

Methodologies for Understanding Behavior of System of Systems

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Outline

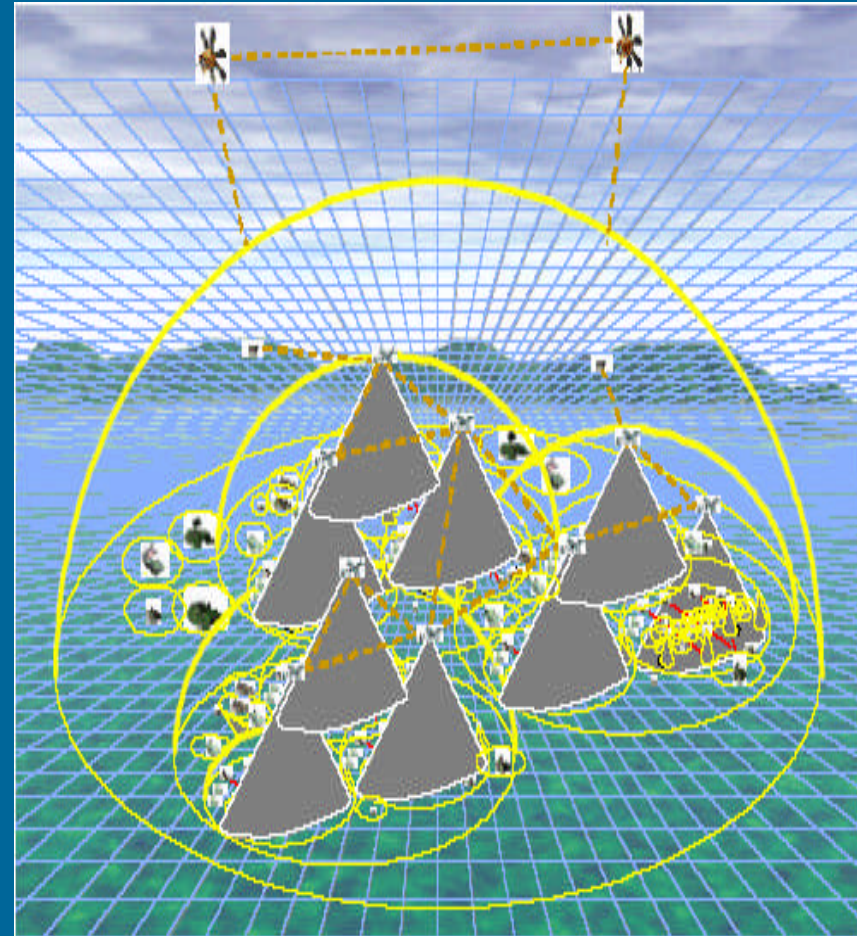
- Introduction
 - System of Systems (SoS) characteristics
 - Network centric operations
 - Challenges and research need for SoS analysis
 - The aim of the presentation
- Modeling Tools for Understanding Behavior of SoS
- Methodology customization for SoS analysis
- Conclusions

Introduction

- We are increasingly a networked society:
 - NATO reorganization and expansion
 - Trans-national mega military systems
 - Asymmetrical threats vs. rapid reaction forces
 - Trans-national enterprises
- We are increasingly dependent on these networks.

Characteristics of SoS

- System of systems (SoS) – A set or arrangements of interdependent systems that are related or connected to provide a given capability.
- Common Characteristics:
 - Operational independence of elements
 - Elements possess the required NCO interoperability
 - Development and existence is evolutionary
 - Emergent behaviors and capabilities
 - Geographically distributed NCO systems



Network Centric Operations

- Effects based planning
- Effects based operations
- Global reach
- Information superiority
- Collaborative decision superiority
- Horizontal and vertical integration
- Joint deployment and sustainability
- Net centric coalition
- Comprehensive situational awareness
- Common Operating Picture
- Rapid, tailored response and agility
- Supports layered approach to security
- Embedded simulation and training

Challenges and Research need for SoS

- Dynamically changing requirements increase uncertainty.
- Continuous rapid technological changes provide opportunities for improved capabilities, but increase complexity of interfaces.
- Diverse spectrum of missions and operations increase complexity of architecting SoSs.
- The need to develop dynamic and evolving communication architecture is vital in architecting SoS.

