Different Facets of Coordination

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Roots of Coordination _ 1

- *Multilinguality* is able to:
  - Support diverse programming paradigms
  - Provide interoperability between them
  - Accommodate diverse execution models
  - Combine code written in a mixture of them but also provide orthogonal programming interfaces
- Typical cases of realizing a multilingual framework is by means of *Module Interconnection Languages* and *Compiler Target Languages*

Roots of Coordination _ 2

- Multilinguality is closely related to *heterogeneity*, since heterogeneous systems demand that the language to be used must support different models of computation (difficult)
- Thus, we resort to using a mixture of languages
- Related historical models are also those of:
  - Blackboard systems, developed traditionally for DAI
  - Objected-Orientation and Actor systems

The Coordination Paradigm

- Separates the computational concerns in some system from the other concerns
- "Computational" can mean a number of things:
  - Execution of software components
  - Operation of hardware devices
  - Behaviour of human beings
- "Other concerns" can also have different meanings such as *communication*, *cooperation*, *synchronization*, etc.

What is Coordination

- Coordination is managing dependencies between activities (Malone and Crowston)
- Coordination is the process of building programs by gluing together active pieces (Carriero and Gelernter)
- Coordination is the additional information processing performed when multiple, connected actors pursue goals that a single author pursuing the same goals would not perform

Coordination Models and Languages

- A *coordination model* is the glue that binds together active pieces
- Ciancarini defines it as a triple **<E, L, M>**
  - E are the entities being coordinated
  - L the media used to coordinate them
  - M the semantic framework, the mode adheres to
- A *coordination language* is the linguistic embodiment of a coordination model

Classification of Coordination Formalisms

- How one should classify coordination models and languages?
  - In terms of the nature of what is being coordinated (types of components)?
  - In terms of the kind of languages being involved?
  - In terms of application domains?
  - In terms of underlying architectures assumed?
  - In terms of other issues such as scalability, openness, etc?

Defining the State of Computation: Data- vs Control-Driven Coordination

- In the data-driven category of models, the state of the computation is usually defined in terms of both *what* is being coordinated (i.e. the data being sent or received) and *how* coordination is achieved (i.e. the coordination patterns employed
- In the control-driven category, the state is usually defined in terms only of the configuration apparatus set up between the involved components, data itself is of little significance

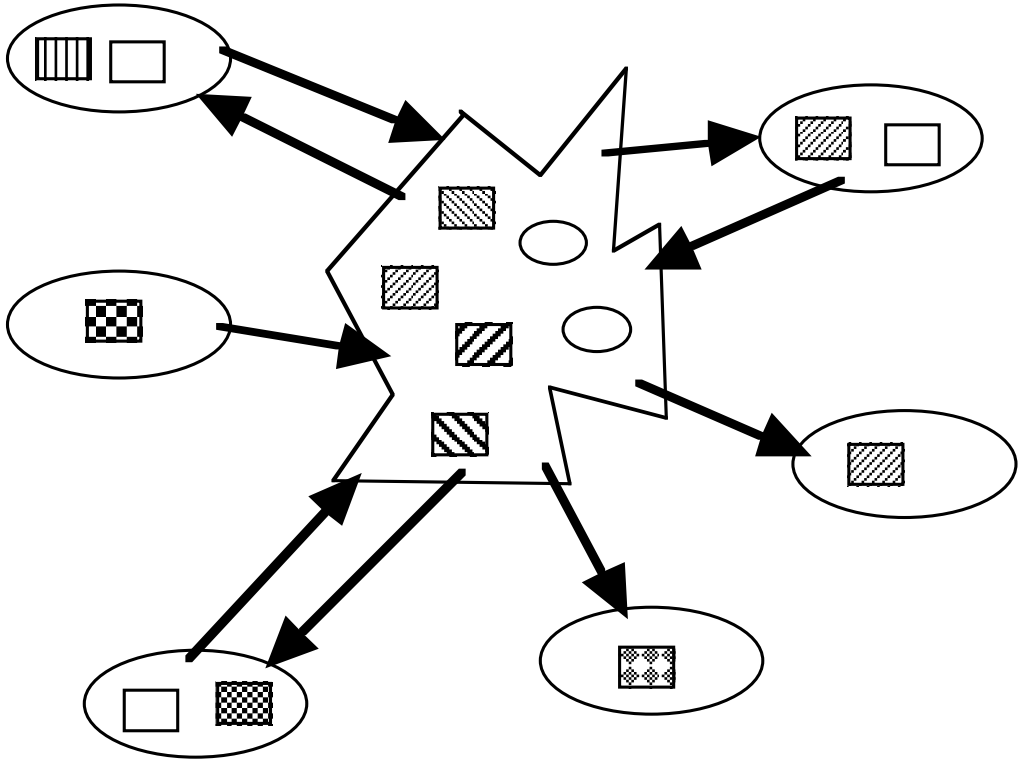
Bird-Eye's View of Data-Driven Coordination

- A process is interested in both handling data as well as setting up coordination patterns
- Stylistically and linguistically, coordination code is intermixed with computation code
- Usually, the coordination "language" is a set of primitives that have to use a host programming language
- The communication medium is essentially based on the Virtual Shared Memory metaphor

Bird-Eye's View of Control-Driven Coordination

- There is a clear separation of components handling data from those that set up coordination patterns
- The two types of code are also clearly separated
- A fully-fledged coordination language is required to work together with some computational one(s)
- Point-to-point "Occam" type of communication is employed with processes having well defined input-output interfaces

Data-Driven Coordination Formalisms



Main Characteristics of Data-Driven Coordination Formalisms

- VSM is realized as as *shared dataspace*, a common, content-addressable data structure
- It is independent in time and space
- Data is represented as a generic tuple structure, in some cases flat, in other cases structured
- Mechanisms for retrieving data vary, and include pattern matching, multiset rewriting, etc.
- Issues of security and openess are handled by adopting a non-flat structure with localized access

Linda

- A set of 4++ primitives (`in` and `inp`, `rd` and `rdp`, `out`, `eval`) are used to access the *Tuple Space* by associative *pattern matching*
- Easy to use, less easy to implement efficiently, issues of tuple storage, exact implementation of `eval`, etc.
- Linda has many friends: C, Prolog, Java, Eiffel, to name but a few; also, it can coexist nicely with many paradigms (imperative, declarative, o-o)

Dining Philosophers in Linda

```
#define NUM 5

philosopher(int i)
{
  while (1)
  {
    think();
    in("room ticket");
    in("fork",i);
    in("fork",(i+1)%NUM);
    eat();
    out("fork",i);
    out("fork",(i+1)%NUM);
    out("room ticket");
  }
}
```

```
main()
{
 int i;
 for (i=0, i<=NUM, i++)
   {
    out("fork",i);
    eval(philosopher(i));
    if (i<(NUM-1))
      out("room ticket");
    }
 }
```

Piranha: Better Load Balancing for Linda _ 1

- Features *adaptive parallelism*, i.e. processor assignment to processes changes dynamically
- A feeder distributes computation and collects results, a number of piranhas perform computations
- Piranhas are statically distributed over a network of w/s, and don't migrate
- They are active if the workload of the node on which they reside allows it

Piranha: Better Load Balancing for Linda _ 2

- Piranhas retreat when the node on which they reside is claimed back by the system, post the rest of the work to the tuple space for other piranhas
- Typical application areas of the model is scientific computing (LU decompositions and Monte Carlo simulations)

Typical Structure of a Piranha program

```
#define DONE -999
int index;

feeder()
{
 int count;
 struct Result result;

 /* put out the tasks */
 for (count=0; count<TASKS; count++)
   out("task",count);

 /* help compute results */
 piranha();

 /* collect results */
 for (count=0; count<TASKS; count++)
   in("result",count,?result_data);
}

retreat()
{
 /* replace current task */
 out("task",index);
}
```

```
piranha()
{
 struct Result result;

  while (1)
  {
    in("task",?index);
    if (index==DONE)
      {
      /* all tasks are done */
       out("task",index);
       }
        else
       {
        /* do the task */
        do_work(index,&result);
        out("result",index,result);
        in("tasks done",?index);
        out("tasks done",i+1);
           if ((i+1)==TASKS)
              out("task",DONE);
        }
      }
  }
```

Bonita: Finer notion of Tuple Retrieval _ 1

- Effectively differentiates in the the `in` and `rd` operations between *asking* for a tuple and actually *getting* it
- `rquid=dispatch(ts,tuple)` puts `tuple` in `ts` and returns a tuple id to be used by other processes to retrieve it
- `rquid=dispatch(ts,template,d|p)` retrieves a tuple from `ts` matching `template`, by removal (`d`) or copying (`p`), and returns its id

Bonita: Finer notion of Tuple Retrieval _ 2

_ `rquid=dispatch_bulk(ts1,ts2,templa te,d|p)`
moves (`d`) or copies (`p`) from `ts1` to `ts2` all tuples matching `template`

_ `arrived(rquid)`
moves (`d`) or copies (`p`) from `ts1` to `ts2` all tuples matching `template`

_ `obtain(rquid)`
suspends until the tuple `rquid` is available

Retrieving Tuples in Bonita

- Linda

```
in("ONE");
in("TWO");
in("THREE");
```

Bonita

```
int rqid1, rqid2, rqid3;

rqid1=dispatch(ts,"ONE",d);
rqid2=dispatch(ts,"TWO",d);
rqid3=dispatch(ts,"THREE",d);

obtain(rqid1);
obtain(rqid2);
obtain(rqid3);
```

- All dispatches are done in parallel, retrieving of tuples is overlapped

Finer Notion of Non-Deterministic Retrieval in Bonita

- Linda

```
while(1)
{
 if (inp("ONE"))
   {do_first(); break;}
 if (inp("TWO"))
   {do_second(); break;}
}
```

Bonita

```
int rqid1, rqid2;

rqid1=dispatch(ts,"ONE",d);
rqid2=dispatch(ts,"TWO",d);

while(1)
{
 if (arrived(rqid1))
  {do_first(rqid1); break;}
 if (arrived(rqid2))
  {do_second(rqid2); break;}
}
```

Bauhaus Linda: More sophisticated Tuple Matching Based on Multisets

- No differentiation between active and passive tuples, tuples and tuple spaces, etc.
- `out {x->R}` applied to `{a {x y Q} {{z}} P}` by `P` yields `{a {x y Q R} {{z}} P}`
- `mset m:=rd {x}` applied to `{a b b {x y} {{z}} P}` by `P` makes `m` get the value `{x y}`
- `mset m:=in {x}` applied to `{a {x y Q} {R {z}} P}` by `P` makes `m` get the value `{x y Q}` and becomes a live set (due to `Q`)

