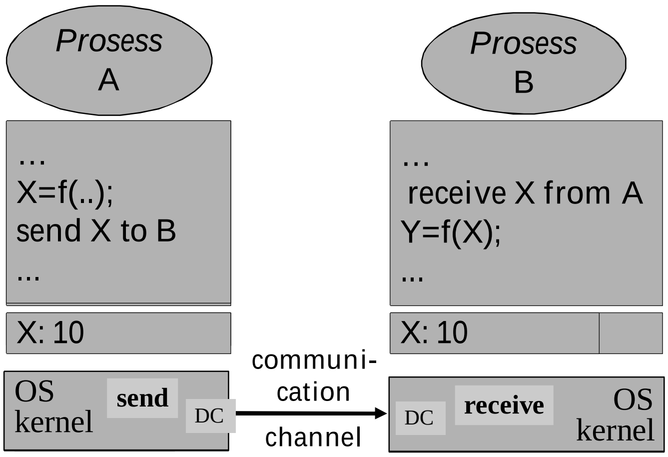
Messages
Channels
Rendezvous
RPC and RMI

Distributed System

- No shared memory
- Communication with messages
- Tighly coupled systems
  - Processes alive at the same time
- Persistent systems
  - Data stays even if processes die
- Fully distributed systems
  - Everything goes



Communication with Messages (4)



- Sender, receiver
- Synchronous/asynchronous communication

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Message Passing

- Synchronous communication
  - Atomic action
  - Both wait until communication complete
- Asynchronous communication (Usual case)
  - Sender continues after giving the message to OS for delivery
  - May get an acknowledgement later on
    - Message received or not
- Addressing
  - Some address for receiver process (prosessi)
    - Process name, id, node/name, …
  - Some address for the communication channel (kanava)
    - Port number, channel name, …
  - Some address for requested service (palvelu)
    - Broker will find out, sooner or later (meklari)
      - After message has been sent?
    - Service address not known at service request time

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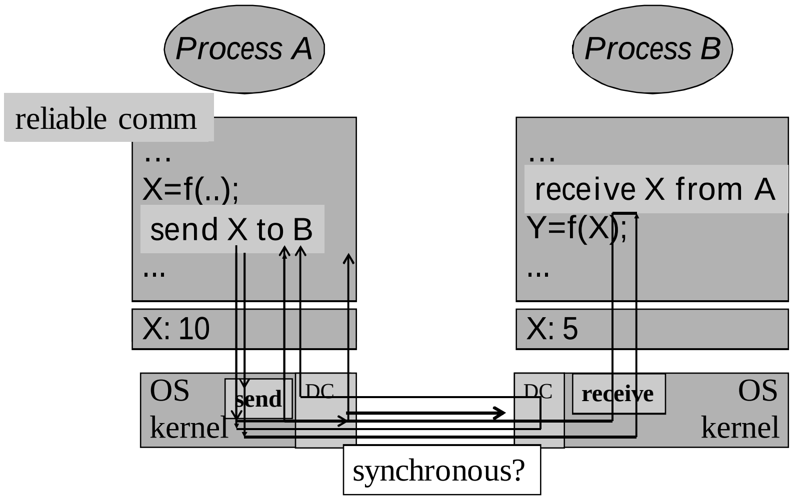
Synchronization levels (10)



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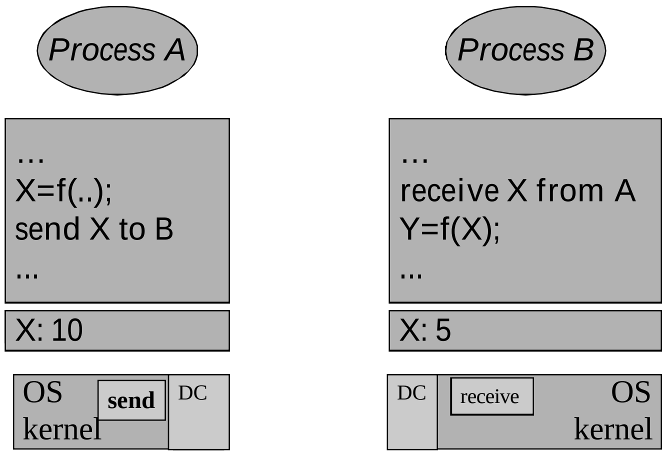
Synchronization levels (1/5)



