A Classification Framework of Adaptation in Multi-Agent Systems

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The Importance of AMAS (i)

- Business and organisation environments are characterised with distributed, decentralised, and highly dynamic business processes where unpredictable situations occur frequently (Jennings *et al.*, 1998).

- In addition, the increase of unstructured information and knowledge augments the complexity to these environments.

- Multi-agent systems (MASs) are increasingly seen as an appropriate technology to build supporting systems for such environments.

The Importance of AMAS (ii)

- But MAS cannot easily cope with the increase of complexity and frequency of changes occurring in its environment.
- It is difficult to anticipate all potential situations an agent may be involved in, and specify the agents' optimal behaviour whilst designing them.
- For this reason, “agents must possess a pervasive property of human behaviour: adaptation” (Hayes-Roth, 1995), which in turn “is not an emergent property but should be a fundamental characteristic” (Guessoum, 2004) in MAS.

The Importance of AMAS (iii)

- This is why in recent years research interest has been attracted to the field of adaptive MAS (AMAS), cf. (Alonso *et al.*, 2003; Kudenko *et al.*, 2005).

- A number of researchers work in the area, following diverse and fragmented approaches. However, exchange of ideas between different groups is rare, and thus systematic analysis of achievements is overdue.

- To facilitate this systematic analysis of achievements, **we propose a classification framework of contributions in the field of AMAS**. **It can be used to highlight gaps in the field and to derive suggestions for further research**.

AMAS Definition

- An AMAS is a MAS situated in an open environment and capable to self-modify its structure and internal organisation by varying its elements' interactions according to environmental changes.
  - The **environmental** *changes* are clearly the main reason for MAS to adapt itself.
  - **AMAS** *internal interactions* are one of the “guiding” (Maes, 1994) and “engineering” (Parunak, 1997) principles to enable adaptation.
  - The **relation** *between the AMAS and its environment* is obviously needed to consider the degree at which AMAS adaptations and environmental changes affect one another.

Classification Framework of Adaptation (i)

- **Nature of environmental changes** is used to characterise the environment either as discrete or continuous.
  - A **discrete environment** is that where changes does not occur smoothly. As a consequence, the environment has states assigned to it and possible event types are known in advance.
  - A **continuous environment** is that where events occur gradually, i.e. there are no discrete changes. The environment can be modelled as a function agents try to either manipulate, anticipate, stabilise, or optimise.

Classification Framework of Adaptation (ii)

- **Nature of AMAS internal interactions** is used to characterise the AMAS either as static or dynamic.
  - A **static AMAS** is that whose internal interactions are predefined. Agent types are restricted to interact specifically with agents of other certain types. Usually, the number of agent types is fixed and small, and the agent diversity is low.
  - A **dynamic AMAS** is that whose internal interactions are not predefined. There is no restriction on agent interactions. Agents interact freely creating complex structures and organisations. There is usually a high diversity of agent types.

Classification Framework of Adaptation (iii)

- **Nature of the strength of the AMAS-Env relation** can be used to characterise the relation either as weak or strong.

  - A **strong relation** is that in which a single change in either the AMAS behaviour or the environment affects the other one almost immediately.

  - A **weak relation** is that in which a single change in either AMAS behaviour or the environment does not affect the other one. It gets influenced after a collection of consecutive changes takes place though. The collection size is determined by the AMAS itself and depends on the particular implementation.

Classification Framework of Adaptation (iv)

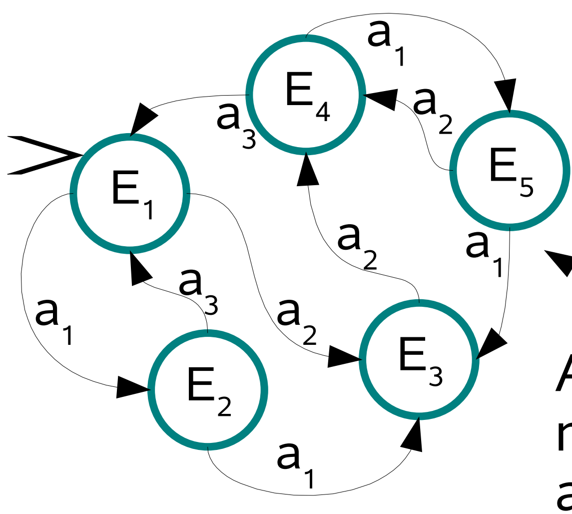
- As a result of combining types of environment, AMAS and relation, and after analysing different approaches (not the results) found in literature to enable adaptation in MAS, five different adaptation classes are obtained:

