Lecture 3: Coordination languages

Contents

Linda and friends

What Linda taught:

programming =
(distributed) coordination + (sequential) computation

The basic idea is to give a *small* set of coordination primitives useful to design a distributed system

The main advantage consists of automatic load balancing implicit in agenda parallelism (associative matching) and simplicity of master/worker software architectures exploited for parallel programming

Moreover, Linda is intrinsically multiparadigm and can support interoperability across languages

However:

- no formal semantics
- no logic to reason on coordination
- no general hints on how to embed a coordination model in a host language
- few hints on how to optimize coordination-level language mechanisms independently from the underlying hardware

Marrying Linda with a host language

Linda is a coordination language, that is it needs to be embedded in a host sequential language to offer a full (parallel) programming language

Linda has been coupled to several conventional languages, like C and FORTRAN (original SCA™ Linda), Pascal, Scheme, Ada, Eiffel, Prolog, etc., and implemented on several hw architectures

Remark: For the Linda family of languages a *semantics gap* existed: they were designed and implemented for several distributed architectures, but not formally defined; the Linda concept itself has been instantiated in different forms by different language designers

Language design issues

The main problems to be solved by a language designer are:

⇒ Data structures and types
Which data structures are allowed in the tuples?
(for instance, in C-Linda pointers are not allowed)

⇒ Matching rules for operations in the Tuple Space
How is defined the matching operation? (for instance, in Prolog-Linda it has to be based on unification)

⇒ Control of tuple operations
Which kind of control structures can be used with Linda operations? (for instance, backtracking is difficult to implement in a distributed setting)

⇒ Definition of `eval`
Which is the semantics of new processes/agents? Which code and data of the parent process they can refer to?
How many active threads can be included in a tuple? How do they synchronize?

Choices in designing a semantics for a Linda-like language

We have studied and compared a number of formal semantics for Linda, and found a number of options in describing the combination of its coordination model with another programming language

• simple matching / constrained matching?

• `eval` is the only means of process creation?

• active tuples actually exist?

• active fields in an active tuple are executed in parallel?

• active tuples are first class objects?

• bulk retrieval operations, if possible, are atomic?

• tuple space name always specified?

• tuple spaces are first class objects?

• scoping hierarchy of tuple spaces?

• garbage collection of tuple spaces?

• a global (root) tuple space as operating environment?

A universal Linda interpreter

In Yale, each Linda implementation was studied and optimized for a specific language/hw architecture; however, a more universal although naive approach can be used

In fact, a simple Linda implementation is easily obtained using a client-server sw architecture

Programs which wish to use the tuple space are clients of servers which implement the Tuple Space;
in [Pinakis 93] there are two types of servers (a pair of such servers has to be present at each node):

- *tuple servers*, which manage a *partition* of currently active tuple types
- *type servers*, which are used to locate tuples of a particular *tuple type*

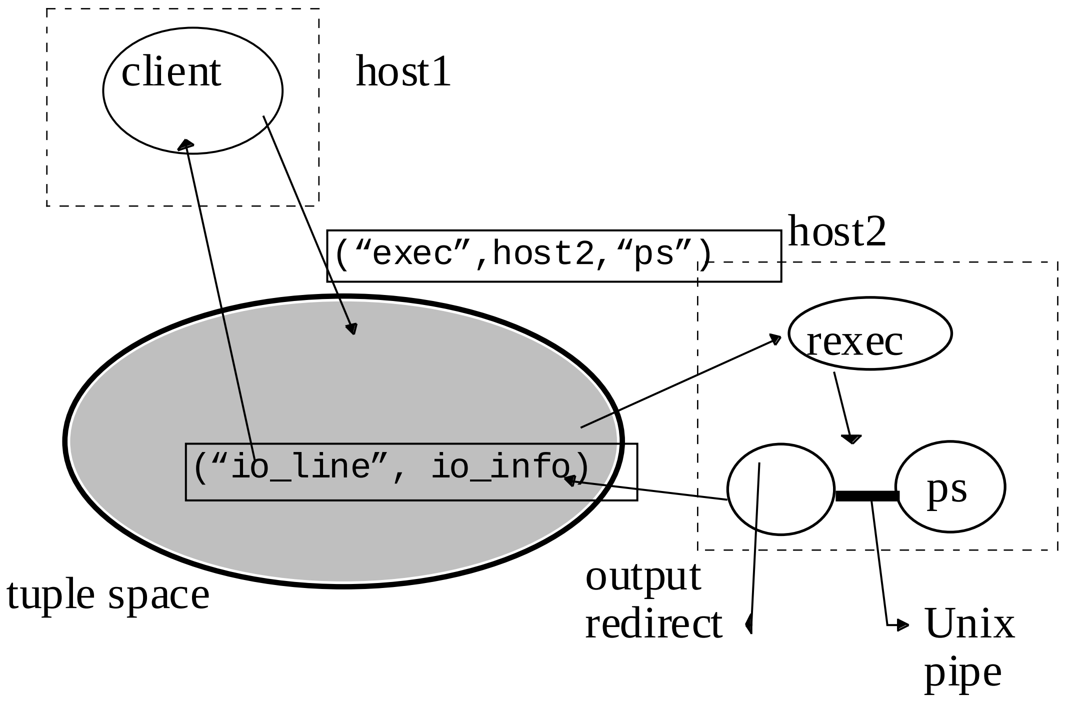
Each tuple type is managed by the tuple server on exactly one host (owner-id) and has a unique tuple-id on that host

Performing a Linda operation therefore involves two steps:
1. determine (owner-id,tuple-id)
2. send request to owner host and possibly wait for reply

Pinakis' solution

The following diagram explains a sw architecture defined by Pinakis

Note: since `eval` operation can easily simulated by in/out/rd and "demon" workers, it is not implemented



Linda and logic programming

There are several ways to define a Linda-based logic language

a) Prolog + non-backtrakable Linda primitives: simple implementation, inconsistent with the “pure logic programming paradigm” (but similar to `assert`/`retract`) [SICSTUS, Tarau’s BinProlog];

b) Prolog + backtrakable Linda primitives: complex implementation (distributed backtracking) similar to DeltaProlog [Monteiro-Porto]; intensional or extensional tuple space [Delta-D-Prolog: Sutcliff and Pinakis 91, Omicini 97]

c) A parallel logic language based on multiset rewriting, i.e. a new parallel logic language with “Linda flavor” [Shared Prolog; μLog; Gammalog]

d) Using non standard semantics, like linear logic [LO by Andreoli; Forum by Miller]

Sicstus™ Prolog-Linda

Sictus Prolog offers some simple Linda-like predicates

One Prolog process is running as a server and one or more processes are running as clients; all processes are communicating via sockets

The server is in principle a blackboard on which the clients can read/write using the Linda operations:
`out`/1 `read`/1 `in`/1
If the data is not present on the blackboard, the predicates suspend the process until they are available.

There are some more predicates: `in_noblock`/1 and `rd_noblock`/1 do not suspend if the data is not available---they fail instead.

A fetch of a conjunction of data is done with `in`/2 or `rd`/2:

```
in([e(1),e(2),...,e(n)],E)
```
E instantiated to the first tuple to become available, among those listed

EXAMPLE: A simple producer-consumer

```
producer :-          % client1
  produce(X),out(p(X)),producer.
produce(X) :- .....

consumer :-     % client2
  in(p(A)), consume(A), consumer.
consume(A) :- .....
```

MultiProlog

The blackboard interpretation of logic programming is based on a Linda-like coordination model

MultiProlog (DeBosschere & Tarau) includes blocking and non-blocking built-ins to manipulate distributed blackboards

```
out(X):- tellt(world,X).
                  %puts X on the server

in(X):- gett(world,X).
   %takes a matching term X from the server

all(X,Xs):- tellt(world,X).
              % puts X on the server

out(X):- tellt(world,X).
              % puts X on the server
```

MultiProlog has been used to build a prototype MUD (LogiMOO) and some prototype applications in the field of electronic commerce [Tarau and others, 1997]

The tuple space coordination model in Shared Prolog

Basic idea: a parallel logic language based on the Tuple Space concept, i.e. a logic language with “Linda flavor”

- *Prolog for sequential computation*
- *shared-dataspace of logic terms*
- *rewriting rules and unification*

A logic tuple space implements a blackboard-like data structure that can be shared by a number of logic processes (Prolog programs)

Shared Prolog (SP) evolved as “kernel language” of a family of coordination languages, all based on extensions of the basic tuple space model.
Extended Shared Prolog (ESP): extends SP with multiple tuple spaces, to design logically distributed systems

SP vs Linda:
- SP uses full logic unification, Linda uses (sequential) typed pattern matching
- In Linda `rd`, `in` and `out` are allowed everywhere in a program; SP is more structured and allows transactions on tuple space

Shared Prolog

A SP program is composed of a *set of theories* and a *dataspace* (or*blackboard),* i.e. a (possibly empty) multiset of Prolog atoms.

