Tuple-based Coordination: An Introduction

Andrea Omicini, Alessandro Ricci
andrea.omicini, a.ricci@unibo.it
Alma Mater Studiorum–
Università di Bologna a Cesena

Outline

- (PART I) Elements of distributed system engineering

  <few important points>
- (PART II) Introduction to (tuple-based) coordination
  - Some tuple space / Linda examples
- (PART III) Hybrid Coordination Models
  - the ReSpecT language and computational model
  - the TuCSoN model and infrastructure
- (PART IV) Linda vs. TuCSoN
  - Some coordination patterns in Linda and TuCSoN

PART I

Elements of distributed systems engineering

Concurrent / Distributed System Scenarios

- Time, Space, Interaction
- Concurrency / Parallelism
  - Multiple independent activities / *loci* of control
  - Active *simultaneously*
- Distribution
  - Activities running on different and heterogeneous execution contexts (machines, devices, ...)
- Interaction
  - *Dependencies* among activities
  - Collective goals involving activities coordination / cooperation

Basic Engineering Principles

- Abstraction
  - Problems should be faced / represented at the most suitable level of abstraction
  - Resulting “abstractions” should be expressive enough to capture the most relevant problems
  - *Conceptual integrity*
- Locality & Encapsulation
  - Design abstractions should embody the solutions corresponding to the domain entities they represent
- Run-time vs. Design-time Abstractions
  - Incremental change / evolutions
  - On-line engineering
  - (Cognitive) Self-organising systems

OOP: Not Enough

- How to model *an independent activity*?
  - Objects? No way
    - Objects encapsulate a state and a behaviour, but not a control flow
      - Objects have autonomy over their state, they can control it
      - Objects have not autonomy over their behaviour, they cannot control it
      - *Control flows along with data*, by means of method invocation (as a reification of message passing)
    - Control is *outside objects*, owned by human designer who acts as a control authority, establishing the control flow
    - Object interaction is limited and disciplined by interfaces, governed by the human designer
- How to model *concurrent* activities? How to model *interaction and coordination* among concurrent activities? How to decouple data and control?
  - Method invocation?? No way!

Information- / Knowledge-driven Engineering

- Control is encapsulated within agents
- Information flows independently of control
  - And determines the evolution of the system
  - Information-oriented interpretation of interaction
    - Interaction in terms of information exchanged
- How to support this view?
- Which are advantages and limits?
  - Data-driven vs. control driven models
    - Later on :)

Task- / Goal-Oriented Engineering

- Task / Goal as abstractions to drive control
  - Within agents
- Individual / Social tasks / goals
  - Task / goal identification
    - Individual to single agents
    - Social to group of agents
  - Task / goal unfolding / folding
    - From individual to social, and viceversa
- Core of agent-oriented engineering

An Example: An Alarm System

- Scenario
  - a building where access to rooms/resources has to be ruled according to some global organisation policy
- Examples of individual taska
  - Monitoring a room
  - Identifying users
  - Informing the police
- Examples of collective tasks
  - Organisation/Security policies
    - When detecting unidentified users in rooms X,Y, lock resources R1, R2 and inform the police
    - From 23.00 to 6.00 only some users are allowed to access the building

Agents and Infrastructures

- Agents need *infrastructures*
  - Providing basic services to support agents at runtime
    - Services for agent life cycle (creation, execution, death, migration..)
  - Providing core abstractions as first-class entities of MASs
    - To enable / promote / govern agent interaction
      - Enabling communication, synchronisation, cooperation, …
    - And social structure / dynamics
  - As well as services for enaction, management, use, evolution of the infrastructural abstractions
- *Keeping the abstractions alive*
  - Support for dynamic system construction, observation, evolution

PART I - SUMMING UP

- The engineering of distributed systems
  - Requires basic SE principles to be satisfied
  - But also calls for abstractions encapsulating the control flow
  - Information-driven Design
- Task- / Goal-oriented approach
  - Individual and Social Tasks / Goals
  - Agents and Artifacts (Infrastructure Abstractions)
- Infrastructure for MASs
  - Providing Abstractions for Agents

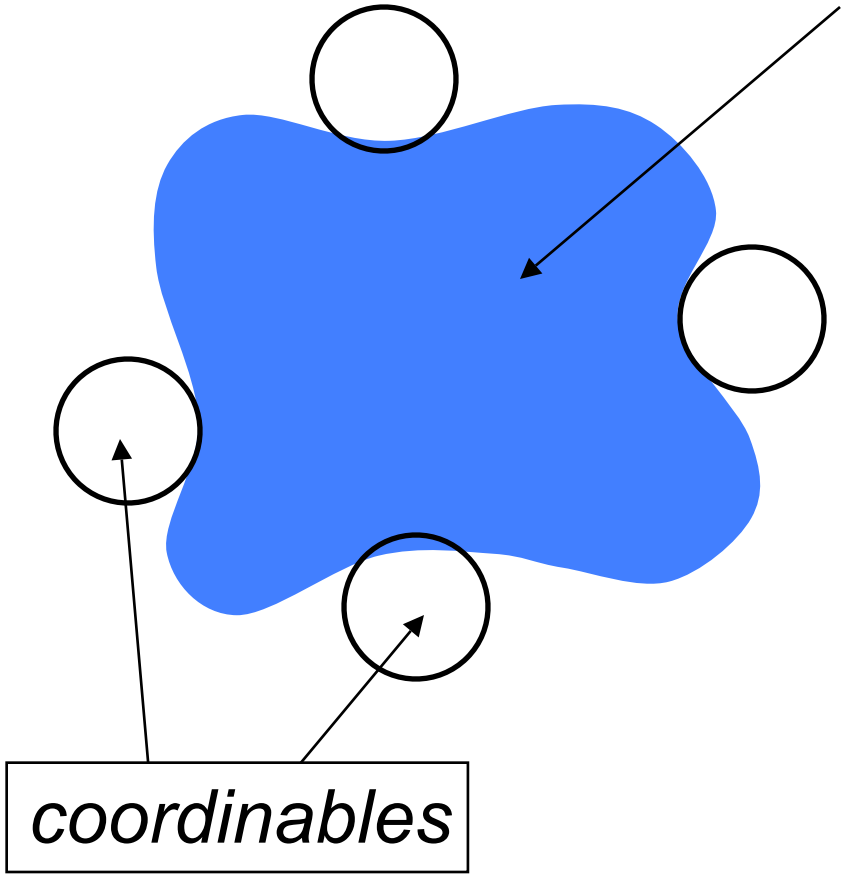
PART II

Introduction to (tuple-based) coordination

The Roots of Coordination Models & Languages

- Concurrent/parallel programming context (~1980s)
  - Programming = Computation + Coordination
    - Coordination as the glue that binds separate activities into an ensemble (Gelernter)
- Software engineering context (~1990s)
  - Coordination = constraining/promoting/managing interaction among independent components
  - Architectures = Components + Connectors

Coordination Meta-model (I)



coordination
medium

what
enable & govern & promote
interactions
among the entities
according to some
coordination laws
- enacted by medium behaviour
- defining coordination semantics

the *glue*

Coordination Meta-model (II)

- Ciancarini 1996
  - Coordinables
  - Coordination Media
  - Coordination Laws

Coordination Meta-model (III)

- Coordinables
  - Entities whose mutual interaction is ruled by the model
  - Examples:processes, threads, objects, users, agents, …
- Focus
  - Observable behaviour of the coordinables
  - Question: are we anyhow concernd here with the internal machinery / functioning of the coordinable, in principle?
    - Wait for a comparision between Linda and TuCSoN…

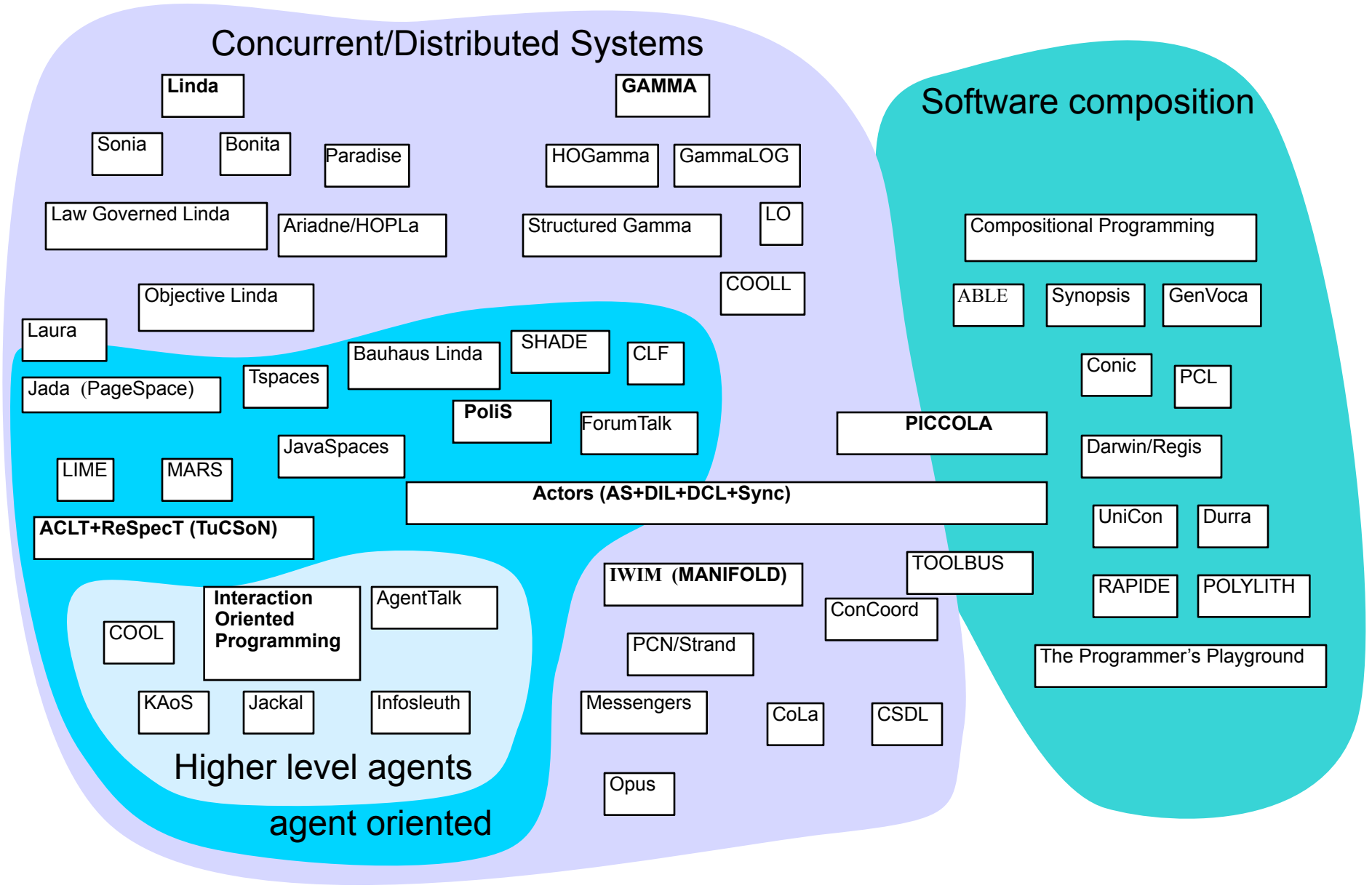
Coordination Meta-model (IV)

