Improving Decision Making by Reducing Uncertainty In Complex Systems of Systems

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NATO's Needs to Understand Uncertainty In Hybrid Warfare

- Hybrid Warfare Environment **Drivers**
  - Increase globalization population, industrialization, urbanization, and economic growth
  - Diminishing available resources, extreme terrorism, climate change, failed or failing states
- **Impacts** - increase in destabilized regional societies have created an era of persistent conflict
  - Increase in political, economic, and ethnic divisions/diffusion of power thus creating a complex hybrid warfare environment.
- **Current State** - Extremist adversaries will use unconventional, asymmetric, immoral warfare tactics and means to achieve their ends
- **Needs** – integrated common platform of System Dynamics and cybernetics supported by MSAL, Big Data Analytics, cognitive, and graph computing components
  - Enables better 1) understanding of risks within an OE to achieve the end state; 2) simulations of optimal operation approaches; 3) deployment of resources

Current Hybrid Warfare Environments

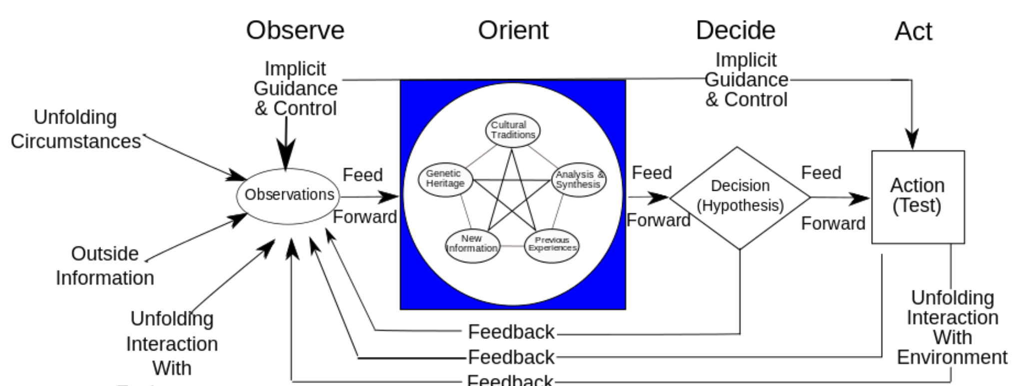
- Insurgents tactic's combine traditional, disruptive, catastrophic, and irregular capabilities to create advantageous conditions
  - Use small groups; engage in complex terrain and urban environments; they hide and fight among the people to offset allied forces
  - Attempt to exhaust/defeat allied forces by creating grey zones
- Hybrid warfare is creating a complex environment characterized by:
  - The proliferation of weapons of mass destruction, the rise of modern competitor states, violent extremism, regional instability, transnational criminal activity, and competition for dwindling resources.
- Response requires a wide Range Of Military Operations (ROMO) from crisis and disaster recovery to major operations and campaigns
  - Complex composition of the NATO entities (enemy, friendly, and neutral), conditions, circumstances and influences that makeup the operation environment
- The Battle of Aleppo is an example of a complex hybrid warfare environment

Challenges of M&S Hybrid Warfare Environments

- Grey zones create a challenge for NATO allied forces in develop capabilities to understand human aspects of these operational environment variables:
  - Political, military, economic, social, information, infrastructure (PMESII)
- PMESII add uncertainty and risk in understanding and making decisions on how
  - Humans will behave/react to traditional, irregular, and non-traditional threats
  - Cultural, demographic, and physical environmental interaction
  - Allied forces should intervene and associated repercussions
- Difficulties in collecting, processing, analyzing, and visualizing of Big Data
  - Impedes ability to: 1) Model strategy—matching the problem to the real world; 2) Model tactics—designing the internal structure of a model; and 3) Model physical phenomena and human behavior

