Digital Engineering and AI – Transformation of Systems Engineering

Tom McDermott
Deputy Director & CTO, SERC
INCOSE Director, Strategic Integration

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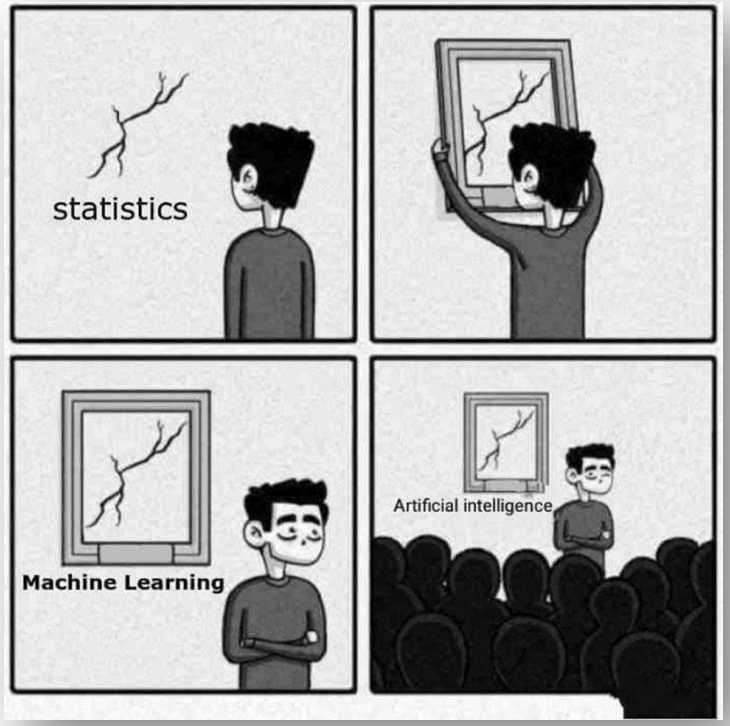
Real Problems

"If you nail two things together that have never been nailed together before, some schmuck will buy it from you." – *Comedian George Carlin*

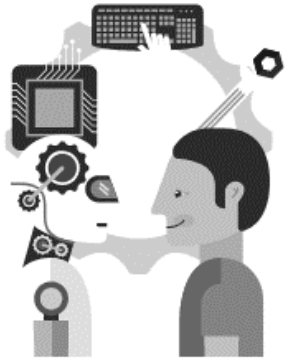
Image source: https://xkcd.com/1838/

"How you bring people into your home is just as important as when they walk through the door. Frame well." — *Richie Norton*



original comic by sandserif (https://www.instagram.com/sandserifcomics/)

An AI Application is a System



- Requirements
- Quality Attributes
- Lifecycle Considerations
- Verification & Validation

- Tradespace Analysis
- Architecture
- Integration
- Test & Evaluation

- Mission/Conops
- Task Analysis
- Human Tasking/ Use Cases
- Training

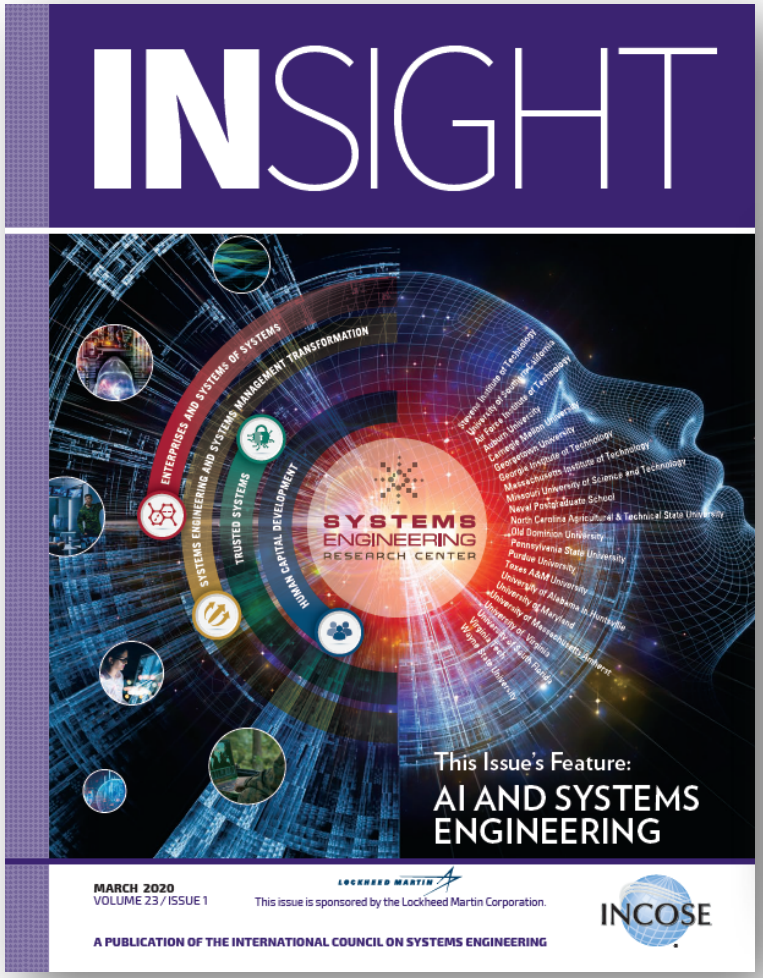
the Future of Systems Engineering

- How do we prepare the future systems engineering process in a world where humans and machines co-adapt to evolve a complex mission in response to dynamic operational conditions?

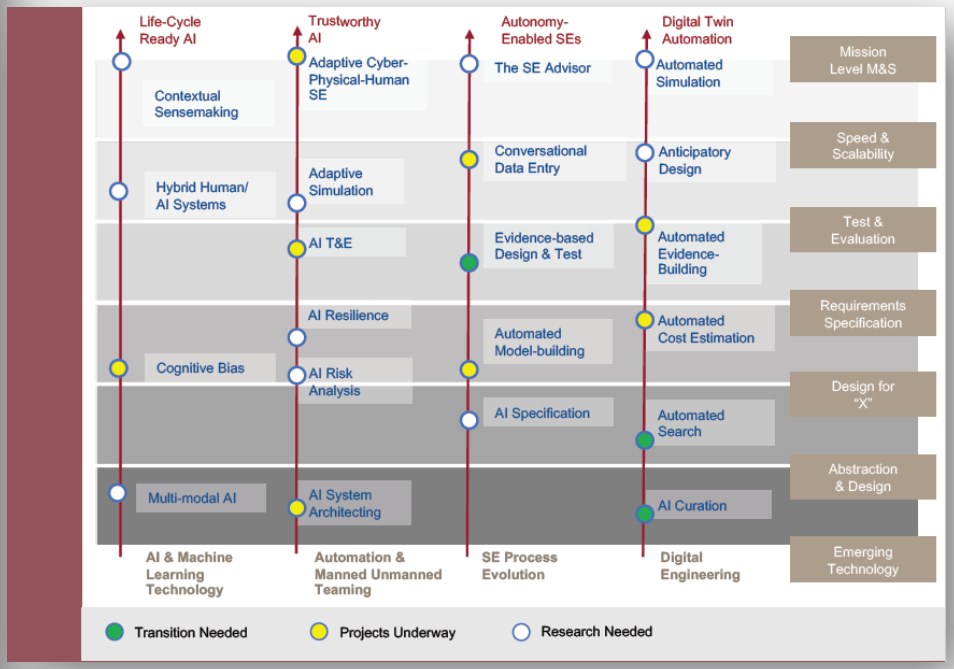
- This is a research roadmap evaluating what these systems might do and how systems engineering will (should) change…