Bauhaus Linda: Structured Multisets

- `move {w}` executed on
  `{a b b {x y Q} {w {z}} P}` by `P`, yields
  `{a b b {x y Q } {w {z} P}}`
- Two variants of `move`, `up` and `down`, cause the issuing process to move up and down the hierarchy

Objective Linda: "Object-Oriented Bauhaus Linda" for Open Systems

- Tuples and tuple spaces are substituted by *objects* and *object spaces*, the former described in an *Object Interchange Language*
- Object spaces are accessible through logicals, i.e. object space references
- Object spaces can be organized in hierarchies and communication can be achieved via several object spaces

Objective Linda's Primitives _ 1

- `bool out(MULTISET *m, double tout)`
  moves the objects in `m` into the object space, operation must be completed within `tout` secs
- `bool eval(MULTISET *m,double tout)`
  similar, but the objects are also activated
- `bool in(OIL_OBJECT *o, int min, int max, double tout)`
  tries to remove at least `min` but not more than `max` objects matching `o` within `tout` secs

Objective Linda's Primitives _ 2

- `bool rd(OIL_OBJECT *o, int min, int max, double tout)`
  same as before, but copies of these objects are cloned
- `infinite_matches` and `infinite_time` are used to indicate infinite number of matched objects in `min` or `max`, and no timeout constraints in `tout` respectively

Law-Governed Linda: Logical Regulation of Tuple Space Traffic

- Whereas the previous models extend the basic language, Law-Governed Linda introduces *controllers*, which interpose themselves between the Tuple Space and the processes accessing it
- All controllers execute the "law" and allow traffic between every process and the tuple space only if it adheres to it
- A law typically specifies access rights, creates local spaces, enforces security mechanisms, etc.

A Secured Message Exchange in Law-Governed Linda

```
_ out([msg,from(Self),to(_)|_])
      :- do(complete).
  in([msg,from(…),to(Self)|_])
      :- do(complete) :: do(return).
  out([X|_]) :- not(X=msg), do(complete).
  in/rd([X|_]) :- not(X=msg),do(complete)
                  :: do(return).
```

- where a message is of the form

  `[msg,from(s),to(t),contents]`

LAURA: Linda for Modelling Open Distributed Systems

- In LAURA, the common communication medium is a *service space* where *agents* post and retrieve offered *services*
- These are described as *interface signatures* comprising a set of *operation signatures*
- Communications among agents is realized by exchanging forms of three types: *service-offer*, *service-request*, and *result-form*
- For signatures a Service Type Language is used

A Service Offered in LAURA

```
SERVE large-agency operation
(getflightticket : cc * <day,month,year> * dest
                   -> ack * <dollar,cent>;
 getbusticket    : cc *
                   <thedate.day, thedate.month,
                   thedate.year> * dest
                   -> ack * <dollar,cent> *line;
 gettrainticket  : cc * <day,month,year> * dest
                   -> ack * <dollar,cent>).
SERVE
```

- Three services are offered, the code of the selected service will be bound to `operation`

A Service Requested in LAURA

```
SERVICE small-agency
 (getflighttticket : cc * <thedate.day,
                           thedate.month,
                           thedate.year>
                     * dest
                     -> ack * <dollar,cent>).
SERVICE
```

- `small-agency` invokes the specified service, passes along parameters such as `cc` and `dest` and waits for an `ack` message with the value of the ticket

Ariadne/HOPLa: Linda for Collaborative Computing

- In Ariadne, the shared dataspace holds tree-shaped data, structured or semi-structured and type definitions governing its structure
- The associated Hybrid Office Language is used to model process behaviour in the form of flexible records
- Some useful constructors is `Set` for collections, `Action` for tasks to be performed either sequentially (`Serie`) or in parallel (`Parl`), etc.

Coordinating an Electronic Discussion in Ariadne/HOPLa

```
Discussion<Process(
    group -> Set+Action( type -> Actor;
                         value -> PS: set);
    discuss -> Thread<Data+Serie(
        message -> String+Action(actor
                                 -> {p | p in PS});
        replies -> Set+Parl(type -> Thread)))
```

- First the group is defined, then the discussion starts with a triggering message, followed by replies in any order by the rest of the actors, each one of them starting an independent thread

Sonia: Applying the Linda Metaphor to Modelling Activities in I.S.

- Sonia is not really an extension of Linda, but rather an adaptation of the latter so that the Linda metaphor can be used in an intuitive way by non specialists in coordination or, indeed, C.S.
- There is an agora, accessed by actors, the latter communicating by posting messages formed as named tuples
- A timeout functionality is introduced, an integral element of any framework modelling I.S.

Communicating in Sonia

- The usual `out`, `in`, and `rd` names have been replaced by more intuitive ones such as `post`, `pick`, and `peek`
- There is also a `cancel` primitive for timeouts
- Posted tuples are named such as `Tuple(:shape "square" :color "red")`, and are retrieved via templates such as `Template(:shape any :color Rule("value='red' or value='blue'"))`

Jada/SHADE: Linda for the WWW

- The shared dataspace paradigm can be realized naturally and profitably in the WWW, and the coordination paradigm can be used for orchestrating the execution of web-based applications, such as groupware, workflow, etc.
- Jada (Java - Linda) can be seen as a basic infrastructure for building such environments
- It can be used for expressing mobile object coordination and multithreading (e.g. PageSpace)

Jada Model

- Classes such as `TupleServer` and `TupleClient` are provided for realizing remote access to a tuple space
- Communication is done via sockets
- A `TupleClient` must know the host and port-id of the `TupleServer`
- Jada can be used either per se, or as a means for designing and implementing higher level coordination languages for the WWW

A Ping-Pong in Jada

```
_  //--PING--
   TupleClient ts = new TupleClient(ts_host);
   while (true) {ts.out(new Tuple("ping"));
                  Tuple tuple = ts.in(new Tuple("pong"));
                 }
   Ping ping = new Ping();
   ping.run();

   //--PONG--
   TupleClient ts = new TupleClient(ts_host);
   while (true) {ts.out(new Tuple("pong"));
                  Tuple tuple = ts.in(new Tuple("ping"));
                 }
   Pong pong = new Pong();
   pong.run();
```

The SHADE Model

- SHADE can be seen as a higher level abstraction of Jada
- Whereas Jada peforms singleton level transactions, SHADE is based on multiset rewriting
- Each SHADE object has a name, class and state; the name is the pattern for delivering messages; the type defines the object's behaviour; the state is the contents of the object's multiset

A Ping-Pong in SHADE

```
class ping_class =
{
 in do_ping;
 send pong, do_pong
 #
 in done;
 terminate
}
```

```
class pong_class =
{
  in do_pong;
  send ping, do_ping
  #
  in done;
  terminate
}
```

- Each class has two methods; when the proper message appears in an object's multiset, say `ping`, the method is triggered and sends `pong`, etc. until a `done` appears for termination

GAMMA: Chemical Reactions via Multiset Rewriting

- GAMMA combines the notion of Chemical reactions in CHAM-like models with multiset rewriting
- A program is viewed as a pair (Reaction Condition, Action), and its execution involves replacing those elements in a multiset satisfying the reaction condition by the products of the action
- This process continues until no more such reactions are possible and the system is stable

The GAMMA Rewriting Operator

- The above behaviour can be captured by means of the G operator, which is defined as follows:

```
G((R1,A1),…,(Rm,Am)) (M) =
  if   _ i _ [1,m] _ x1,…,xn _ M,  Ri(x1,…,xn)
  then M
  else let x1,…,xn _ M, let i _ [1,m]
       such that  Ri(x1,…,xn) in
    G((R1,A1),…,(Rm,Am)) ((M-{x1,…,xn})+Ai(x1,…,xn))
```

where {…} represents multisets and (Ri,Ai) are pairs of closed functions representing reactions

A GAMMA Example

- What the `G` operator says is that the effect of a pair `(Ri,Ai)` on a multiset `M` is to replace in `M` a subset of elements `{x1,…,xn}` such that `Ri(x1,…,xn)` is true for the elements of `Ai(x1,…,xn)`
- A prime number generator is written as follows:

```
prime_numbers(N) = G((R,A))
                   ({2,…,N}) where
                   R(x,y) = multiple(x,y)
                   A(x,y) = {y}
```

Other GAMMA Operators _ 1

- **T**`ransmuter(C,f)`, applies operation `f` to all the elements of the multiset until no element satisfies the condition `C`

  R`educer(C,f)`, reduces the size of the multiset by applying the operation `f` to pairs of elements satisfying `C`

  O`ptimiser(<,f1,f2,S)`, optimises the multiset according to a criterion expressed through the ordering < between the functions `f1` and `f2`, while preserving the structure `S` of the multiset

Other GAMMA Operators _ 2

- **E**`xpander(C,f1,f2)`, which decomposes the elements of a multiset into a collection of basic values according to the condition `C` and by applying `f1` and `f2` to each element
  S`(C)`, which removes from the multiset all those elements satisfying `C`

Fib in GAMMA

```
_ fib(n)=m where
  {m}= sigma(gen({n}))
  gen(N)=G((R1,A1),(R2,A2))(N) where
         R1(n)=n>1 A1(n) R2(0)=true A2(0)={1}
  sigma(M)=G((R,A))(M) where
           R(x,y)=true A(x,y)={x+y}
_ fib(n) = add(zero(dec({n})))
  dec = E(C,f1,f2)
        where C(x)=x>1, f1(x)=x-1, f2(x)=x-2
  zero = T(C,f) where C(x)=(x=0), f(x)=1
  add = R(C,f) where C(x,y)=true, f(x,y)=x+y
```

LO: Linear Logic Meets Multiset Rewriting

- Linear Objects view the shared dataspace as a multiset; messages are broadcasted into it and also retrieved by means of a set of interaction rules
- Messages posted to the shared medium are treated as resources which are “consumed” when taken out from it, thus behaving as Linear Logic ops
- `<multiset> <broadcast> <built-ins>  <goal>`

```
multiset = a1 @ … @ an
broadcast = ^a | ^a @ broadcast
goal= a1 @ … @ an | goal1 & … & goaln | #t | #b
```

