SYSTEMS ENGINEERING Research Center
DEPARTMENT OF DEFENSE - UARC

MISSOURI S&T
Smart Engineering Systems Lab
Engineering Management and Systems Engineering Department

PENNSTATE 1855

AN ADVANCED COMPUTATIONAL APPROACH TO ACKNOWLEDGED SYSTEM OF SYSTEMS ANALYSIS & ARCHITECTING USING AGENT-BASED BEHAVIORAL MODELING

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Research Question

- How does the system behavior of the constituent systems affect the SoS development and the resulting SoS architecture?

Research Question (con't)

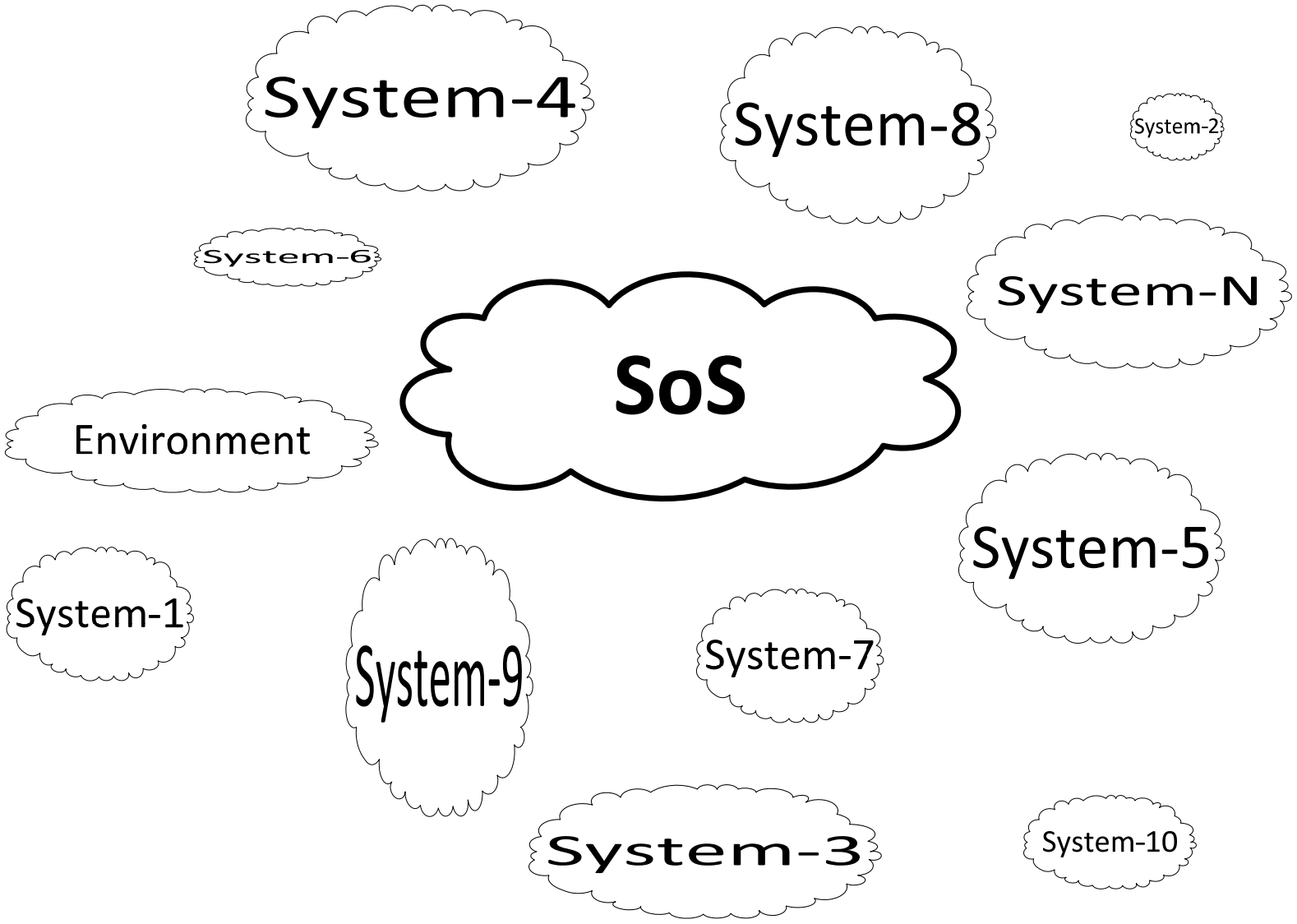
- Relationship between system behavior and length of the SoS development
- Relationship between the system behavior and the resulting SoS architecture
- Provide insight into SoS development to aid SoS manager in decision-making

Background

- System of Systems (SoS)
  - Arrangement of Systems*
  - Integrated Systems
  - Delivers Unique Capabilities
- SoS Architecture
  - Represents which systems are in the SoS
  - Represents which systems Interface

*Defense Acquisition Guidebook, May 2010.

Background (con't)



Background(con't)

- SoS Manager
  - Program Office
  - Organization
  - Might Not Exist
    - Presidential National Voice Conferencing (PNVC)
- SoS Critical in DoD
  - DoD Chief Information Officer
    - Information Support Plan

Background (con't)

- Types of SoS
  - Virtual
    - No SoS Manager
    - No Central Purpose
  - Collaborative
    - No SoS Manager
    - Systems Voluntarily Work Together

Background (con't)

- Types of SoS (con't)
  - Acknowledged
    - SoS Manager
    - SoS Capabilities Depend on System Cooperation
    - Systems Have Their Own Priorities, Goals
  - Directed
    - Centrally Located SoS Manager
    - Specific Purposes
    - Systems Exist to Fulfill SoS Specific Purposes

Background (con't)