INCOSE FuSE
Future of Systems Engineering

INCOSE INSIGHT: SERC AI Roadmap

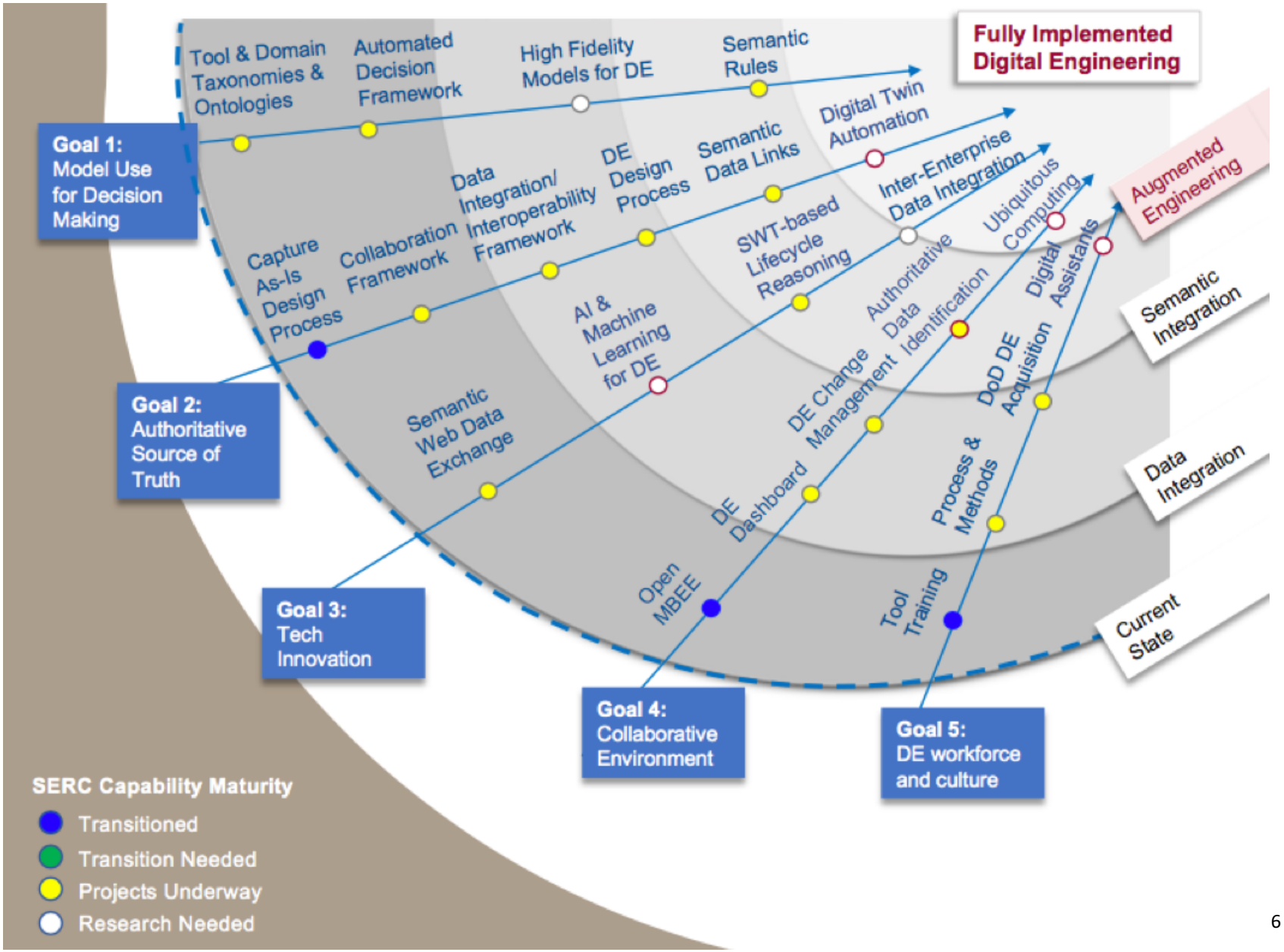


Spring AAAI virtual meeting



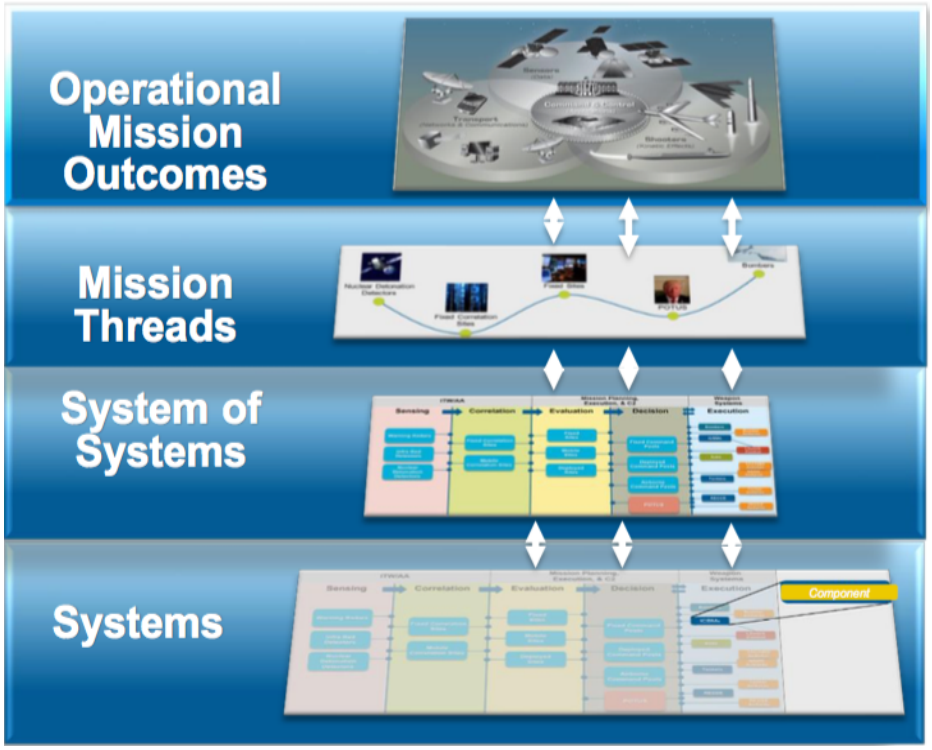
SYSTEMS ENGINEERING RESEARCH CENTER

Digital Engineering for Systems Engineering Roadmap: Goals are Mutually Supportive not Orthogonal



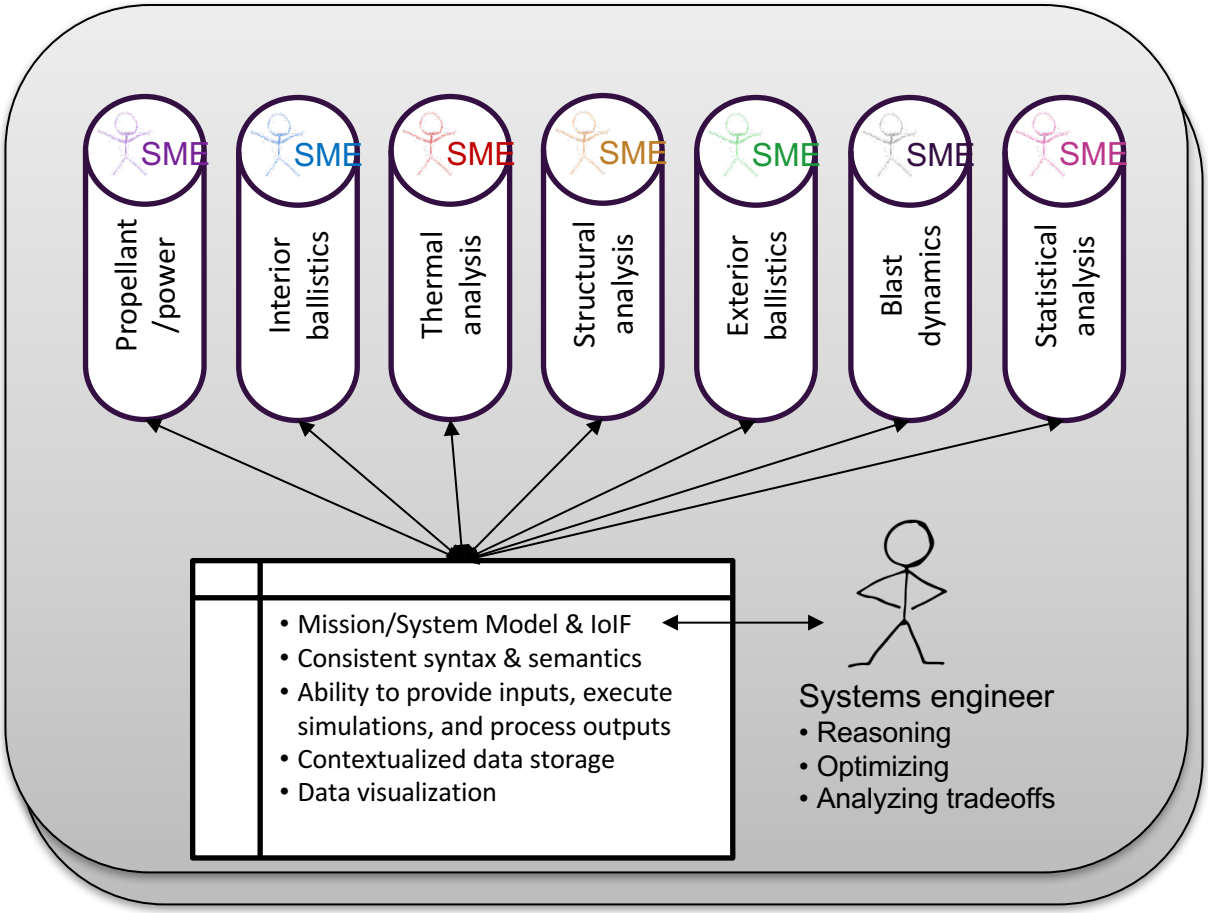
DoD DE Strategy – Discussion Framework

- DE/MBSE helps refactor and strengthen implementation of Systems Engineering principles (Goal 3)
- DE requires a formalized system/design representation that links information in an Authoritative Source of Truth (Goal 2)
  - Semantically linked system/design information to enable tradespace analyses and decision making (Goal 1)
- Need computation and methodological infrastructure for access and visualize on need-to-know basis (Goal 4)
  - Will evolve to more automated tools as it matures



Extending the DoD Digital Engineering Strategy to Missions, Systems of Systems, and Portfolios
P. Zimmerman, T. Gilbert, J. Dahmann
22nd Annual NDIA Systems and Mission Engineering Conference
Tampa, FL| 23 October 2019

