SoSECIE Webinar

Welcome to the
2020 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

We will start at 11AM Eastern Time

Skype Meeting +1 (703) 983-2020, 46013573#

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August

NDIA SE Division SoS Committee Industry Chairs:
Mr. Rick Poel, Boeing
Ms. Jennie Horne, Raytheon
OSD Liaison:
Dr. Judith Dahmann, MITRE

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- I have muted all participant lines for this introduction and the briefing.
- If you need to contact me during the briefing, send me an e-mail at sosecie@mitre.org.
- Download the presentation so you can follow along on your own
- We will hold all questions until the end:
  - I will start with questions submitted online via the CHAT window in Skype.
  - I will then take questions via telephone; State your name, organization, and question clearly.
- If a question requires more discussion, the speaker(s) contact info is in the brief.

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2020-2021 System of Systems Engineering Collaborators Information Exchange Webinars

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October 6, 2020
A System-of-Systems Approach to Optimize a Real-time Risk Situational Awareness System
Dr. Flavio Oquendo

October 20, 2020
Situation Awareness and Decision Making for Constituent Systems
Dr. Pontus Svenson and Dr. Jakob Axelsson

November 3, 2020
Challenges for System of Systems in the Agriculture Application Domain
Dr. Benjamin Weinert and Dr. Mathias Uslar

November 17, 2020
Achieving System-of Systems Interoperability Levels Using Linked Data and Ontologies
Dr. Jakob Axelsson

December 1, 2020
Achieving System Integration through Interoperability in a large System of Systems (SoS)
Mr. Oliver Hoehne

2021-2022 System of Systems Engineering Collaborators Information Exchange Webinars

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January 26, 2021
Addressing the Sustainable Development Goals with a System-of-Systems for Monitoring Arctic Coastal Regions
Evelyn Honoré-Livermore, Roger Birkeland and Cecilia Haskins

February 23, 2021
Interface Management- the Neglected Orphan of Systems Engineering
Paul Davies

March 9, 2021
Distributed Architecture for Monitoring Urban Air Quality: A Systems Engineering Approach
Adrián Unger, Tom McDermott and Philip Dewire

April 6, 2021
Holistic architecture description for a future Global Health Assurance Systems of Systems
Adrián Unger

SoS Meta-Architecture Selection for Infrastructure Inspection System Using Aerial Drones

Dr. Cihan Dagli, Muhammad Monjurul Karim
Department of Engineering Management and Systems Engineering
Missouri University of Science and Technology

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Outline

> Introduction
> Proposed Methodology
> Result and Discussion
> Conclusions

Developing Meta Systems Architectures for

Cyber Physical Systems for Next Decades

There will be *multi-faceted systems* in different levels of implementation that entail complex logic with many levels of reasoning in intricate arrangement, organized by web of connections and demonstrating self-driven adaptability which are designed for autonomy and exhibiting emergent behavior that can be visualized.

They will impact manufacturing industry, defense, healthcare, energy, transportation, emergency response, agriculture and society overall.

Developing Meta Systems Architectures for Leading Innovation

Cyber Physical Systems for Next Decade

The success will depend on how the current challenges related to;

Cybersecurity,

Interoperability,

Privacy,

Human System Integration

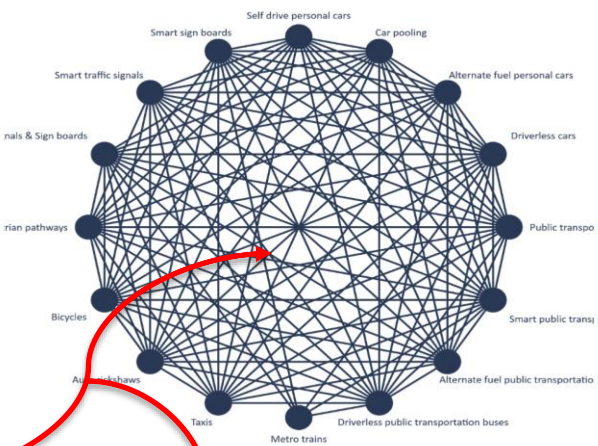
are handled.

Industry 4.0. Society 5.0 are the term used

Developing Meta Systems Architectures

Developing Meta Systems Architectures

Can we determine these architecture based on context, dynamic stability and pluralism using a structured interactive approach?



Human System Integration,
Cybersecurity, Interoperability,
Privacy, Safety,

Industry 4.0/ Society 5.0

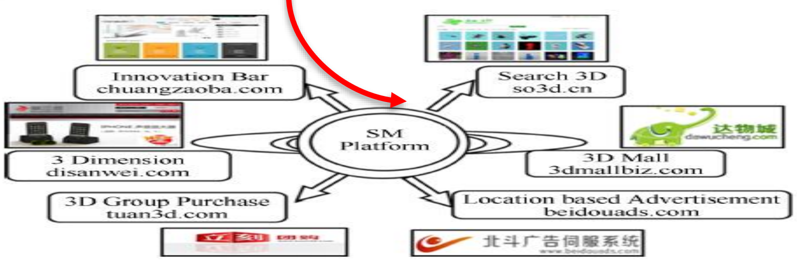


Fig. 6. Type 2 SM platform with 3D printing.

From Mind to Products: Towards Social Manufacturing and Service Gang Xiong, et.al.
IEEE/CAA JOURNAL OF AUTOMATICA SINICA, VOL. 5, NO. 1, JANUARY 2018

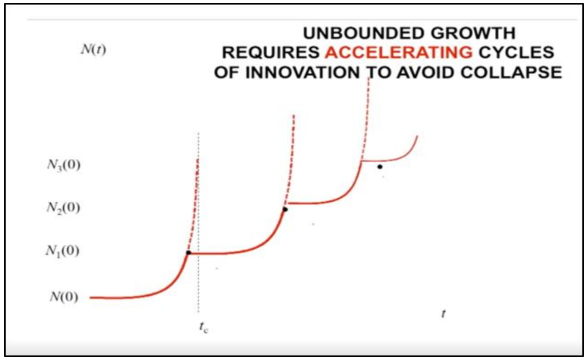
Developing Meta Systems Architectures

- Structuring the modeling effort (context)

- Optimization methods yielding targeted solution sets (pluralism)

- Visualization of architectures (context)

- Interactive architectures allowing
- “what-if” experimentation
- (dynamic stability)



Developing Meta Systems Architectures

Developing Meta Systems Architectures

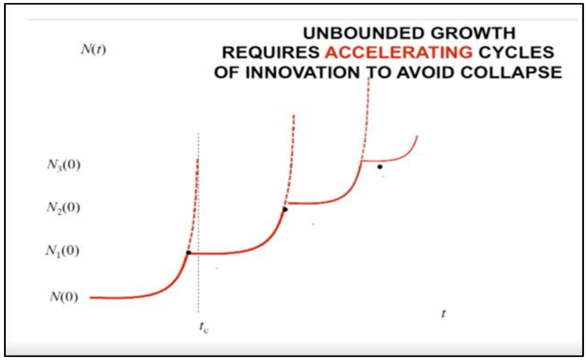
SoS Explorer is Missouri S&T's solution
http://emse.mst.edu/sos-explorer/

A novel optimization method called "MOEA-DM" tailored to the needs of cyber physical systems