For instance, supose we have to specify a reservation system including a database (stored in the blackboard),
a set of theories corresponding to the agencies,
and a theory corresponding to the airline company

The system is activated by an initial goal:
`database || airline || agency_1 || … || agency_n`

The symbol "||" stands for parallel execution, i.e. this goal is composed of n+2 AND-parallel processes.

One of the atoms in the initial goal must correspond to a blackboard: in this example it is the `database`.

Here the blackboard initially contains the number of free seats for each flight; its initial configuration is given by the following rule:

```
database:- {flight(1,p1),…,flight(k,pk)}.
```

where in `flight(i,p`$_i$`)` `i` is the flight number and `p`$_i$ the number of free seats

A theory

```
agent agency_i:-
eval
  not ready(agency_i)
  |                 initialization
  {ready(agency_i)}
♦
  {ready(agency_i)}
  |                 query to the system
  read(C),exec(C,Ci)
  {query(Ci)}
♦
  {result(agency_i,R)}
  |              answer from the system
  write(R)   {ready(agency_i)}
withexec(reserve(F,N),reserve(F,N,agency_i)
).exec(info(F),info(F,agency_i)).
```

Informal semantics

Each agent is able to perform some operations on tuples

• associative (blocking) *test* of a tuple contained in the dataspace;
in SP the *test* operation has a broader semantics than `read` in Linda: a number of predefined tests on the dataspace are allowed, depending on the chosen type system for tuple arguments.

• associative (blocking) *consumption* of a tuple contained in the dataspace; this operation also has a broader semantics than `in` in Linda: several tuples can be collected and consumed by special operators that return multisets.

• *asynchronous creation* of a tuple inside the dataspace.

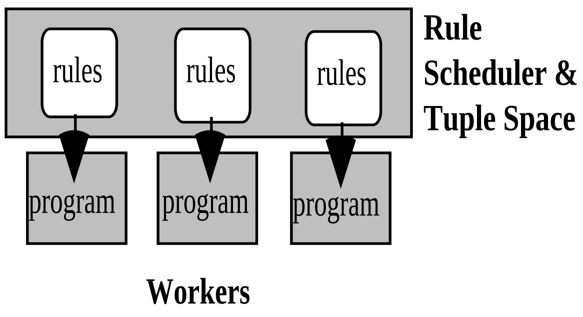
In SP there is no need of an operation like `eval` for creating active tuples because we adopt a ``chemical'' semantics, that is tuples that match coordination rules are implicitly active.

Programming in Shared Prolog

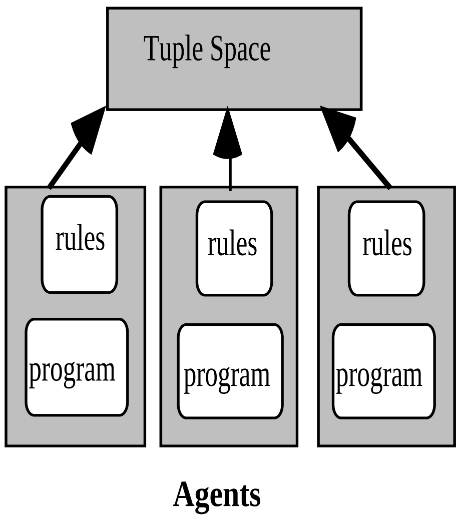
```
% program to find the best path in a DAG
% (it is acyclic!)

[in(s,0), in(a,1), in(b,1), in(c,1), in(d,2),
 in(e,3), in(f,1), in(g,1), in(h,3), in(i,2),
 in(j,1), in(k,2), in(l,2), in(m,1), in(t,4),
 e(s,a,5), e(s,b,6), e(s,c,4), e(a,d,2), e(a,e,5),
 e(b,d,1), e(b,e,3), e(c,e,4), e(c,f,1), e(d,g,7),
 e(d,h,2), e(e,h,1), e(e,i,3), e(f,h,2), e(f,i,2),
 e(g,j,4), e(g,k,2), e(h,k,3), e(h,l,2), e(i,l,4),
 e(i,m,3), e(j,t,5), e(k,t,1), e(l,t,4), e(m,t,2),
b(s,s,0)] @ best.


agent best :-
eval
   b(X,A,C1), [e(A,B,C2)]   % guard
   |                         % commit
   NewC is C1+C2,      % Prolog goal
   [p(X,B,NewC)] % out
#
   [p(A,B,C1), in(B,N)], p(A,B,C2)
   C1 >= C2
   |
   DecrN is N-1,
   [p(A,B,C2), in(B,DecrN)]
#
   [p(A,B,C), in(B,1)]
   |
   [b(A,B,C)]
.
```

Implementing Shared Prolog

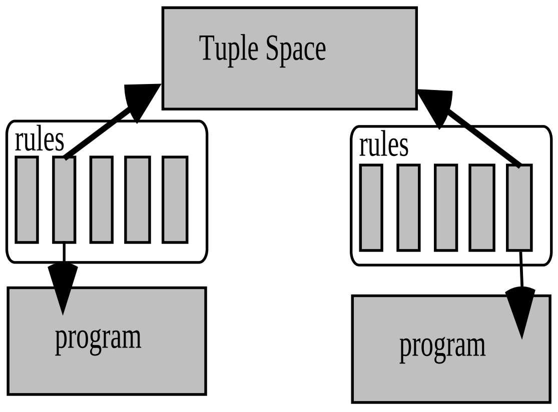
a) Distributed workers.



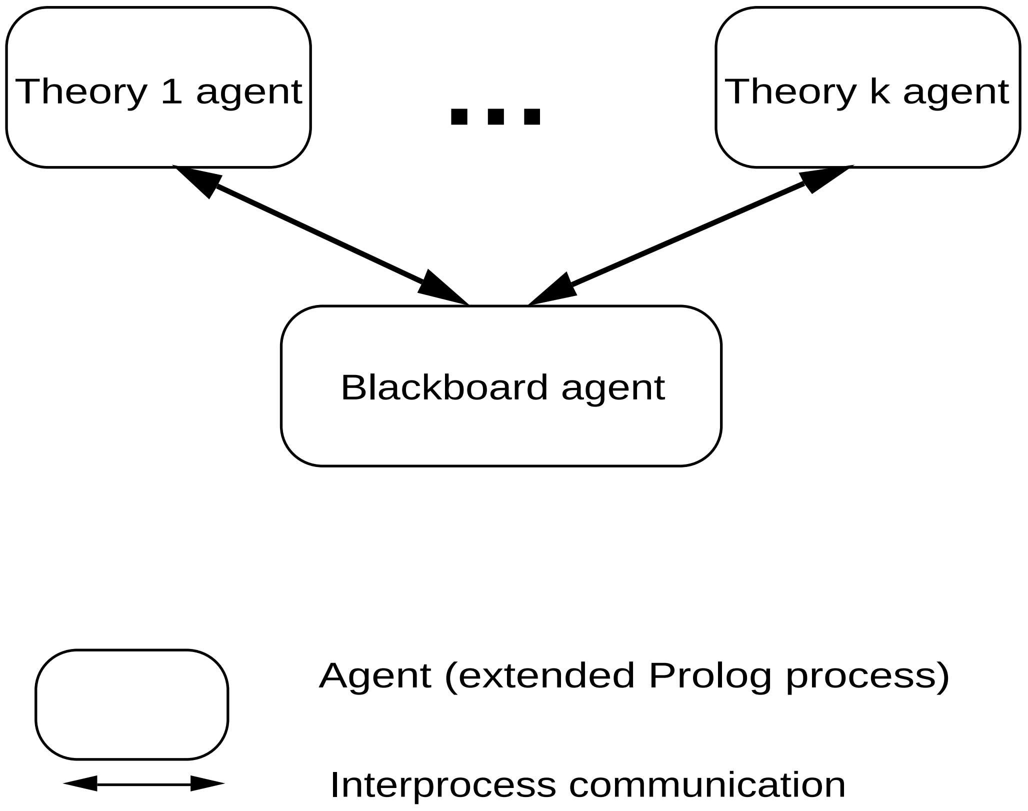
b) Distributed agents.