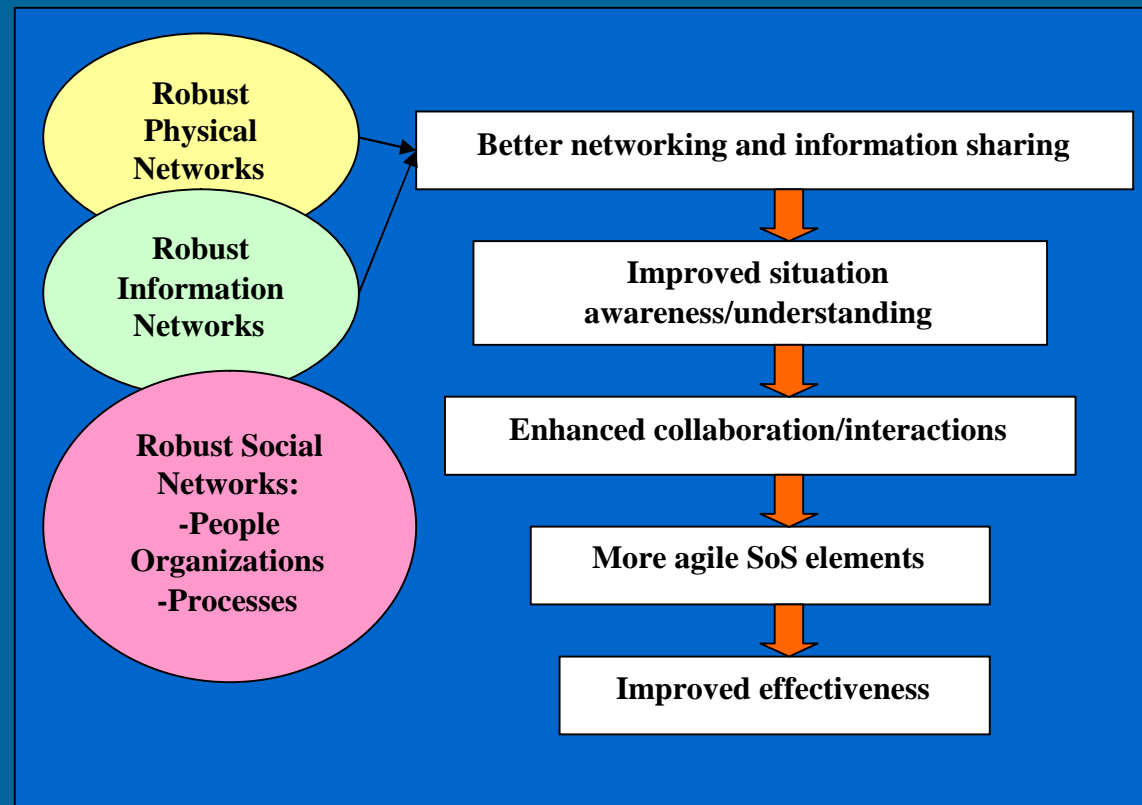
Challenges and Research need for SoS

- Interoperability is the main challenge which must be met.
- Interoperability-related enablers, such as
 - Architecture frameworks
 - Technical architectures
 - Levels of information systems interoperability
- The challenge arises due to missing linkages between these interoperability-related enablers and SE processes.
- All these challenges open various research needs for SoS