Coordination in LO

- The code fragment below is part of a program for the Mastermind game

```
coder(S) @ current(I) @ ^go(I)   coder(S)
/* coder calls the player (“go(I)”) */

coder(S) @ try(I,G) players(N) @ ^result(I,G,A)
@ { answer(S,G,A) next_player(N,I,I1) }
          coder(S) @ current(I1) @ players(N).
/* player I gets answer A to the guess G */

coder(S) @ try(I,G) @ ^victory(I,G) @
    { answer(S,G,G) }   #t.
/* player I has guessed the answer A */
```

COOLL: Modular LO

- COOLL extends LO with modularity and group communication; a program is a set of theories:
  `theory` `theory_name  method1 # … # methodN`
- Communication is either group or broadcast
  `Communications = ^A | !(dest,msg)`
  `dest` being the name of a theory to receive `msg`
- Methods have the form `Conditions => Communications=>Body` where the first invokes methods, the second broadcasts and the third changes configurations

The Mastermind in COOLL

```
_  theory coder
       current(I) => !(players(N),go(I)) => #b
   #
       try(I,G) @{ code(S) @ players(N) } @
                   { { answer(S,G,A),
                       next_player(N,I,I1) } }
                   => !(players(N ),result(I,G,A))
                   => current(I1)
   #
       try(I,G) @{ code(S) } @
                   { { answer(S,G,G)} }
                   => ^victory(I,G)
                   => #t.
```

Synchronizers: Law Enforcers on Objects

- Synchronizers can be seen as the equivalent of the controllers in Law-Governed Linda for the case of an Actor system
- They express coordination patterns by specifying and enforcing constraints that restrict access to a set of objects
- Constraints are defined in terms of object interfaces rather than internal computations performed by them

Xpect and CLF: Coordination for Workflow

- The Coordination Language Facility and its system Xpect is another evolution of LO
- In CLF *coordinators* coordinate resource manipulations on *participants* by means of scripting rules
- The LHS of a scripting rule contains tokens which are intended to be removed from participants while the RHS contains tokens to be inserted into the involved participants

CLF Rules and Signatures

- The rule: `p(X,Y) @ q(Y,Z) <> r(X,Z)`
  - (i) finds a resource satisfying the property `p(X,Y)` and another one satisfying the property `q(Y,Z)` for consistent values `X`, `Y`, `Z`
  - (ii) extracts these two resources atomically
  - (iii) inserts a resource satisfying `r(X,Z)`
- Signatures are used to denote i-o relationships:
  `p(X,Y): -> X,Y` `q(X,Y): X -> Y`
  Here, `p`'s arguments are both output while `q`'s first one is input (required) and the second one output

Hotel Reservation in CLF

```
customer(a,b): -> a,b is LOOKUP Agency.customer
roomRes(a,b): a,b -> is LOOKUP Agency.roomRes
vacancy(a,b,c): a,b -> c is LOOKUP Hotel.vacant

customer(name,date) @ vacancy(date,"single",no)
    <> roomRes(name,no)
```

- Tokens are assigned services, customer generates requests like `("George","1/1/00"), ("John","2/2/99")`, an instance of the rule is created for every request proceeding in parallel
- Further rules are needed to resolve conflicts

Synchronizers

- Based on the Actor model, they are a set of tools able to express coordination patterns within a multi-object language framework
- This is expressed by specifying and enforcing constraints that restrict invocation of objects
- Constraints are defined in terms of object interfaces, rather than internal representations
- An abstract syntax is used, independent of particular languages

A Synchronizer for Dining Philosophers

```
PickUpConstraint(c1,c2,phil)
{
 atomic((c1.pick(sender) where sender=phil),
        (c2.pick(sender) where sender=phil)),
(c1.pick where sender=phil) stops
}
```

- The synchronizer enforces atomic access to the two chopsticks `c1` and `c2`; when `phil` has successfully acquired both chopsticks, the constraint is terminated. The synchronizer applies only to `pick` messages (sent by an `eat` process)

MESSENGERS: Coordination of Mobile Code for Distributed Systems

- A messenger is a message carrying not only data but also a process to manipulate the data
- Each node in a distributed system visited by a messenger executes the process until some navigational command tells it to move elsewhere
- A distributed applications is viewed as a collection of functions whose coordination is managed by a group of messengers
- Inter- and Intra-object coordination is supported

A Manager-Worker Mobile farm in MESSENGERS _ 1

```
_  manager_worker()
   {
    create(ALL);
    hop(ll = $last);
    while ((task = next_task()) != NULL)
       {
        hop(ll = $last);
        res = compute(task);
        hop(ll = $last);
        deposit(res);
       }
   }
```

A Manager-Worker Mobile farm in MESSENGERS _ 2

- The Messenger script is injected into the init node of some daemon
- Logical nodes are created connected to the current node on every neighboring daemon, replicas of the script are created on each node and activated
- Each Messenger hops back to the original node via the most recently traversed logical link (`$last`), gets a new task to perform, hops back to its node, does the task and deposits the result back

The hop Primitive

- `hop(ln=n; ll=l; ldir=d)`
  `ln` is a logical node, `ll` a logical link, `ldir` the link's direction
- `(n,l,d)` is a destination specification, `n` being an address, variable or constant (including the special node `init`), `l` a virtual link, variable or constant (denoting a jump to the designated node), `d` a symbol denoting direction ("forward", "backward", "either")

Compositional Programming

- Shares the same goals with coordination, namely reusability of code, separation of communication from computational concerns, etc
- In a compositional system, the properties of program components are preserved when combined with other components
- Recurring patterns of parallel computation (*mergers*, *streamers*) can be identified, isolated and reused

Compositional Programming Derived from Concurrent Logic Programming

- Essentially the CLP formalism is used to express the coordination patterns, the computational parts written in other languages
- Over the years some particular coordination patterns in CLP have been identified and are offered to the user as logical "*skeletons*"
- These skeletons can be realized in either a concrete CLL (e.g. Strand) or by means of a generic notation (e.g. PCN)

Strand

- Strand is the simplest of CLLs, derived from Parlog and Flat Concurrent Prolog
- It features *one-way unification*, *flat guards*, *dependent AND-parallelism*, *list composition* and *shared single-assignment variables*
- The WAM-based implementation of Strand is considered to be one of the fastest in the family of CLLs (the Janus group being the fastest)
- Computational models are written in C, Fortran

Genetic Sequence Alignment Algorithm in Strand (part of the code)

```
_  cps([Seq|Sequences],CpList) :-
     CpList := [CPs|CpList1],
     c_critical_points(Seq,CPs),
     cps(Sequences,CpList1).
   cps([],CpList) :- CpList := [].

   divide(Seqs,Pin,Alignment) :-
     Pin =\= [] | split(Seqs,Pin,Left,Right,Rest),
                  align_chunk(Left,LAlign) @ random,
                  align_chunk(Right,RAlign) @ random,
                  align_chunk(Rest,RestAlign) @ random,
              combine(LAlign,RAlign,RestAlign,Alignment).
   divide(Seqs,[],Alignment) :-
     c_basic_align(Seqs,Alignment).
```

Program Composition Notation (PCN)

- Strand is a concrete CL language and therefore requires a WAM-based implementation
- PCN is a set of notations, able to express concurrent logic coordination patterns
- Being essentially a set of add-on primitives, PCN can be implemented as an extension of some host computational language (typically C, C++, Fortran, etc.)
- Of course, the system is now also faster

Genetic Sequence Alignment Algorithm in PCN (same code)

```
_  cps(sequences,cplist)
   { ? sequences ?= [seq|sequences1] ->
           { ||cplist = [cps|cplist1],
                 c_critical_points(seq,cps),
                 cps(sequences1,cplist1)
           },
           sequences ?= [] -> cplist = []
   }
   divide(seqs,pin,alignment)
   { ? pin != [] ->
           { || split(seqs,pin,left,right,rest),
              align_chunk(left,lalign) @ node(random),
             align_chunk(right,ralign) @ node(random),
            align_chunk(rest,restalign) @ node(random),
            combine(lalign,ralign,restalign,alignment)
           },
           pin == [] -> c_basic_align(seqs,alignment)
   }
```

Compositional Programming Derived from Functional Programming

- Here skeletons are realized as higher order functions which represent reusable coordination patterns, related to data partitioning, placement and communication
- The virtues of functional programming (such as compositionality of functions, lack of side-effects, ability to transform programs while preserving their properties, etc.) allow reasoning of programs to be done at the functional specification level

Configuration Functional Skeletons

```
distribution (f,p) (g,q) A B
  = align  (p _ partition f A)
           (q _ partition g B)
```

- functions `f` and `g` specify the partitioning strategy of `A` and `B`, respectively, and `p` and `q` specify any initial data rearrangement that may be required
- `partition` divides a sequential array into a parallel array composed of sequential subarrays
- `align` pairs subarrays in two distributed arrays together into a new configuration, an array of tupls

Computational Function Skeletons

- A skeleton for a matrix addition performed in parallel using the previous configuration skeleton:

```
matrixAdd A B = (gather _ map _ SEQ_ADD)
                (distribution fl dl)
  where  C = SeqArray ((1..SIZE(A,1)), (1:SIZE(A,2)))
         fl = [((row_block p),id),
               ((row_block p),id),
               ((row_block p),id)]
         dl = [A,B,C]
```

- Note that `SEQ_ADD` is defined in some other computational language

CoLa: Coordination for DAI

- CoLa is a set of primitives, independent from the host language, especially suited for Distributed AI
- In CoLa one can express communication abstractions (*correspondents*) and topologies, and *local views of computation* for a process
- For each process, there is a *Range of View* which defines the set of correspondents the process can communicate with, and a *Point of View* indicating the specific communication topology adopted

A Point of View in CoLa

```
_  with csTopoVision          -- CoLa base topology class
   class csTreeVision is        -- Define Point of View
      father(csCor, const csCor);   -- father node in PV
      son(csCor, const csCor);        -- son node in PV
   end class;

   implementation csTreeVision is   -- Implem of the PVs
      son is rule son(X,Y)
                  :- csTopoVision.isLinked(X,Y).
      father is rule father(X,Y) :- son(Y,X).
      -- Prolog like clauses
   end implementation;
```

A Range of Vision in CoLa

```
_  procedure p(T: in csTreeVision) is
     F: csSet := {X in T | father(X,self)};
     -- Compute correspondence
     S: csSet := {X in T | son(X,self);
     myMsgDep :=
        csMsgSendAssDep(highest_prio(S),T,csREAD);
     myMsgId :=
        csMsgAss(myMsgBody,myMsgDep,csFIFO);
     csMsgSend(myMsgId-- Send in the tree topology
    … … …
   end procedure
```