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  - Acknowledged
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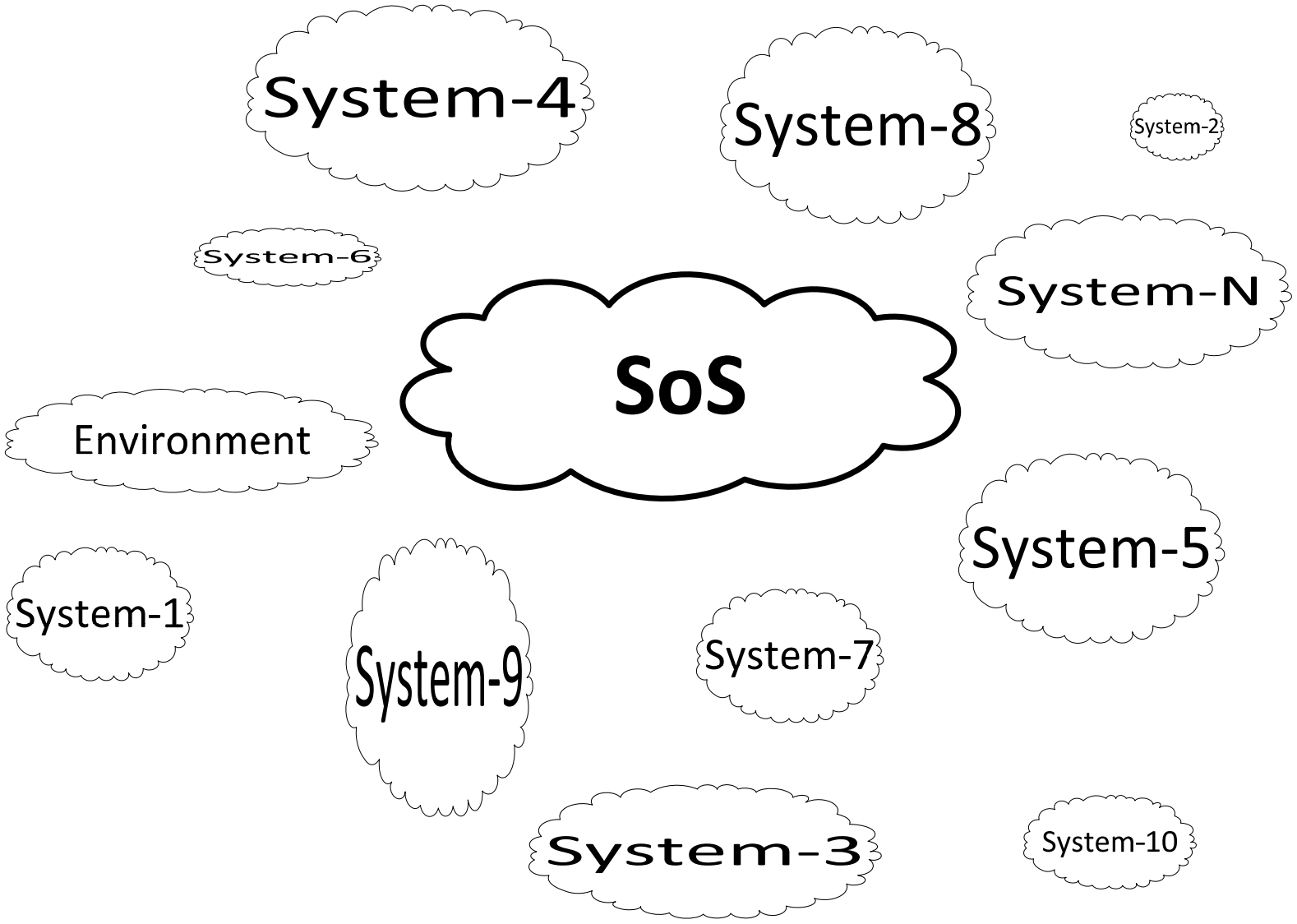
Background (con't)

- Agent-Based Model (con't)
  - Agents
    - Independent processes
    - Execute concurrently not serially
  - Relationships Between Agents
    - Interfaces
    - How Agents Interact
  - No Hierarchy, Flat Universe

Background (con't)



Research Objectives

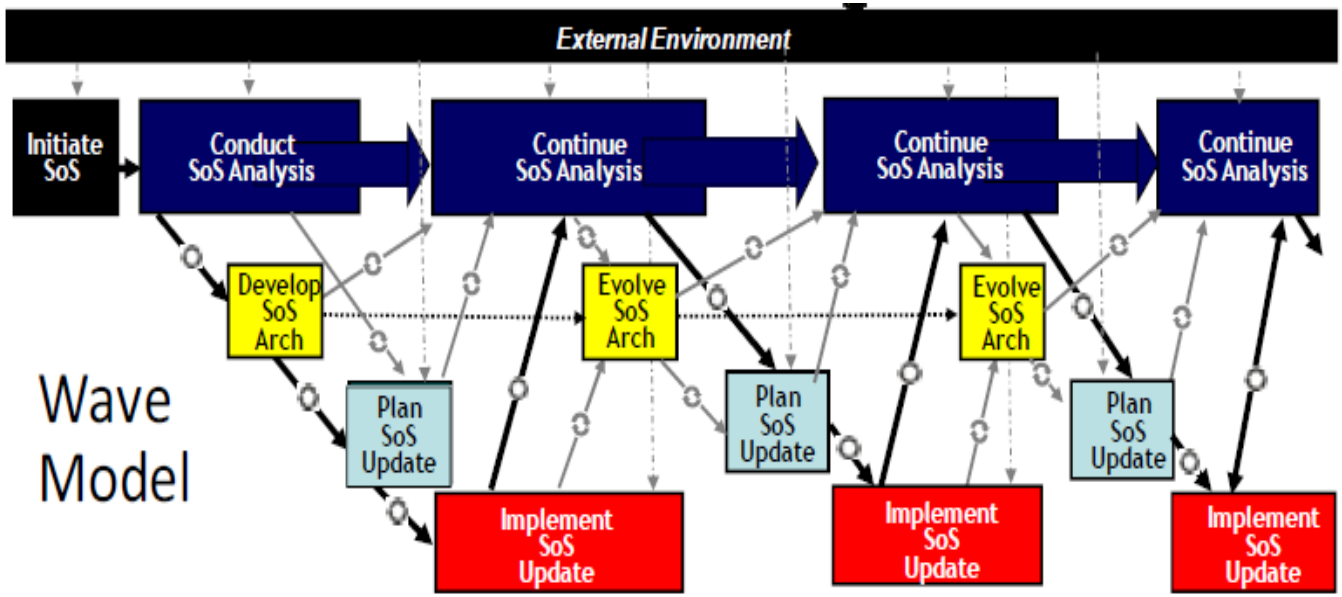
- Develop a Model for SoS Development
  - Represents the actual SoS Behavior
  - Applicable/Adaptable to Any Domain
- Support Overall Model of SoS Development
  - SoS Managers Use as Aid for SoS Development
  - Develop Conclusions About SoS Development
  - Perform “What if” Analysis

Research Steps

- Develop model that represents the SoS development
- Determine how to measure the length of SoS development
- Create a representation for the SoS behavior and the system behavior
- Assessment of SoS architecture

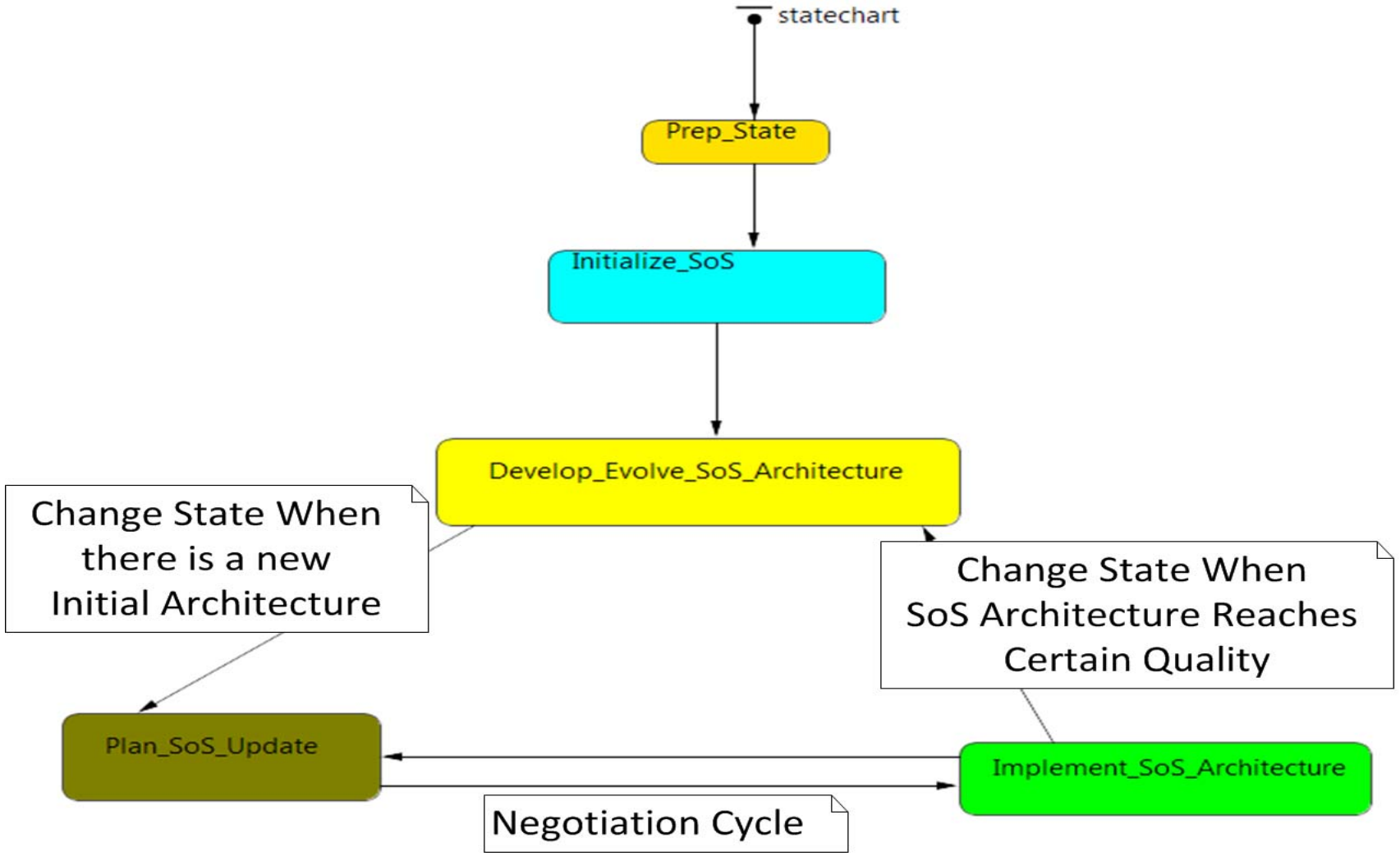
Research Steps (con't)

