Digital Engineering and AI – Transformation of Systems Engineering

INCOSE Atlanta

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SYSTEMS ENGINEERING RESEARCH CENTER

The Systems Research and Impact Network

The *Networked* National Resource to further systems research and its impact on issues of national and global significance

- ***Catalyze*** SE researchers and end users
- ***Accelerate*** SE competency development
- ***Transform*** SE practice

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Research Council Members



- **Enterprise Systems and Systems of Systems**
  - *Dan DeLaurentis, Purdue*
  - *Bill Rouse, Stevens (NAE)*
  - *Oli deWeck, MIT*

- **Human Capital Development**
  - *Jon Wade, Stevens*

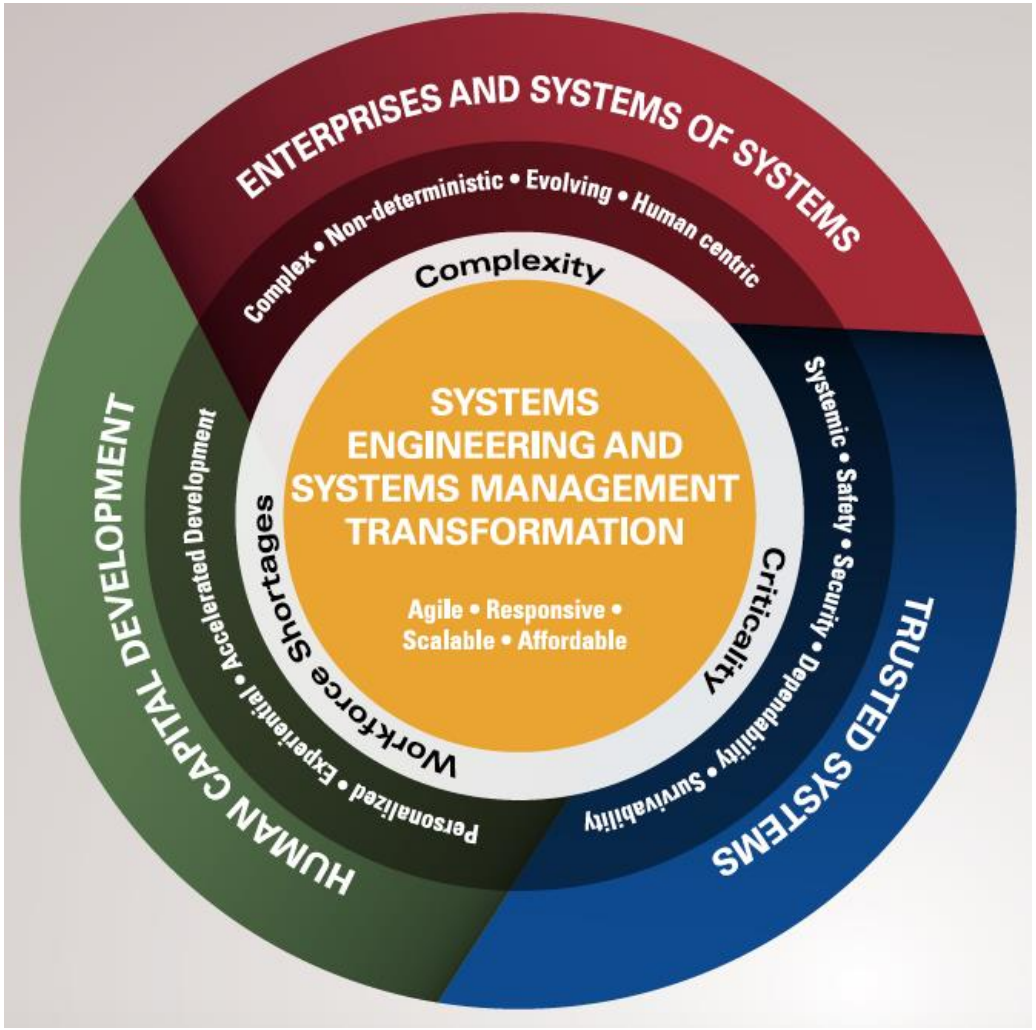


- **Trusted Systems**
  - *Barry Horowitz, UVA (NAE)*
  - *Kevin Sullivan, UVA*
  - *John Colombi, AFIT*
  - *Val Sitterle, Georgia Tech*



- **Systems Engineering and Systems Management Transformation**
  - *Mark Blackburn, Stevens*
  - *Barry Boehm, USC (NAE)*
  - *Paul Collopy, UAH*

SERC Research Thematic Areas



Enterprises and SoS

- *Enterprise and System of Systems Modeling and Analysis*
- *Mission Engineering*

Trusted Systems

- *Systemic Security*
- *Systemic Assurance*

Human Capital Development

- *Evolving Body of Knowledge*
- *Experience Acceleration*
- *SE and Technical Leadership*
- *Emerging/Critical Areas*

SE & Systems Mgmt Transformation

- *SE for Velocity and Agility*
- ***Digital Engineering***
- ***SE Methods for AI and Autonomous Systems***

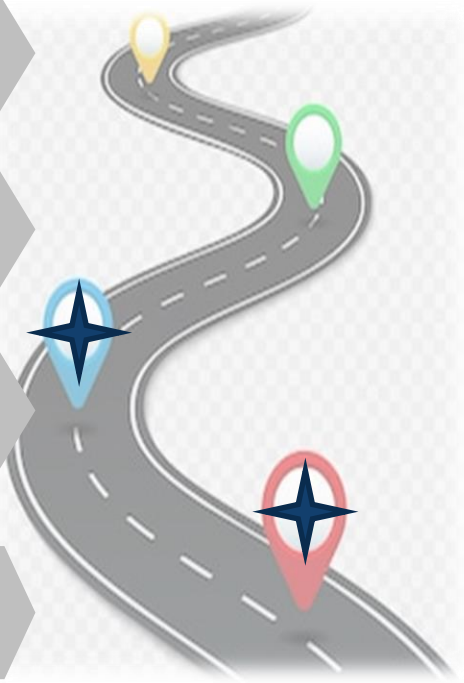
SERC Research Areas and Missions

Mission Engineering

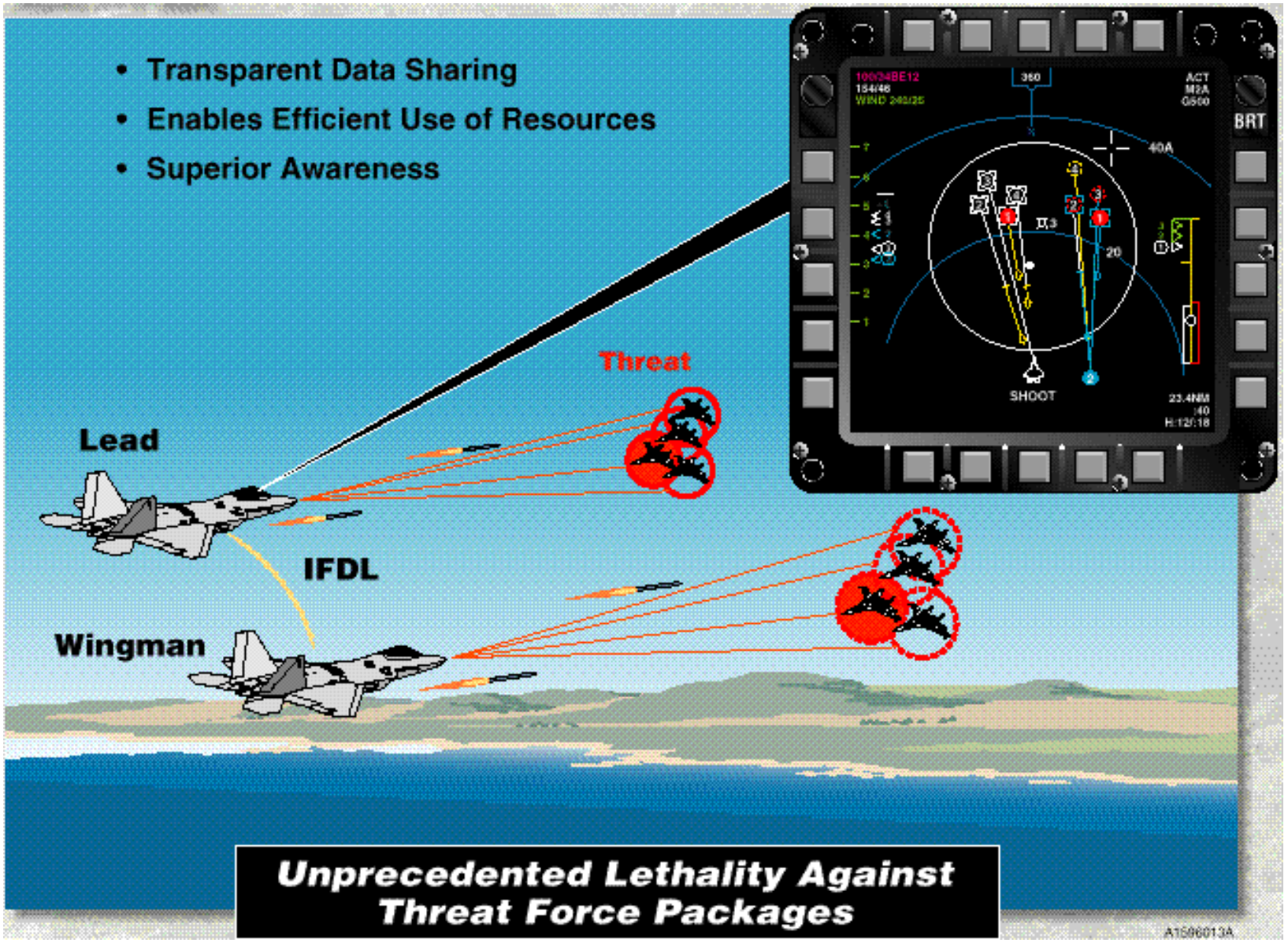
	TRUSTED SYSTEMS	ENTERPRISES AND SYSTEMS OF SYSTEMS	SYSTEMS ENGINEERING AND MANAGEMENT TRANSFORMATION	HUMAN CAPITAL DEVELOPMENT
V	**VELOCITY** Developing and sustaining capabilities that support emergent and evolving mission objectives (deter and defeat emergent and evolving adversarial threats and exploit opportunities, affordably and with increased efficiency)			
S	**SECURITY** Designing and sustaining the demonstrable ability to safeguard critical technologies and mission capabilities in the face of dynamic (cyber) adversaries			
A	**AI & AUTONOMY** Developing and supporting system engineering MPTs to understand, exploit and accelerate the use of AI and autonomy in critical capabilities			

Digital Engineering

SERC Technical Plan Roadmaps



Is this an Autonomous Aircraft?



