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Digital Engineering and AI – Transformation of Systems Engineering

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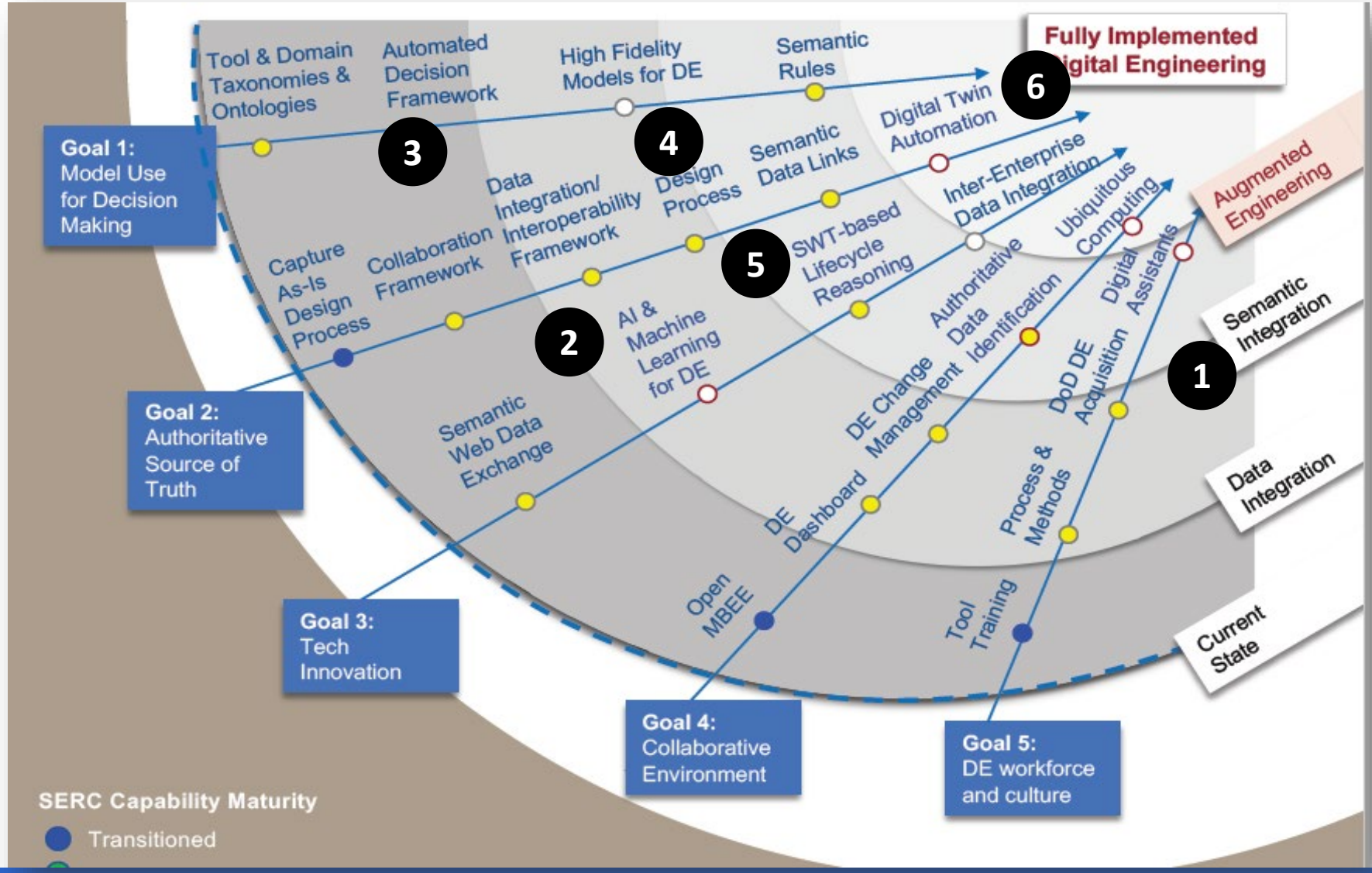
the Future of Systems Engineering

- 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

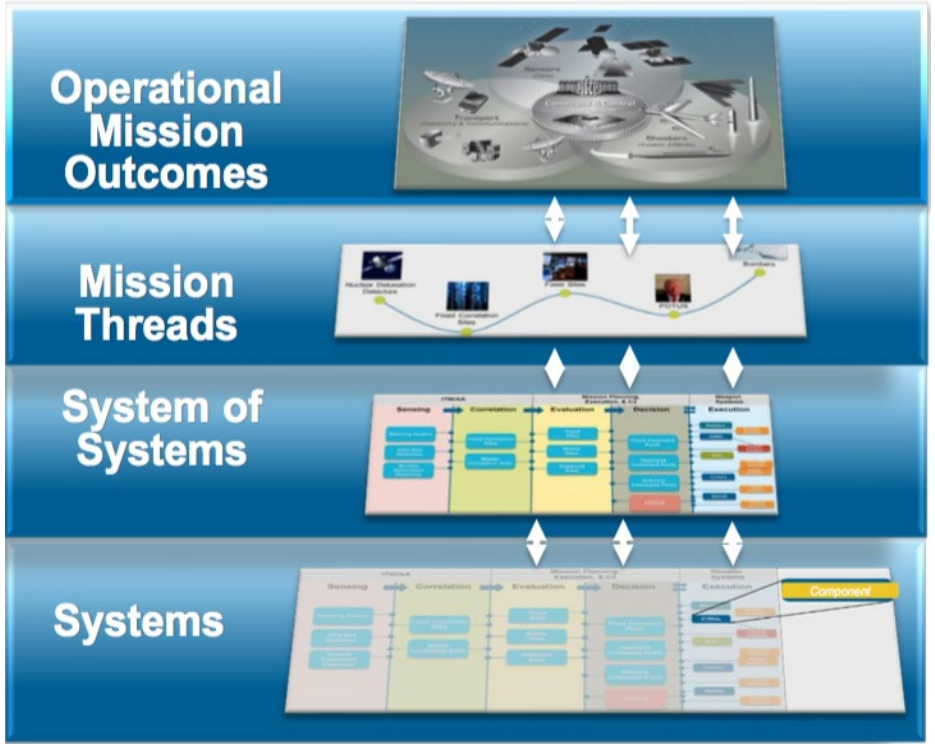
But first: SERC Digital Engineering Roadmap