- SoS Development Cycle Based on Wave Model*



*Dahmann, J., Rebovich, G., Lane, J. A., Lowry, R., & . Baldwin, K. (2011). An Implementers' View of Systems Engineering for Systems of Systems. *Proceedings of IEEE International Systems Conference.* Montreal.

SoS Agent State Diagram



Approach

- Negotiation cycle exists between the SoS manager and the constituent systems
- Use the number of negotiation cycles as a measure of the length of the SoS development
- Use a SoS architecture to represent the capabilities at the SoS level
- Assess the SoS architecture to know when the SoS development ends

Assumption

- Goal of SoS development is providing the SoS capabilities to the warfighter in time to support the mission need
- Overall system behavior is the aggregate behavior of all the systems taken as a whole

Contribution

- Agent-Based Model (ABM) of System of Systems (SoS) Development
  - Generic Domain
  - Generic Initial SoS Architecture
  - Generic System Behavior
  - Generic SoS Behavior
- SoS Framework Adaptable to …

Contribution (con't)

- Agent-Based Model (ABM) of System of Systems (SoS) Development
  - Executable
  - Follows Wave Model
  - Integrates with Models developed in other tools such as Matlab

Contribution (con't)

- Fuzzy Decision Analysis for SoS Behavior
  - Fuzzy Negotiation Model
    - Uses Fuzzy Systems
    - Uses Fuzzy Associative Memory

Research Objectives

- Represent the SoS Development
  - Reflect Real SoS
  - Executable
  - Applicable/Adaptable to Any Domain

Research Objectives (con't)

- Represent the SoS Behavior
  - Actions/Decisions of Acknowledged SoS During Negotiation with Systems
  - Fuzzy Assessor to Qualitatively Evaluate SoS Architecture
- SoS Negotiation Model
  - Interact with Systems for Capabilities

Research Objectives (con't)

- Support DoD Movement Toward SoS
  - Use as Aid for SoS Development
  - Develop Conclusions About SoS Development
  - Perform "What if" Analysis

SoS Development Model (con't)

- Agent-Based Model Representing SoS Development
- Two Agents
  - SoS
  - System

SoS Development Model (con't)

- One Instance of SoS Agent
- Multiple Instances of System Agent
  - Depending on Number of Systems in SoS
  - Systems are Independent Entities
    - Goals
    - Priorities
    - Behavior

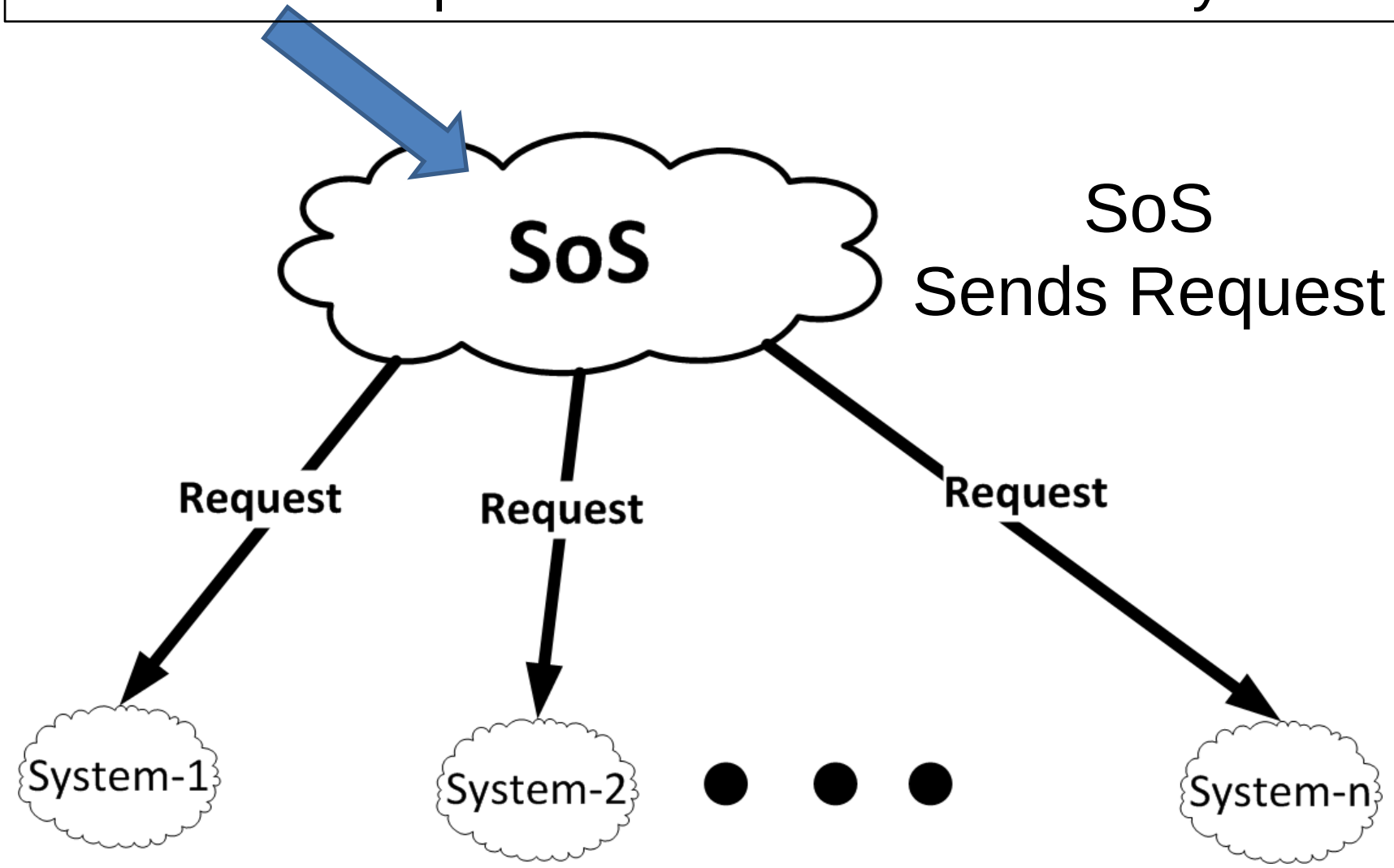
SoS Development Model (con't)