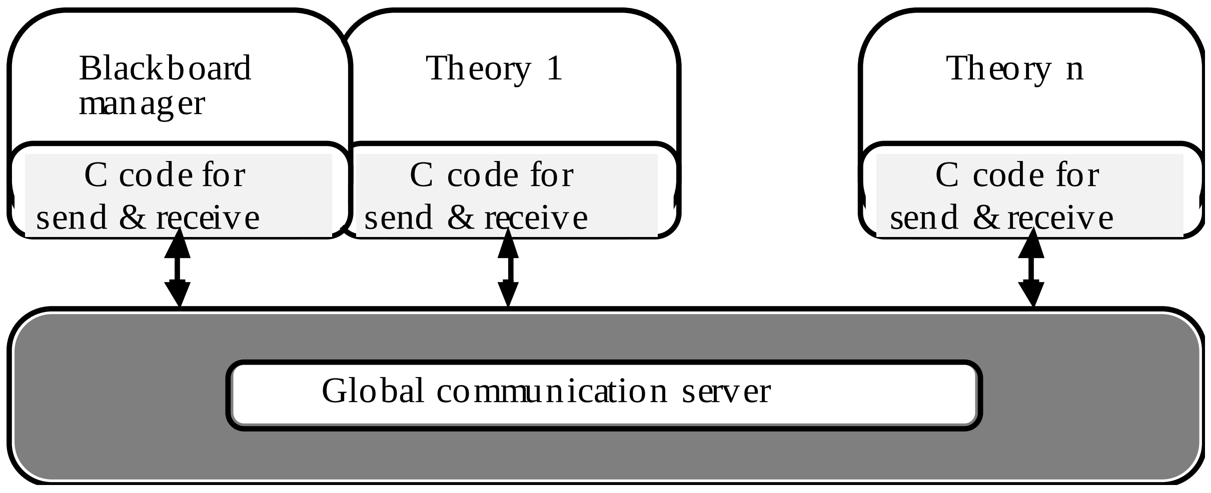


c) Distributed rules.



Implementing Shared Prolog




Blackboard manager
Theory 1
Theory n
C code for send & receive
C code for send & receive
C code for send & receive
Global communication server

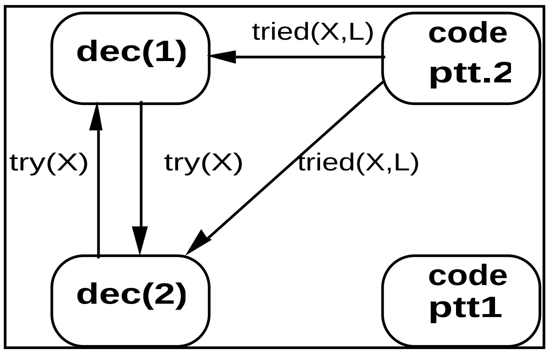
Analyzing coordination in SP

Flow Graphs of SP Programs

Let a be an atom, P1 and P2 be patterns

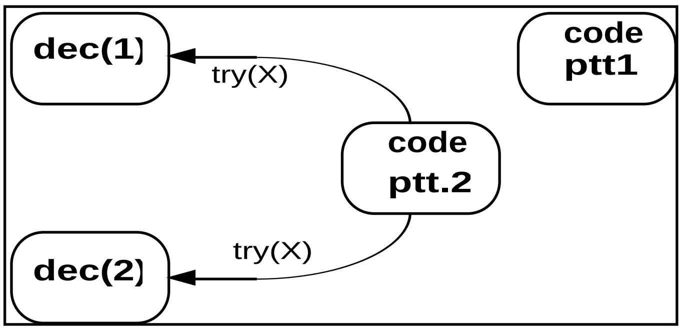
- **OUT_FLOW**

has an edge labeled with a if
a ∈ Out(P1)
AND
(a ∈ Read(P2) OR a ∈ In(P2))



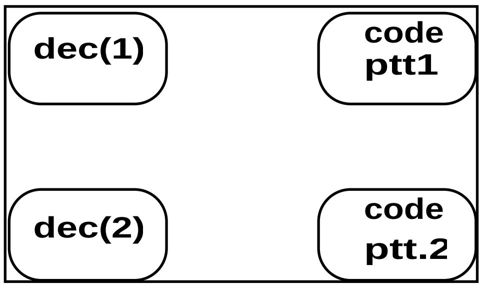
- **IN_FLOW**

has an edge labeled with a if
a ∈ In(P1)
AND
(a ∈ Read(P2) OR a ∈ In(P2))



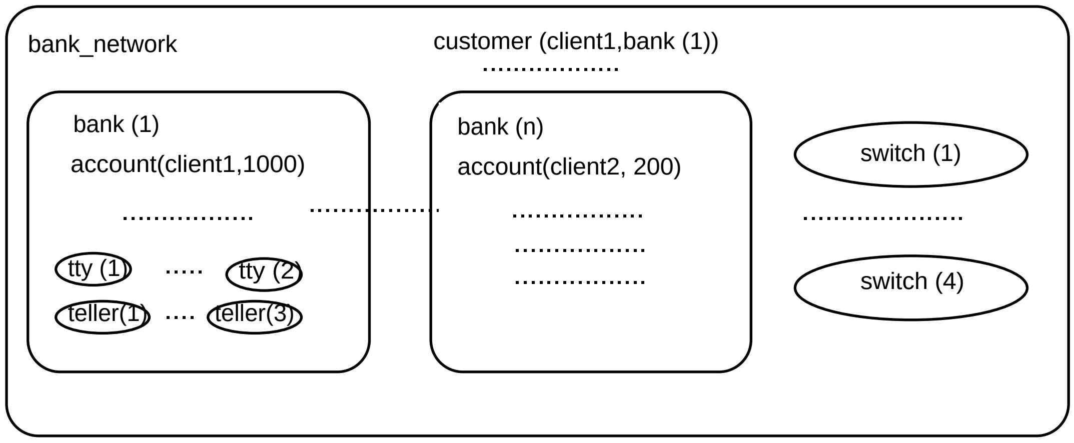
- **CONFLICT_FLOW**

P1 and P2 are connected if
they belong to the same theory
OR
In(P1) ∩ In(P2) ≠ ∅

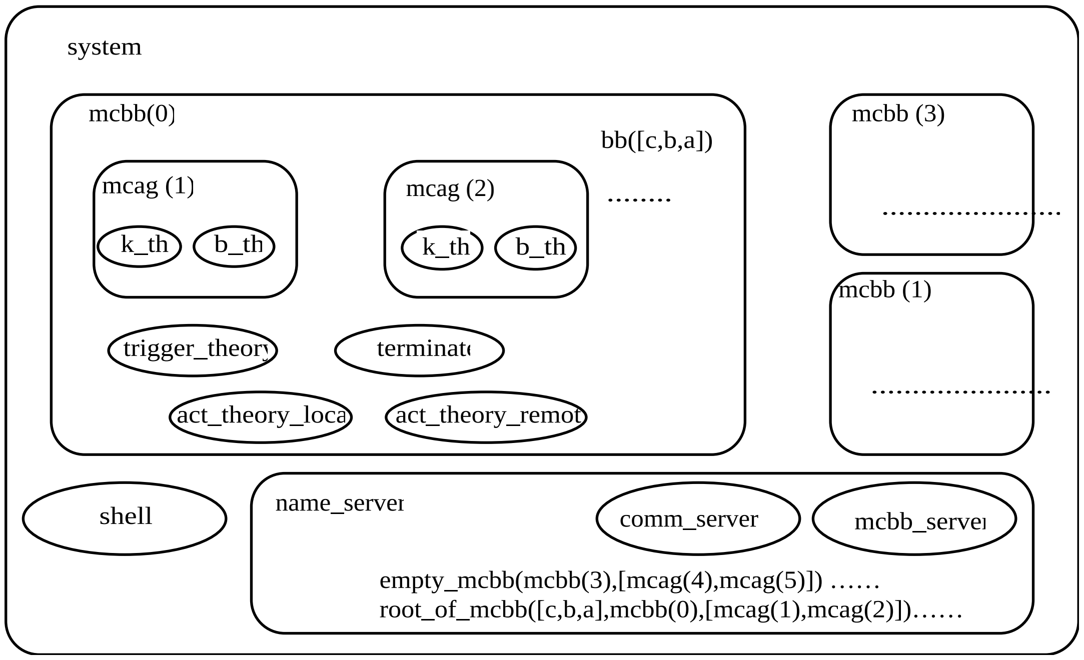


Extended Shared Prolog (ESP)

