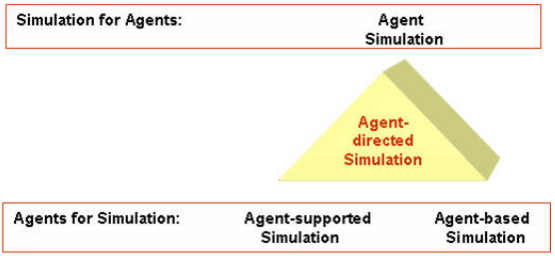

Towards a Taxonomy of Agents and Multi-Agent Systems

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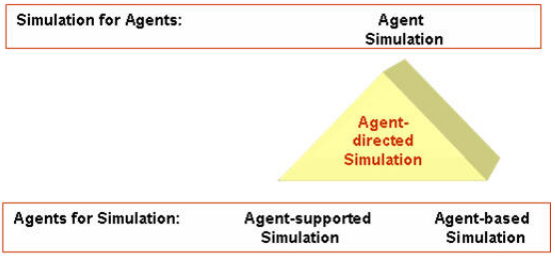
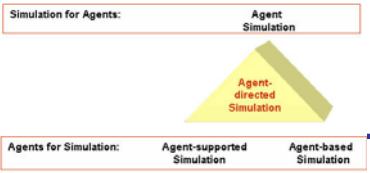


This paper summarizes the results of an independent study by Lisa Jean Moya under the mentorship of Andreas Tolk. We thank all contributing researchers and companions for their encouraging and constructive discussions, in particular Dr. Levent Yilmaz.



Goals of the work

- Begin consolidating divergent research into an overarching taxonomy for agents and multi-agent systems
  - Supporting concepts from Wooldridge, Ferber, Weiß, et al
- Develop ability to characterize agents & MAS according to its characteristics
  - Use characterization to understand and predict behavior
  - Guide development characterizations for agents in specific applications
  - Formalize agents and MAS

Work grew out of an independent course of study

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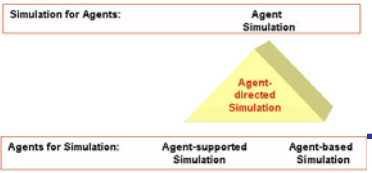
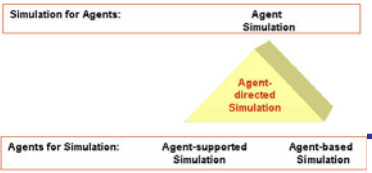


Factors leading to an agent system

- A complex environment, which may be open, dynamic, or uncertain
- Agents are a metaphor in the system
- Data, expertise, or control is distributed
- Interaction with legacy systems is necessary



Towards a Taxonomy for Agents and MAS

Agents can be found supporting

- Web services
- Manufacturing
- Environmental management
- Modeling and simulation
- Decision-making and intelligence frameworks

Agents decide to act rather than reacting, or being invoked, on input. That reaction is not necessarily consistent or deterministic.