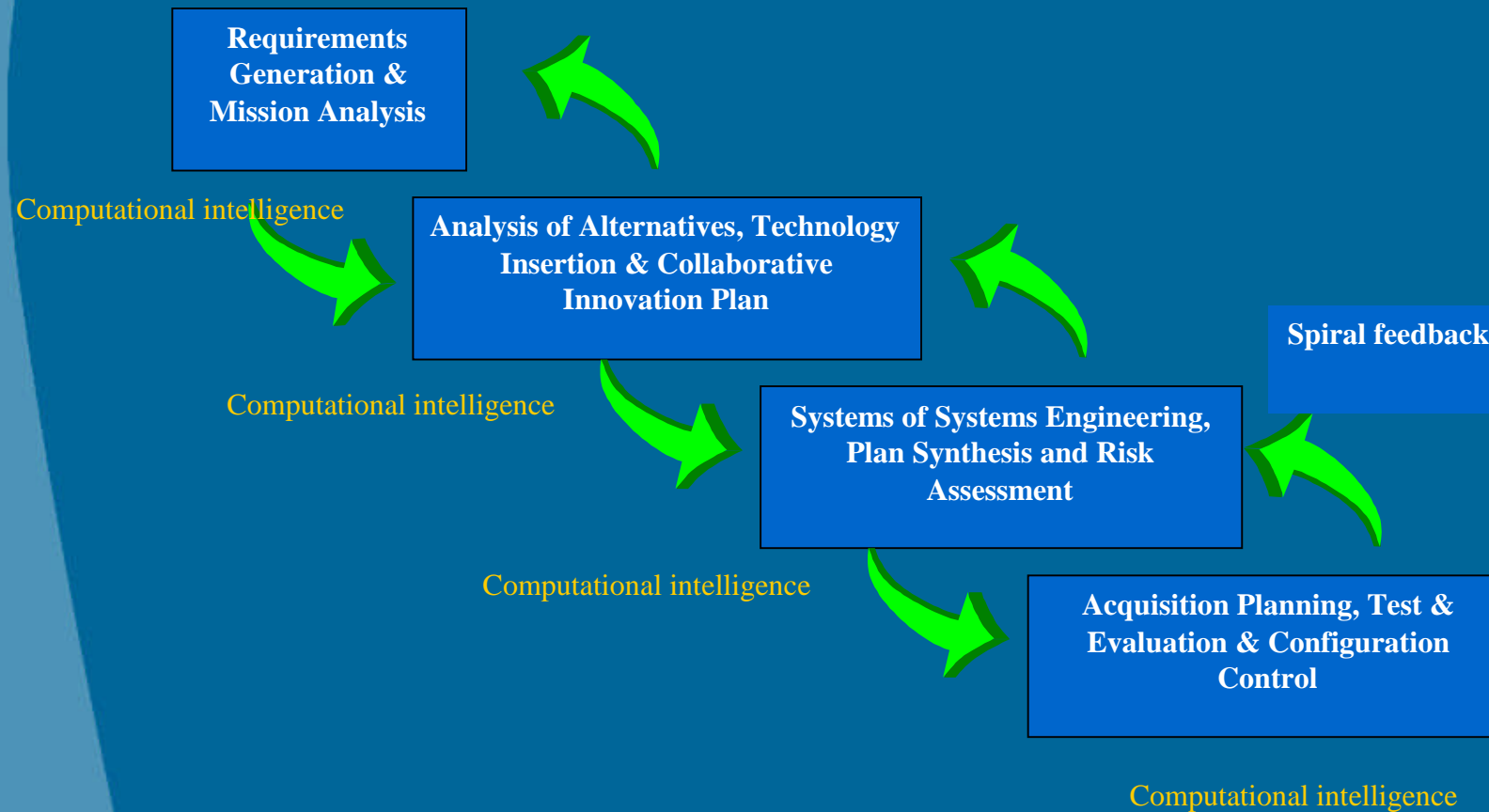
The Aim of the Presentation

- Discuss several computational intelligence tools for modeling and understanding behavior of SoS.
- Identify the areas where these tools can help SoS architects in dealing with the mentioned challenges.
- Identify methodology customization for analysis of SoS.