Engineered Complex Systems

Complexity is often a By-Product of our Desire for Functionality

Increasingly Rapid
Expansion of Functionality

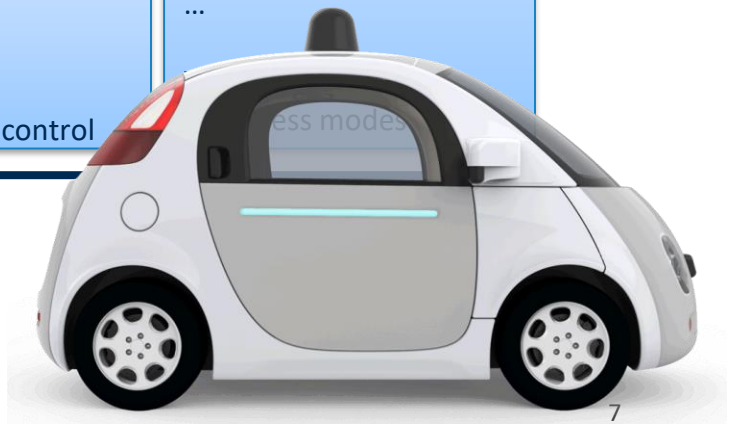
Electronic injection
Cruise control
Central locking

Automatic gearbox
Climate control
Automatic Braking (ABS)
Seat heating
Automatic mirrors

Navigation system
Infotainment system
Adaptive cruise control
Xenon lighting
Voice input
Emergency call
Vehicle assist
Dynamic stability control

Night vision system
Pedestrian detection
Automatic parking
Voice control that
actually works
Heads-up display
Bluetooth
Internet access
Battery electric (BEV)
…

1970 1990 2010



The Digital Car

Five Goals of the DoD Digital Engineering Strategy*

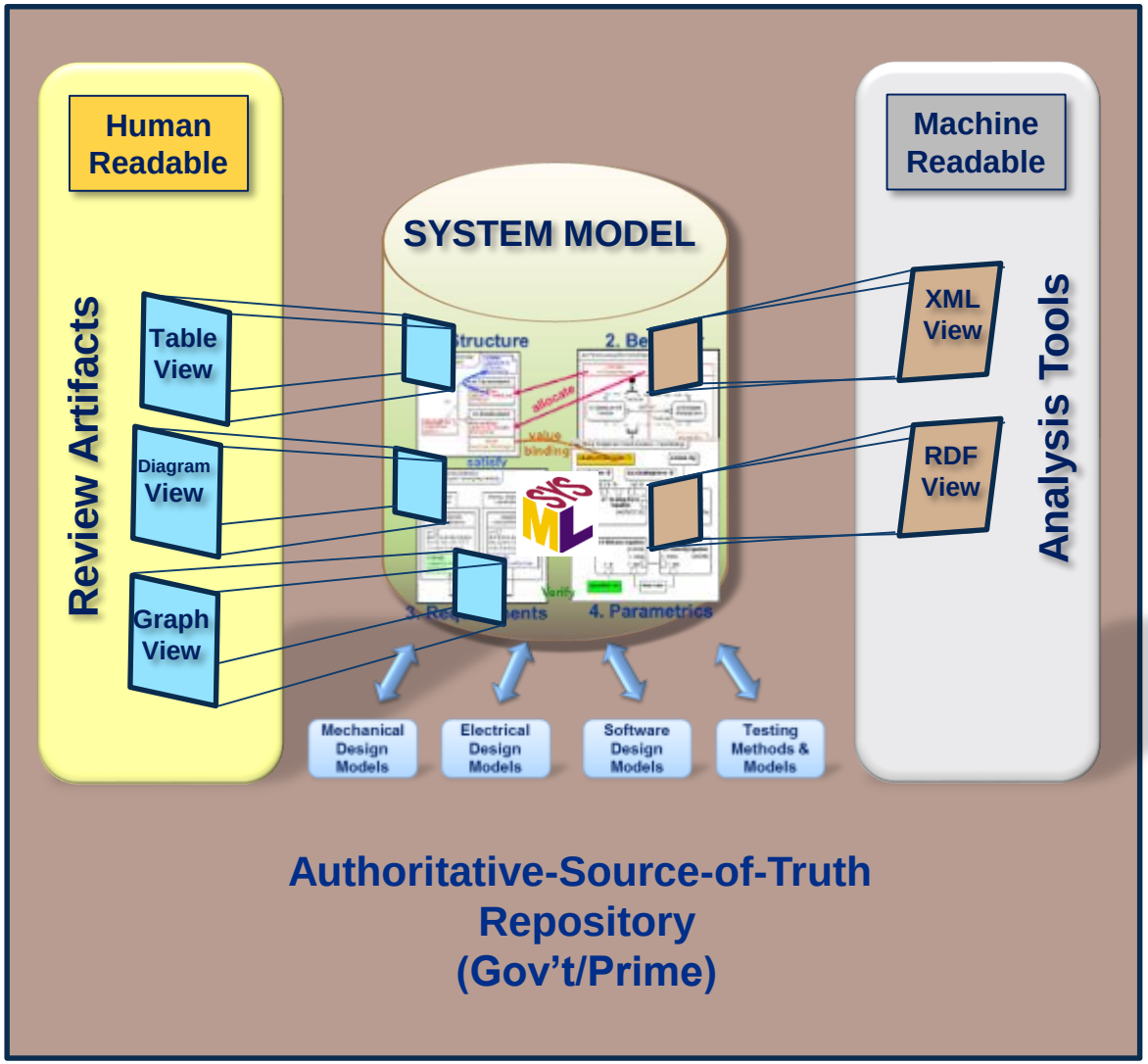
- Goal 1: Formalize the development, integration, and use of models to inform enterprise and program decision-making.
- Goal 2: Provide an enduring, authoritative source of truth.
- Goal 3: Incorporate technological innovation to improve the engineering practice.
- Goal 4: Establish a supporting infrastructure and environments to perform activities, collaborate, and communicate across stakeholders.
- Goal 5: Transform the culture and workforce to adopt and support digital engineering across the lifecycle.

* Department of Defense Digital Engineering Strategy, June 2018

How do we know if an organization has adopted Digital Engineering?

- It has a documented business strategy for use of models/digital artifacts and top-down executive level support for Digital Engineering transformation
- It has an established infrastructure for a Collaborative Integrated Modeling Environment (IME) and the associated Authoritative Source of Truth (AST)
  - Well defined model management processes. This includes methods, methodologies, tools and licenses, a model curation activity, and model exchange practices
  - Established model quality assurance (validation, issue tracking, and improvement)
  - Established means for linking descriptive system models with discipline specific models
  - Established procedures in place for conducting model and modeling reviews directly in the IME and AST across disciplines and across customers/suppliers
  - Established means for generating stakeholder role-specific views directly from the AST
- Established policies and procedures for using models/digital artifacts for contracting and contract deliverables (including procedures for dealing with data rights and IP rights)
- Established workforce development based on modeling methods using case studies in business relevant domains of interest

