   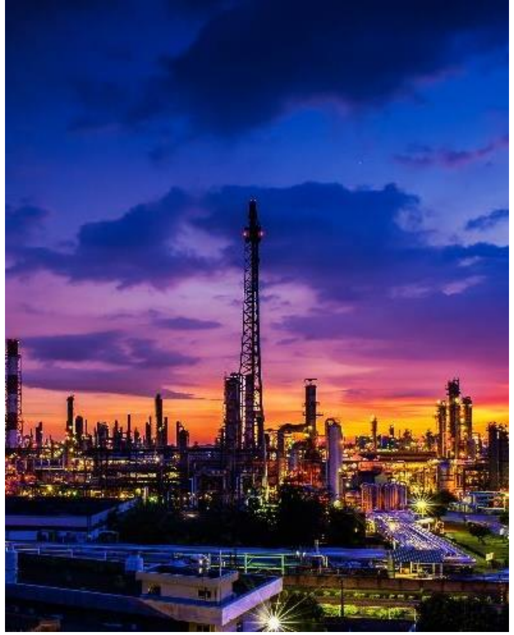 

REINFORCEMENT LEARNING FOR EMERGENT BEHAVIOR EVOLUTION IN COMPLEX SYSTEM-OF-SYSTEMS

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Honeywell | Aerospace
THE POWER OF CONNECTED

PRESENTATION OUTLINE

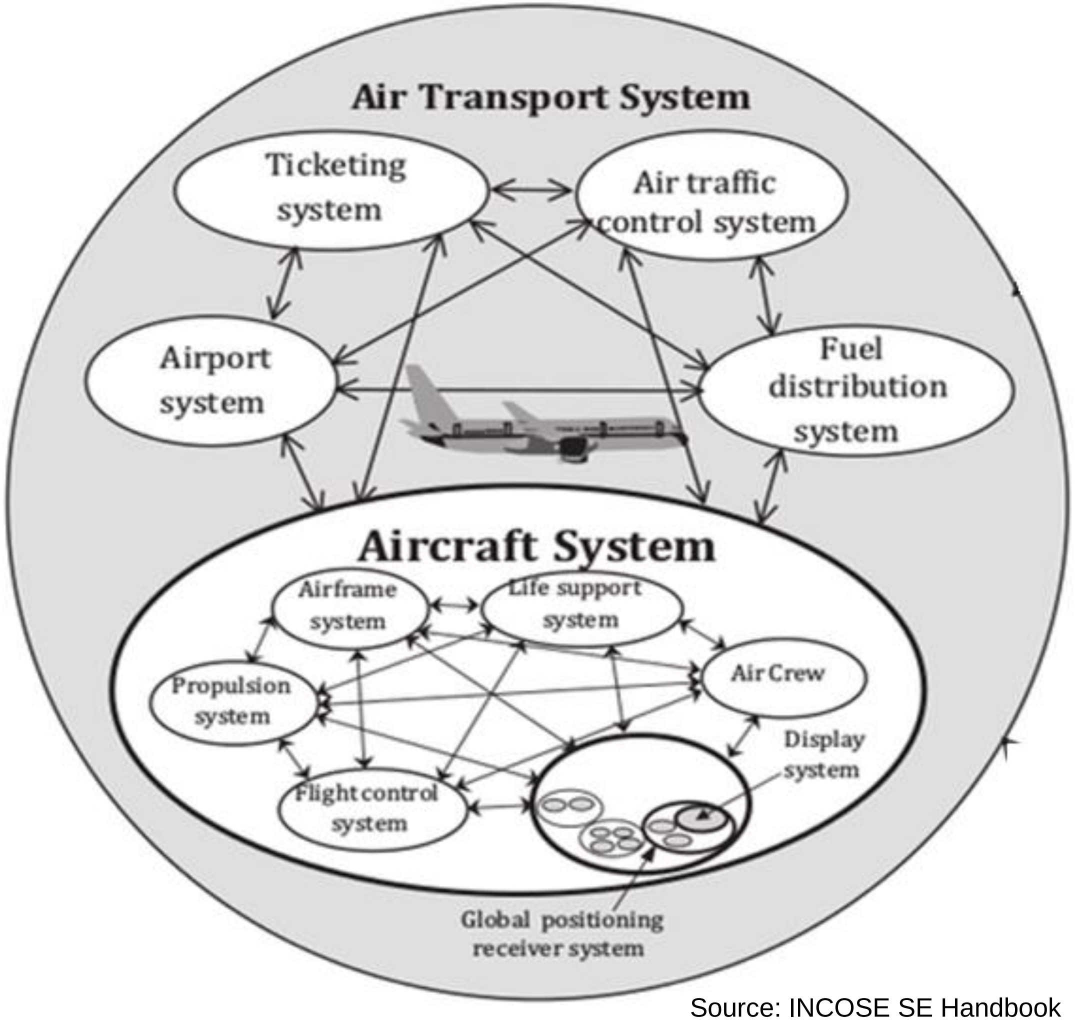
1. **System of Systems**
   - Introduction
   - Measures of Effectiveness
   - Emergent Behavior
   - Autonomous Systems
2. **Proposed Approach**
   - Reinforcement Learning
3. **Illustration and Implementation**
4. **Results**
5. **Conclusion and Future Steps**