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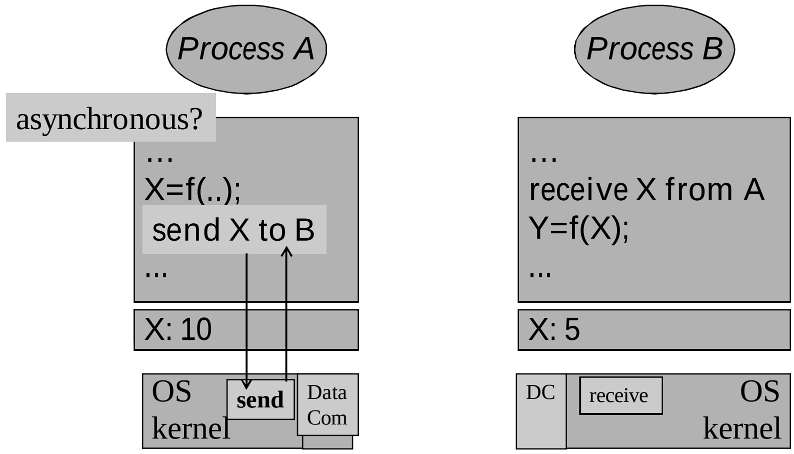
Synchronization levels (2/5)



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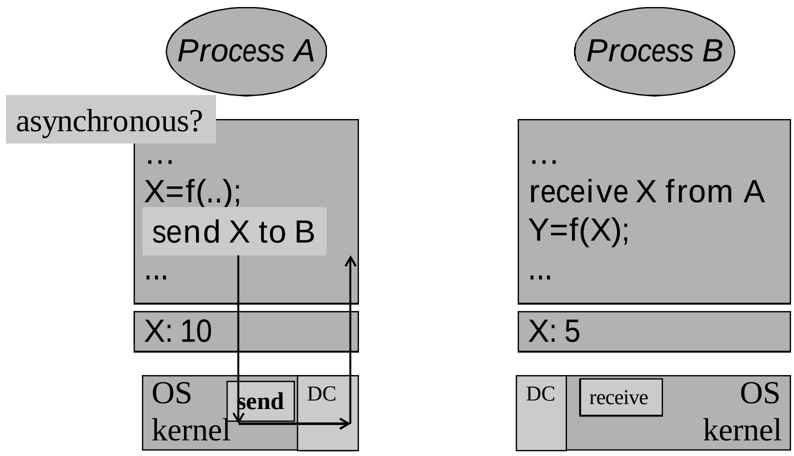
Synchronization levels (3/5)



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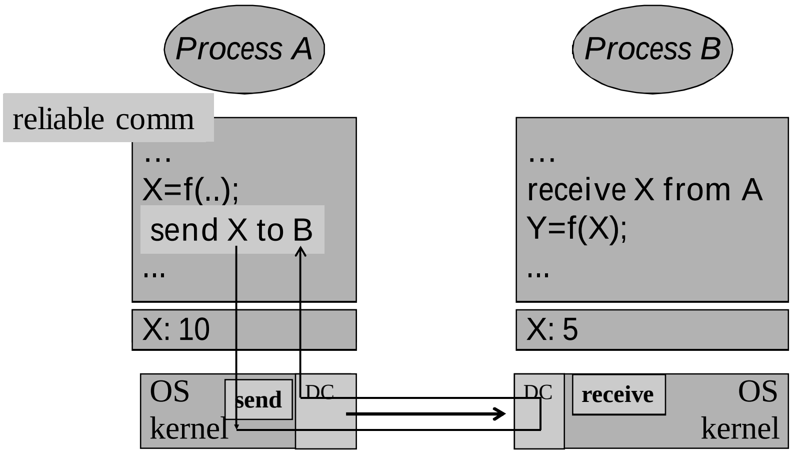
Synchronization levels (4/5)



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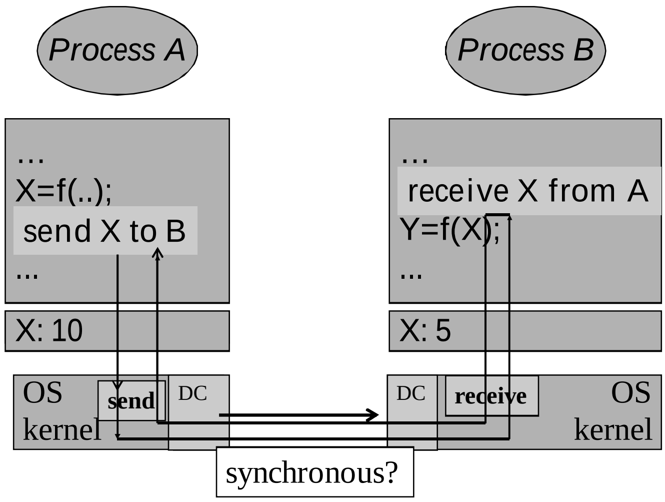
Synchronization levels (5/5)