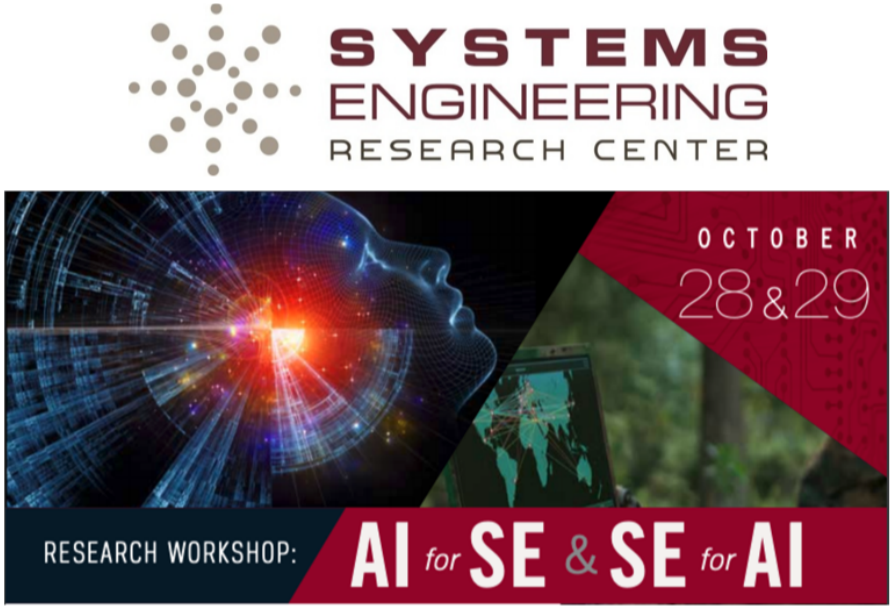
Aspirational High-level Research Vision, facilitated by Digital Engineering



Strategic/mission-level decision-maker

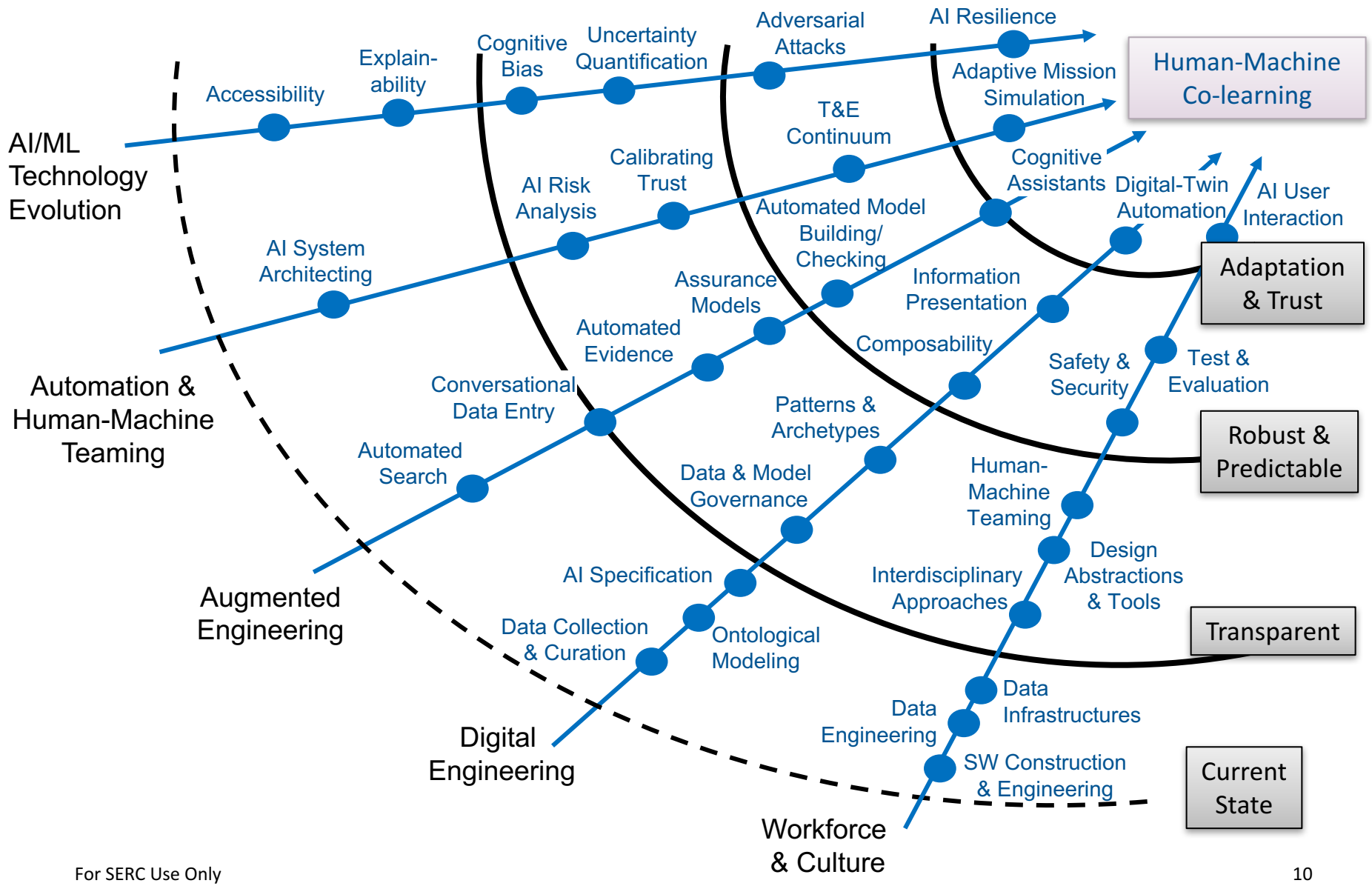
- Setting requirements & objectives
- Exploring tradeoffs
- Adjusting requirements & objectives based on capability information

SE4AI Research Workshop



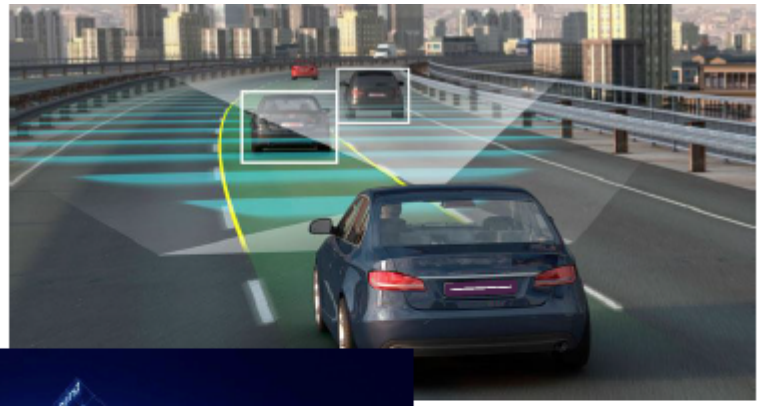
- Machine Learning/ Artificial Intelligence
- Artificial Intelligence for Systems Engineering (AI4SE)
- Systems Engineering for Artificial Intelligence (SE4AI)
- Digital Engineering

SE4AI/AI4SE Roadmap



Human-Machine Co-learning

- Adaptive Cyber-Physical-Human Systems – modeling of cyber-physical systems as influenced by humans, from requirements analysis to design