Combining Task and Data Parallelism

- The issue of combining task parallelism with data parallelism is closely related to that of coordinating multidisciplinary applications
- In a way, data parallelism can be viewed as the computational part of a coordination based framework, whereas task parallelism plays the role of communication
- Many of the models proposed here (Braid, Fx, Opus, Orca) use a shared communication medium

Braid

- Braid is a data parallel extension to the object-oriented, C++ like, task parallel language Mentat
- Braid extends Mentat by introducing data parallel Mentant classes, whose objects are partitioned among a number of available processes; operations on these objects are executed in a data parallel way
- Communication between tasks is achieved by means of shared objects

Combining Task and Data Parallelism in Braid

```
_ dataparallel mentat class data_par_obj {
                // private member variables
     public:
        int AGG row_sums ROW();
        …
  }

  float x,z; int y;
  control_par_obj A, B;
  data_par_obj my_image;

  x=A.op1(); y=my_image.row_sums();
  z=B.op1(x,y);
```

Fx

- Fx adds task parallel directives to HPF
- A task corresponds to an execution of a *task subroutine*, which is a data parallel subroutine where only its actual arguments can be modified
- A number of task subroutines can be invoked within a parallel session (task parallelism)
- Communication is done via a shared medium at procedure boundaries and is the responsibility of the compiler rather than the programmer

Data Parallelism in Fx

```
template t(n)
align A(i,j) with t(i)
align B(i,j) with t(j)
distribute t(cyclic)
do i=1,n
  A(i,:) = A(i,:) + B(:,i)
enddo
```

- The **`template`**, **`align`**, and **`distribute`** directives are used to distribute the rows of `A` and the columns of `B` cyclically across the node array; loop iterations are independent and can execute in parallel

Task Parallelism in Fx

```
begin parallel
   do i=1,10
      call src(A,B) output:A,B
      call p1(A) input:A output:A
      call p2(B) input:B output:B
      call sink(A,B) input: A,B
   enddo
end parallel
```

- Forty tasks are created, in each iteration `src` sends the two arrays to `p1` and `p2`, the latter after operating on them pass them to `sink`; `p1` and `p2` can execute in parallel, and pipelining is supported

Opus

- A coordination superlanguage for HPF, where processes communicate via a *Shared Abstraction (SDA)*, a Linda-like common forum
- An SDA is in fact an ADT, containing data specifying its state and methods for manipulating this state
- SDAs can be used either as data servers between concurrently executing processes (data par) or as computation servers driven by a controlling task

A Data Server for a FIFO Bounded Buffer in Opus

```
_  SDA TYPE buffer_type(size)
     INTEGER              ::size
     REAL, PRIVATE        ::fifo(0:size-1) ! FIFO buffer
     INTEGER, READ ONLY ::count=0       ! no of full elements
     INTEGER, PRIVATE     ::px=0              ! producer index
     INTEGER, PRIVATE     ::cx=0              ! consumer index
          …
     CONTAINS
         SUBROUTINE put(x) WHEN (count .LT. size)
             ! implementation in Fortran
         END
         SUBROUTINE get(x) WHEN (count .GT. 0)
             ! implementation in Fortran
         END
           …
   END buffer_type
```

Managing the Task Parallelism for the FIFO Buffer

```
PROCESSORS R(128)

SDA(buffer_type)::buffer1, buffer2
…
CALL buffer1%CREATE(256) ON PROCESSORS R(1)
CALL buffer2%CREATE(1024) ON PROCESSORS R
```

- Each one of the two `CREATE` statements generates an SDA with some buffer size, the first goes to `R(1)` and the second to the rest of the processors; `buffer1` and `buffer2` are used as handles

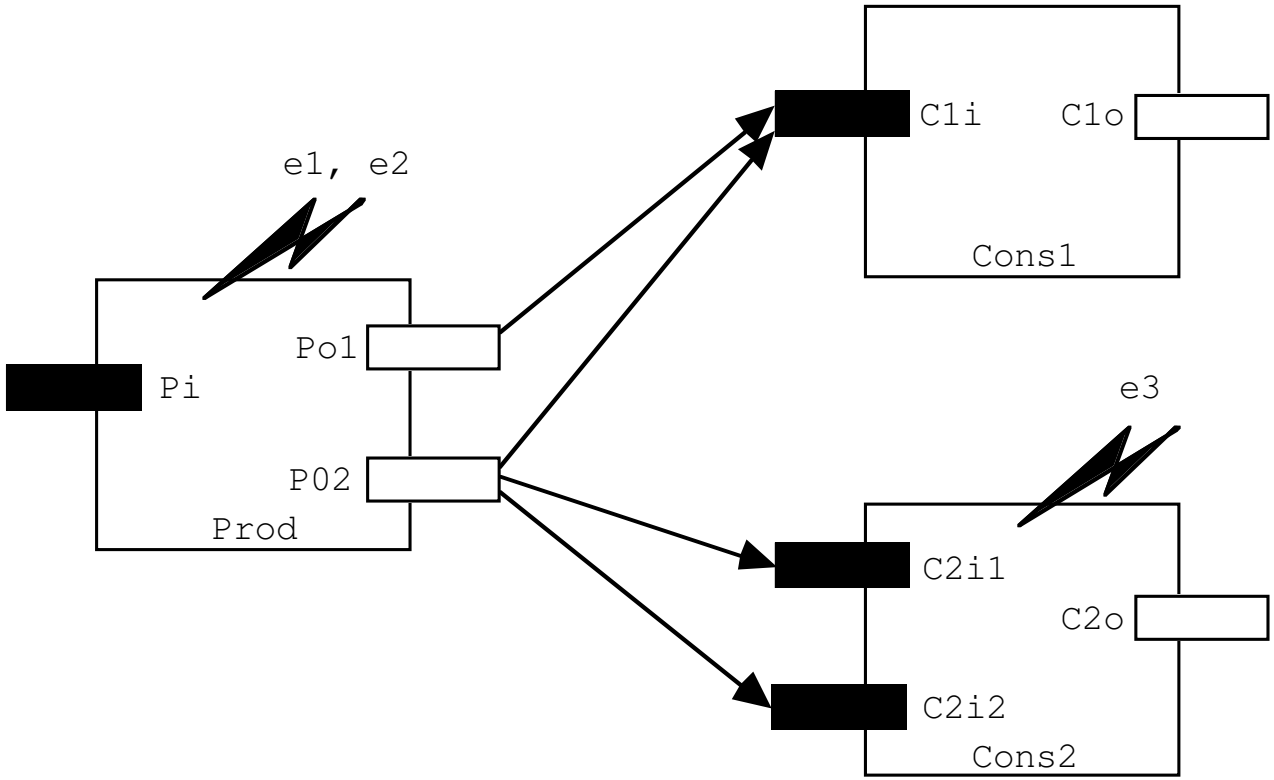
Orca

- Orca is quite similar to Opus and can be seen as an object-based DSM system
- Communication in Orca is done via *shared objects*, instances of ADTs, by applying user-defined ADT operations on them
- Data parallelism is expressed through *partitioned objects*, containing arrays that can be distributed among multiple processors

Mixed Task and Data Parallelism in Orca

```
_  PROCESS Worker(P,M1,M2:integer; procs:CPUlist)¨
       A: fftObject[1..N];
   BEGIN
     A$$partition(N);
     A$$distribute_on_list(Procs,P,BLOCK);
     FOR i IN M1..M2 DO readmatrix(i,A); 2Dfft(A); OD;
   END;
   PROCESS Coordinator(Ncpus,NWorkers,NMatrs: integer);
       P,S: integer;
   BEGIN
     P:=Ncpus/NWorkers; S:=NMatrs/NWorkers;
     FOR i IN 0..NWorkers-1 DO
       FORK Worker(P, i*S, (i+1)*S-1, [i*P..(i+1)*P-1])
       ON (i*P); OD;
   END;
```

Control-Driven Coordination Formalisms



Main Characteristics of Control-Driven Coordination Formalisms

- Processes communicate in a point-to-point manner by means of well defined interfaces, usually referred to as (input or output) *ports* which are used to set up *streams* or *channels*
- Changes to such network configurations are often triggered by means of raising and observing *events*
- Processes are normally treated as black boxes and the actual data being exchanged do not affect the state of the computation

Configuration and (Dynamic) Reconfiguration Languages

- Configuration Management is effectively control-driven coordination for the following reasons:
  - Configuration languages are separate entities from computational ones used to implement components
  - Components are context independent and specify visible behaviour via well defined interfaces
  - Complex components are definable as composition of simpler ones
  - Changes are expressed at the configuration level as changes to component instances or interconnections

Architecture Description Languages (ADL) and Software Architectures

- ADLs and Software Architecture languages is yet another way of viewing coordination, because they share a number of common requirements such as: component abstraction and composition, communication abstraction, ability to model dynamic behaviour, etc.
- Often, components are represented as black boxes, with ports as interfaces being connected by means of connectors (the control-driven paradigm)

Proteus Configuration Language

- In PCL the unit of configuration is a *family entity*, representing one or more *versions* of a component
- A family entity comprises a composition structure, a type, attributes, a parts section specifying its composition, and version descriptors
- A component may have a number of *ports*, signifying *offered* and required *services*
- Evolution is specified by version descriptions triggered by *action* ports

Specifying Components in PCL

```
_  family nurse inherits application_component is
     classification
        REALISATION => concrete
     end
     attributes
      persistent_state = true
      monitors: integer range 0..3
     end
     parts
      IN_PORTS =>  alarm_in[monitors]
      OUT_PORTS => data_out[monitors]
                   quit -- action port for removal
     end
   end
```

Dynamic Reconfiguration in PCL

```
_  version initial_pms of ward is
     attributes
       nurses := 3, monitors := 4
     relationships
       CB1:component_binding => nurse[1],monitor[1]
       CB2:component_binding => nurse[2],monitor[2]
       CB3:component_binding => nurse[3],monitor[3,4]
   end
   version nurse[3]_quit inherits initial_pms of ward is
     attributes
       nurses := 2
     relationships
       CB2:component_binding => nurse[2],monitor[3,4]
   end
```

Conic

- Conic is based on a variant of Pascal and features *logical nodes* configured together by means of *links* established between *entry* and *exit ports*
- Logical nodes are system configuration units, comprising sets of tasks executing concurrently; sets of nodes form *groups*
- Dynamic reconfiguration is limited; evolutions must be completely specified at compile time and the system must be quiescent or info may be lost