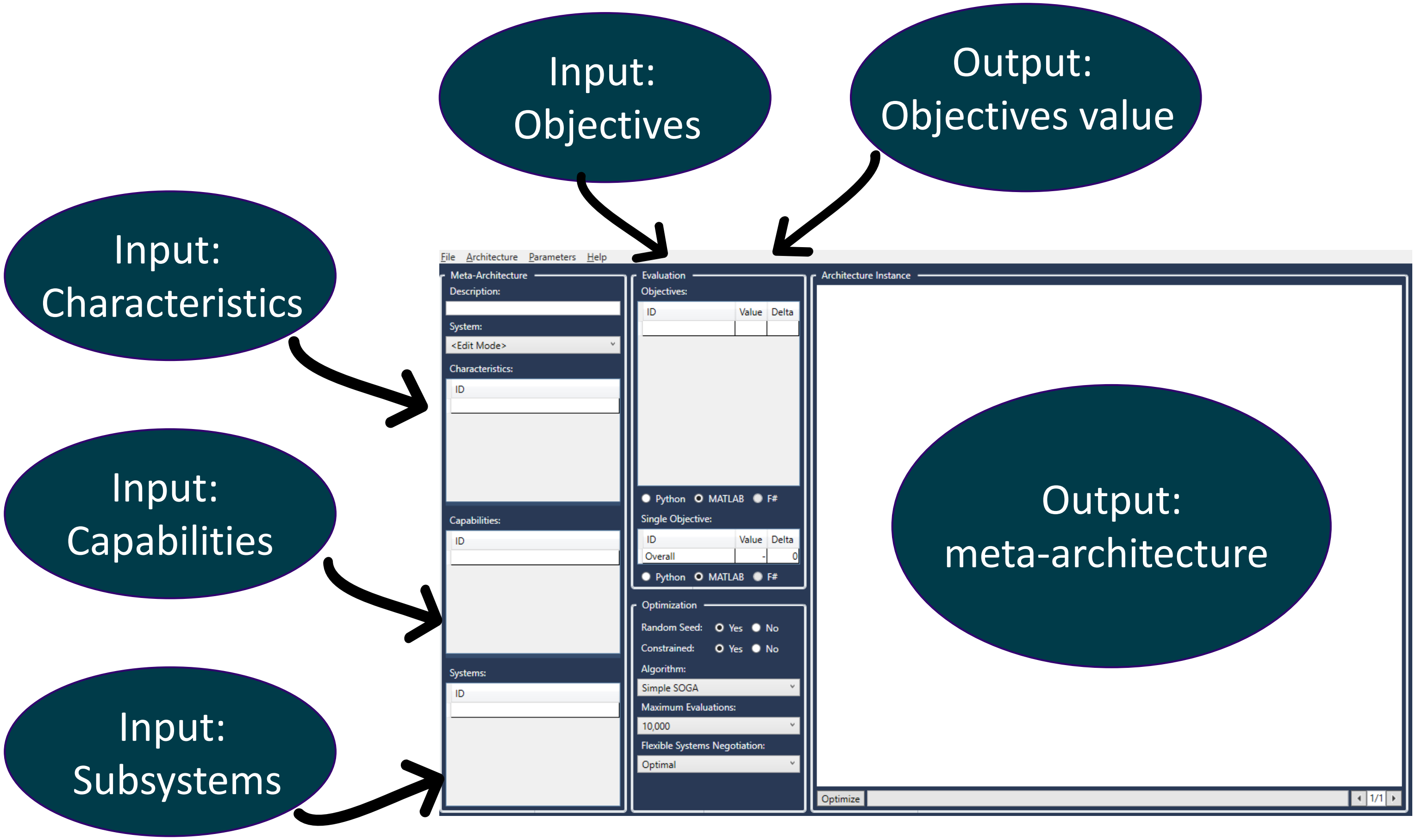
Many-objective optimization

Use of clustering to cultivate a limited set of solutions of interest

Visualization of architectures
Interactive "what-if" experimentation



SoS Explorer Architecting Tool



Current Practice of Infrastructure inspection

> Data collection- dangerous, dull or dirty

the necessity of blocking traffic

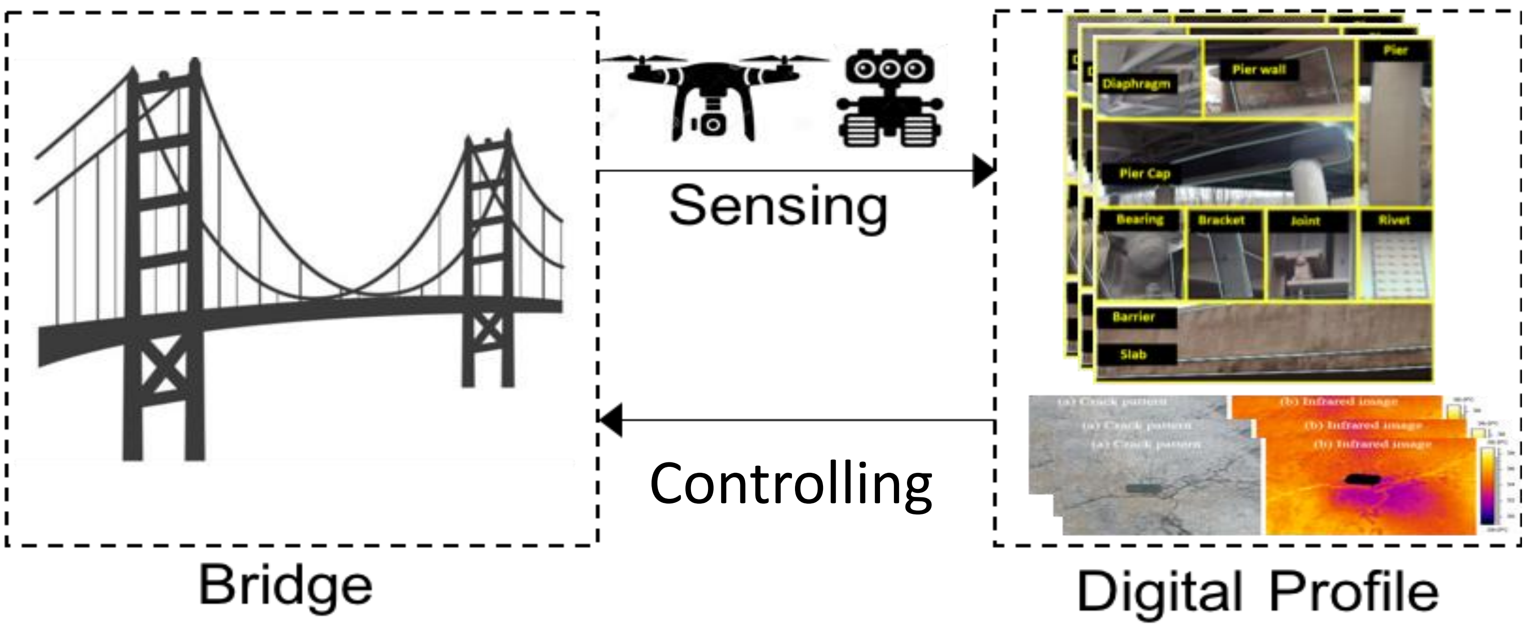
dangerous field activities involved in visual inspection

