A Stepwise Refinement based Development of Self-Organizing Multi-Agent Systems: Application on the Foraging Ants

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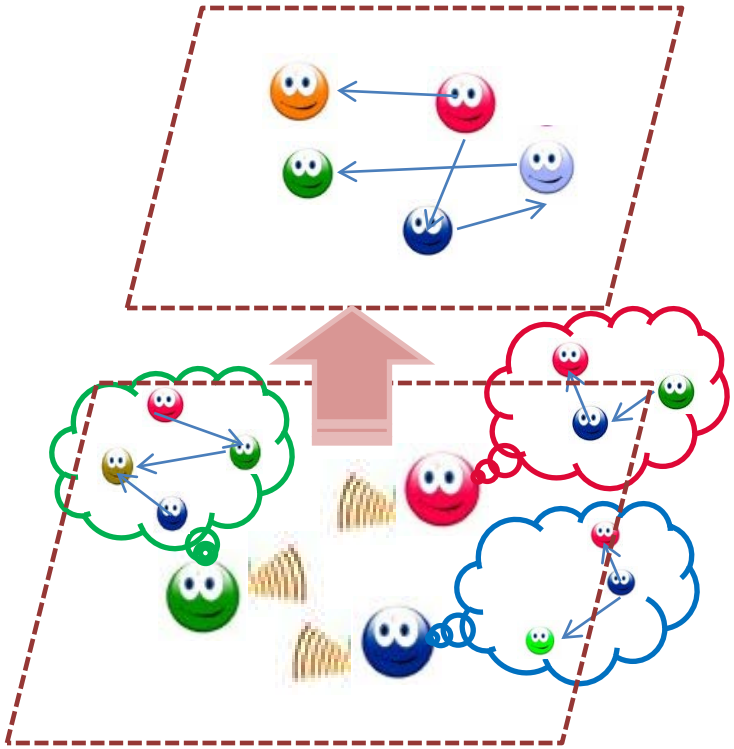
EUMAS'2013 12-13 Décembre 2013 Toulouse, France