		Relation w/ Env	Environment: Discrete	Environment: Continuous
AMAS	Static	Strong	Automaton	Control System
AMAS	Static	Weak	Semi- Isolated Evolution	Semi- Isolated Evolution
AMAS	Dynamic	Weak	Complex Interactions	Complex Interactions
AMAS	Dynamic	Strong	Ecosystem	Ecosystem

Adaptation Classes (i)

- **Adaptation as an Automaton**: AMAS adapts its behaviour according to the current environment state and to the state it wants to bring the environment to

AMAS		Relation w/ Env	Environment: Discrete	Environment: Continuous
A	Static	Strong	Automaton	Control System
M	Static	Weak	Semi- Isolated Evolution	
A	Dynamic	Weak	Complex Interactions	
S	Dynamic	Strong	Ecosystem	



E_n = Environment state

a_m = Agent action

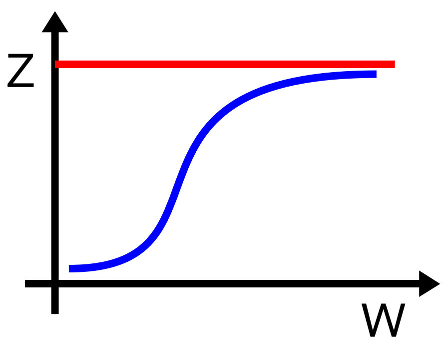
Adaptation is achieved by navigating through the automaton

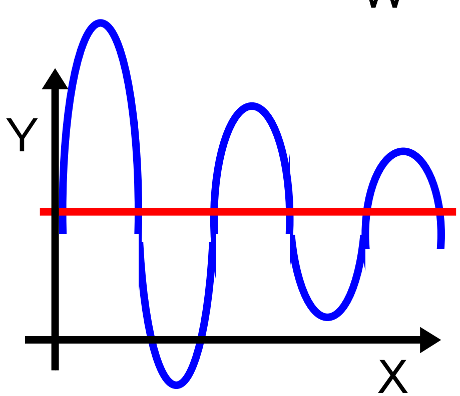
It assumes that only foreseen events will happen in the environment

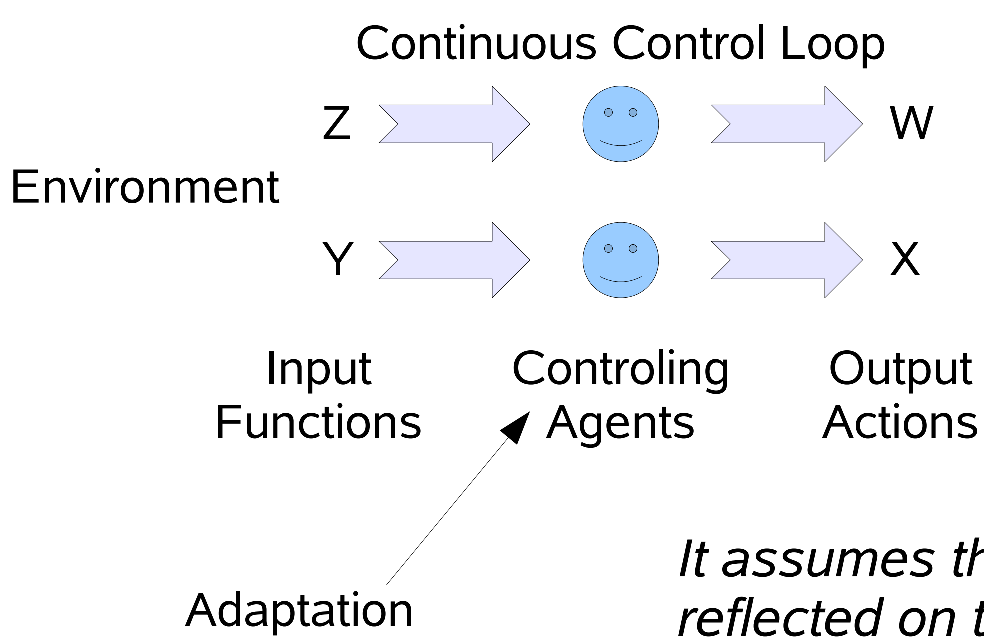
Adaptation Classes (ii)