Model and Simulation Hybrid Warfare Environments

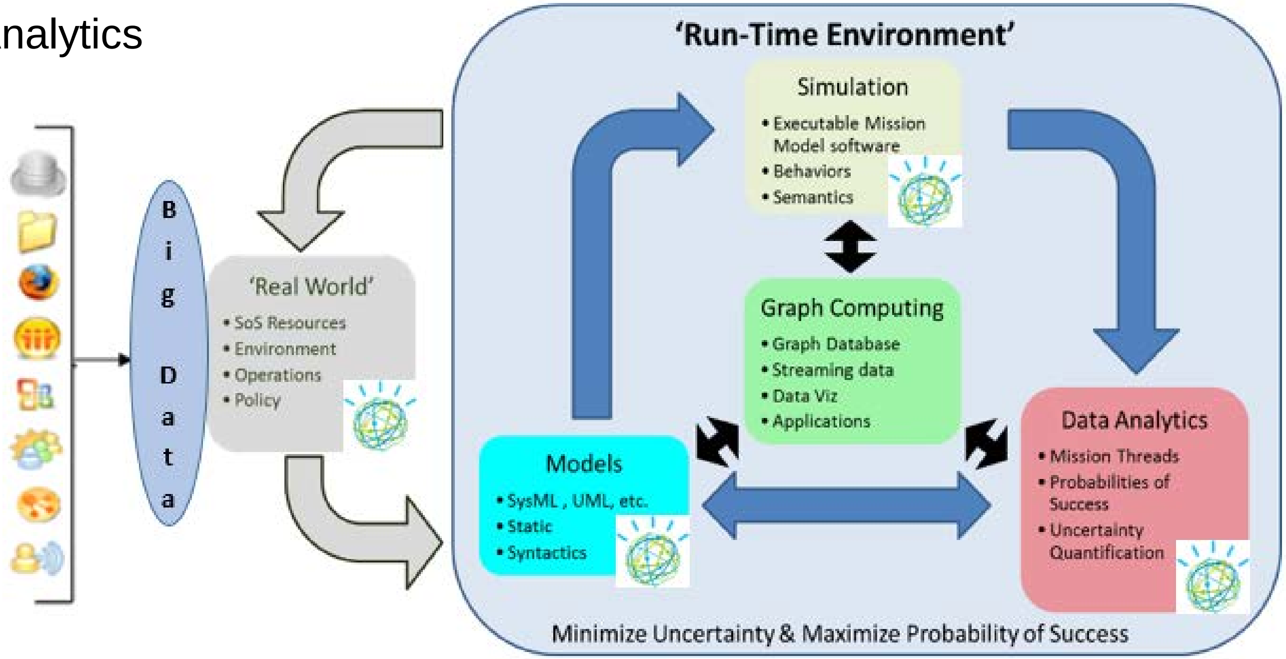
- **System dynamics** – Complex Systems are composed of interconnected parts that as a whole exhibit one or more properties not obvious from individual parts properties
- **Observe-Orient-Decide-Act** (OODA) loop –represents decision-making behavior in a SoS simulation
  - **Observe:** Big Data analytics, IoT, and NLP enhances understanding of PMESII variables
  - **Orient:** dynamical systems and cybernetics enables creation of an abstract model of the real-world – helps understand and predict impacts of hybrid warfare
  - **Decide:** the determination of a course of action based on one's current mental perspective. Cognitive computing augments human thinking in understanding and reasoning
  - **Act:** Simulate and analyze entities inter-behaviors to derive optimal approach
- **Feedback Thinking** – Cognitive systems learn from M&S information feedback loops



John Boyd's OODA Loop

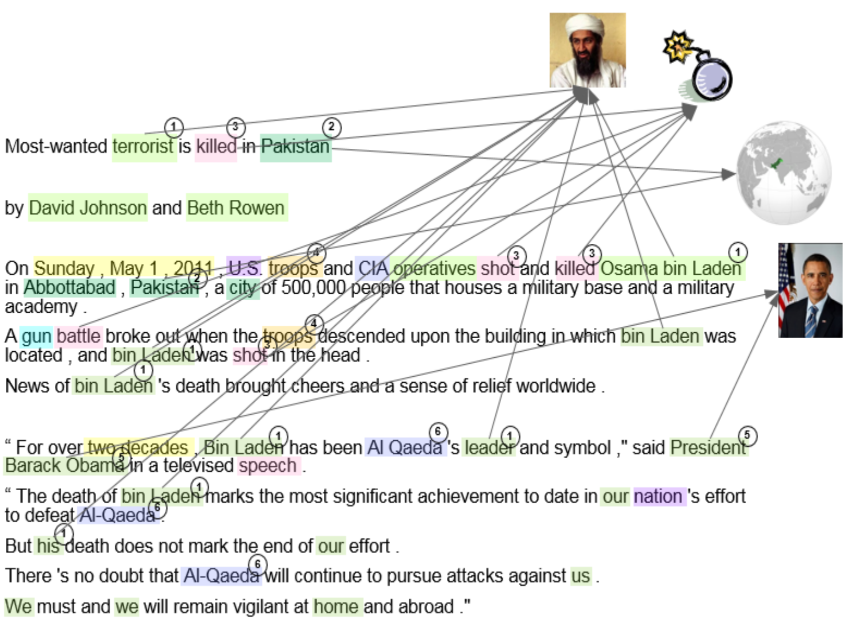
Systems Thinking Understanding Real-World