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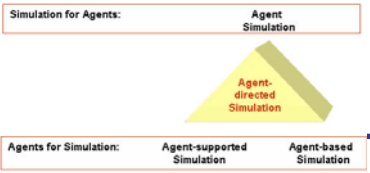
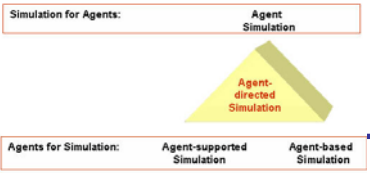
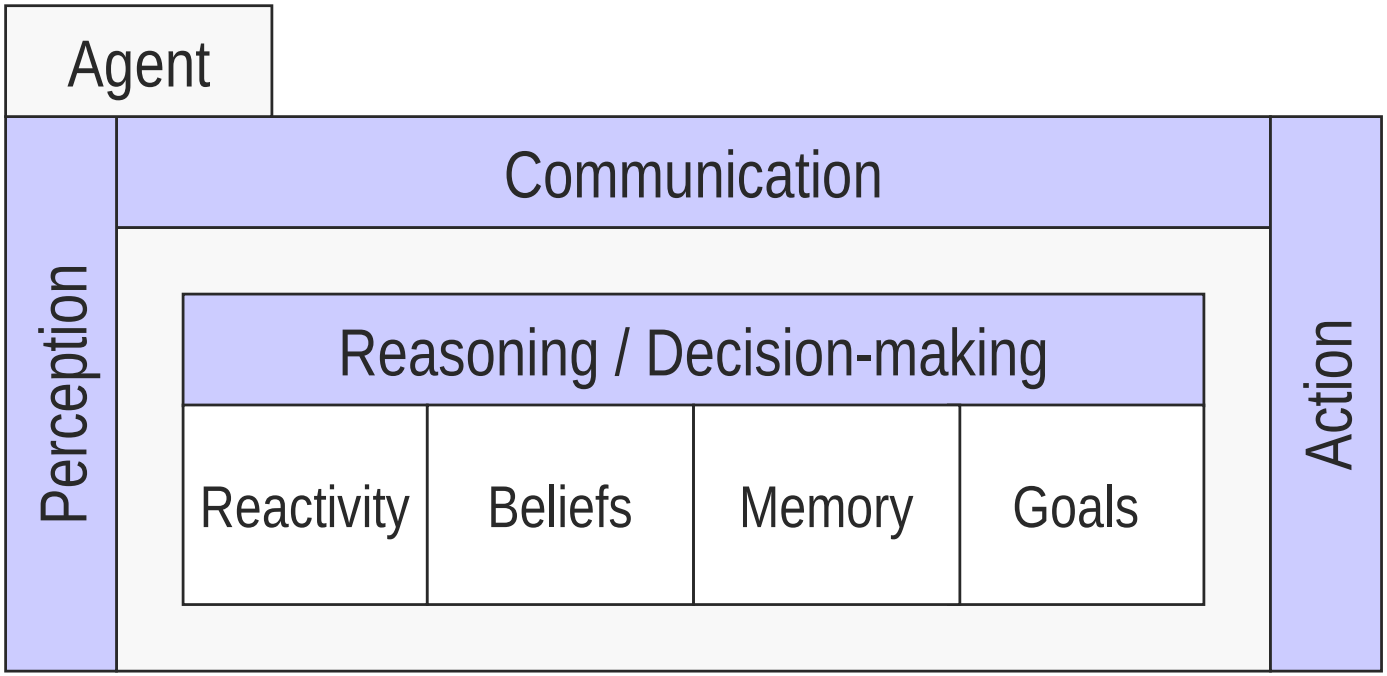


What is an agent?

- Consistent attributes
  - Situated in an environment
  - Perceive that environment
  - Perform autonomous action
- Other common attributes
  - Communication
  - Cooperation
  - Mobility
  - Learning
  - Rationality