- Coordination Media
  - Abstractions enabling and ruling agent interactions
  - The core around which the components of the system are organised
- Examples
  - semaphors, monitors, channels, tuple spaces, blackboards, pipes

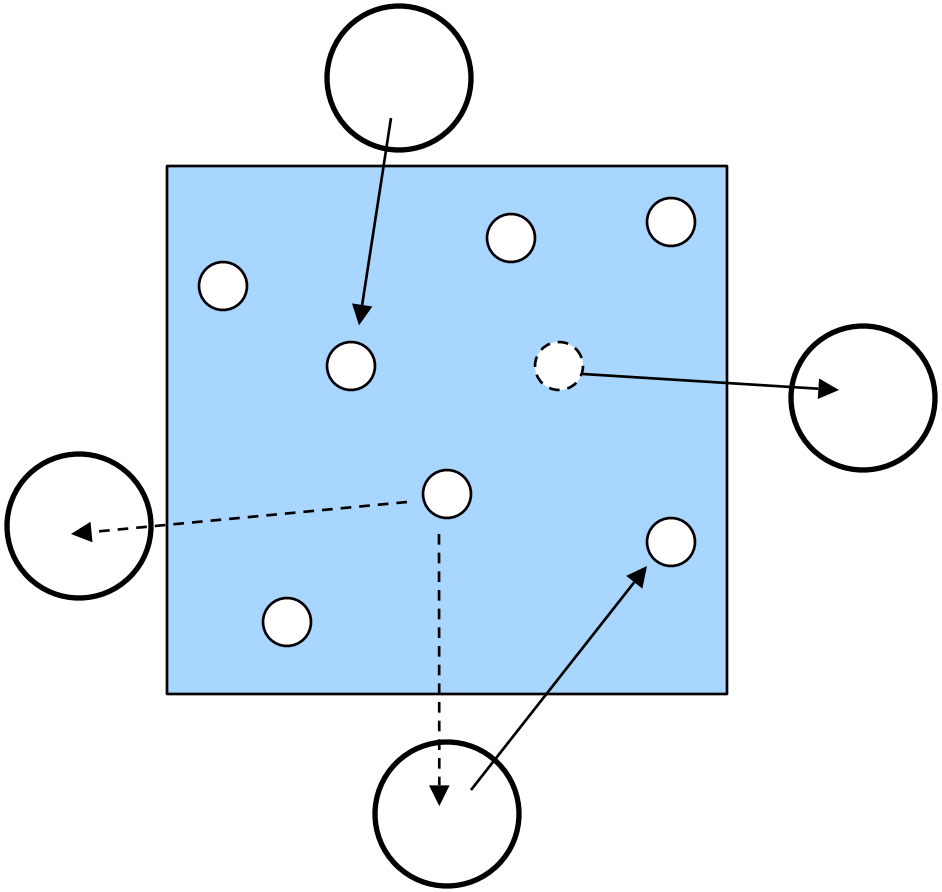
Coordination Meta-model (V)

- Coordination Laws
  - Define the behaviour of the coordination media in response to interaction
    - Interaction *events*
  - Expressed in terms of
    - The communication language
      - Syntax used to express and exchange data structures
      - Examples: Tuples, XML elements, FOL Terms, (Java) Objects, ….
    - The coordination language
      - Set of interaction primitives and their semantics
      - Examples: in/out/rd.. (Linda), send/receive (channels), push/pull (pipes..)

Model/Language Families (1999)



The Tuple Space Model



Coordinables synchronise, cooperate, compete based on tuples available in the tuple space, by associatively accessing, consuming and producing tuples

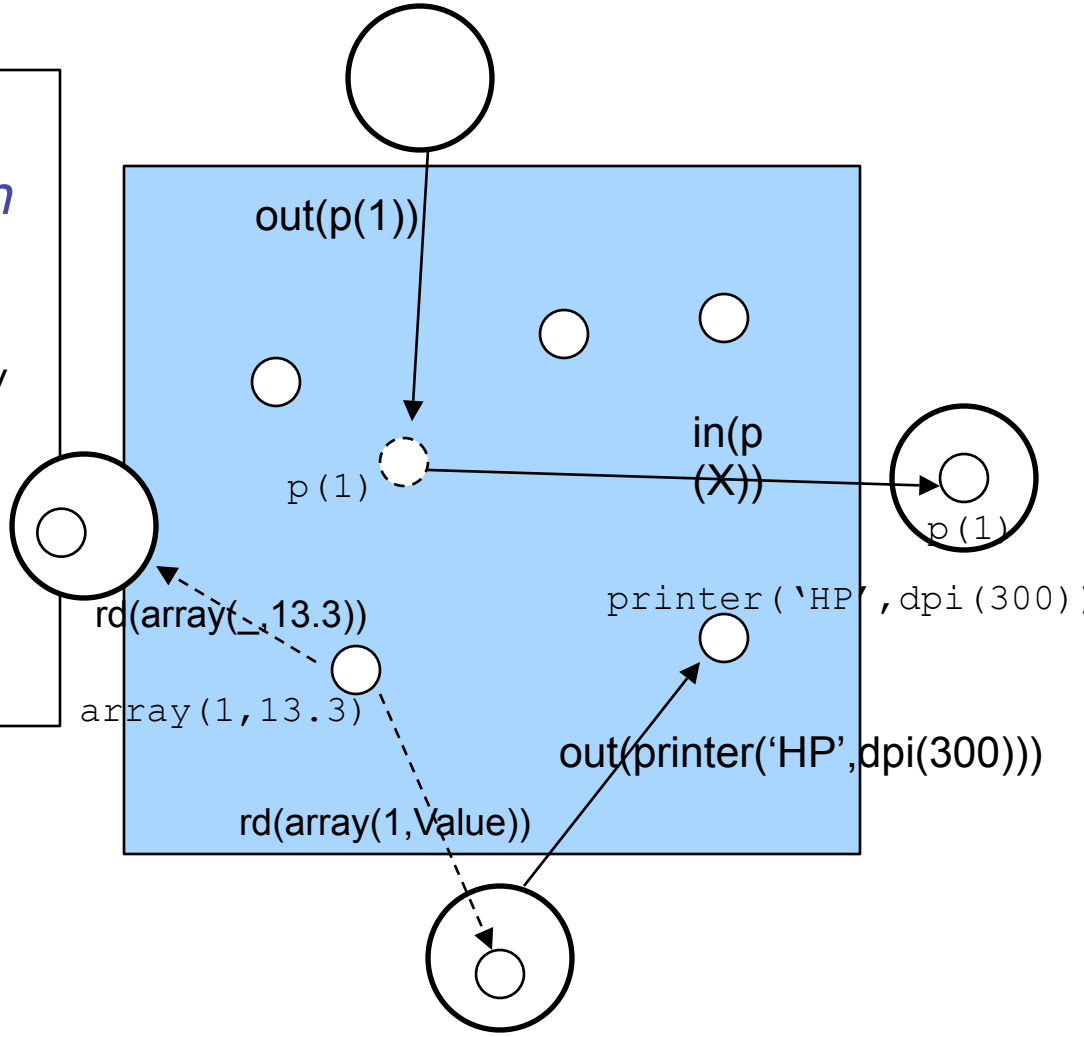
- Coordination medium: Tuple Space
  - Multiset / bag of data object/structures called *tuples*
- Communication Language: Tuples
  - Tuple = ordered collection of (possibly heterogeneous) information items
- Coordination Language → set of operations to put and retrieve tuples to/ from the space

A Language for Tuple Spaces: Linda

- Communication Language
  - Tuple, Templates (anti-tuples) and tuple matching
    - Examples: p(1), printer('HP',dpi(300)), my_array(0,0.5), matrix (m0,3,3,0.5), tree_node(node00,value(13),left(_),right(node01)), …
- Coordination primitives
  - out(T)
    - Puts in the space the tuple T
    - Examples: out(p(1)), out(printer('HP',dpi(300)), out(array(1,13.4)), out (course('Denti Enrico','Poetry',hours(150))…
  - in(TT)
    - Removes from the space a tuple matching the template TT
      - Blocking behaviour
      - non-determinism
    - Examples: in(p(X)), in(printer(Name,dpi(300)), in(array(1,Value))…
  - rd(TT)
    - Reads (without removing) from the space a tuple matching template TT
      - Blocking behaviour
      - Non-determinism

Tuple Spaces/Linda features

- *Generative Communication*
  - until explicitly withdrawn, the tuples generated by coordinables have an independent existence in the tuple space. A tuple is equally accessible to all the coordinables, but is bound to none
- *Associative Access* to the tuple space
  - accessing tuple through content, not address



Generative Communication Properties

- Communication orthogonality
  - Both senders and the receivers can interact even without having prior knowledge about each others
  - → Space uncoupling (also called distributed naming)
  - → Time uncoupling
- Free Naming
  - → Support for continuation passing, Structured naming and inverse Structured naming
    - Flexibility exploiting tuple matching
      - Job allocation & Reminder example (Gelernter)

→ Seamless support for…

- Distributed data structures management
  - Partial data structures
- All form of communication & Synchronisation

→ Basic orthogonal mechanisms that can be composed flexibly to obtain high level coordination patterns

- Need for formal semantics
  - The out issue by Zavattaro

Associative Access Properties

- Content-based coordination
  - Synchronisation based on tuple content
    - Absence / presence of tuples with some content
- Information-driven coordination
  - Patterns of coordinaiton based on information availability
- Reification
  - Making events become tuples
  - Classes of events

Suspensive Semantics

- in, rd
  - In Linda
    - the coordination medium makes the primitives waiting in case a matching tuple is not found
    - the coordinable performing the primitive is expected to wait for its completion
- Twofold “wait”
  - In the coordination medium
    - Coordination on absense / presence
  - In the coordinable
    - Hypothesis on the internal behaviour of the coordinable

Tuple Spaces / Linda Extensions

- Extending the communication language
  - XML based tuples (ex: XMLSpaces)
  - Java object tuples (ex: JavaSpaces,Tspaces, MARS)
  - Logic-based tuples (ex: Shared Prolog, ReSpecT)

  …
- Extending the coordination language
  - adding coordination primitives:
    - Non-blocking behaviour
      - inp, rdp
    - Bulk-primitives
      - Inall, rdall, copy, copycollect,…
- Extending medium structure and topology
  - multiple tuple spaces (ex: TuCSoN ...)
  - nested spaces (ex: Bauhaus Linda)
- Extending medium behaviour
  - Programmable tuple spaces (ex: ReSpecT/TuCSoN, MARS…)
  - Event management (ex: JavaSpaces)