Example: Authoritative Source of Truth for Machine Readable Analyses

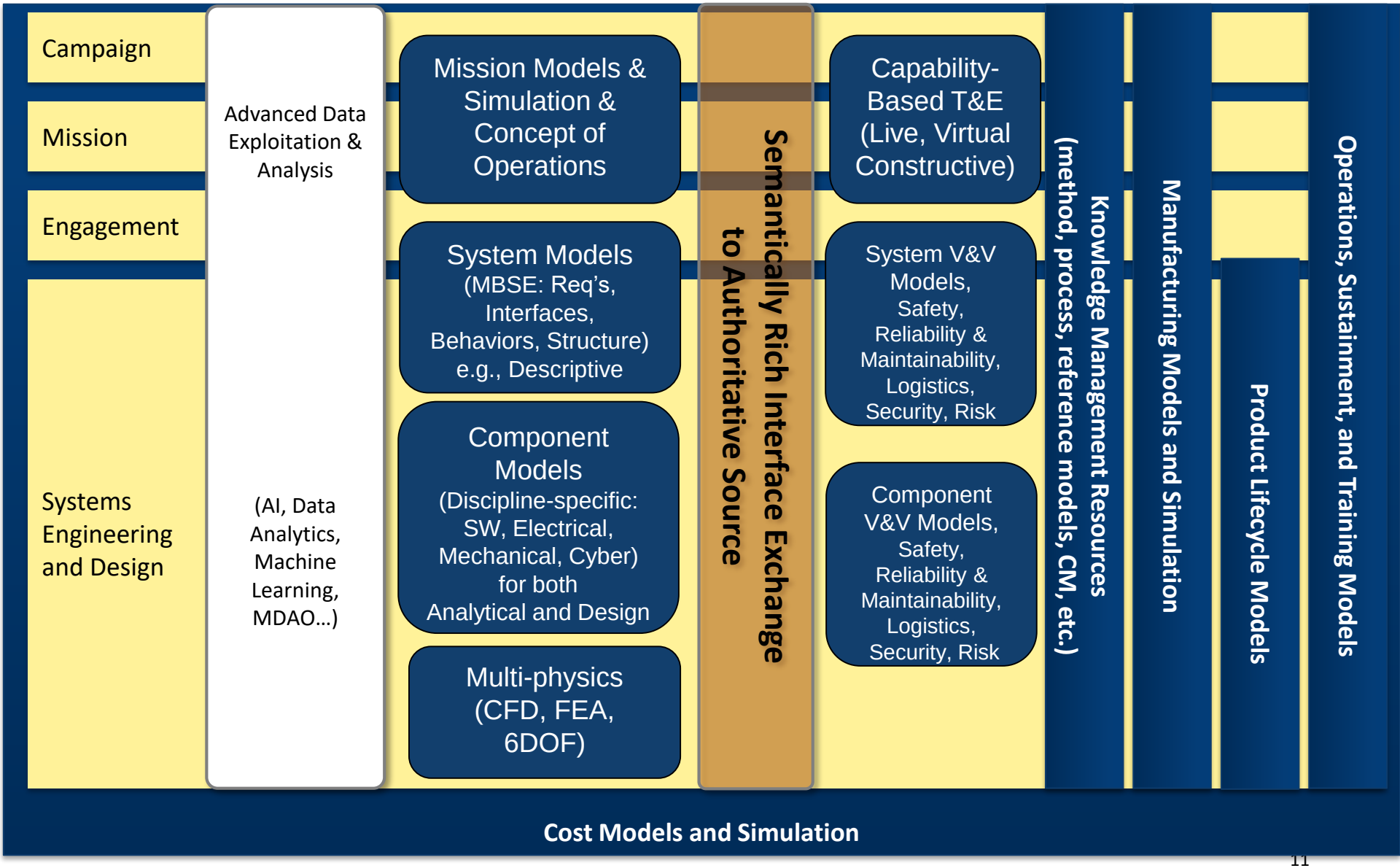


The entire set of models and tools is held in a single repository and becomes the Authoritative-Source-of-Truth for the duration of system development

- Ability to *interrogate the design information* and extract data into the format necessary for the given task
  - Leverages formalism
  - Transformation rules are *reusable*
  - Provides *machine and human readable formats*
- Leverage the model by reviewing *the model itself*
- Stakeholders *focus on the views of the system model* that address their concerns

* NAVAIR Industry Day, March 2018 **NAVAIR Public Release 2017-370. Distribution Statement A – "Approved for public release; distribution is unlimited"**

Reference Architecture for an IME in support of Digital Engineering



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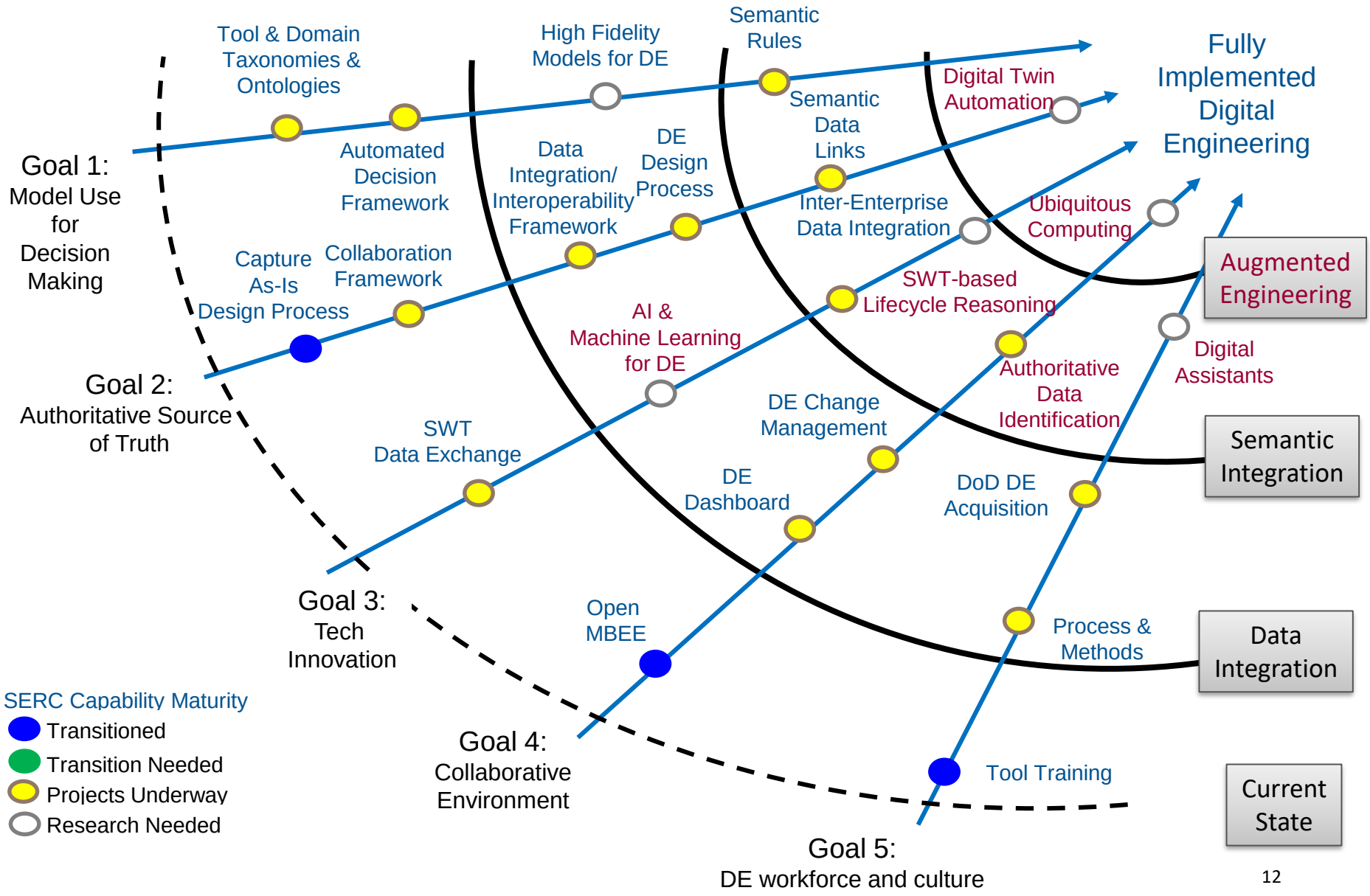
Research Roadmap: Digital Engineering for Systems Engineering



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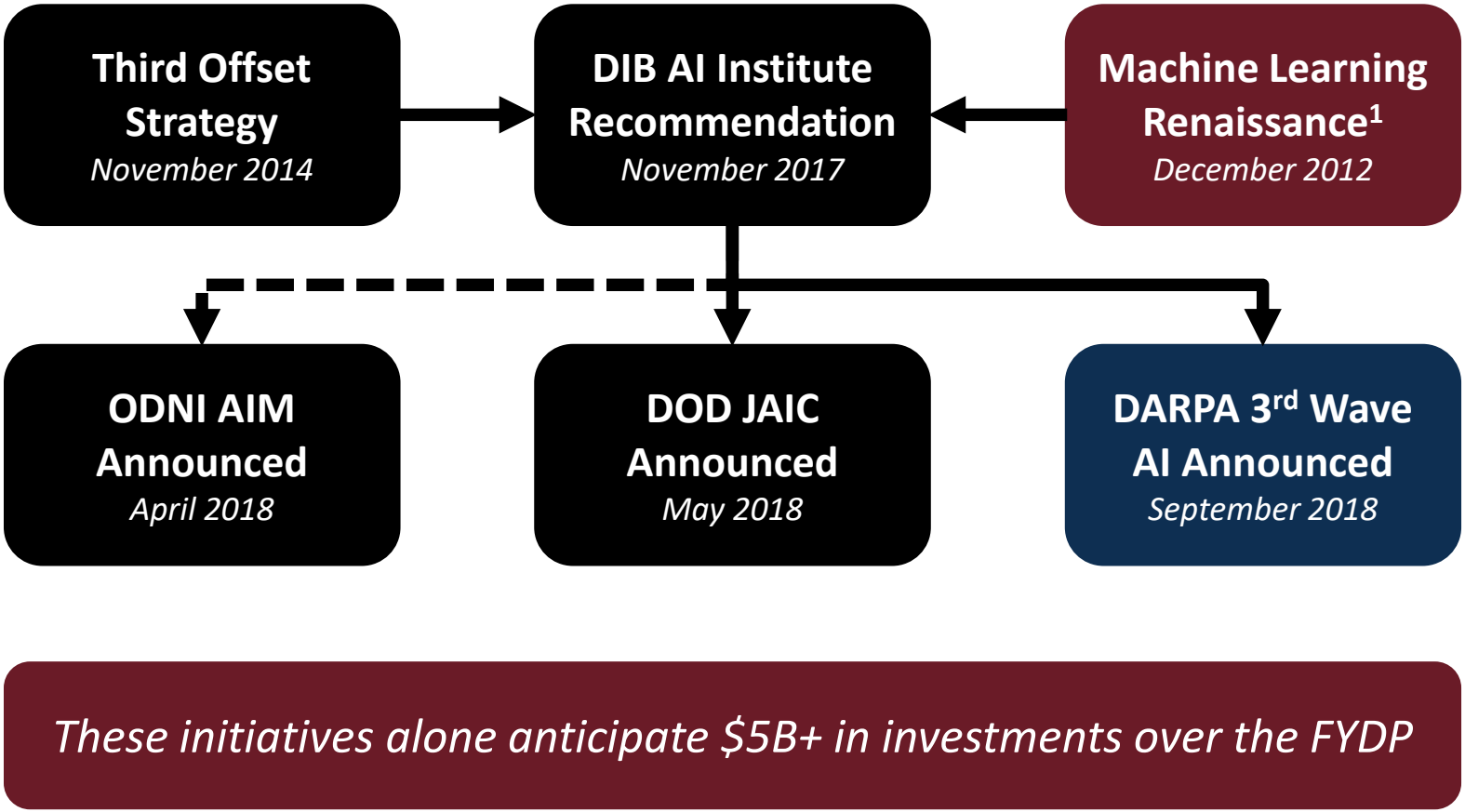
Which of These Digital Innovations will Transform the Engineering Disciplines?