SYSTEM-OF-SYSTEMS (SoS) - INTRODUCTION

- System-of-Systems are systems-of-interest whose system elements are themselves systems - they typically entail large-scale inter-disciplinary problems involving multiple, heterogeneous and distributed systems

- Each system has an independent purpose and viability, in addition to the SoS by itself having an independent purpose and viability

- Typically entail large scale interdisciplinary problems involving multiple, heterogeneous, distributed systems

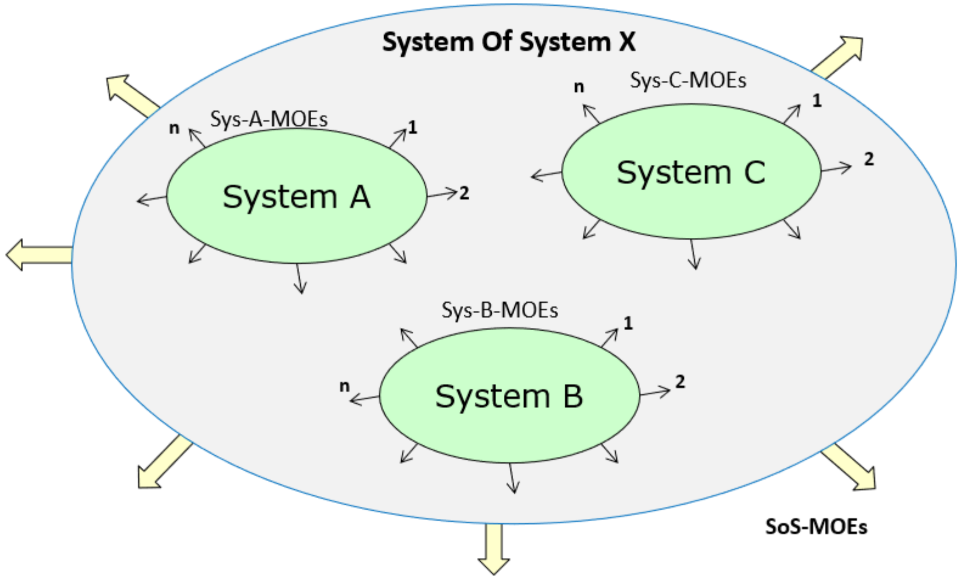


Source: INCOSE SE Handbook

Image Credit: https://www.quora.com/How-would-you-define-a-system-in-perspective-of-Industrial-Systems-Engineering

MEASURES OF EFFECTIVENESS

- Metric to evaluate achievement of the objective
- Manifest at the boundary of the system and SoS.