Benefits

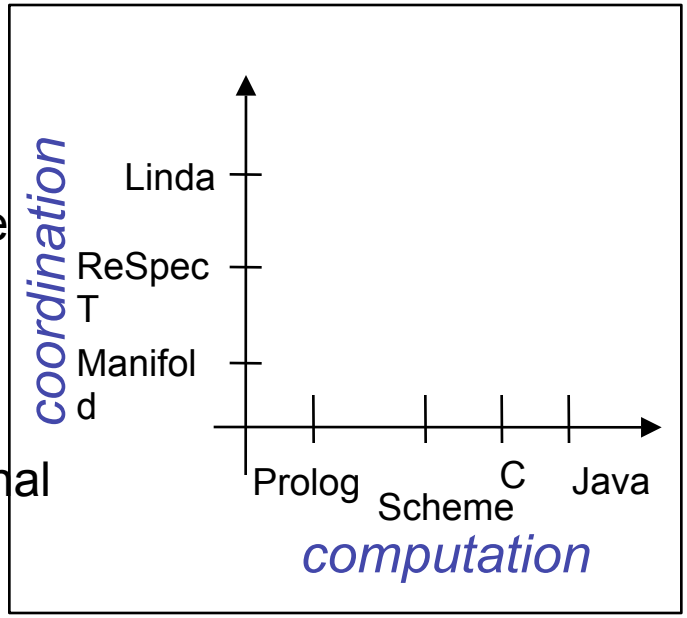
- *Ortogonality (Separation) of* Coordination *and* Computation *Languages*
  - computational languages as sort of degenerate coordination language in the form of global variables and argument passing
  - Ex: “Linda and friends”
    - Linda+C, Linda+Prolog, Linda+Fortran,…
- *Generality*
  - The same general purpose coordination language can be used in different coordination contexts, gluing different kind of computations

→ *Heterogeneity*

- gluing computation of heterogeneous computational models, all in the same coordination context

→ *Portability/Reusability*

- Reusability (recycle-ability) in reusing application, implementation, tools and heterogeneous programmer expertise in the same coordination context



Data- vs. Control-driven Coordination

- What if
  - We need to start an activity after N agents have asked for a resource?
  - In general, we need to coordinate over the coordination acts, rather than on their content?
- Control-driven coordination
  - That does not fit our information-driven context, however
- Toward hybrid coordination models
  - Linda plus… what?

PART II - SUMMING UP

- Coordination models/languages & technologies provide first class issues to model and develop coordination abstractions / artifacts
  - Promotes the separation between computation and coordination/interaction issues
  - Several models with different expressiveness
- Tuple Space / Linda coordinaiton
  - Shared tuple spaces as coordination artifacts
  - Benefits of the generative communication / associative access
  - Limits of data-driven coordination

PART III

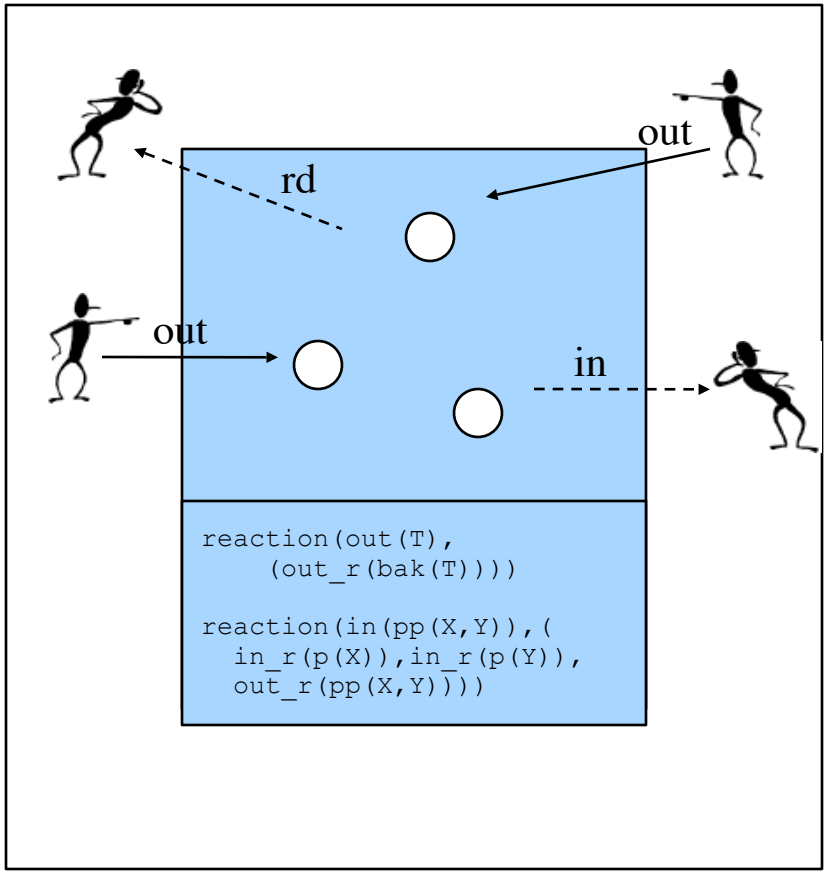
ReSpecT & TuCSoN

ReSpecT at a glance

- Reaction Specification Tuples
- From tuple spaces to *tuple centres*
  - *programmable* tuple spaces
    - ReSpecT tuple centres behave as tuple spaces when their behaviour specification is empty
  - programmable (coordination) artefacts
    - either at the application or at the infrastructure level
- ReSpecT tuple centres
  - encapsulate any computable coordination activity
    - they can observe any interaction event
    - they can affect the interaction space
    - ReSpecT is Turing-equivalent

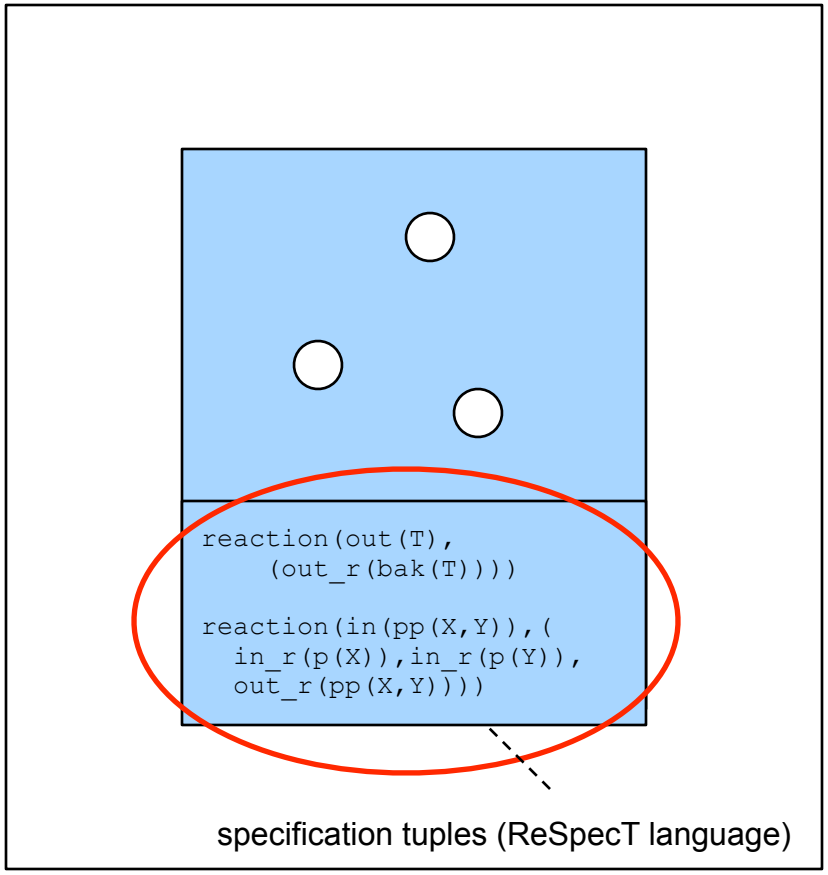
ReSpecT Tuple Centres

- Programmable (logic) tuple spaces
  - Logic tuples as communication language
- *General purpose / customisable* coordination artefacts



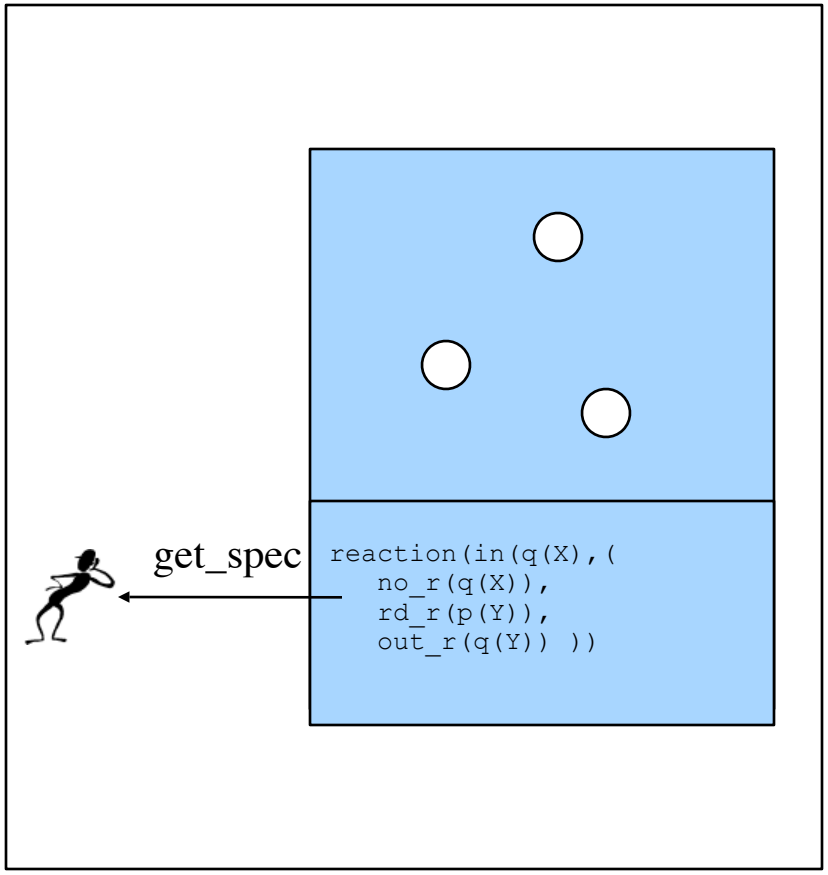
Tuple Centre Features: Programmability

- *Programmable*
  - Tuple centre behaviour can be *programmed* to enact the desired coordination policies
  - *ReSpecT* language as programming language
    - Programs as set of logic tuples (*reactions*) specifying medium behaviour reacting to interaction events
  - [idea] Tuple centres as a general purpose coordination artifacts customizable by means of the ReSpecT logic based language



