GDT4MAS: a formal model and language to specify and verify multiagent systems

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Sketch of the presentation

- General presentation
- The GDT4MAS model
- Proofs
- Small case study

Conclusion and Perspectives

- Holonic extension

General Presentation

GDT4MAS model Motivations

- Main goal
  - Writing executable and provable specifications
- What about standard MAS models ?
  - Lack of required properties for formal specifications
- What about standard Formal Methods ?
  - Not adapted to agents developed independently
  - Not « goal oriented »
- Properties studied
  - Safety properties (« nothing bad happens »)
  - Liveness properties (« something good will happen »)

GDT4MAS model
Main concepts

- Theorem proving instead of Model checking
  - May fail, but more general
  - Complexity reduced
  - Can be performed on partial specifications
- Compositional system
- Refinement Principle
- Using experienced systems as much as possible
  - Set theory (like in B, Z or VM)
  - Existing provers (PVS, krt, etc.)
  - Proof schemas are integrated to the method

Adequation of the GDT4MAS model to complex systems

- Specifying numerous entities/agents is easy to perform
- Goal execution may fail
- Using theorem proving rather than model checking reduces the complexity of the proof
- The main part of the proofs can be performed on entities/agents specified independently

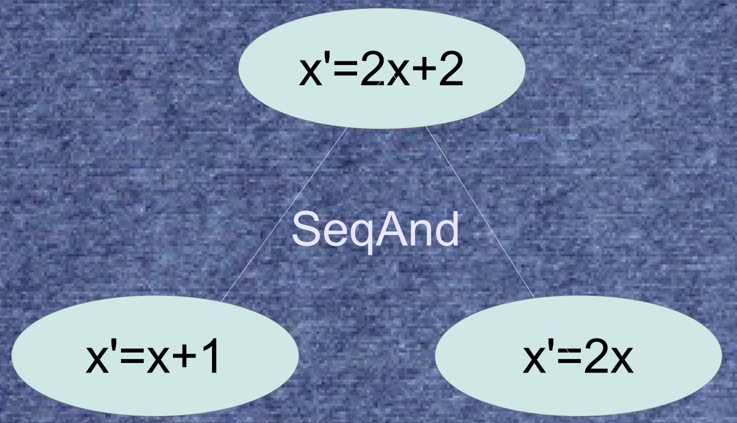
The GDT4MAS model

Environment and Agent types

- Environment
  - A set of typed variables
  - An invariant property
  - A set of agents, instances of given agent types
- Agent type
  - A set of internal variables
  - A set of Surface Variables
  - An invariant
  - A behaviour specified by a GDT

Goal Decomposition Tree (1)

- A tree of goals
- A goal is specified by a Satisfaction Condition
- A non-leaf goal is decomposed into subgoals thanks to decomposition operators
- An NNS goal may fail
- A GPF specifies what happens if a goal resolution fails (GPFs are inferred from leaf goals)



First-or
Primed
Unprimed variable : value before the goal execution

Guaranted Property in case of Failure

Goal Decomposition Tree (2)

- Leaf goals
  - Action goals : the goal is achieved by an action of the agent
  - External goals : the goal must be achieved by another agent
  - Unrefined goals
- Decomposition operators
  - And/SeqAnd
  - Or/SeqOr
  - Case
  - Iter
  - SyncSeqAnd/SyncSeqOr

Decomposition Informal Semantics

- N <== N1 SeqAnd N2

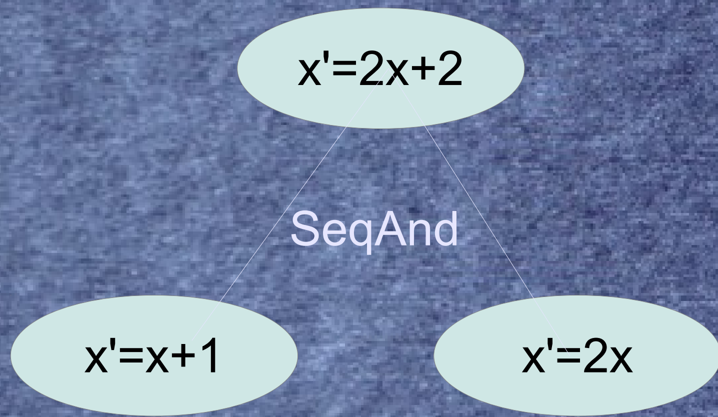
```
boolean achieve(Goal N) {
    boolean success , subGoalSuccess ;
    subGoalSuccess = achieve(N1) ;
    if (subGoalSuccess) {
        subGoalSuccess = achieve(N2) ;
        if (subGoalSuccess) {
            return true ;
        }
    }
    return evaluate(sc_N) ;
}
```

Proofs

Main concepts

- Proof Schemas
  - Formulae integrated to the method
  - Express necessary conditions to guarantee the correctness of the specification
- Reuse
  - Good theorem provers exist in first order-logic
  - Proof schemas must generate predicates, called proof obligations, in order to be able to use any existing first-order logic prover
- Maximization of the proof success rate
  - The simplest the proofs are, the more the prover may succeed
  - => proofs must be as independent as possible