1. Richer degree of semantics, automation
2. Adopt semantic technologies & tools
3. Formalize information related to domain & disciplinary ontology
4. Create interoperability across domains & disciplines
5. Automated reasoning to support decision making
6. Continue to do this across the product lifecycles

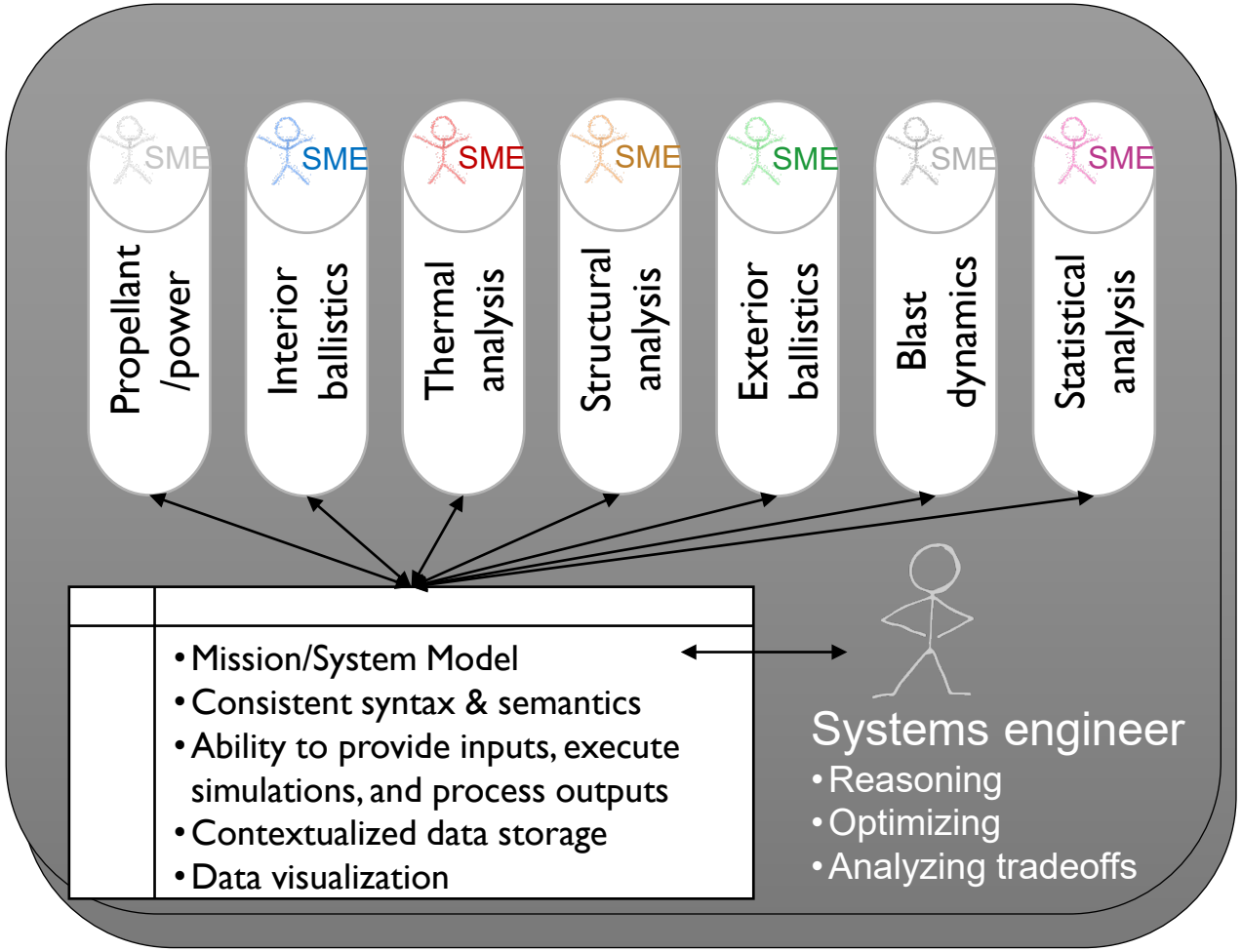
DoD DE Strategy – Discussion Framework

- 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

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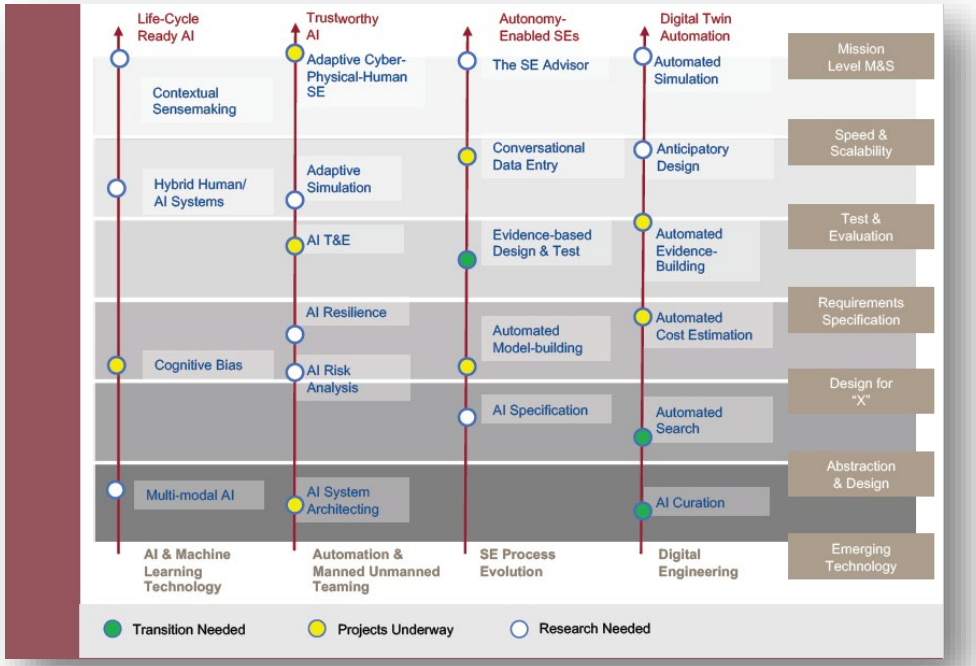
INCOSE INSIGHT: SERC AI Roadmap