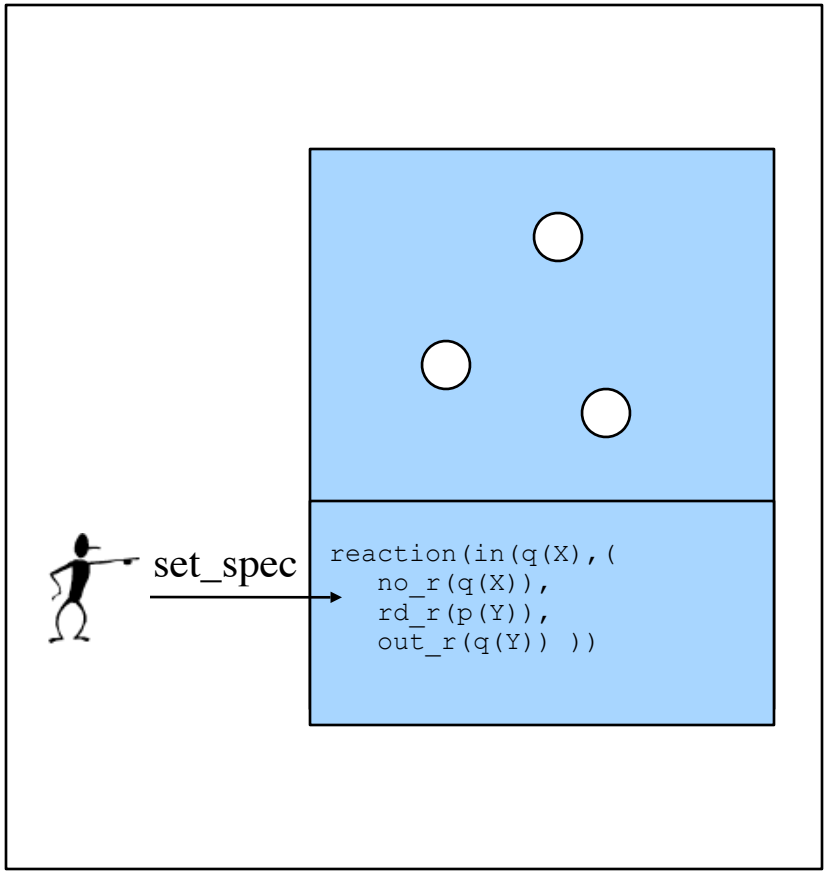
Tuple Centres Features: Inspectability

- *Inspectable at runtime*
  - Tuple centre behaviour can be inspected dynamically, at runtime
- (ReSpecT) Uniformity of languages
  - Same structure / same primitives for communication and coordination
- Theory of communication / theory of coordination
  - As FOL theories

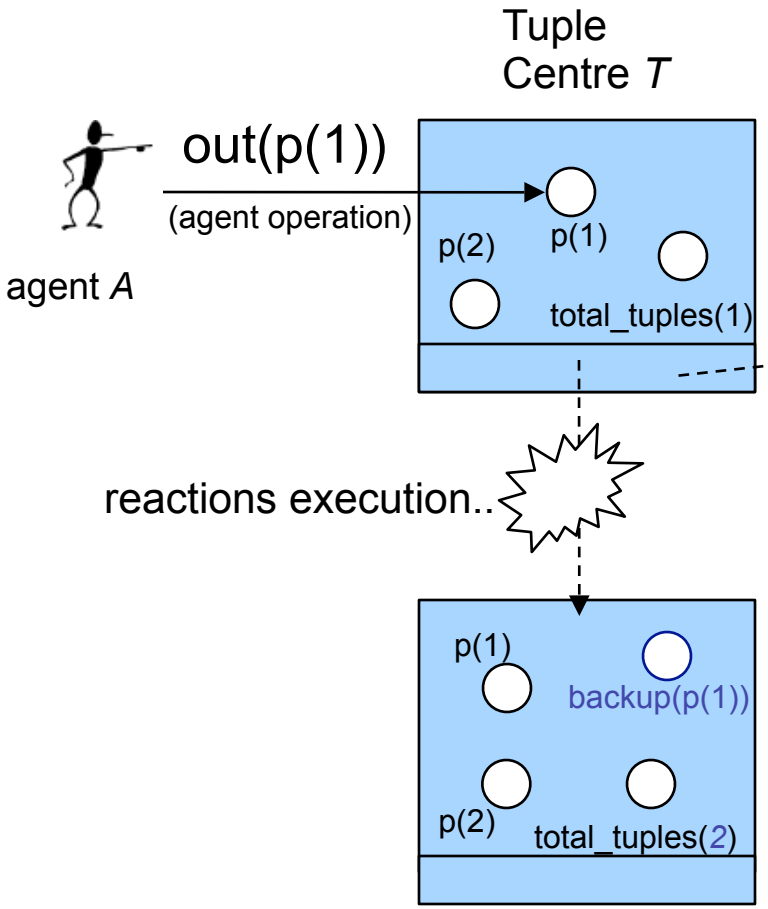


Tuple Centres Features: Malleability

- *Adaptable at runtime*
  - Tuple centre behaviour can be changed/adapted dynamically, at runtime, by reprogramming the artifact
- Locality / Encapsulation
  - Tuple centres embed coordination laws
    - A tuple centre can is a full-fledged coordination abstraction
  - Reaction model ensure encapsulation of low-level coordination policies



Simple examples



Current behaviour of the tuple centre (pseudocode):

When a tuple T is inserted, produce a tuple `backup(T)`

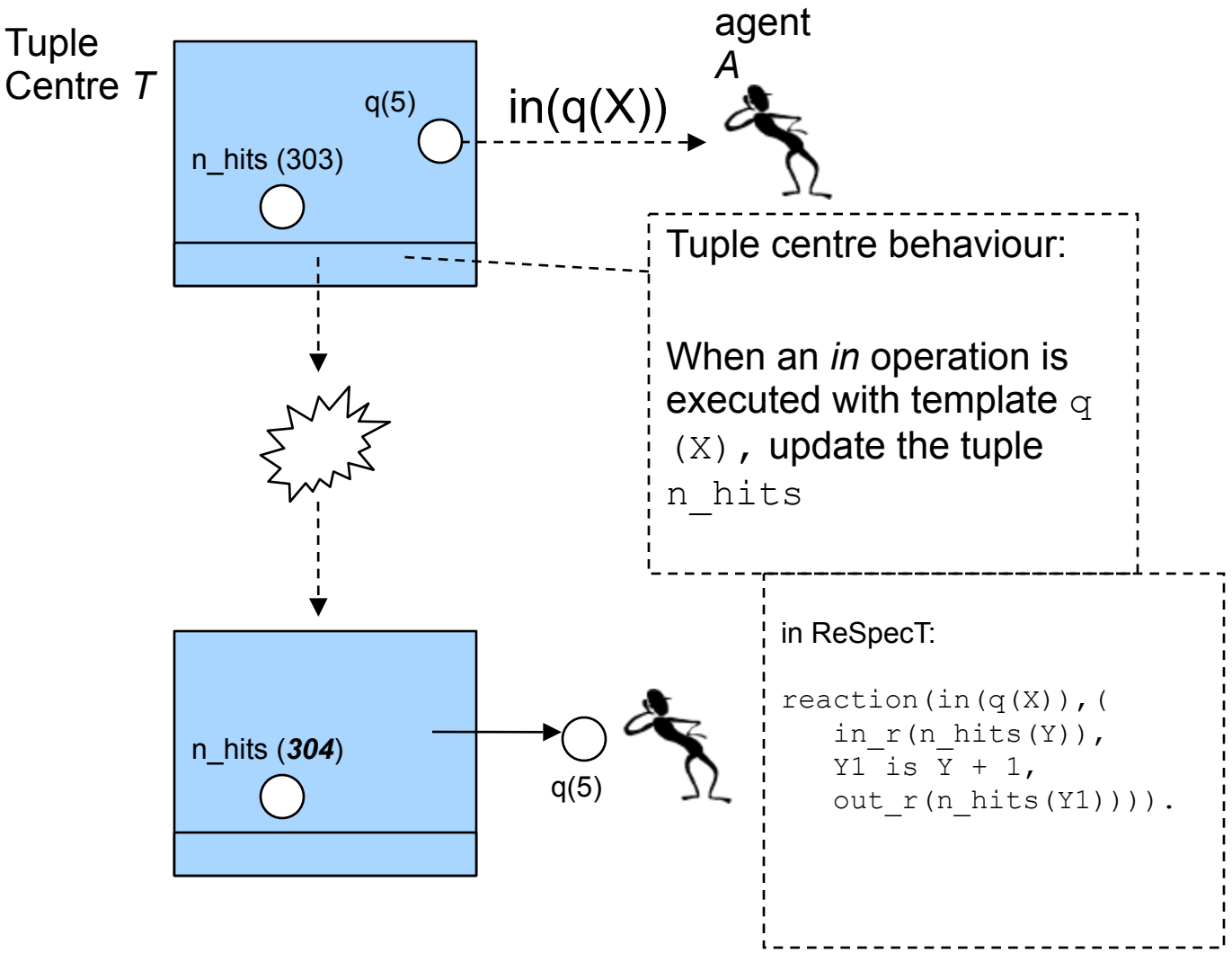
When a tuple p(X) is inserted, update the tuple `total_tuple(N)` (retrieve and store the tuple with N incremented)…

in ReSpecT:

```
reaction(out(T),(
    out_r(backup(T)))).

reaction(out(p(X)),(
    in_r(total_tuples(N)),
    N1 is N + 1,
    out_r(total_tuples(N1)))).
```

Simple examples

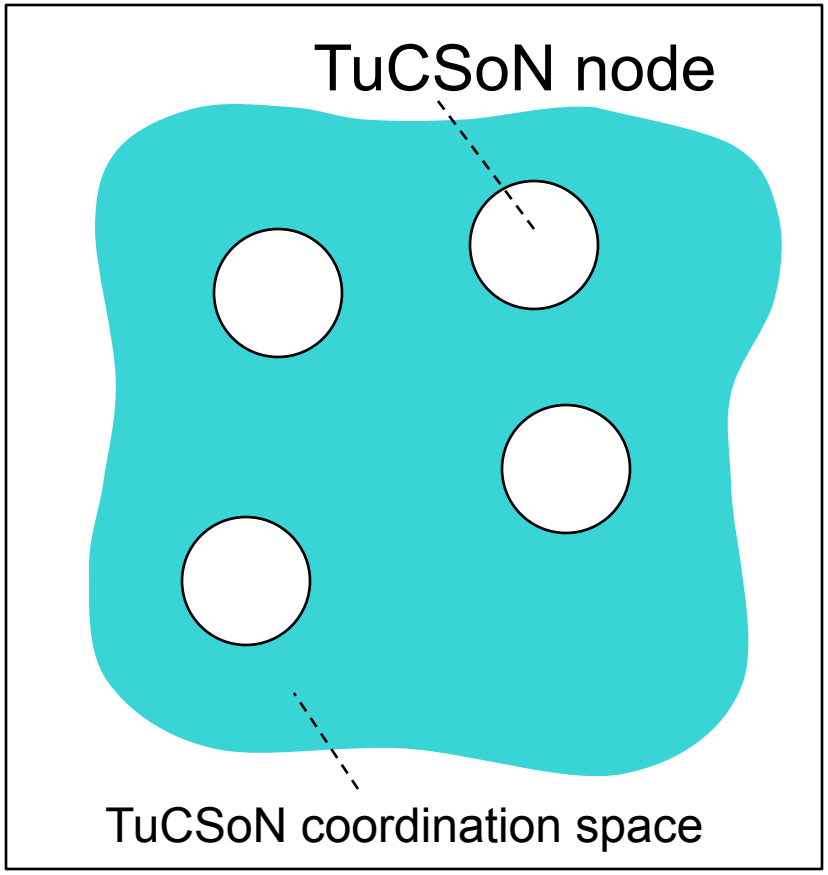


TuCSoN at a glance

- Tuple Centre Spread over the Network
- ReSpecT tuple centres + Agent Coordination Contexts (ACC)
- Tuple centres are distributed over the network, collected in *nodes*
  - distributed social coordination artefacts
  - distributed topology
- An ACC is assigned to each agent entering a TuCSoN-based MAS
  - individual boundary artefacts