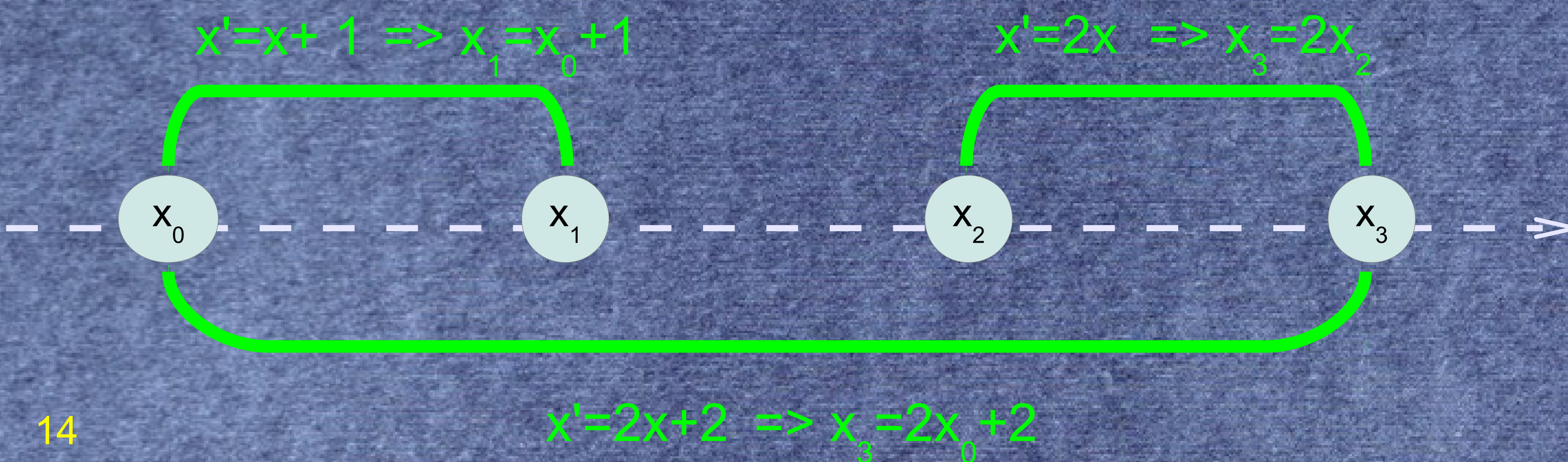
Proving decomposition correctness



x environment variable

=>

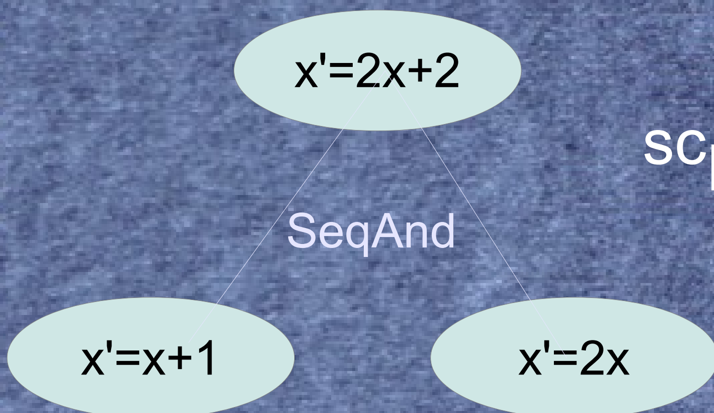
$x_2 = ?$



Simplified Proof Schema Theory

- Notations
  - $p^{i\quad j}$: v => v_i, v' => v_j
  - $(x'=x+1)^{0\quad 1}$ => $x_1=x_0+1$
  - $stab^{i\quad j}$: $V\ (v_i=v_j)$ v internal/surface variable
  - If x unique internal variable $stab^{0\quad 1}$: $x_0=x_1$
- SeqAnd SPS (N <== N1 SeqAnd N2)
  - $sc_{N1}^{0\to 1} \quad stab^{1\to 2} \quad sc_{N2}^{2\to 3} \to sc_{N}^{0\to 3}$
- Context is missing !

Simplified Proof Schema Example



$sc_{N1}^{0\to1} \quad stab^{1\to2} \quad sc_{N2}^{2\to3} \to sc_{N}^{0\to3}$

- x internal variable
  - $(x'=x+1)^{0\to1} \quad (x_1=x_2) \quad (x'=2x)^{2\to3} \to (x'=2x+2)^{0\to3}$
  - $(x_1=x_0+1) \quad (x_1=x_2) \quad (x_3=2x_2) \to (x_3=2x_0+2)$
- x environment variable
  - $(x'=x+1)^{0\to1} \quad (x'=2x)^{2\to3} \to (x'=2x+2)^{0\to3}$
  - $(x_1=x_0+1) \quad (x_3=2x_2) \to (x_3=2x_0+2)$