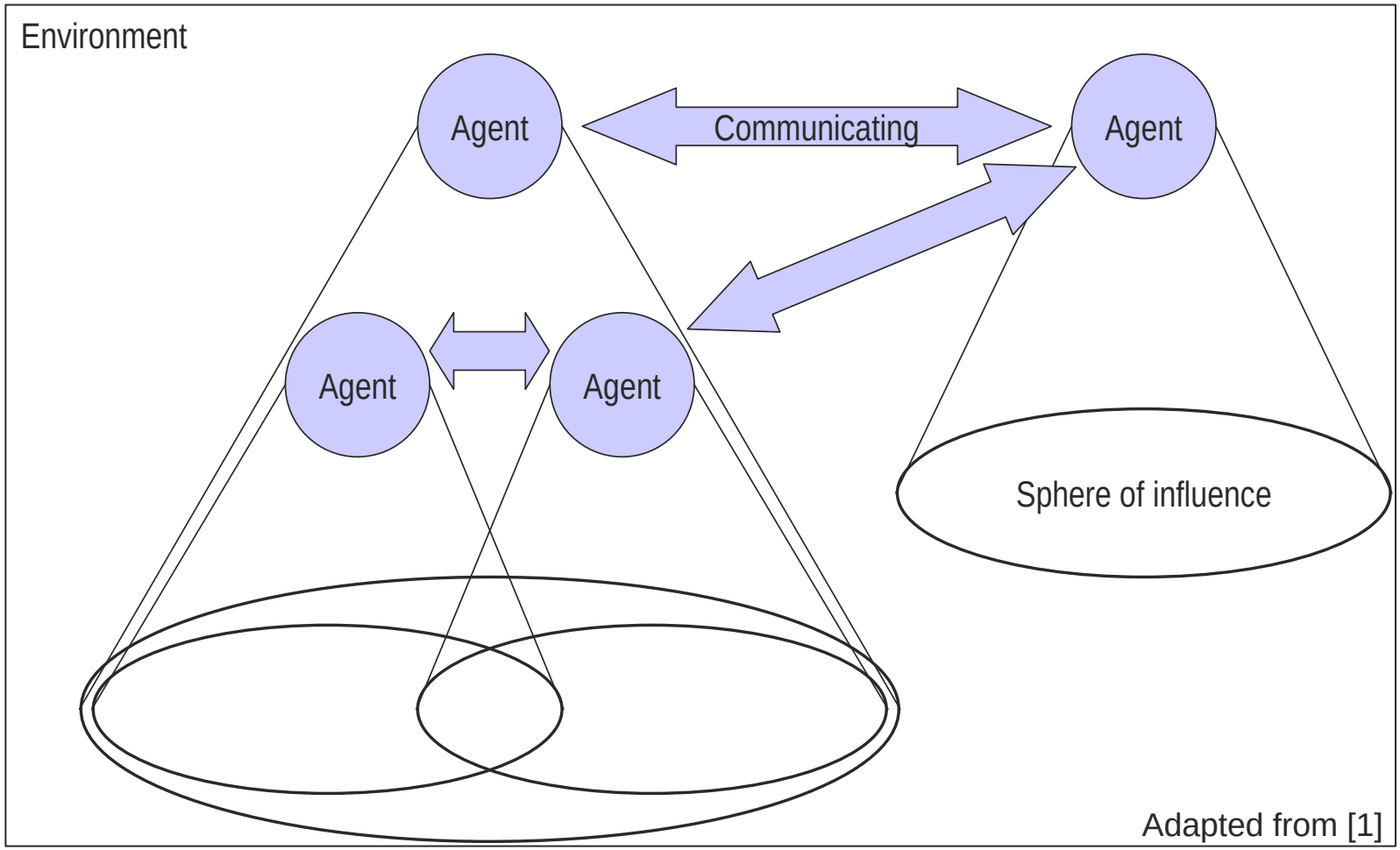


Typical agent



Towards a Taxonomy for Agents and MAS

Typical multi-agent system



[1] Wooldridge, M.J. 2002. *An Introduction to MultiAgent Systems*. John Wiley and Sons. West Sussex, England.

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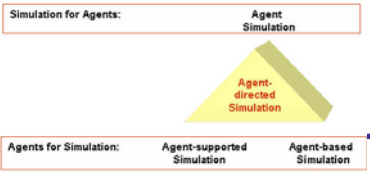
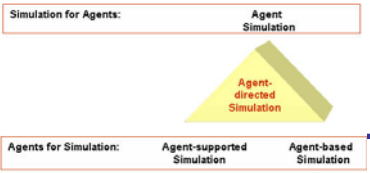


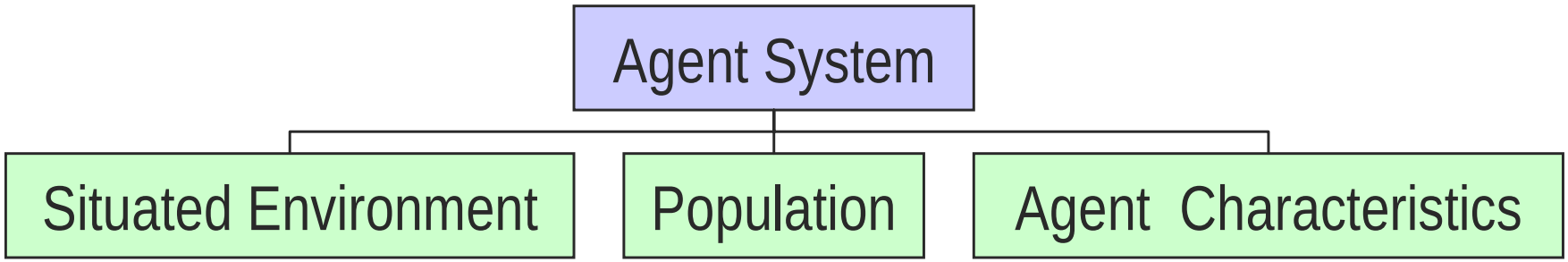
Other taxonomic descriptions

- Agents
  - Decision-making architectures
  - Cooperative & learning properties
  - Function, class, or capability
- Multi-agent systems
  - Functional environment
  - Interaction
  - Actions and knowledge