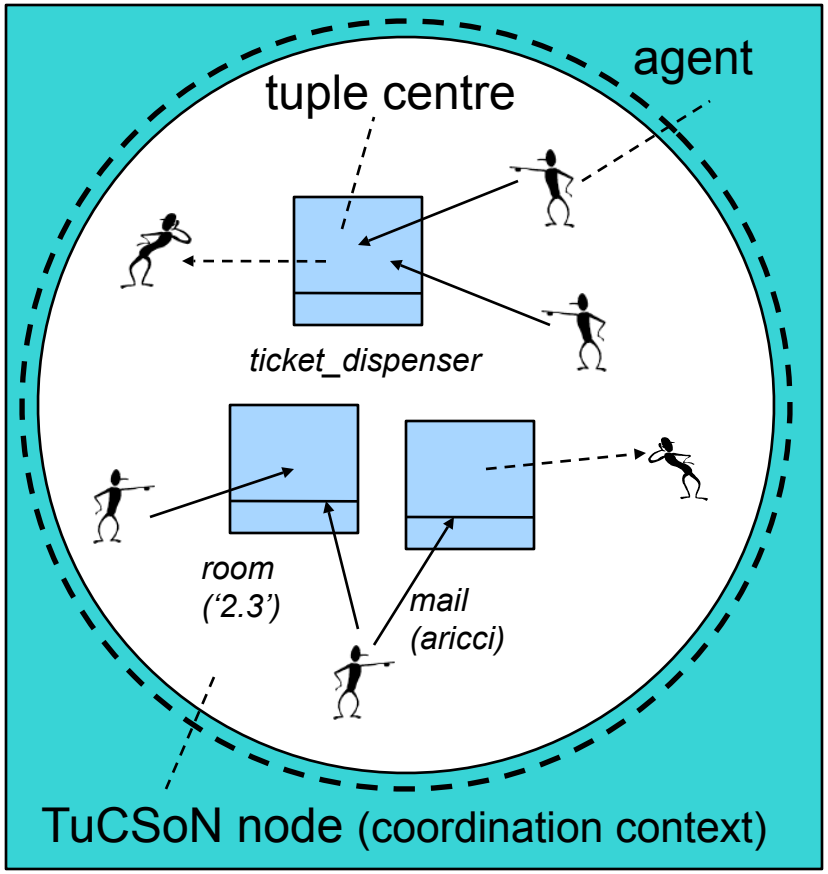
TuCSoN Coordination Space

- Coordination space = set of distributed *nodes*
  - Each TuCSoN node is an Internet node
    - Identified by the IP (logic) address
- TuCSoN Topology
  - Here, Internet topology
  - HiMAT (Cremonini 1999)
    - Hierarchical, dynamic, configurable topology



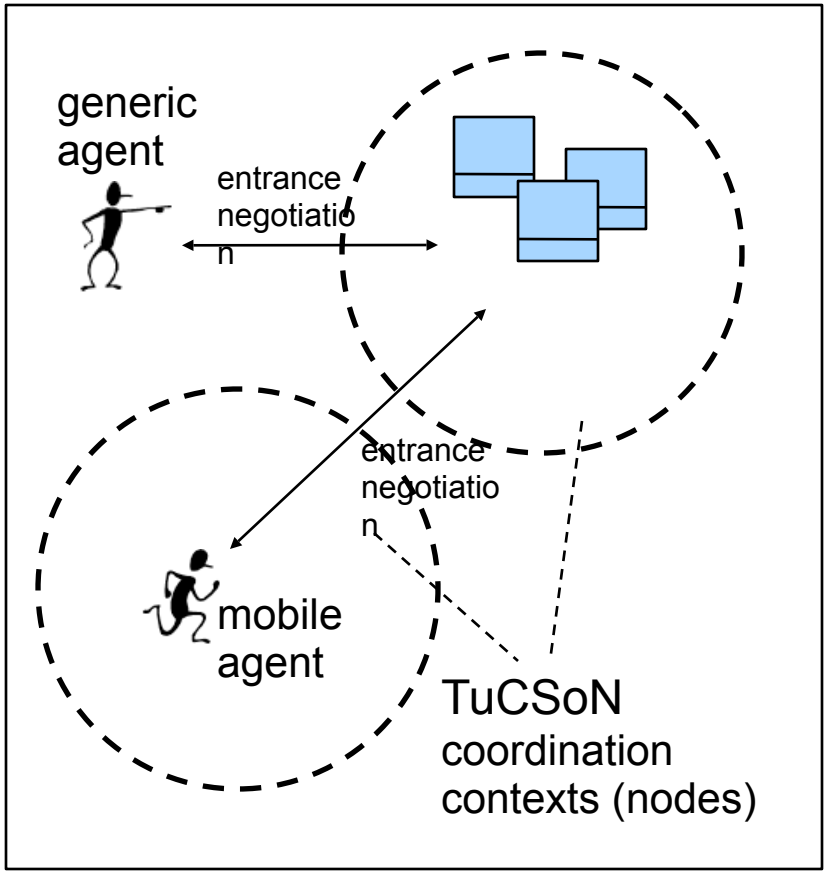
TuCSoN Node/Context

- Each TuCSoN node defines a *coordination context*, providing an open/dynamic set of *tuple centres* as coordination artifacts
  - Identified by means of a logic name (term)
    - *Ex: ticket_dispenser, mail (aricci), room('2.3'),…*
  - full tuple centre identifier: <name>@<node>
    - Ex: mail(aricci) @myhome.org, room('2.3') @ingce.unibo.it, ticket_dispenser@137.204.191.188, …



TuCSoN Node / Context

- In order to access and use the tuple centres of a node, an agent must *enter* the coordination context
  - Either logically or physically (mobile agents)
- ACC
  - Agent Coordination Context (Omicini 2002)



TuCSoN Technology (1)

- TuCSoN API
  - Virtually any hosting language
    - Currently: Java, Prolog
      - Support for Java and Prolog agents
  - Heterogeneous hardware support:
    - Currently: desktop PC, PDA (Compaq iPaq, Palm)
    - WiP: LEGO, embedded computing

TuCSoN Technology (2)

- TuCSoN Service
  - Booting the TuCSoN Service daemon
    - The host becomes a TuCSoN node
    - With current version (1.3.0):
      java -cp tucson.jar alice.tucson.runtime.Node
- TuCSoN Tools
  - ***Inspectors***
    - Fundamental tool to monitor tuple centre communication and coordination state, and to debug tuple centre behaviour
    - *debugger for coordination artifacts*
      - Observing and debugging agent interaction
    - With current version (1.3.0):
      java -cp tucson.jar alice.tucson.ide.Inspector
  - TuCSoNShell
    - Shell interface for human agents
    - With current version (1.3.0):
      java -cp tucson.jar alice.tucson.ide.CLIAgent

PART III - ReSpecT

ReSpecT Model and Language

Programmable Tuple Spaces

- Tuple Centres = Programmable Tuple Spaces
  - The behaviour of the medium in response to communication events is no longer fixed once and for all by the model, but can be defined according to the required coordination policies
    - Coordination laws no longer fixed, but specified/programmed according to the coordination need
  - The medium behaviour is enriched in terms of state transitions (*reactions*) performed in response to the occurrence of standard communication events (ex: insertion of a tuple, retrieve of a tuple, …)
  - Tuple centres as general purpose *reactive* associate blackboards
- Same standard tuple space interface…
  - entities perceive the tuple centre as a standard tuple space
- …but can behave in a very different way with respect to a tuple space, since its behaviour can be specified so as to encapsulate the coordination rules governing the interaction

Tuple Centre Behaviour: Reactions

- More formally, tuple centres enhance tuple spaces with with *behaviour specification,* defining tuple centre behaviour in response to communication events
  - Communication events examples: the tuple T has been inserted in the space, an *in* operation been beformed with template TT,…
- Behaviour specification is expressed in terms of a *reaction specification language*, and associates any communication event possibly occurring in the tuple centre to a (possibily) empty set of computational activities called *reactions*
- Reactions should be able to
  - Compute
    - ReSpect is Turing-equivalent
  - Act on the communication/coordination state
    - ReSpecT can access and modify the current tuple centre state, by adding, removing, reading tuples…
  - Fully observe the triggering communication event
    - The operation related generating communication events, the entity identity performing the operations,…

Tuple Centre Dynamics

- Multiple reactions in one shot
  - Each communication event may trigger a multeplicity of reactions which are executed locally to the tuple centre
- Default tuple space behaviour
  - When a communication event occurs, a tuple centre first behaves like a standard tuple space, then executes all the triggered reactions before serving any other entity-triggered communication event and any other coordination primitives invocation
  - A tuple centre with empty behaviour = a tuple space
- Atomicity
  - The observable behaviour of a tuple centre in response to a communication event is still perceived by coordinable as a single-step/atomic state transition of the medium, as in the case of tuple spaces
    - Reactions are not observable by coordinables

The ReSpecT Language

- ReSpecT is a language for the specification of the behaviour of tuple centres
  - Logic tuples as communication language
    - based of first-order logic, where a tuple is a fact
    - *Unification* as tuple matching mechanism
      - Examples: p(1,_) and p(1,2) match, p(X,X,1) and p(1,Y,Z) match, p(X,X) and p(1,2) don't match…
- Reactions defined through logic tuples too
  - A *specification tuple* **`reaction(Op,R)`** associates the event generated by the incoming communication operation Op to the reaction R. Example:
    reaction(out(p(1)), …)
  - A reaction is defined a sequence of *reaction goals*, which may access properties of the occurred communication event, perform simple term operations, manipulate tuples in the tuple centre. Examples:

```
reaction(out(T), ( out_r(backup(T)) )).
reaction(out(p(X)), ( in_r(total_tuples(N)), N1 is N + 1,
                      out_r(total_tuples(N1)) )).
reaction(in(q(X)), ( no_r(q(_)), out_r(q(5)) )).
```