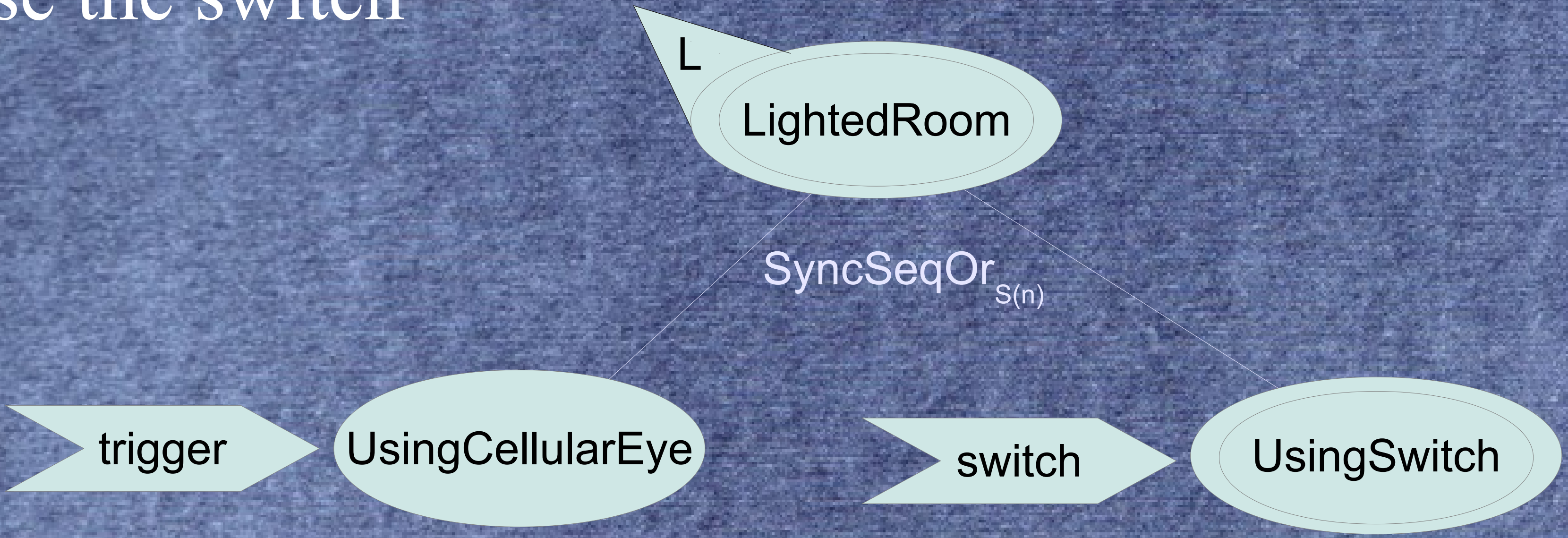
Other kinds of proofs

- Invariants
  - Only at the action level
- Termination
  - Loop termination proven using a variant
- Actions applicability
  - For action goals, thanks to action preconditions
- Action goals resolution
  - Thanks to precondition and postcondition of actions
- External goal achievement
- MAS level proofs
- ...

Small case study

Description

- A robot must light several rooms (if the room is already lighted, its goal is achieved).
- If it enters in a room using a door with a cellular eye, the room should be lighted
- But if it detects the room is still in the dark, it must use the switch



More Formal aspects Variables

- Type
  - NUM : set of Room numbers ; NUM **N**
- Environment variable
  - S NUM → Bool : set of room states
- Internal variable
  - InRoom NUM : current room
  - n NUM : room to lighten

More formal aspects
Satisfaction conditions

- Goal LightedRoom (LR)
  - sc_{LR} = S(n) = true
- Goal UsingCellularEye (UCE)
  - sc_{UCE} = S'(n) = true   inRoom'=n   n'=n
- Goal UsingSwitch (US)
  - sc_{US} = S(n) = false $\rightarrow$ S'(n) = true $\wedge$ n'=n

More formal aspects
Actions

- Trigger (NNS)
  - Precondition
    - True
  - Postcondition
    - S'(n) = true   inRoom'=n
  - GPF
    - S'(n) = false   inRoom'=n   n'=n
- Switch (NS)
  - Precondition
    - InRoom = n
  - Postcondition
    - S'(n) = ←S(n)   n'=n

Proof obligations generated (1)

lumieres THEORY BEGIN
max :nat
roomSet(l : nat) : TYPE= {n : nat / n ≤ l}
N, n_3, n_2, n_1, n0, n1 : VAR roomSet(max)
S, S_3, S_2, S_1, S0, S1 : VAR [roomSet(max) → bool]
InRoom, inRoom_3, inRoom_2, inRoom_1, inRoom0, inRoom1 VAR roomSet(max)

LR01 : THEOREM
(¬ S_1(n_1)) & (S_1(n_1) = S0(n_1)) &
(inRoom_1 = inRoom0) & (n_1 = n0) & S1(n0) & (inRoom1 = n0) & (n1 = n0)
⇒
S1(n1)

LR02 : THEOREM (¬ S_3(n_3)) & (S_3(n_3) = S_2(n_3)) &
(inRoom_3 = inRoom_2) & (n_3 = n_2) & (¬ S_1(n_2)) & (inRoom_1 = n_2) &
(n_1 = n_2) & (inRoom0 = inRoom_1) & (S0(n_1) = S_1(n_1)) &
(n0 = n_1) & (¬ (S0(n0)) ⇒ S1(n0)) & (n1 = n0
⇒
S1(n1)

Proof obligations generated (2)

UCE02 : THEOREM $(\neg S\_1(n\_1))$ &
$(S\_1(n\_1) = S0(n\_1))$ & $(inRoom\_1 = inRoom0)$ & $(n\_1 = n0)$ & $S1(n0)$ &
$(inRoom1 = n0)$ & $(n1 = n0)$
$\Rightarrow$
$(S1(n0)$ & $(inRoom1 = n0)$ & $(n1 = n0))$

US01 : THEOREM
$(\neg S\_3(n\_3))$ & $(S\_3(n\_3) = S\_2(n\_3))$ &
$(inRoom\_3 = inRoom\_2)$ & $(n\_3 = n\_2)$ &
$(\neg S\_1(n\_2))$ & $(inRoom\_1 = n\_2)$ &
$(n\_1 = n\_2)$ & $(inRoom = inRoom\_1)$ & $(S(n\_1) = S\_1(n\_1))$ & $(n = n\_1)$
$\Rightarrow$
$(inRoom = n)$

US02 : THEOREM $(\neg S\_3(n\_3))$ &
$(S\_3(n\_3) = S\_2(n\_3))$ & $(inRoom\_3 = inRoom\_2)$ &
$(n\_3 = n\_2)$ & $(\neg S\_1(n\_2))$ &
$(inRoom\_1 = n\_2)$ & $(n\_1 = n\_2)$ &
$(inRoom0 = inRoom\_1)$ & $(S0(n\_1) = S\_1(n\_1))$ &
$(n0 = n\_1)$ & $(S1(n0) = \neg S0(n0))$ & $(n1 = n0)$
$\Rightarrow$
$((\neg S0(n0) \Rightarrow S1(n0))$ & $(n1 = n0))$
END lumieres

Proof ?