- SoS Depends on What Systems Provide
- SoS Influence Systems
  - Funding
  - Adjust Deadlines
  - Adjust Performance

SoS Development Model (con't)

- Each Instance of System Agent
  - Independent Behavior
  - Negotiation Model
    - Developed independently of the SoS Negotiation Model
  - Can use any type of Negotiation Model

Initial Set of Capabilities Desired from the Systems

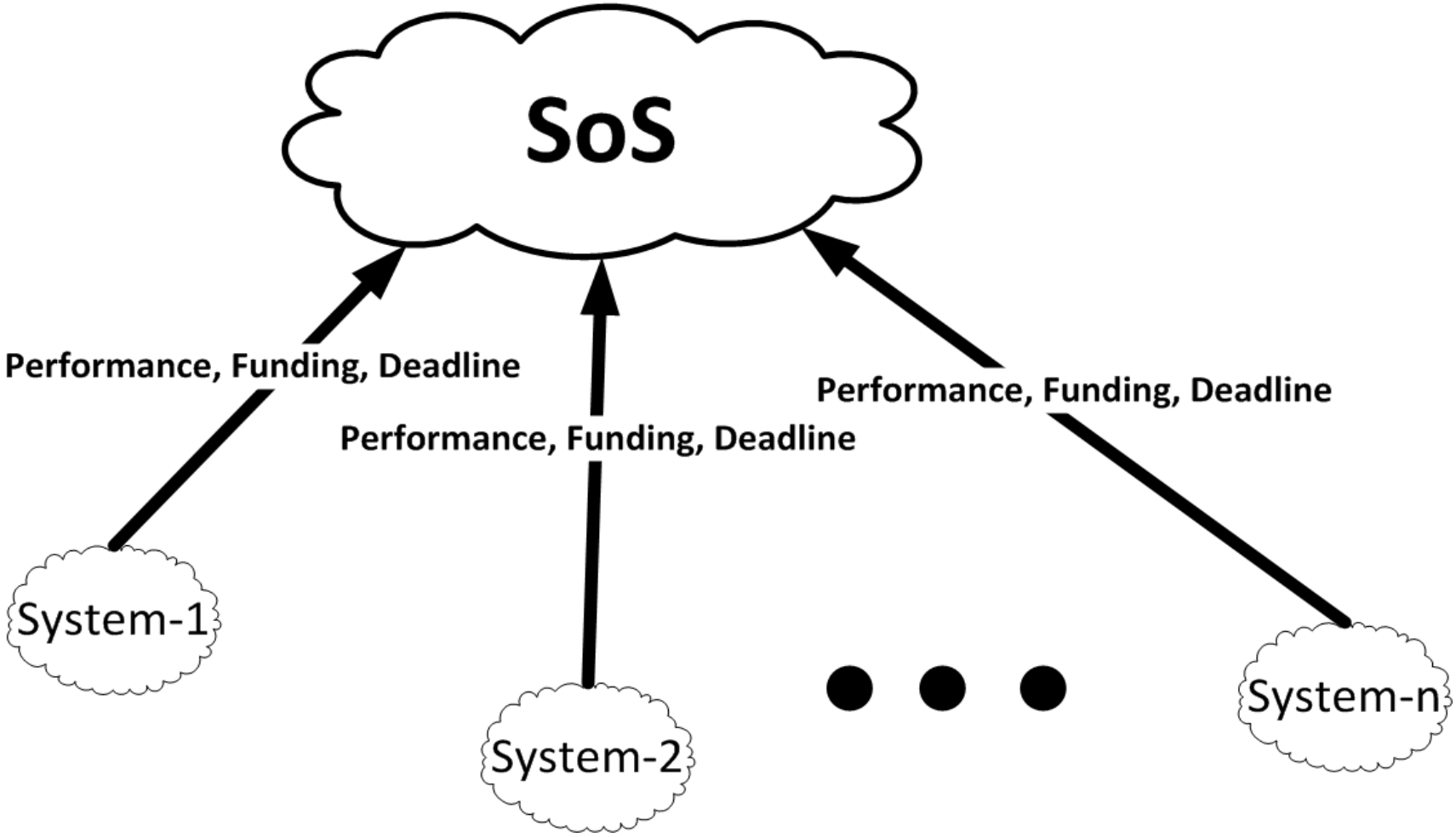


SoS
Sends Request

System Agent

- Evaluates Request from SoS
- Priorities and Deadlines
- Independent Behavioral Model
  - Each system can have a different model
- Responds to SoS with Participation Criteria
  - Delta Performance
  - Delta Deadline
  - Delta Funding