- 5G mobility – enhanced bandwidth and connectivity mobile services
- Collaborative telepresence – Highly realistic, haptics enabled video conferences
- AI and ML – Artificial Intelligence and Machine Learning
- Immersive Realities – Human, Augmented, and/or Virtual Reality technology integration
- Blockchain – Blockchain derived technologies to manage workflows
- Cloud Evolution – Evolving cloud computing architectures
- NL/Chatbots/social robots – true human realistic natural language interfaces
- IoT – Internet of Things sensors and architectures
- Low-code SW – Domain specific design languages/visual composition design methods
- DevSecOps – Secure Continuous development and deployment environments
- Quantum computing – Evolving non-binary computing architectures
- Advanced Manufacturing – Rapid programming/realization of hardware design
- DNA-based Data Storage – High speed, ultra-high capacity storage devices
- Digital Identities – Computer (not human) determines identity verification

* SERC Project WRT-1001 presented to the Digital Engineering Working Group 08/2019

AI Eats the World…
(while Engineering goes Digital)

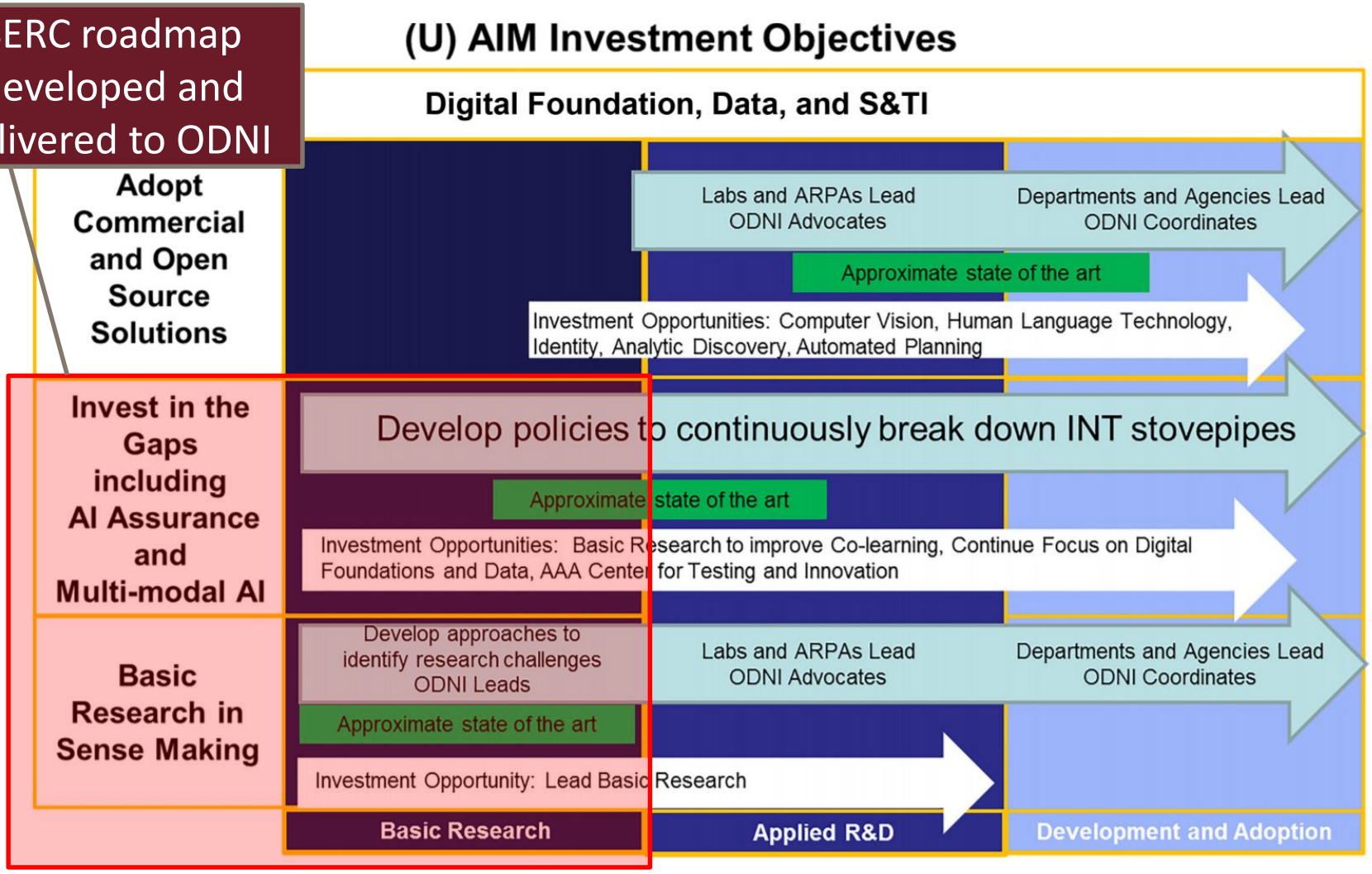


[1] Krizhevsky, Sutskever, Hinton, "ImageNet Classification with Deep Convolutional Neural Networks", NIPS 2012

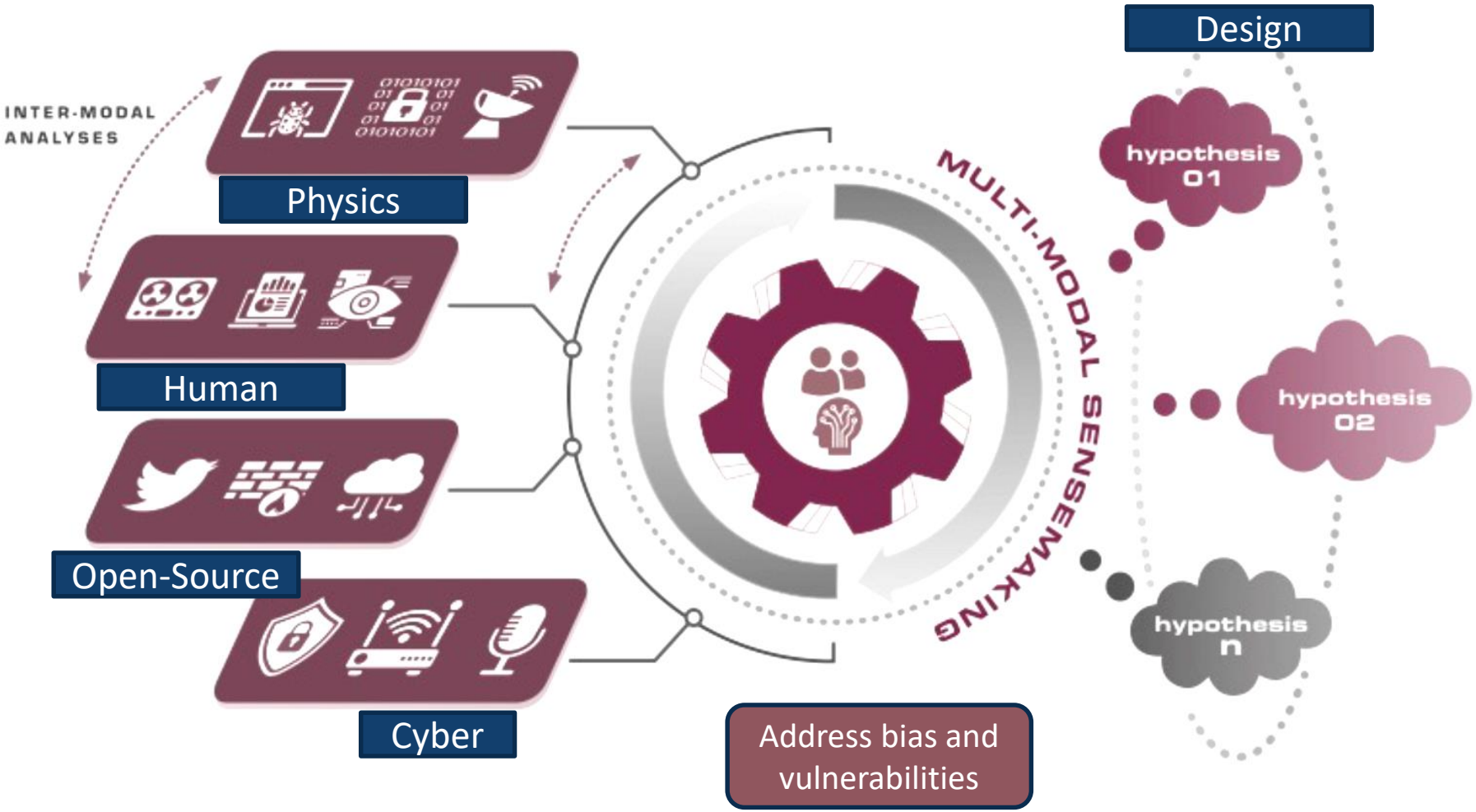
ODNI AIM Initiative

Unclassified Strategy: https://www.afcea.org/event/sites/default/files/files/AIM%20Strategy.pdf