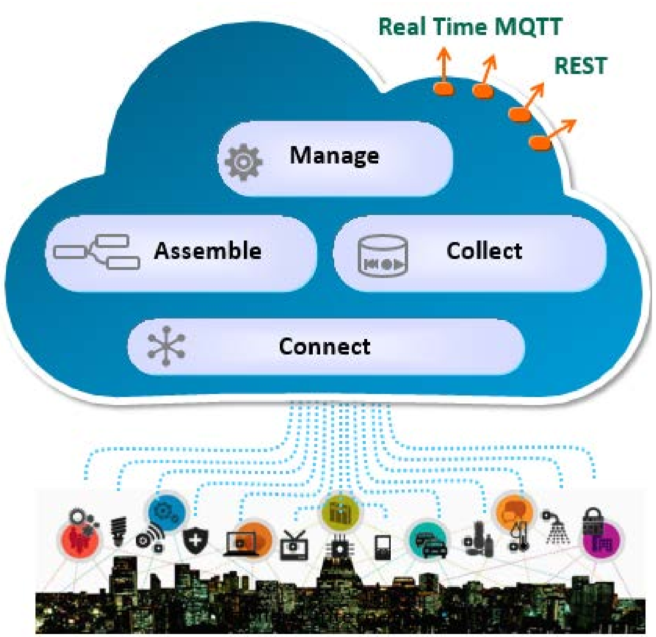
- System thinking and cybernetics supported by Model Simulation Analytics Looping (MSAL) allows M&S of complex and unpredictable systems from the tactical to campaign level
  - Mission environment (real-world model)
  - Mission model (abstract model of a real-world instance under test)
    - Goals and Mission Threads (plausible outcomes)
  - Intelligent human behaviors (Cognitive Systems)
  - Simulate optimal operation approaches to achieve end-state goals
- **Enabling Technologies**:
  - Model-Simulation-Analysis-Looping (MSAL)
  - Big Data and Advance Analytics
  - Internet of Things (IOT)
  - Cognitive Computing
  - Graph Computing



Dynamically Modeling the Real-World

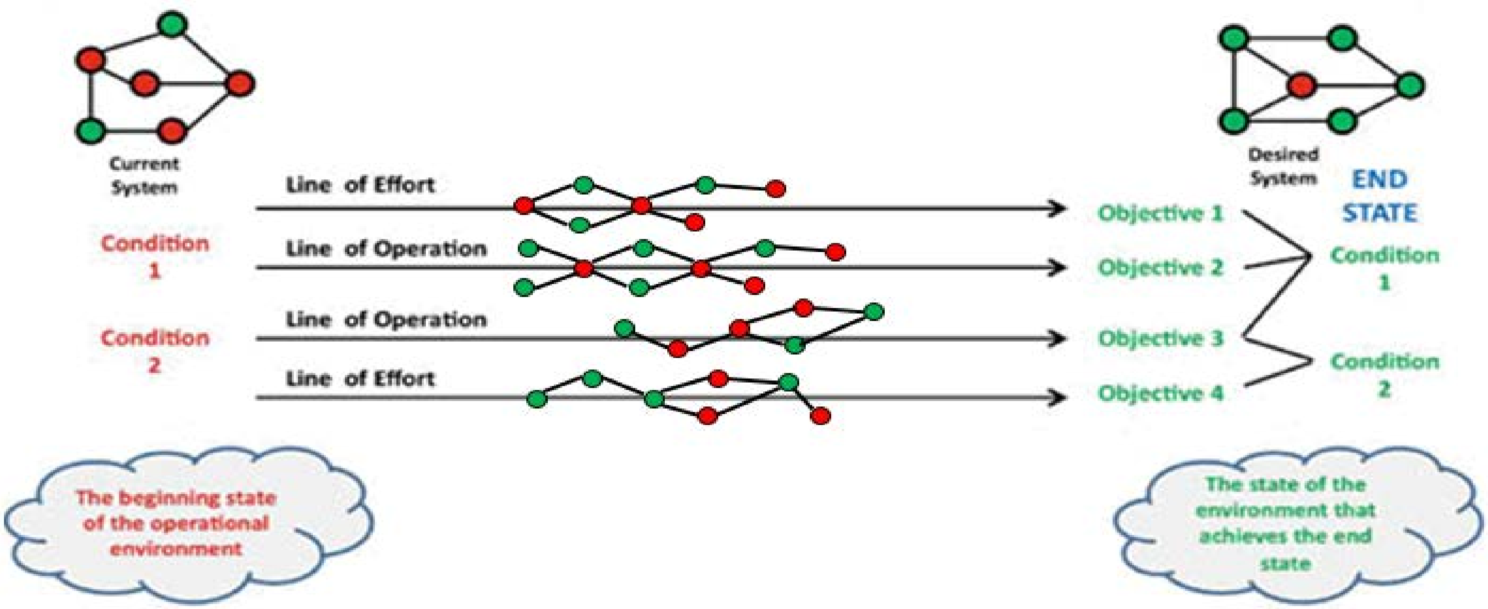
- In a hybrid warfare environment – the mission environment represents the PMESII-PT OE variables, relations, and feedback loops as they exist in the real-world
- Big Data technologies, Natural Language Processing (NLP), contextual analytics, and graph computing enables the collection of structured/unstructured data.
- Dynamically construct a Common Operating Picture (COP) that represents the complexities and uncertainties of the population, human and organizational behaviours, and their interconnections to real-world (ontologies)
- IoT (Internet of Things) is a key technology to collect environment data from the entities/systems represented in your mission environment (real-world)