ReSpecT Primitives

Main ReSpecT predicates for reactions

Tuple space access and modification	
`out_r(T)`	succeeds and inserts tuple `T` into the tuple centre
`rd_r(TT)`	succeeds, if a tuple `T` matching template `TT` is found in the tuple centre, by unifying `T` with `TT`; fails otherwise
`in_r(TT)`	succeeds, if a tuple `T` matching template `TT` is found in the tuple centre, by unifying `T` with `TT` and removing `T` from the tuple centre; fails otherwise
`no_r(TT)`	succeeds, if no tuple matching template `TT` is found in the tuple centre; fails otherwise
Communication event information	
`current_tuple(T)`	succeeds, if `T` matches the tuple involved by the current communication event
`current_agent(A)`	succeeds, if `A` matches the identifier of the agent which triggered the current communication event
`current_op(Op)`	succeeds, if `Op` matches the operation which triggered the current communication event
`current_tc(N)`	succeeds, if `N` matches the identifier of the tuple centre where the reaction is executed
`pre`	succeeds in the *pre* phase of any operation
`post`	succeeds in the *post* phase of any operation
`success`	succeeds in the *pre* phase of any operation, and in the *post* phase of any successful operation
`failure`	succeeds in the *post* phase of any failed operation

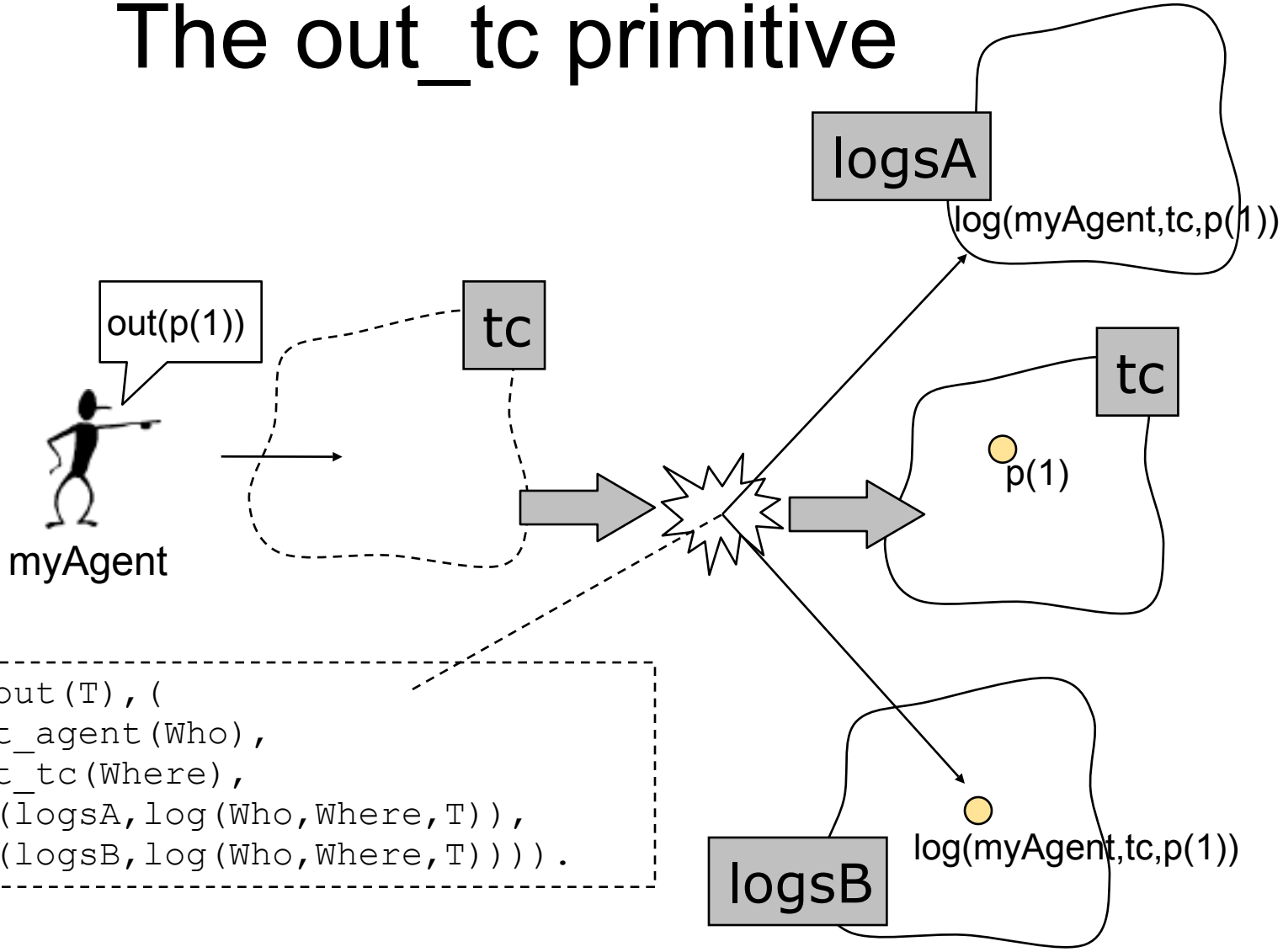
The ReSpecT Language

- Reaction goals are executed sequentially
  - Reaction goals can trigger new reactions
    - Reacting on out_r, in_r, rd_r, no_r primitives..
- Success/failure semantics of each reaction execution
  - A reaction as a whole is either a *successful* or *failed reaction* if *all* its reaction goals succeed or not
  - *Transactional semantics*
    - a successfull reaction can atomically modify the tuple centre state, a failed yelds no results at all
- The execution order of (possibly) multiple triggered reactions is not deterministic
- All the reactions triggered by a given communication event are executed before serving any other communication event
  - Coordinables perceive only the final result of the execution of the communication event *and* the set of all the triggered reactions

Multiple Coordination Flows

- Tuple centres can be use to encapsulate (portions of) coordination flows
  - each ReSpecT tuple centre conceptually represents a single coordination flow
    - is a single (conceptually localised) reactive abstraction
    - coordinates a group of coordinated entities (coord. locality)
    - according to the programmed policy
- Decomposition always calls for composition abilities
  - composing multiple coordination flows
- Simple yet powerful solution
  - out_tc

The out_tc primitive




```
reaction(out(T),(
    current_agent(Who),
    current_tc(Where),
    out_tc(logsA,log(Who,Where,T)),
    out_tc(logsB,log(Who,Where,T)))).
```

The extended model

- The execution of a reaction can now
  - = change the tuple space state, fire new reactions
  - + produce an ouput event
- The ReSpecT tuple centres state at a given time carries
  - = the tuple space state, the pending reactions, the pending queries
  - + the set of pending output events to be sent
- Semantics of out_tc(tc,tuple) primitive
  - – tuple space state unchanged, fires no reactions
  - – schedules production of output event <tc,tuple>

Facts about ReSpecT

- Turing-equivalent language
  - Powerful enough to express any computation/algorithm acting on the interaction space
  - → General purpose enaugh to support the specification of any compuatble coordination policies
  - → Expressivity issues
- Formal semantics
  - Fundamental to understand coordination activities
  - The basis for supporting formal analysis and reasoning about interaction dynamics
- A new, general language / model underway
  - but not yet implemented :)
- Now, it can be used also at the application level
  - e.g., from tuProlog
    - contact A. Ricci is you really need this

PART III - Technically TuCSoN

TuCSoN live?

<TuCSoN on the fly>

- Booting a TuCSoN node
- Using a tuple centre (as a human agent)
  - TuCSoN shell tool
- Inspecting and debugging tuple centres
  - TuCSoN inspector

<Development in TuCSoN>

- Building simple systems
  - Experiments with the “Hello world” simple Java agent
  - Creating simple coordination among Java, human and Prolog agents

TuCSoN in Java (1)

```
import alice.tucson.api.*;
import alice.logictuple.*;

public class Test {
  public static void main(String[] args) throws Exception {
    TucsonContext cn = Tucson.enterDefaultContext();
    TupleCentreId tid = new TupleCentreId("test_tc");
    cn.out(tid, new LogicTuple("p",new Value("hello world")));
    LogicTuple t=cn.in(tid, new LogicTuple("p",new Var("X"));
    System.out.println(t);
  }
}
```

TuCSoN in Java (2)

```
import logictuple.*;
import tucson.api.*;

public class Test2 {
    public static void main (String args[]) throws Exception{

        AgentId aid=new AgentId("agent-0");
        TucsonContext cn = Tucson.enterContext(new DefaultContextDescription(aid));

        // put the tuple value(1,38.5) on the temperature tuple centre
        TupleCentreId tid=new TupleCentreId("temperature");
        LogicTuple outTuple=LogicTuple.parse("value(1,38.5)");
        cn.out(tid,outTuple);

        // retrieve the tuple using value(1,X) as a template
        LogicTuple tupleTemplate=new LogicTuple("value",
                                                new Value(1),
                                                new Var("X"));
        LogicTuple inTuple=cn.in(tid,tupleTemplate);

        cn.exit();
        System.out.println(inTuple);
    }
}
```

TuCSoN in Java: A simple agent

```
import alice.tucson.api.*;
import alice.logictuple.*;

class MyAgent extends Agent {
  protected void body(){
    try {
      TupleCentreId tid = new TupleCentreId("test_tc");
      out(tid, new LogicTuple("p",new Value("hello world")));
      LogicTuple t=in(tid, new LogicTuple("p",new Var("X"));
      System.out.println(t);
    } catch (Exception ex){}
  }
}

public class Test {
  public static void main(String[] args) throws Exception {
    AgentId aid=new AgentId("alice");
    new MyAgent(aid).spawn();
  }
}
```

TuCSoN in Prolog (tuProlog)

```
:- load_library('alice.tuprologx.lib.TucsonLibrary').
:- solve(go).

go:-
  test_tc ? out(p('hello world')),
  test_tc ? in(p(X)),
  write(X), nl.
```

<TuCSoN environment overview>

- A look to the API
  - Java and Prolog
- A look to infrastructure & tools deployment
- A look to some agents

<TuCSoN Internals>

- A look to the design & development
  - “alice” open source project
    - Tuple centre framework (alice.tuplecentre)
    - tuProlog (alice.tuprolog, alice.tuprologx)
    - ReSpect (alice.respect, alice.logictuple)
    - TuCSoN (alice.tucson)