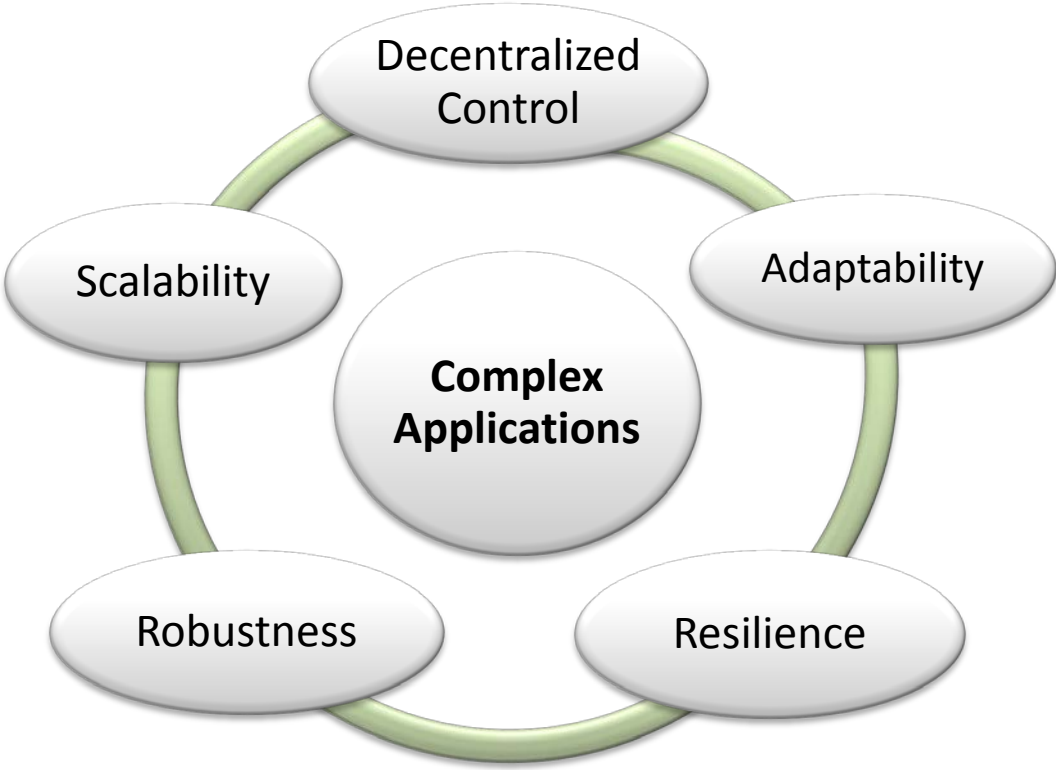
EUMAS 2013

Talk outline

- Context & Motivations
- Formal Development of SO-MAS
- Case Study: Foraging Ants
- Perspectives