- **Adaptation as a Control System**: environment is perceived as a function agents have to either manipulate, anticipate, stabilise, or optimise according to tasks and goals

AMAS		Relation w/ Env	Environment: Discrete	Environment: Continuous
A	Static	Strong	Automaton	Control System
M	Static	Weak	Semi- Isolated Evolution	
A	Dynamic	Weak	Complex Interactions	
S	Dynamic	Strong	Ecosystem	





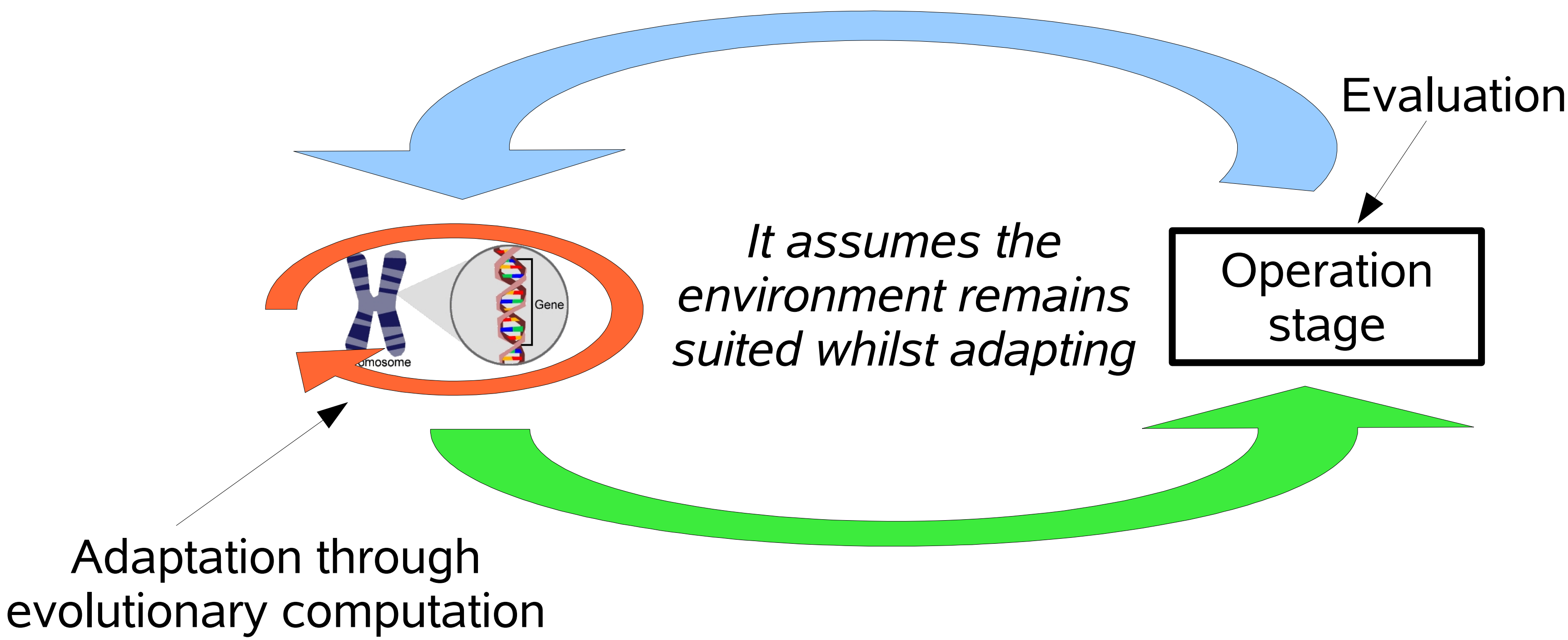


It assumes that only events reflected on the input function will happen in the environment