Extended Shared Prolog adds (nested) multiple ts to SP



A run-time for ESP



Linda and OO programming

In [MatsuokaKawai 88] we find the first proposal for an OO Linda, based on a reformulation of the TS coordination model for OO programming in SmallTalk

• tuples and tuple spaces become objects; an object now can retain a msg/tuple even if does not have the ability to understand it, or can transparently delegate it

• sender and receiver have to be symmetrical (in Linda they are not, because all the receivers must share the same info on shared tuples): so both out tuples in TS,
and in this model we have both receiver and sender tuples

• logical distribution of tuple spaces, to improve efficiency and security, and offer naming scope to tuples

Class Tuple (Tuple)
a tuple is an arbitrary sequenced collection of element objects, including tuple spaces; matching in compicated by inheritance

Class Formal (Formal arguments)
this is only used in communication matching

Class TS(Tuple Space)
<TupleSpace> put:<Tuple> like `out` in Linda
<TupleSpace> set:<Tuple> synchronous `out`
<TupleSpace> get:<Tuple> like `in` in Linda
<TupleSpace> read:<Tuple> like `read` in Linda

The model also introduced operations to manipulate multiple tuples (bulk operations)

[Jellinghaus 90] introduced Eiffel Linda

Objective Linda

Objective Linda [Kielman 97] introduces a concept of Object Interchange Language, a language independent notation to describe abstract data types

An *OIL_object* defines the basic operations needed by all types: for instance, there is a match predicate which takes as parameter an object of the same type and decides if it matches some requirements

Operations belonging to the coordination model are based on the types interfaces: a reader has to specify the type of object it wishes to get from the object space

```
class BARRIER_SYNC inherit OIL_OBJECT
redefine match end

creation create

feature barrier_id : STRING;
 create (id: STRING) is
    do barrier_id := id; end;
 match (candidate : like current): BOOLEAN
is
    do Result :=
      candidate.barrier_id = barrier_id; end;
end
```

Objective Linda

Since Objective-Linda is intended as a tool for designing open systems, all operations include a time-out; moreover, `out` and `eval` return a boolean value to signal successful completion.

```
out(m:MULTISET; timeout:REAL):BOOLEAN
eval(m:MULTISET; timeout:REAL):BOOLEAN
```

`in` and `rd` take as parameter the object (`OIL_OBJECT`) to search; the operation has to find at least `min` such objects and return `max` of them by the `timeout`

```
in(o:OIL_OBJECT;min,max:INTEGER;timeout:REAL):MULTISET
rd(o:OIL_OBJECT;min,max:INTEGER;timeout:REAL):MULTISET
```

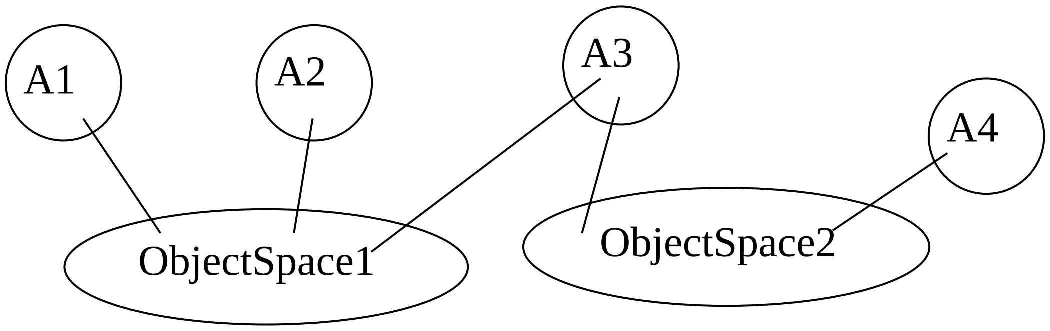
	min	max	timeout	behavior
`out`			0	immediately fail on errors
			t	wait t secs before failing on errors
			infinite	Linda `out`
`eval`			0	immediately fail on errors
			t	wait t secs before failing on errors
			infinite	Linda `eval`
`in`	0	0	nay	empty op
	0	1	0	Linda `inp`
	1	1	infinite	Linda `in`
	1	n	any	consume up to n objects
	1	infinite	any	consume all matching objects
	infinite	any	t	sleep t secs
`rd`	0	0	any	empty op
	0	1	0	Linda `rdp`
	1	1	infinite	Linda `rd`
	1	n	any	consume up to n objects
	1	infinite	any	consume all matching objects
	infinite	any	t	sleep t secs

Multiple tuple spaces in Objective Linda

Configurations is Objective Linda include object spaces and OIL objects both passive and active (agents).

Agents by default can access two special object spaces:

• their *context*, which is the space inside which the eval op for such an object has been issued
• their *self*, which is a space directly associated to the object



Other object spaces are accessible through *logicals*, which are references which can be passed around by active objects

When an object intends to let another object to access a space, it outs its logical to another space, from where it can be retrieved with a special `attach` operation:

```
attach(o:OS_Logical; timeout:Real): Object_Space
```

Formal semantics for Objective Linda has been studied in [HolvoetKielmann97] using a special Petri Net semantic model

Linear Objects

Linear Objects (LO) [Andreoli Pareschi 91] is an object based language based on the IAM coordination model.

An LO program is a set of methods (rewriting rules)
An agent is represented by a multiset
Interagent coordination is possible via broadcast

<*multiset*> <*broadcast*> <*built-ins*> **o–** <*goal*>

Multisets are described as: a_1 @ … @ a_n

Goals have the forms: a_1 @ … @ a_1 | goal1 & … & $goal_n$ | T

A *query* is <P, G> where P is a program and G a goal

Semantics:
Given a query <P,G>, a computation consists of the construction of a *target_proof*, that is a tree whose nodes are labelled by LO sequents of the form P |- C; branches are obtained using the following inference rules:

• Decomposition

$$\frac{P \vdash G_1 , G_2 , C}{P \vdash G_1 @ G_2, C} \qquad \frac{}{P \vdash \top ,C} \qquad \frac{P \vdash G_1,C \quad P \vdash G_2,C}{P \vdash G_1 \& G_2 , C}$$

• Propagation: if (Head @ Tell o- G) $\in$ P

$$\frac{P \vdash G_1 , C}{P \vdash \| Head @ Tell \|, C}$$

A target_proof for a query <P,G> is a tree whose root is
P |– G , C   Leaves are labelled by [⊤]

A proof tree

Suppose that the method `p @ q o- (r@s) & t` is triggered in the multiset `{p,q,u}`

The resulting computation is depicted by the proof tree

$$\cfrac{\cfrac{\cfrac{r,s,u}{r@s,u} \qquad t,u}{(r@s)\&t,u}}{p,q,u}$$

In other words, the computational interpretation of linear sequents can mirror the IAM

Programming with LO

A safe queen program

Coordination code

```
queens(N) <>-
      board(N,0,[]).

board(N,N,B)@{remote_format('Safe board:~q~n',[B])} <>-
      top.

board(N,I,B) @ {check_new_boards(N,B,LB),I1 is I+1} <>-
      make_boards(N, I1, LB).

make_boards(N, I, []) <>-
      top.

make_boards(N, I, [H|T]) <>-
      make_boards(N, I, T) &
        board(N, I, H).
```