Specifying Components in Conic

```
_  group module patient;
   use monmsg: bedtype, alarmstype;
   exitport alarm: alarmstype;
   entryport bed: signaltype reply bedtype;
   << code >>
   end.

   group module nurse;
   use monmsg: bedtype, alarmstype;
   entryport alarm[1..maxbed]: alarmstype;
   exitport bed[1..maxbed]: signaltype
                            reply bedtype;
   << code >>
   end.
```

Dynamic Reconfiguration in Conic

```
system ward;
create
   bed1: patient at machine1;
   nurse: nurse at machine2;
link
   bed1:alarm to nurse.alarm[1];
   nurse.bed[1] to bed[1].bed;
end.
manage ward;
create
   bed2: patient at machine1;
unlink
   bed1:alarm from nurse.alarm[1];
   nurse.bed[1] from bed[1].bed;
link
   bed2:alarm to nurse.alarm[1];
   nurse.bed[1] to bed[2].bed;
end.
```

Darwin & Regis

- Darwin and its associated system Regis extend Conic in a number of ways:
  - Language independence
  - Stronger notion on dynamic reconfiguration by means of direct component instantiation specified at run-time
  - Components can interact through user-defined communication primitives
  - Input ports of a component are *provided* to the environment for other processes to post there data and output ones are *requiring* a port reference to post data

Specifying Components in Darwin

```
component supervisor (int w)
{ provide result <port,double>;
  require labour <component,int,int,int>;
}
component worker (int id, int nw, int intervals)
{ require result <port,double>;
}
component calcpi2(int nw)
{
  inst
    S:supervisor(nw);
  bind
    worker.result -- S.result;
    S.labour -- dyn worker;
}
```

Dynamic Reconfiguration in Darwin

```
_  supervisor::supervisor(int nw)
   {
    const int intervals=400000;
    double area=0.0;
    for (int i=0; i<nw; i++)
      { labour.at(i);
        labour.inst(i,nw,intervals);
      }
    for (int i=0; i<nw; i++)
      { double tmp;
        result.in(tmp);
        area+=tmp;
      }
    printf("Approx pi %20.15lf\n",area);
   }
```

Durra

- Components consist of *application tasks* featuring *input-output ports* and communication *channels*
- At run-time, tasks create *processes* and channels create *links*
- Dynamic reconfiguration is done by raising and observing *events*; however, as in Conic, unrestricted dynamic creation of tasks is not possible; also, before breaking a link, a task must raise a *safe* message so that data is not lost

Specifying Components in Durra

```
task producer
ports
 output: out message;
attributes
 processor="sun4";
 procedure_name="producer";
 library="/usr/durra/srclib";
end producer;
```

```
task consumer
ports
 input: in message;
attributes
 processor="sun4";
 procedure_name="consumer";
 library="/usr/durra/srclib";
end consumer;
```

```
channel fifo(msg_type:identifier, buffer_size:integer)
ports
   input: in msg_type;   output: out msg_type;
attributes
   processor="sun4"; bound=buffer_size;
   package_name="fifo_channel";
   library="/usr/durra/channels";
end fifo;
```

Dynamic Reconfiguration in Durra

```
task dynamic_producer_consumer
 components
   p: task producer;  c[1..2]: task consumer;
   buffer: channel fifo(message,10);
 structures
   L1: begin
          baseline p, c[1], buffer;
          buffer: p.output >> c[1].input;
       end L1;
   L2: begin
          baseline p, c[2], buffer;
          buffer: p.output >> c[2].input;
       end L2;
 reconfigurations
   enter => L1;
   L1 => L2 when signal(c[1],1);
 end dynamic_producer_consumer;
```

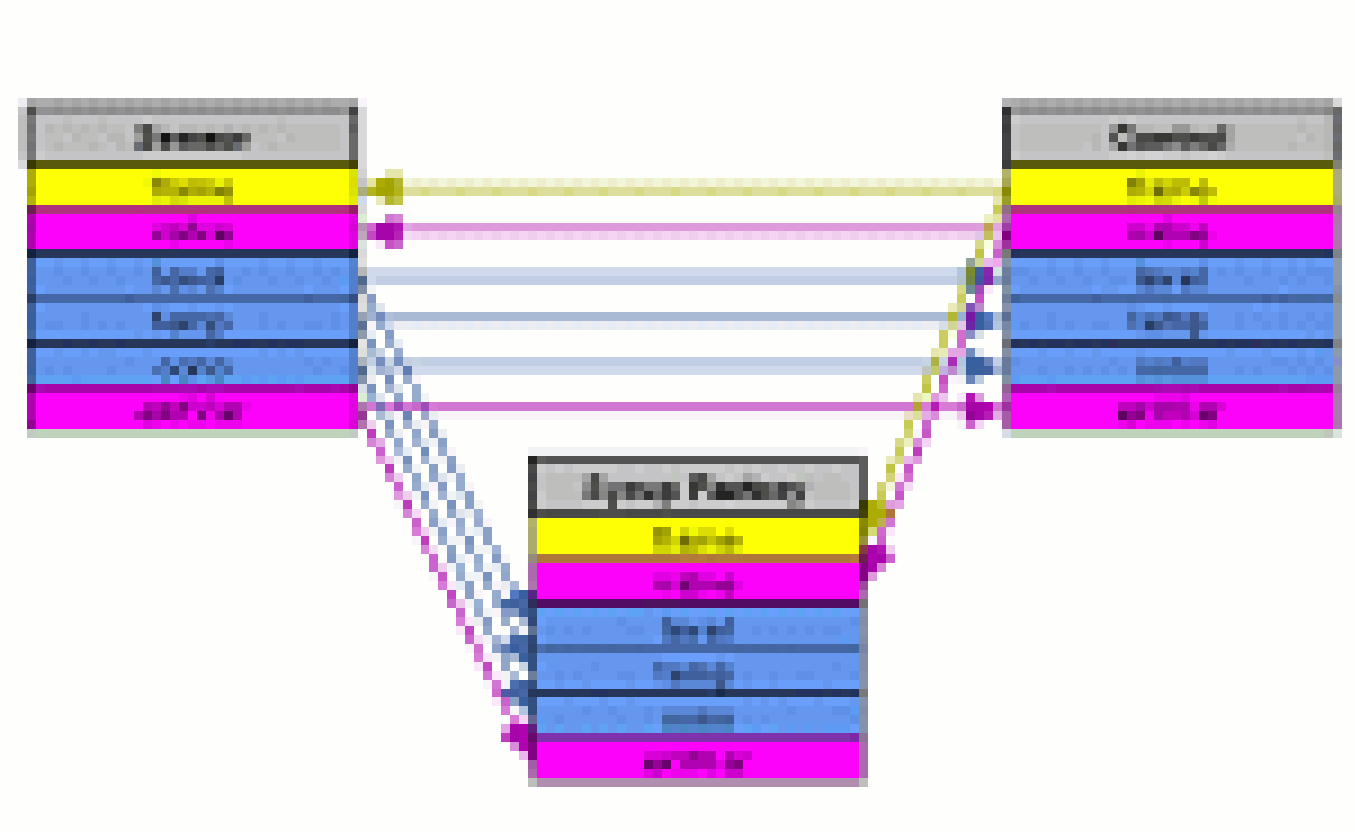
The Programmer's Playground

- This configuration formalism is based on the notion of *I/O abstractions*, where each module has a presentation that consists of data structures that may be externally observed and/or manipulated
- An application consists of a set of modules and a *configuration of logical connections* among the data structures in the module presentations
- Updating data structures, causes communication to occur *implicitly* based on the logical connections

Dynamic Reconfiguration in the Programmer's Playground

- This is achieved by means of *logical handles*, which define *virtual connections* between input and output "ports"
- Every logical handle defines an i-o relationship between a number of ports; associating a handle with another one, effectively creates a set of virtual links between the two groups of ports
- At a physical level, however, connections are implemented as being point-to-point

The Graphical Form of a Program in the Programmer's Playground



Textual Programming in the Programmer's Playground: Producer

```
_  #include "PG.hh"

   PGint next=0;
   PGstring mess;

   send_next(PGstring mess, static int i)
   { if (strcmp(mess,"ok")==0) next=i++; }

   main()
   {
      PGinitialise("producer");
      PGpublish(next,"next_int",READ_WORLD);
      PGpublish(mess,"ok",WRITE_WORLD);
      while (1)
         PGreact(mess,send_next);
      PGterminate();
   }
```

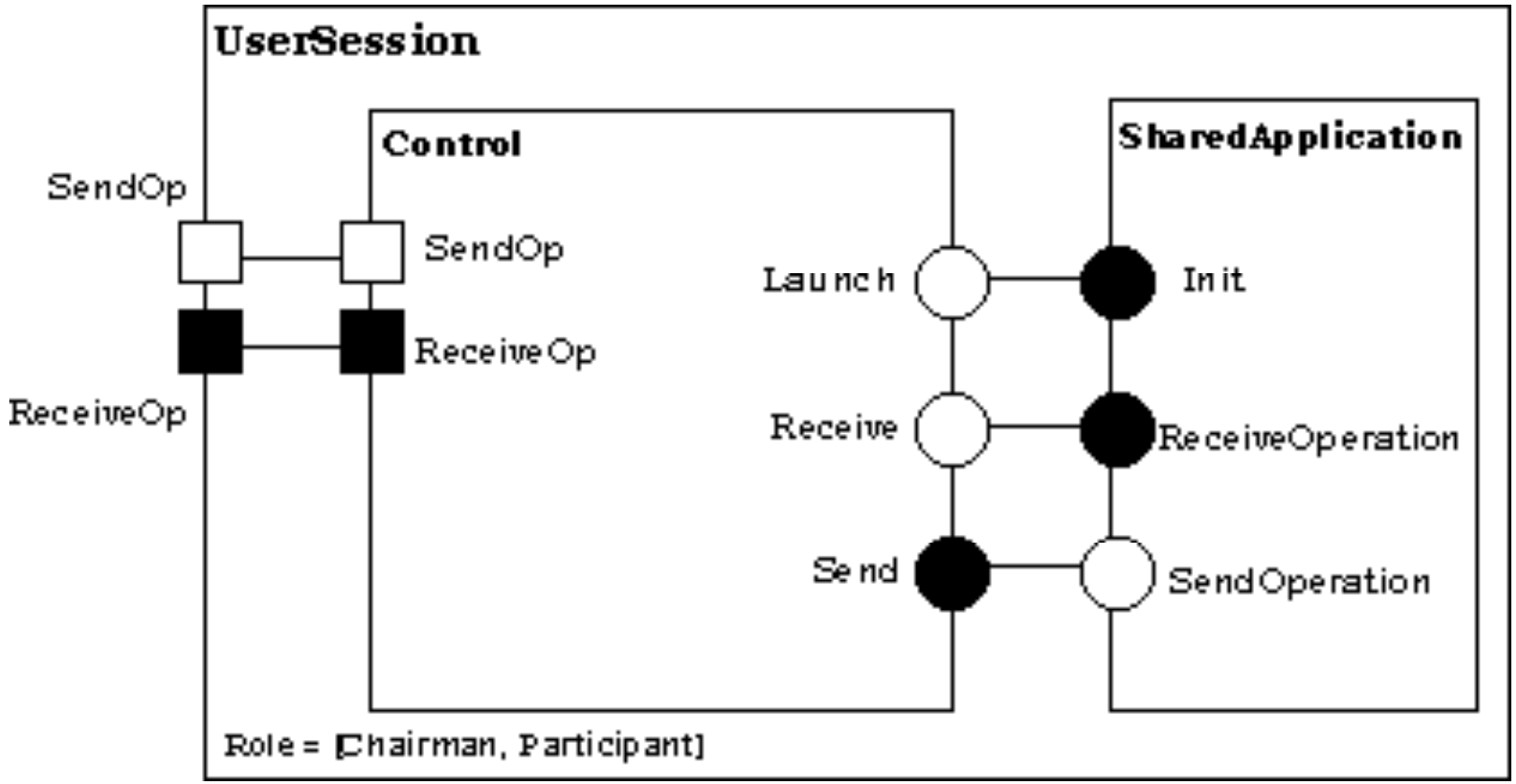
Textual Programming in the Programmer's Playground: Consumer

```
_  #include "PG.hh"

   PGint next=0;
   PGstring mess;

   void consume_int(PGint i)
   { /* consumes list of integers */ }

   main()
   {
      PGinitialise("consumer");
      PGpublish(mess,"ok",READ_WORLD);
      PGpublish(next,"next_int",WRITE_WORLD);

      while (1)
         { PGreact(next,consume_int); mess="ok"; }
      PGterminate();
   }
```