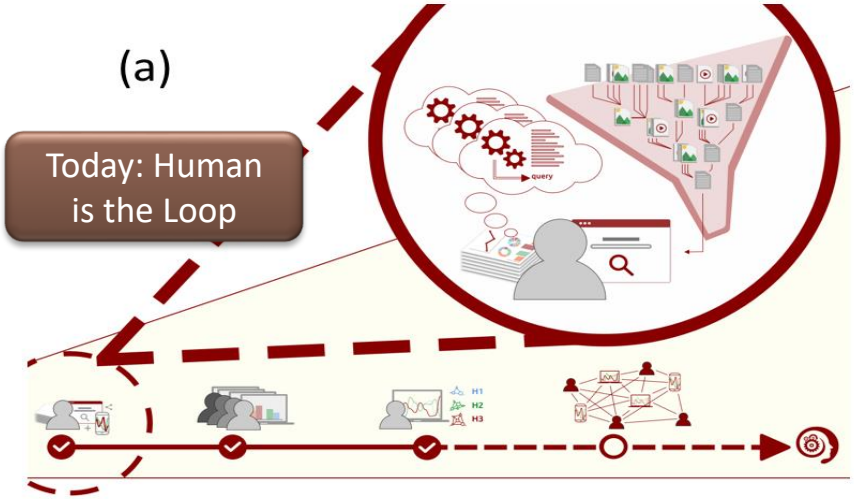
SERC roadmap developed and delivered to ODNI

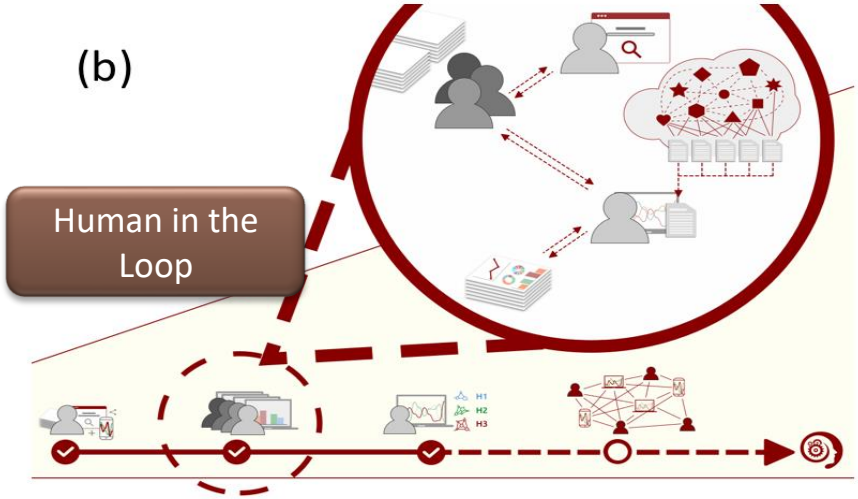


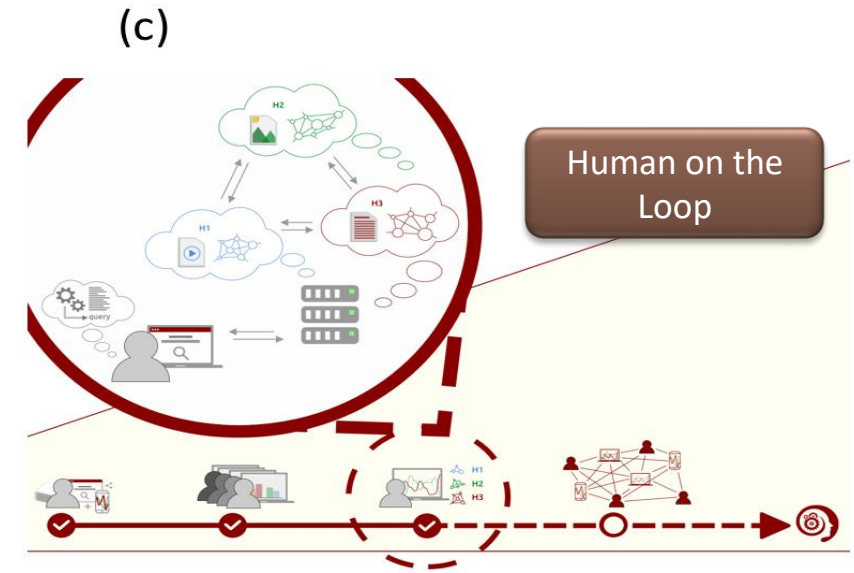
Multi-Model Sensemaking



Hybrid Systems for Sensemaking: Evolution of AI for SE



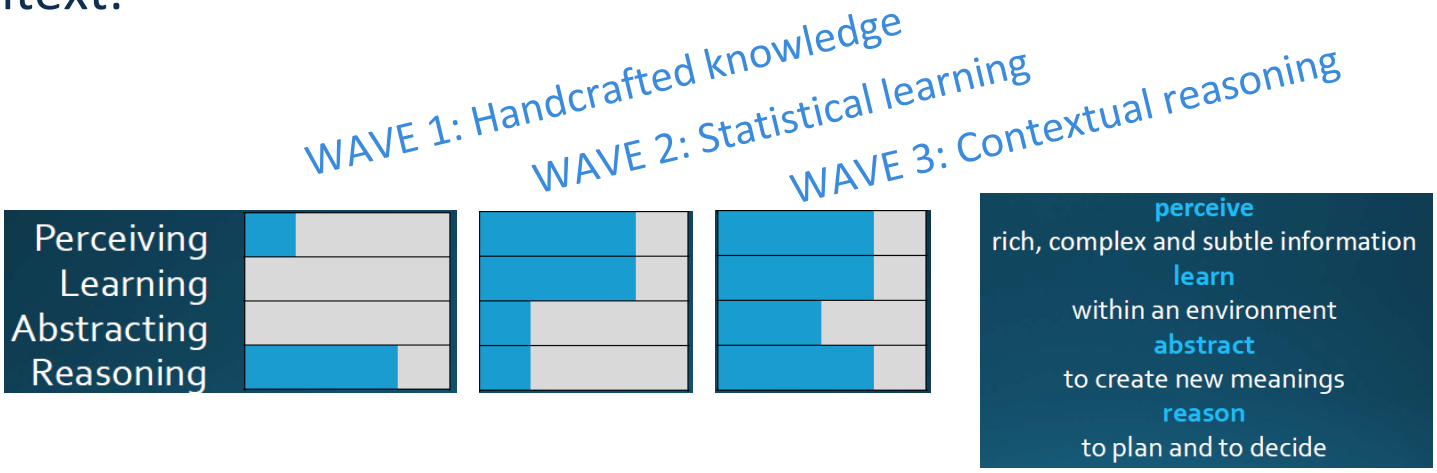




As human leaves loop, lifecycle issues and contextual learning become more and more important

Fundamental Research in AI and ML Technology – needed for use in design

- Multi-Modal AI – holistic analysis of multi-modal data with the aim to produce actionable intelligence for decisions
- Cognitive Bias – intentionally or unintentionally misleading decision-making in AI systems
- Contextual Adaptation and Sensemaking – AI that perceives and learns context:



- Design principles for AI – confident exploration of design space for learning-enabled systems

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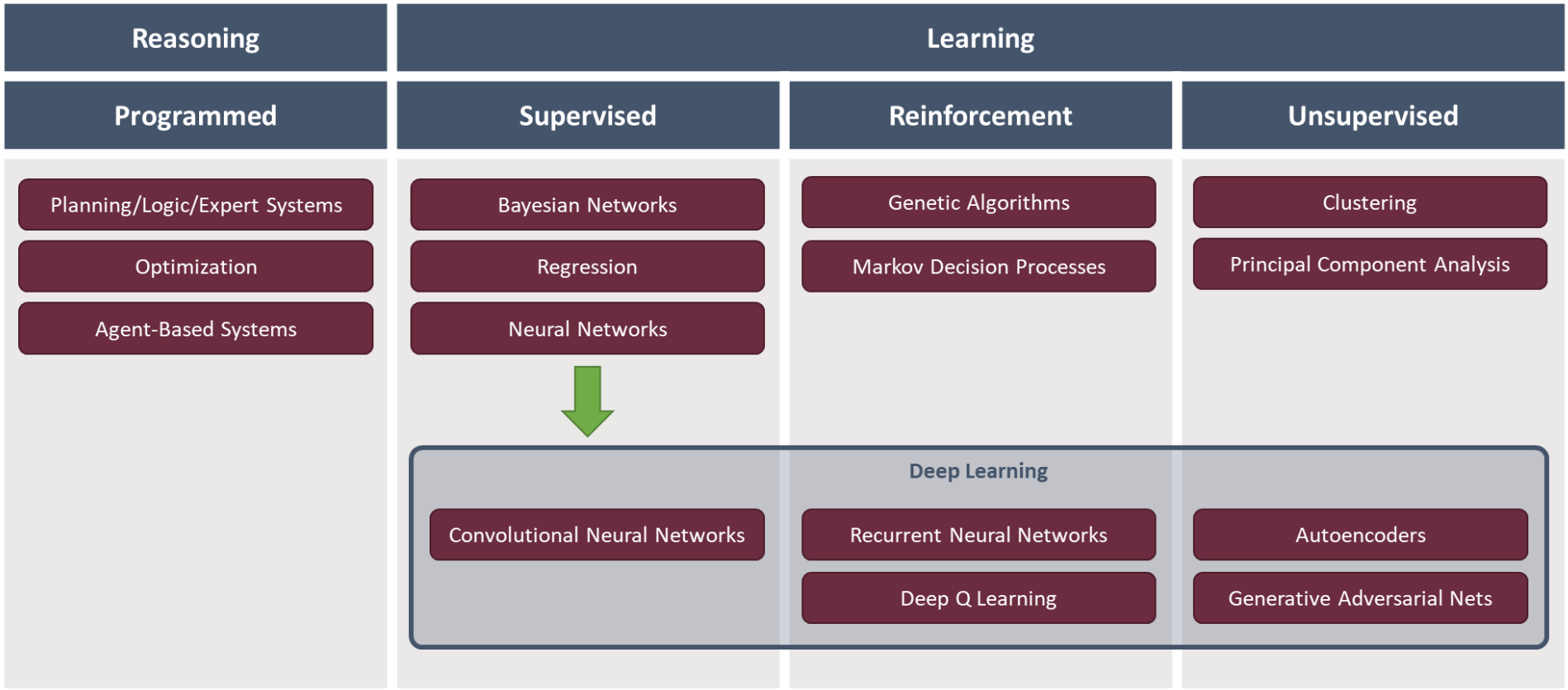
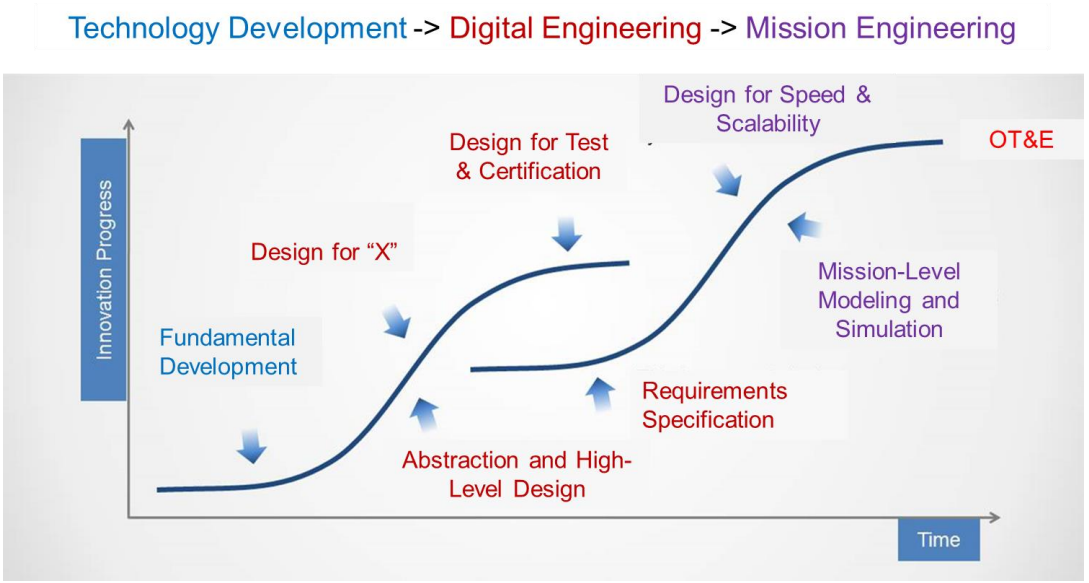
[Incomplete] Artificial Intelligence Taxonomy