Context & Motivations



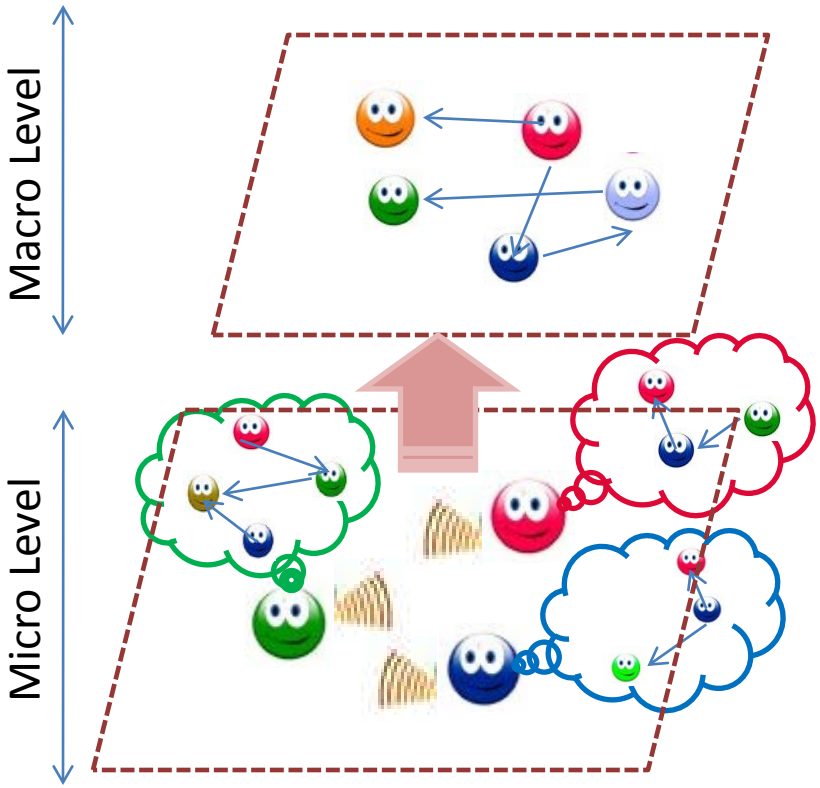


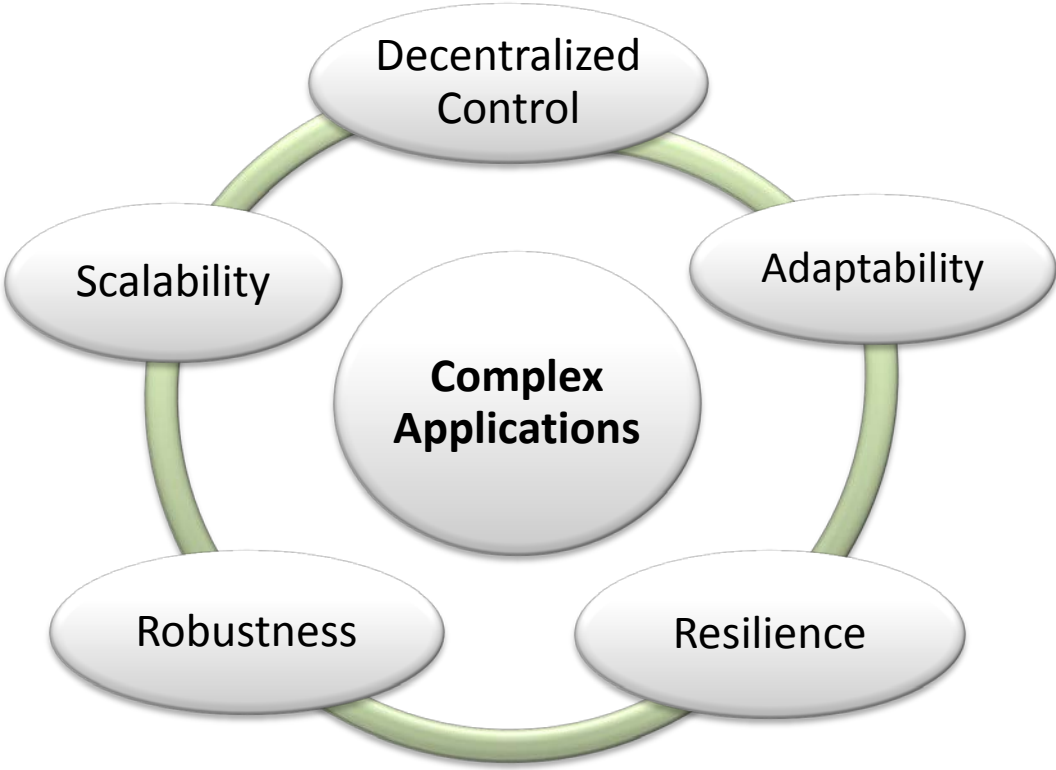
What guarantees related to robustness and resilience can be given?

➔Need for rigourous approaches

➔Our proposition: an approach based on formal techniques.

Our Approach in a Nutshell





What guarantees related to robustness and resilience can be given?

➔Need for rigourous approaches allowing a systematic verification.

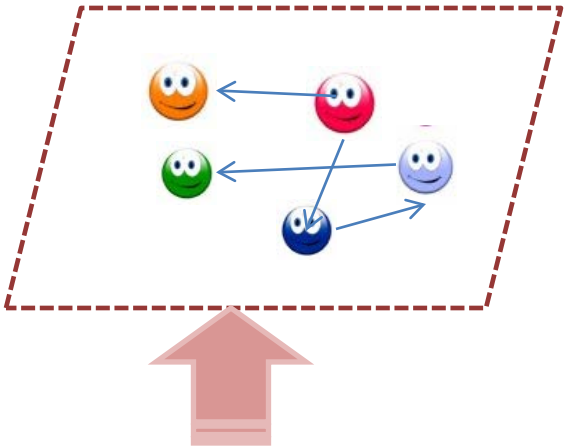
➔Our proposition: an approach based on formal techniques.

Our Approach in a Nutshell

The approach relies on:

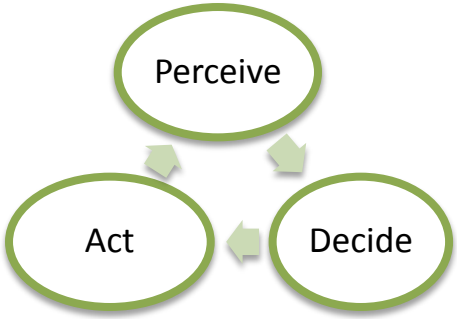
❶ **Two levels of observation: Micro & Macro**

Macro Level



Micro Level

agent≙ <properties, representations, sensors, actuators, decisions, actions, perceptions>



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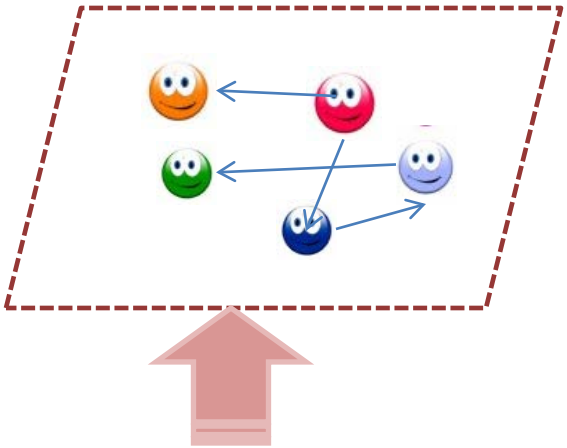