Abstract Model - Understanding, Projecting, and Forming Societal Behavior

- The MAL framework provides the capabilities to leverage models to developed tactical, operational, and strategic missions.
- Enables modeling of the **mission model** that are abstractions of the real world under test
- Provides an operational design approach to link ends, ways, and means to achieve end state
- Mission model is a set of a scenario, major systems/actors, behaviors, and interactions
- The **mission threads** (plausible outcomes) are based on the underlying combinatorics of everything in the mission environment model (real-world)



The operational approach typically consists of the commander's broad description of lines of operation and/or lines of effort that should address the problem and transform the existing system conditions into desired system conditions to achieve the military and strategic end states.

M&S Graphs and Graph Analytics

Graphs and graph analytics apply to M&S in several ways:

- Definition of the execution of events in the simulation (an event string is a graph path)
- Fundamental components of a simulation model are a set of state variables and a set of events
- The model emulates the system being studied by producing state trajectories/paths, that is, time plots of the values of the system's state variables
  - Measures of performance are determined as statistics of these state trajectories
- Definition of scenarios (mission) – is an identification of the major systems/actors that must be represented by the simulation
  - Event based and cast as a directed acyclic graph (DAG) with branches at decision points

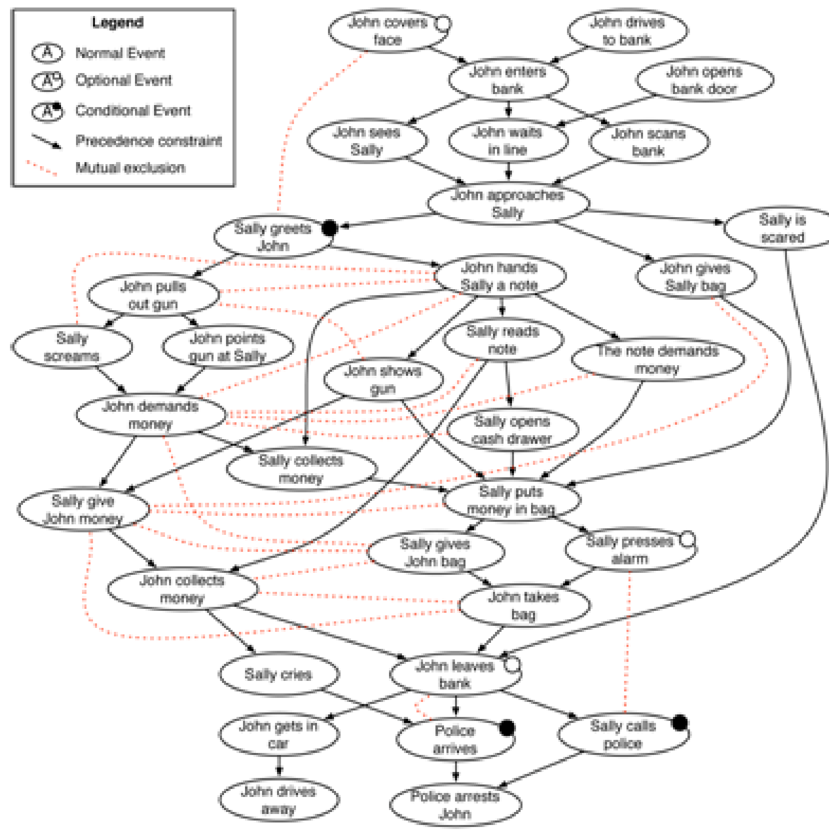
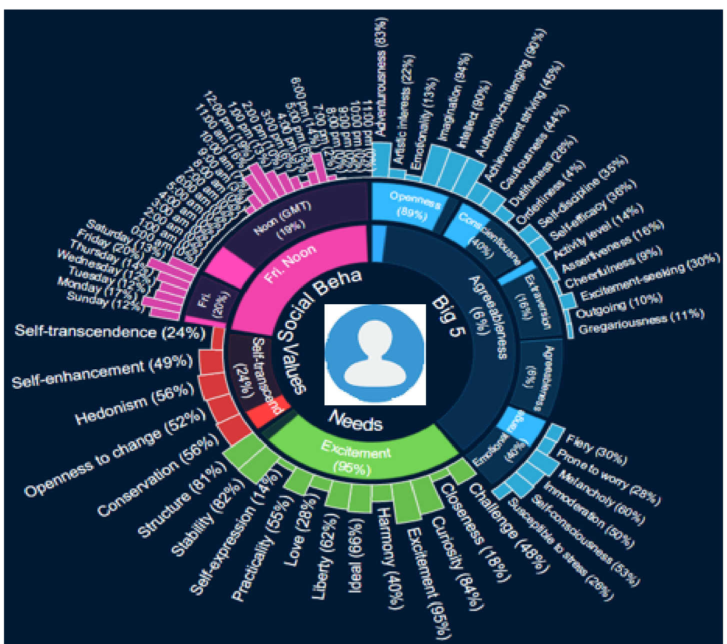