SoS Conceptual Framework



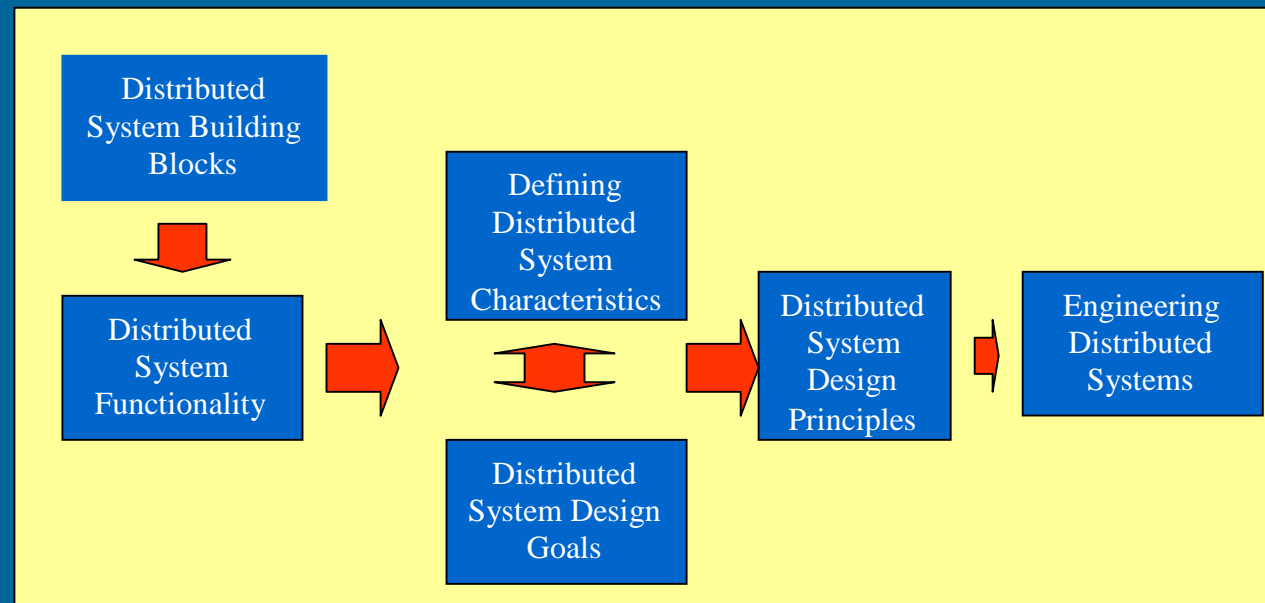
SoS Design Approach



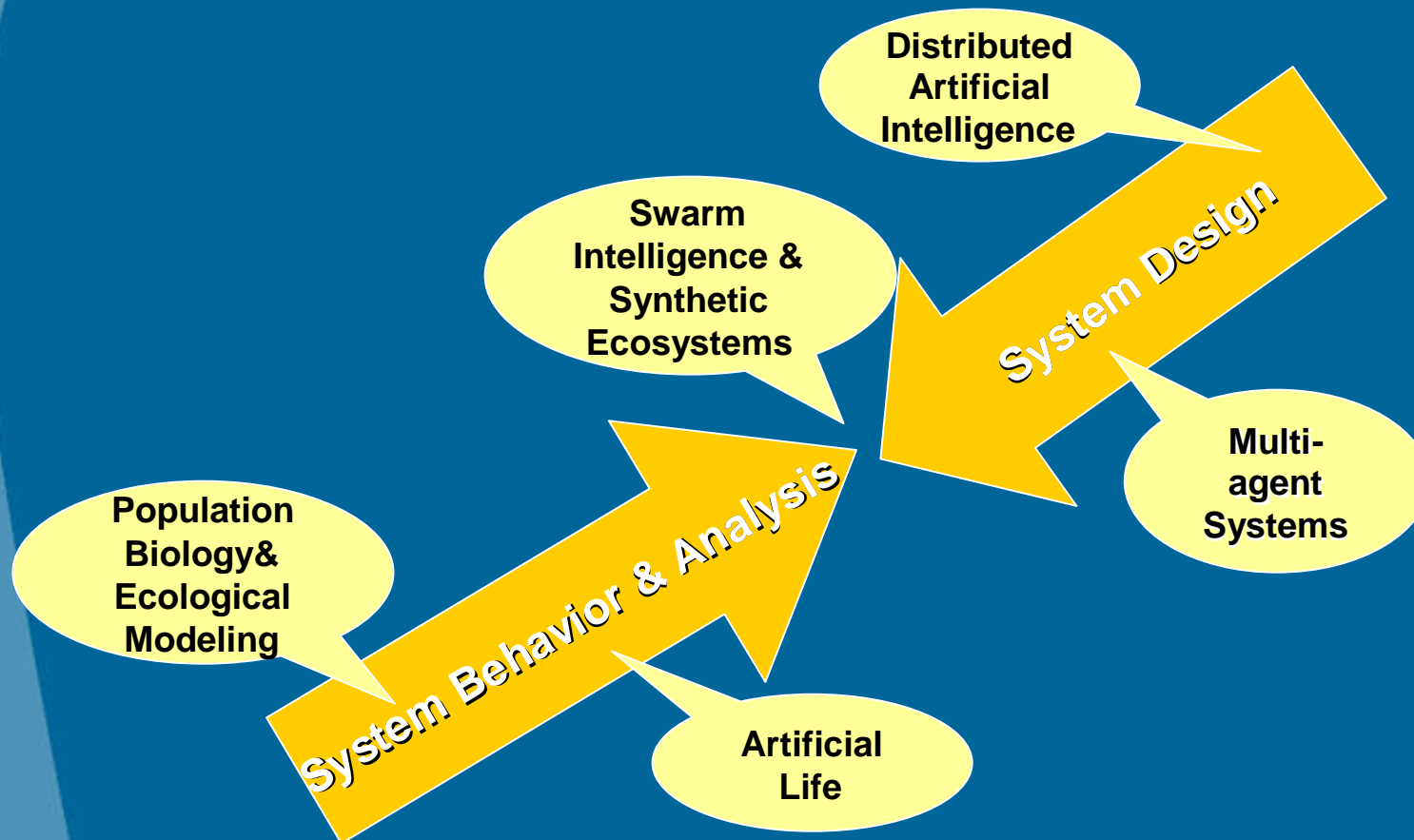
Modeling Tools for Understanding Behavior of SoS

- Distributed systems modeling
- Complexity theory
- Agent based modeling
- Evolutionary strategies and programming
- Swarm intelligence and optimization
- Emergent behavior analysis of architectures
- Fuzzy logic
- Cooperative and collaborative system modeling and simulation
- Adaptive system architecture generation