Olan

- Olan is an object-oriented configuration language where a configuration is viewed as a hierarchy of interconnected *components*
- Components have well-defined interfaces called *services*, either *provided* or *required*; service exchange is realized by means of *connectors*
- *Notifications* are used as an event broadcasting mechanism (through connectors though), which can cause *reactions* by the observing processes

Graphical Presentation of Olan Components



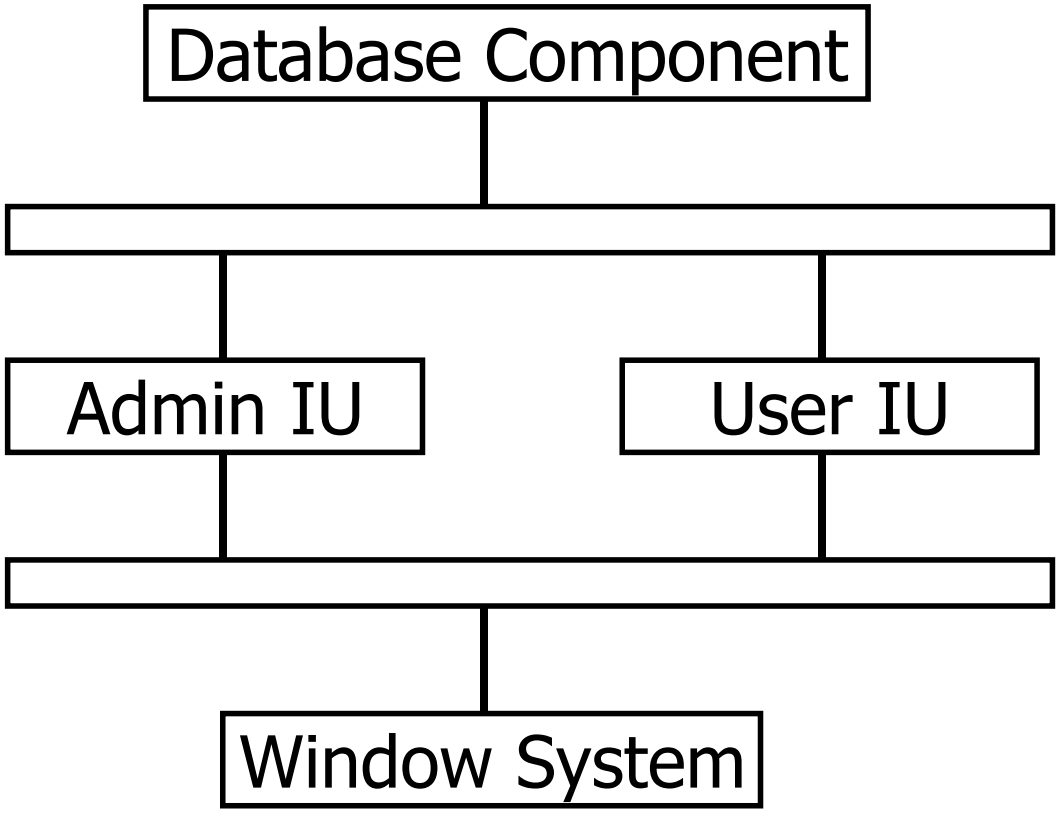
Textual Presentation of Olan Components

```
component class UserSession
interface
   require SendOp (in operation);
   provide ReceiveOp (in operation);
   …
implementation
   theCont = dyn inst CoopController; // dynamic inst
   theAppl = inst SharedAppl;

// mapping using methodcall connector
connector
   ReceiveOp => theCont.ReceiceOp;
   theCont.SendOp => SendOp;

// interactions
theCont.Launch => theAppl.Init;
theCont.SendOp => theAppl.ReceiveOp;
```

C2

- C2 is a style for building systems with complex user interfaces
- Architectures consist of components (written in any language) and connectors
  - Architecture is layered
  - Connectors broadcast messages up or down one layer
  - Request messages only go up; Notifications only go down
  - Components connect to one connector above and one below

A Graphical C2 Example



A Textual C2 Component Description

```
component StackADT is
interface
   top_domain in null; out null;
   bottom_domain
     in  PushElement (value : stack_type);
     out ElementPushed (value : stack_type);
parameters null;
methods
   procedure Push (value : stack_type);
   function Pop () return stack_type;
behavior
   received_messages PushElement;
       invoke_methods Push;
       always_generate ElementPushed;
end StackADT;
```

UniCon

- In UniCon, a system is comprised of (possibly nested) *components* which have, among other things, a number of *players* (i.e. ports)
- In addition, there exist connectors associated with *roles*, that specific named entities of the components (i.e. the players) must play
- Both components and connectors are defined in terms of a name, a type, an interface and an implementation

A Primitive Component and Connector in UniCon

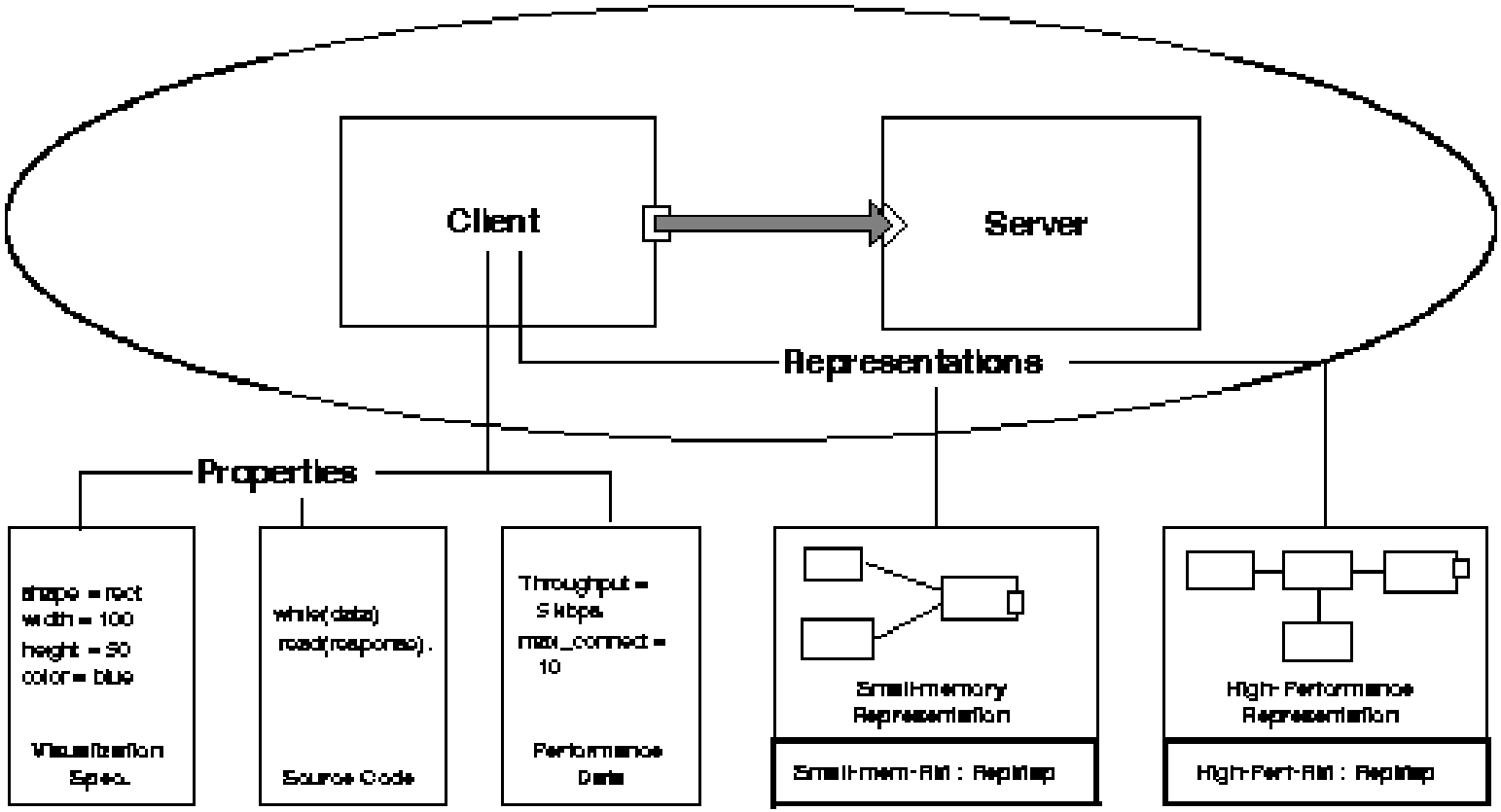
```
_  COMPONENT Sort
     INTERFACE IS
       TYPE Filter
       PLAYER input is StrIn
          SIGNATURE(“line”)
          PORTBINDING(stdin)
       PLAYER output is StrOut
          SIGNATURE(“line”)
           PORTBINDING(stdout)
     IMPLEMENTATION IS
       VARIANT sort IN “sort”
          IMPLTYPE (Executable)
          INITACTUALS (“-f”)
   END
```

```
CONNECTOR Unix-pipe
   PROTOCOL IS
    TYPE Pipe
     ROLE source is source
        MAXCONNS(1)
     ROLE sink is sink
        MAXCONNS(1)
IMPLEMENTATION IS
   BUILTIN
END
```