Prolog computation code (fragment)

```
check_new_boards(N, B, LB) :-
        new_boards(N, B, LB1),
        safe_boards(LB1, LB).

new_boards(0, _, []).
new_boards(X, B, [NB|LB]) :-
        X1 is X-1,
        append(X, B, NB),
        new_boards(X1, B, LB).

safe_boards([], []) :- !.

safe_boards([H|T], [H|T1]) :-
        safe(H),
        safe_boards(T, T1), !.

safe_boards([_H|T], T1):-
        safe_boards(T, T1), !.
```

Programming with LO

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Programming with LO

A customer has to buy and sell stocks. There are 3 stock markets: Tokyo, Paris, NewYork. To initialize them, we insert in each one some buy and sell offers. These offers are contained in the "stock_prices" list.
There is a manager is waiting for an order. When an order from a client arrives, the manager takes care of it and a new manager is created to receive other orders.

```
main @ client_list(Buy,Sell,I,B) <>-
  stock_market(tokyo) @
            buy(sony,110,99,john,tokyo) @
            buy(honda,500,300,mary,tokyo) @
            sell(toshiba,100,50,mary,tokyo) @
            sell(sony,115,25,jim,tokyo) &
  stock_market(paris) @
            buy(bull,90,876,mary,paris) @
            buy(lacoste,523,391,john,paris) @
            sell(renault,150,643,susan,paris) &
  stock_market(newyork) @
            buy(sony,200,300,morris,newyork) @
            sell(renault,120,400,mary,newyork) &
  manager @ client_list(Buy,Sell,I,B) &
  counter.
```

Brokers need counter to avoid waiting indefinitely offers from stock markets. When the counter receives a "begin(I,N1)" message (I is the broker name, N1 is the name of the stock type) from a broker, it acts as a timer for him and a new counter is created to satisfy other requests from other brokers. When the fixed time is expired, counter sends a "end(I,N1)" message to the broker I and ends his work.

```
counter @ begin(I,N1) <>-
          counter(I,N1) @ timer(20000) & counter.

counter(I,N1) @ timer(X) @ {X>0, Y is X-1} <>-
          counter(I,N1) @ timer(Y).

counter(I,N1) @ timer(0) @ ^end(I,N1) <>- #t.
```

ForumTalk

LO has been implemented as a coordination language combined with host languages like Prolog and Modula-3

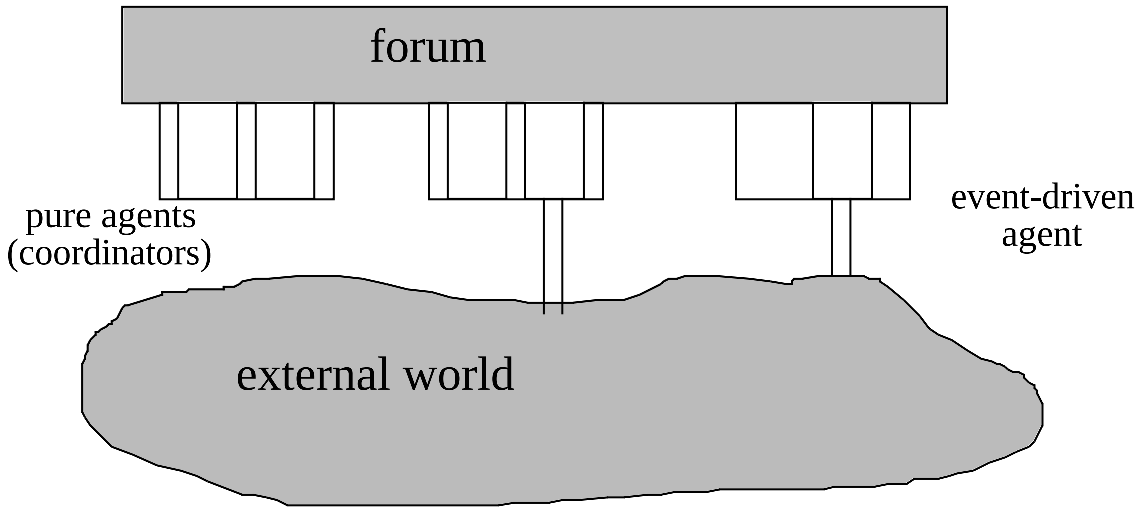
LO (like Linda) is not suitable for open systems design, because the program should be completely known before execution to be statically analyzed

The main coordination medium in LO was the Forum, a sort of tuple space used for broadcast

This coordination medium was abstracted from LO and used as basic coordination model of ForumTalk [Andreoli 96], a coordination platform to which LO programs could plug in at run time

The architecture of ForumTalk consists of a coordination service implemented by several servers; the servers maintain a big LO proof-tree to which the servers can dynamicalyy connect by the following ops:

- `forum-join`: register the server in the session; the tree is expanded at that node
- `agent-start`: starts an agent (a normal LO program) on the server where it is invoked

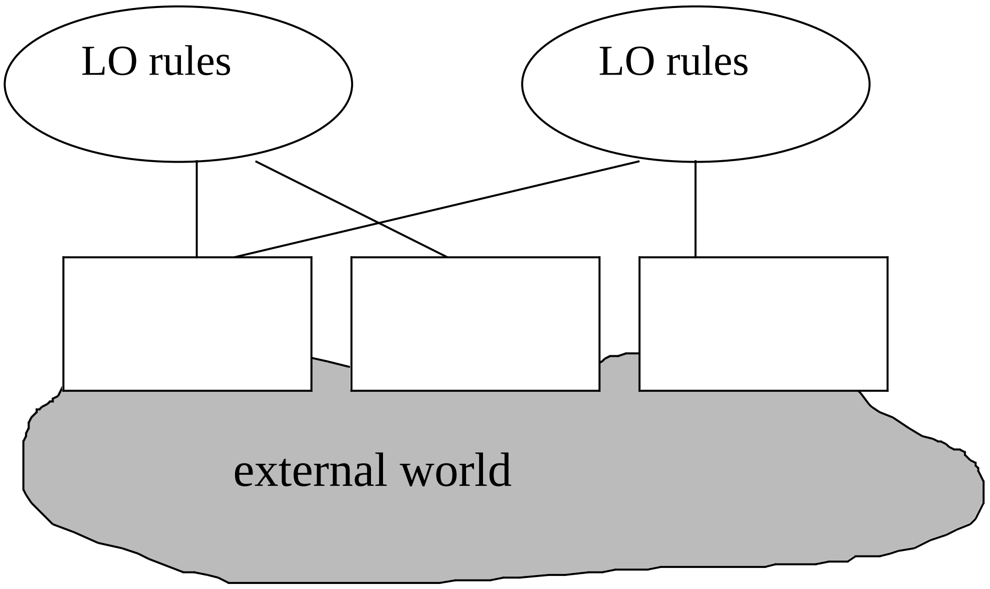


Coordination Language Facility (CLF)

The transactional nature of multiset rewriting as embedded in the LO model is at the basis of CLF [Andreoli et al. 1996], a software platform that merges OOP and transaction systems to coordinate access to distributed resources

• objects can dynamically offer new services
• multiparty negotiation can be specified and implemented

The sw architecture of a CLF application includes a number of application servers (*participants*) which are coordinated by one or more rule-based clients (*coordinators*) which execute LO programs



CLF basic coordination protocol

The CLF platform is implemented as an extension of client/server plus the following protocol:

Inquiry: (synchronous) a client inquires if a server holds or may produce a resource; the server (starts a thread and) answers with a stream of actions it may perform on demand to make such a resource available

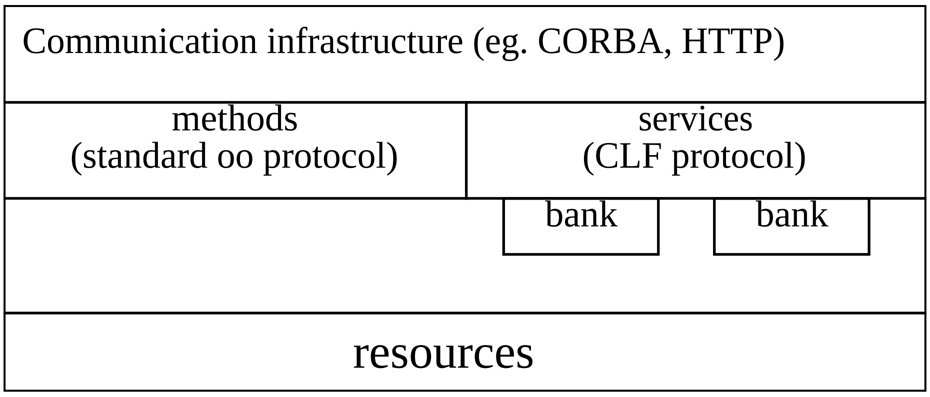
Reservation: (synchronous) the client requests the server to reserve one of the actions returned during the Inquiry phase. Accepting a reservation means that the server commits to perform the action on demand, with no possibility of failure.