Adaptation Classes (iii)

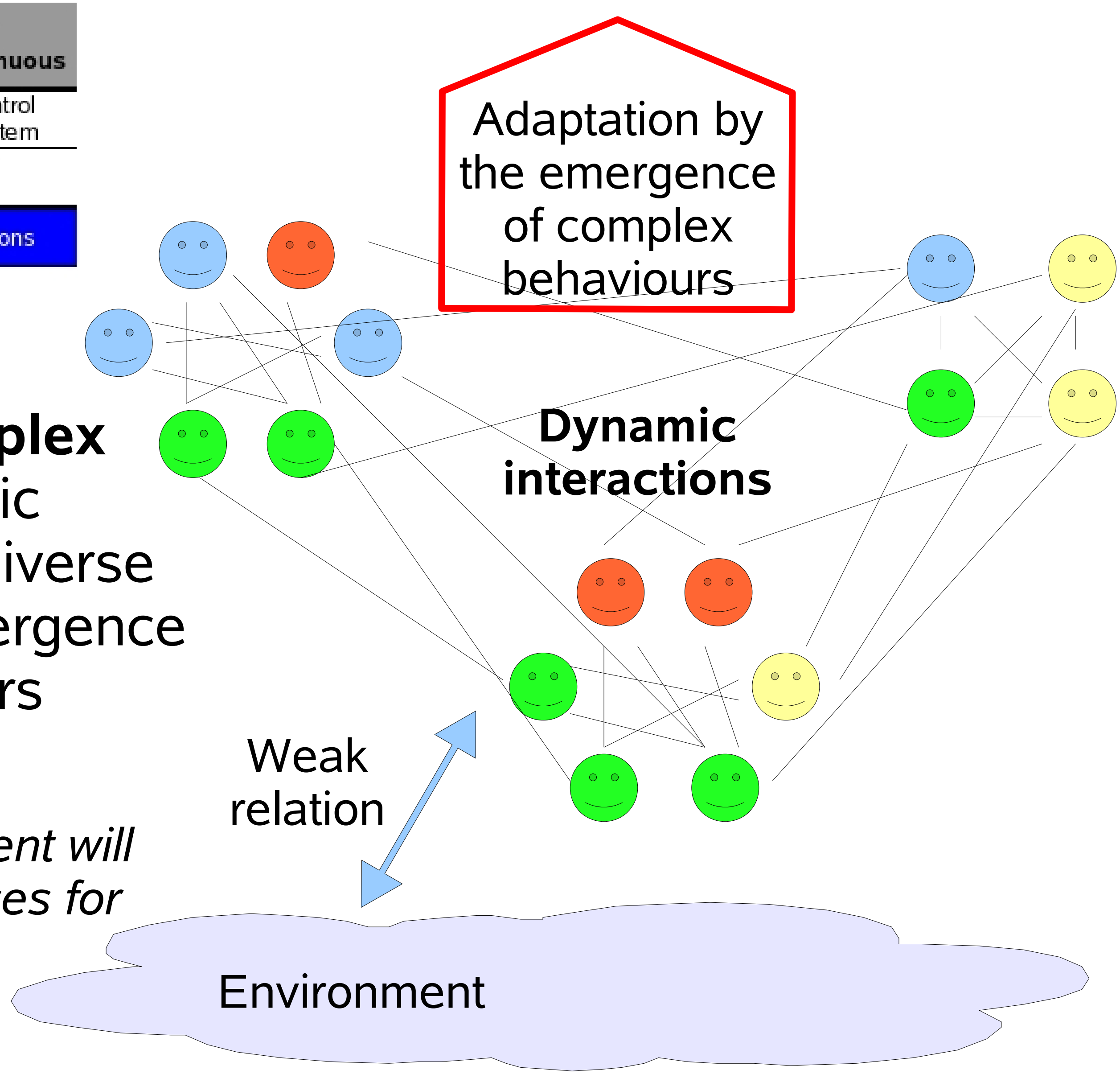
- **Adaptation as Semi-isolated Evolution**: it is accomplished by modifying agents' internal structure using evolutionary computation in a separated stage from operation