PART IV

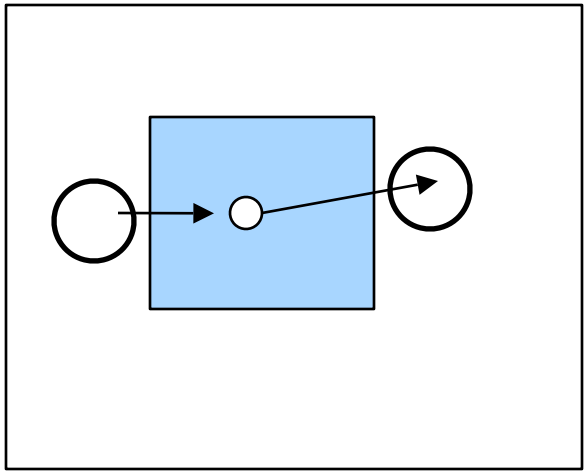
Linda vs. TuCSoN

Coordination Patterns: Linda vs. TuCSoN / ReSpecT

- Basic coordination
  - Communication & Interoperability
    - Managing information flow
  - Basic Synchronisation
    - Managing temporal dependencies
  - Basic Resource sharing / allocation
    - Task allocation
- Articulated coordination
  - Workflow Management
  - Transactions
  - Event-based Patterns
    - Notifications
    - Publish/Subscribe

Enabling Communication (I)

- Message Passing



SENDER:

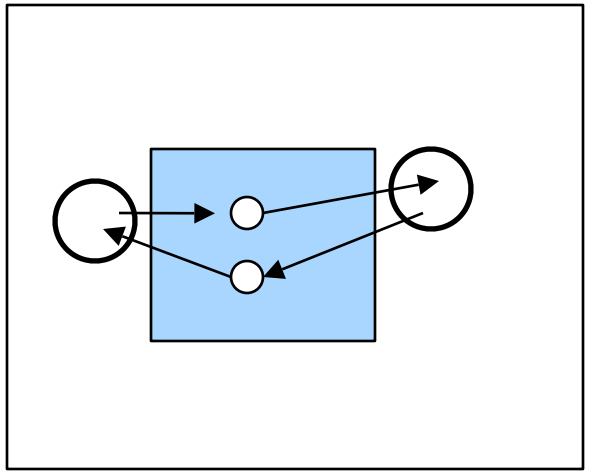
```
out(msg(agentB,content('test',13)))
```

RECEIVER (called agentB):

```
in(msg(agentB,Info))
```

Enabling Communication (II)

- RPC style



SERVICE USER:

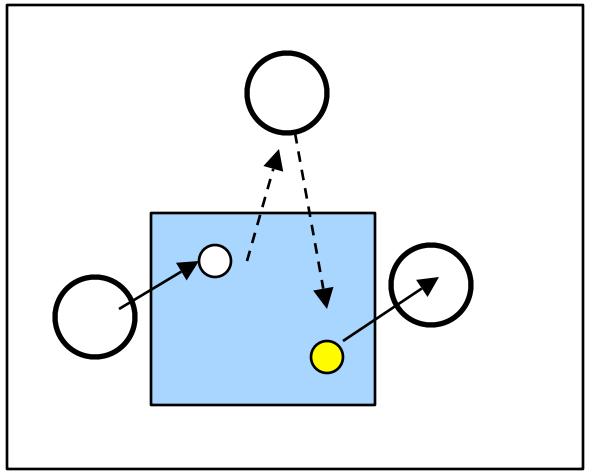
```
…
out(compute_sum(5,8,me))
in(compute_sum_result(me,Value)
…
```

SERVICE PROVIDER

```
in(compute_sum(X,Y,Who))
Sum ← X + Y
out(compute_sum_result(Who,Sum))
```

Enabling Interoperability

- Mediating between different ontologies



Good, *but*
-the mediation as a coordination activity is charged upon an entity (the service mediator), not upon the medium
(Conceptual mismatch → engineering drawbacks)

SERVICE USER

```
…
out(compute_sum(5,8,me))
in(compute_sum_result(me,Value)
…
```

SERVICE PROVIDER

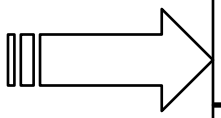
```
in(make_sum(term(X,Y)))
Sum ← X + Y
out(sum_result(X,Y,Sum))
```

SERVICE MEDIATOR

```
in(compute_sum(X,Y,Who))
out(service_requested(sum(X,Y),Who))
out(make_sum(term(X,Y)))
in(sum_result(X,Y,Sum))
in(service_requested(sum(X,Y),Who))
out(compute_sum_result(Who,Sum))
```

Interoperability in TuCSoN

- Ontology mediation charged upon the medium



Linda Style

SERVICE USER:

```
…
out(compute_sum(5,8,me))
in(compute_sum_result(me,Value)
…
```

SERVICE PROVIDER

```
in(make_sum(term(X,Y)))
Sum ← X + Y
out(sum_result(X,Y,Sum))
```

SERVICE MEDIATOR

```
in(compute_sum(X,Y,Who))
out(service_requested(sum(X,Y),Who))
out(make_sum(term(X,Y)))
in(sum_result(X,Y,Sum))
in(service_requested(sum(X,Y),Who))
out(compute_sum_result(Who,Sum))
```

TuCSoN Style

SERVICE USER:

```
…
out(compute_sum(5,8,me))
in(compute_sum_result(me,Value)
…
```

SERVICE PROVIDER

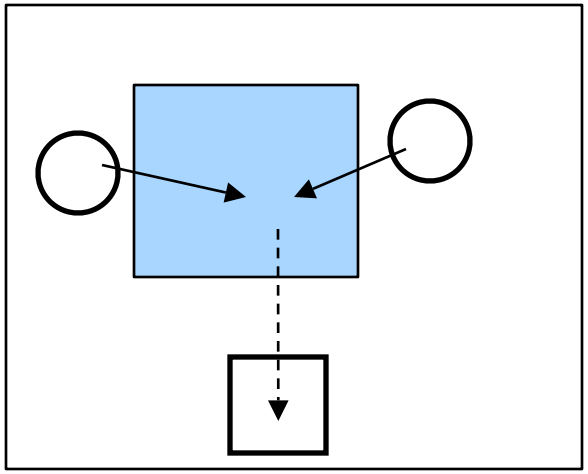
```
in(make_sum(term(X,Y)))
Sum ← X + Y
out(sum_result(X,Y,Sum))
```

MEDIATION POLICY in ReSpecT

```
reaction(out(compute_sum(X,Y,Who)),(
    in_r(compute_sum(X,Y,Who)),
    out_r(service_requested(sum(X,Y),Who)),
    out_r(make_sum(term(X,Y)) )).
reaction(out(sum_result(X,Y,Sum)),(
    in_r(sum_result(X,Y,Sum)),
    in_r(service_requested(sum(X,Y),Who)),
    out_r(compute_sum_result(Who,Sum)) )).
```

Basic Synchronisation (I)

- Synchronisation



Synchronised agent:

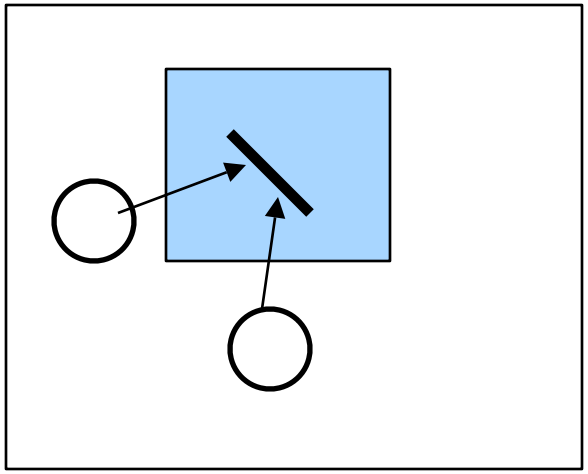
<outside sync region>
…
`in(token)`
<inside sync region>
`out(token)`
…
<outside sync region>
…

HYPOTHESIS:
Initial space content with the tuple `token`

To have synchronised region
allowing N users inside
→ N tuples `token`

Barrier Synchronisation (II)

- Barrier Synchronisation



Agent A:

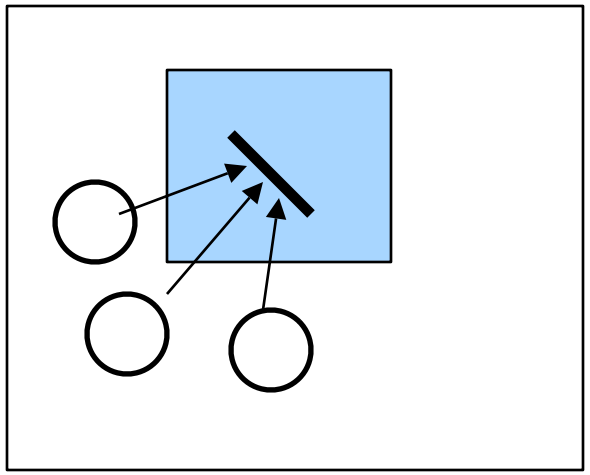
…
<before barrier>
…
`out(ready(agentA))`
`rd(ready(agentB))`
<agents A and B
are now synchronised>

Agent B:

…
<before barrier>
…
`out(ready(agentB))`
`rd(ready(agentA))`
<agents B and A
are now synchronised>

Barrier Synchronisation (III)