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Message Passing

- Symmetric communication
  - Cooperating processes at same level
  - Both know about each others address
  - Communication method for a fixed channel
- Asymmetric communication
  - Different status for communicating processes
  - Client-server model
    - Server address known, client address given in request
- Broadcast communication
  - Receiver not addressed directly
  - Message sent to everybody (in one node?)
  - Receivers may be limited in number
    - Just one?
    - Only the intended recipient(s) will act on it?

Wait Semantics

- Sender
  - Continue after OS has taken the message — Usual case
    - Non-blocking send
  - Continue after message reached receiver <u>node</u>
    - Blocking send
  - Continue after message reached receiver <u>process</u>
    - Blocking send
- Receiver
  - Continue only after message received — Usual case
    - Blocking receive
  - Continue even if no message received
    - Status indicated whether message received or not
    - Non-blocking receive

Message Passing

- Data flow
  - One-way
    - Synchronous may be one-way
    - Asynchronous is always one-way
  - Two-way
    - Synchronous may be two-way
    - Two asynchronous communications
- Primitives
  - One message at a time
  - Need addresses for communicating processes
  - Operating system level service
  - Usually not programming language level construct
    - Too primitive: need to know node id, process id, port number,…

data flow
vs.
control flow!

Channels

- History of languages utilizing channels
  - Guarded Commands
    - Dijkstra, 1975
  - Communicating Sequential Processes
    - CSP, Hoare, 1978
  - Occam
    - David May et al, 1983
    - Hoare as consultant
    - Inmos Transputer

vartioidut komennot

kommunikoivat sarjalliset prosessit

Edsger Dijkstra

C.A.R. Hoare

David May

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Guarded Commands (Dijkstra)

- Way to describe predicate transformer semantics
- Communication not really specified
- Guarded command
  - Condition or guard
  - Statement

C → S

predikaatti-muunnos-semantiikka

greatest common divisor

```
x, y = X, Y     -- statement (unguarded)
do   -- loop command, loop terminates when x = y
 x ≠ y →
    if     -- conditional command (itself guarded)
        x > y → x := x-y     -- guarded statement in the if
        y > x → y := y-x
    fi
od
print x ; -- another statement, also unguarded
```

guard

vartioitu lauseke

can be also input/output statement

http://en.wikipedia.org

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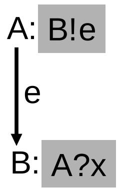
Communicating Sequential Processes – CSP (Hoare)

- Language for modeling and analyzing the behavior of concurrent communicating systems
- A known group of processes A, B, …
- Communication:
  - output statement: B!e
    - evaluate e, send the value of e to B
  - input statement: A?x
    - receive the value from A to x
  - input, output: blocking statements
  - output & input: "distributed assignment"
    - Communicate value from one process to a variable in some other process



CSP communication

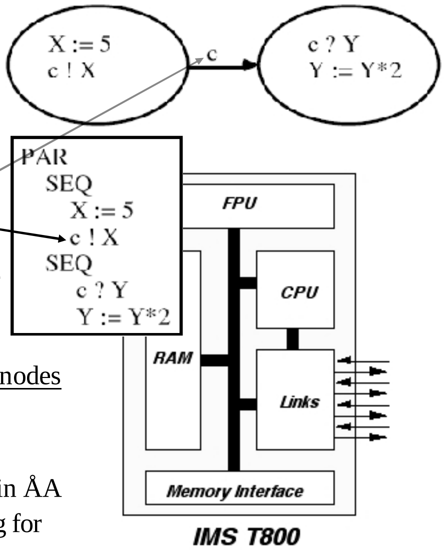
- Input/output statements
  - Destination!port (e_1, …, e_n) ;
  - Source?port (x_1, …, x_n) ;
- Binding
  - Communication with **named processes**
  - Matching types for communication
- Example: **Copy** (West => Copy => East)

