# Andrews Figures, Chapter 01

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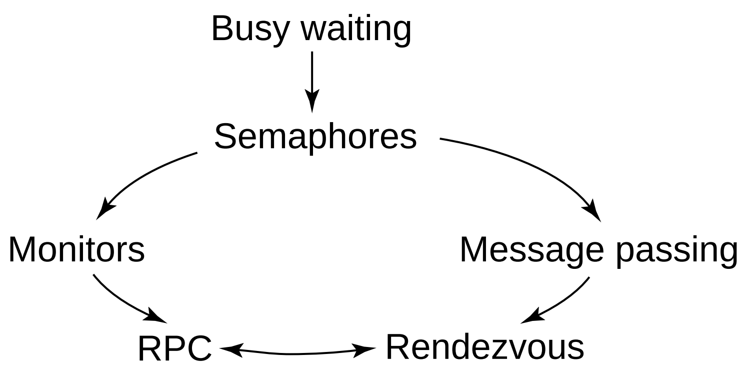

Relationships between programming mechanisms.

```
chan input(char), output(char [MAXLINE]);
process Char_to_Line {
  char line[MAXLINE]; int i = 0;
  while (true) {
    receive input(line[i]);
    while (line[i] != CR and i < MAXLINE) {
      # line[0:i-1] contains the last i input characters
      i = i+1;
      receive input(line[i]);
    }
    line[i] = EOL;
    send output(line);
    i = 0;
  }
}
```

**Figure 7.1** Filter process to assemble lines of characters.

```
chan in1(int), in2(int), out(int);
process Merge {
  int v1, v2;
  receive in1(v1);  # get first two input values
  receive in2(v2);
  # send smaller value to output channel and repeat
  while (v1 != EOS and v2 != EOS) {
    if (v1 <= v2)
      { send out(v1); receive in1(v1); }
    else   # (v2 < v1)
      { send out(v2); receive in2(v2); }
  }
  # consume the rest of the non-empty input channel
  if (v1 == EOS)
    while (v2 != EOS)
      { send out(v2); receive in2(v2); }
  else   # (v2 == EOS)
    while (v1 != EOS)
      { send out(v1); receive in1(v1); }
  # append a sentinel to the output channel
  send out(EOS);
}
```

**Figure 7.2** A filter process that merges two input streams.

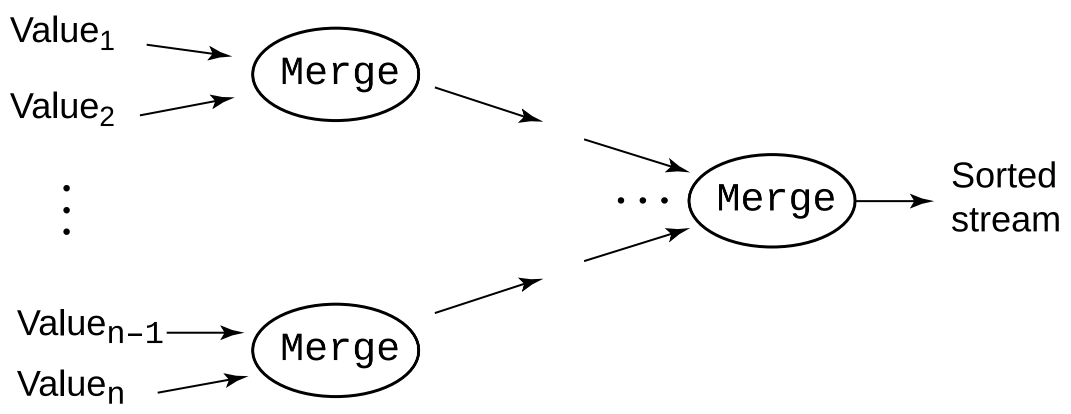

**Figure 7.3** A sorting network of **`Merge`** processes.

```
chan request(int clientID, types of input values);
chan reply[n](types of results);
process Server {
  int clientID;
  declarations of other permanent variables;
  initialization code;
  while (true) {   ## loop invariant MI
    receive request(clientID, input values);
    code from body of operation  op;
    send reply[clientID](results);
}
process Client[i = 0 to n-1] {
  send request(i, value arguments);    # "call" op
  receive reply[i](result arguments);   # wait for reply
}
```