Initial Roadmap



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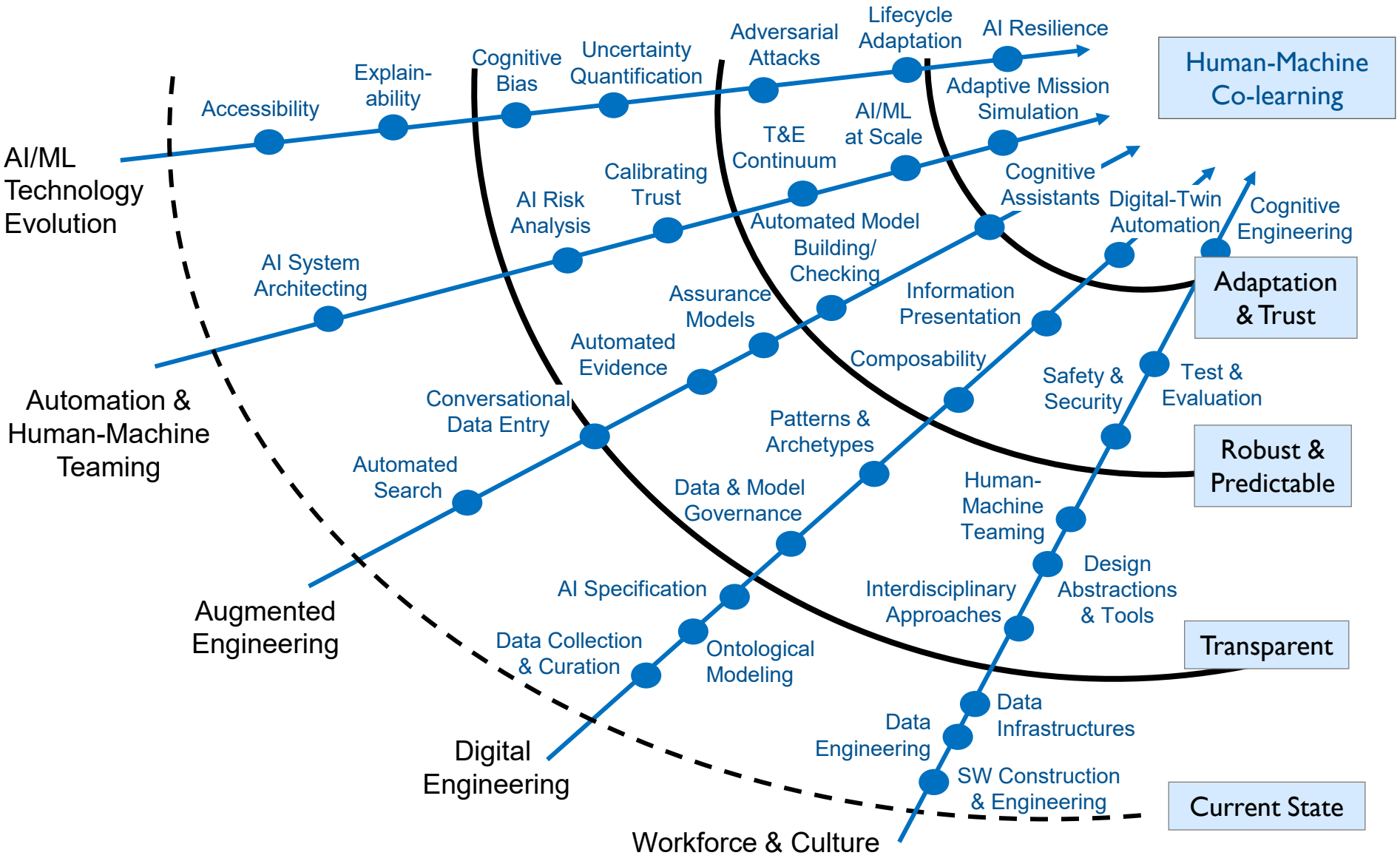
SE4AI/AI4SE Roadmap



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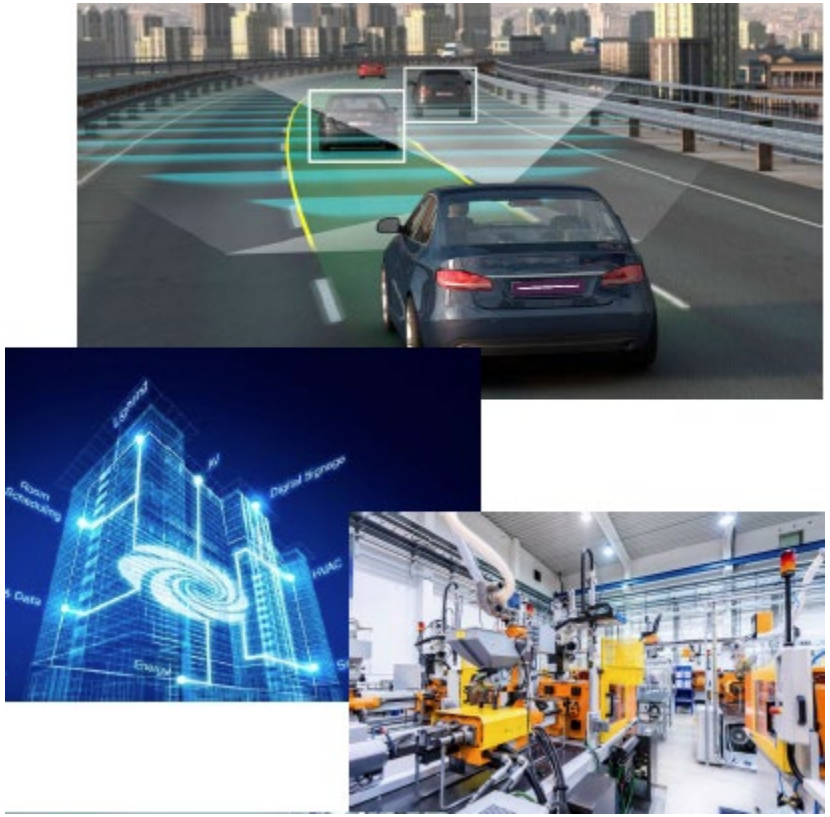
Human-Machine Co-learning