difficulty of accessing elevated bridge structures

time-consuming in data collection

Data-driven decision support for preservation

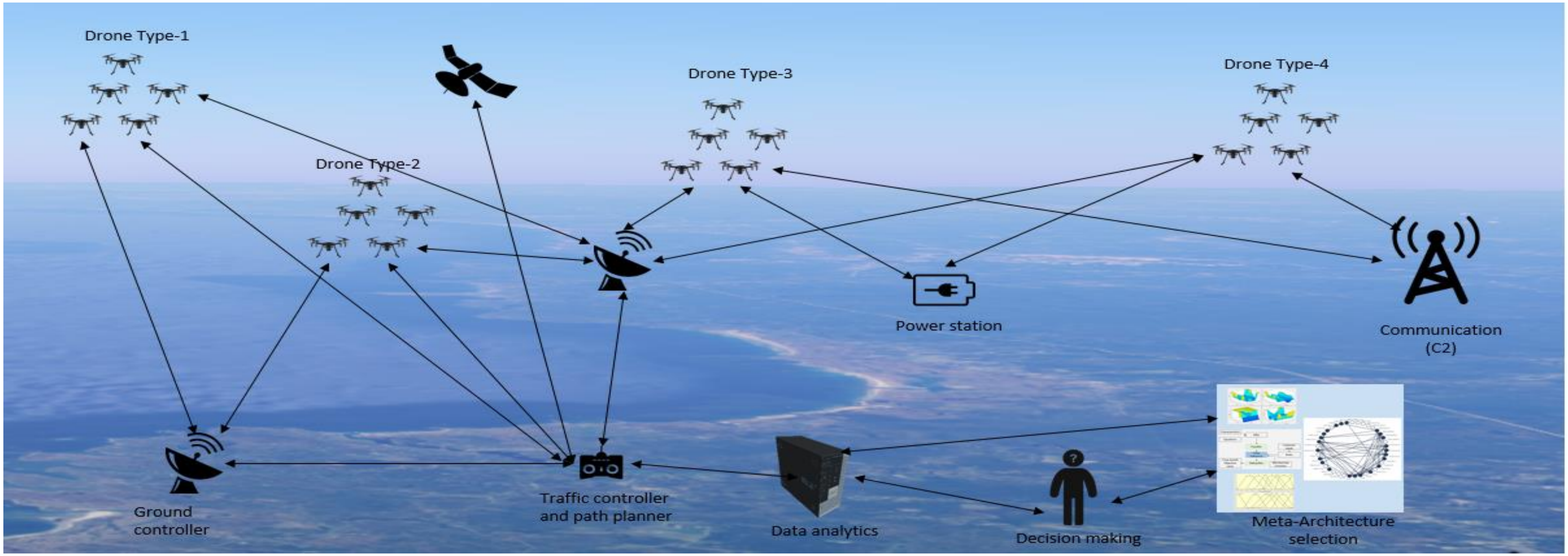
- Cyber Physical Systems
  - Sensing the physical world
  - Modeling in cyber world
  - Controlling the physical world



Overview of the System

- To address the cost, accessibility, and safety concerns of the current inspection practice
- Different types of drones are used
  - Thermal imaging capacity (heavy industry)
  - Weather resistance (working on extreme weather)
  - Long flight (long bridge)
  - Heavy payload (heavy lifting)
- To control all the drones at different location it needs different subsystem
  - Flight controller
  - Ground controller
  - Warning system
  - Etc.

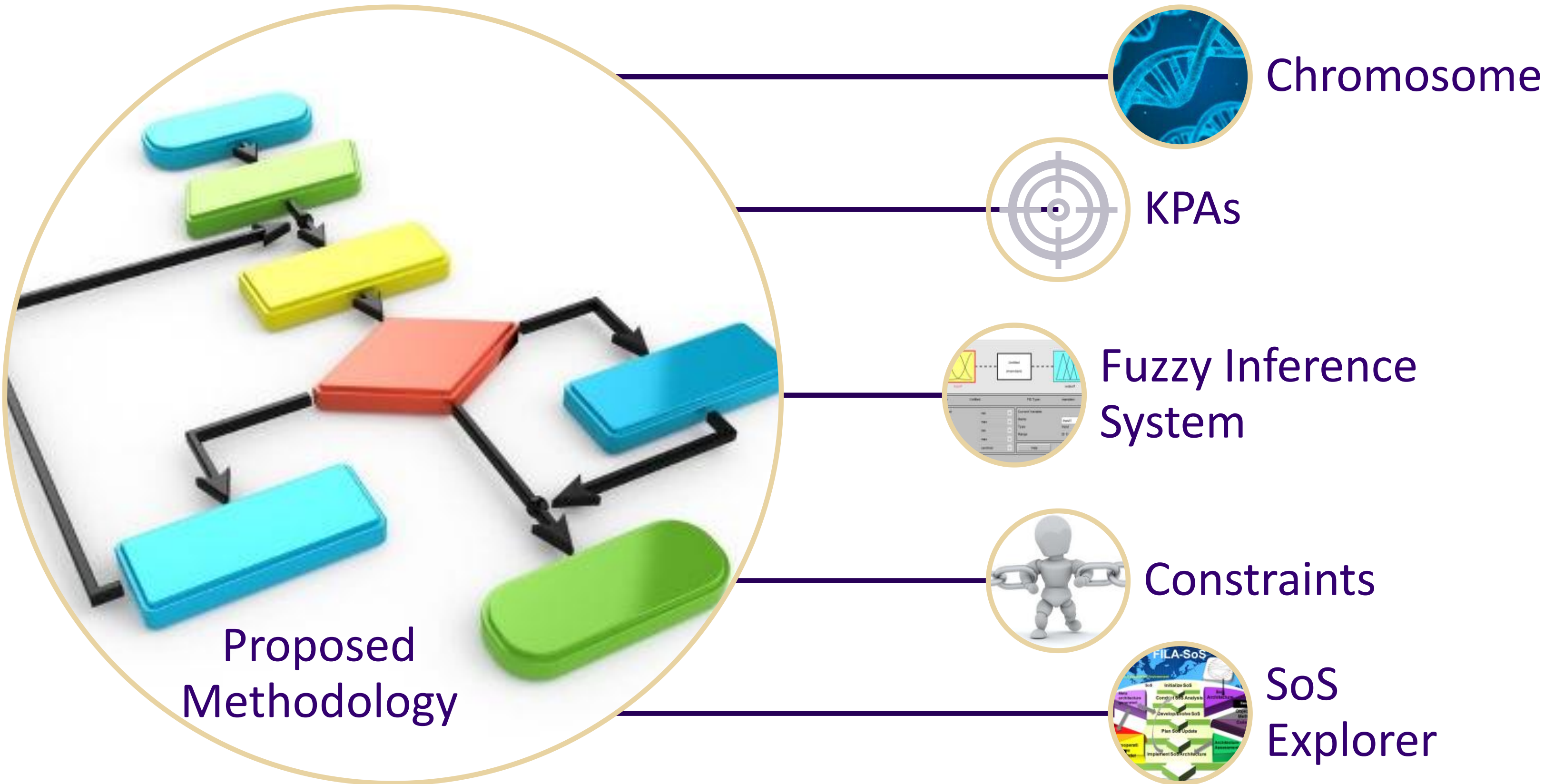
Overview of the System



- Combination of different systems to control the drone operation can create many system of systems (SoS) meta-architecture
- Can be thousands of meta architecture
  - Difficult to select best meta-architecture

> Introduction
> Proposed Methodology
> Results
> Conclusions

Proposed Methodology

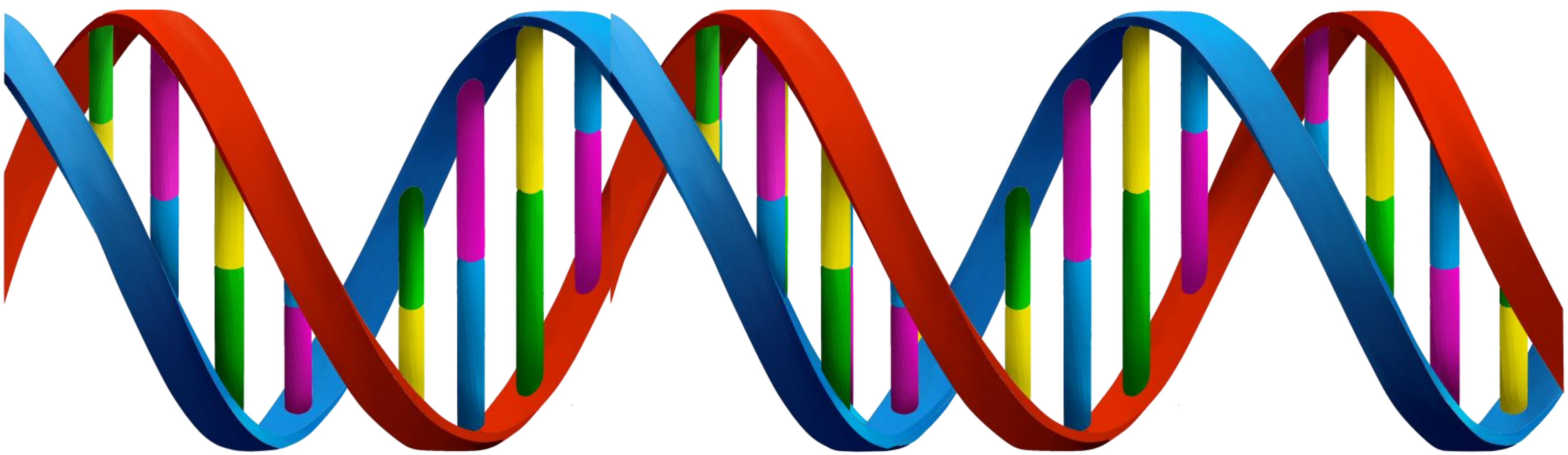


Proposed Methodology

- Generate and evaluate SoS meta-architecture for infrastructure inspection
  - Define the Chromosome
  - KPAs are identified
  - Identify the capabilities of SoS
  - Determine the characteristics of the capabilities
  - Crisp value of the KPAs are calculated using fuzzy inference system
  - A GA optimization technique is used to calculate the overall meta-architecture assessment score