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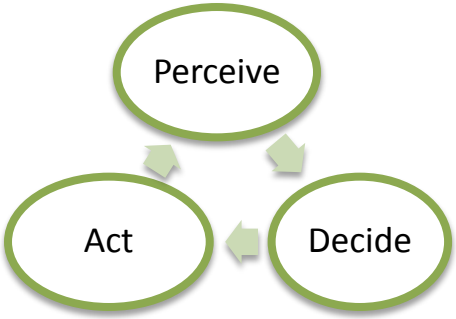

➔ **To give guarantees about the correctness of the local behavior: Deadlock free**

Our Approach in a Nutshell

The approach relies on:

❶ **Two levels of observation: Micro & Macro**

❷ **Stepwise refinement steps Event-B**

❸ **Proof Event-B / TLA**

Macro Level

Robustness analysis: convergence and stability

Resilience analysis: ability of the SO mechanisms to recover from errors without explicitelly detecting an error

Micro Level

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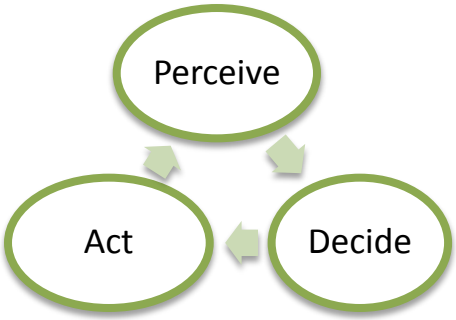

➔**To give guarantees about the correctness of the local behavior: Deadlock free**

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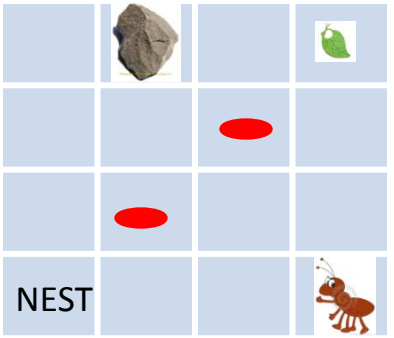
Foraging ants case Study: Description

- Micro Level
  - Every ant is an agent
  - Properties : current location
  - Representations: food, pheromone, obstacles and ants
  - Decision: choose the next location
  - Actions: Move, Drop pheromone, Harvest food, Drop food
  - Local properties
    - LocProp1: the ant functions according to the perceive-decide-act cycle
    - LocProp2, LocProp3: Deadlock freeness respectively in decide and act step of the ant life cycle
    - LocInv1: the ant should avoid obstacles.
    - LocInv2: a given location can not contain both obstacle and food.



- Macro level
  - C1. The ants are able to reach any source of food.
  - C2. The ants are able to bring all the food to the nest
  - S1. When a source of food is reached, the ants are able to focus on its exploitation
  - R1. The ants focusing on exploiting a source of food, are able to continue their foraging activity when this source of food suddenly disappears

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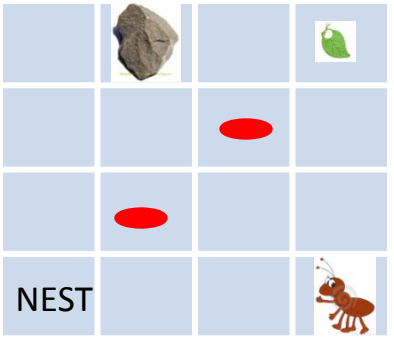