West:
```
do true ->
   Copy!c;
   …
od
```

Copy:
```
do true ->
  West?c;
  East!c ;
od
```

East:
```
do true ->
  Copy?c;
  …
od
```

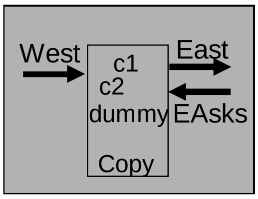
OCCAM Language



- Communication through **<u>named channels</u>**
  - Globally defined
    - Somewhere, in advance
  - Each channel has <u>one</u> sender and <u>one</u> receiver
    - both <u>processes</u> in some <u>nodes</u>
- Transputer
  - Multicomputer
    - E.g., 100 node Hathi-2 in ÅA
  - Automatic message routing for channels
  - Programmed with OCCAM

OCCAM Example

(Andrews, p 331)

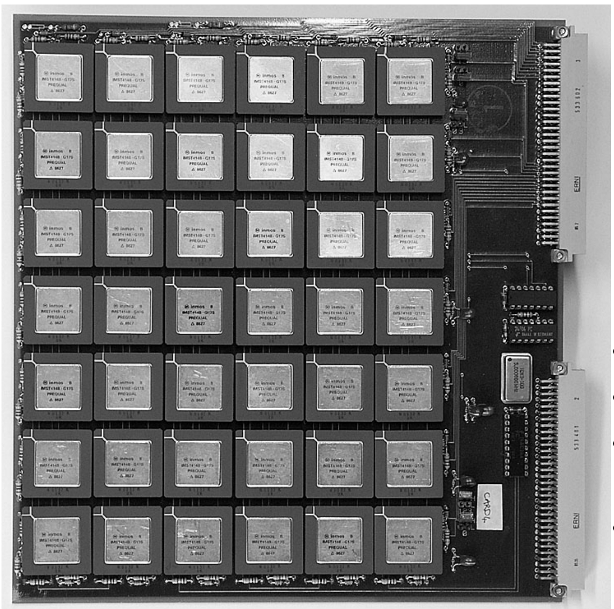



```
PROC Copy (CHAN OF BYTE West, EAsks, East)
  BYTE  c1, c2, dummy;  -- buffer size = 2
  SEQ
    West ? c1                  - - West has 1st byte
    WHILE TRUE
      ALT
        West ? c2              - - West has new byte
          SEQ
            East ! c1          - - send previous byte
            c1 := c2           - - copy to buffer c1
        EAsks ? dummy          - - East wants a byte
          SEQ
            East ! c1          - - send previous byte
            West ? c1          - - receive next one
```

block here, until other end ready ("guards")

- How to bind processes to nodes? 8 vs. 100 nodes?
- How to bind channels to processes, physical system?
  - 4 physical ports (N, S, E, W) in each processor

Discuss



Inmos Transputer

- B0042
- 2D array
- 10 boards 420 cpu's
- 30 boards 1260 cpu's

http://www.cs.bris.ac.uk/~dave/transputer.html

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Channels

- Communication through <u>named channels</u>
  - Typed, global to processes
  - Programming language concept
  - <u>Any one</u> can read/write (usually limited in practice)
- Pipe or mailbox
- <u>Synchronous</u>, one-way (?)
- How to tie in with many nodes?
  - Not really thought through! Easy with shared memory!

many readers/writers? same process writes and reads?

Algorithm 8.1: Producer-consumer (channels)

channel of <u>integer</u> ch

producer	consumer
integer x	integer y
loop forever	loop forever
p1: x ← produce	q1: ch ⇒ y
p2: ch ⇐ x	q2: consume(y)

buffer size?

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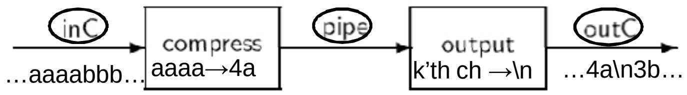
Filtering Problem



- Compress many (at most MAX) similar characters to pairs …
  - {nr of chars, char}

"compress"

- … <u>and</u> place newline (\n) after every K'th character in the compressed string

"output"