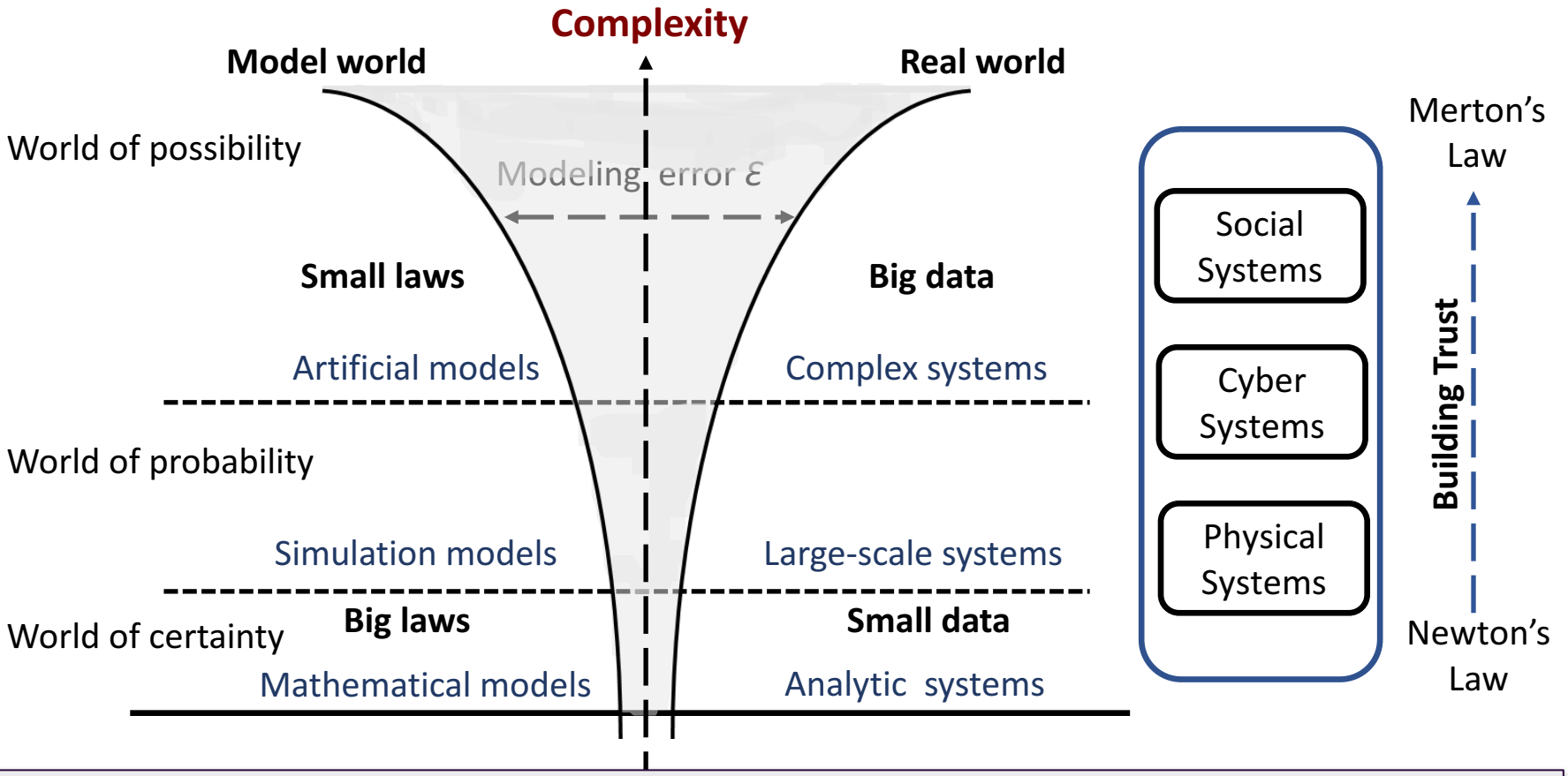


- Adaptive Mission Simulation – Computer based simulation and training that supports non-static objectives (pick-up games)

- **AI Resilience –**
  AI systems that self-adapt to changing operational boundaries while maintaining rigorous safety and security and policy constraints

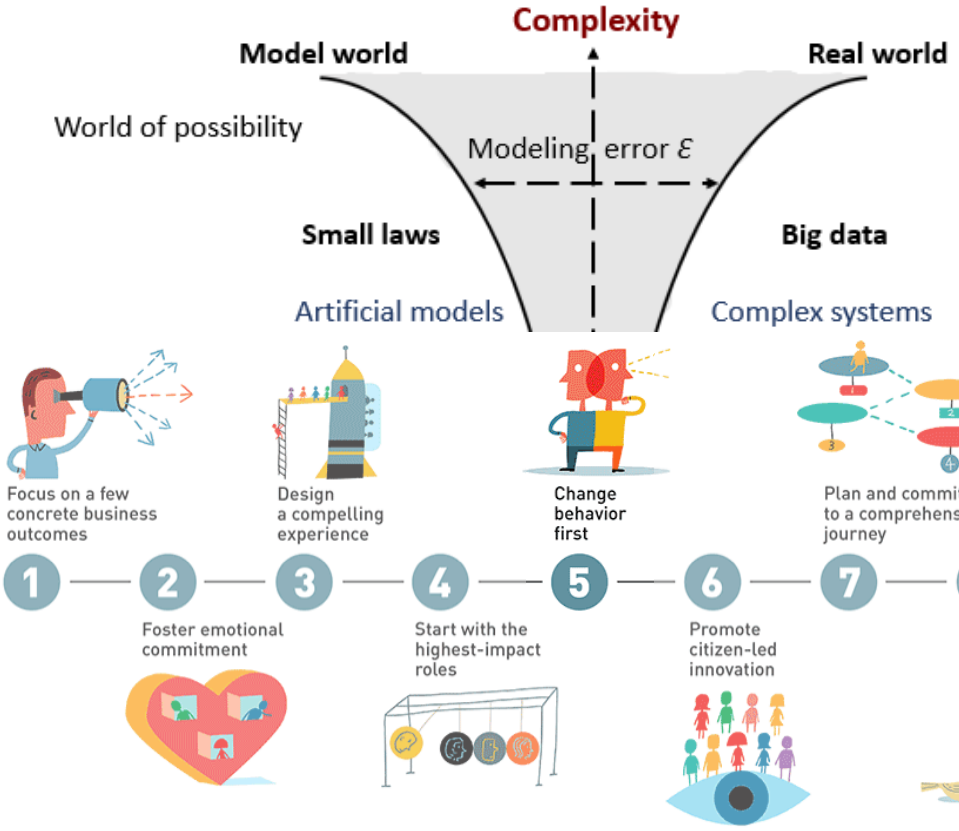
Complexity vs. Intelligence: the cognitive gap

"to generate big data from small data, then reduce big data to specific laws, where software learn from millions of scenarios to make the best decisions while interacting in parallel with real-world physical systems"



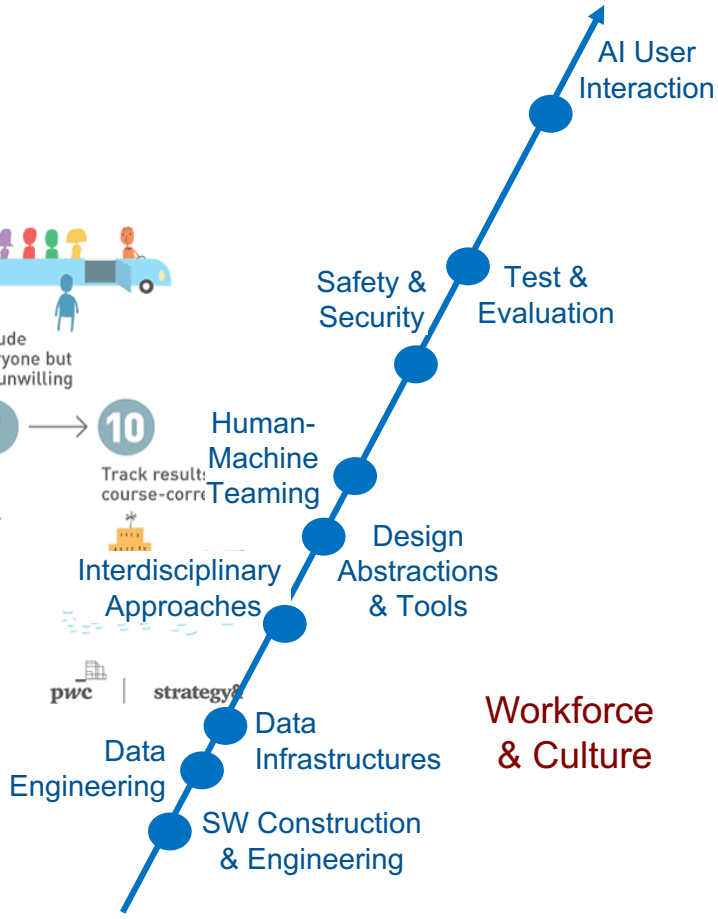
From: Wang, et al. Parallel intelligence: toward lifelong and eternal developmental AI and learning in cyber-physical-social spaces

AI: the latest workforce & cultural shift



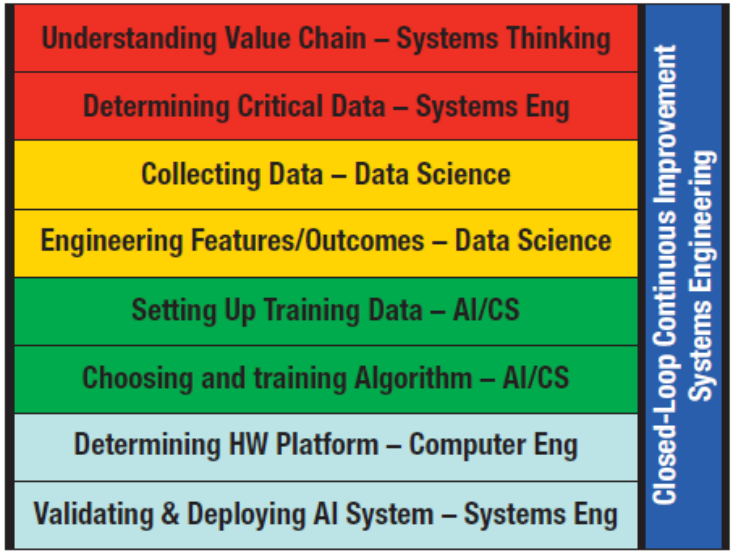
For further insights: strategy-business.com/transformwork

Infographic: Opto Design/James Yang. ©2019 PwC. All rights reserved.



Workforce and Culture

- Digital Engineering Competencies
- Integrating AI/ML experts with Domain experts, all disciplines
- Evolving tools to align with design and disciplinary abstractions =>
- Human-Machine Teaming no longer a specialty discipline



https://www.mitre.org/publications/technical-papers/human-machine-teaming-systems-engineering-guide

- Threat models, safety, security, resilience, and other 'iliities
- Evolving test and evaluation competency
- Training the Users to appropriately interact with AI's

Wade, J., Buenfil, J. and Collopy, P. (2020), A Systems Engineering Approach for Artificial Intelligence: Inspired by the VLSI Revolution of Mead & Conway. INSIGHT, 23: 41-47.