MOE Relationship Matrix

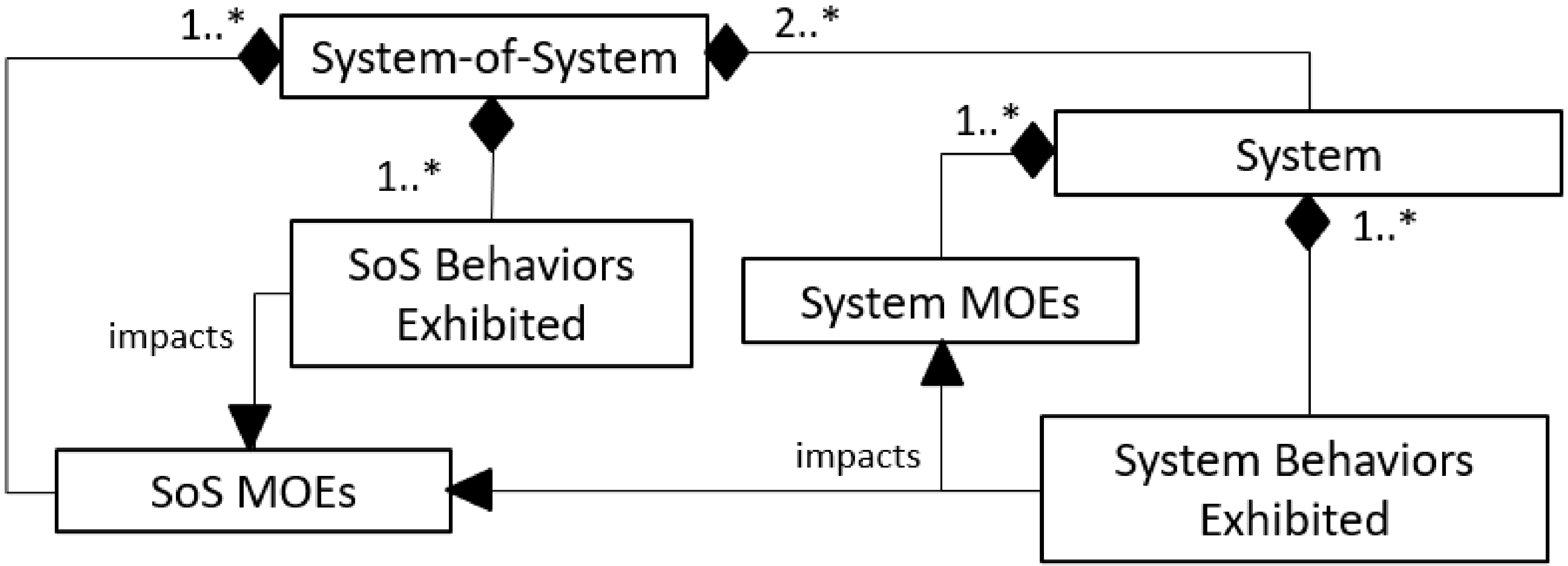
Relative importance of each SoS MOE

System Of System - MoEs	SoS MoE Weight	SysA-MoE-1	SysA-MoE-2	SysA-MoE-3	SysB-MoE-1	SysB-MoE-2	SysC-MoE-1	SysC-MoE-2
		MOEs of constituent Systems						
SoS-MoE-1	9	9	9	7				
SoS-MoE-2	7			5	7	7	7	
SoS-MoE-3	5	7	9	5				
SoS-MoE-4	1	9	9	7				7
	Raw score	125	135	130	49	49	49	7
	Relative Weight	21%	22%	21%	8%	8%	8%	1%
	Rank	3	1	2	5	5	5	8