- 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



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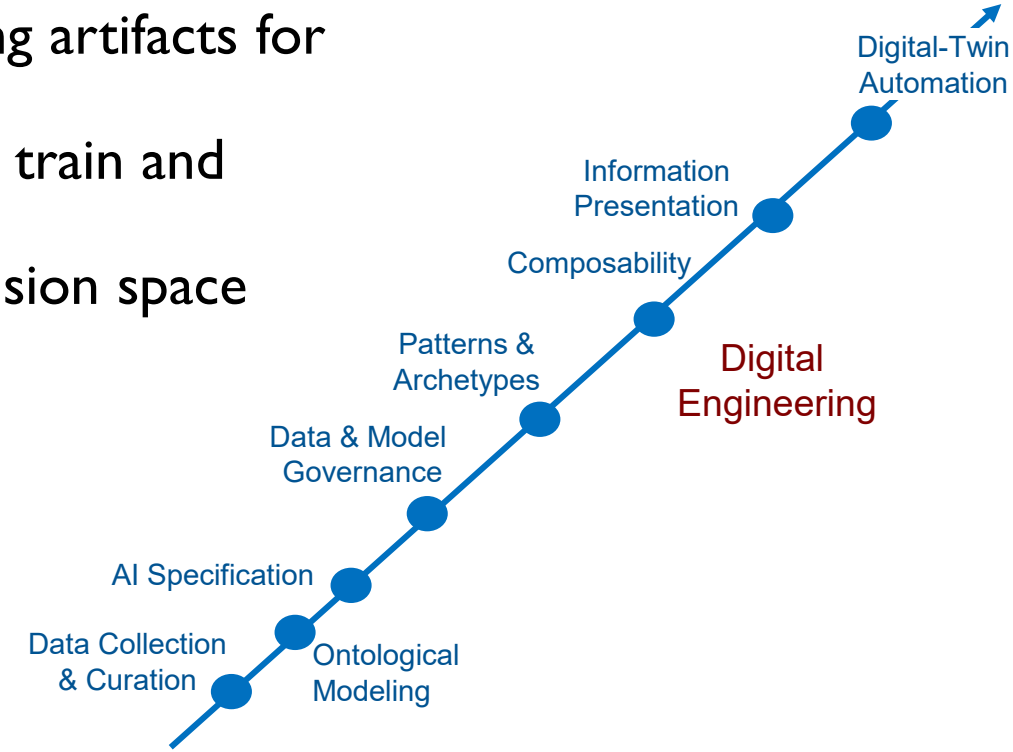
AI Enabled Digital Engineering

- 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?



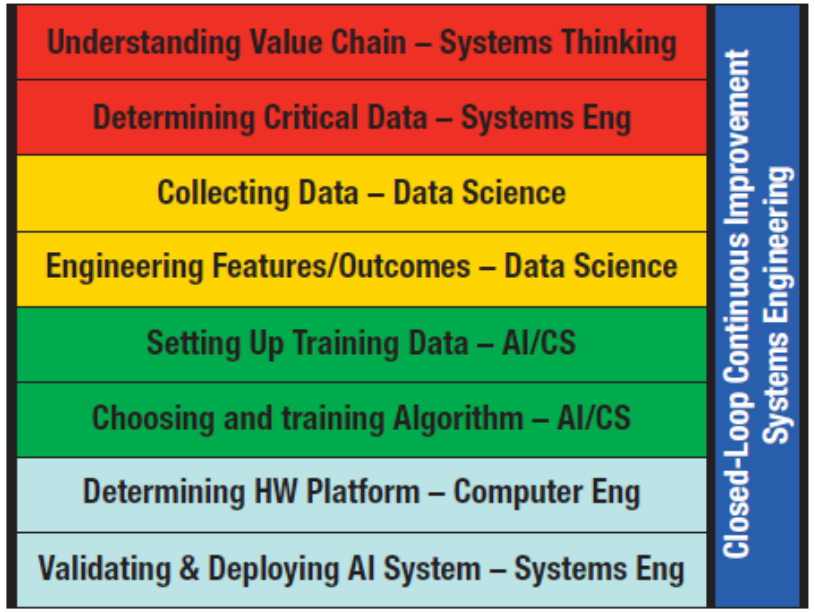
The Digital (Mission) Twin

- A digital twin is a virtual world model of a physical system, product, process, or service that is continuously updated to mirror real-world performance.
- A digital (mission) twin operates as a mission level simulation using digital twins to continuously monitor and improve human-machine interactions.

Image: www.geospatialworld.net/videos/what-is-digital-twin-how-does-it-work/

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



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.

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

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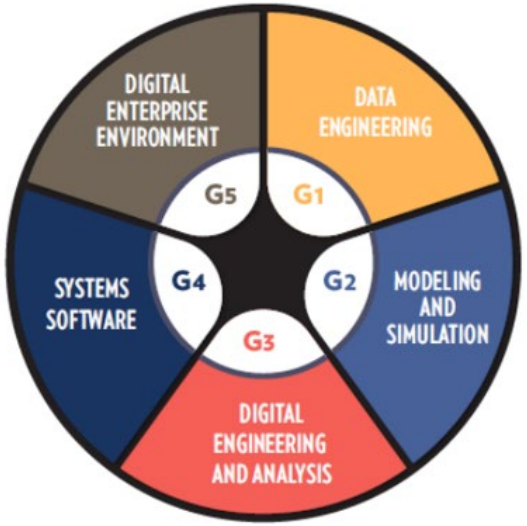
Role & Competency Frameworks

Archetype	Description	Concentration
Lead AI	Decides policy and doctrine, including how AI tools can or will be used; builds AI vision and plan	Policy
		Command
		Agency/Function Lead
Drive AI	Ensures appropriate AI tools and capabilities are developed and delivered across DOD	Acquisitions Manager
		Capability Manager
		Technical Manager
		Product Manager
Create AI	Creates AI tools to meet current and future needs	AI Researcher
		AI/ML Engineer
		Testing & Evaluation Engineer
		Data Scientist
		Deployment Engineer
Embed AI	Embedded with Employ AI, establishes AI systems and provides end-user support at tactical edge	Technician
Facilitate AI	Represents users to ensure appropriate AI tools are developed and delivered to address use cases	Product Owner
		UI/UX
		Other Technical Experts
Employ AI	End-users of AI tools, provide feedback on and requirements for AI tools	Operations
		Intelligence
		Logistics & Maintenance
		Health
		Support

2020 DoD Artificial Intelligence Education Strategy



FOUNDATIONAL DIGITAL COMPETENCIES	
F1	Digital Literacy
F2	Digital Engineering Value Proposition
F3	DoD Policy/Guidance
F4	Coaching and Mentoring
F5	Decision Making
F6	Software Literacy

LEGEND:
C# - Competency Title
F# - Foundational Competency Title
G# - Competency Group
S# - Competency Subgroup