Digital Engineering Competency Framework (DECF)

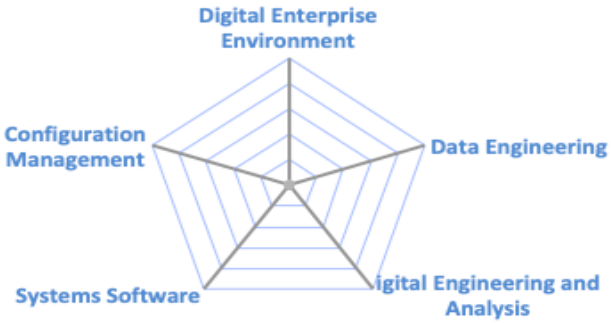
There are 5 competency groups and 22 competencies identified for the DECF

1. Digital Enterprise Environment		
Digital Enterprise Environment Development	1	Digital Environment Development
Digital Enterprise Environment Management	2	Management
	3	Communications
	4	Planning
Digital Enterprise Environment Operations and Support	5	Digital Environment Operations
	6	Digital Environment Support
Digital Enterprise Environment Security	7	Digital Environment Security

5. Configuration Management	
22	Configuration Management

2. Data Engineering	
8	Data Governance
9	Data Analytics

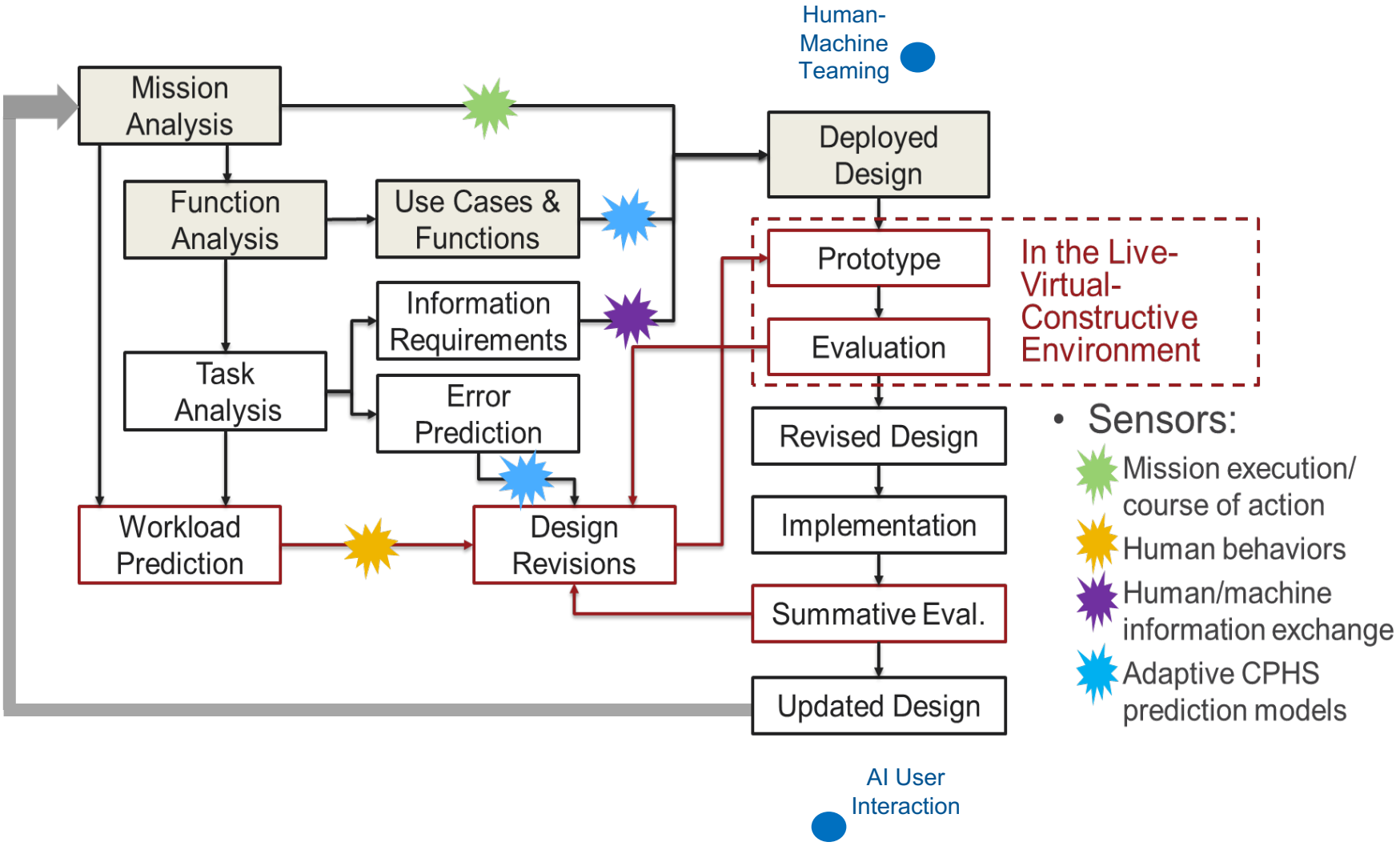
4. Systems Software	
20	Software Construction
21	Software Engineering



3. Digital Engineering and Analysis		
Modeling, Simulation, and Analysis	10	Modeling, Simulation, and Analysis
Coaching and Mentoring	11	Coaching and Mentoring
Systems Engineering	12	Model-Based Systems Engineering Process
	13	Digital Architecting
	14	Digital Requirements Modeling
	15	Digital Verification
Systems Engineering Management	16	Digital Model-Based Reviews
	17	Project Management
	18	Organizational Development
	19	Digital Engineering Policy and Guidance

Foundational Digital Competencies

Systems Engineering with an HMT viewpoint



Challenges for Test & Evaluation of AI

- Testing & Evaluation is a continuum
  - —Information accumulates over time across varying operating envelopes

Freeman, L. (2020), Test and Evaluation for Artificial Intelligence. INSIGHT, 23: 27-30.

- The continuum does not end until the system retires
- Integrating information from disparate data sources requires methods
  - —Integrating different data under 1 model to draw conclusions at appropriate levels
- Data Management is foundational
- AI systems require a probabilistic risk-based approach
- Previous test metrics apply, but may have different interpretations
  - —Task & mission level performance, course of action, non-functional requirements
- An expanded definition of threat is necessary
- Operational relevance is essential
- All AI areas need testbeds
- The T&E workforce and culture must evolve

AugI - Transforming Engineering

- "The most critical gap in fundamental engineering today results from the design and analysis teams losing sight of long term outcomes in the midst of technical complexity
- "The right people are not available at the right time for decision making

  ...or are waiting impatiently
- "The volume of information is too great
- "Analyses are triggered by questions we decide to ask, not by new information in the flow of data"

Source: Neches and Madni, Towards Affordably Adaptable and Effective System Vol. 16, No. 2, 2013

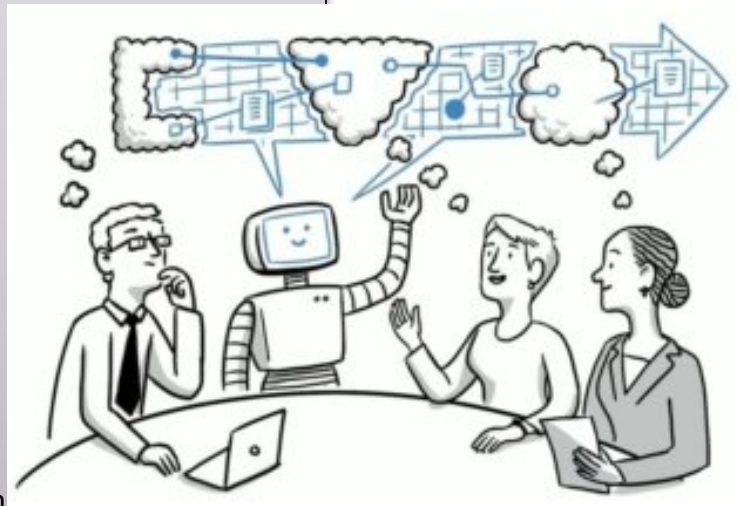
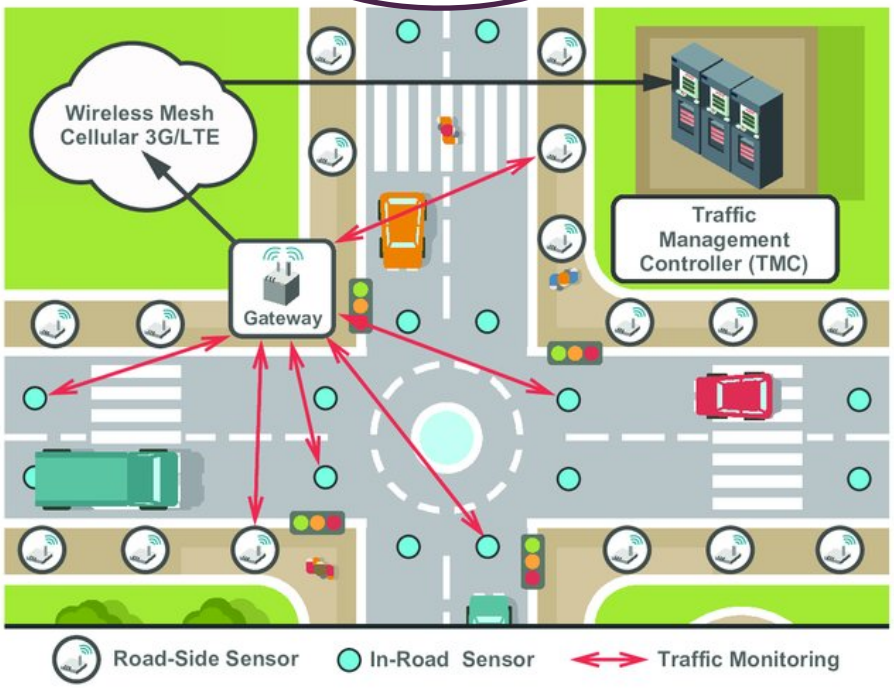