**Figure 7.4** Clients and server with one operation.

```
type op_kind = enum(op_1, ..., op_n);
type arg_type = union(arg_1, ..., arg_n);
type result_type = union(res_1, ..., res_n);
chan request(int clientID, op_kind, arg_type);
chan reply[n](res_type);
process Server {
  int clientID; op_kind kind; arg_type args;
  res_type results; declarations of other variables;
  initialization code;
  while (true) {    ## loop invariant MI
    receive request(clientID, kind, args);
    if (kind == op_1)
      { body of op_1; }
    ...
    else if (kind == op_n)
      { body of op_n; }
    send reply[clientID](results);
  }
}
process Client[i = 0 to n-1] {
  arg_type myargs; result_type myresults;
  place value arguments in myargs;
  send request(i, op_j, myargs);    # "call" op_j
  receive reply[i](myresults);      # wait for reply
}
```

**Figure 7.5** Clients and server with multiple operations.

```
monitor Resource_Allocator {
  int avail = MAXUNITS;
  set units = initial values;
  cond free;   # signaled when a process wants a unit
  procedure acquire(int &id) {
    if (avail == 0)
      wait(free);
    else
      avail = avail-1;
    remove(units, id);
  }
  procedure release(int id) {
    insert(units, id);
    if (empty(free))
      avail = avail+1;
    else
      signal(free);
  }
}
```

**Figure 7.6** Resource allocation monitor.

```
type op_kind = enum(ACQUIRE, RELEASE);
chan request(int clientID, op_kind kind, int unitid);
chan reply[n](int unitID);
process Allocator {
  int avail = MAXUNITS; set units = initial values;
  queue pending;  # initially empty
  int clientID, unitID; op_kind kind;
  declarations of other local variables;
  while (true) {
    receive request(clientID, kind, unitID);
    if (kind == ACQUIRE) {
       if (avail > 0) {  # honor request now
          avail--; remove(units, unitID);
          send reply[clientID](unitID);
       } else   # remember request
          insert(pending, clientID);
    } else {   # kind == RELEASE
       if empty(pending) {  # return unitID to units
          avail++; insert(units, unitid);
       } else {  # allocate unitID to a waiting client
          remove(pending, clientID);
          send reply[clientID](unitID);
       }
    }
  }
}
process Client[i = 0 to n-1] {
  int unitID;
  send request(i, ACQUIRE, 0)    # “call” request
  receive reply[i](unitID);
  # use resource unitID, then release it
  send request(i, RELEASE, unitID);
   ...
}
```

**Figure 7.7** Resource allocator and clients.

| *Monitor-Based Programs* | *Message-Based Programs* |
|---|---|
| permanent variables | local server variables |
| procedure identifiers | **`request`** channel and operation kinds |
| procedure call | **`send request(); receive reply`** |
| monitor entry | **`receive request()`** |
| procedure return | **`send reply()`** |
| **`wait`** statement | save pending request |
| **`signal`** statement | retrieve and process pending request |
| procedure bodies | arms of case statement on operation kind |