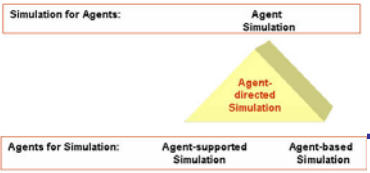
Taxonomy includes agents, their environments, and their population focusing on properties. We assume a situated environment.



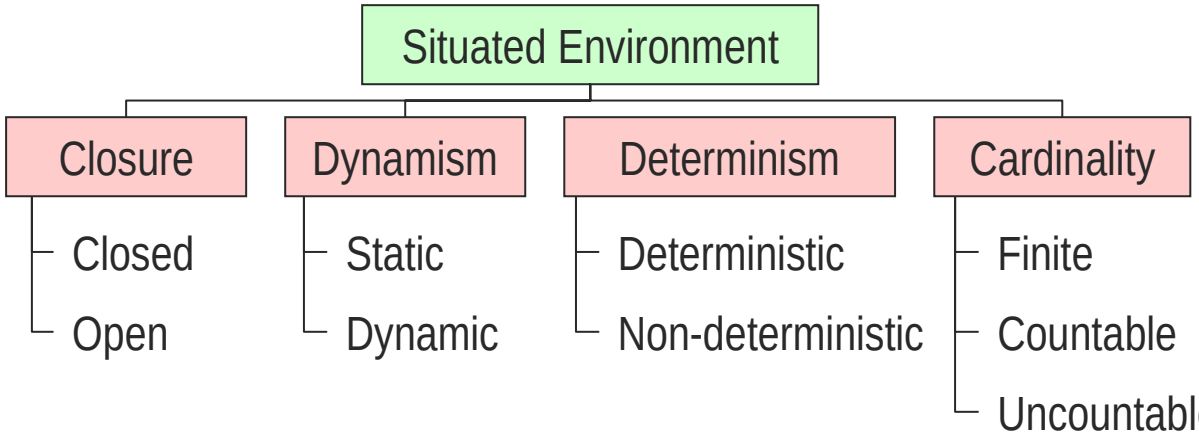
Taxonomy overview



- Situated environment – "world information;" objects agents can affect and be affected by
- Population – characteristic descriptions of the MAS
- Agent characteristics – decision, action, perception, goals, etc.



Situated Environment



- Closure – can agents outside the environment affect the system
- Dynamism – how does the environment change
- Determinism – consistency of effect (in the environment)
- Cardinality – objects able to be affected or perceived

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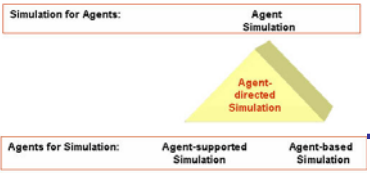

Definitions – Situated Environment

- Closed: Changes in the environment can be fully described by the agent system. Agents not situated in the environment cannot affect the system.
- Open: Not closed.
- Static: All changes in the environment are caused by the agents situated within it.
- Dynamic: Changes in the environment are caused by randomness or from elements in an open environment. Not determined from the agent's point of view.
- Deterministic: Any agent action will have the same effect on the environment given identical environmental conditions.
- Non-deterministic: Agent actions have uncertain effects even given (apparent) identical circumstances. Differs from an agent's perception of that effect