Relative impact of each System MOE on each SoS MOE

System A is a key player in the SoS

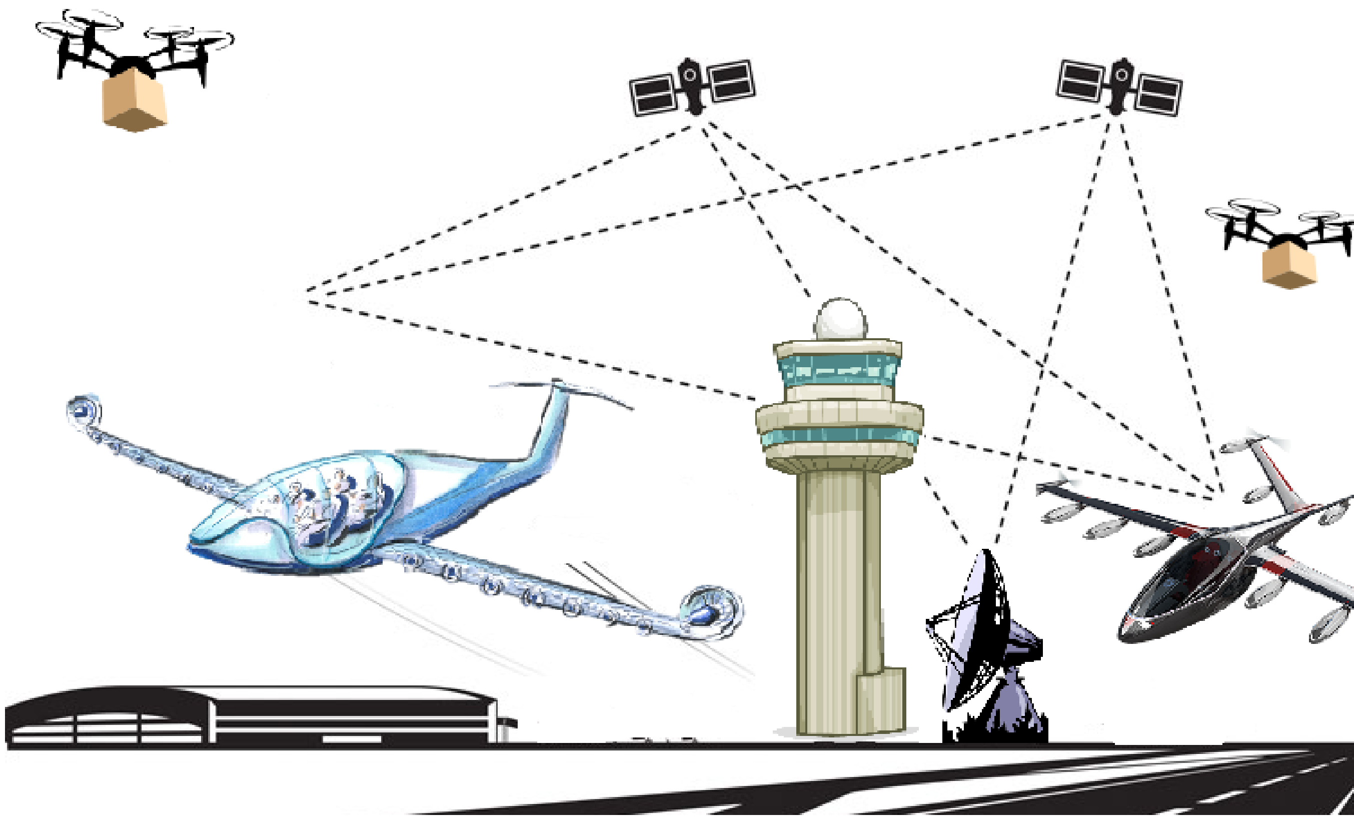
COMPLEX SOS – EMERGENT BEHAVIOR



Emergence refers to the ability of a system to produce a highly-structured collective behavior over time, from the interaction of individual subsystems

AUTONOMOUS SYSTEMS

- Numerous increasingly autonomous systems developed independently.
  - Example: Drones, Urban Air taxi…
- Use AI/Machine Learning techniques
- Currently, their goals are tied to their own mission.



How to develop autonomous systems that optimally balance SoS-level and System-level MOEs?