**Table 7.1** Duality between monitors and message passing.

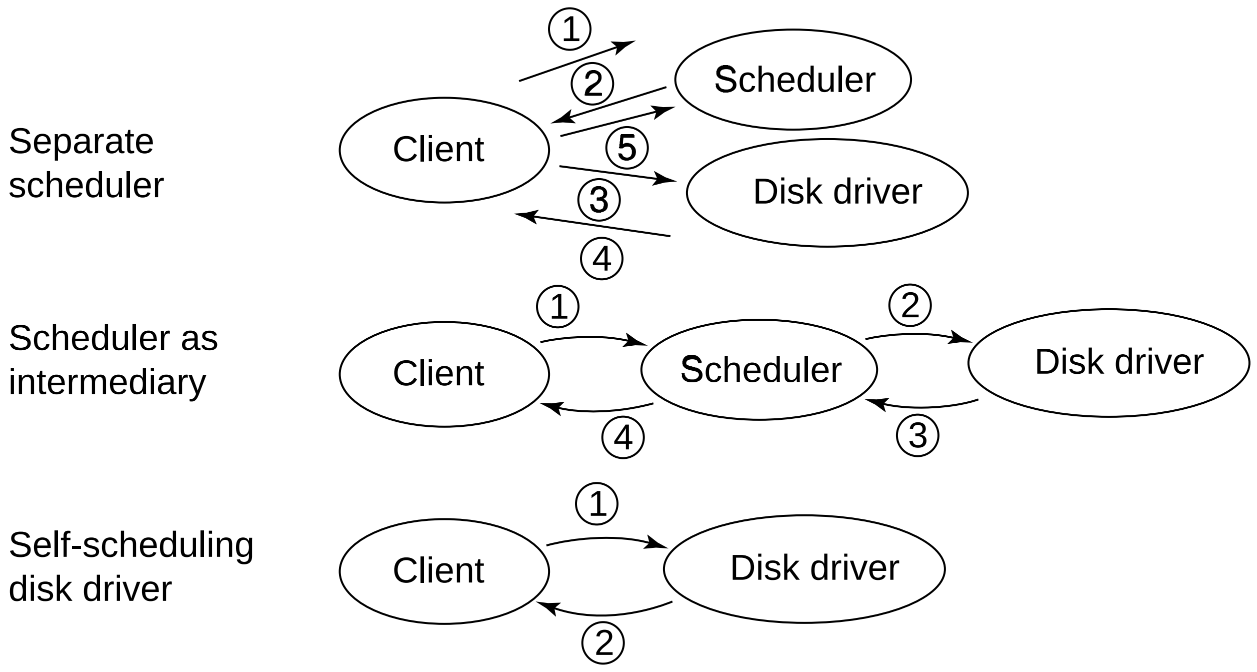

**Figure 7.8** Disk scheduling structures with message passing.

```
chan request(int clientID, int cyl, types of other arguments);
chan reply[n](types of results);
process Disk_Driver {
  queue left, right;  # ordered queues of saved requests
  int clientID, cyl, headpos = 1, nsaved = 0;
  variables to hold other arguments in a request;
  while (true) {     ## loop invariant SST
    while (!empty(request) or nsaved == 0) {
      # wait for first request or receive another one
      receive request(clientID, cyl, ...);
      if (cyl <= headpos)
        insert(left, clientID, cyl, ...);
      else
        insert(right, clientID, cyl, ...);
      nsaved++;
    }
    # select best saved request from left or right
    if (size(left) == 0)
      remove(right, clientID, cyl, args);
    else if (size(right) == 0)
      remove(left, clientID, cyl, args);
    else
      remove request closest to headpos from left or right;
    headpos = cyl; nsaved--;
    access the disk;
    send reply[clientID](results);
  }
}
```

**Figure 7.9** Self-scheduling disk driver.

```
type kind = enum(READ, WRITE, CLOSE);
chan open(string fname; int clientID);
chan access[n](int kind, types of other arguments);
chan open_reply[m](int serverID);  # server id or error
chan access_reply[m](types of results);  # data, error, ...

process File_Server[i = 0 to n-1] {
  string fname; int clientID;
  kind k; variables for other arguments;
  bool more = false;
  variables for local buffer, cache, etc.;
  while (true) {
    receive open(fname, clientID);
    open file fname; if successful then:
    send open_reply[clientID](i); more = true;
    while (more) {
      receive access[i](k, other arguments);
      if (k == READ)
        process read request;
      else if (k == WRITE)
        process write request;
      else   # k == CLOSE
        { close the file; more = false; }
      send access_reply[clientID](results);
    }
  }
}

process Client[j = 0 to m-1] {
  int serverID;  declarations of other variables;
  send open("foo", j);    # open file "foo"
  receive open_reply[j](serverID);  # get back server id
  # use file then close it by executing the following
  send access[serverID](access arguments);
  receive access_reply[j](results);
   ...
}
```

**Figure 7.10** File servers and clients.

```
chan values(int), results[n](int smallest, int largest);
process P[0] {   # coordinator process
  int v;   # assume v has been initialized
  int new, smallest = v, largest = v;  # initial state
  # gather values and save the smallest and largest
  for [i = 1 to n-1] {
    receive values(new);
    if (new < smallest)
      smallest = new;
    if (new > largest)
      largest = new;
  }
  # send the results to the other processes
  for [i = 1 to n-1]
    send results[i](smallest, largest)
}
process P[i = 1 to n-1] {
  int v;   # assume v has been initialized
  int smallest, largest;
  send values(v);
  receive results[i](smallest, largest);
}
```