Chromosome

Sub systems + Interfaces = Chromosome



Partial Chromosome representation

- Systems and interfaces are represented as 1's and 0's
- 1 indicates presence and 0 indicates absence

Systems				Interfaces			
System1	System2	...	System n	Interface 1-2	Interface 1-3	...	System (n-1) - n
0	1	...	0	1	1	...	1

$$S(X,i)=\begin{cases}1, \textit{ if the } i^{th} \textit{ system is selected in } X, \\ 0, \textit{ otherwise}\end{cases}$$

$$I(X,i,j)=\begin{cases}1, \textit{ if the } i^{th} \textit{ and } j^{th} \textit{ system have an Interface in } X, \\ 0, \textit{ otherwise}\end{cases}$$

Note: X is the chromosome, i and j are indices for subsystems

Capabilities and Characteristics

Capability- ability to execute a particular course of action

System	Notation	Thermal	Infrared	GPS	Radar	Lider	WeaRes	Autopilot	Payload	DeepLear	Battery
Falcon 8 (1)	Sys 1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Falcon 8 (2)	Sys 2	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Falcon 8 (3)	Sys 3	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Thermal cam (1)	Sys 4	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Thermal Cam (2)	Sys 5	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Matrice100 (1)	Sys 6	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE
Matrice100 (1)	Sys 7	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE
Matrice100 (2)	Sys 8	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE
Matrice100 (3)	Sys 9	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE
XT thermal (1)	Sys 10	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
XT thermal (2)	Sys 11	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
XT thermal (3)	Sys 12	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Payload (1)	Sys 13	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Payload (2)	Sys 14	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Long range camera (1)	Sys 15	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
Long range camera (2)	Sys 16	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
L I2 (1)	Sys 17	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
L I2 (2)	Sys 18	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
L I2 (3)	Sys 19	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
RTF (1)	Sys 20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
RTF (2)	Sys 21	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
RTF (3)	Sys 22	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
Warning system (1)	Sys 23	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE
Warning system (2)	Sys 24	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE
Aeryon S	Sys 25	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Flight Con (1)	Sys 26	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE

Capabilities

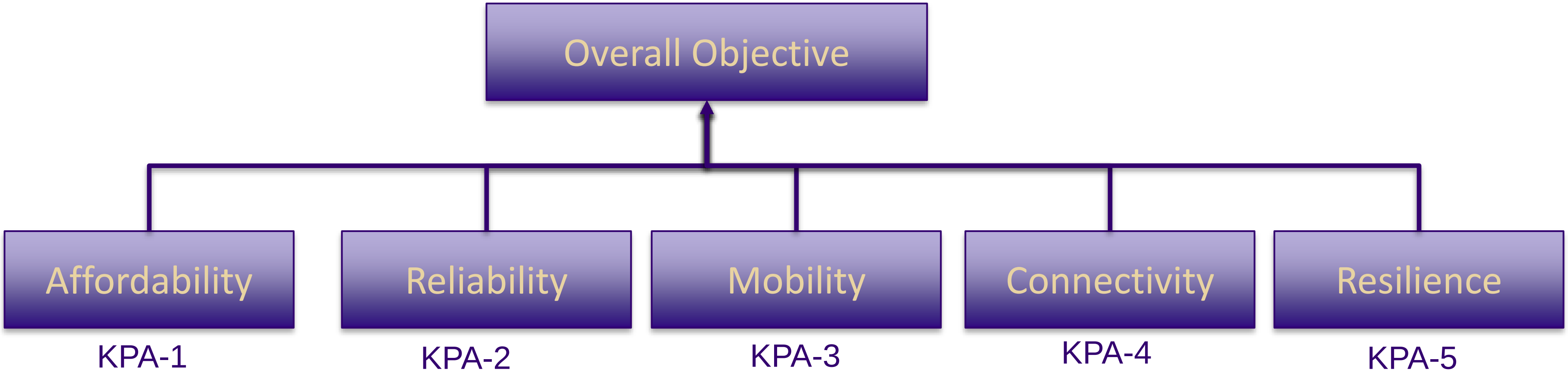
Characteristics- quantifiable parameters of systems

System	Notation	Capability	I/F Dev co	OpsCost	Perf	DevTime	FlightTim	DataTrans	MTBF	Recovery
Falcon 8 (1)	Sys 1	3	0.2	10	10	1	7	0.2	7	6
Falcon 8 (2)	Sys 2	3	0.2	10	10	1	7	0.2	7	4
Falcon 8 (3)	Sys 3	3	0.2	10	10	1	7	0.2	7	5
Thermal cam (1)	Sys 4	3	0.1	9	18	1	17	0.8	9	9
Thermal Cam (2)	Sys 5	3	0.1	9	18	1	17	0.8	9	3
Matrice100 (1)	Sys 6	4	0.7	8	12	1	13	0.9	16	1
Matrice100 (1)	Sys 7	4	0.7	8	12	1	13	0.9	16	4
Matrice100 (2)	Sys 8	4	0.7	8	12	1	13	0.9	16	1
Matrice100 (3)	Sys 9	4	0.7	8	12	1	13	0.9	16	9
XT thermal (1)	Sys 10	3	0.4	5	0	1	9	0.7	5	1
XT thermal (2)	Sys 11	3	0.4	5	0	1	9	0.7	5	5
XT thermal (3)	Sys 12	3	0.4	5	0	1	9	0.7	5	15
Payload (1)	Sys 13	1	0.8	9	3	0	3	0.3	12	15
Payload (2)	Sys 14	1	0.8	9	3	0	3	0.3	12	6
Long range camera (1)	Sys 15	3	0.7	9	7	0	2	0.4	19	13
Long range camera (2)	Sys 16	3	0.7	9	7	0	2	0.4	19	10
L I2 (1)	Sys 17	3	0.2	14	10	0	19	1	1	12
L I2 (2)	Sys 18	3	0.2	14	10	0	19	1	1	2
L I2 (3)	Sys 19	3	0.2	14	10	0	19	1	1	7
RTF (1)	Sys 20	2	0.5	5	15	1	7	0.6	11	12
RTF (2)	Sys 21	2	0.5	5	15	1	7	0.6	11	11
RTF (3)	Sys 22	2	0.5	5	15	1	7	0.6	11	8
Warning system (1)	Sys 23	4	0.3	20	3	1	12	0.8	14	4
Warning system (2)	Sys 24	4	0.3	20	3	1	12	0.8	14	13
Aeryon S	Sys 25	1	0.9	11	20	0	18	0.5	6	5
Flight Con (1)	Sys 26	1	0.5	17	7	1	8	0.5	12	14

Characteristics

Key Performance Attributes (KPA)

- Used to evaluate overall performance of SoS
- Formal method to fulfill stakeholder needs
- 5 attributes are selected for drone operation in inspection



Key Performance Attributes (KPA)

- Affordability: it is related to the sum of the participating systems' individual costs along with the cost of implementing included interfaces.
- Reliability: Reliability is related to both the SoS uptime and the performance attribute. The uptime can be calculated from the mean time between failure (MTBF) characteristics. Reliability can be modeled as the harmonic mean between uptime and performance attribute.
- Mobility: This measures the ability to move freely and easily. Mobility is calculated by averaging the selected systems flight time values per the characteristics matrix.
- Connectivity: This is the measure of state of being connected. Connectivity of the SoS is calculated by averaging the data transfer values per the characteristics matrix.
- Resilience: Measures the ability to continuously deliver the intended use despite adverse weather condition or any other tough condition. Calculated in terms of the ability to respond and recover from the failure.