AI/SE Research Framework

- AI/ML and Autonomy encompass a broad range of methods, processes, tools, and technologies
- There is not yet a clear vision for a roadmap linking AI/ML, Autonomy, and SE – but we can categorize research areas in an evolutionary framework
- Major "verticals":
  - —AI/ML Technology
  - —Automation & Teaming
  - —SE Process Evolution
  - —Digital Engineering



The "Double S" curve of Tech innovation provides an effective categorization of SE Research contributions to emerging technology

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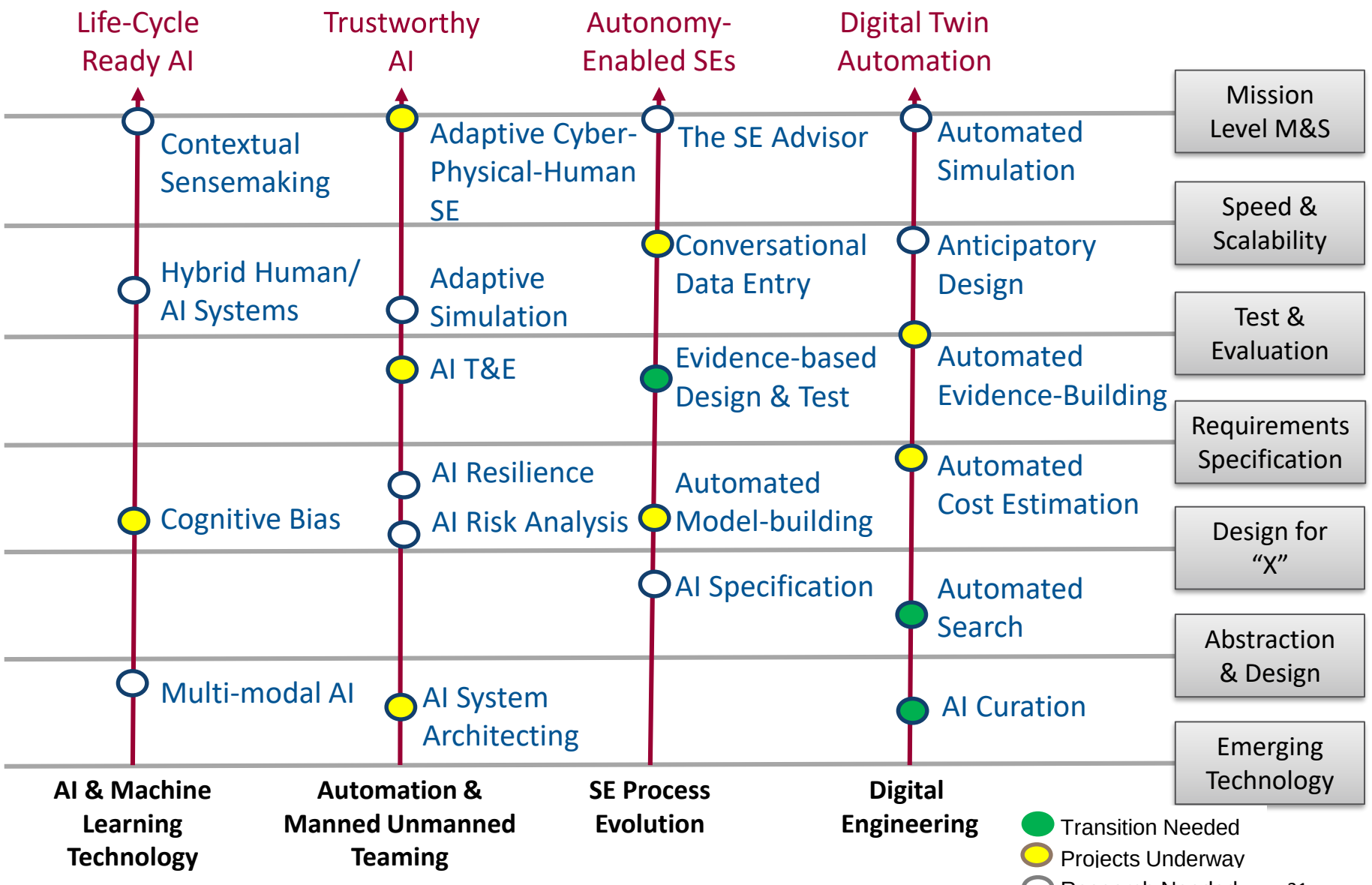
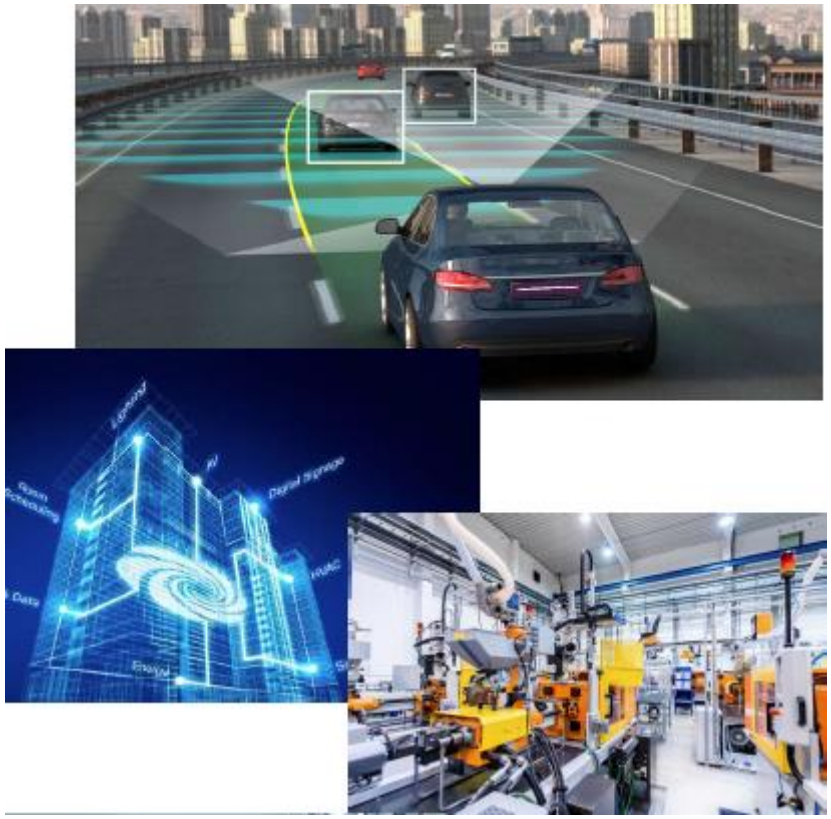
SERC AI/Autonomy/SE Research Classification Framework