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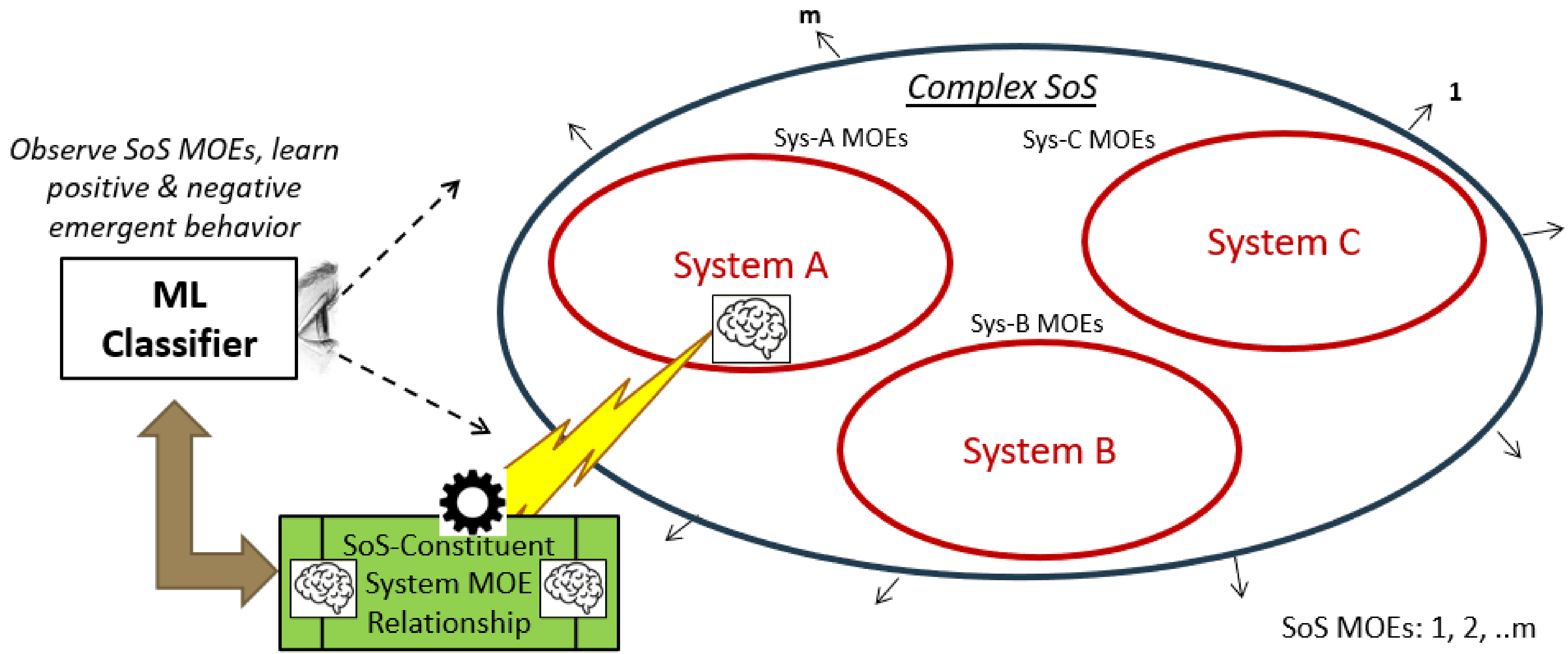
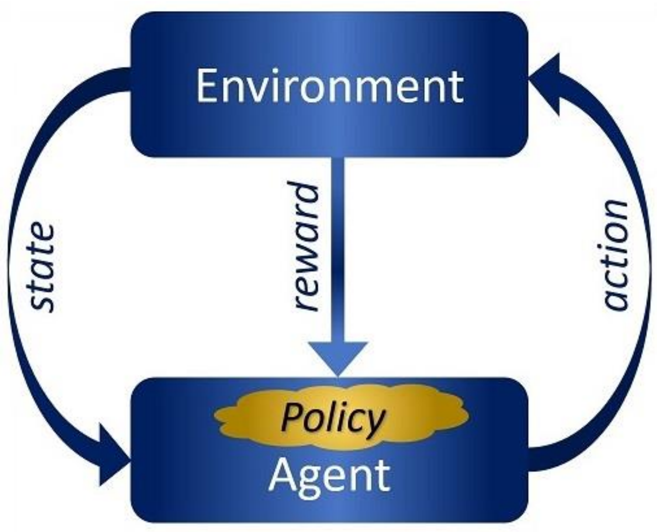
APPROACH OVERVIEW



REINFORCEMENT LEARNING (RL)



- Agent “learns” an optimal policy by iteratively interacting with the environment
  - performing an **action** and receiving **reward** from the environment.