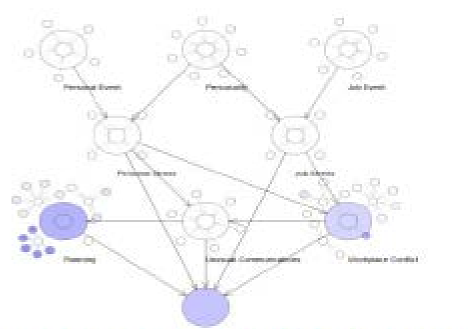
Figure 9: Hypothetical bank robbery scenario

Modeling Human, Organizational, and Societal Behaviors

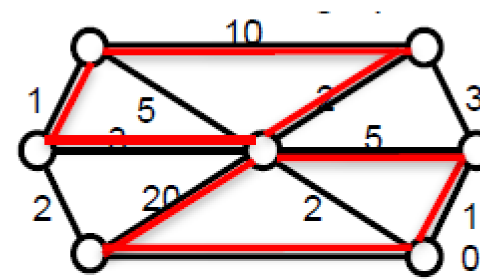
NATO OTAN

- Modeling individual and group interactions using micro (individual), macro (organizational), and meso-level (interaction)
  - Social decision models, social network models, link analysis, and ABM
  - Model political, social psychology, sociology, and economics behavior
  - Contextual, cognitive analytics, graph database and spatiotemporal analytics (space/time)
  - Enable prediction of behavior, anomalies in pattern of life, and cross person/group analysis
- MAL framework along with the above technologies and models enable design of mission threads
  - 1) identify high-value target lists within groups; 2) exploit adversary's weakness; and 3) employ asymmetric tactics to disrupt the adversary's irregular warfare methods, social/culture networks, logistic/supply networks, and economic activities