Confirmation/cancelation: (asynchronous) The client may either confirm or cancel an action it has reserved. If confirmed the action must be executed leading to the deletion of the corresponding resource.

Insert: (asynchronous) the client requests the insertion into the server of a resource.

Structure of a CLF object

A CLF object can be implemented in any language, and can encapsulate any kind of resources



The interface of the object defines the properties (services) which are visible to the clients. Each service is implemented by a *bank*, which may encapsulate as wrapper a legacy application

The CLF library provides classes of objects in the target languages (currently C++ and Python)

Example

This example extends the flight reservation service already described for LO

```
journey_request(Name,From,To) @
flight_from(From,TransferAt,FlightNum1) @
flight_to(TransferAt,To,FlightNum2) @
book_seat(Name,FlightNum1) @ book_seat(Name,FlightNum2)
<>- print_ticket(Name,FlightNum1,FlightNum2)
```

This coordination rule involves three participants:
- a user terminal which holds the tokens `journey_request` and `print_ticket`
- a flight database which holds the tokens `flight_from` and `flight_to`
- a travel agency which holds the tokens `book_seat`

```
signatures:
  journey_request(Name,From,To):->Name,From,To
  flight_from(From,To,FlightID):From->To,FlightID
  flight_to(From,To,FlightID):From,To->FlightID
  book_seat(Client,FlightID):Client,FlightID->

interfaces:
  journey_request  = user_terminal
  flight_from      = all_flight_info
  flight_to        = all_flight_info
  book_seat        = travel_agent
```

Actor Spaces

The ActorSpace model [Callsen Agha 94] is a model which extends actor-style point-to-point asynchronous communication with pattern-directed invocation and broadcasting

The target systems to be designed are open, meaning that clients cannot be trusted, so security must be enforced

Client: requests service from a server
Server: provides a service to a set of clients
Manager: surveys the system and adjusts it to suit needs as they arise

ActorSpace (AS) adds new concepts to Actors:

- *attributes*, i.e. patterns that abstractly describe an external view of an actor; pattern matching can be used to pick actors whose attributes satisfy a given pattern. Thus in AS two forms of addressing coexist: an actor may be accessed by name or by pattern matching
- *actorSpaces*: a passive container of actors, i.e. a scoping mechanism for pattern matching; actorSpaces can be nested. Actors and ActorSpaces may be made visible or invisible in an AS. A manager is associated to each AS, that validates capabilities and enforces visibility changes
- *capabilities*: provide secure access control

Communication operations:
• `send(pattern@actorSpace,message)`
(one to one)
• `broadcast(pattern@actorSpace,message)`
(one to many)

Coordination in Java and the WWW

The WWW was born as a (huge) distributed hypertext document management system, but it rapidly become something more, and it is still evolving

The availability of a Java VM on most Internet hosts offers a world-wide programmable infrastructure (a *cyberspace*?)

When a browser downloads and executes a Java applet this is *mobility of code*

Some applications require complex coordination management:
- “intelligent” homes with networked appliances
- software distribution and maintenance
- infotainement (e.g. MUD, Internet playing clubs)
- electronic commerce
- workflow systems for active docs (eg based on XML/Java)

Jada

Jada [Ciancarini&Rossi 1996] is a simple combination of Java with Linda-like coordination

Jada (`www.cs.unibo.it/~rossi/jada/index.html`) provides:

• mobile object coordination: no syntax extension for Java, just a set of classes. Each Jada data type used is a Java object

• dynamic tuple creation: being an object, a tuple can be created with `new` and many different constructors are provided in order to build a tuple from a string, an array of objects or a set of arguments

• multithreading support: in Jada different threads can access the same tuple space; blocking requests are managed at thread-level

• open systems support: at any time threads or applications can perform an operation on a tuple space.

• associative access to collections of tuples: we provided special arguments for `in` and `read` requests (*any*) in order to allow the use of multiple matching tuples

• no `eval`

Jada design choices

We designed Jada as a minimalist language, aiming to simplicity rather than performance

• The basic objects used in Jada are Tuple and TupleSpace
• To allow remote access to a tuple space the TupleServer and TupleClient classes are also provided.

TupleServer is a multithreaded class which translates requests received from instances of the TupleClient class in calls to the methods of the TupleSpace class

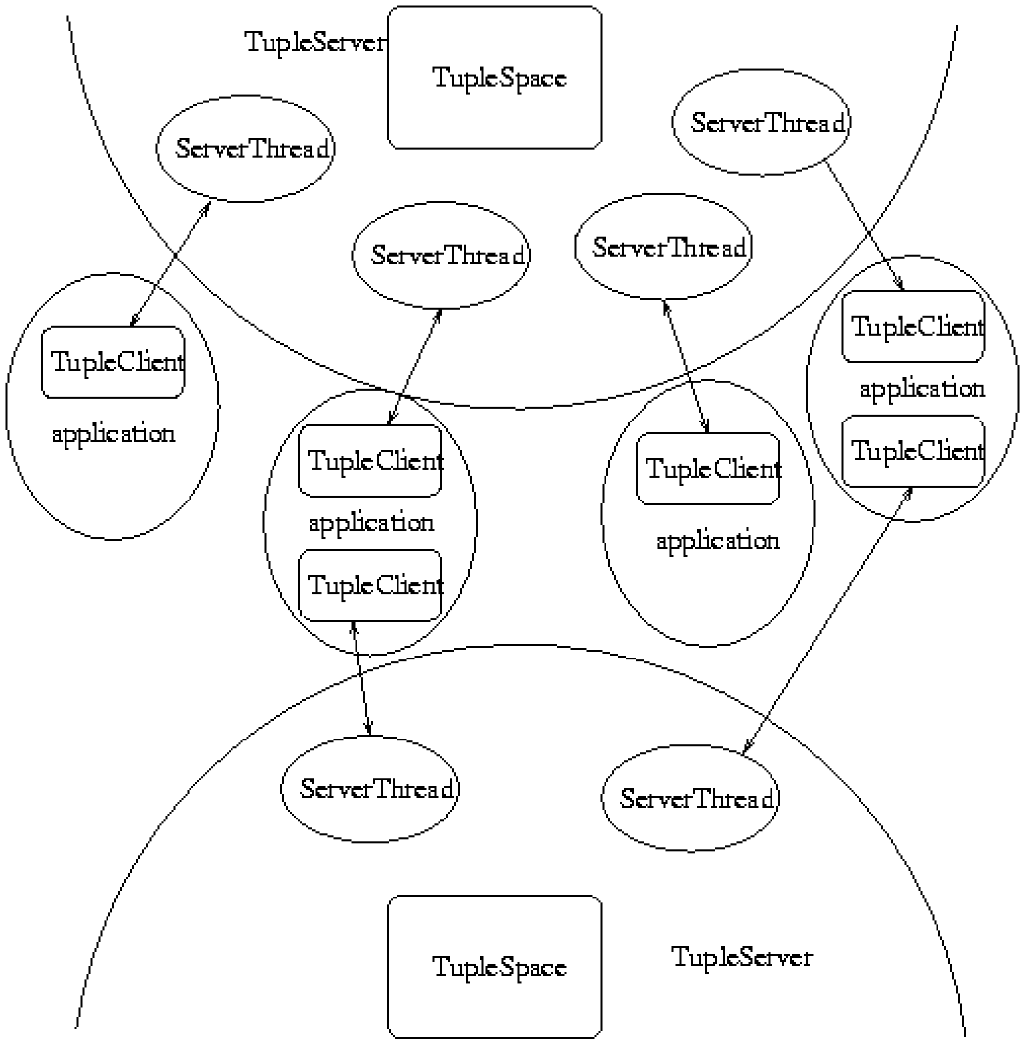
A TupleClient interfaces with a remote TupleServer object (which really holds the tuple space) and asks it to perform the Linda-like operations and to return the result