Design rewards using MOE Relationship Matrix

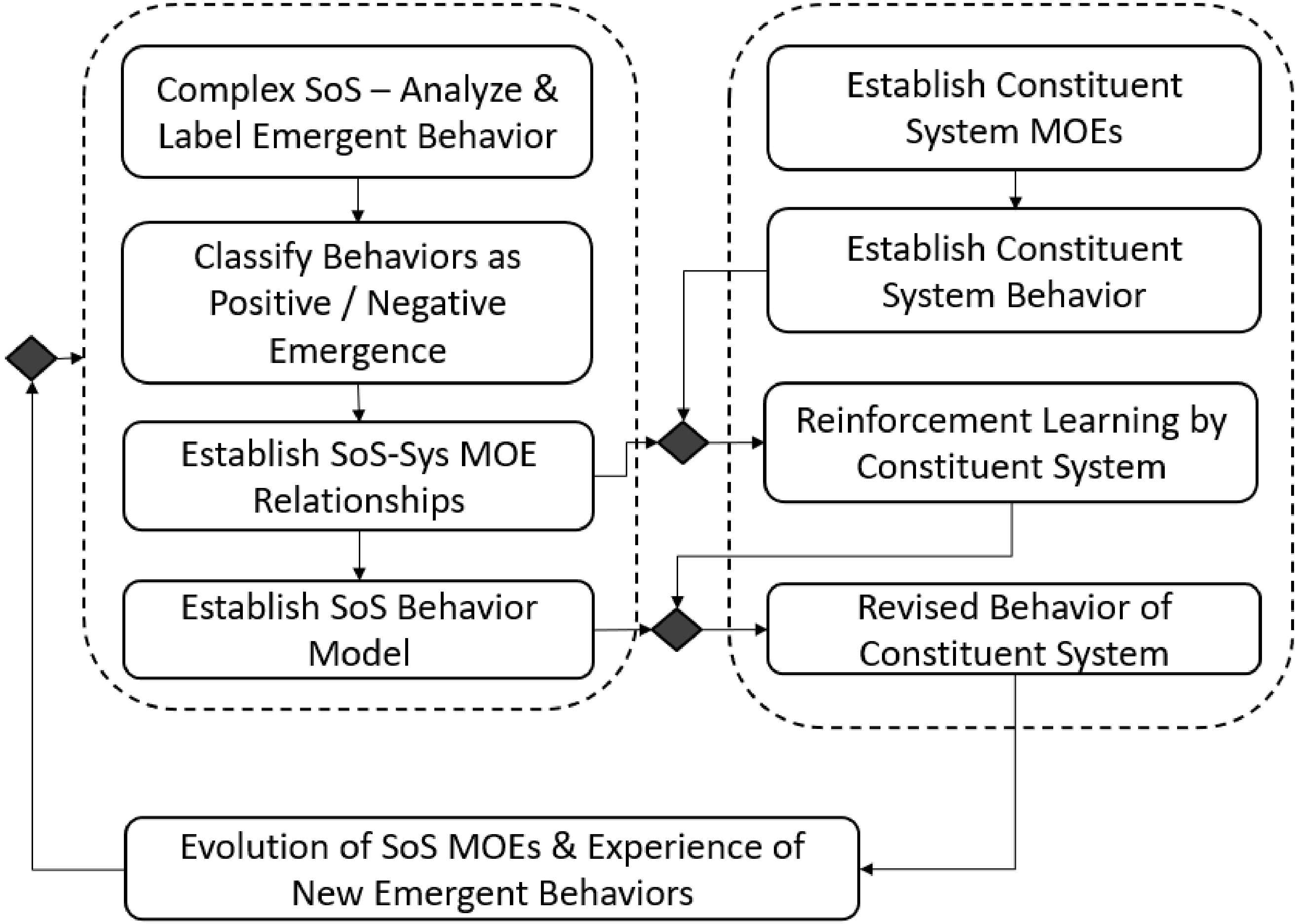
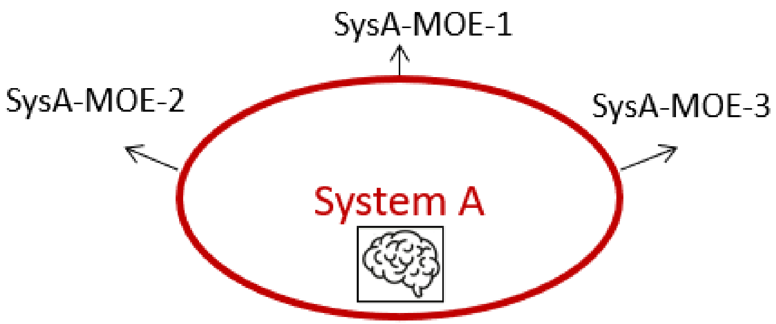