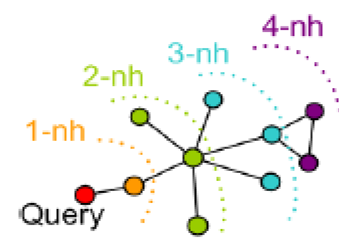




Bayesian network inference



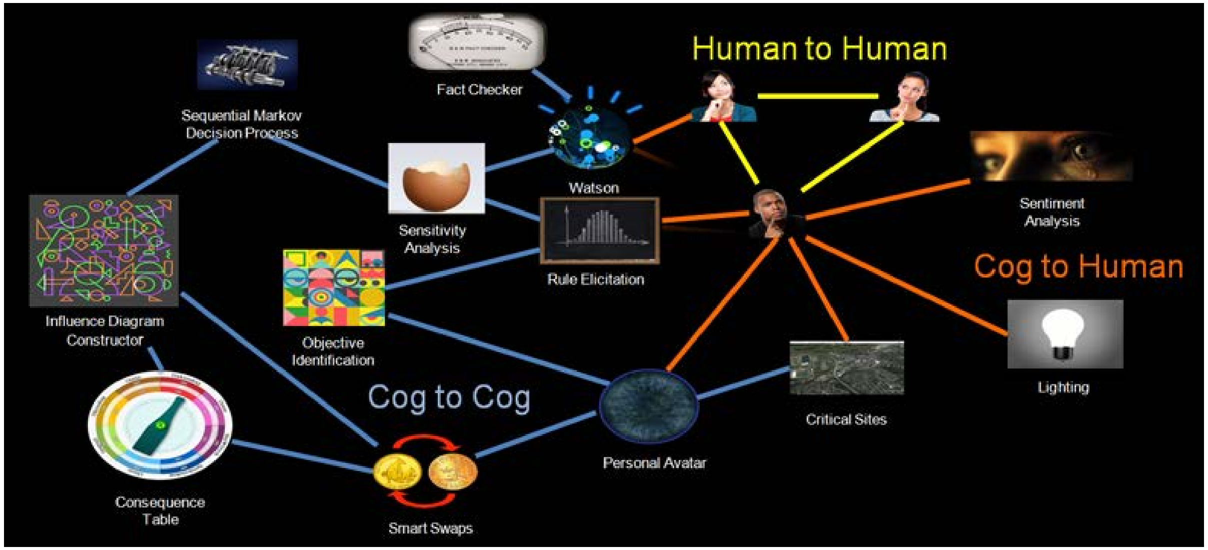
Graph matching

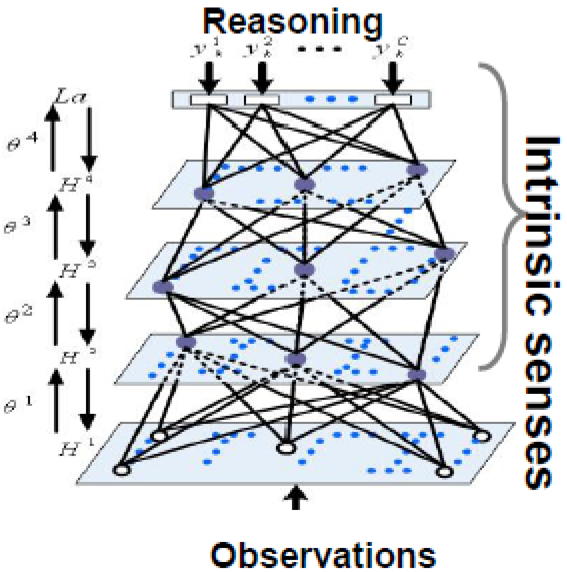


K-neighborhood

Create Intelligent Human Behaviors and Interactions

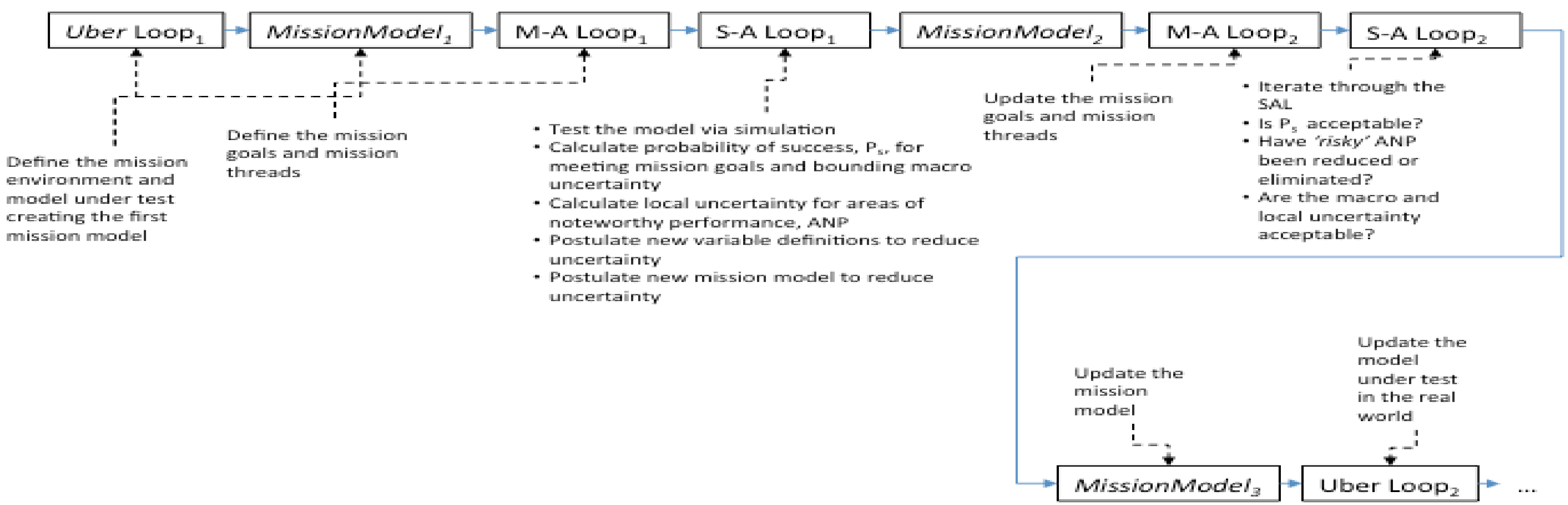
- Symbiotic Cognitive Systems (Cogs) agents enable human thinking, behaviors, and interactions
- Cogs are based on three core technologies: NLP, probabilistic computing, and machine learning (ML)
- Cogs work together in a distributed simulated/live environment to apply probabilistic computing and ML to every stimulus event and learn through feedback loops.
- Perform abductive reasoning on a computationally derived set of complementary, contradicting, and competing theories to:
  - Help understand heated dynamics, counter intuitive, anomalistic events, relationships, inter-correlations between entities that go against human intuition
- Cogs improve complex decision making by applying evidence base decision making cross vast corpora