G1 DATA ENGINEERING			
S1	Data Engineering	C1	Data Governance
		C2	Data Management
G2 MODELING AND SIMULATION			
S2	Modeling and Simulation	C3	Modeling
		C4	Simulation
		C5	Artificial Intelligence/Machine Learning
		C6	Data Visualization
		C7	Data Analytics
G3 DIGITAL ENGINEERING AND ANALYSIS			
S3	Digital Systems Engineering	C8	Digital Architecting
		C9	Digital Requirements Modeling
		C10	Digital Validation and Verification
		C11	Model-Based Systems Engineering Processes
S4	Engineering Management	C12	Digital Model-Based Reviews
		C13	Project and Program Management
		C14	Organizational Development
		C15	Digital Engineering Policy and Guidance
		C16	Configuration Management
G4 SYSTEMS SOFTWARE			
S5	Systems Software	C17	Software Construction
		C18	Software Engineering
G5 DIGITAL ENTERPRISE ENVIRONMENT			
S6	Digital Enterprise Environment Development	C19	Digital Environment Development
S7	Digital Enterprise Environment Management	C20	Management
		C21	Communications
		C22	Planning
S8	Digital Enterprise Environment Operations and Support	C23	Digital Environment Operations
		C24	Digital Environment Support
S9	Digital Enterprise Environment Security	C25	Digital Environment Security

Digital Engineering Competency Framework (DECF)

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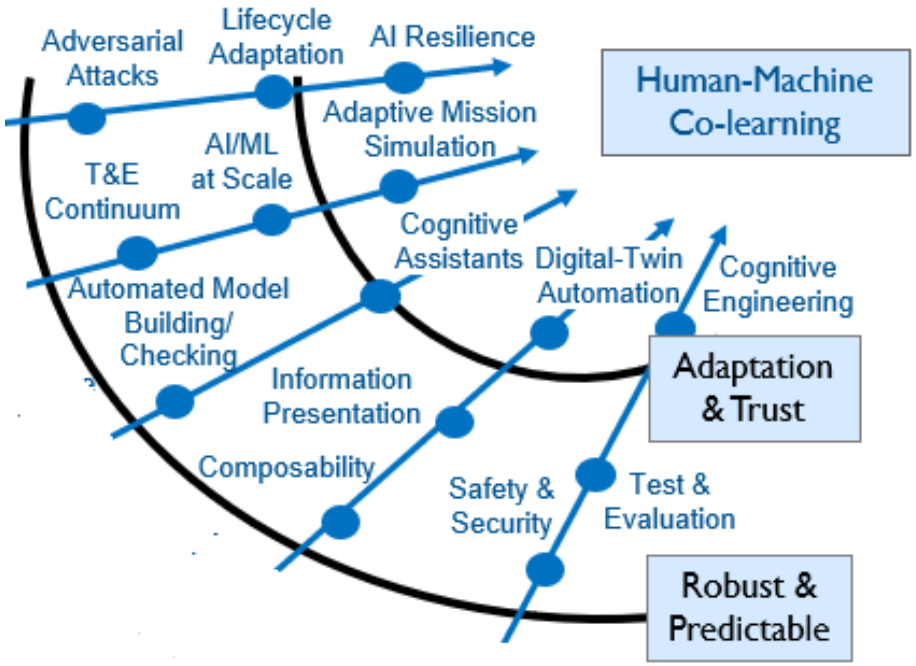
Challenges for Test & Evaluation of AI

- Testing & Evaluation is a continuum
  - Information accumulates over time across varying operating envelopes
- Lifecycle Adaptation
  - The continuum does not end until the system retires
- All AI areas need testbeds
- Operational relevance is essential
- Data Management is foundational
- Integrating information from disparate data sources requires methods
- 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
- The T&E workforce and culture must evolve



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

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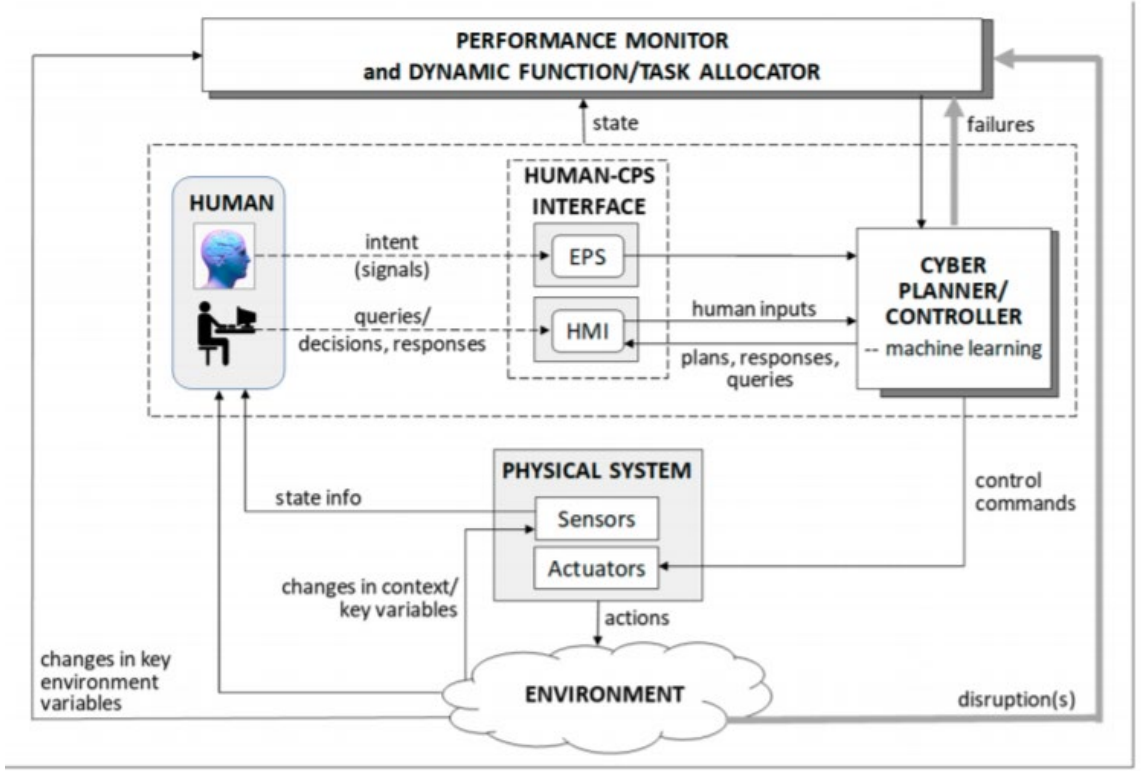
Testbeds