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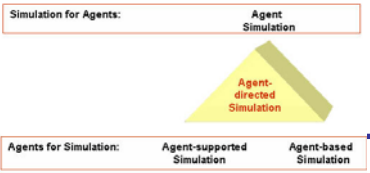
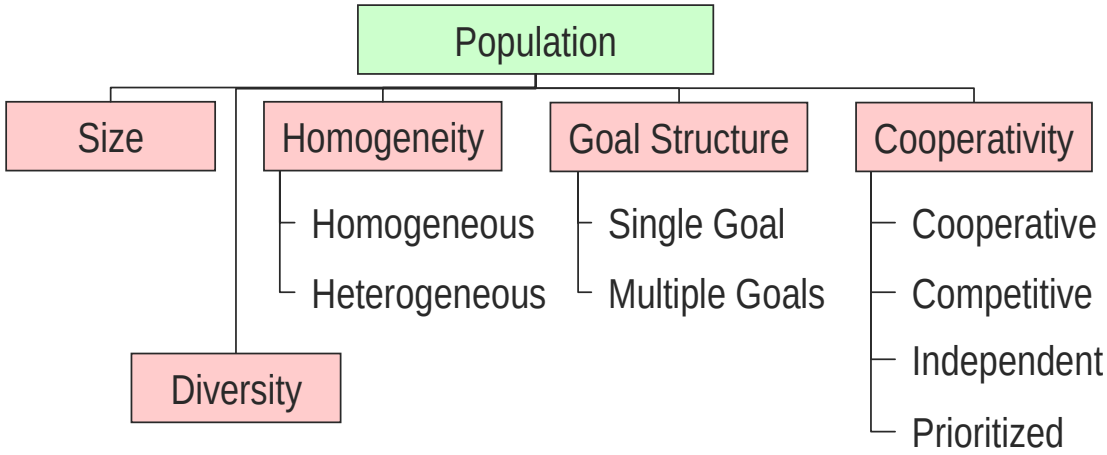


Towards a Taxonomy for Agents and MAS

Population



- Size and Diversity – number of agents; types of agents
- Homogeneity – agent population of the same/different type
- Goal structure – types & uniformity of goals
- Cooperativity – inclination of population to cooperate

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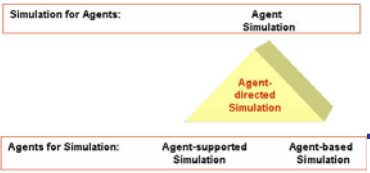
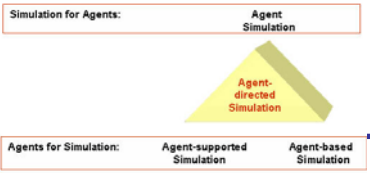


Definitions – Population

- Homogeneous: Every agent within the environment has uniform structure and composition; this includes but is not limited to goals, rules, architecture, etc.
- Heterogeneous: Not homogeneous.

- Single goal: All agents within the environment act in accordance with a single goal. This goal could be layered with sub-goals that could vary in the population. A single goal in a multi-agent system does not necessarily imply that the agents having the goal are cooperative in its achievement.
- Multiple goals: Agents in the system each have their own goals to achieve; alternatively, a single agent may have multiple goals that it pursues.



Definitions – Population

(continued)

- Cooperative: Agent is willing to help other agents achieve their goals, potentially sacrificing achievement of its own.
- Competitive: Agent acts primarily to achieve its goals, and cooperation never occurs at the expense of its own goals.
- Independent: Agents act on goals independently without cooperative mechanisms (either explicitly or through rule-based mechanisms).
- Prioritized: Goals may have a prioritization structure that guides pursuit and cooperation.

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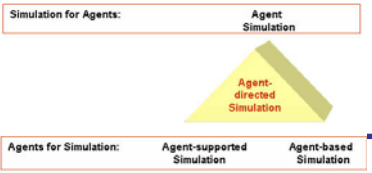

Agent Characteristics

- Agent Characteristics
  - Reasoning
    - Architecture
      - Tropistic
      - Deliberative
      - Hybrid
    - Beliefs
      - Environment
      - Next goal (self)
      - Next goal (others)
    - Goals
      - Implicit
      - Explicit
    - Reactivity
  - Perception
    - Access
      - Complete
      - Partial
    - Accuracy
    - Memory
      - Historical environment
      - Past actions (self)
      - Past actions (others)
      - Action effects (others)
      - Action effects (self)
  - Action
    - Communication
      - Local
      - Networked
      - Mobile
      - Protocol
    - Negotiation
      - Blackboard
      - Broker
      - Mediator
      - System