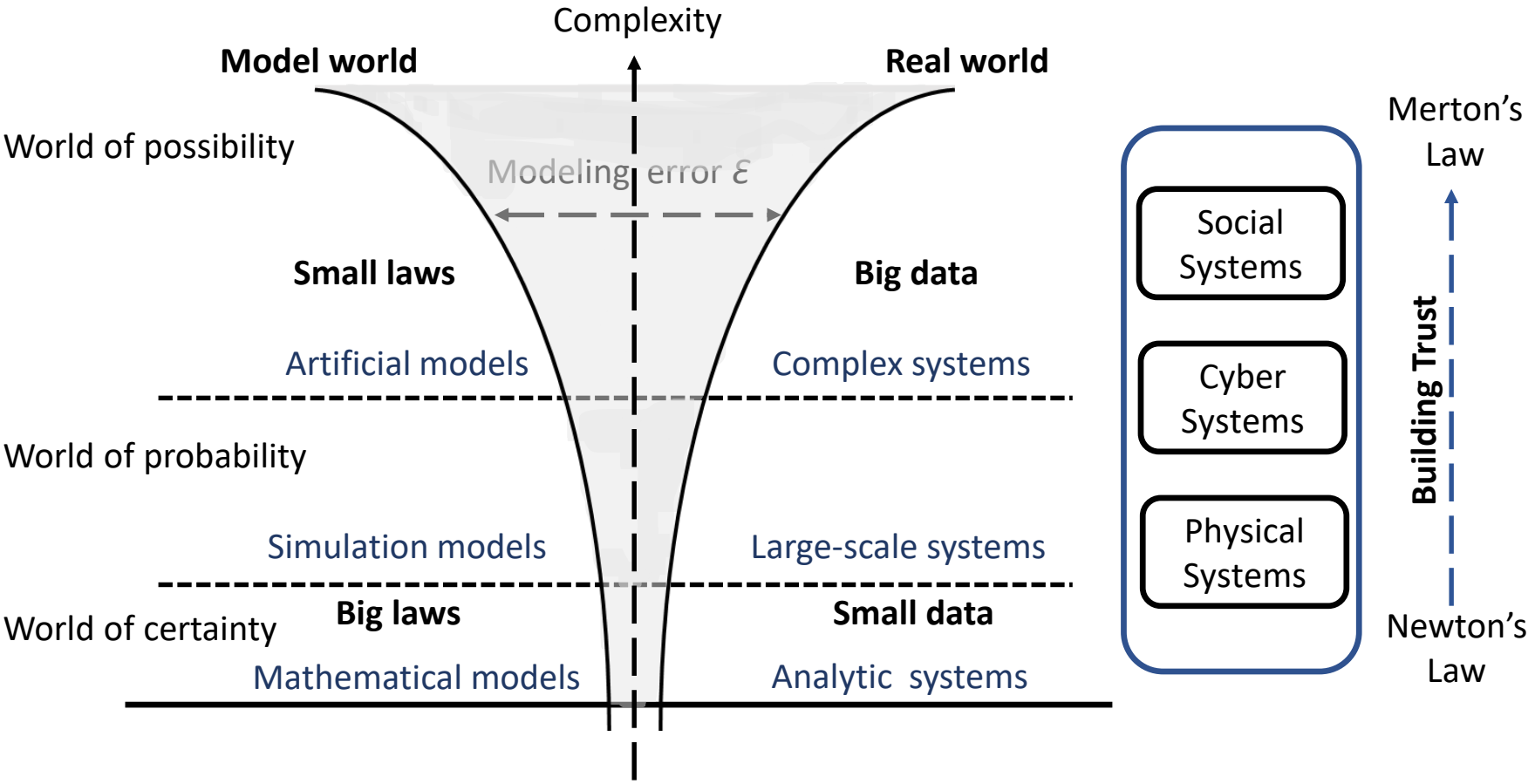


Automation and Manned/Unmanned Teaming

- Adaptive Cyber-Physical-Human Systems – modeling of cyber-physical systems as influenced by humans, from requirements analysis to design
- Adaptive Simulation – Computer based simulation and training that supports non-static objectives (pick-up games)
- **Trustworthy AI – AI systems that self-adapt while maintaining rigorous safety and security and policy constraints**

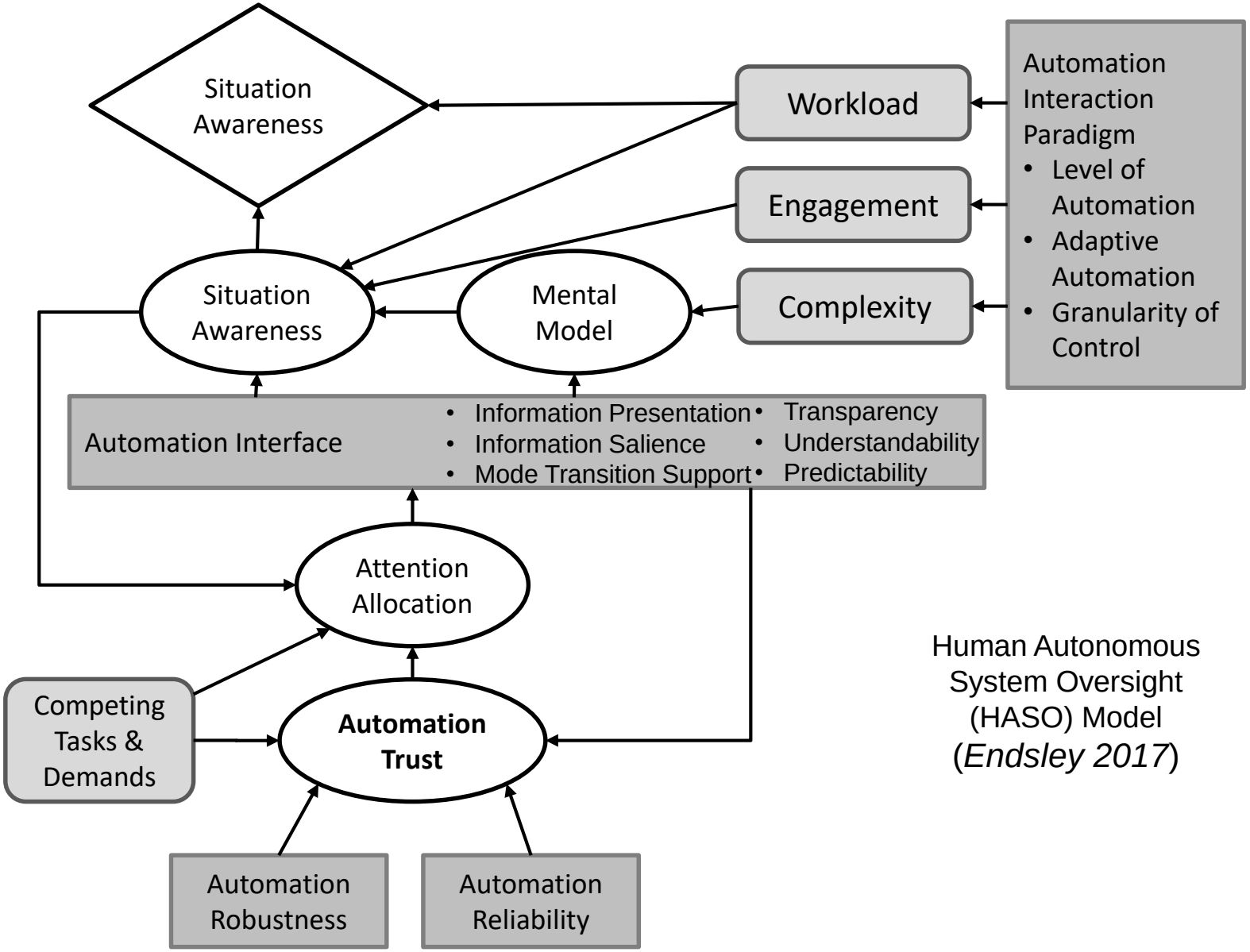


Complexity vs. Intelligence: the cognitive gap



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

Automation & Situational Awareness



Human Autonomous System Oversight (HASO) Model (*Endsley 2017*)

Excerpt from the DoD AI Strategy

1. **Objective: Scaling AI's impact across DoD through a common foundation that enables decentralized development and experimentation.**
   - Ensure interoperability is considered early in the design lifecycle. This will help mitigate the risk of creating AI tools that are powerful for narrow applications but fail in joint settings. In addition, USD(R&E) will help mature the DoD's AI Engineering discipline. This includes developing the systems engineering, sustainment and assessment methods, processes, and tools to deploy AI-embedded capabilities.

Systems Engineering Process Evolution

- AI abstraction – library tools and methods that abstract AI algorithms and modules to general engineering
- AI Specification – a requirements specification and management process for adaptation and learning in systems (blending agile, devops, etc.)
- Evidence-based design and test – formal methods and processes that move from explicit verification of composition to evidence building
- Conversational data entry: human-computer interaction processes to convert natural language and other media to formal models
- The SE Advisor – a conversational system that automates many mundane data exploration and engineering calculation tasks
- **Autonomy enabled SEs – we become masters at deploying "autonomy as a design variable"**

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

AI Enabled Digital Engineering

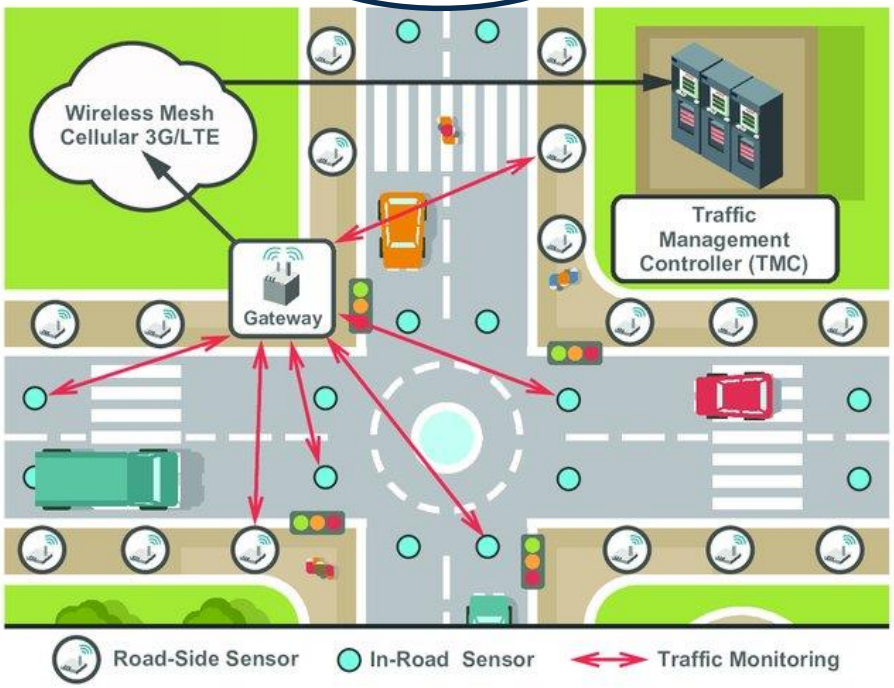
- AI Curation - data management and curation to support evolving application of AI capabilities
- Automated search, model-building, and cost estimation – application of ML to historical data and relationships
- Automated evidence building – automation of certification processes via models and Quality Assurance data
- Anticipatory design – anticipating system emergence (failures, etc.) from design & operational data
- Automated Simulation – use of simulation to train and evaluate ML, evolution of GANs
- **Digital Twin Automation – real-time continuous learning from real system and shadow simulations**

  — From zero history to unlimited history?