**Figure 7.11** Exchanging values: centralized solution.

```
chan values[n](int);
process P[i = 0 to n-1] {
  int v;   # assume v has been initialized
  int new, smallest = v, largest = v;  # initial state
  # send my value to the other processes
  for [j = 0 to n-1 st j != i]
    send values[j](v);
  # gather values and save the smallest and largest
  for [j = 1 to n-1] {
    receive values[i](new);
    if (new < smallest)
      smallest = new;
    if (new > largest)
      largest = new;
  }
}
```

**Figure 7.12** Exchanging values: symmetric solution.

```
chan values[n](int smallest, int largest);
process P[0] {  # initiates the exchanges
  int v;   # assume v has been initialized
  int smallest = v, largest = v;  # initial state
  # send v to next process, P[1]
  send values[1](smallest, largest);
  # get global smallest and largest from P[n-1] and
  #   pass them on to P[1]
  receive values[0](smallest, largest);
  send values[1](smallest, largest);
}
process P[i = 1 to n-1] {
  int v;   # assume v has been initialized
  int smallest, largest;
  # receive smallest and largest so far, then update
  #   them by comparing their values to v
  receive values[i](smallest, largest)
  if (v < smallest)
      smallest = v;
  if (v > largest)
      largest = v;
  # send the result to the next processes, then wait
  # to get the global result
  send values[(i+1) mod n](smallest, largest);
  receive values[i](smallest, largest);
}
```

**Figure 7.13** Exchanging values using a circular ring.

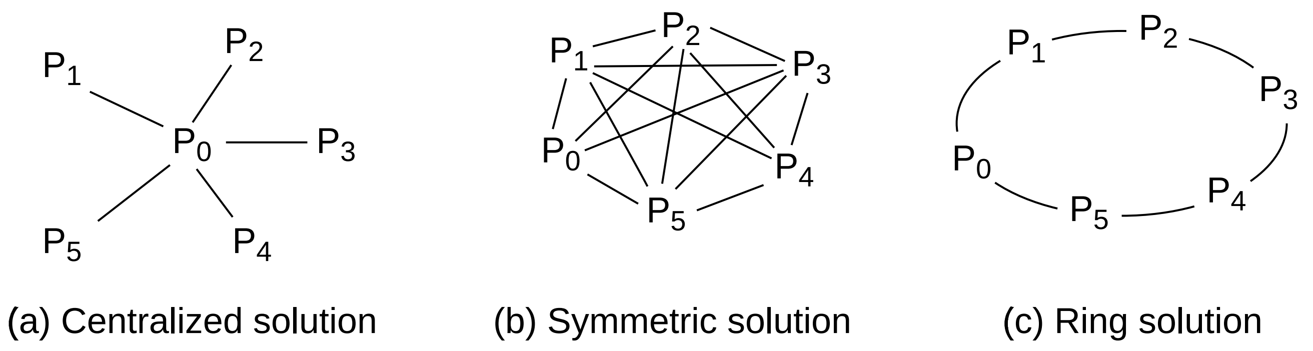

**Figure 7.14** Communication structures of the three programs.

```
channel values(int);

process Producer {
  int data[n];
  for [i = 0 to n-1] {
    do some computation;
    synch_send values(data[i]);
  }
}

process Consumer {
  int results[n];
  for [i = 0 to n-1] {
    receive values(results[i]);
    do some computation;
  }
}
```

Producer/consumer example using synchronous message passing.

```
channel in1(int), in2(int);
process P1 {
  int value1 = 1, value2;
  synch_send in2(value1);
  receive in1(value2);
}
process P2 {
  int value1, value2 = 2;
  synch_send in1(value2);
  receive in2(value1);
}
```

Exchanging values with synchronous message passing.

```
process GCD {
  int id, x, y;
  do true ->
    Client[*]?args(id, x, y);  # input a "call"
    # repeat the following until x == y
    do x > y -> x = x - y;
    [] x < y -> y = y - x;
    od
    Client[id]!result(x);  # return the result
  od
}
```

```
 ... GCD!args(i,v1,v2); GCD?result(r); ...
```