Image: https://internetofbusiness.com/ai-will-augment-and-diversify-human-thinking-says-tata-communications/

A Vignette: Autonomy Enabled SE and a Traffic Management Digital Twin

5pm in San Francisco: A momentary power glitch causes city traffic sensors and the command center to lose time synchronization. Resetting the system does not clear the problem.



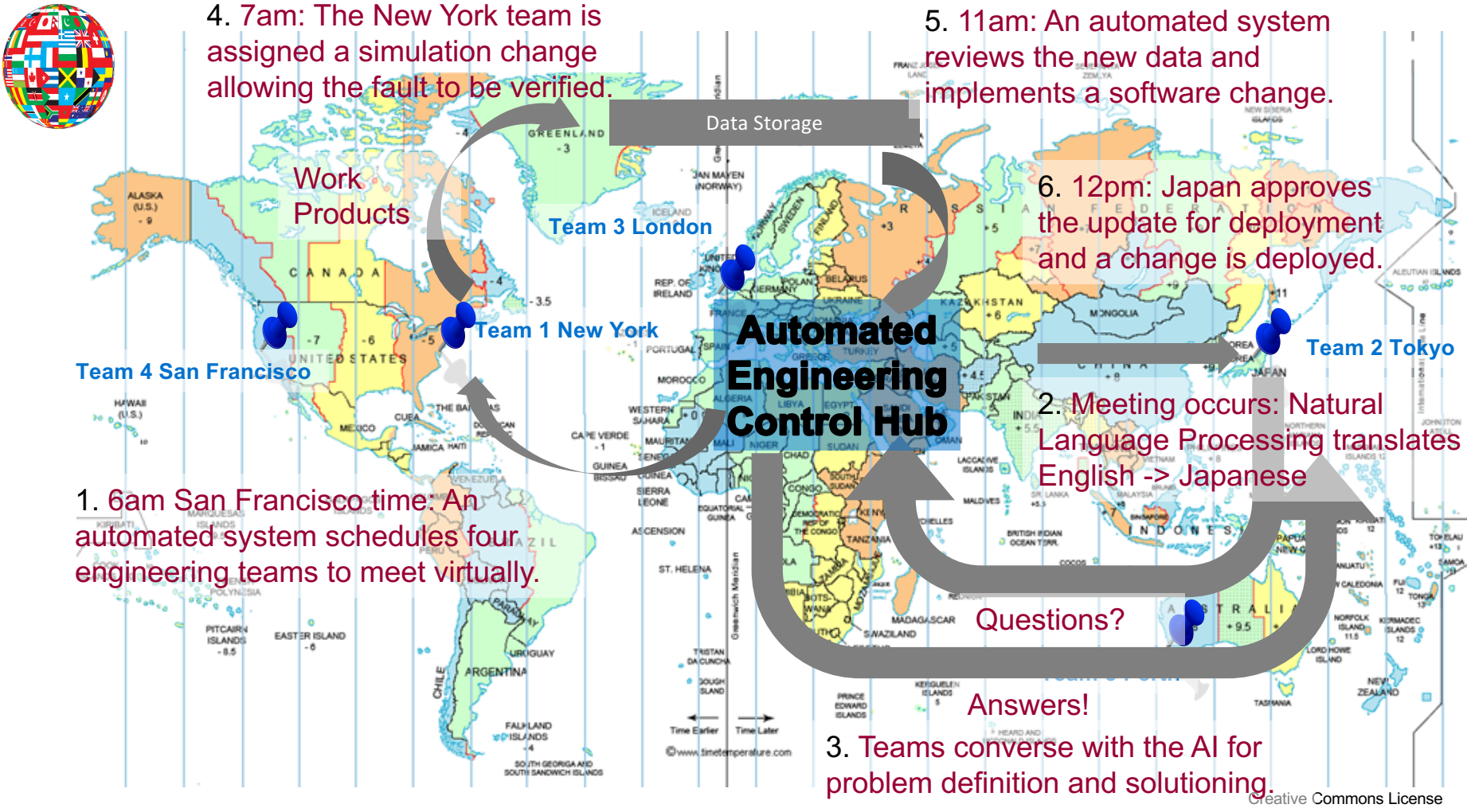
A Harmonized Perspective on Transportation Management in Smart Cities: The Novel IoT-Driven Environment for Road Traffic Modeling, Sensors 16(1872)

Overnight: Automated processes run thousands of simulations and cannot replicate the problem. The AI decides to call an engineering team together.

https://executive-bulletin.com/other/etisalat-digital-and-ericsson-demonstrate-unified-iot-platform-for-smart-traffic-management-at-gitex-2018

❖ **Presented at INCOSE 2019, courtesy INCOSE Future of SE Initiative**

AI for SE in Day to Day Operations



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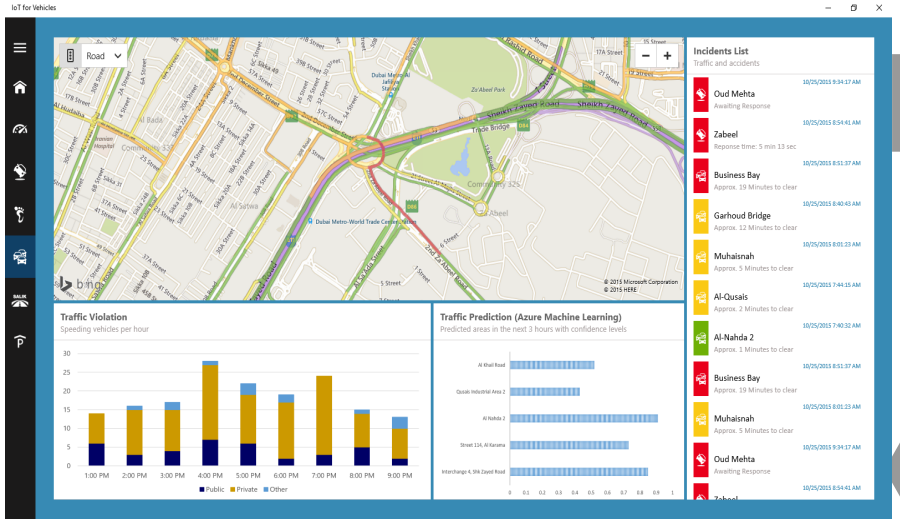
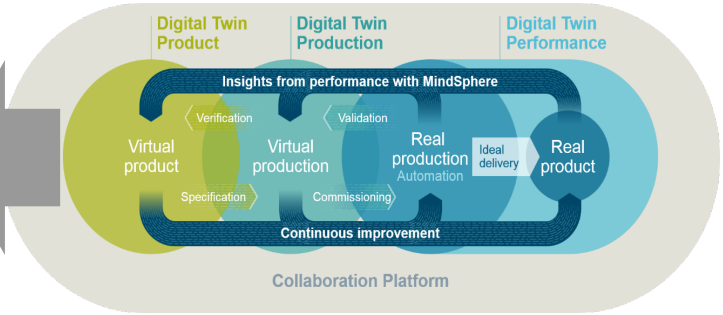
Will we be able to Trust this level of Automation?