		Relation w/ Env	Environment	
			Discrete	Continuous
AMAS	Static	Strong	Automaton	Control System
		Weak	Semi- Isolated Evolution	
	Dynamic	Weak	Complex Interactions	
		Strong	Ecosystem	



Adaptation Classes (iv)

		Relation w/ Env	Environment	
			Discrete	Continuous
A	Static	Strong	Automaton	Control System
M		Weak	Semi- Isolated Evolution	
A	Dynamic	Weak	Complex Interactions	
S		Strong	Ecosystem	

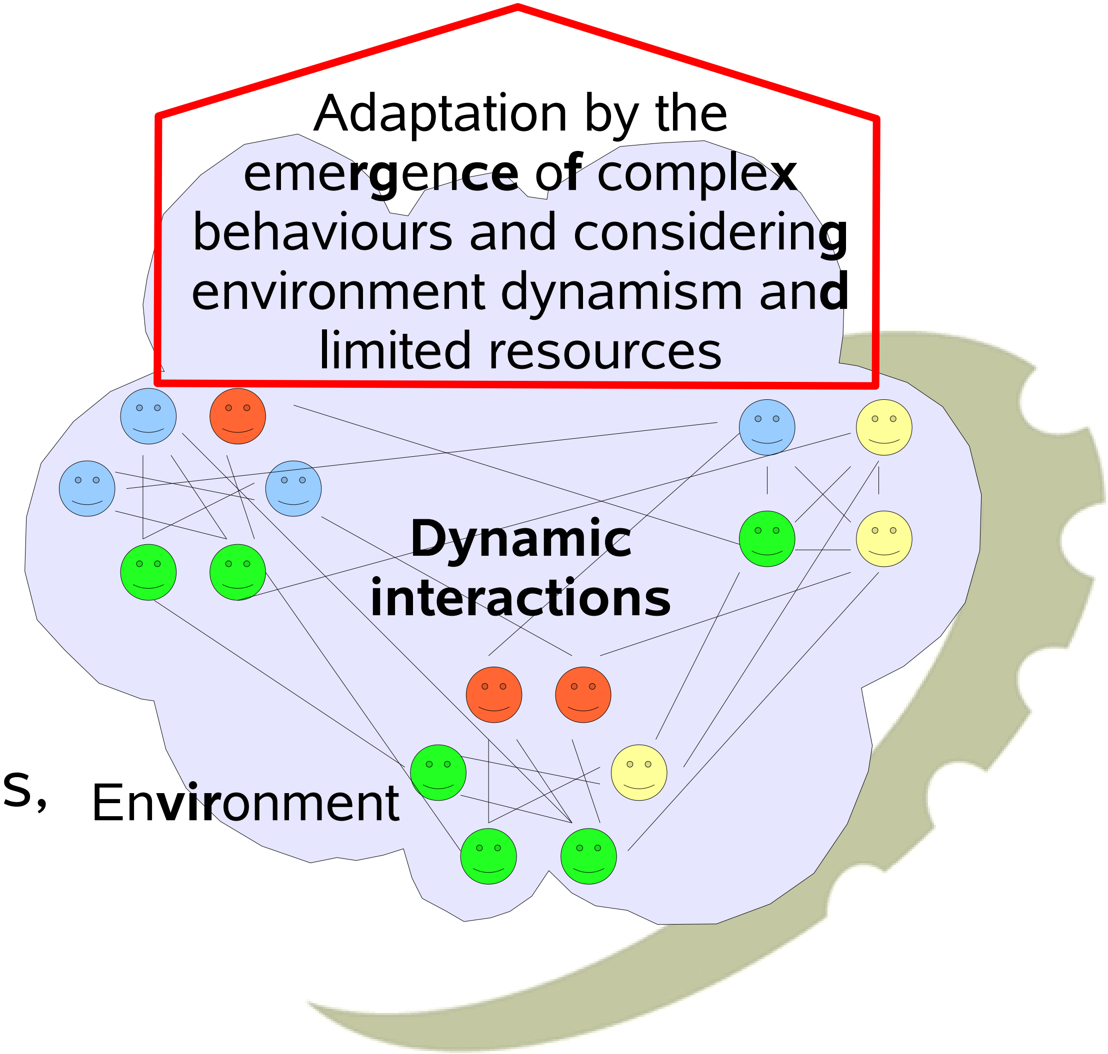


- **Adaptation as Complex Interactions**: dynamic interactions among diverse agents allow the emergence of complex behaviours