Greatest common divisor process and interface in CSP.

```
process Copy {   # one character buffer
  char c;
  do West?c -> East!c; od
}


process Copy {   # two character buffer
  char c1, c2;
  West?c1;
  do West?c2 -> East!c1; c1 = c2;
  [] East!c1 -> West?c1;
  od
}


process Copy {   # ten character buffer
  char buffer[10];
  int front = 0, rear = 0, count = 0;
  do count < 10; West?buffer[rear] ->
        count = count+1; rear = (rear+1) mod 10;
  [] count > 0; East!buffer[front] ->
        count = count-1; front = (front+1) mod 10;
  od
}
```

Versions of copy processes in CSP.

```
process Allocator {
  int avail = MAXUNITS;
  set units = initial values;
  int index, unitid;
  do avail > 0; Client[*]?acquire(index) ->
        avail--; remove(units, unitid);
        Client[index]!reply(unitid);
  [] Client[*]?release(index, unitid) ->
        avail++; insert(units,unitid);
  od
}
```

Resource allocator in CSP.

```
process P1 {
  int value1 = 1, value2;
  if P2!value1 -> P2?value2;
  [] P2?value2 -> P2!value1;
  fi
}
process P2 {
  int value1, value2 = 2;
  if P1!value2 -> P1?value1;
  [] P1?value1 -> P1!value2;
  fi
}
```

Exchanging values in CSP.

```
process Sieve[1] {
  int p = 2;
  for [i = 3 to n by 2]
    Sieve[2]!i;   # pass odd numbers to Sieve[2]
}
process Sieve[i = 2 to L] {
  int p, next;
  Sieve[i-1]?p;               # p is a prime
  do Sieve[i-1]?next ->       # receive next candidate
    if (next mod p) != 0 ->   # if it might be prime,
      Sieve[i+1]!next;        #   pass it on
    fi
  od
}
```

**Figure 7.15** Sieve of Eratosthenes in CSP.

```
CHAN OF BYTE comm :
PAR
  WHILE TRUE     -- keyboard input process
    BYTE ch :
    SEQ
      keyboard ? ch
      comm ! ch
  WHILE TRUE     -- screen output process
    BYTE ch :
    SEQ
      comm ? ch
      display ! ch
```

Producer/consumer example in Occam.

```
PROC Copy(CHAN OF BYTE West, Ask, East)
  BYTE c1, c2, dummy :
  SEQ
    West ? c1
    WHILE TRUE
      ALT
        West ? c2    -- West has a byte
          SEQ
            East ! c1
            c1 := c2
        Ask ? dummy  -- East wants a byte
          SEQ
            East ! c1
            West ? c1
```

Copy process in Occam.

```
COPY1 = West?c:char -> East!c -> COPY1


COPY = West?c1:char -> COPY2(c1)

COPY2(c1) =   West?c2:char -> East!c1 -> COPY2(c2)
            []
              East!c1 -> West?c1:char -> COPY2(c1)


GCD = Input?id.x.y -> GCD(id, x, y)

GCD(id, x, y) = if (x = y) then
                  Output!id.x -> GCD
                else if (x > y) then
                  GCD(id, x-y, y)
                else
                  GCD(id, x, y-x)
```