Formulation of Distributed Networked Systems



Trajectories of Research into Distributed Systems Modeling



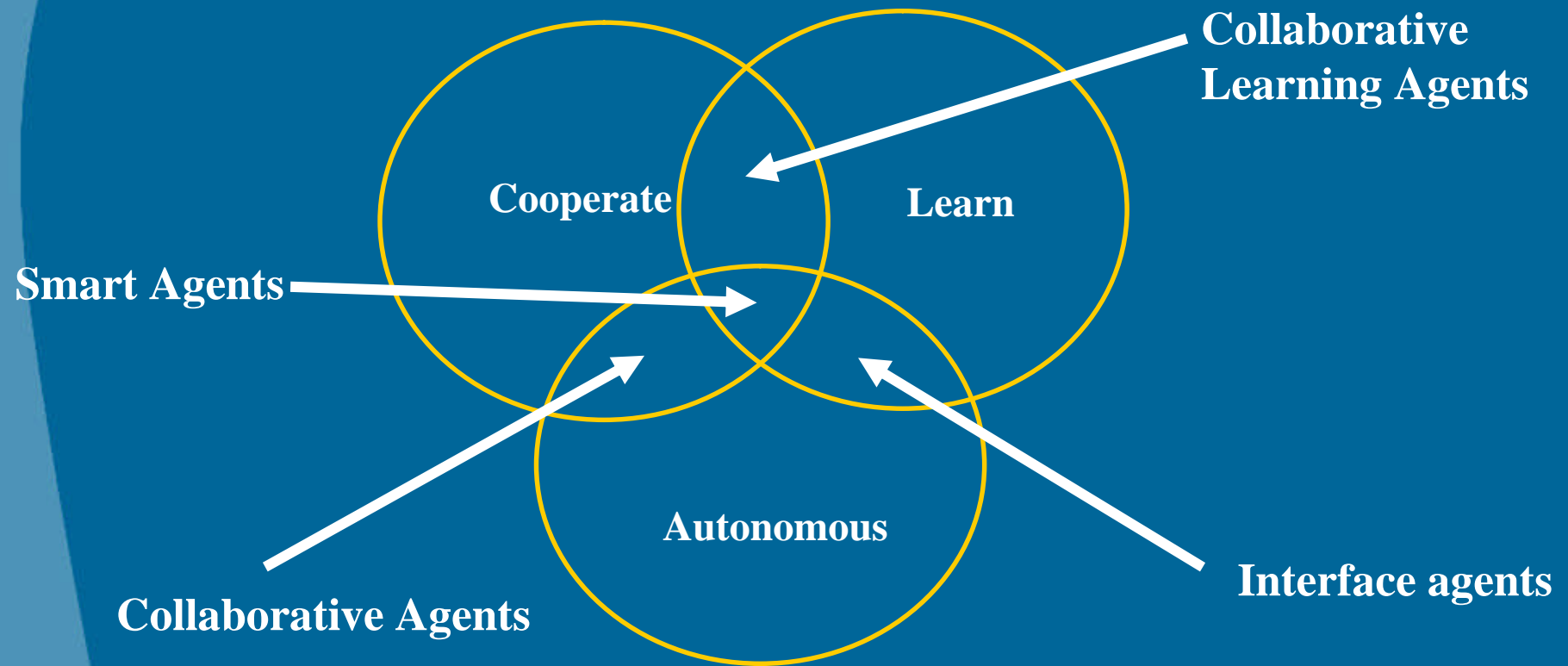
Complexity Theory and SoS analysis

- Long term planning is impossible:
 - SoS grow by adding components
- Dramatic change can occur unexpectedly:
 - Small perturbations can also cause huge changes on the overall system behavior
 - Potential for cascading failures in SoS
- Complex systems exhibit patterns and short-term predictability:
 - Next time period behavior of systems can be predicted when reasonable specifications of conditions at one time period are given
 - SoS testing and validation is based on this characteristic
- Organizations can be turned to be more innovative and adaptive:
 - Emergent order and self organization provide a robust solution for SoS to be successful in competitive and rapidly changing environmental conditions