- **Fully-automated data search & Model building**



https://blogs.msdn.microsoft.com/msgulfcommunity/2015/11/03/iot-for-cars-connected-cars-and-virtual-radars-gitex-2015-innovation-demo/

- **Man-Machine teaming with Cognitive engineering assistants**

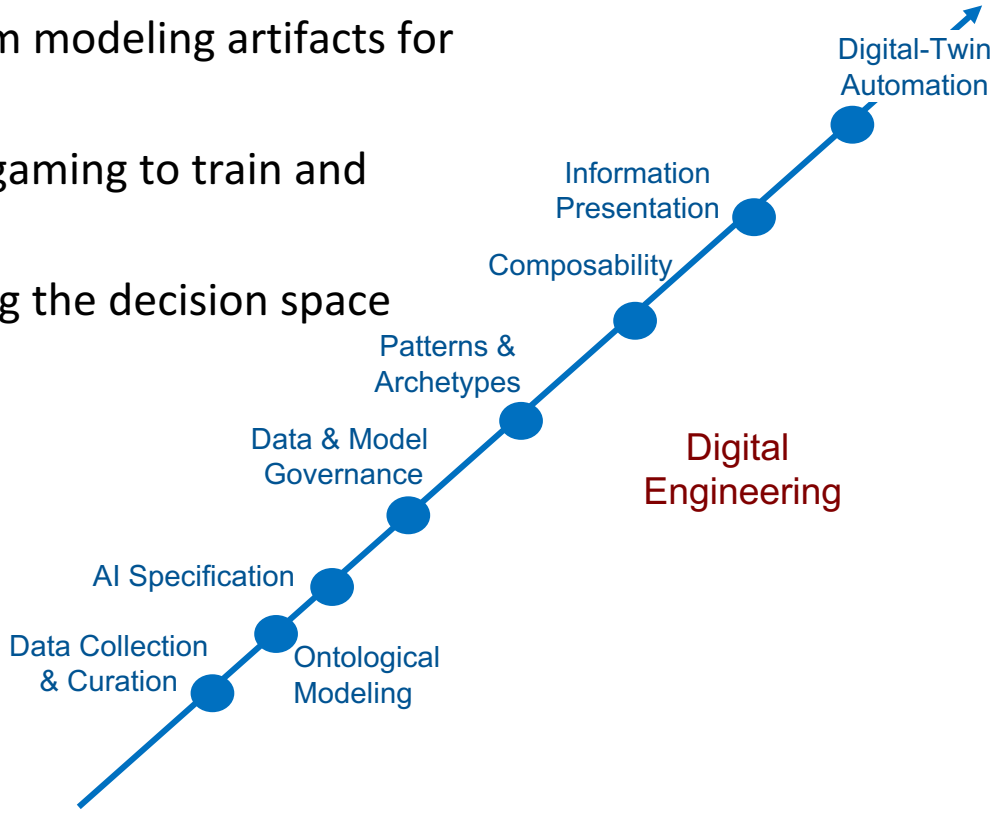


- **Continuously operating and updated Mission level Digital Twin simulations**

Full Lifecycle Integration

AI Enabled Digital Engineering

- AI Curation - data collection, management, curation and governance to support evolving application of AI capabilities – scale of the data at issue
- Ontological Modeling – move from schematic representation to semantic representation
- AI Specification – what will be allocated to the machine, in both product and process
- Patterns and Archetypes – learning from modeling artifacts for creating and checking
- Composability – use of simulation and gaming to train and evaluate ML in contexts
- Information Presentation – representing the decision space for human understanding and learning
- **Digital Twin Automation – real-time continuous learning from real system and shadow simulations**
  - **From zero history to unlimited history?**



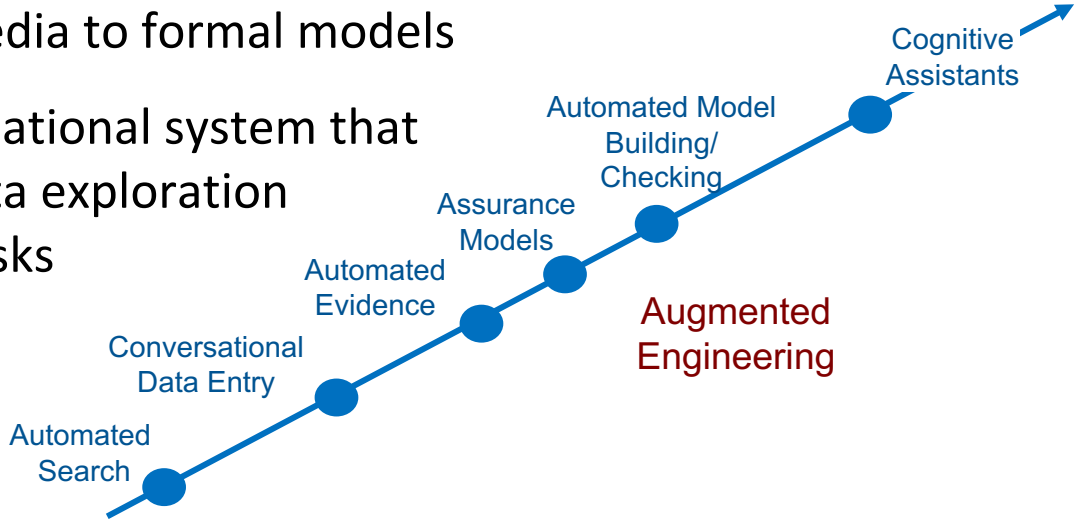
Architectural Implications of AugI

- Inspectable, explainable, potentially suboptimal algorithms preferred to opaque/black-box optimization techniques
- Flexible human-AI collaboration at multiple levels based on problem context, tasks
- Shared contextual awareness especially during adaptive collaborative response
- Selective information aggregation to maximize situation and contextual awareness (context-sensitive declutter) without cognitive overload
- Mutual augmentation to maximize joint performance
- Mutual learning of priorities/preferences in different engineering/ operational contexts
- Shift from traditional human-AI function allocation to human-AI synergy exploitation across various contexts

Madni, A.M. (2020), Exploiting Augmented Intelligence in Systems Engineering and Engineered Systems. INSIGHT, 23: 31-36.

Systems Engineering Process Evolution

- Automated Search – improving time consuming data gathering and analysis
- Automated Evidence – formal methods and processes that move from explicit verification of composition to evidence building
- Assurance Models– anticipating system emergence (failures, etc.) from design & operational data
- Automated Model Building/Checking – finding patterns and archetypes in modeling artifacts for creating and checking
- Conversational data entry: human-computer interaction processes to convert natural language and other media to formal models
- Cognitive Assistant – a conversational system that automates many mundane data exploration and engineering calculation tasks



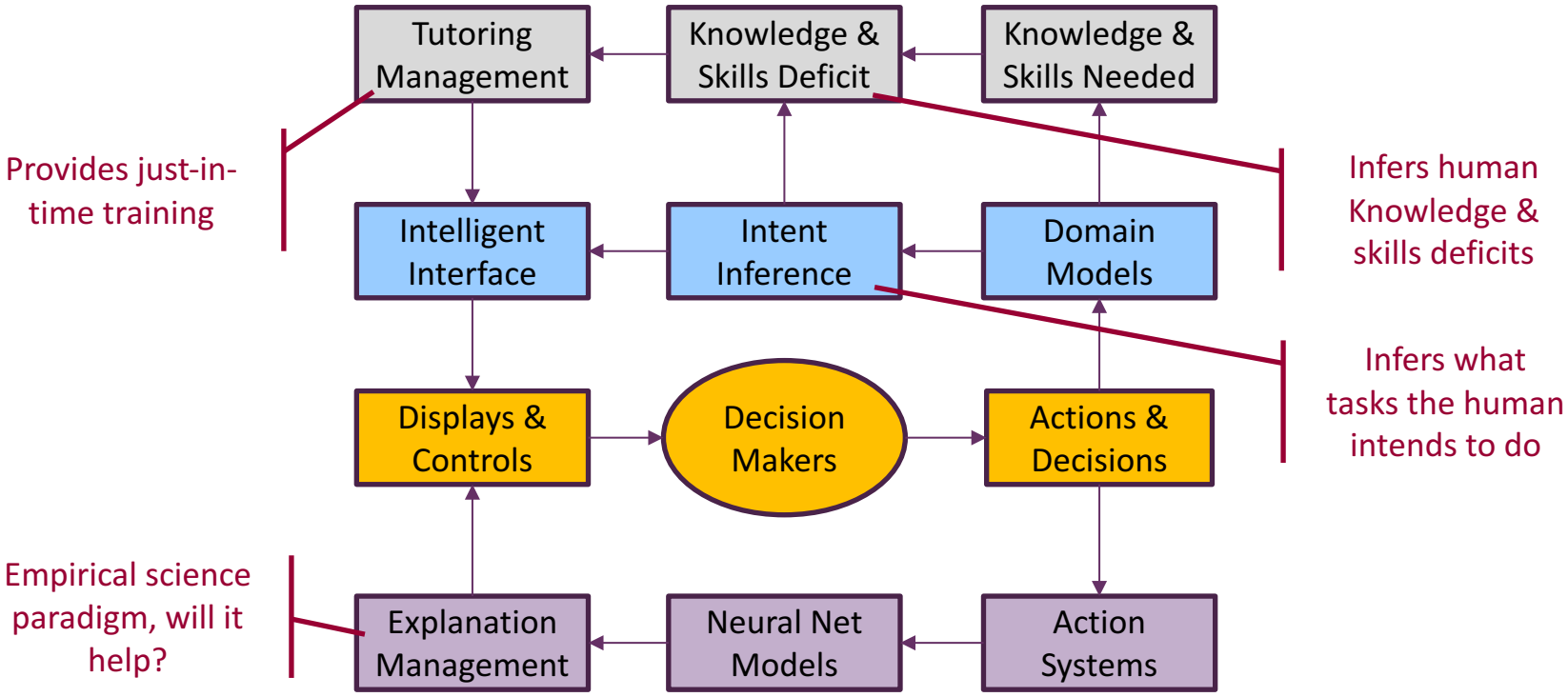
Sample research: AI/ML in model building and checking