- Barrier Synchronisation with 3+ entities



Agent A:
…
`out(ready(agentA))`
`rd(ready(agentB))`
`rd(ready(agentC))`
…

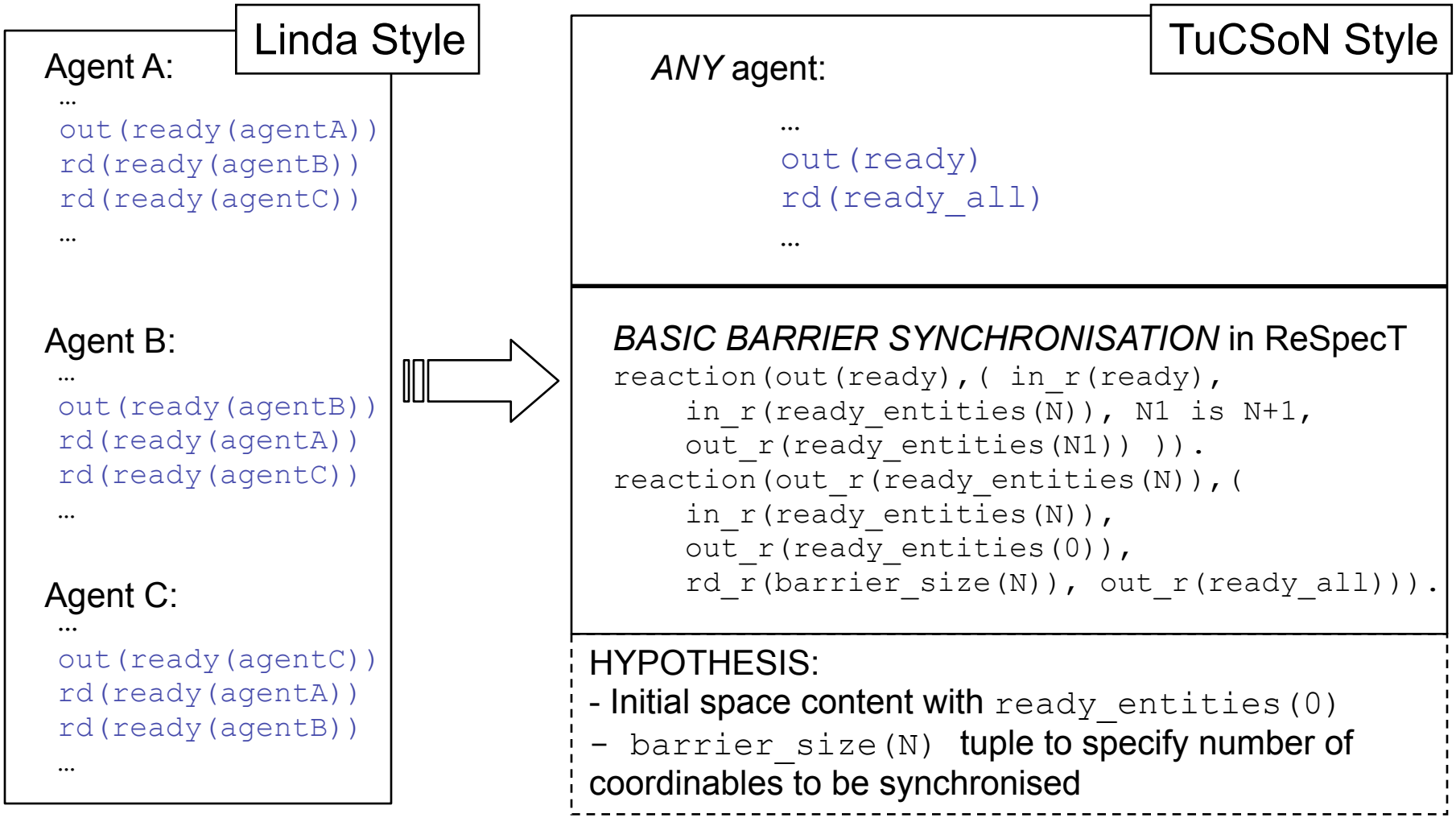
Agent B:
…
`out(ready(agentB))`
`rd(ready(agentA))`
`rd(ready(agentC))`
…

Agent C:
…
`out(ready(agentC))`
`rd(ready(agentA))`
`rd(ready(agentB))`
…

Good, *but*
-Adding an agent → changing the behaviour of all the other agents
-Every agent must be aware of all the other ones

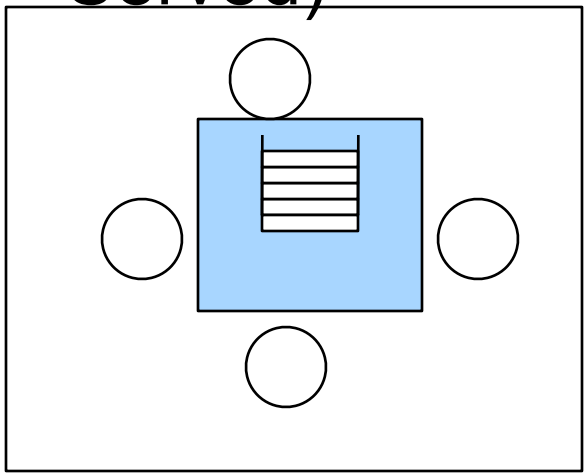
Barrier Synchronisation in TuCSoN

- Encapsulating the barrier synchronisation policy



Resource Sharing / Allocation

- A dynamic/open set of agents accessing the same resource (ex: a printer) according to a coordination policy (ex: First Come First Served)



Each user agent:

```
…
in(next_ticket(T))
T1 ← T + 1
out(next_ticket(T1))
in(turn(T))
  <use the resource>
out(turn(T1)
…
```

Good, *but*
-Changing the coordination policy → changing all the other entities
-Malicious/Failing agents?

HYPOTHESIS: Initial space content includes the tuples:

```
next_ticket(0)
turn(0)
```

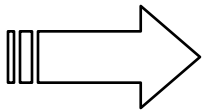
Resource Sharing / Allocation in TuCSoN (I)

- Encapsulating Sharing Policy
  - Scale down complexity to a synchronisation problem

Linda Style

Each user agent:

```
…
in(next_ticket(T))
T1 ← T + 1
out(next_ticket(T1))
in(turn(T))
  <use the resource>
out(turn(T1)
…
```



TuCSoN Style

EACH USER:

```
…
in(resource_token(<my name>))
<use the resource>
out(resource_token(<my name>))
…
```

SHARING COORDINATION LAWS in ReSpecT:

```
reaction(in(resource_token(Who)),( pre,
  in_r(tickets(N)), N1 is N + 1,
  out_r(tickets(N1)),
  out_r(turn(Who,N)) )).
reaction(out_r(turn(Who,N)),(
  rd_r(current_turn(N)),
  out_r(resource_token(Who)) )).
reaction(out(resource_token(Who)),(
  in_r(resource_token(Who)),in_r(turn(Who,N)),
  in_r(current_turn(N)), N1 is N+1,
  out_r(current_turn(N1)) )).
reaction(out_r(current_turn(N)),(
  rd_r(turn(Who,N)),
  out_r(resource_token(Who)) )).
```

Resource Sharing / Allocation in TuCSoN (II)

- Changing / Adapting Sharing Policy
  - From FIFO strategy to LIFO strategy

unchanged behaviour for agents

Each user agent:

```
…
in(resource_token(<my name>))
<use the resource>
out(resource_token(<my name>))
…
```

changing only the glue code

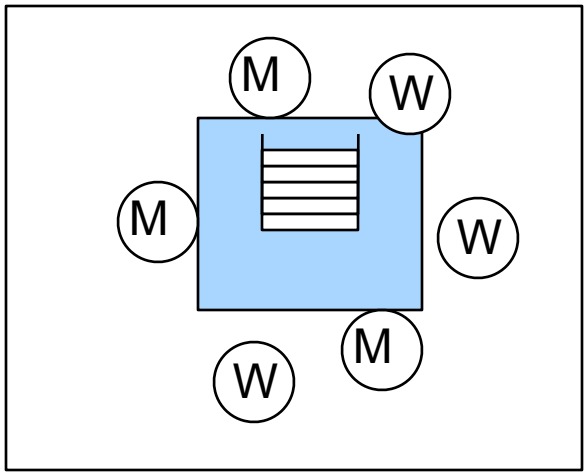
LIFO SHARING POLICY:

```
reaction(in(resource_token(Who)),( pre,
  in_r(last(N)), N1 is N + 1,
  out_r(last(N1)),
  out_r(heap(Who,N1)),
  out_r(check) )).

… [OK, you got the idea]
```

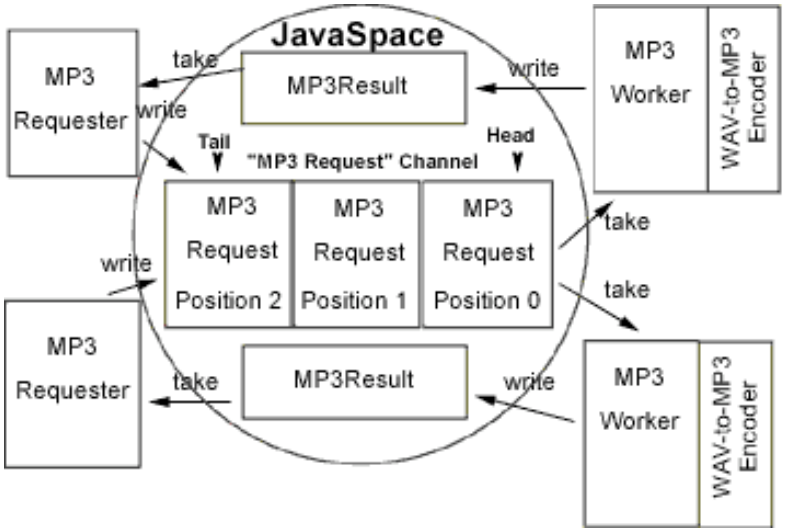
Task Allocation

- Task allocation to an open set of *workers*, with task request provided by an open set of *masters,* according to some policy
  - MP3 Service Case Study: building a distributed Internet-based MP3 encoding service
    - masters request WAV → MP3 conversion
    - workers provide the conversion
    - service provision policy: FIFO
      - possibly dynamically/adaptable



from the articles "*Make Room for JavaSpaces*" by Susan Hupfer – Java World electronic magazine, Jiniology Serie

Also in the book:
"Java Spaces: Principle and Patterns" AW.



Task Allocation: The Linda Approach

MP3 REQUESTER (master)

```
while (true) {
    acquireFromGUI(FileName)
    readRawData(FileName,RawData)
    in(tail(T))
    T1 ← T + 1
    out(tail(T1))
    out(mp3request(T1,FileName,
                   RawData,myId))
    in(mp3result(FileName,
                 ResultData,myId))
}
```

MP3 CONVERTER (worker)

```
while (true) {
    rd(tail(T))
    in(head(H))
    if (T<H){
        out(head(H))
    } else {
        H1 ← H + 1
       out(head(H1))
       in(mp3request(H,FileName,Data,
                     FromWho))
       MP3Data ← from_raw_to_data(Data)
       out(mp3result(FileName,
                     MP3Data,FromWho))
    }
}
```

good, but the coordination burden is almost upon the coordinables
-changing policy → changing coordinables
-...

Task Allocation: The TuCSoN Approach

MP3 REQUESTER (master)

```
while (true) {
    acquireFromGUI(FileName)
    readRawData(FileName,RawData)
    out(mp3request(FileName,RawData,myId))
    in(mp3result(FileName,ResultData,myId))
}
```

MP3 REQUESTER (worker)

```
while (true) {
    in(mp3request(FileName,Data,FromWho))
    MP3Data ← from_raw_to_data(Data)
    out(mp3result(FileName,MP3Data,FromWho))
}
```

FIFO TASK ALLOCATION POLICY in ReSpecT

```
reaction(out(request(_,_,_)),(
  rd_r(workers_available(N)),
  N>0)).
reaction(out(request(Name,Data,From)),(
  rd_r(workers_available(N)),
  N == 0,
  in_r(tail(T)), T1 is T + 1, out_r(tail(T1)),
  in_r(request(Name,Data,From)),
  out_r(req_queue(T1,Name,Data,From)))).
reaction(in(request(Name,Data,From)),( pre,
  rd_r(head(H)),rd_r(tail(T)),
  T < H)).
```

```
reaction(in(request(Name,Data,From)),( pre,
  in_r(head(H)), rd_r(tail(T)),
  T >= H,
  H1 is H + 1, out_r(head(H1)),
  in_r(req_queue(H,N1,D1,F1)),
  out_r(request(N1,D1,F1)))).
reaction(in(request(_,_,_)),( pre,
  in_r(workers_available(N)),
  N1 is N + 1,out_r(workers_available(N1)))).
reaction(in(request(_,_,_)),( post,
  in_r(workers_available(N)),
  N1 is N - 1, out_r(workers_available(N1)))).
```

APPENDIX

Selected Bibliography & References

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