Examples of Modern CSP.

```
#include "linda.h"
#define LIMIT 1000     /* upper bound for limit */

void worker() {
  int primes[LIMIT] = {2,3};  /* table of primes */
  int numPrimes = 1, i, candidate, isprime;

  /* repeatedly get candidates and check them */
  while(true) {
    if (RDP("stop"))  /* check for termination */
      return;
    IN("candidate", ?candidate);    /* get candidate */
    OUT("candidate", candidate+2);  /* output next one */
    i = 0; isprime = 1;
    while (primes[i]*primes[i] <= candidate) {
      if (candidate%primes[i] == 0) { /* not prime */
        isprime = 0; break;
      }
      i++;
      if (i > numPrimes) {  /* need another prime */
        numPrimes++;
        RD("prime", numPrimes, ?primes[numPrimes]);
      }
    }
    /* tell manager the result */
    OUT("result", candidate, isprime);
  }
}

real_main(int argc, char *argv[]) {
  int primes[LIMIT] = {2,3};  /* my table of primes */
  int limit, numWorkers, i, isprime;
  int numPrimes = 2, value = 5;
  limit = atoi(argv[1]);  /* read command line */
  numWorkers = atoi(argv[2]);

  /* create workers and put first candidate in bag */
  for (i = 1; i <= numWorkers; i++)
    EVAL("worker", worker());
  OUT("candidate", value);

  /* get results from workers in increasing order */
  while (numPrimes < limit) {
    IN("result", value, ?isprime);
    if (isprime) {   /* put value in table and TS */
      primes[numPrimes] = value;
      OUT("prime", numPrimes, value);
      numPrimes++;
    }
    value = value + 2;
  }
  /* tell workers to quit, then print the primes */
  OUT("stop");
  for (i = 0; i < limit; i++)
    printf("%d\n", primes[i]);
```

```
#include <mpi.h>

main(int argc, char *argv[]) {
  int myid, otherid, size;
  int length = 1, tag = 1;
  int myvalue, othervalue;
  MPI_Status status;

  /* initialize MPI and get own id (rank) */
  MPI_Init(&argc, &argv);
  MPI_Comm_size(MPI_COMM_WORLD, &size);
  MPI_Comm_rank(MPI_COMM_WORLD, &myid);

  if (myid == 0) {
    otherid = 1; myvalue = 14;
  } else {
    otherid = 0; myvalue = 25;
  }
  MPI_Send(&myvalue, length, MPI_INT, otherid,
           tag, MPI_COMM_WORLD);
  MPI_Recv(&othervalue, length, MPI_INT, MPI_ANY_SOURCE,
           tag, MPI_COMM_WORLD, &status);
  printf("process %d received a %d\n", myid, othervalue);

  MPI_Finalize();
}
```

**Figure 7.17** MPI program to exchange values between two processes.

```
// Read a file and send it back to a client
import java.io.*; import java.net.*;

public class FileReaderServer {
 public static void main(String args[]) {
  try {
   // create server socket and
   // listen for connection on port 9999
   ServerSocket listen = new ServerSocket(9999);

   while (true) {
     System.out.println("waiting for connection");
     Socket socket = listen.accept();  // wait for client
     // create input and output streams to talk to client
     BufferedReader from_client =
       new BufferedReader(new InputStreamReader
         (socket.getInputStream()));
     PrintWriter to_client = new PrintWriter
         (socket.getOutputStream());

     // get filename from client and check if it exists
     String filename = from_client.readLine();
     File inputFile = new File(filename);
     if (!inputFile.exists()) {
       to_client.println("cannot open " + filename);
       to_client.close(); from_client.close();
       socket.close();
       continue;
     }

     // read lines from filename and send to the client
     System.out.println("reading from file " + filename);
     BufferedReader input =
       new BufferedReader(new FileReader(inputFile));
     String line;
     while ((line = input.readLine()) != null)
       to_client.println(line);
     to_client.close(); from_client.close();
     socket.close();
  }}
  catch (Exception e) // report any exceptions
    { System.err.println(e); }
}}
```

**Figure 7.18** A file reader server in Java.

```
// Get file from RemoteFileServer and print on stdout
import java.io.*; import java.net.*;

public class Client {
 public static void main(String[] args) {
  try {
   // read command-line arguments
   if (args.length != 2) {
     System.out.println("need 2 arguments");
     System.exit(1);
   }
   String host = args[0];
   String filename = args[1];

   // open socket, then input and output streams to it
   Socket socket = new Socket(host,9999);
   BufferedReader from_server =
     new BufferedReader(new InputStreamReader
       (socket.getInputStream()));
   PrintWriter to_server = new PrintWriter
       (socket.getOutputStream());

   // send filename to server, then read and print lines
   // until the server closes the connection
   to_server.println(filename); to_server.flush();
   String line;
   while ((line = from_server.readLine()) != null) {
     System.out.println(line);
   }
  }
  catch (Exception e)    // report any exceptions
    { System.err.println(e); }
}}
```

**Figure 7.19** A file reader client in Java.