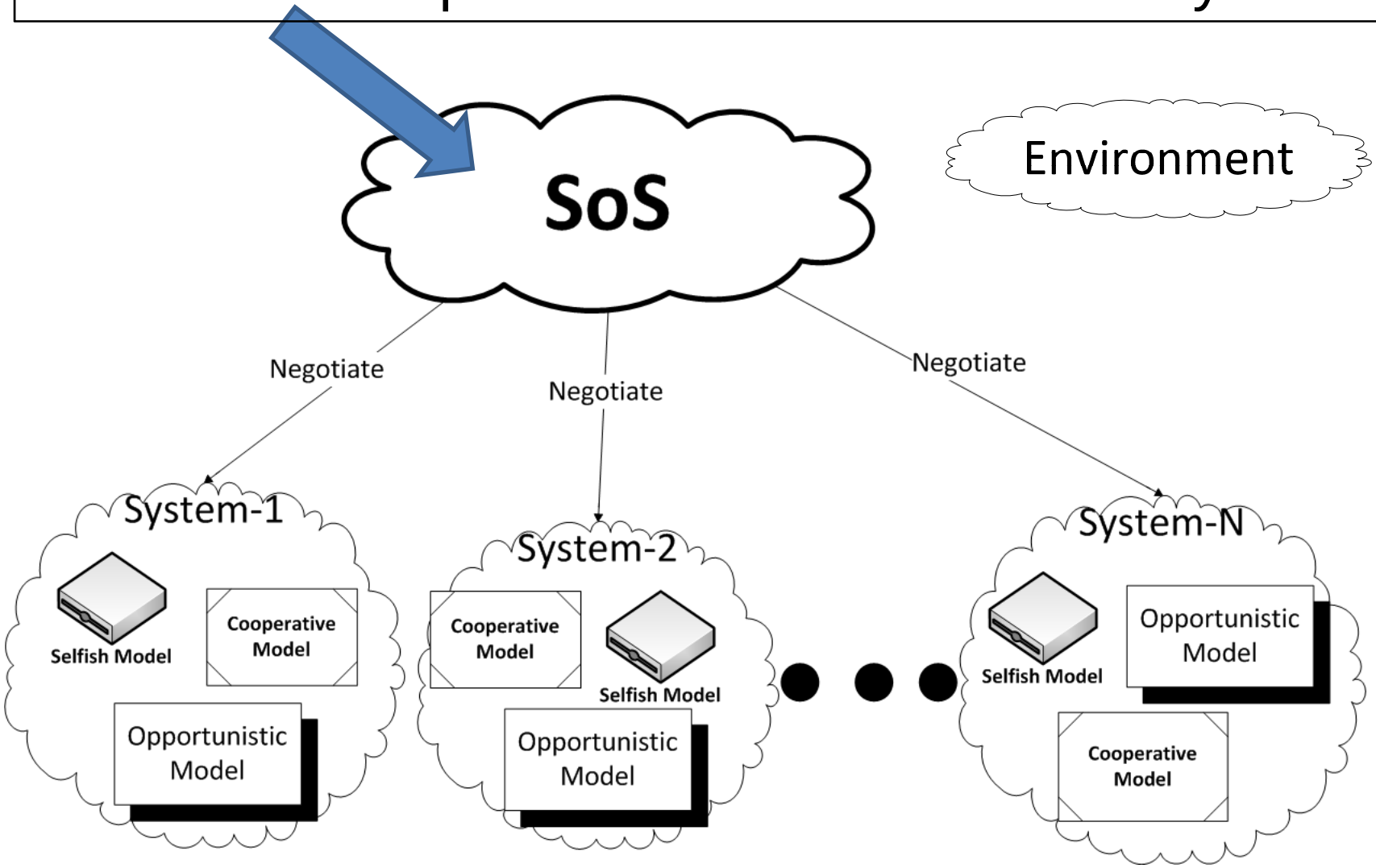
Systems' Response



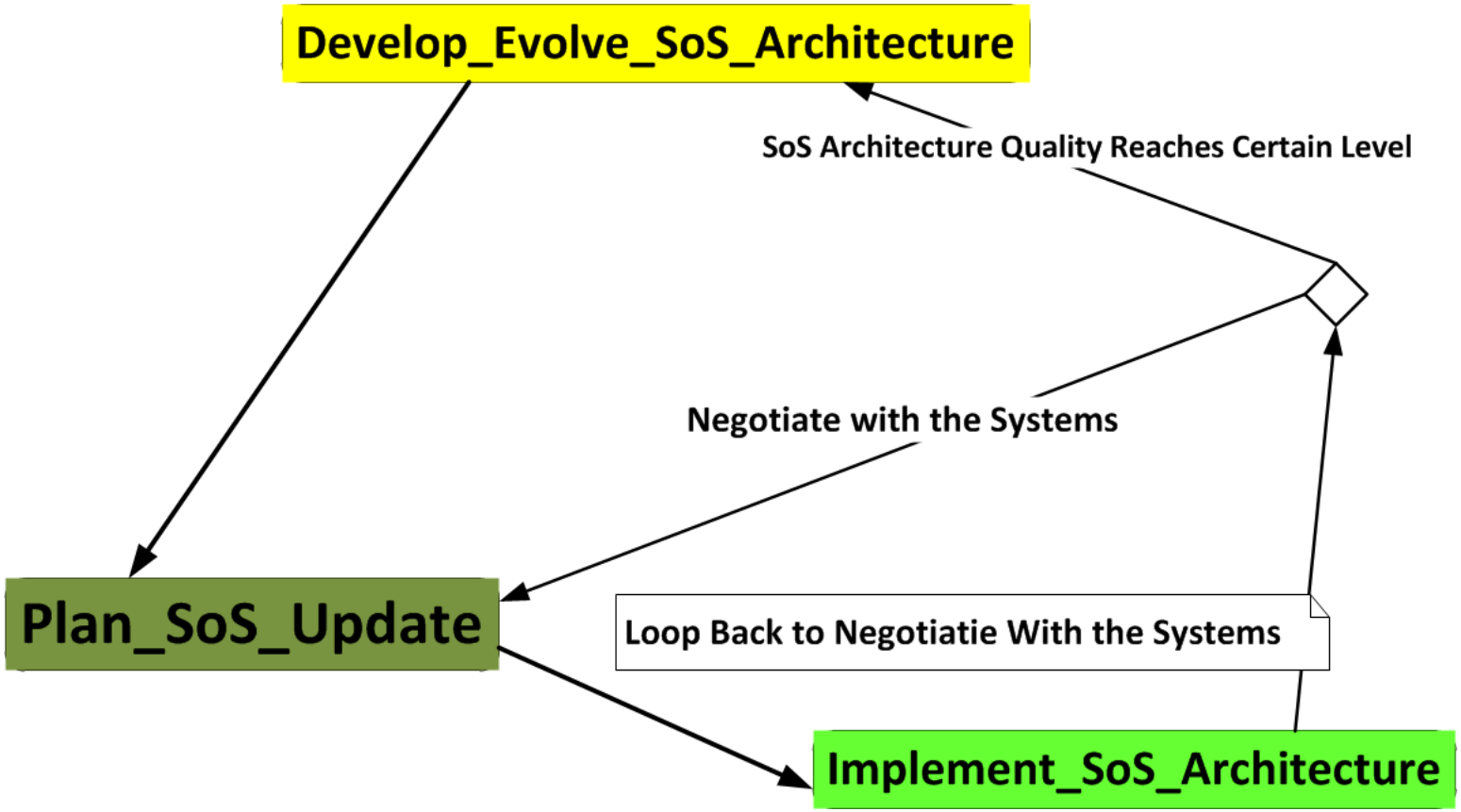
SoS Negotiation

- Fuzzy Decision Analysis
- Fuzzy Negotiation

Initial Set of Capabilities Desired from the Systems



SoS Negotiation Model



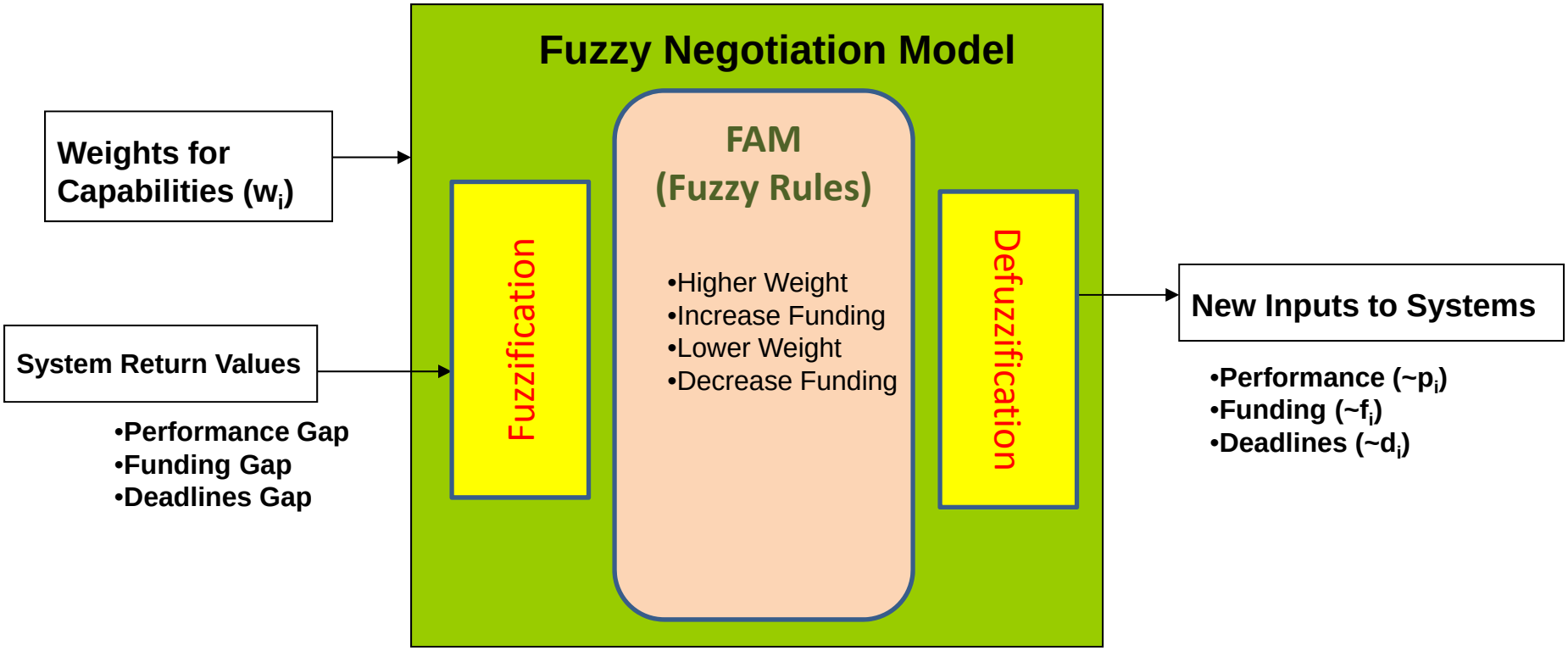
Fuzzy Decision Analysis

- Fuzzy Negotiation Model
  - Fuzzification of Crisp Values
  - Fuzzy Rules in Fuzzy Associative Memory
  - Fuzzy Output
  - Defuzzification to Crisp Value

Fuzzy Negotiation

- Determine Actions
  - Inputs:
    - Delta Performances, Delta Funding, Delta Deadlines
    - Weights for Each Capability
  - Outputs:
    - Funding Adjustment
    - Deadlines Adjustment
    - Performance Adjustment

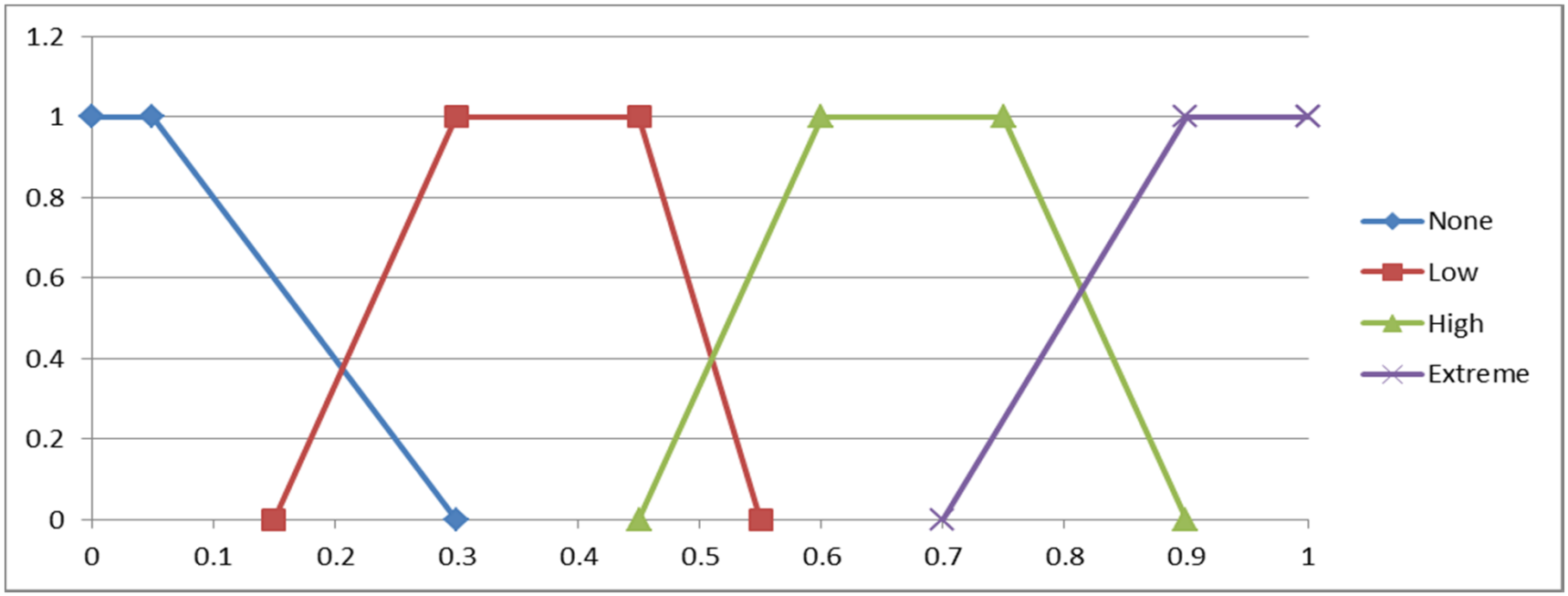
Fuzzy Decision Analysis



Fuzzification of Gap Values

	None	Low	High	Extreme
Performance Gap	0	< 2	< 7 and > 2	> 7
Funding Gap	0	< 3.5	< 6.5 and > 3.5	> 6.5