Agent-based Modeling and Sos Analysis

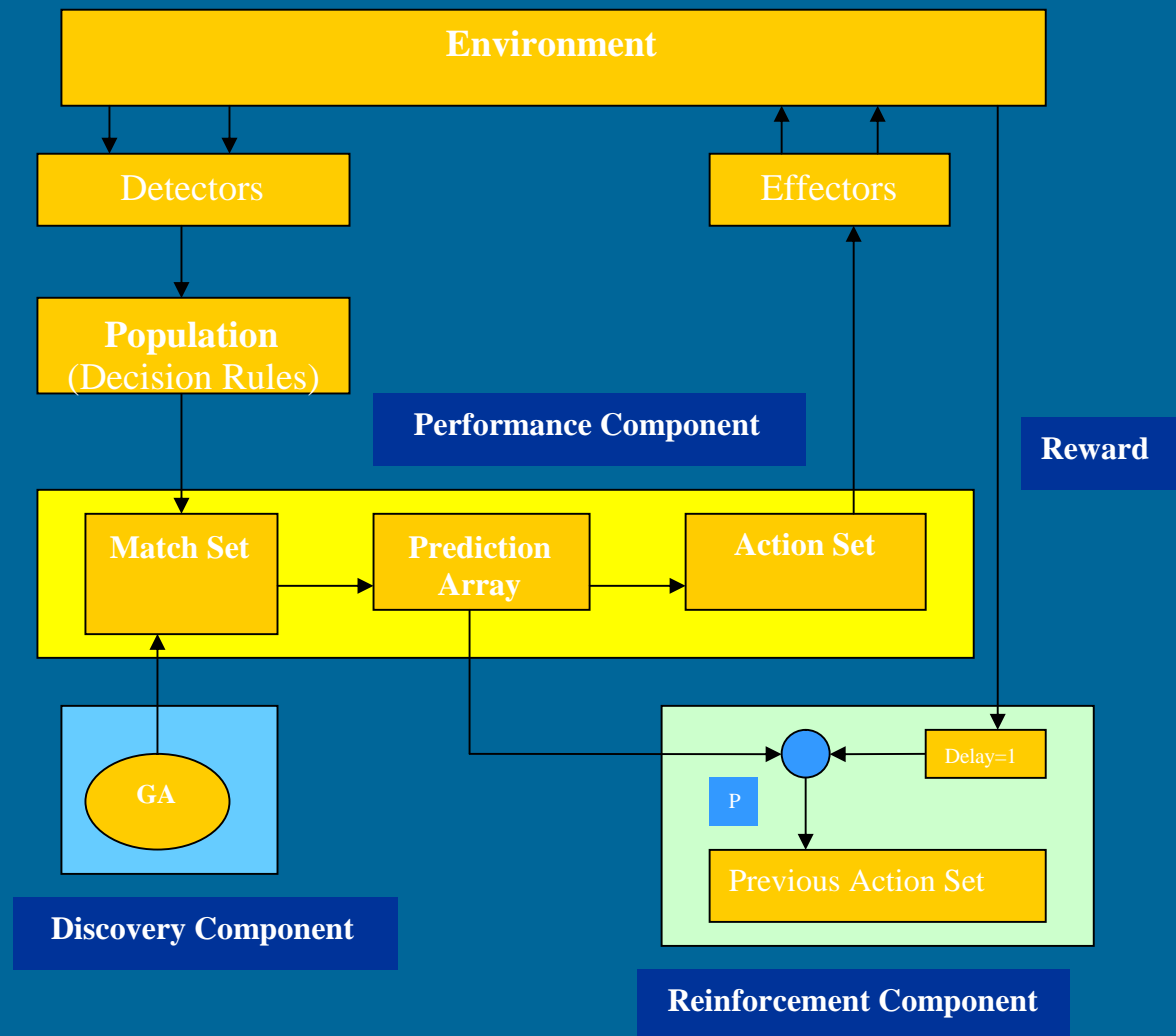


Distributed Agent Paradigm

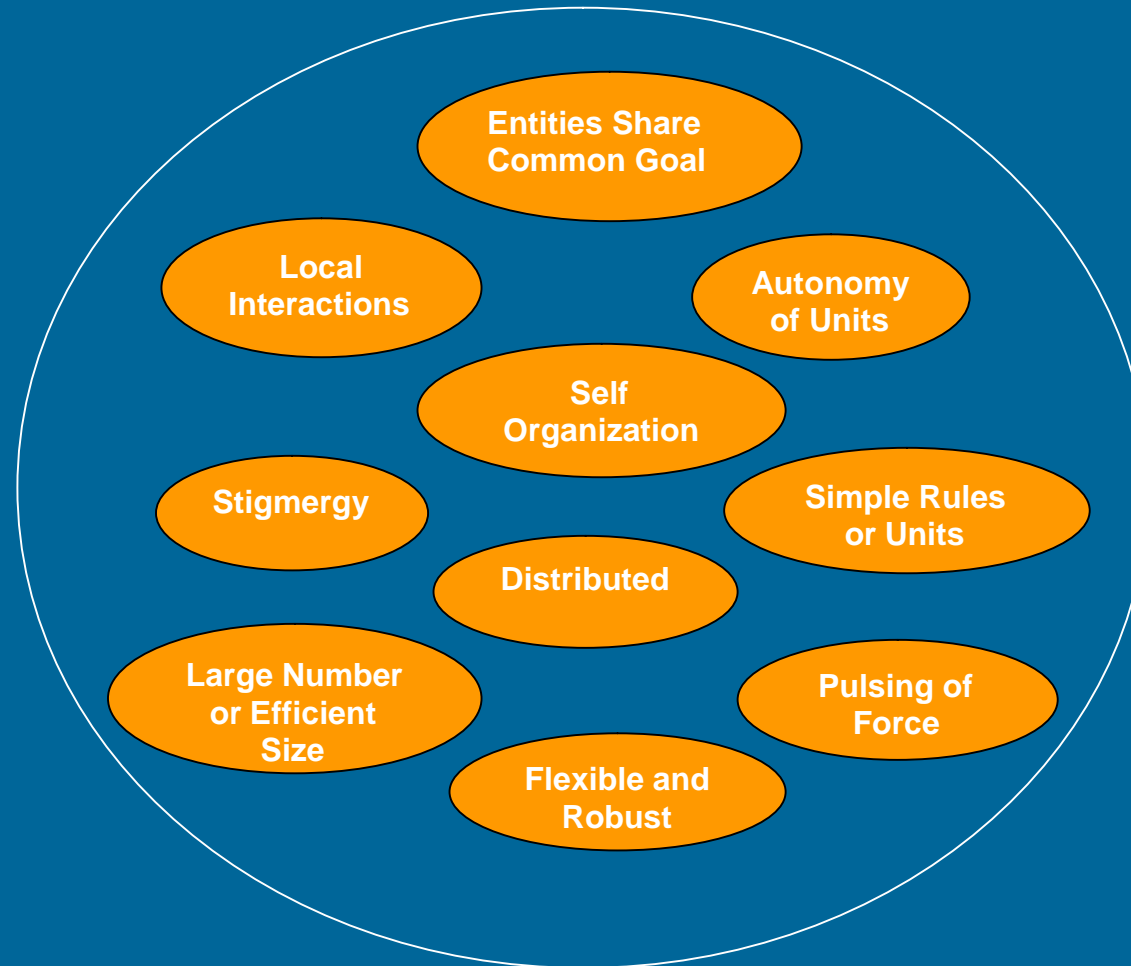


Agent Types

Evolution in Agent Paradigm: Reinforcement Learning & Genetic Algorithms



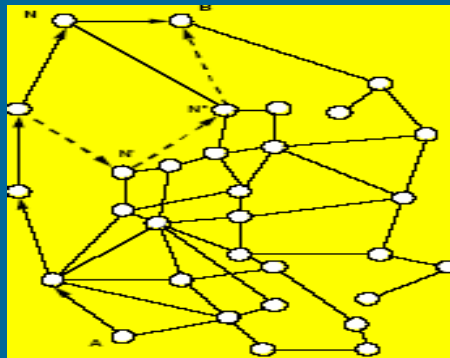
Swarm Intelligence Systems



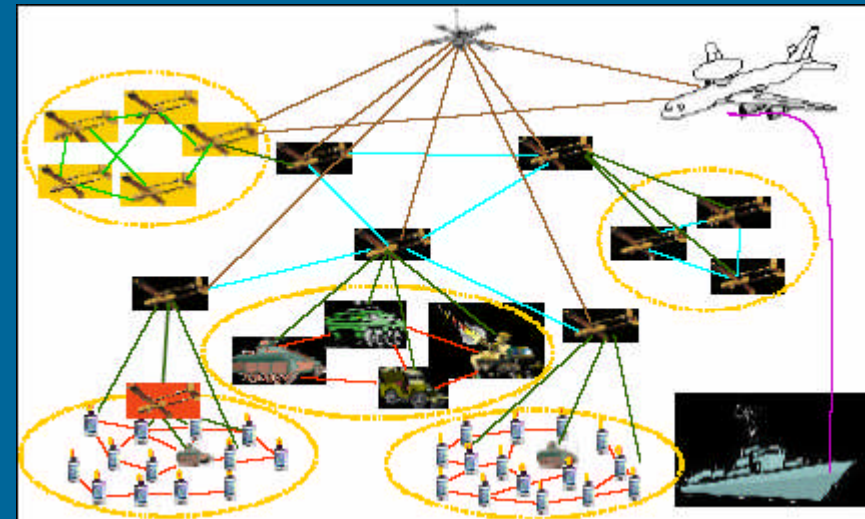
Swarm Systems and SoS Analysis



Collaborative Swarm Robots



Swarm Routing in Communication Networks

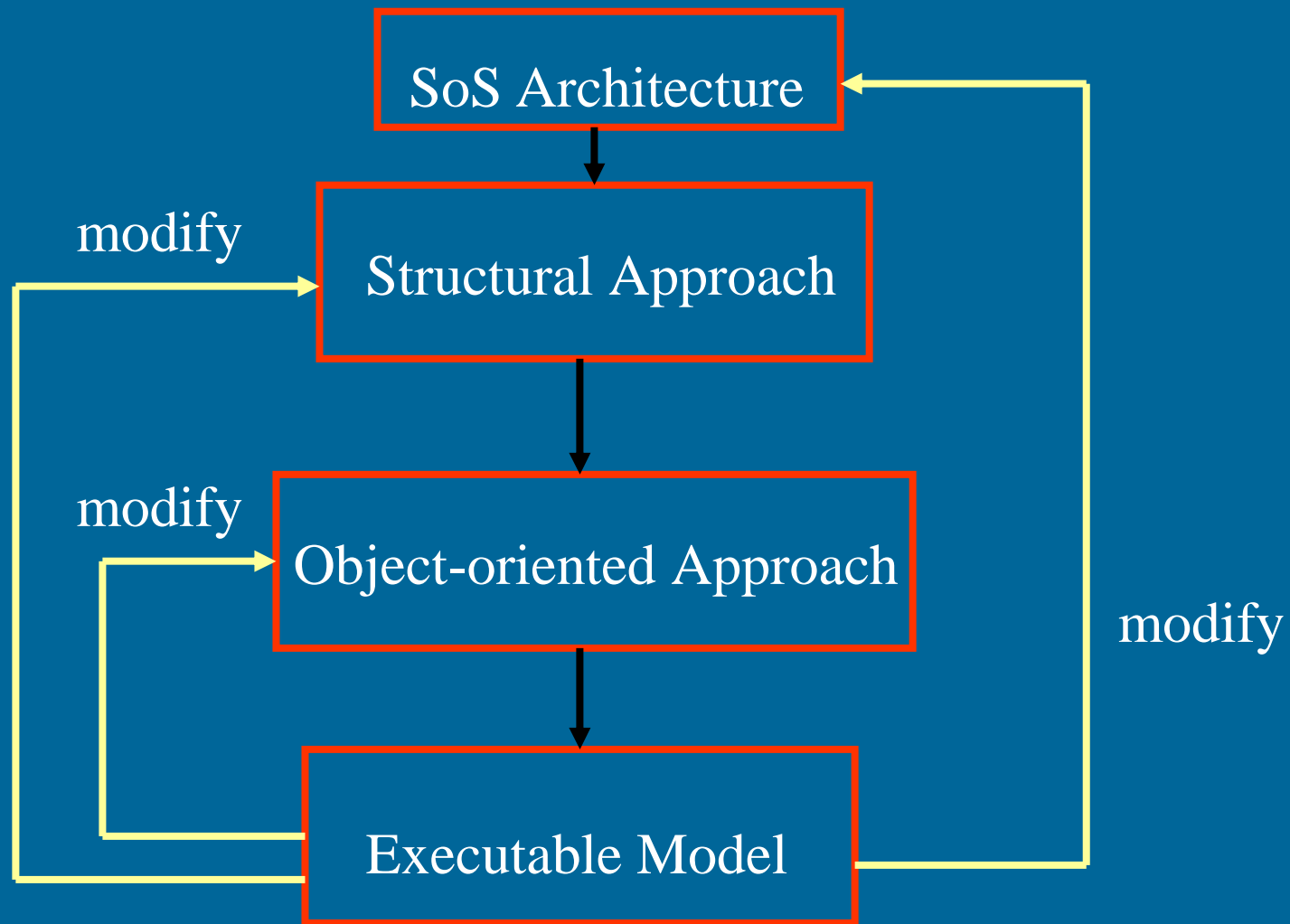


Military Swarm Scenario

Emergent Behavior Analysis of SoS Architectures

- Three step analysis
 1. Structural approach: Model and develop a common understanding platform for SoS using Department of Defense Architecture Framework (DoDAF)
 - Operational View
 - Systems View
 - Technical Standard View
 2. Object-oriented approach: Model and identify end users' requirements, states and sequence of events that system can undergo
 3. System behavior analysis: Use an executable model such as Petri-Nets for architecture evaluation and validation

Emergent Behavior Analysis of SoS Architectures



Areas Computational Intelligence Tools can help SoS architects