Both TupleServer and TupleClient are based on TupleSpace:

- TupleServer includes a tuple space and uses it to perform requested operations;
- TupleClient differs from TupleSpace: the access to the tuples is tranformed in requests for the TupleServer

The Jada objects TupleServer and TupleClient communicate using sockets.
TupleClient needs to know host and port of TupleServer, so a set of constructors is provided to specify TupleServer host and port

Jada software architecture



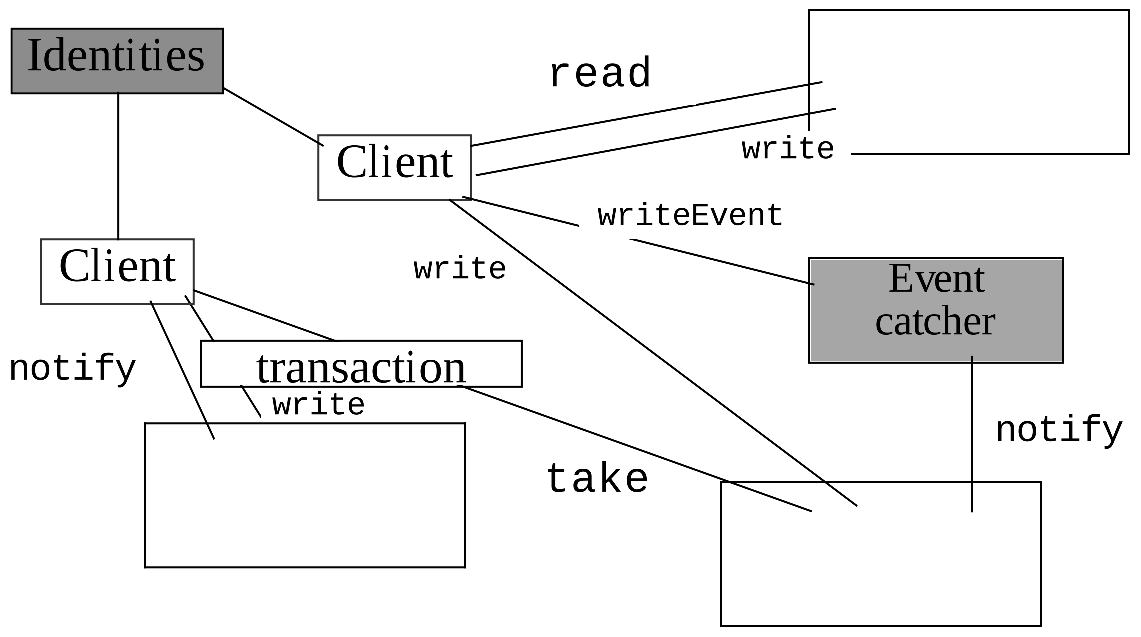
JavaSpaces™ (SunSoft)

JavaSpaces™ [JavaSoft 98, `java.sun.com/products/javaspaces`] is a Jini component providing orchestration and data exchange mechanisms for Java

A JavaSpace is a multiset of entries; an entry is a typed group of objects expressed in a special Java class. Clients can perform the following operations:

- write (out) an entry in a JavaSpace
- read an entry from a JS matching a given template
- take (in) an entry from a JS matching a given template
- notify an object when entries that match a given template are writen into this JS

JavaSpace provides atomic transations to group multiple operations across multiple JS



Tspaces™ (IBM)

TSpaces™ [Wyckoff98, `www.almaden.ibm.com/cs/TSpaces`] is apparently similar to JavaSpaces: it is a platform for enhancing Java with coordination mechanisms

The tuplespace operators are: `write` (like `out`); blocking and non-blocking `read`, and `take` (like `in`); multiset-oriented operators, and some novel operators like `rhonda` (associative rendez-vous)

Agents can register to be notified of events happening in a TSpace server

The main novelty introduced by Tspaces wrt JavaSpaces is that the tuple space is implemented as a relational database, and operations are transactions

Security policies can be established settiung user and group permissions on Tuplespaces

The WWW meets Linda

The basic reason for supporting WWW applications with Linda-like coordination is that I/O processing and data processing can be easily separated.

CGI scripts become responsible for I/O, and communicate with applications via the Tuple Space

• applications can use services on different hosts

• the application can written with multiparadigm languages

• the CGI script is only responible for displaying the data

• coordination between interface and application is centered in the Tuple Space

The WU Linda toolkit [Schoenfeldinger 95] combines the tuple space coordination model with some popular scripting languages, like Perl and TCL/TK

PageSpace

The initial idea in PageSpace [Ciancarini et al 98] was to use a tuple space as WWW server, to coordinate access to “active” pages by associative invocations; we have enhanced such an idea, using a concept of coordination language for Java applets

During the project, we have

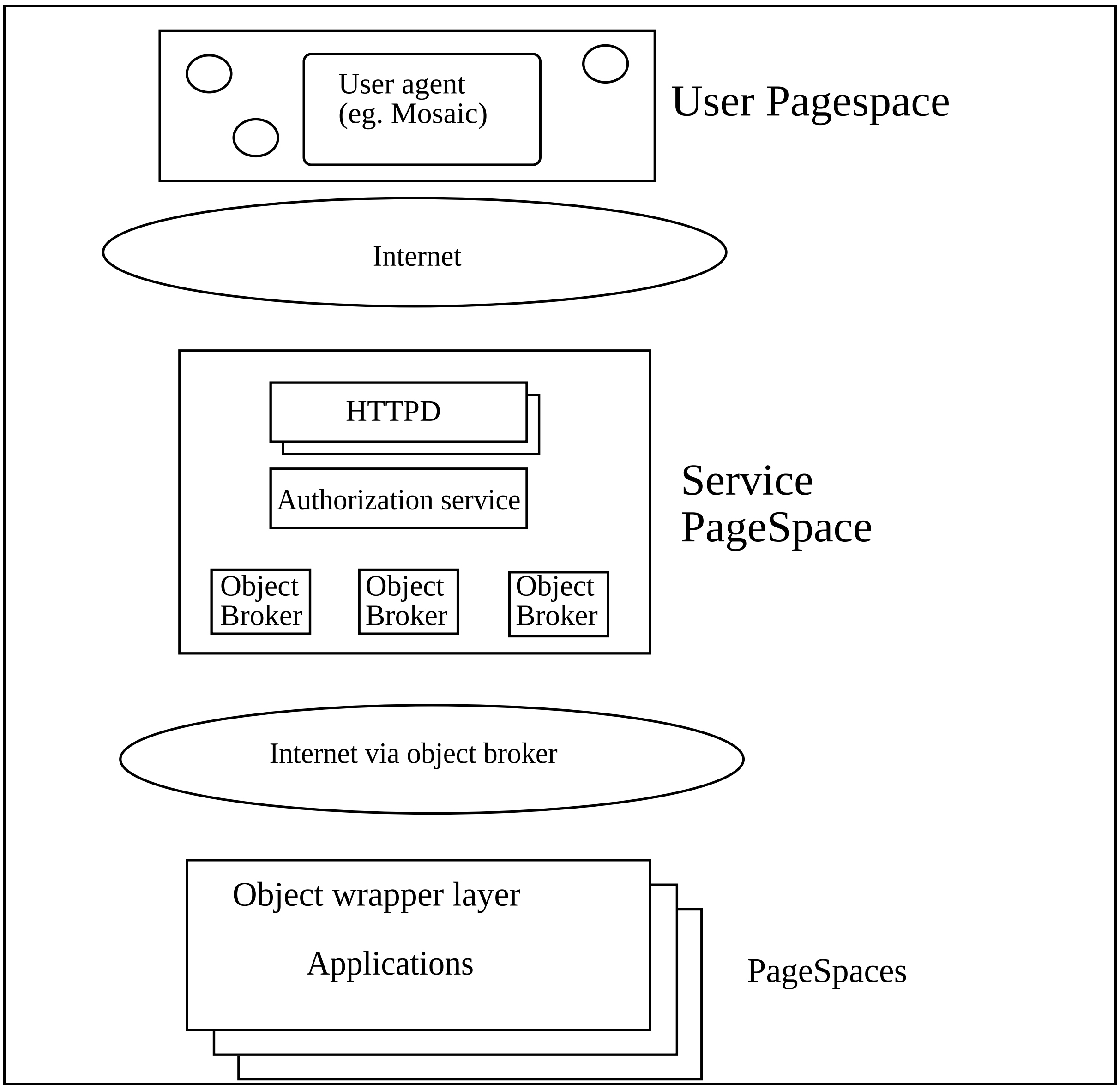
• studied and classified groupware applications of WWW