ILLUSTRATION & IMPLEMENTATION

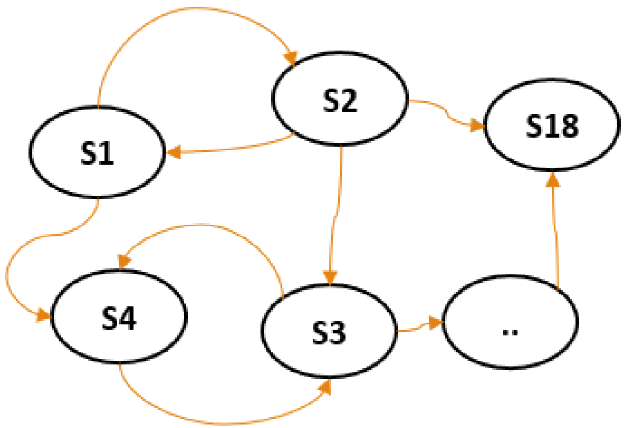


Levels of Performance of System-A in terms of MOEs

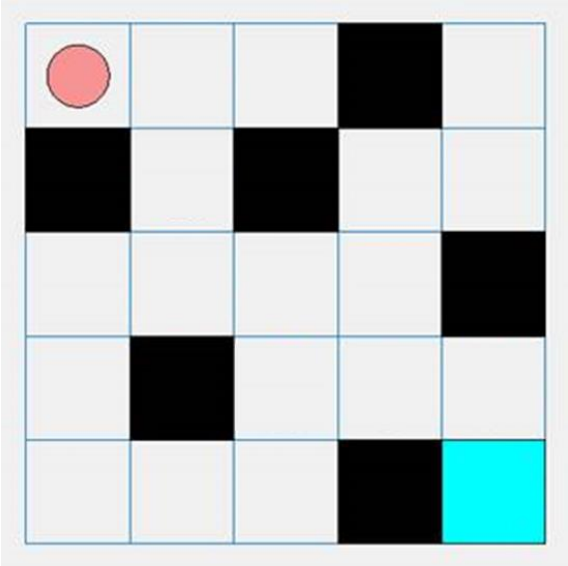
SysA-MOE-1	SysA-MOE-2	SysA-MOE-3
V1-1	V2-1	V3-1
V1-2	V2-2	V3-2
V1-3		V3-3