- Why is it called "Conway's problem"?
  - "Classic <u>coroutine</u> example"

vuorottaisrutiinit

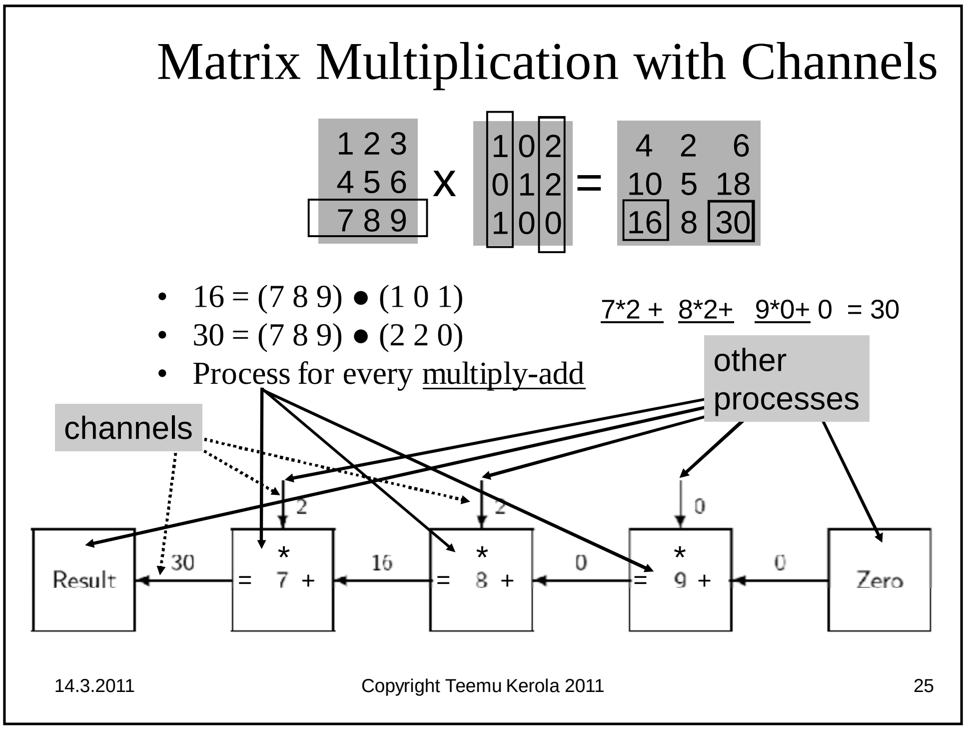
Conway, M. "Design of a separable transition-diagram compiler," *CACM* 6, 1963, pages 396–408.

Filtering Problem with Channels

Algorithm 8.2: Conway's problem

constant integer MAX ← 9
constant integer K ← 4
channel of integer inC, pipe, outC

compress		output	
	char c, previous ← 0		char c
	integer n ← 0		integer m ← 0
	inC ⇒ previous		
	loop forever (no last char?)		loop forever
p1:	inC ⇒ c	q1:	pipe ⇒ c
p2:	if (c = previous) and (n < MAX − 1)	q2:	outC ⇐ c
p3:	n ← n + 1	q3:	m ← m + 1
	else		
p4:	if n > 0	q4:	if m >= K
p5:	pipe ⇐ intToChar(n+1)	q5:	outC ⇐ newline
p6:	n ← 0	q6:	m ← 0
p7:	pipe ⇐ previous	q7:	
p8:	previous ← c	q8:	