• designed the middleware necessary to support these applications, formulating it in terms of coordination primitives

• built some prototypes based on some coordination languages (Paradise, Shade/Java, Laura)

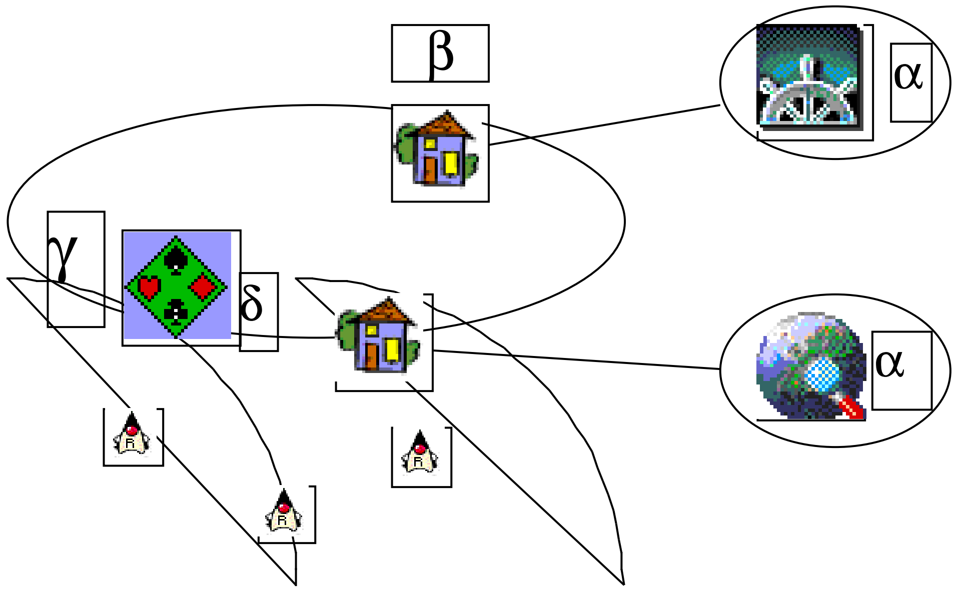
• built a proof-of-concept application for electronic commerce

A vision of PageSpace as middleware



Designing a pagespace

We have developed a reference middleware architecture for PageSpace, consisting of a number of components



α pagespace client: browser+coordinated helpers
β homeagent: (persistent) user broker in a pagespace
γ coordination environment (e.g. tuple space, service space)
δ application agent (eg. to play, to buy, etc)
ε coordination runtime server in the local host
ζ gateway agent to other platforms (eg. CORBA)

We are currenly working especially on the preliminary design of γ extending and integrating Java capabilities

A kernel has been obtained combining Java with Linda (Jada)

We have used Jada to implement and test two different coordination environments, respectively based on Laura (service space) and Shade (workflow and transaction space)

Some applications of PageSpace

We have studied a number of applications of PageSpace in office automation, electronic commerce, process centered environments, concurrent engineering

• process-centered environments

• distributed auction bidding, financial services

• infotainement servers integrated in the WWW

Example: process-centered environment.

PageSpace is used for storing and retrieving (XML-based) documents that represent the status of a software process; a number of tools can be invoked following some (rule-based) workflow process

Example: distributed auction bidding.

A number of customers use a pagespace to sell and buy goods represented as XML documents using some stock exchange mechanisms

Kinds of Mobile Entities

Mobility of data
   Clients and servers usually only exchange ASCII data

Mobility of reference
   Each agent has a reference to a “working location”, but it can change such a reference, “moving” in a static structure

Code mobility [plain Java]
   Programs move (on demand) from a site to another

Agent migration [Aglets, etc]
   Agent images (code & store) can move from a location to another, travelling some “itinerary”

Threads migration
   Agent images and scheduling state (code & store & execution state) travel some “itinerary”

Closure mobility [Cardelli’s Obliq]
   An agent moves and keeps its environment

Ambient mobility [Bauhaus, Ambient]
   Both agents and their operating environments can move

Macondo: mobility by migration

Macondo (Mobile Agents and CoordinatioN for Distributed applicatiOns) [CGR00] is a Linda-based coordination environment where Java agents can migrate

The coordination media consist of a set of distributed object spaces (similar to tuple spaces, but tuples are Java objects); agents can migrate from a space to another one

An object space is used to coordinate mobile agents, namely to manage their relationship with other agents in the same place and with the underlying runtime system

Agents at any time reference the local object space using the following operations:
- `in`,`read`,`out` an object in the local object space
- `register`, to request the runtime to issue a notification when some specific object appears in the object space
- `go`, to migrate to another place

Some manager agents can create and destroy places

We have used Macondo for designing groupware applications for mobile users

`www.cs.unibo.it/~cianca/wwwpages/macondo/index.html`

KLAIM

KLAIM (Kernel Language for Agents Interaction and Mobility) [DFP88, `music.dsi.unifi.it/klaim.html`] has a coordination model based on (flat) multiple tuple spaces.

The language is a simple extension of Linda with new primitives:

`new-loc(l)` creates a new location (tuple space) l
`eval(P)@l` creates a new process at location l
`out(t)@l` creates a new tuple at location l
`in(t)@l` consumes a tuple from location l
`rd(t)@l` reads a tuple from location l

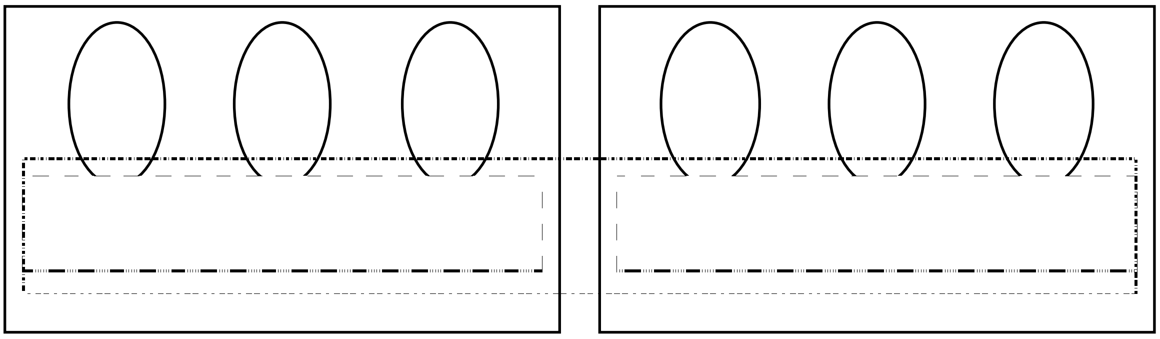
The basic novelty of KLAIM is that any entity (agent, locality, set of localities) is typed, thus it is possible to statically enforce important properties of coordinable mobile systems, like security

LIME

LIME (Linda in a Mobile Environment) adopts the view that physical and logical mobility coincide. A wireless network includes mobile hosts; each host can be the home of one or more mobile agents [PMR99, `swarm.cs.wustl.edu/~picco/lime`]

Each agent own a local tuple space; when the host containing the agent joins a network, the local tuple space becomes public and it is "merged" with the global tuple space formed by spaces of agents already included in the network

The global tuple space is thus "transient": if an agent leaves the network, all "its" tuples not already consumed leave as well



Conclusions

Linda's tuple space is a simple embodiment of a concept of *software bus*, namely an interoperability platform (*cf* CORBA)

The tuple space can be implemented in several ways; an optimized implementation needs a static analysis phase

Marrying Linda with a conventional language needs a study of data structures used for coordination entities and media

The combination of Linda with logic languages has been studied especially from the point of view of parallel programming: large grain parallelism is especially suited to logic programs

The combination of a coordination model with object oriented languages is quite promising; still, a lot of research effort is necessary to understand the coordination requirements of distributed objects and define suitable coordination languages

The combination of coordination technologies with WWW is especially promising because they support in a very natural way concepts like open-endness and agent migration