Deadline Gap	0	< 2	< 8 and > 2	> 8

Funding Gap Membership Function



Fuzzy Rules

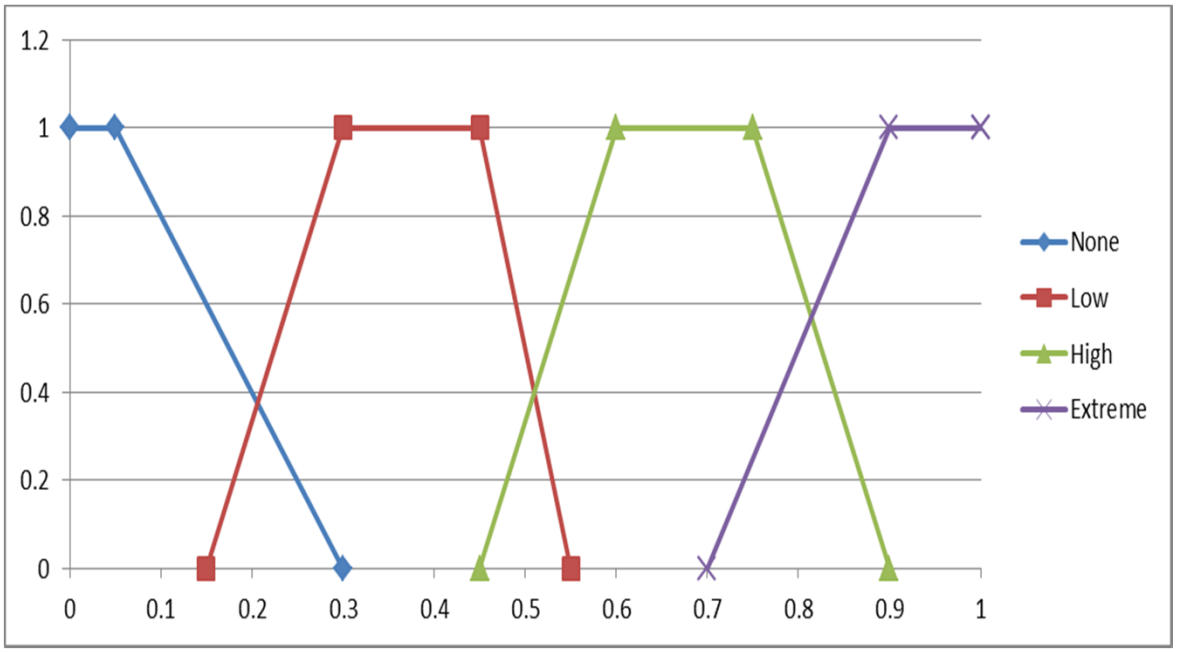
Inputs				Outputs	
Performance Gap	**Weight**	**Funding Gap**	**Deadline Gap**	**Funding**	**Deadline**
none	none	none	none	decrease little	do nothing
low	none	none	none	do nothing	shorten
high	none	none	none	increase little	extend
extreme	none	none	none	increase little	big delay
none	low	none	none	decrease little	do nothing
low	low	none	none	do nothing	shorten
high	low	none	none	increase little	extend
extreme	low	none	none	increase little	big delay
none	high	none	none	do nothing	do nothing
low	high	none	none	do nothing	do nothing
high	high	none	none	increase much	do nothing
extreme	high	none	none	increase much	do nothing
none	heavy	none	none	do nothing	do nothing
low	heavy	none	none	increase little	do nothing
high	heavy	none	none	increase much	do nothing
extreme	heavy	none	none	increase much	do nothing