Key Performance Attributes (KPA) Equations

- Affordability = $-\sum_{i=1}^{N_S} S(X,i)\left(C_{Cost,i} + \sum_{j=1}^{N_S} S(X,j)C_{interface,j}\right)$

- Reliability = $\dfrac{2\left(\frac{\sum_{i=1}^{N_S} S(X,i)C_{UT,i}}{\sum_{i=1}^{N_S} S(X,i)} * P\right)}{\frac{\sum_{i=1}^{N_S} S(X,i)C_{UT,i}}{\sum_{i=1}^{N_S} S(X,i)} + P}$

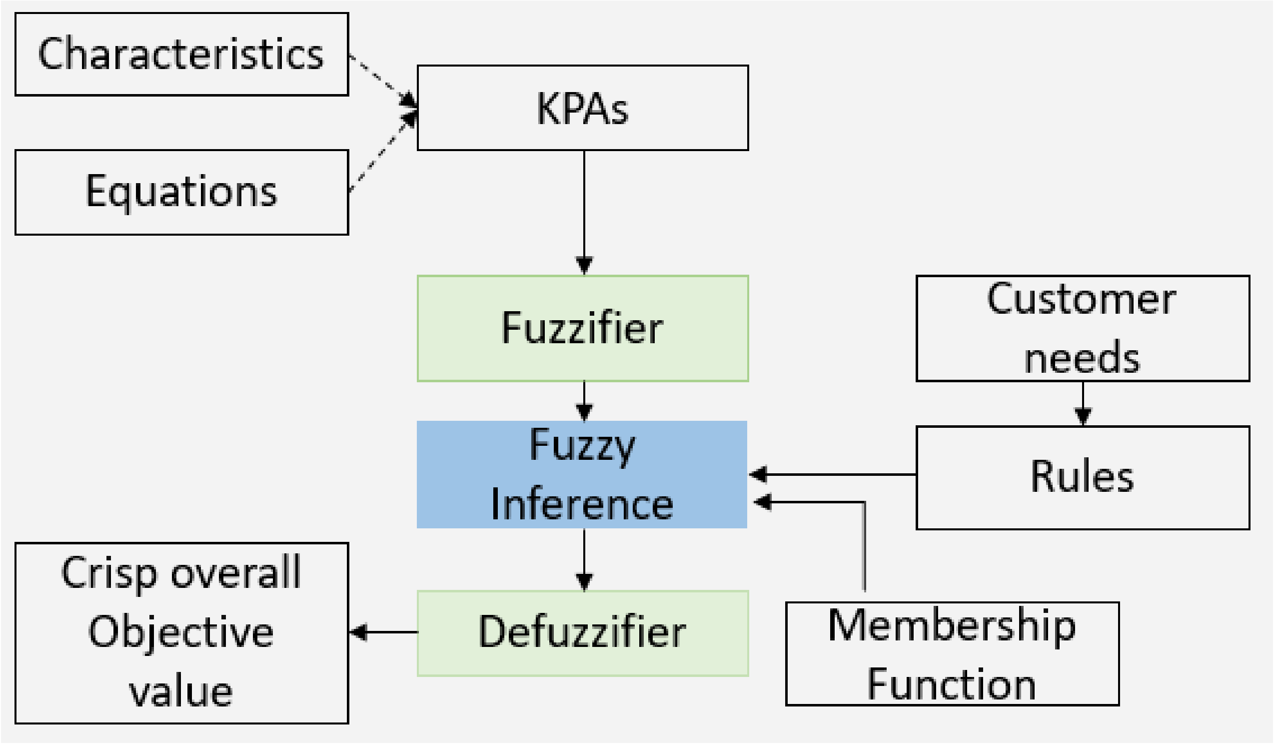
- Mobility = $\dfrac{\sum_{i=1}^{N_S} S(X,i)C_{FT,i}}{\sum_{i=1}^{N_S} S(X,i)}$

- Connectivity = $\dfrac{\sum_{i=1}^{N_S} S(X,i)C_{DTR,i}}{\sum_{i=1}^{N_S} S(X,i)}$

- Resilience = $\sum_{i}^{Ns} S(X,i) * \beta C_{recover,i}) \prod_{j}^{Ns}[1 + \delta S(X,j)I(X,i,j)]$

Fuzzy Inference System

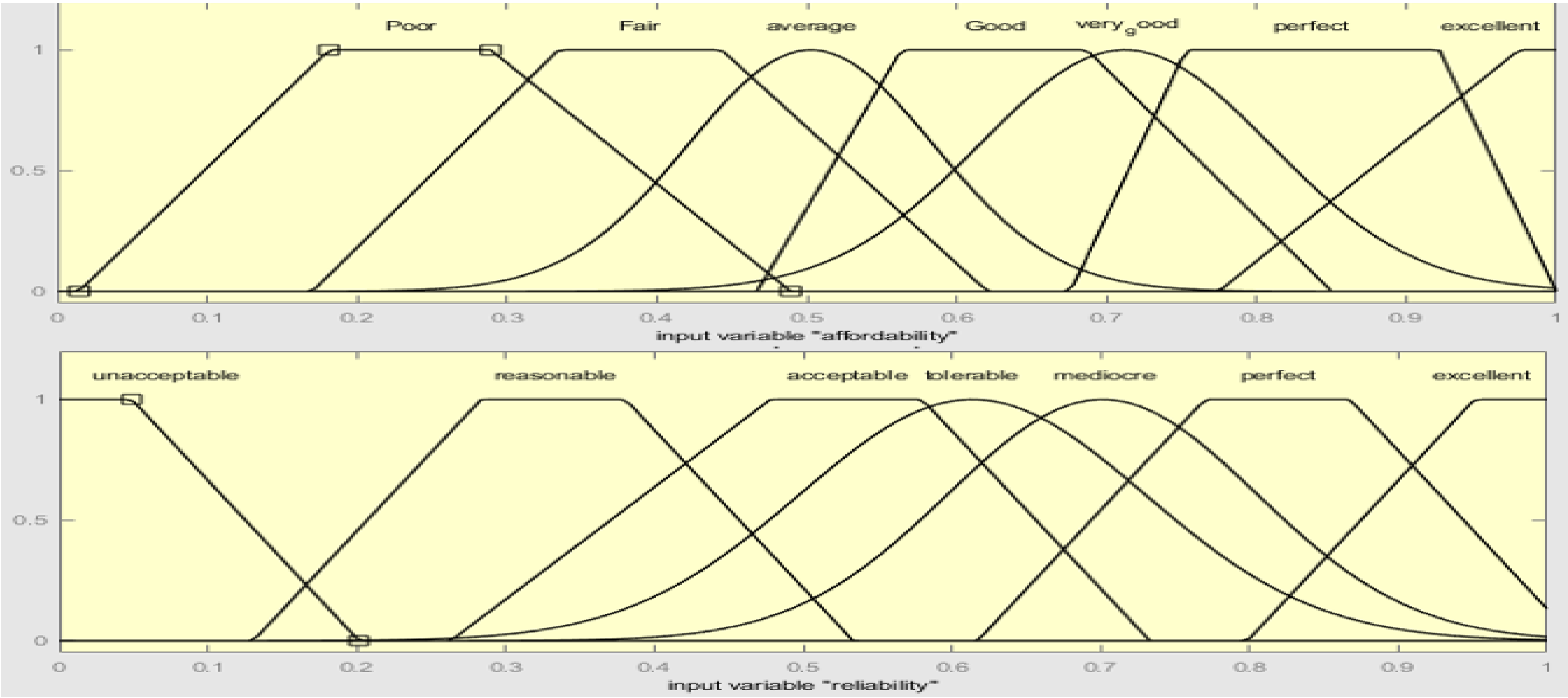
> Crisp KPA values computed from ‘characteristic value’ using equations, serve as inputs to the Fuzzy Inference System (FIS)



Fuzzy Inference System Cont.