Matrix Multiplication with Channels
1 2 3
4 5 6
7 8 9
x
1 0 2
0 1 2
1 0 0
=
4 2 6
10 5 18
16 8 30
• 16 = (7 8 9) ● (1 0 1)
• 30 = (7 8 9) ● (2 2 0)
• Process for every multiply-add
7*2 + 8*2+ 9*0+ 0 = 30
other processes
channels
Result
30
16
0
0
Zero
2
2
0
= 7 +
= 8 +
= 9 +
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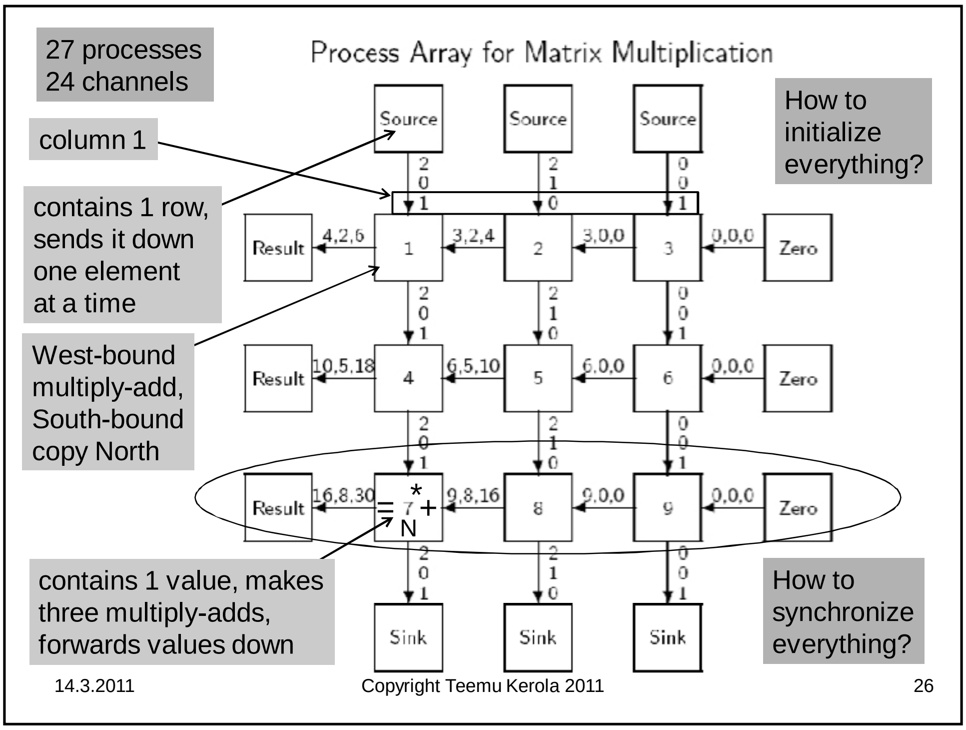
Process Array for Matrix Multiplication
27 processes
24 channels
column 1
contains 1 row, sends it down one element at a time
West-bound multiply-add, South-bound copy North
contains 1 value, makes three multiply-adds, forwards values down
How to initialize everything?
How to synchronize everything?
Source
Source
Source
Result
Result
Result
Zero
Zero
Zero
Sink
Sink
Sink
4,2,6
3,2,4
3,0,0
0,0,0
10,5,18
6,5,10
6,0,0
16,8,30
9,8,16
9,0,0
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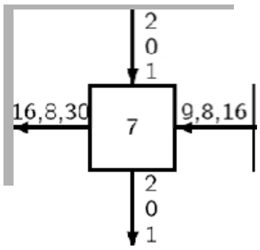
Algorithm 8.3: Multiplier process with channels

```
        integer FirstElement
        channel of integer North, East, South, West
        integer Sum, integer SecondElement
    loop forever
p1:    North ⇒ SecondElement
p2:    East ⇒ Sum
p3:    Sum ← Sum + FirstElement · SecondElement
p4:    South ⇐ SecondElement
p5:    West ⇐ Sum
```

Relative names?

← wait 1st for this (*)
← and then for this



- How to map processes to nodes?
- How to map channels to processes?
  - North channel of one process the South channel of some other
- North-South data flow has priority (*)
  - Waiting even when data-flow East-West available
  - Node on East may be blocked unnecessarily

Discuss

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Algorithm 8.4: Multiplier with channels and selective input

```
        integer FirstElement
        channel of integer North, East, South, West
        integer Sum, integer SecondElement
    loop forever
      either
p1:      North ⇒ SecondElement
p2:      East ⇒ Sum
      or
p3:      East ⇒ Sum
p4:      North ⇒ SecondElement
p5:   South ⇐ SecondElement
p6:   Sum ← Sum + FirstElement · SecondElement
p7:   West ⇐ Sum
```

If message from North available, do this

If message from East available, do this

sequential block

- Guarded statement
  - Execute one selective input statement
    - Nondeterministic selection (if both available)
    - p2 follows p1, it does not compete with p3

Discuss

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Dining Philosophers with Channels

- Each fork i is a process, forks[i] is a channel
- Each philosopher i is a process

Algorithm 8.5: Dining philosophers with channels			
channel of boolean forks[5]			
philosopher i		**fork i**	
	boolean dummy		boolean dummy
	loop forever		loop forever
p1:	think	q1:	forks[i] ⇐ true
p2:	forks[i] ⇒ dummy	q2:	forks[i] ⇒ dummy
p3:	forks[i⊖1] ⇒ dummy	q3:	
p4:	eat	q4:	mutex?
p5:	forks[i] ⇐ true (would *false* be ok?)	q5:	deadlock?
p6:	forks[i⊖1] ⇐ true	q6:	

- Would it be enough to initialize each *forks[i]* <= *true* ?
  - Do you really need *forks[i]* => *dummy* in fork i? Why?