Performed automatically by PVS
(with its basic strategy, grind)

Conclusion

- An expressive model
- A compositional model
- A compositional formal verification system
- An operational semantics and a translation process in any imperative language
- A proven model
- A complexity-limited proof process, using existing theorem provers
- http://users.info.unicaen.fr/~bmermet/GDT/

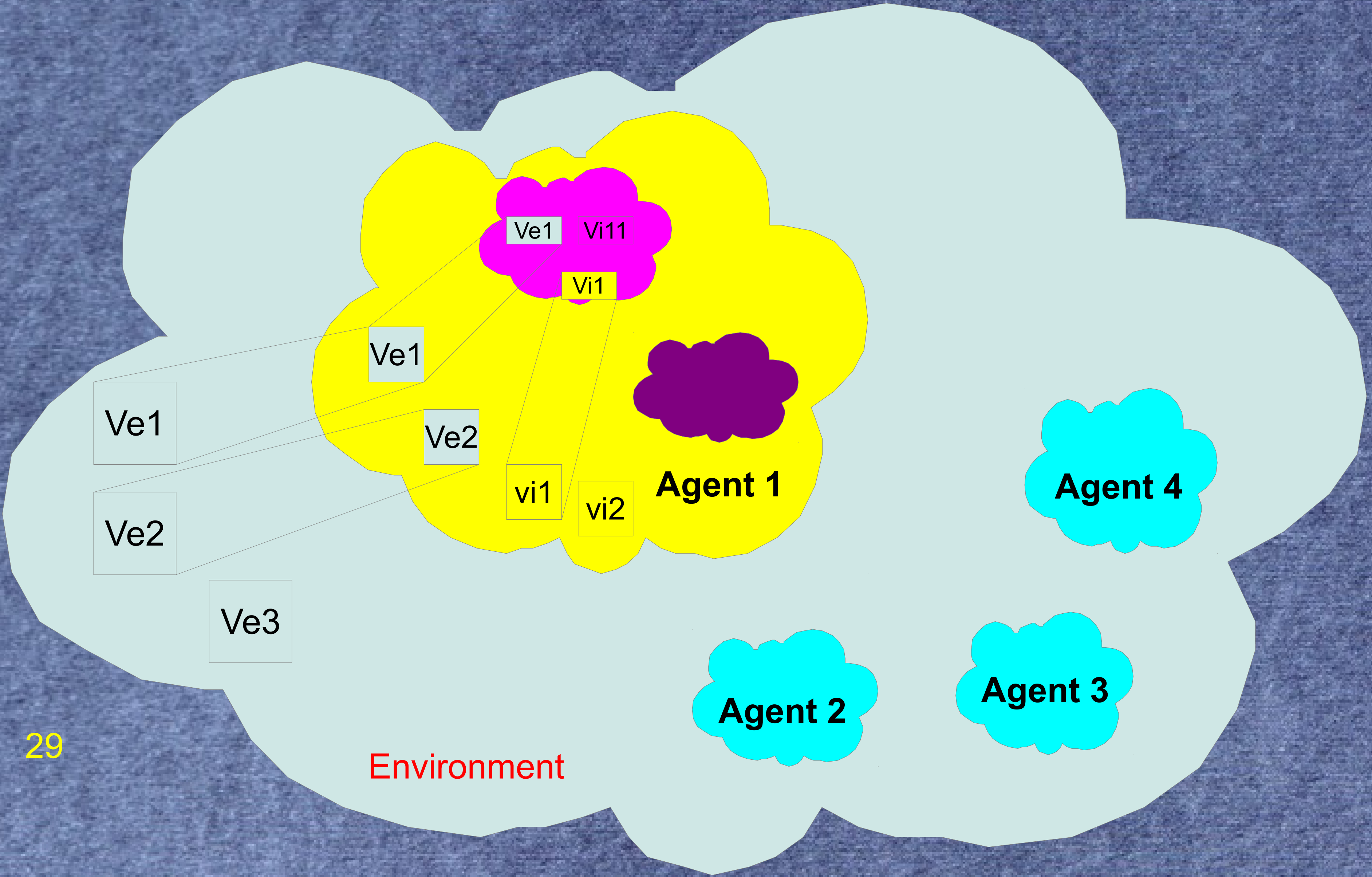
Perspectives

- Increasing expressiveness using holonic agents (see next slides)
- Designing communication protocols
- Developing of an IDE (on-going work)

Holonic extension

- Main concept
  - Parts of an agent behaviour may be implemented by MAS
- New decomposition operators
  - ParAND
    - To solve a goal of the « parent », several subagents must achieve their main goal
  - ParOR
    - To solve a goal of the « parent » agent, several agents start their execution, but the success of one is enough