> ## Membership Function

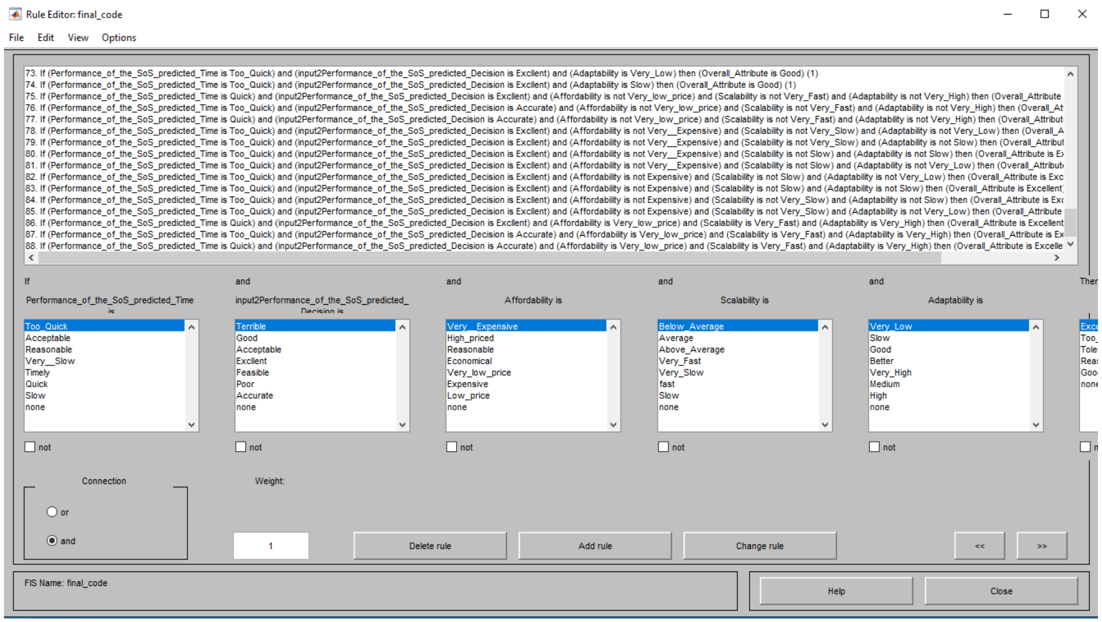
- Membership functions are used for mapping the real-world values to the fuzzy variables.
- overlapping between the boundaries of each granulations reduce the uncertainties



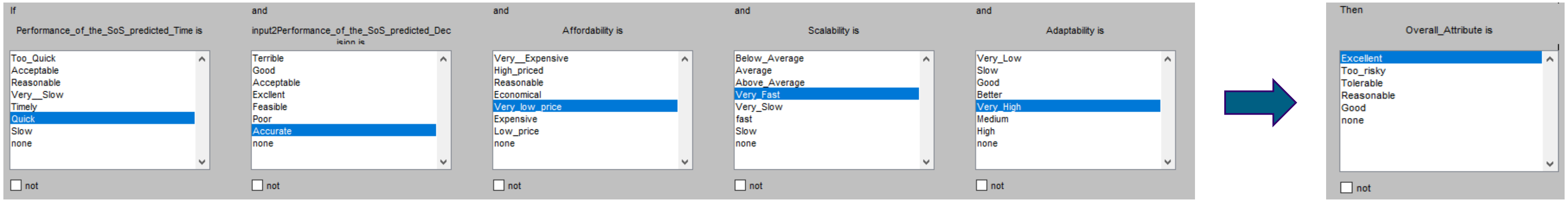
Fuzzy Inference System Cont.

- Linguistic Rules
  - Linguistic: If All the attributes are Perfect or equivalent, then the SoS is Excellent
  - Fuzzy Rule base definition: 1. If (affordability is perfect) and (reliability is perfect) and (Mobility is perfect) and (Connectivity is perfect) and (Resilience is perfect) then (output is excellent)
  - For this study 25 if-then rules are generated and integrated to a fuzzy logic system
  - A centroid defuzzification is used to achieve a crisp architecture fitness value from the fuzzy output

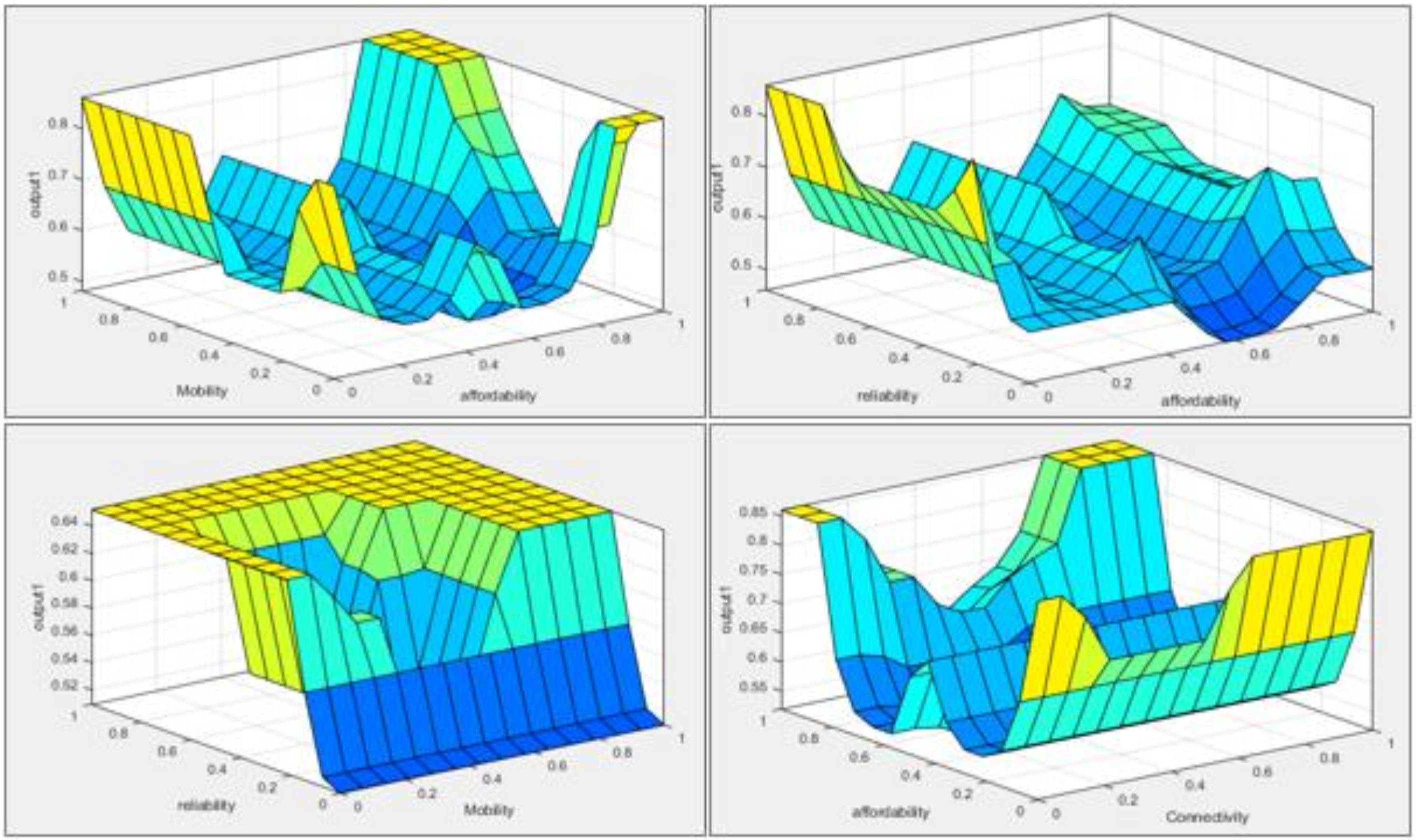
Fuzzy Inference System Cont.