Discuss

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Rendezvous (1978, Abrial & Andrews)

- Synchronization with communication
  - No channels, usage similar to procedure calls
  - One (*accepting*) process waits for one of the (*calling*) processes
    - One request in service at a time

asymmetric

  - Calling process must know id of the accepting process
  - Accepting process does not need to know the id of calling process
  - May involve parameters and return value
- Good for client-server synchronization
  - Clients are calling processes `server.service(parm, result)`
  - Server is accepting process `accept service(p, r)`
  - Server is active process
  - Language construct, no mapping for real system nodes

Algorithm 8.6: Rendezvous

	client		server
	integer parm, result		integer p, r
	loop forever		loop forever
p1:	parm ← . . .	q1:	
p2:	server.service(parm, result)	q2:	accept service(p, r)
p3:	use(result)	q3:	r ← do the service(p)

- Can have many similar clients
- Implementation with messages (e.g.)
  - Service request in one message
    - Arguments must be marshalled (make them suitable for transmission)
  - Wait until reply received
  - Reply result in another message

Guards in Rendezvous

- Additional constraint for accepting given service call
- Accept service call, if
  - Someone requests it and
  - Guard for that request type is true
    - Guard is based on local state
- If many such requests (with open guards) available, select one randomly
- Complete one request at a time
  - Implicit mutex

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Ada Rendezvous

Bounded Buffer in Ada

Export public ops defined before task body

```
task body Buffer is
  B: Buffer_Array;
  In_Ptr, Out_Ptr, Count: Index := 0;
begin
  loop
    select
      when Count < Index'Last =>
        accept Append(I: in Integer ) do
          B(In_Ptr) := I;
        end Append;
      Count := Count + 1; In_Ptr := In_Ptr + 1;
    or
      when Count > 0 =>
        accept Take(I: out Integer ) do
          I := B(Out_Ptr);
        end Take;
      Count := Count – 1; Out_Ptr := Out_Ptr + 1;
    or
      terminate;
    end select;
  end loop;
end Buffer;
```

```
…
Buffer.Append (456);
Buffer.Append (333);
…
```

```
…
Buffer.Take(x);
Buffer.Take(y);
…
```

Terminates when no rendezvous processes available? Tricky! How to know? No concurrent operations!

How is buffer mutex problem solved?

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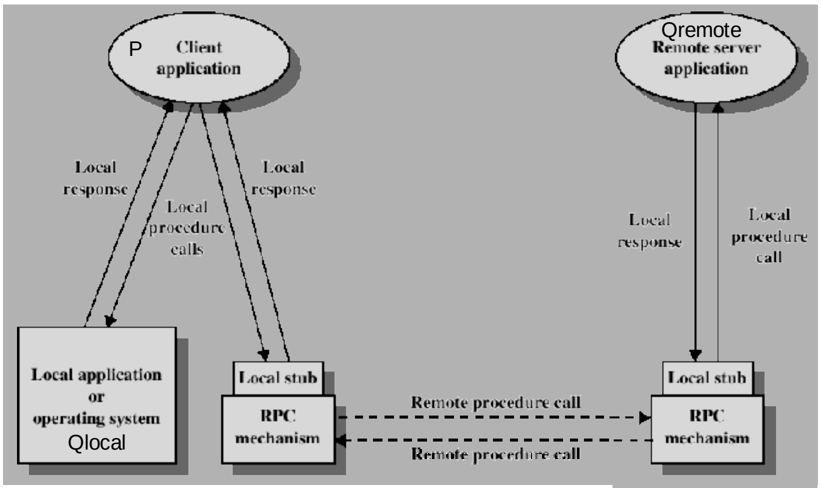
Remote Procedure Call

- Common operating system service for client-server model synchronization
  - Implemented with messages
  - Parameter marshalling
    - Semantics remain, implementation may change
  - Mutex problem
    - Combines monitor and synchronized messages?
      - Automatic mutex for service
    - Multiple calls active simultaneously? Usual case
      - Mutex problems solved within called service
  - Semantics similar to ordinary procedure call
    - But no global environment (e.g., shared array)
  - Two-way synchronized communication channel
    - Client waits until service completed (usually)

RPC System Structure

P calls Q



(Sta05 Fig 14.12)