Simulating the Optimal Goal-Based Mission Threads

- SAL is to test the dynamic behavior of a model along a goal-based, mission thread via iterative simulation and analytics to quantify both performance and uncertainty
- PMESII variables are binned to run optimization approaches and calculate local uncertainty for Areas of Noteworthy Performance (ANPs) for each mission model/thread to achieve goals
    - Streaming and/or historical data is used to run the "run-time environment
    - Measure performance, costs and schedule, and uncertainty of ANP
    - Performs sensitivity studies to identify input variables causing signification uncertainty
    - Iterative looping and uncertainty quantification reduce epistemic to aleatoric uncertainties
- Modelers can use graph computing, Social Network Analysis (SNA), link analysis, and agent based models (ABMs) to understand, forecast, form, and intervene in urban situations

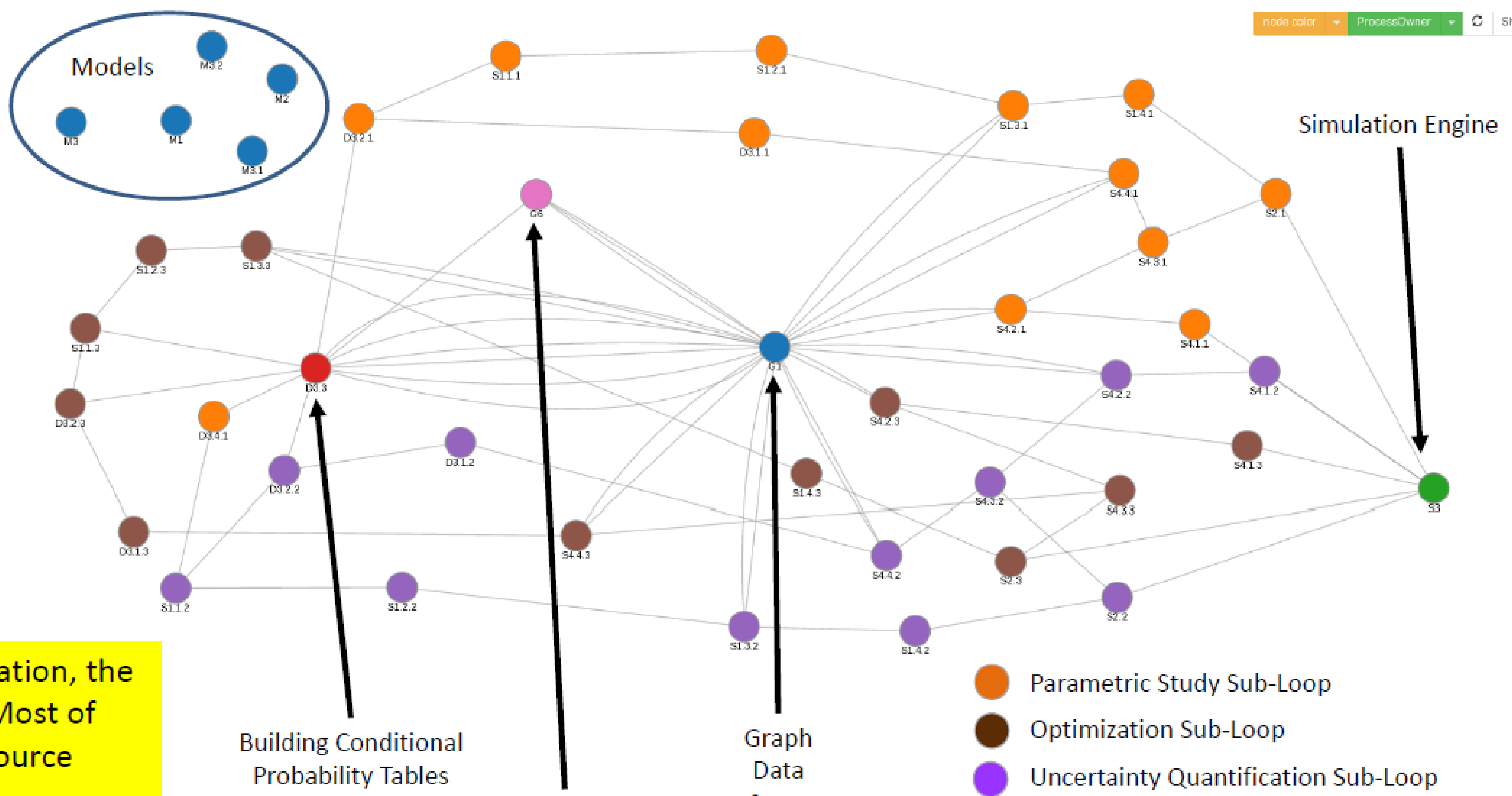


Reducing Uncertainty In Decision Making

- Conduct uncertainty quantification to identify noteworthy performance, global maximums and minimums, and model's areas to be optimized
- Uncertainty quantification aims to reduce uncertainties in the real-world/simulation models
- Run simulations to determine how likely certain outcomes are if some aspects of the system are not exactly known - Forward propagation / Inverse uncertainty assessment and parameter
- Quantitative risk models are used to calculate the impact of the uncertain parameters