- 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

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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 Systems, Systems Engineering Vol. 16, No. 2, 2013

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

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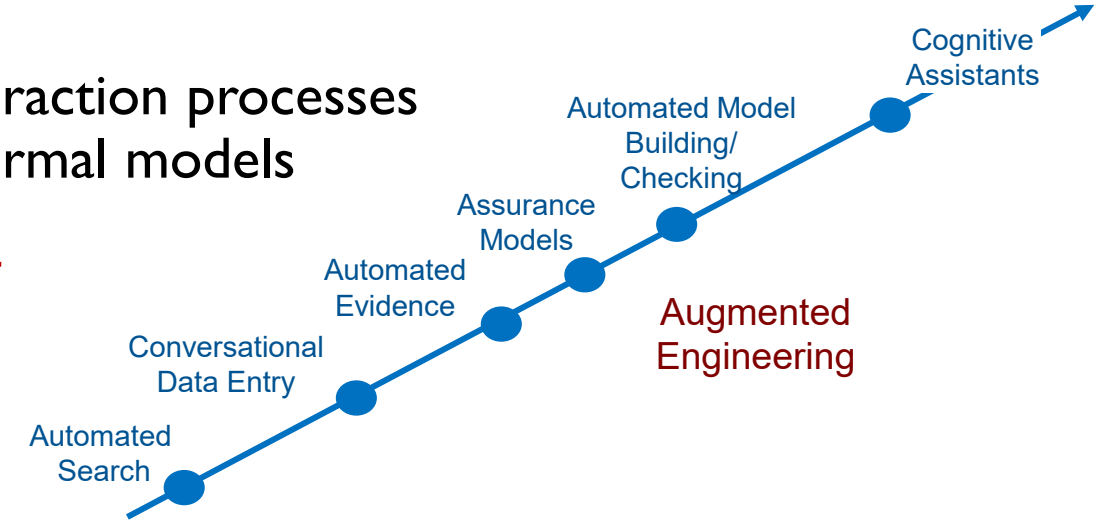
Systems Engineering Process Evolution

- 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



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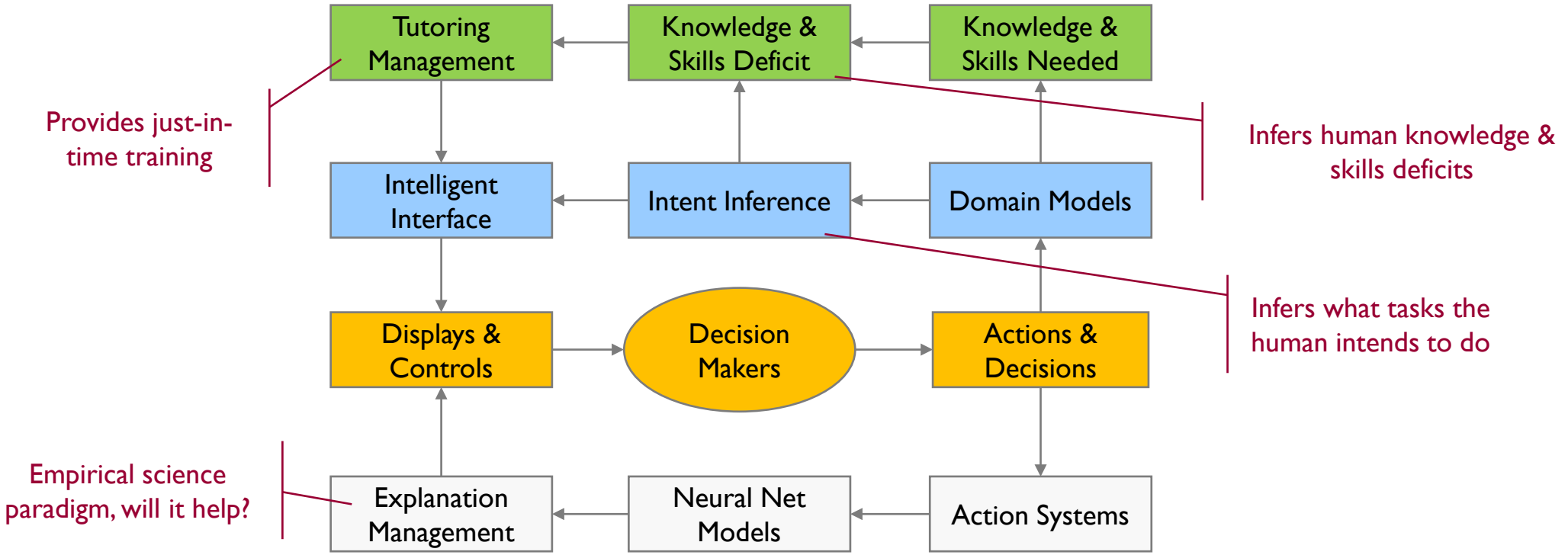
Architecture for Augmented Intelligence

- "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.

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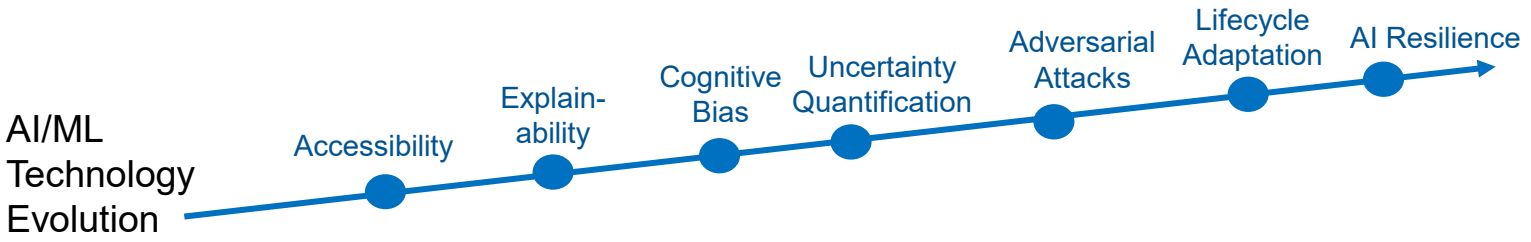
Evolution of AI/ML Technology