Holonic agents Principle



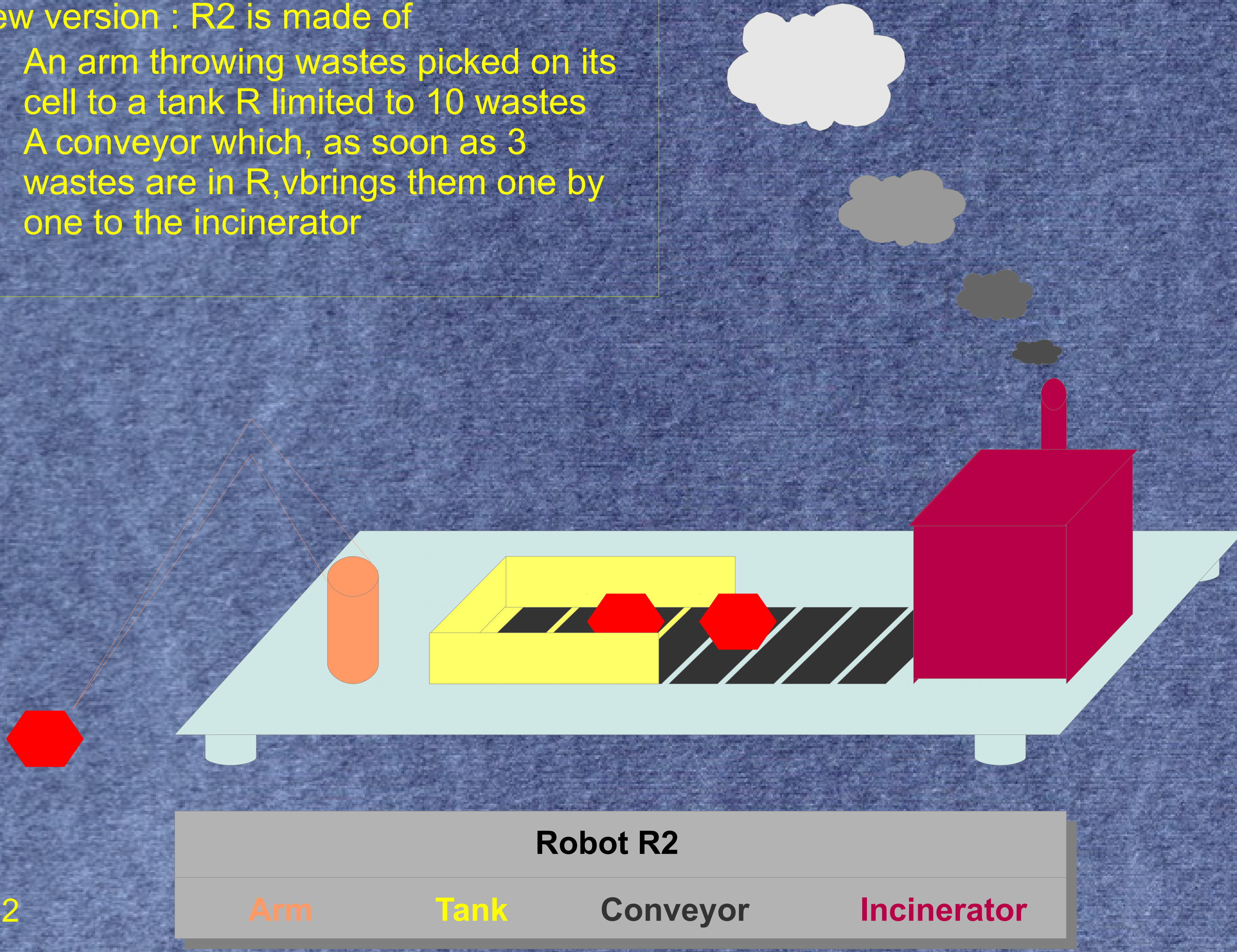
The *Robots On Mars* problem

- 2 robots (R1 and R2)
- Robot R1
  - explore Mars (a grid) looking for pieces of garbage
  - When one is found, it brings it to R2, comes back the cell it was, and continues its exploration
- Robot R2
  - Does not move
  - Burns pieces of garbage brought by R1 on its cell