- Checking for typical error archetypes:
  - —Ability to assert completeness of a specification
  - —Ability to assert completeness of an input-state-behavior space
- Ability to assist in learning and narrowing a trade space*
  - —Human-machine interaction improves option selection
  - —Human-machine interaction decreases human learning
- Human-Machine Team: AI/ML identifies missing behaviors and human adds them to the model
  - —Model must be explainable
  - —AI must assist the designer in explaining its decisions

*Fostering human learning from cognitive assistants for design space exploration – D. Selva (Texas A&M University)

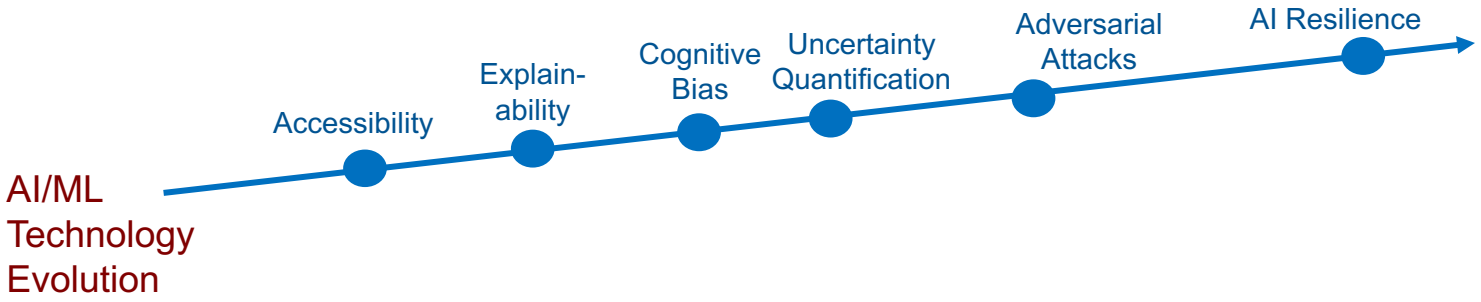
Architecture for Augmented Intelligence

- "Humans see displays and controls, and decide and act. Humans need not deal with anything other than these three architecture elements. The overall system frames human's roles and tasks and provides support accordingly."



Rouse, W.B. (2020), AI as Systems Engineering Augmented Intelligence for Systems Engineers. INSIGHT, 23: 52-54.

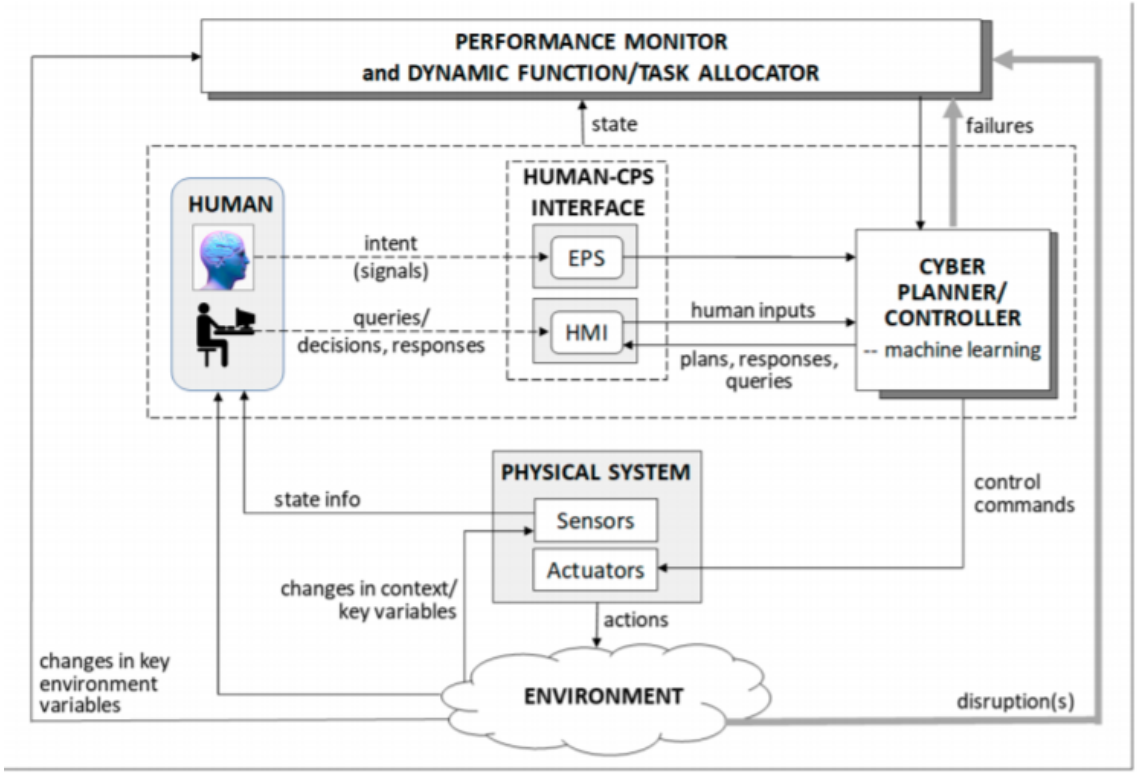
Evolution of AI/ML Technology



- Make the algorithms and methods accessible
- Make the AI/ML decision space explainable and teachable
- Address intentionally or unintentionally misleading decision-making in AI systems
- Quantify the probabilistic nature of these algorithms
- Characterize the performance outside of design boundaries

Testbeds

- Capturing human behavior models
- Evaluating time varying processes in human and machine contexts
- Human cognitive & emotional state determination
- Dynamically allocating tasks and functions based on contextual change



Madni and Madni, Architectural Framework for Exploring Adaptive Human-Machine Teaming Options in Simulated Dynamic Environments, Systems 2018, 6, 44

Motivating a new SE Evaluation Framework

Evaluations must align with the new problem and system behavior space induced by the cascading effects of new 1) mission requirements 2) capabilities and 3) problem sets and system behavior.

Capabilities → Problem Sets and System Behavior → Evaluation Coverage and Capability

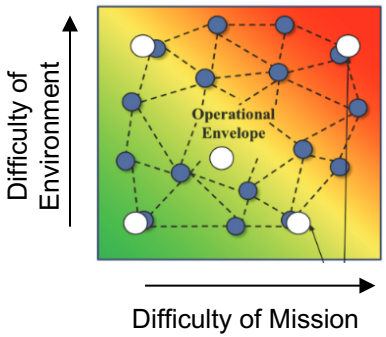
1. New mission requirements motivate the development of more capable AI systems, albeit with new challenges.

Old		New	
• "Weak" AI • Rule-Based • Expert Systems • Control Systems	• Theoretically sound • Generalize poorly • Hand-crafted	• "Strong" AI • Machine Learning	• Generalize better • Theoretically weak • Low intelligibility
Linear Models Kernel Methods	• High Bias • Computationally "hard"	Neural Networks	• Low Bias • Expressive • High Variance • Unstable Training
"Small Data"	• Not representative • of population	"Big Data"	• Low signal-noise

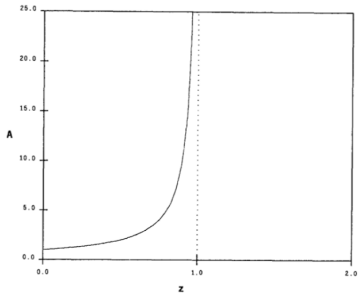
2. Now capable of handling more challenging environments.

Old	New
Observable	Partially-Observable
Static	Dynamic
Deterministic	Stochastic
Discrete	Continuous
Low Dimensionality	High Dimensionality
	Adversarial
	Distributed

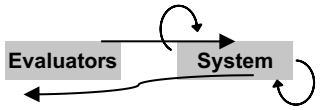
1. New capabilities enable the introduction of new problem sets and the challenges therein.



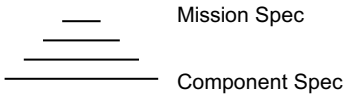
2. Emergent behavior with scale



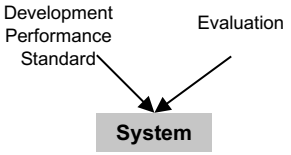
1. Internal vs External Evaluation



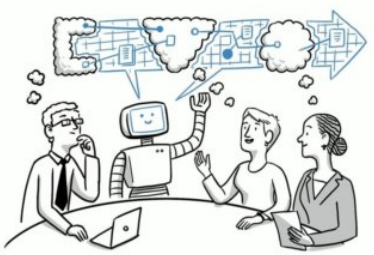
2. Level of Evaluation



3. Development vs Evaluation Vanishing Boundary



Summary: Key AI/Autonomy Research Goals



- **AI for SE:** AI/ML to support the practice of SE
  - —Support scale in digital model construction
  - —Create confidence in design space exploration
- **SE for AI:** SE approaches to systems with AI/ML capabilities
  - —Principles of learning-based systems design
  - —Models of life cycle evolution, Model curation methods
- **Lifecycle Ready AI:**
  - —AI-related agility: new SE methods and tools that anticipate adaptation
  - —Technical and management policies for assurance
- **Systems Validation of AI:**
  - —Early visibility for deployment, validation of post-deployment changes
  - —System level testbeds – to study systems, not just data & algorithms

Questions and Discussion