- Workforce: Make the algorithms and methods accessible
- Technology: 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
    - Address changing characteristics of real systems
      - System-level behaviors with system-level resilience

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Summary: Key AI/Autonomy Research Goals

- AI4SE: AI/ML to support the practice of SE
  - Support scale in digital model construction
  - Create confidence in design space exploration
- SE4AI: SE approaches to systems with AI/ML capabilities
  - Principles of learning-based systems design
  - Models of life cycle evolution, Model curation methods
- Systems Lifecycles for 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

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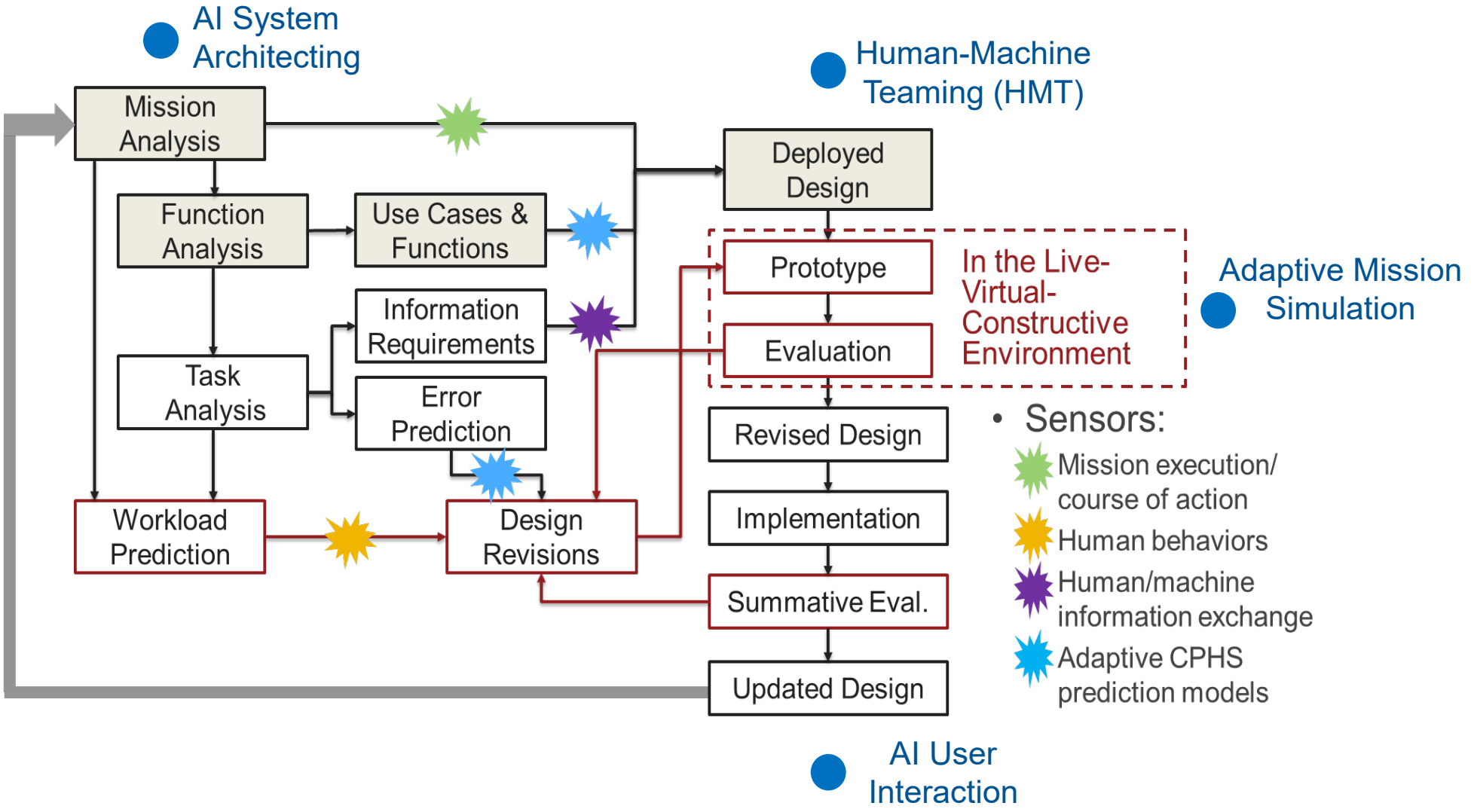
Systems Engineering with an HMT viewpoint



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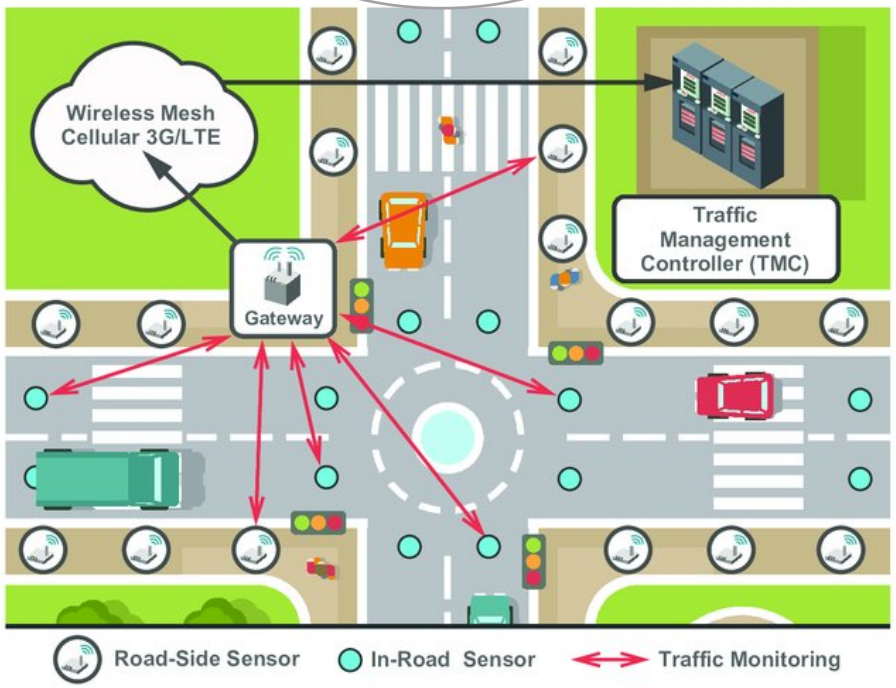
A Vignette: Autonomy Enabled SE and a Traffic Management Digital Twin