Architecture Description Interchange Language (ACME)

- ACME features the usual constituents of an ADL: *components* forming *systems*, and communicating by means of *connectors* via (typed) *ports*
- There are *roles* associated with connectors, e.g. an *event broadcast* connector has an *event-announcer* role and a number of *event-receiver* roles
- There may be more than one description for some component; *rep-maps* are then used to associate internal representations with external interfaces

An ACME Component System



Textual ACME

```
System simple_cs = {
Component client = { Port send-request; };
Component server = { Port receive-request; };
Connector rpc = { Roles { caller, callee}};
Attachments {
    client.send-request to rpc.caller;
    server.receive-request to rpc.callee;
}
```

Rapide

- Rapide, features components defined by means of *interfaces*, *connections* and *constraints*
- Interfaces define the behaviour of components, connections define communication among components using only those features specified by their interfaces, and constraints restrict the behaviour of components and interfaces
- There exist *events* which can be parameterized with types and values

A Producer-Consumer Scenario in Rapide _ 1

```
_  type Producer(Max: Positive) is interface
      action out Send(N: Integer);
      action in Reply(N: Integer);
   behavior
      Start => Send(0);
      (?X in Integer) Reply(?X)
                     where ?X < Max => Send(?X+1);
   end Producer;
   type Consumer is interface
      action in Receive(N: Integer);
      action out Ack(N: Integer);
   behavior
      (?X in Integer) Receive(?X) => Ack(?X);
   end Consumer;
```

A Producer-Consumer Scenario in Rapide _ 2

```
architecture ProdCons() return SomeType is
    Prod: Producer(100);
    Cons: Consumer;
connect
    (?n in Integer)
    Prod.Send(?n) => Cons.Receive(?n);
    Cons.Ack(?n) => Prod.Reply(?n);
end architecture ProdCons;
```

- The coordinator above creates two process instances, one for producer and one for consumer, and associates the output event of the former with the input event of the latter and vice versa

POLYLITH

- POLYLITH is effectively a MIL, enhanced with functionality usually found in coordination languages such as ports and events
- Components are modules with interfaces for each communication channel upon which running instances of a module will exchange messages
- An abstract decoupling agent, a *software bus*, is used as a communication channel; processes can be “plugged” into or “unplugged” from it

A Producer-Consumer Example in POLYLITH _ 1

```
_  main(argc,argv)
   /* a.c (exec in a.out) */
   {
    char str[80];
    …
    mh_write(“out”,…,”msg1”);
    …
    mh_read(“in”,…,str);
    …
   }
   service “A”:
   {
    implementation:
         {binary: “a.out”}
    source “out”: {string}
    source “in”: {string}
   }
```

```
main(argc,argv)
/* b.c (exec in b.out) */
{
  char str[80];
  …
  mh_read(“in”,…,str);
  …
  mh_write(“out”,…,”msg2”);
  …
}
service “B”:
{
 implementation:
       {binary: “b.out”}
  source “out”: {string}
  source “in”: {string}
}
```

A Producer-Consumer Example in POLYLITH _ 2

```
_ orchestrate “example”:
  {
   tool “foo”: “A”
   tool “bar”: “B”
   tool “bartoo”: “B”
   bind “foo out” “bar in”
   bind “bar out” “bartoo in”
   bind “bartoo out” “foo in”
  }
```

_ Using the primitives `mh_read` and `mh_write`, the two modules send a message `msg1` or `msg2` to their out (source) ports and receive a message of type string into their in (sink) ports

TOOLBUS

- TOOLBUS is similar to POLYLITH, in that a software bus (*toolbus*) is used as the communication medium
- The building block is a "*tool*"; types and numbers of tools must be defined statically; however, any number of instances of these tools may be active
- Adapters are used for data compatibility between different tools; configurations are expressed in terms of *T-scripts* which can be formally reasoned

Coordinating a Set of Tools in TOOLBUS

```
_  define COMPILER =
   ( rec-msg(compile,Name) . snd-eval(compiler,Name) .
     ( rec-value(compiler,error(Err),loc(Loc)) .
       snd-note(compile-error,Name,error(Err),loc(Loc))
           ) * rec-value(compiler,Name,Res) .
               snd-msg(compile,Name,Res)
   ) * delta
   define EDITOR =
   subscribe(compile-error) .
   ( rec-note(compile-error,Name,error(Err),loc(Loc)) .
   snd-do(editor,store-error(Name,error(Err),loc(Loc)))
   + rec-event(editor,next-error(Name)) .
     snd-do(editor,visit-next(Name)) .
     snd-ack-event(editor)
   ) * delta
```

COCA: Groupware Using Coordination

- COCA is a Prolog-based groupware coordination language, featuring *channels* and *roles*
- Communication is realized using *IP multicast*, the metaphor being a dual bus architecture:
  - A *collaboration* bus connects all participants and provides basic communication among them
  - A *conference* bus connects a local instance of the COCA virtual machine with the various collaboration tools (video, audio, drawing, etc.); the VM is also connected to the collaboration bus

A Presentation Scenario in COCA

```
collaboration "presentation"
{ collaboration-bus { channel(remote). }
  role "slide viewer"
  { conference-bus { channel(l-in), channel(l-out) }
  on-arrive(gate(remote),id(URL),slide(X)) :-
     l-out(id(URL),slide(X)).
  on-arrive(gate(l-in),id(URL),slide(X)) :-
     remote(id(URL),slide(X)).
}
```

- COCA VMs communicate via `remote`, and actors within some VM communicate via the local i/o channels, `l_out` to display received slides and `l_in` to forward local ones for remote display

MANIFOLD

- MANIFOLD is a “traditional” coordination language (i.e. not an ADL, configuration language, etc.) featuring *ports*, *events* and *streams*
- Coordinators are written in a fully fledged control-driven language which clearly separates the coordination patterns from the computational ones
- Changes to a system are done dynamically by *state transitions* triggered by observing raised events

A Conferencing System Modelled in MANIFOLD _ 1

```
event leave.
manifold Session(event) import.
manifold Connect(process p1, process p2)
{
 begin: (p1 -> p2, p2 -> p1, terminated(self)).
 leave.p1|leave.p2: .
}
manifold Participate(process me)
{
 ignore join.me.

 begin: while true do
          {
           begin: terminated(self).
           join.*other: Connect(me,other).
          }.
 leave.me: .
}
```

A Conferencing System Modelled in MANIFOLD _ 2

```
manifold User()
{
 event remove_me.
 begin: (Participate(self),
         raise(join),
         Session(remove_me),
         terminated(self)).
 remove_me: raise(leave).
}
```

- `Session` implements the actual conferencing activity, `Connect` establishes a communication link between two processes, `Participate` creates a `Connect` process for every new `User`

ConCoord

- ConCoord can be seen as a “structured” MANIFOLD, comprising the same structures as the latter; events can be parameterized with data
- Coordinators in ConCoord are created in a hierarchical manner, where inner ones have no access to outer ones, in terms of observing raised signals or establishing i/o connections
- State changes are communicated by message passing and communication can be synchronous

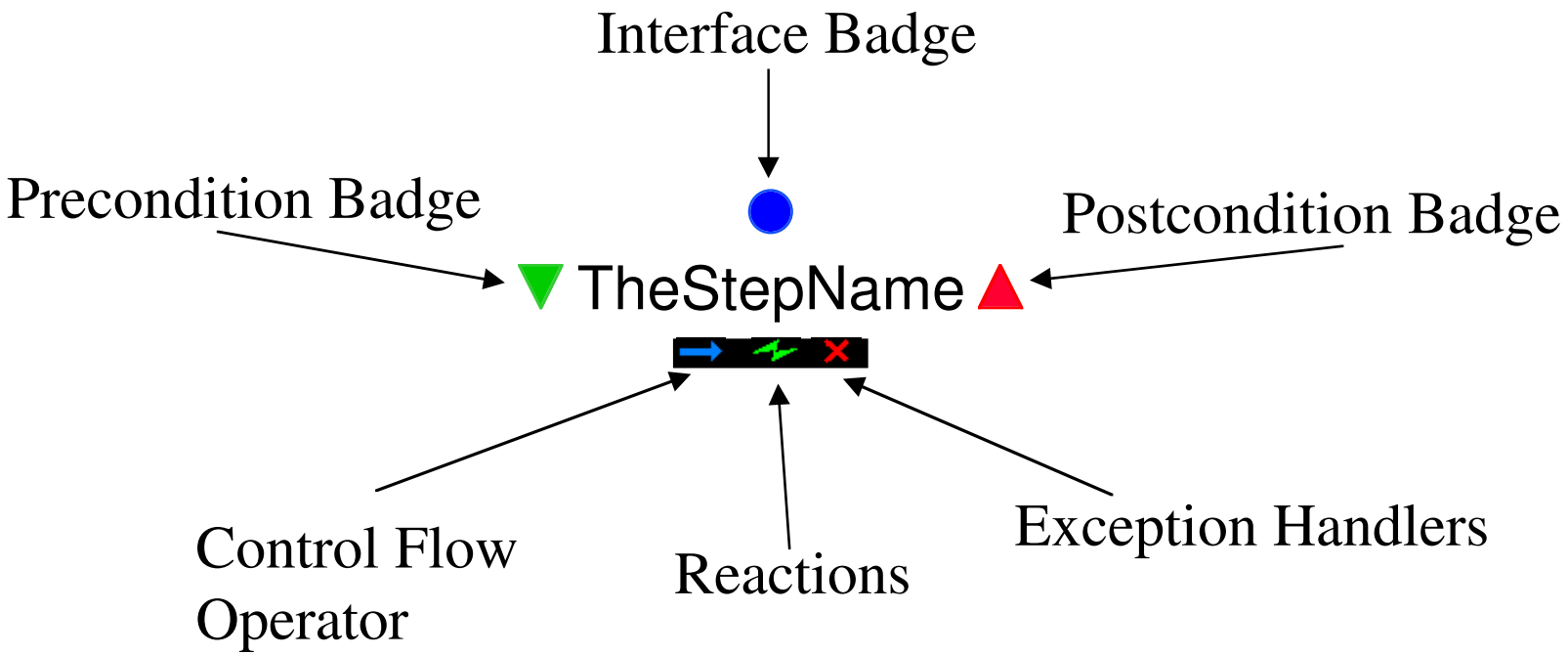
A Pipeline of Generic Processes in ConCoord

```
_  coordinator <t_node, t_data> gen_dyn_pipeline
   {
    inport <t_data> in;
    outport <t_data> out;
    states error(), done();
    create t_node n bind in -- n.left, n.out -- out;
    loop
    { choose
      {
        sel(t_node n | n.new and not n.right--)
            =>    create t_node new_n
                  bind n.right -- new_n.left,new_n.out -- out;
        sel(t_node n | n.new and n.right--)
            =>    error();
      }
    }
   }
```