Image: https://survicate.com/customer-feedback/ai-in-marketing/

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

4. 7am: The New York team is assigned a simulation change allowing the fault to be verified.

5. 11am: An automated system reviews the new data and implements a software change.

Data Storage

Work Products

Team 3 London

Team 1 New York

Team 4 San Francisco

Automated Engineering Control Hub

Team 2 Tokyo

6. 12pm: Japan approves the update for deployment and a change is deployed.

2. Meeting occurs: Natural Language Processing translates English -> Japanese

1. 6am San Francisco time: An automated system schedules four engineering teams to meet virtually.

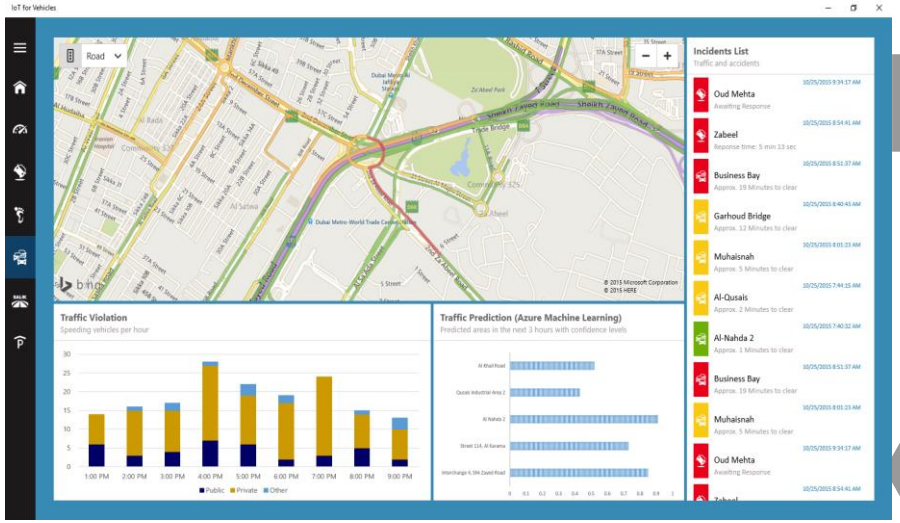
Questions?

Answers!

3. Teams converse with the AI for problem definition and solutioning.

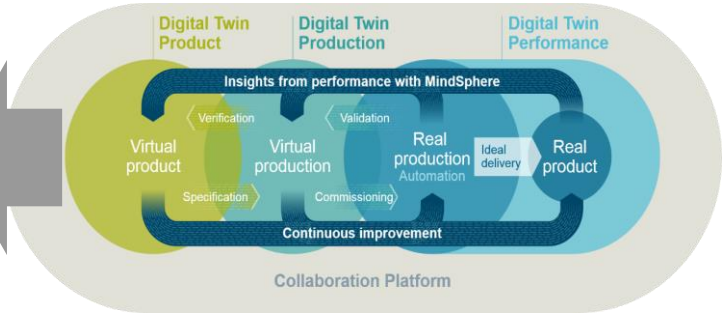
Will we be able to Trust this level of Automation?

- 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



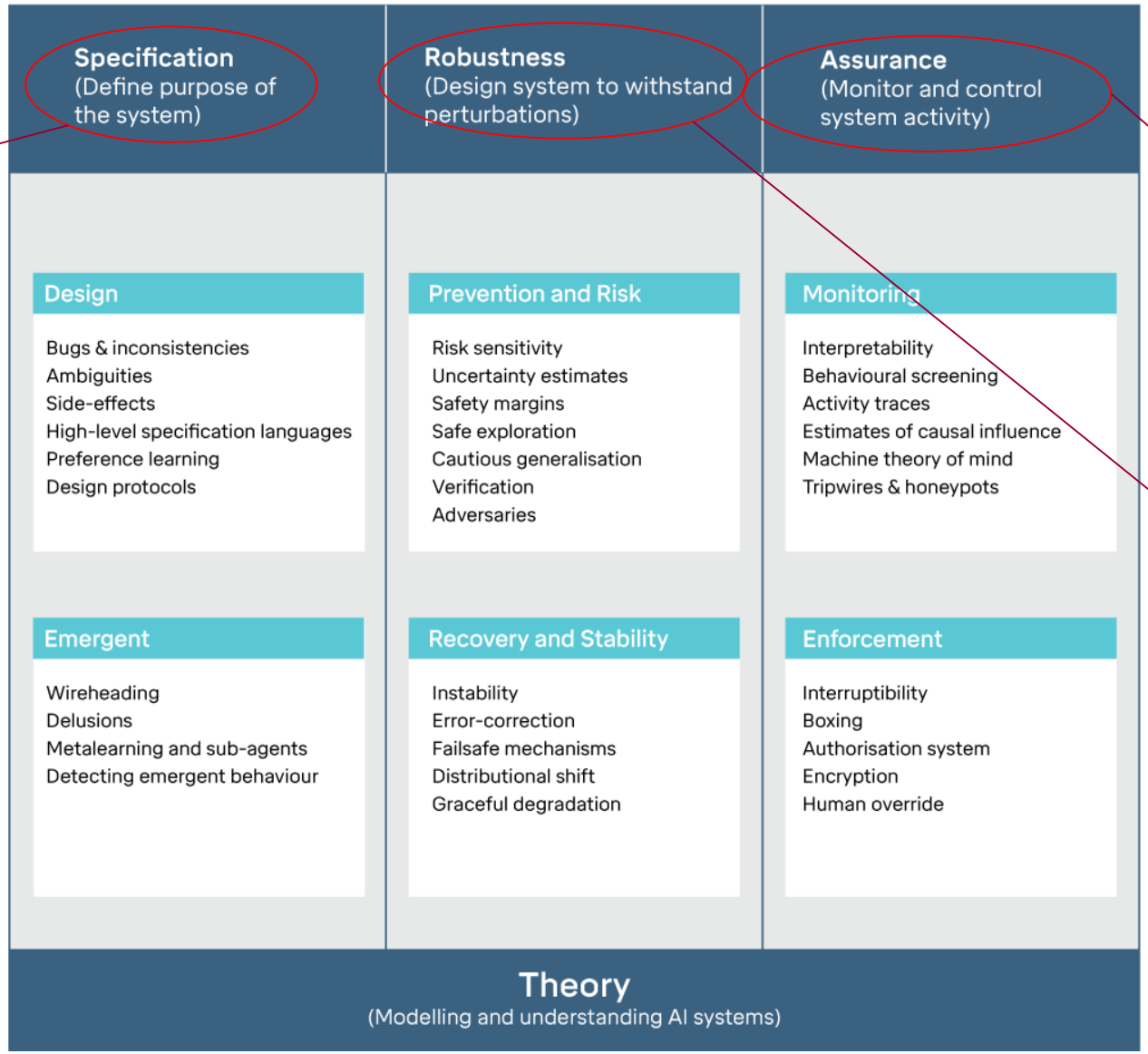
- Continuously operating and updated Mission level Digital Twin simulation

Full Lifecycle Integration

Can AI be Life-Cycle Ready: Research is Beginning

Google DeepMind Framework for Dependable/Safe AI

System Modeling, Problem Formulation, Goals, Metrics, Requirements

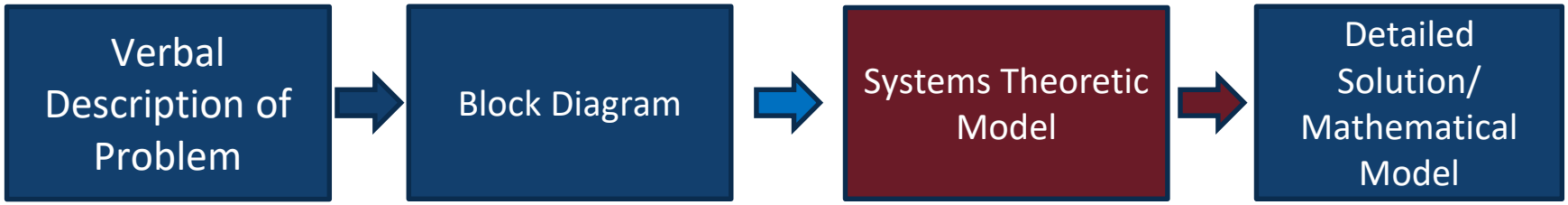


Oversight, Safety, Security, Resilience

Stability, Feedback, Behavioral Similarity, Time-Invariance

Building Theoretical Foundations for Lifecycle AI

- **Systems theory** provides an approach for modeling lifecycle challenges faced by AI systems in a framework naturally rooted in systems design and analysis
- Mathematical superstructure for learning that allows learning algorithms to be formally studied in the context of the systems within which they operate
- Models of random processes undergone by systems can lead to principled design and operational decision-making



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 that assure lifecycle-ready AI
- **Systems Validation of AI:**
  - —Early visibility for deployment, validation of post-deployment changes
  - —System level testbeds – to study systems, not just data & algorithms

Imagination has always led Technology in human history… I feel like for the first time, Technology is ahead of Imagination…

Questions and Discussion