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RPC Module

```
module mname
  op opname(formals)  [returns result]
body
  variable declarations;
  initialization code;
  proc opname(formal identifiers)  returns result identifier
    declarations of local variables;
    statements
  end
  local procedures and processes;
end mname
```

Export public ops

Call: `call mname.opname(arguments)`

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RPC Example: Time Server

```
module TimeServer
  op get_time() returns int;   # retrieve time of day
  op delay(int interval);      # delay interval ticks
body
  int tod = 0;           # the time of day
  sem m = 1;             # mutual exclusion semaphore
  sem d[n] = ([n] 0);    # private delay semaphores
  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(interval) {    # assume interval > 0
    int waketime = tod + interval;
    P(m);
    insert (waketime, myid) at appropriate place on napQ;
    V(m);
    P(d[myid]);    # wait to be awakened
  }
```

mutex

(And00 Fig 8.1)

(process Clock{} on next slide)


```
  process Clock {
    start hardware timer;
    while (true) {
      wait for interrupt, then restart hardware timer;
      tod = tod+1;
      P(m);
      while (tod >= smallest waketime on napQ) {
        remove (waketime, id) from napQ;
        V(d[id]);  # awaken process id
      }
      V(m);
    }
  }
end TimeServer
```

- Internal process
  - Keeps the time
  - Wakes up delayed clients
- Service RPC's:

time = TimeServer.get_time();
TimeServer.delay(10);

Discuss

Linux machine>> man rpc

```
RPC(3)                                                    RPC(3)

NAME
     rpc - library routines for remote procedure calls

SYNOPSIS AND DESCRIPTION
     These routines allow C programs to make procedure calls on other
     machines across the network.  First, the client calls a procedure to
     send a data packet to the server.  Upon receipt of the packet, the
     server calls a dispatch routine to perform the requested service, and
     then sends back a reply.  Finally, the procedure call returns to the
     client.
```

```
callrpc(host, prognum, versnum, procnum, inproc, in, outproc, out)
     char *host;
     u_long prognum, versnum, procnum;
     char *in, *out;
     xdrproc_t inproc, outproc;
```

remote process

decode/encode parameters/results

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Remote Method Invocation (RMI)

rmi server

```
package example.hello;

import java.rmi.Remote;
import java.rmi.RemoteException;

public interface Hello extends Remote {
        String sayHello() throws RemoteException;
}
```

http://java.sun.com/j2se/1.5.0/docs/guide/rmi/hello/hello-world.html

- Java RPC
- Start rmiregistry
  - Stub lookup (default at port 1099)
- Start rmi server
  - Server runs until explicitly terminated by user

rmiregistry &

start rmiregistry

java -classpath *classDir* example.hello.Server &

start java -classpath *classDir* example.hello.Server

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rmi server

```
package example.hello;
import java.rmi.registry.Registry;
import java.rmi.registry.LocateRegistry;
import java.rmi.RemoteException;
import java.rmi.server.UnicastRemoteObject;
public class Server implements Hello {
    public Server() {}
    public String sayHello() {
        return "Hello, world!"; }
    public static void main(String args[]) {
        try { Server obj = new Server();
            Hello stub = (Hello) UnicastRemoteObject.exportObject(obj, 0);
                    // Bind the remote object's stub in the registry
            Registry registry = LocateRegistry.getRegistry();
            registry.bind("Hello", stub);
            System.err.println("Server ready");
        }   catch (Exception e) {
            System.err.println("Server exception: " + e.toString());
            e.printStackTrace();
        }
}
```

Output: Server ready

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rmi client

```
package example.hello;
import java.rmi.registry.LocateRegistry;
import java.rmi.registry.Registry;

public class Client {
    private Client() {}
    public static void main(String[] args) {
        String host = (args.length < 1) ? null : args[0];
        try {
            Registry registry = LocateRegistry.getRegistry(host);
            Hello stub = (Hello) registry.lookup("Hello");
            String response = stub.sayHello();
            System.out.println("response: " + response);
        } catch (Exception e) {
            System.err.println("Client exception: " + e.toString());
            e.printStackTrace();
        }
    }
}
```

Output: response: Hello, world!

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Summary

- Distributed communication with messages
  - Synchronization and communication
  - Computation time + communication time = ?
- Higher level concepts
  - Guarded commands (theoretical background)
  - CSP (idea) & Occam (application)
  - Named Channels (ok without shared memory?)
  - Rendezvous
  - RPC & RMI (Java)

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