RoM New version

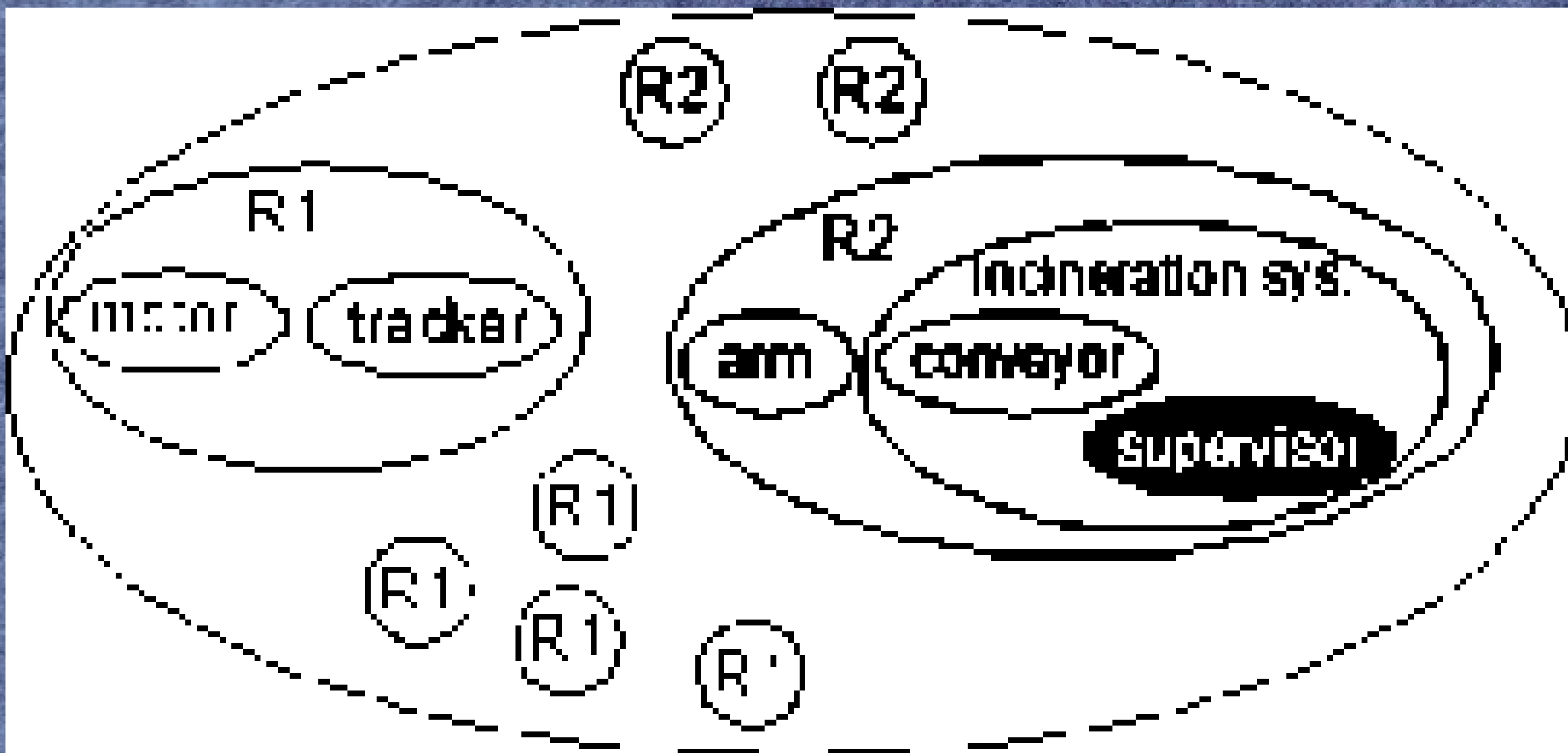
- Several robots R1 and R2
- R1 made of several components
- R2 made of serveral components

- New version : R2 is made of
  - An arm throwing wastes picked on its cell to a tank R limited to 10 wastes
  - A conveyor which, as soon as 3 wastes are in R,vbrings them one by one to the incinerator