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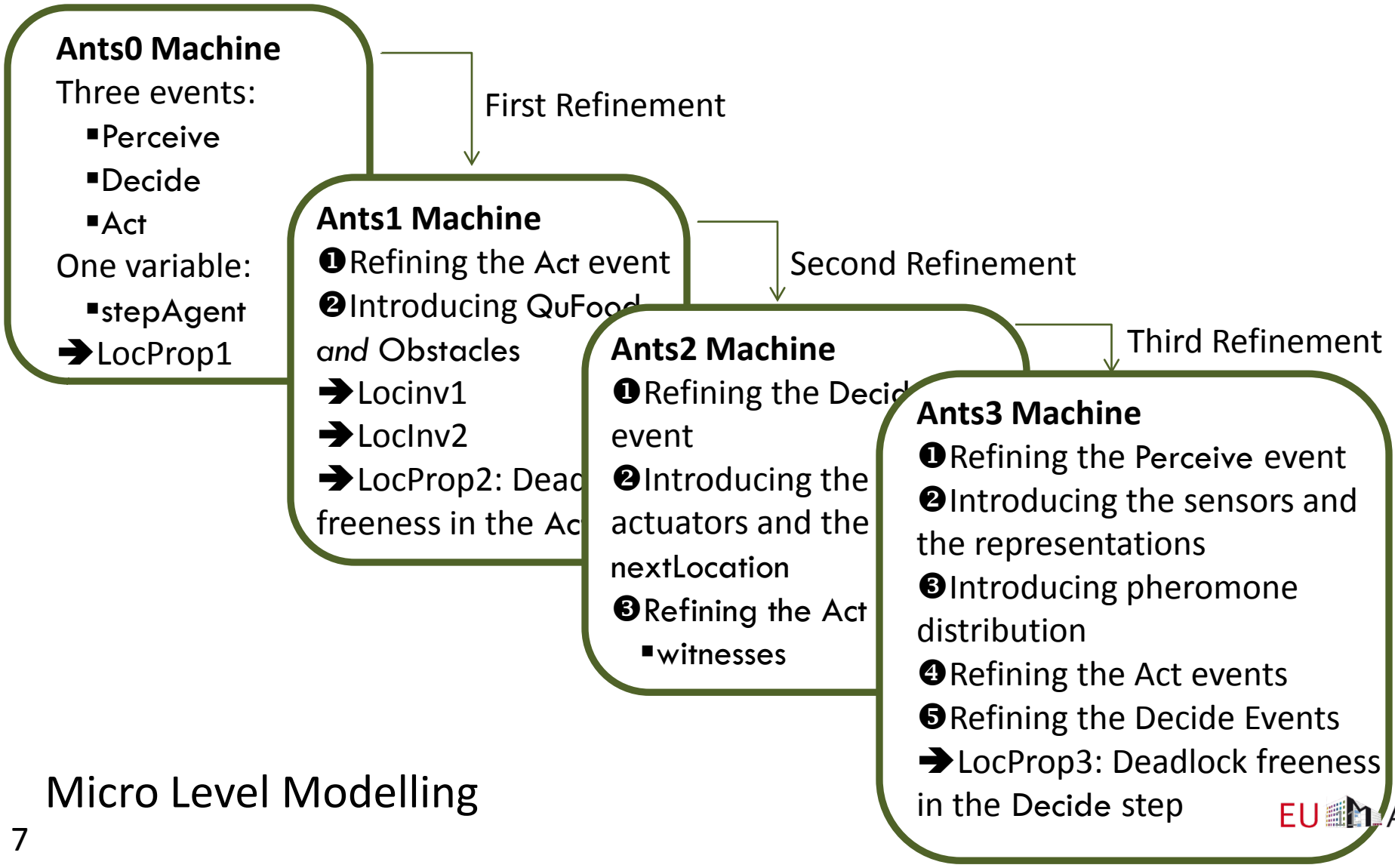
Event-B and Rodin

- Event-B
  - A formal language for systems modelling and analysis based on set theory and first order logic .
  - Key feature: use of refinement to represent the system at different level of abstraction
  - An Event-B model can be
    - Context: static part
    - Machine: dynamic part
- Rodin tool
  - Gives an effective support for refinement and mathematical proof
    - Generating Proof Obligations
    - Offering an interactive environment for doing proof

Our Approach Applied to the Ants



Micro Level Modelling

Global Properties Modelling – Stability

- Purpose: to prove the stability property
  - S1. When a source of food is reached in a particular location *loc1*, the ants are able to focus on its exploitation.
  - QuFood(loc1) will decrease
- More formally:
  - $P \triangleq Inv \wedge QuFood(loc1)=n+1$
  - $Q_{Harvest} \triangleq Inv \wedge QuFood(loc1)=n$
  - $P \rightsquigarrow Q_{Harvest} \triangleq \Box(P \Rightarrow \Diamond Q_{Harvest})$

Global Properties Modelling – Stability (cont.)