Implementation

- Fuzzy Rules Implemented as Fuzzy Associative Memory (FAM)
- Represent Each Fuzzy Linguistic Value as Integer
- FAM is Multi-Dimensional Array
  - Indexed by Fuzzy Linguistic Value
  - Output is Fuzzy Linguistic Value

Map Funding Gap Fuzzy Values

- Funding Gap Enumerated Type:
  - None
  - Low
  - High
  - Extreme



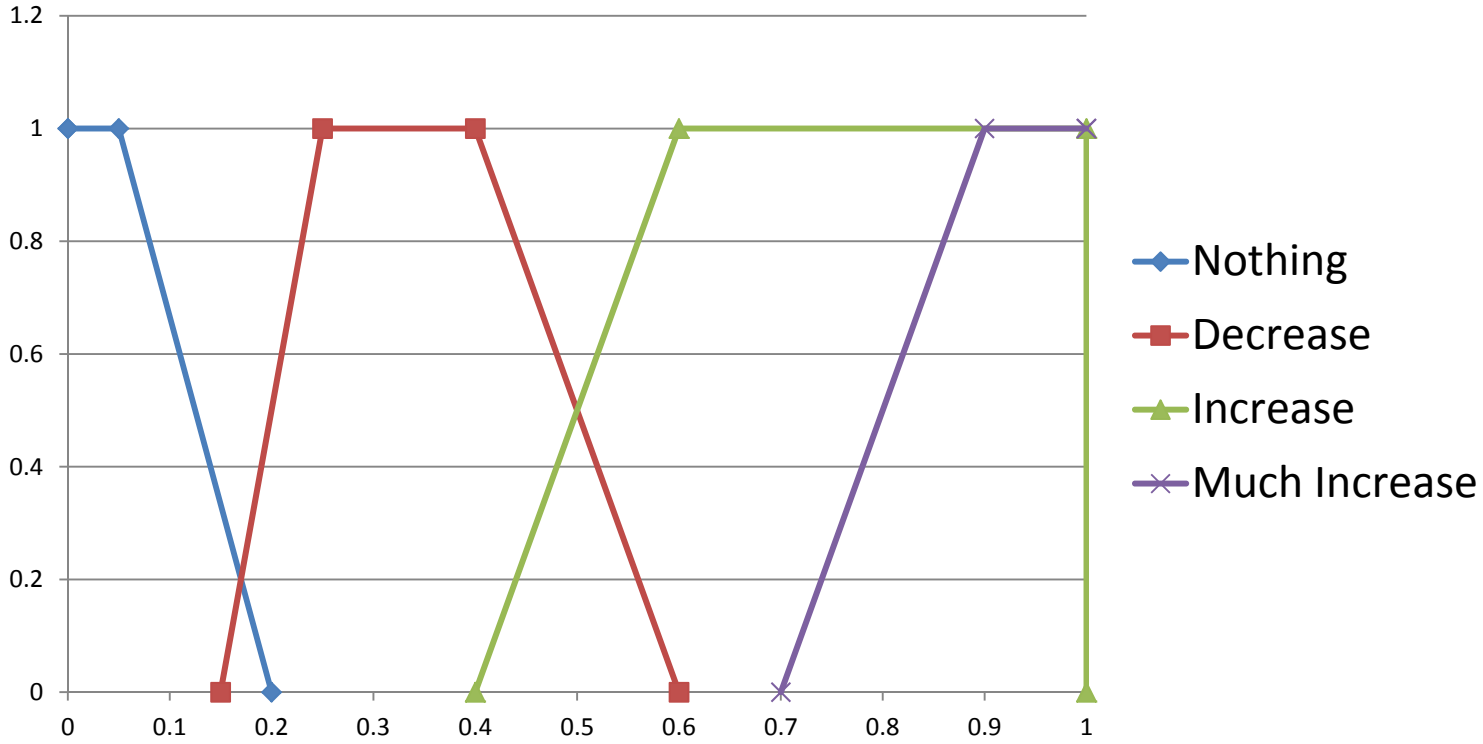
Index into FAM

- If Performance Gap=High, Weight=Heavy, Funding Gap=None, then Output=Increase Funding Much