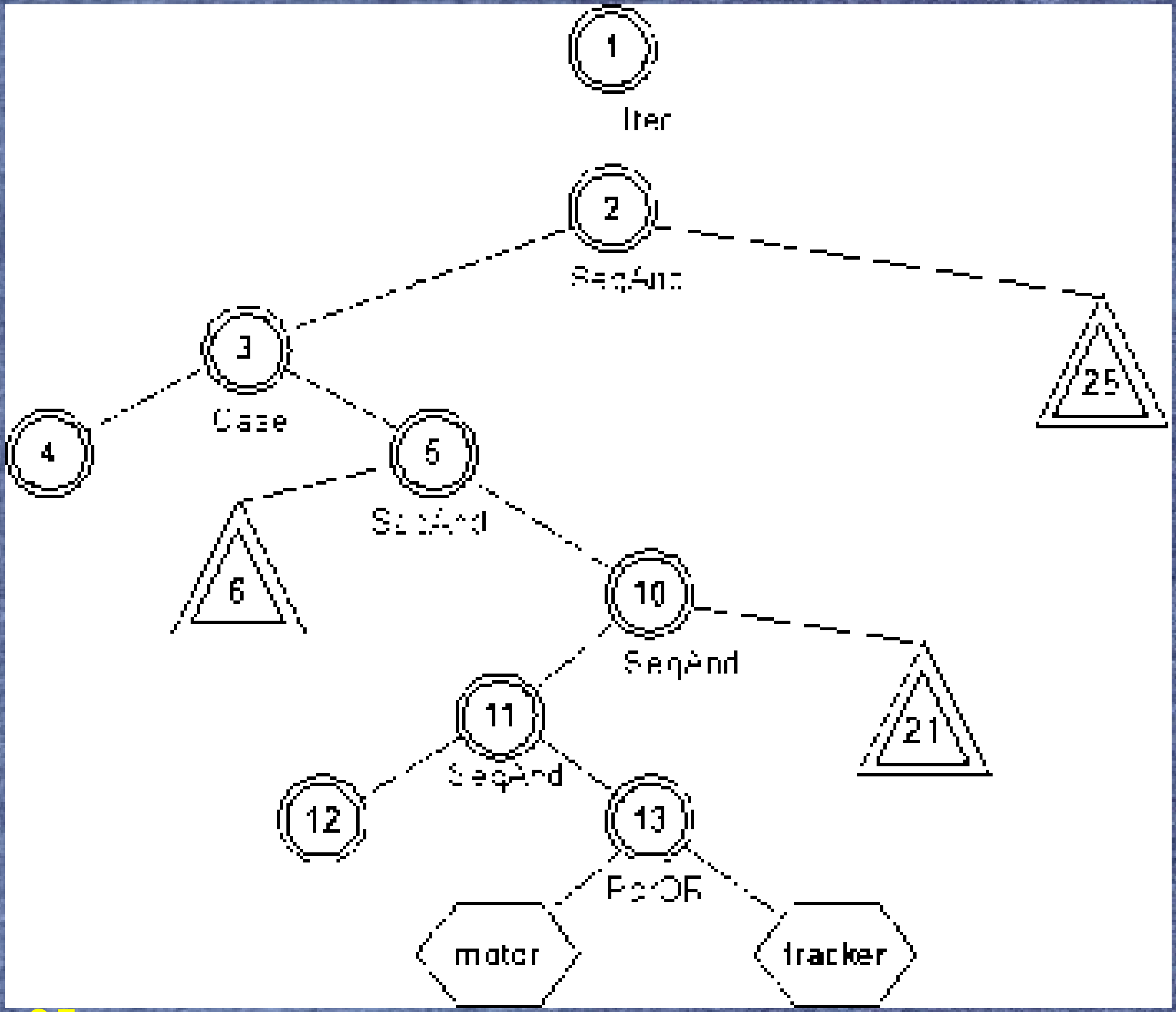


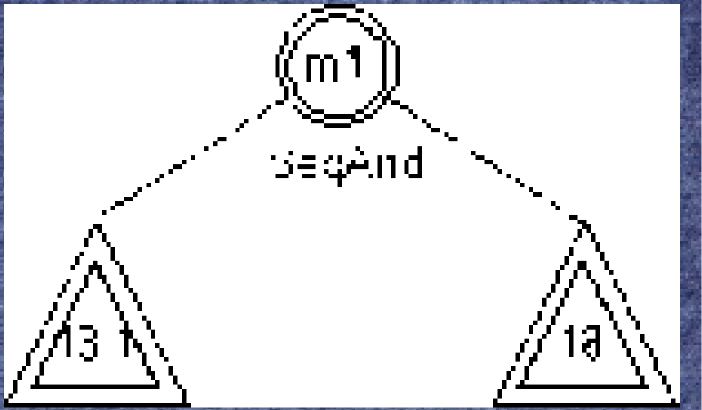
- New version : R1 brings wastes to the nearest robot R2 that is « up »
  - A tracker detects maintain the coordinates of the nearest « up » Robot R2 ;
  - A motor moves R1 either to explore the grid, or, if it holds a garbage, to the target chosen by the tracker