States as mapped to various performance levels of MOEs

STATES	SysA-MOE-1	SysA-MOE-2	SysA-MOE-3
S1	V1-1	V2-2	V3-1
S2	V1-2	V2-1	V3-3
S3	V1-3	V2-1	V3-2
…	…	…	…
S18	V1-3	V2-2	V3-3



State Transitions

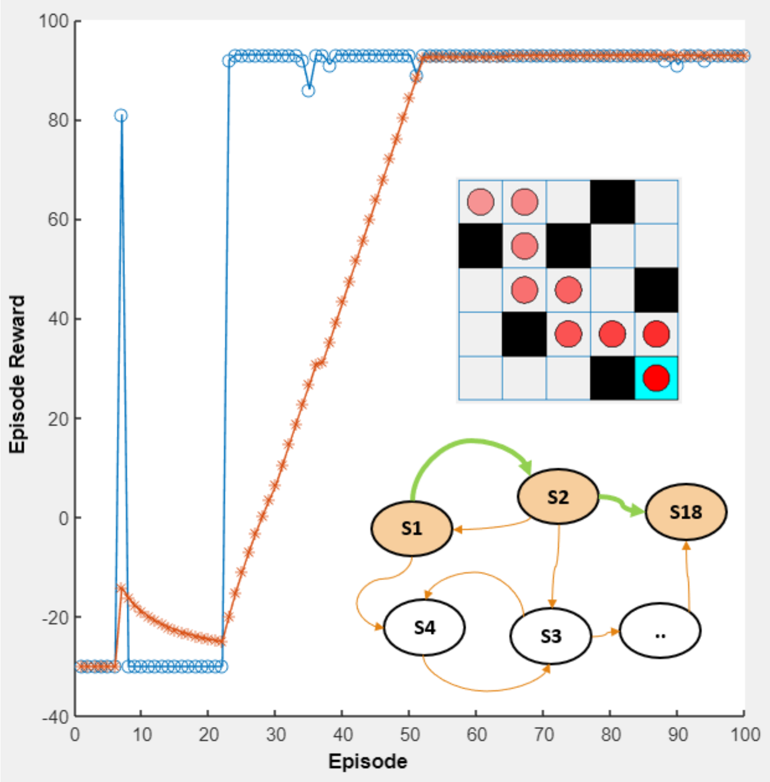


Grid World Environment in Matlab

RESULTS

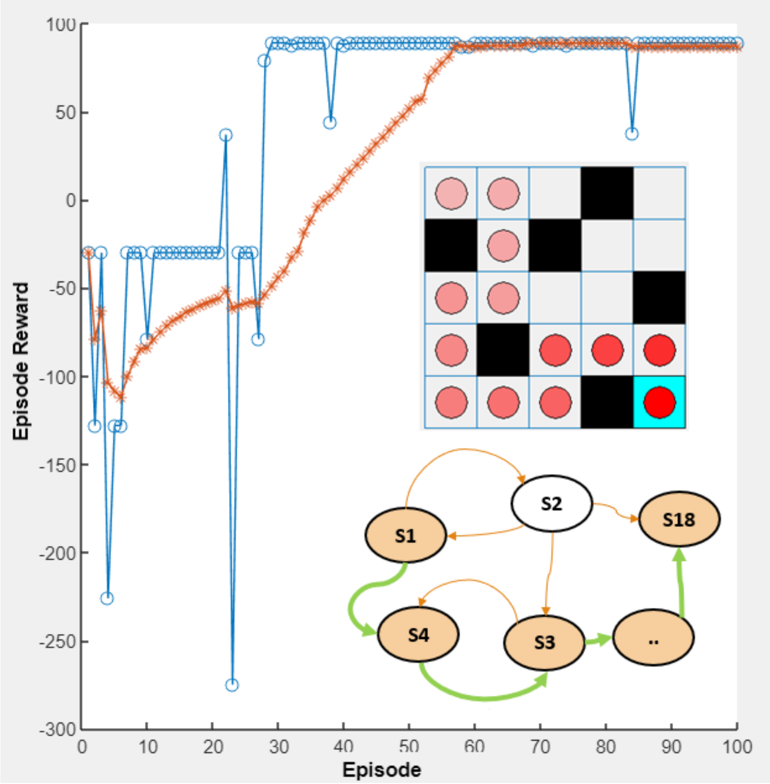
Case 1:

Learning based on system MOEs only (No SoS MOE)



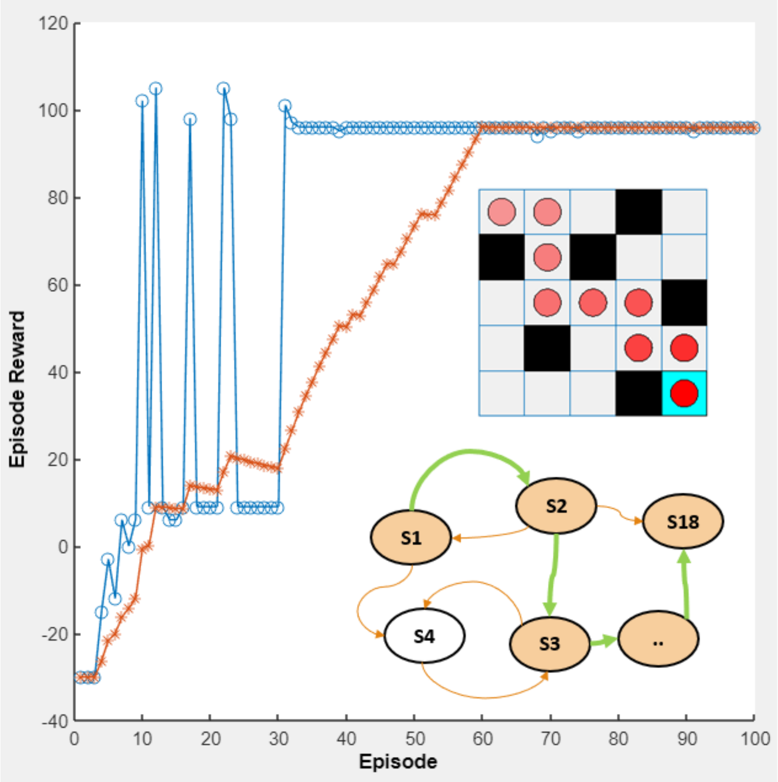
Case 2:

Learning based on system+SoS MOEs
Scenario: Low SoS MOEs for [3,3]



Case 3:

Learning based on system+SoS MOEs
Scenario: High SoS MOEs for [3,4]



CONCLUSION AND FUTURE STEPS

- Defined an approach to use RL for training systems of SoS using MOE Relationship Matrix
- Demonstrated the idea using a proof-of-concept application.
- Next Steps:
  - Analyze the scalability of our approach in more complex systems
  - Explore the use of deep RL algorithms

THANK YOU

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