- Reasoning – decision-making architecture
- Perception – sense & memory of environment
- Actions – agent capabilities
  - Limited focus
  - Not exclusive
  - Not exhaustive

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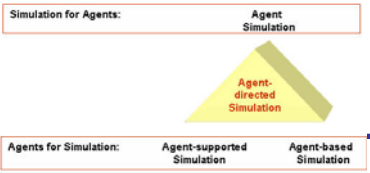

Definitions – Reasoning agent characteristics

- Deliberative: Deliberative architectures follow the classical artificial intelligence paradigm using physical symbolic representation and manipulation
- Tropistic: Tropistic architectures are those that use rule-based decision processes instead of a symbolic one. Intelligent action emerges from the parts rather than resulting from explicit reasoning
- Hybrid: Hybrid approaches bring the two previous approaches together providing more time bounded reactivity to the environment while keeping the structured reasoning processes

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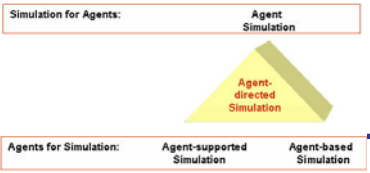

Definitions – Perceptions agent characteristics

- Access: Identifies the degree to which an agent can sense and has access to its environment.
- Accuracy: Reflects the agent's capabilities both to sense its environment accurately and to deal with uncertain or contradictory sensory inputs.
- Memory: Identifies the agent's ability to utilize past states, actions, and results in support of future decision making.

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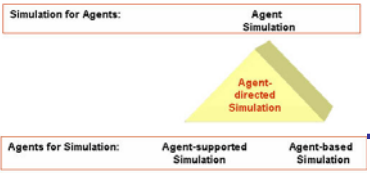

Definitions – Actions agent characteristics

- Local: Local agents only have access to resources at the local level. In a personal computing environment, these agents work on behalf of users, e.g., personal assistants or help systems
- Network: Network agents have access to remote sources of information, e.g., search engines
- Mobile: Mobile agents have a more active ability to search out and obtain information applicable to large computer network environments
- Blackboard: Agents with the capabilities to store data and requests for that data
- Broker: Agents monitor requests and link agents together
- Mediator: Agents mediate goal conflicts between agents
- System: Agents provide overall system monitoring

Neither exclusive nor exhaustive

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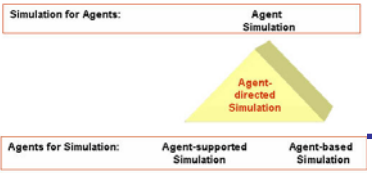

Additional research & applications

- Improvements
  - Expand & deepen Actions branch: negotiation, communication, other capabilities
  - Expand & deepen Reasoning branch
    - Other decision-making architectures
    - Detail w.r.t. identified architectures
    - Characteristics s.a. decision traceability, coherence, & validity
- Other sources
  - Develop branches using a design view (bottom-up) approach
  - Other work: e.g., holons & organizational theory
- Relate taxonomy to formal definitions, validity, characteristic behaviors, system composition, etc.

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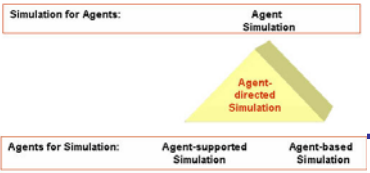

Towards a Taxonomy for Agents and MAS

Taxonomy

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      - Open
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      - Deterministic
      - Non-deterministic
    - Dynamism
      - Static
      - Dynamic
    - Cardinality
      - Finite
      - Countable
      - Uncountable
  - Population
    - Size
    - Diversity
    - Homogeneity
      - Homogeneous
      - Heterogeneous
    - Goal Structure
      - Single Goal
      - Multiple Goals
    - Cooperativity
      - Cooperative
      - Competitive
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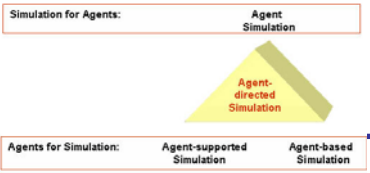

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