Assume a single, given:
- Mission Environment (M1)
- Model Under Test (M2)
- Mission Model (M3)
- Mission Goals (M3.1)
- Mission Threads (M3.2)

The simulation engine, graph data store, CPT tables and the Bayes Solver are common to all three sub-loops

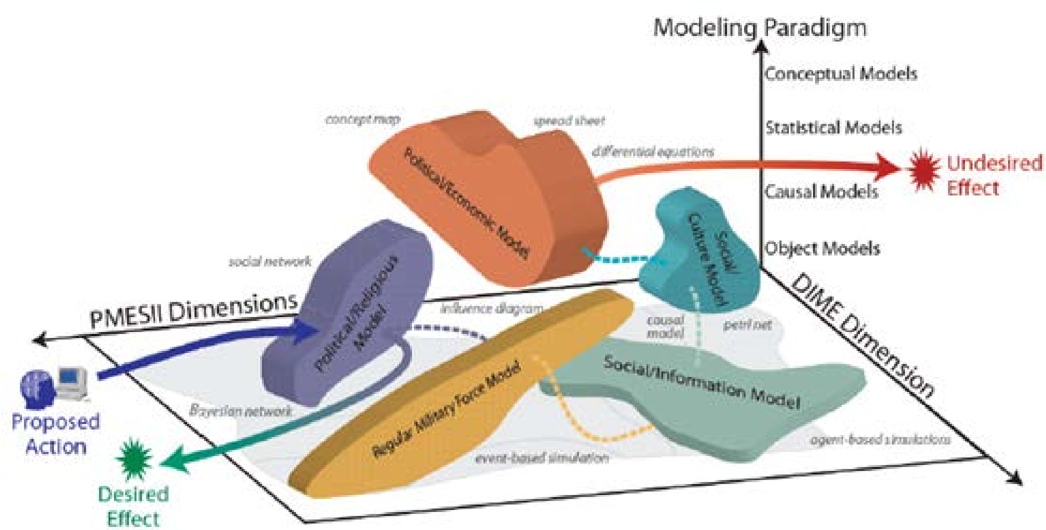


The focus is on integration, the edges, of the graph. Most of the nodes are open source software.

Conclusion

The MSAL framework supported by Big Data, graph computing, cognitive computing and IoT enables a NATO platform that overcomes many traditional M&S problems:

- Automates the process of real-world data collection and graphically depicting COP of the OE
- Validates the robustness of the models in the face of errors in the data. (Detection of abnormal/hidden entities (e.g., criminals, terrorists) and private relations (covert operations, political influence, etc.))
- Understands human and organization behaviors – dealing with uncertainty and adaptation
- Enables ingesting massive amounts of data, scalable computing, and interconnecting different simulation modes across the M&S pyramid
- Improves campaign planning involving complex systems of systems (SoS) to quickly understand the operational environment; define the problem; visualize the military end-state; and intervene with an optimal operational approach (ways/means) **to achieve the desired end state**.



SOURCE: Adapted from Allen (2004).

Questions and Discussions

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