Example:



FIS output surfaces



Constraints

Restricting Infeasible Architecture

> a meta-architecture without any drones will be infeasible

Algorithm: At least one drone has to be selected

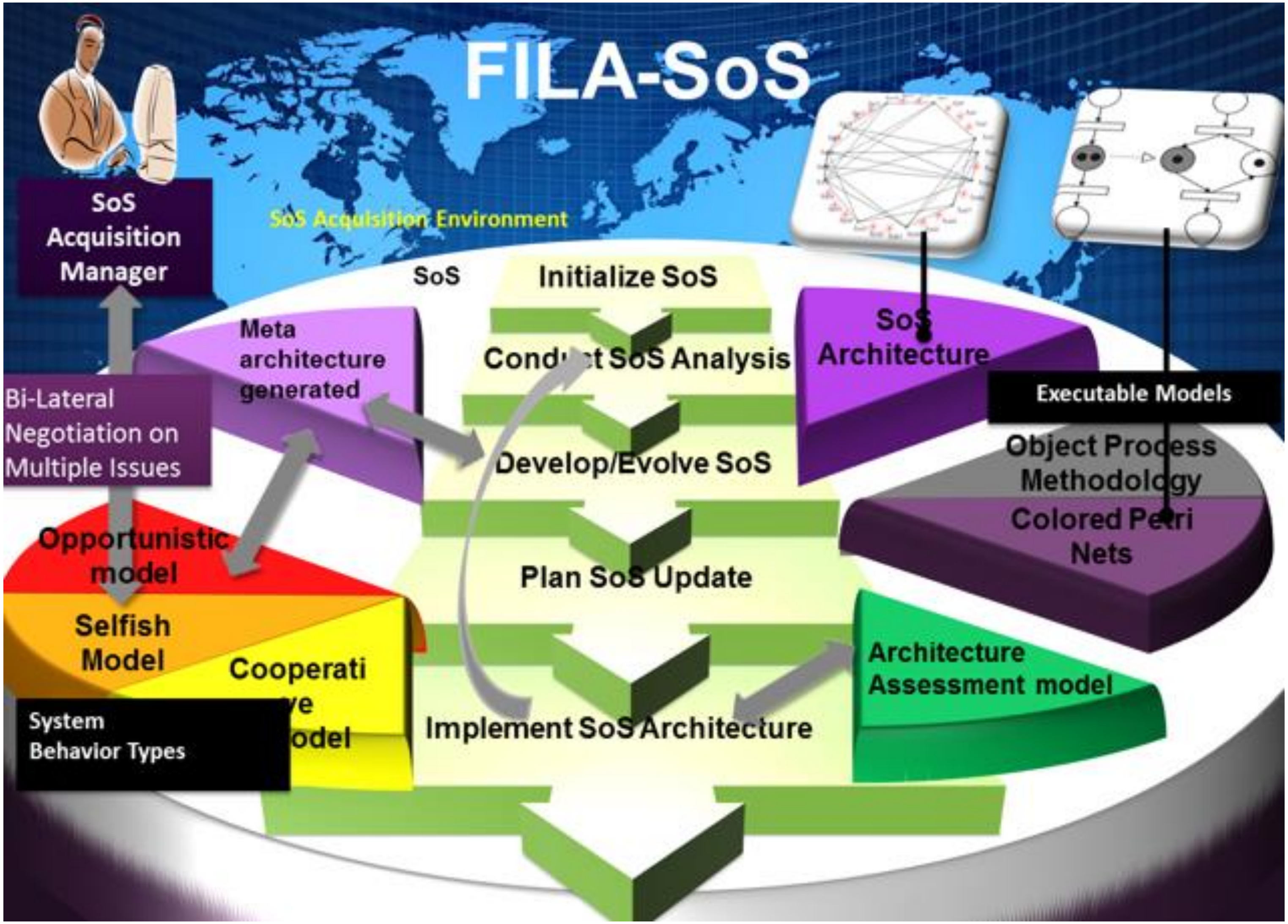
Procedure
  $X' = X$ {copy chromosome}
  for i: 1 to N_s do {for each system i}
    for j: 1 to N_s do {for each system j}
      if $i \neq j$ *then* {only considers different systems}
        if $I(X, i, j)$ then {if interface is present}
          if $\neg(S(X, i)$ *and* $S(X, j)$ *and* $F_{ij})$ then {if not feasible}
            $X' = SetInterface(X', i, j, 0)$ {remove interface}
            if $k \leq 1$ then {number of selected drones}
              $X' \leftarrow SetSystem(X, k, true)$ {add drone}
          end if
        end if
      end if
    end for
  end for
  return X'
end procedure

$k = number\ of\ selected\ drones$

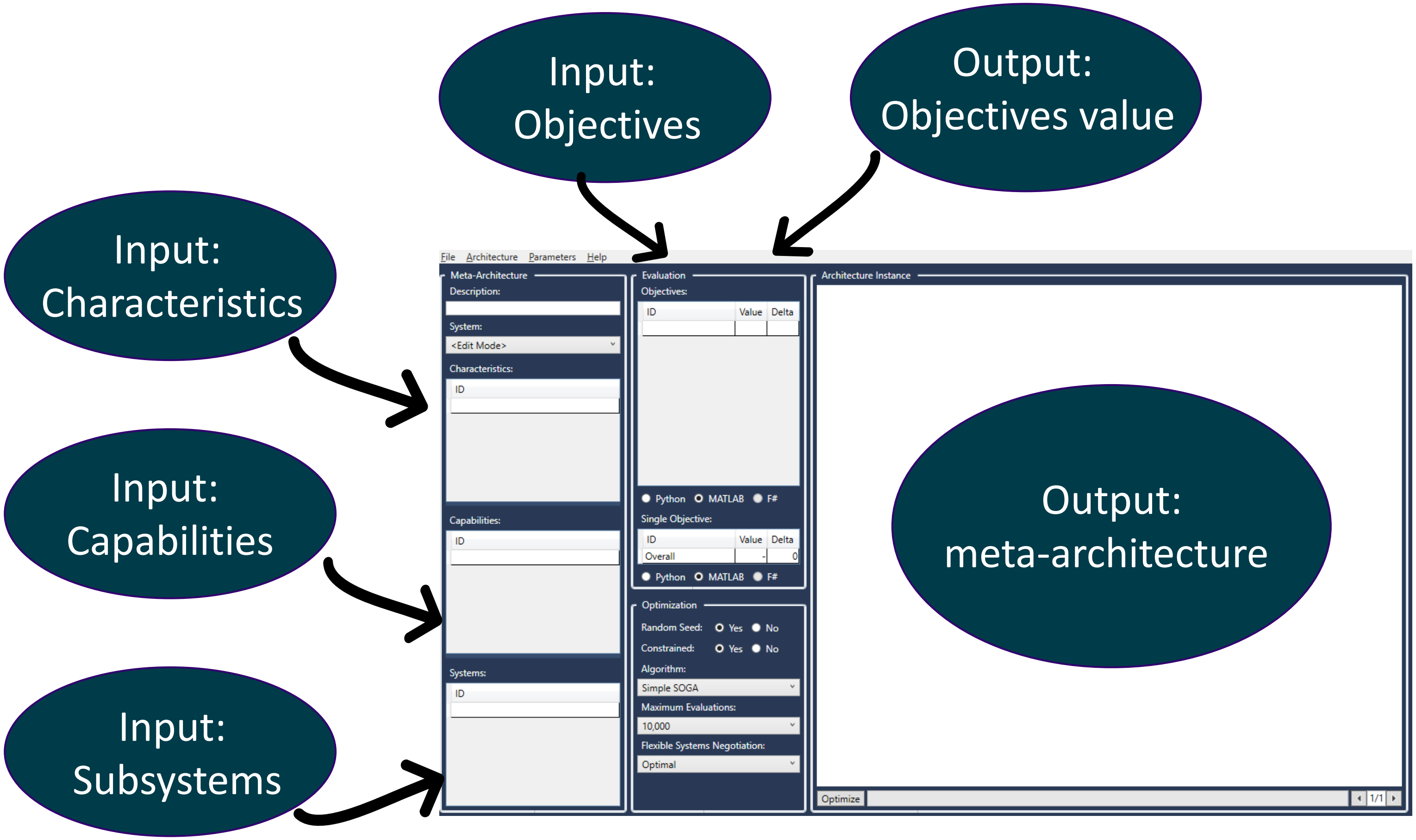
Optimization with GA

- GA to select good SoS
- Chromosomes represents the system and their interfaces
- Population size determines the number of chromosomes
- Fuzzy assessor calculates the architecture fitness value
- New offspring is generated after selection, crossover and mutation operation
- New population replace the old population
- New fitness values are calculated
- Optimal meta-architecture can be found after several generations
- We used SoS explorer