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**

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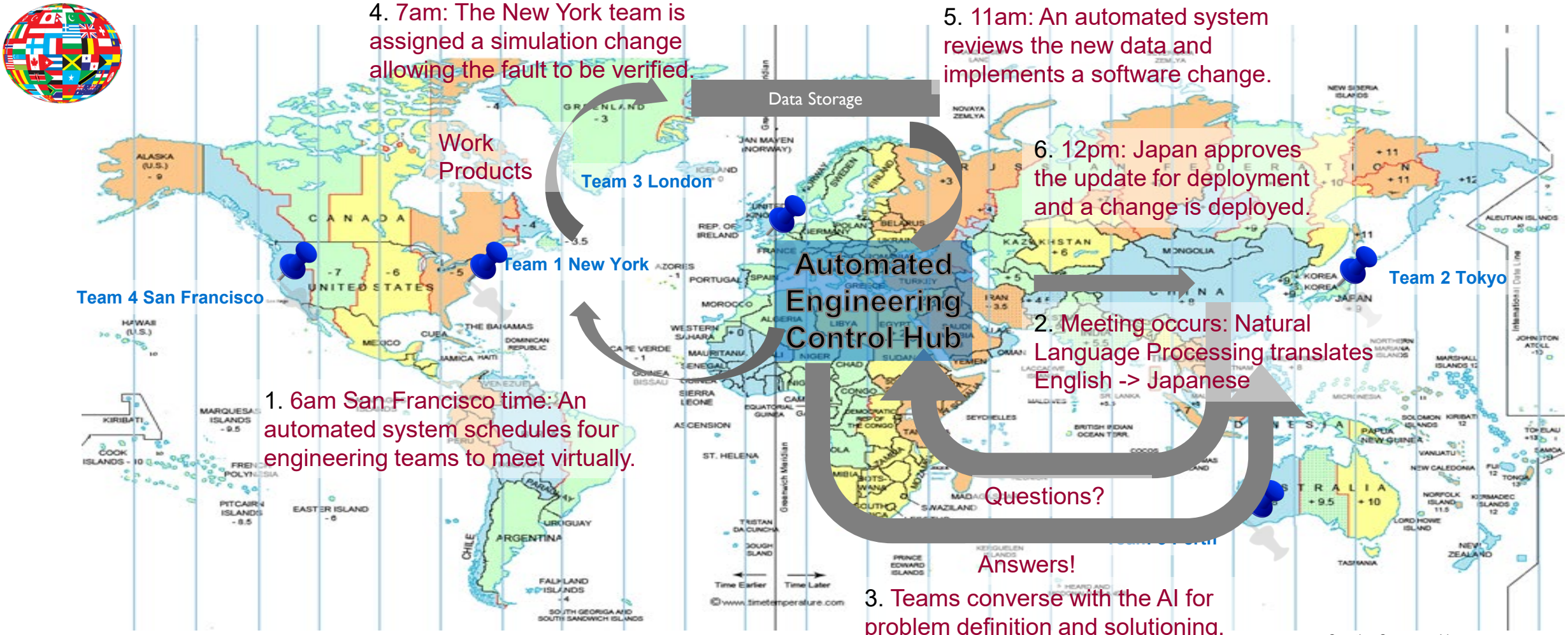
AI for SE in Day to Day Operations



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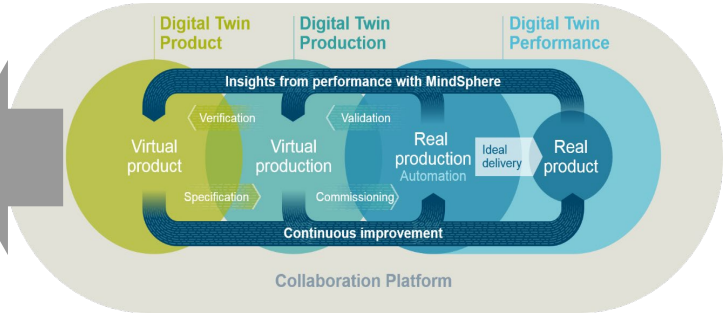
Will we be able to Trust this level of Automation?

- **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

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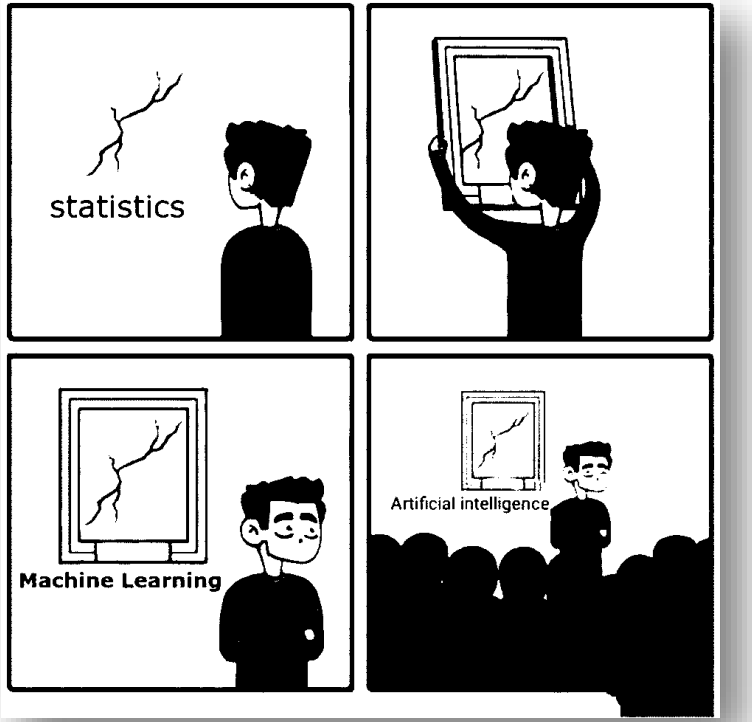
Real Problems

"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/)

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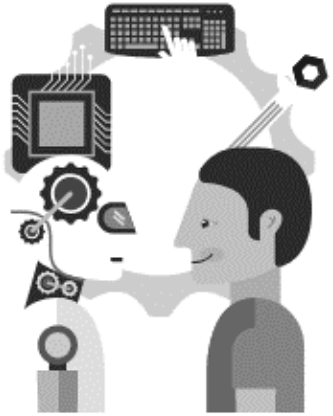
An AI Application is a System



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

- Tradespace Analysis
- Architecture
- Integration
- Test & Evaluation

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