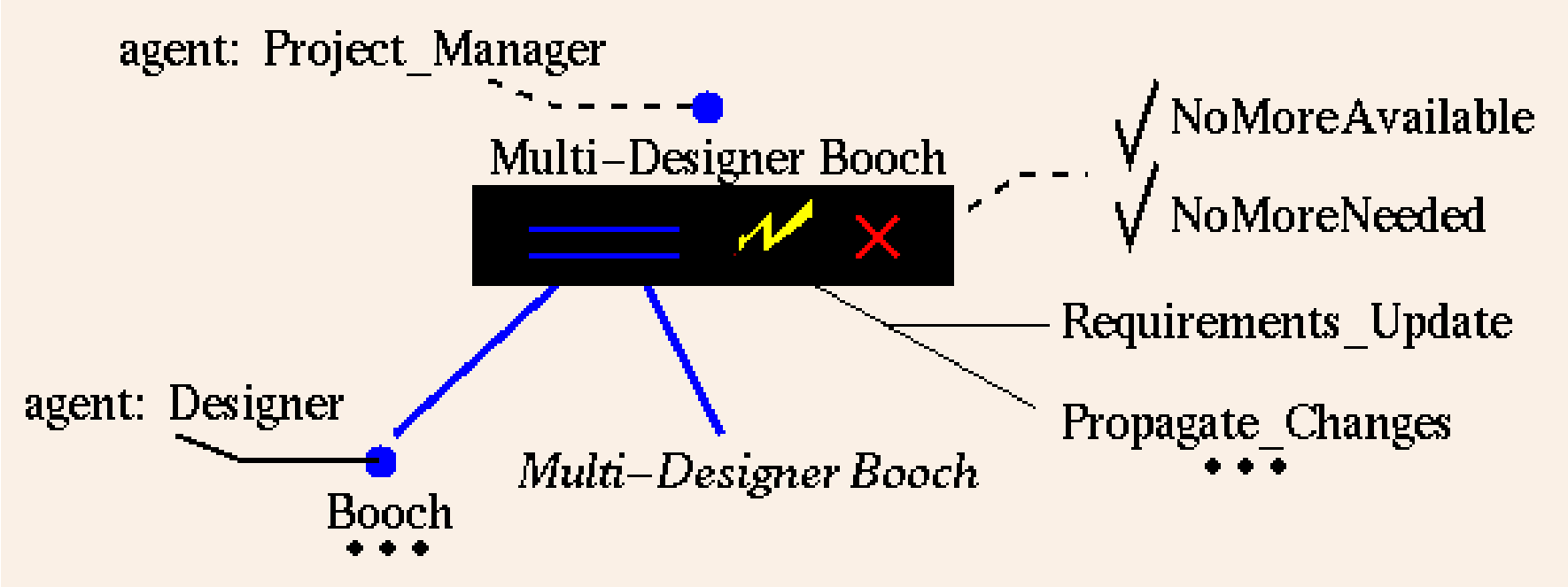
Little-JIL

- A graphical coordination language featuring:
  - Explicit resource specification and dataflow
  - Proactive and reactive control constructs
  - Hierarchical decomposition of steps which are the central abstraction in the language
  - Control flow operators restrict execution of substeps
    - » Sequential & Parallel (AND), Choice & Try (OR)
  - Processes are viewed as agents who need coordination
  - Precondition and postcondition guards
  - Exception Handling

Little-JIL Step Notation



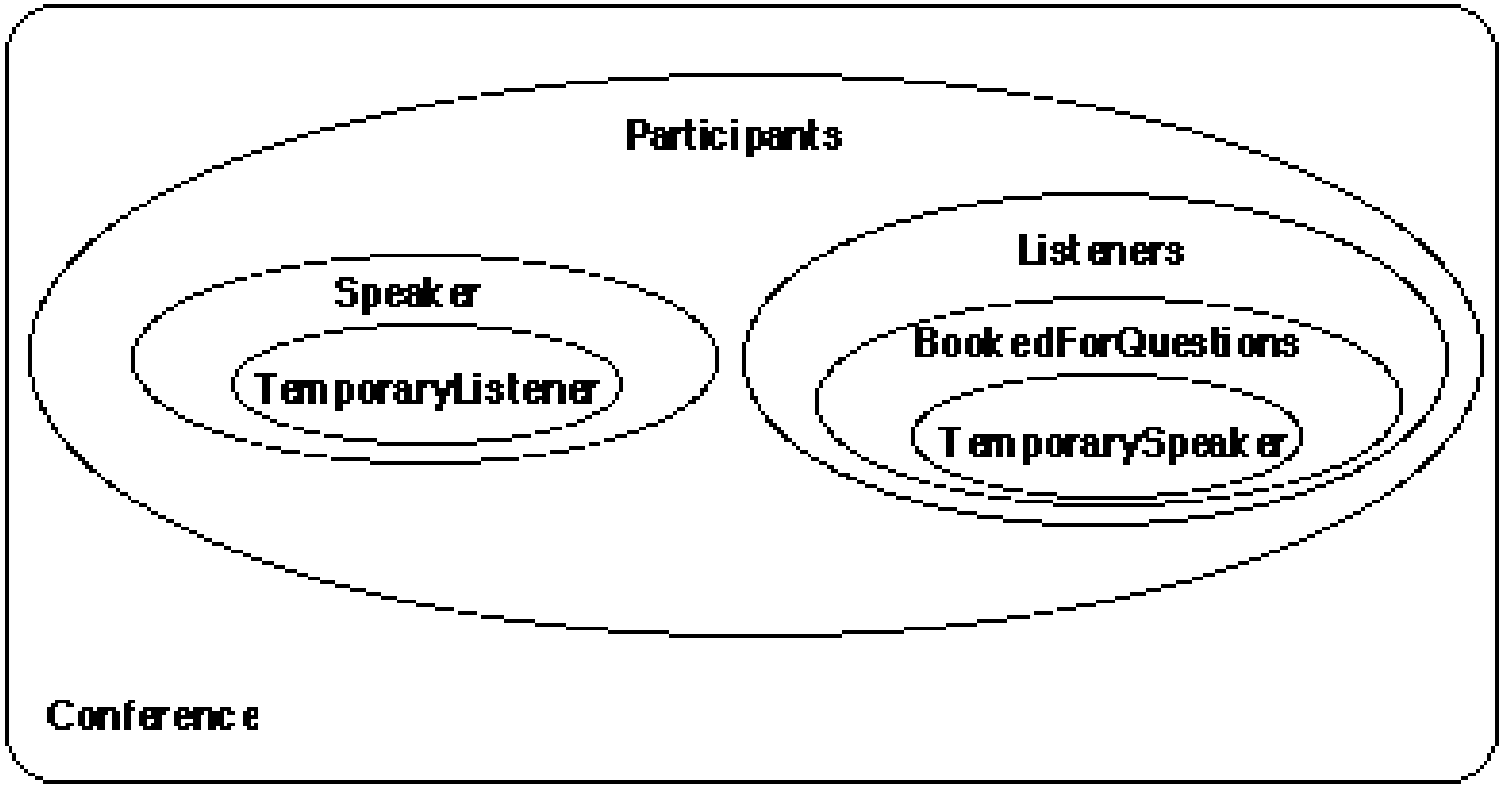
Agent Coordination in Little-JIL



Cooperative Systems Design Language (CSDL): Cooperation Using Coordination

- CSDL supports the definition of the coordination aspects of a cooperative system
- *Configurations* comprise users and applications managed by *coordinators*; the latter consist of:
  - a *specification* defining groups and cooperation policies in terms of *requests* exported selectively to members of different groups
  - a *body* defining *access rights* associated with groups
  - a *context* defining coordinator dependencies in terms of groups mapping

A Cooperative System in CSDL



Specifying ab X-Windows Coordinator in CSDL _ 1

```
_  coordinator XWindow
   { group ConnectedUsers;
     group Output nestedIn ConnectedUsers;
     group Input  nestedIn Output;
     invariant #Input <= 1;
     requests
     { exportedTo extern
       { join Output other
         { actions: insert ConnectedUsers other;
                    insert Output other; }
         join Input other
         { requires: other in Output and #Input = 0;
           actions: insert Input other; } }
         leave Output other
         { actions: extract Output other;
                    extract ConnectedUsers other; }
   }
```

Specifying ab X-Windows Coordinator in CSDL _ 2

```
coordinator body XWindow
{
  S: switcher inOut XSwitcher;
  group ConnectedUsers { connected; inOff; outOff; }
  group Output { outOn; }
  group Input { inOn; }
}
```

- The specification includes an *invariant* stating constraints on group cardinality and membership, and requests (`join`, `leave`) exported selectively
- Exchange of information is done via *logical switches* that model multiplexing of data streams

Conclusions _ 1

- In the traditional coordination languages, there will be further work and convergence on the issue of the communication medium: structured and localized, but not unrestricted broadcasting or point-to-point
- With the development of Internet technologies, there will be a new class of coordination formalisms, especially suited for that purpose, such as XML

Conclusions _ 2

- Also, new application areas will be explored such as Cooperative Information Systems, Open and Distributed Multimedia, E-Commerce, Mobile Computing, etc.
- Thus, there will be a closer collaboration between traditional coordination programming groups and ones using coordination in a different setting (CSCW, workflow, collaboration, groupware, etc.)
- Coordination will (successfully?) marry CORBA