SoS Explorer Architecting Tool



SoS Explorer Architecting Tool



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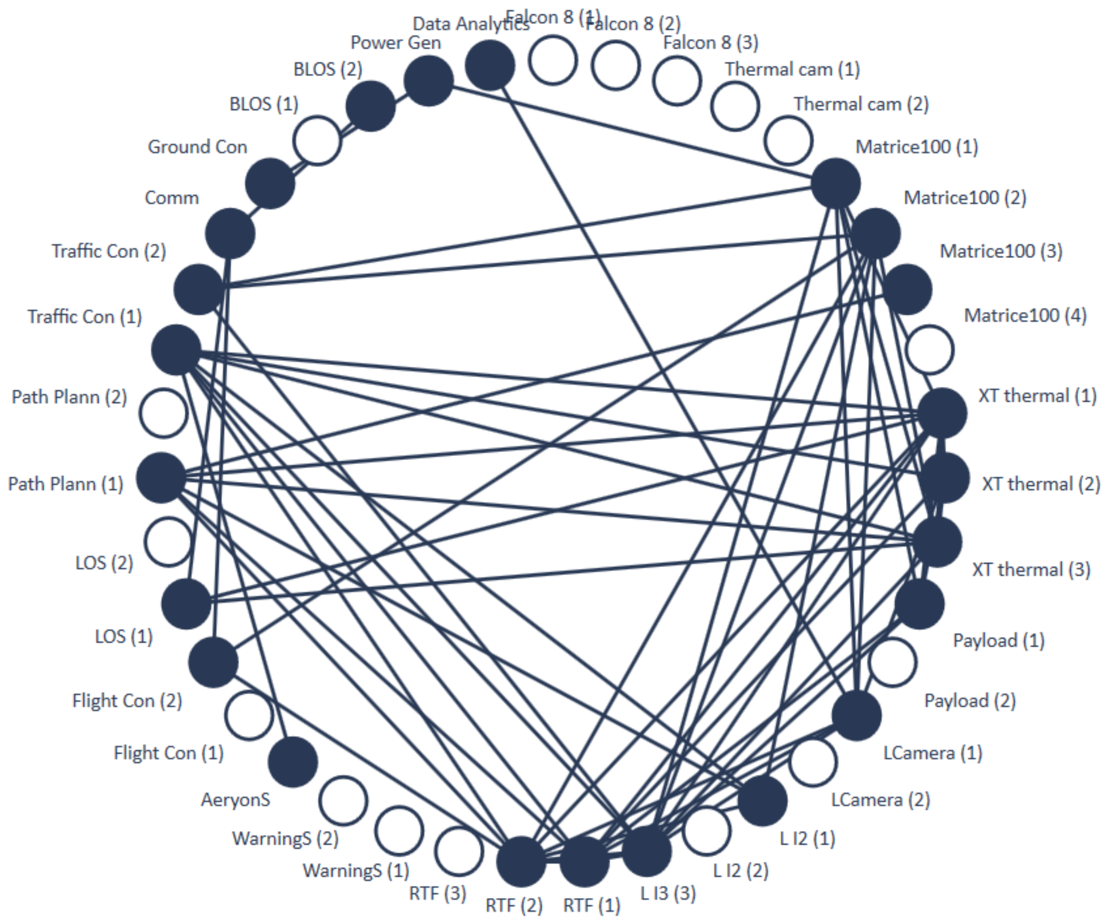
Meta-architecture

- Simple SOGA
  - GA run for 10000 generations
  - Initial population = 40
  - Crossover rate 90%
  - Mutation rate 2.5%

Objectives:	
ID	Value
Reliability	0.47
Affordability	0.88
Mobility	0.55
Connectivity	0.62
Resilience	0.60

Overall = 0.77

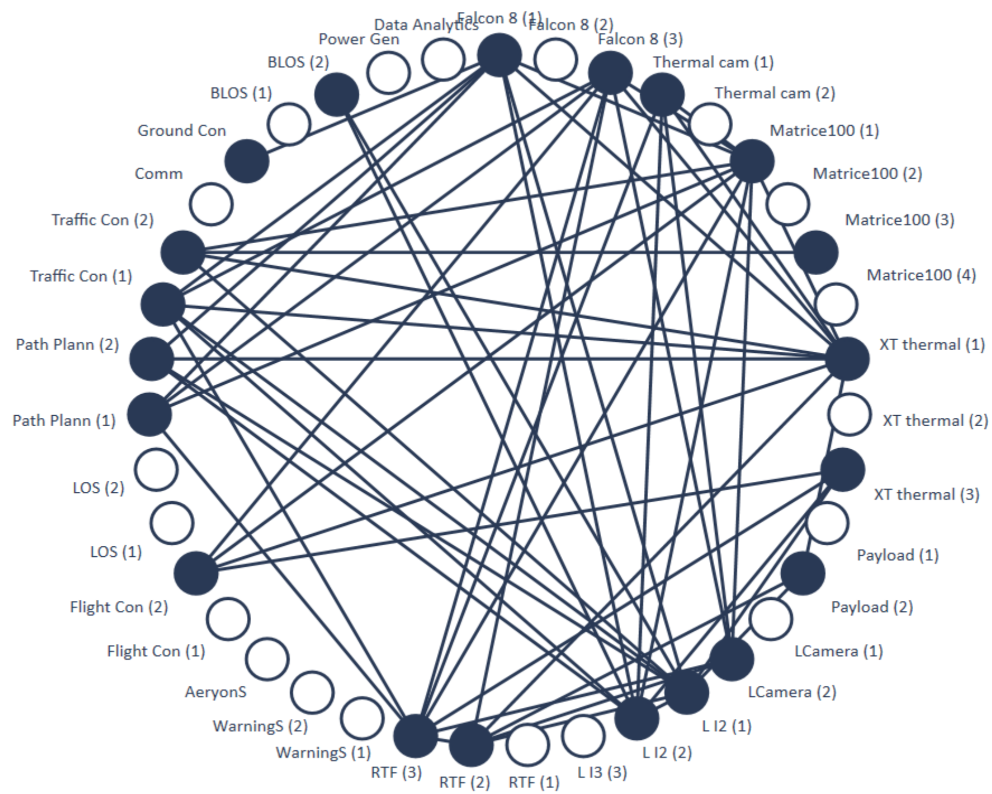


Meta-architecture

- Simple SOGA
  - GA run for 10000 generations
  - Initial population = 52
  - Crossover rate 90%
  - Mutation rate 2.5%

Objectives:	
ID	Value
Reliability	0.46
Affordability	0.90
Mobility	0.53
Connectivity	0.61
Resilience	0.49

Overall = 0.76



> Introduction
> Proposed Model
> Results
> Conclusions

Conclusions

- A method is proposed
  - Generate, assess, and select an optimal SoS meta-architecture for drone swarm technology
  - GA is embedded with FIS
    - Transforms KPA inputs into crisp meta-architecture assessment
- Help the decision makers to select best meta-architecture for drone swarm operation based on the needs

Thanks!
Comments and Questions?

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