SF1.1 $\quad \mathrm{P} \wedge [N]_{QuFood(loc1)} \Rightarrow (P' \vee Q'_{Harvest})$

SF1.2 $\quad \mathrm{P} \wedge \langle N \wedge A_{Harvest} \rangle_{QuFood(loc1)} \Rightarrow Q'_{Harvest}$

SF1.3 $\quad \Box P \wedge \Box [N]_{QuFood(loc1)} \Rightarrow \Diamond Enabled \langle A_{Harvest} \rangle_{QuFood(loc1)}$

SF1.H $\quad \Box [N]_{QuFood(loc1)} \wedge SF_{QuFood(loc1)}(A_{harvest}) \Rightarrow P \rightsquigarrow Q_{Harvest}$

- N ≜ Act_Mov_Random ∨ Act_Mov_Foll_Food ∨ Act_Mov_Foll_Phero ∨ Act_Harv_Food
- $A_{Harvest}$ ≜ Act_Harv_Food
- SF1.1: progress step, either P or $Q_{Harvest}$ can be reached.
- SF1.2: inductive step, $Q_{Harvest}$ is reached.
- SF1.3: $\langle A_{Harvest} \rangle_{QuFood(loc1)}$ will be eventually enabled
- $SF_{QuFood(loc1)}(A_{Harvest})$ ≜ $\Box\Diamond Enabled\langle A_{Harvest} \rangle_{QuFood(loc1)} \Rightarrow \Box\Diamond \langle A_{Harvest} \rangle_{QuFood(loc1)}$

Global Properties Modelling – Stability (cont.)

➔Assumption: Once an ant smells food on *loc1*, other ants will be able also to smell this food and follow it .

$WF_{QuFood(loc1)}(A_{FollowFood}) \triangleq \Diamond\Box Enabled\langle A_{FollowFood}\rangle_{QuFood(loc1)} \Rightarrow \Box\Diamond \langle A_{FollowFood}\rangle_{QuFood(loc1)}$

- SF1.3 $\triangleq \Box P \wedge \Box[N]_{QuFood(loc1)} \Rightarrow \Diamond Enabled \langle A_{Harvest}\rangle_{QuFood(loc1)}$
- Purpose: to prove

$SF1.31 \triangleq \Box[N]_{QuFood(loc1)} \Rightarrow P \rightsquigarrow \Diamond Enabled \langle A_{Harvest}\rangle_{QuFood(loc1)}$

$Q_{FollowFood} \triangleq Enabled \langle A_{Harvest}\rangle_{QuFood(loc1)}$

$A_{FollowFood} \triangleq Act\_Follow\_Food$

$$\begin{array}{ll} \text{WF1.311} & P \wedge [N]_{QuFood(loc1)} \Rightarrow (P' \vee Q'_{FollowFood}) \\ \text{WF1.312} & P \wedge \langle N \wedge A_{FollowFood}\rangle_{QuFood(loc1)} \Rightarrow Q'_{FollowFood} \\ \text{WF1.313} & P \Rightarrow Enabled\langle A_{FollowFood}\rangle_{QuFood(loc1)} \end{array}$$

$$\text{WF1.31} \quad \Box[N]_{QuFood(loc1)} \wedge WF_{QuFood(loc1)}(A_{FollowFood}) \Rightarrow P \rightsquigarrow Q_{FollowFood}$$

Perspectives

- Global properties proof under Rodin tool
- Reasoning about the convergence and resilience global properties.
- Generalizing the approach by defining design patterns in order to automate the formal development.
- Integration of the proposed formal framework within a SO-MAS development method.

Thank You!

Questions & Feedback

are Welcome