Output = FAM[High, Heavy, None] = Increase Much

Adjust Funding Output

- Output is Much Increase

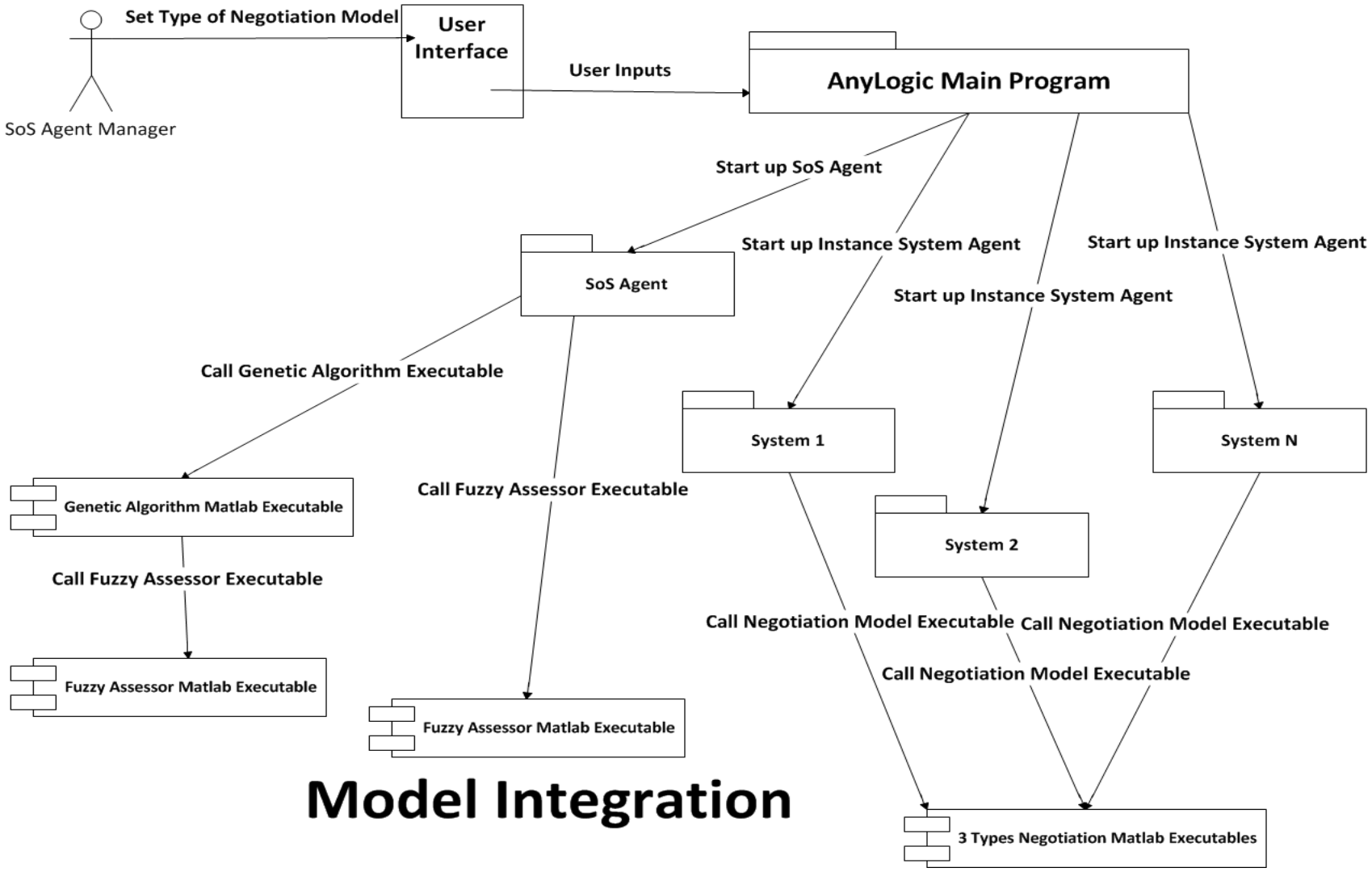


Implementation (con't)

- FAM Read from Excel File at Initialization
- Fuzzy Rules in Excel File
- Model Independent of Fuzzy Rules
  - Simulation can be run multiple times with different fuzzy rules
  - Possible to have the model update rules as simulation runs

Integration

- SoS development model can invoke multiple models
  - Model to generate the initial SoS architecture
    - E.g. genetic algorithm developed in MATLAB
  - Architecture assessor
  - System behavior model
  - SoS behavior Model



Model Integration

Integration (con't)

- Generic SoS development model
  - Independent of SoS and system behavior models
  - Can use different system behavior models
  - No Need to Rebuild for Different Domains
    - Domain details are in Excel files

Conclusions

- SoS development model exists
  - Generic to any domain
  - Provides insight into the SoS development to support SoS decision-making
  - Flexible to use any SoS or system behavioral models
- Currently running multiple levels of system cooperation and collecting data

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Questions

Backup

Fuzzy Systems

- Fuzzy Sets
  - Opposite of Traditional (Crisp) Set
  - Provides Method of Handling Ambiguity
  - Degree to Which Each Element is Member
  - Two Parts to Fuzzy Set:

Membership Function

Membership Grade

Fuzzy Systems

- Fuzzy Sets (con't)
  - Two Parts to Fuzzy Set:

Membership Function

$$\mu: X \rightarrow [0,1]$$

Membership Grade

– Degree of Membership

Fuzzy Systems

- Fuzzy Sets (con't)
  - Fuzzy Set Operations
    - Addition/Union

$$\mu_{A\cup B}(x) = \mu_A(x) + \mu_B(x) = \max\{\mu_A(x), \mu_B(x)\}$$

    - Multiplication/Intersection

$$\mu_{A\cap B}(x) = \mu_A(x) * \mu_B(x) = \min\{\mu_A(x), \mu_B(x)\}$$

Fuzzy Systems (con't)

- Fuzzy Set Operations
  - Complement

$$\mu_{A'}(x) = 1 - \mu_A(x)$$

  - Alpha-Level

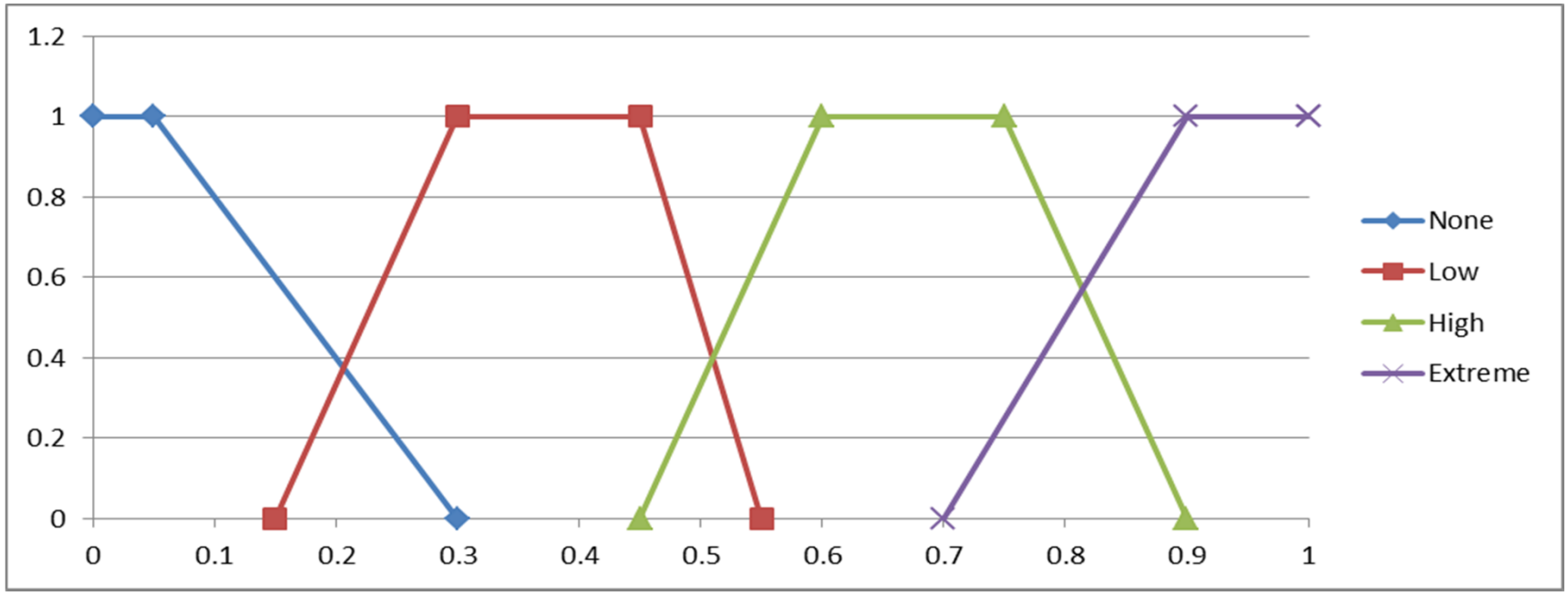
$$\{x \in X \mid \mu_A(x) \geq \alpha\}$$

Fuzzy Systems (con't)

- Fuzzy Sets (con't)
  - Linguistic Variables
    - Words
    - Phrases
    - For Example:
      - Very Tall
      - Tall
      - Medium
      - Short

Fuzzy Systems (con't)

- Fuzzy Sets (con't)
  - Deadline Gap Fuzzy Membership Function



Fuzzy Systems (con't)

- Fuzzy Inference Engine
  - Fuzzy Rules:
    - If Deadline Gap=High, Weight=Heavy, Funding Gap=None, then Output=Increase Funding Much

Future Work

- Develop Intelligence Model
  - SoS Agent Learns
    - Updates Fuzzy Rules During Execution
    - Update Fuzzy Membership Functions During Execution
    - Improves Fuzzy Decision Analysis