It assumes the environment will provide unlimited resources for AMAS to consume

Adaptation Classes (v)

		Relation w/ Env	Environment: Discrete	Environment: Continuous
A	Static	Strong	Automaton	Control System
M	Static	Weak	Semi- Isolated Evolution	
A	Dynamic	Weak	Complex Interactions	
S	Dynamic	Strong	Ecosystem	



- **Adaptation as an Ecosystem**: dynamic interactions among diverse agents with limited resources, allow the emergence of complex behaviours

Examples:
ECHO (Holland, 1995)
DIET (Marrow *et al.*, 2001)

There is a lack of supporting experiments for the ideas presented under this approach

Related Classification Framework (i)

- Alternative classification framework (Hayes-Roth, 1995) of adaptive intelligent systems (single agents, not MAS):
  - **Perception Strategy**: switching between perceptual strategies according to needs and limitations.
  - **Control Mode**: guiding behaviour by interleaving actions according to constraints and environment uncertainty.
  - **Reasoning Tasks**: interrupting and resuming of reasoning tasks according to objectives.
  - **Reasoning Methods**: balancing between internal model construction and the demand for model usage.
  - **Meta-control Strategy**: allocating computing resources for many tasks in order to maximise utility.

Related Classification Framework (ii)

- Mapping between Hayes-Roth's framework and ours:
  - Perception Strategy → Automaton
  - Control Mode → Control System
  - Reasoning Tasks → Automaton
  - Reasoning Methods → Control System
  - Meta-control Strategy → Control System
- **Our framework covers Hayes-Roth's and gives additional views of adaptation**.

Future Work in AMAS (i)

- Current research efforts on adaptation in MAS are mainly focused in the first four classes of our framework.

- Examples from the Ecosystem class:
  - ECHO (Holland, 1995): proposed adaptation properties (*aggregation, non-linearity, flow and diversity*) for emergence of complex behaviours.
  - DIET (Marrow *et al.*, 2001): proposed an architecture to tackle resource variations as an ecosystem of agents.

- **They did not present enough experimental support for their claims. Others did later, but somehow they failed.**

Future Work in AMAS (ii)

- (Smith & Bedau, 2000) and (Smith & Bedau, 2000a) presented experiments on ECHO (Holland, 1995).
  - They argue that Holland's ideas are correct, but the problem is that we still have to figure out how to address them.
- (Hoile et al., 2002) and (Marrow et al., 2002) presented experiments on DIET (Marrow et al., 2001).
  - They addressed the idea by using an evolutionary computation approach.
- There are still gaps in research when tackling adaptation as an ecosystem. **We suggest that the Ecosystem class is where research efforts on AMAS should be concentrated in the future.** - *But how?*

Future Work in AMAS (iii)

- **MAS community** has envisaged a set of “engineering” (Parunak, 1997) and “guiding” (Maes, 1994) principles for MAS development which give support to Holland's adaptation properties.
- **Biology community** have been deriving descriptive formulae for analysing Holland's adaptation properties in ecosystems (Otsuka, 2004), (Kolasa, 2005), (Maurer, 2005), (Green & Sadedin, 2005).
- We believe that in order to accomplish adaptation within the Ecosystem class, it is necessary **to combine ideas and principles from MAS and biology communities.**

Conclusions

- Adaptation in MASs is clearly desirable for open environments, such as organisations, where unexpected situations frequently occur, and complexity and unpredictability are in constant growing.

- Seeing adaptation in MAS using the presented classification framework helps one to visualise previous attempts and address future research.

- Our suggestion is to address research efforts on adaptation as Ecosystems by combining ideas from both MAS and biology communities.

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Questions ?

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Thank you !

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