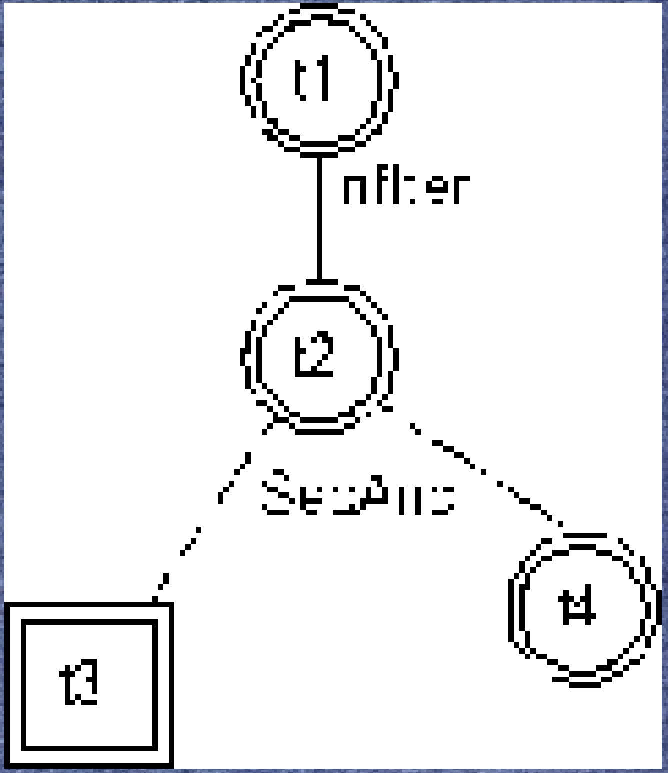
Structure of the MAS



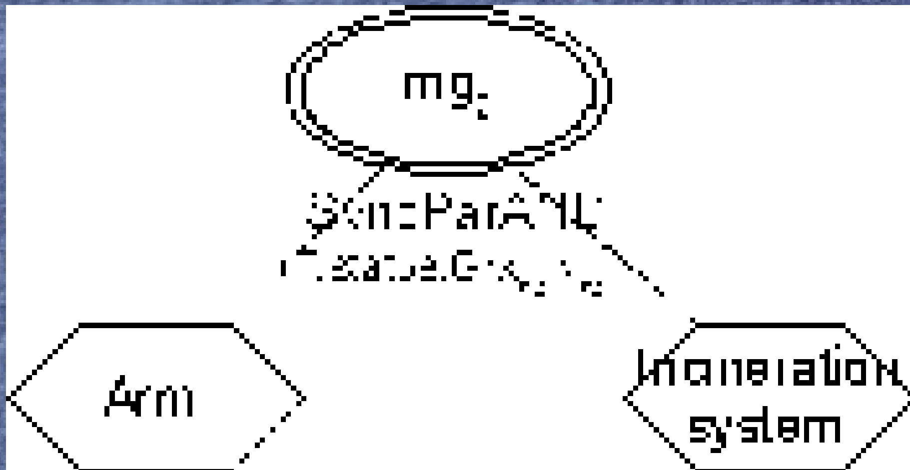
Robot R1

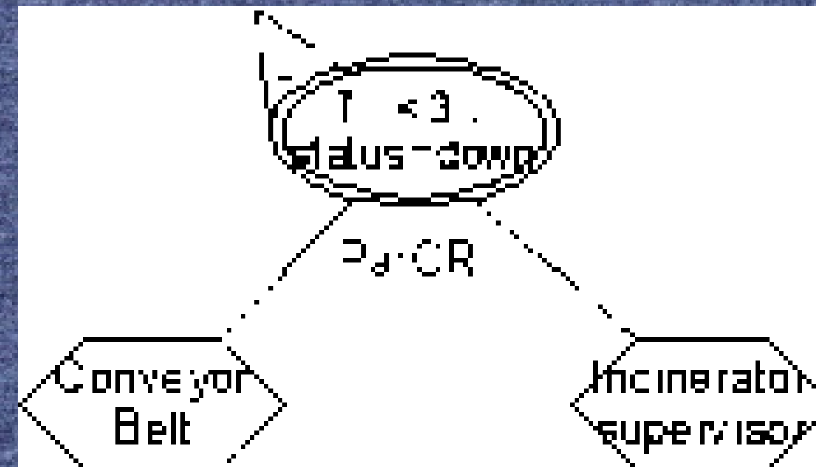

1
Iter
2
SeqAnd
3
Case
25
4
5
6
10
SeqAnd
11
21
12
13
motor
tracker

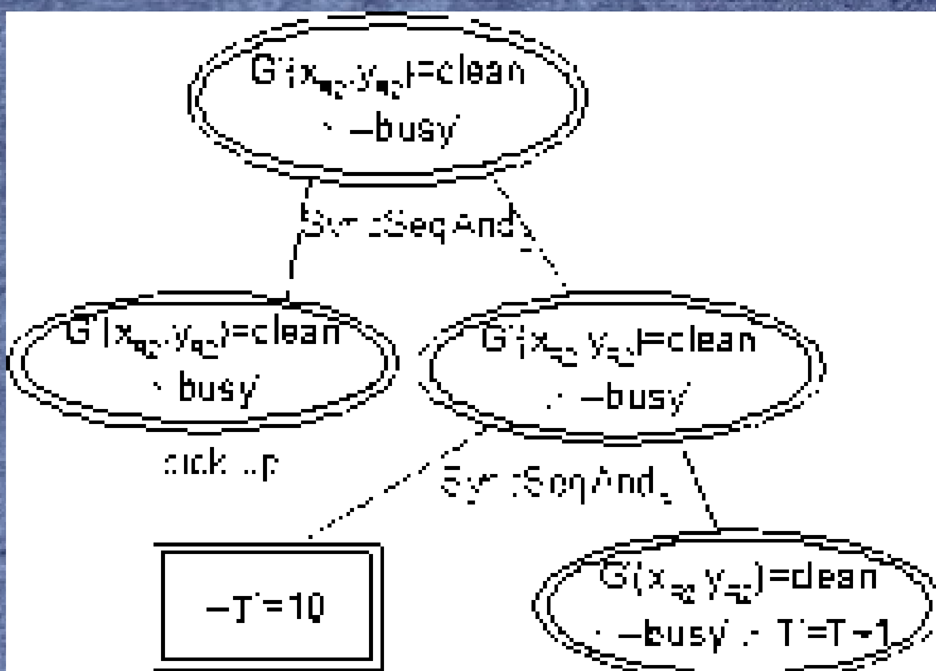

m1
SeqAnd

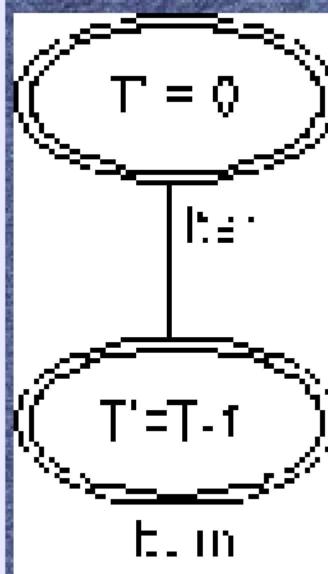

t1
t2
t3
t4

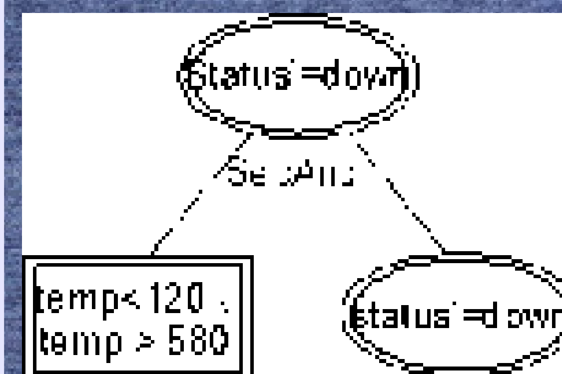
Robot R2


Arm
Incineration system


ParOR
Conveyor Belt
Incinerator supervisor


busy
¬T'=10


T' = 0
T'=T-1


temp< 120
temp > 580

Simplifying usage of PDOs Design patterns

- Several actuators
- Several achievement goals
- Roles composition
- Interruptible task
- Combination of cognitive and reactive behaviour
- Communication reception

JFSMA'12
Journées Francophones sur les Systèmes Multi-Agents 2012

- XXème édition
- Lieu : Honfleur
- Dates : 24-26 octobre
- Program Committee
  - Chair : Pierre Chevaillier
- Organizing Committe
  - Chair : Bruno Mermet