- Each architecture provides a compromise between four attributes: system cost, schedule, system risk and system performance
- The role of computational intelligence tools is to aid SoS designers in critical technical analysis:
 - Decision aiding algorithms
 - Testing and validating as well as development of
 - Command and control architecture
 - Communication links
 - Logistic infrastructure
 - Common architectures/modules
 - Sensor technology
 - Platform capabilities

Methodology customization for SoS analysis

- New modeling and simulation algorithms based on biologically inspired approaches should be added to systems engineer's tool box to cope with modeling and analyzing emerging systems.
- Ability to learn and evolve new architectures from the previously generated ones, based on systems performance values, need to be incorporated in modeling and simulation process.

Methodology customization for SoS analysis

- DoDAF architectural framework should be modified for commercial SoS
- Both structural and object-oriented analysis is required for comprehension of SoS
- Simulation tools that combine various modeling paradigms (discrete, agent-based, system dynamics) should be used in analysis of SoS to capture different behavioral views

Methodology customization for SoS analysis

- Supervised learning technique cannot handle rapidly evolving SoS.
- A supervised learning assisted reinforcement learning architecture is more suitable for modeling data prediction and analysis in SoS.
- Therefore, Adaptive Critic Designs and Q-learning will be considered as potential reinforcement learning candidates.
- After sufficient coarse learning, fine learning is applied which employs reinforcement learning algorithms.
- RL agent will model system evolution

Conclusions

- Modeling and simulation for generating architecture alternatives is essential.
- Classical systems engineering practices, modeling and simulation approaches need to evolve to cope with system of systems.
- New engineering tools are required to complement the existing ones for modeling and simulation and automatic architecture generation.

Conclusions

- Computational intelligence tools help in creating the desired behavior for the SoS

Questions?

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