Future Directions for MBSE Research and Education:
What to Focus on and Why?

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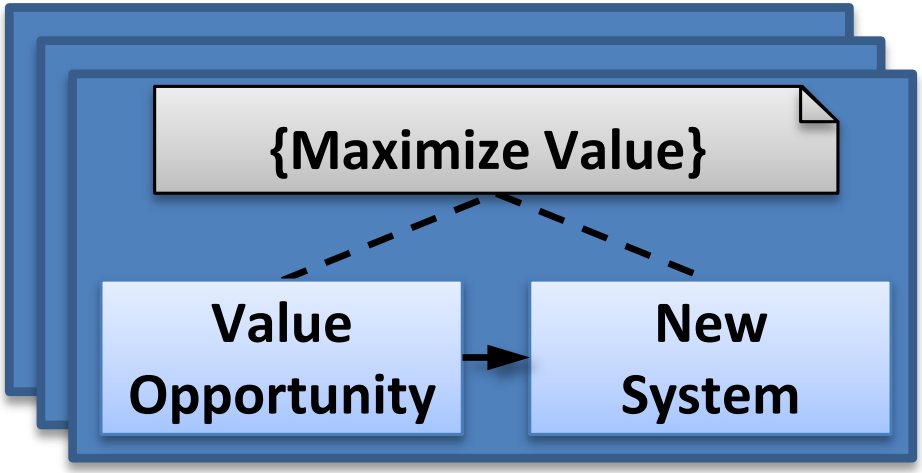
Objective and Outline

Provide a framework for a discussion on SE research and education

- Outline
  - Context: Conceptual model for Systems Engineering
  - Three types of research — in an MBSE context
    - » MBSE based on novel enabling technologies
    - » Theoretical foundation for SE
    - » MBSE methods and tools for a specific context
  - MBSE in Education

Systems Engineering: Maximizing Value



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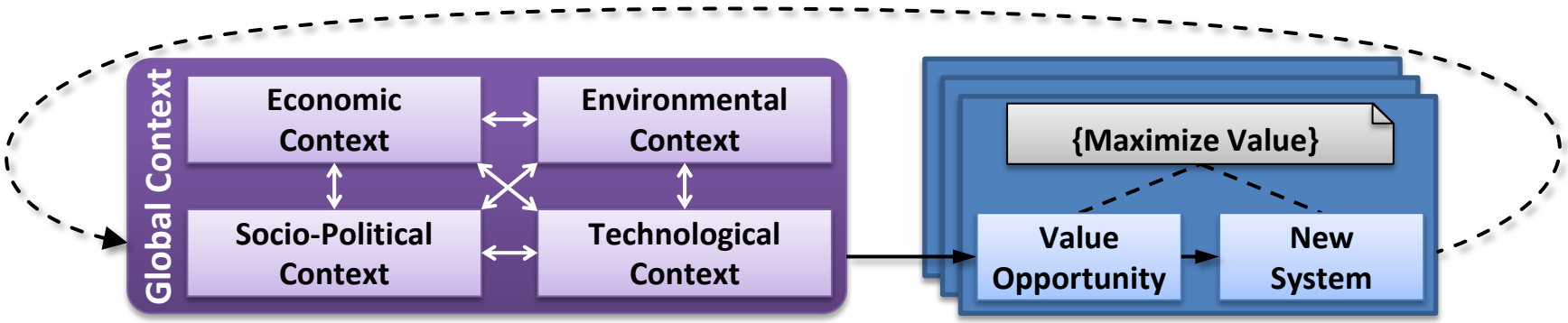
Systems Engineering: Maximizing Value

Value Opportunities in a Global Context



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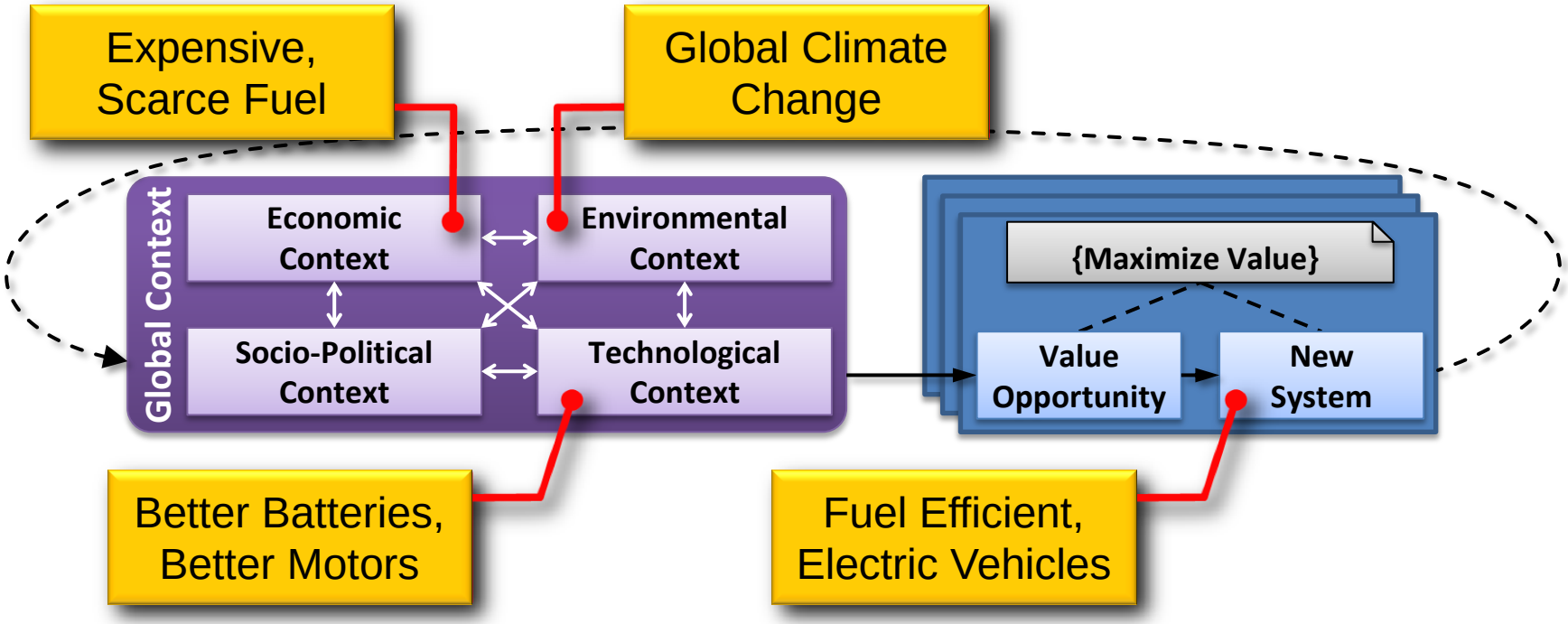

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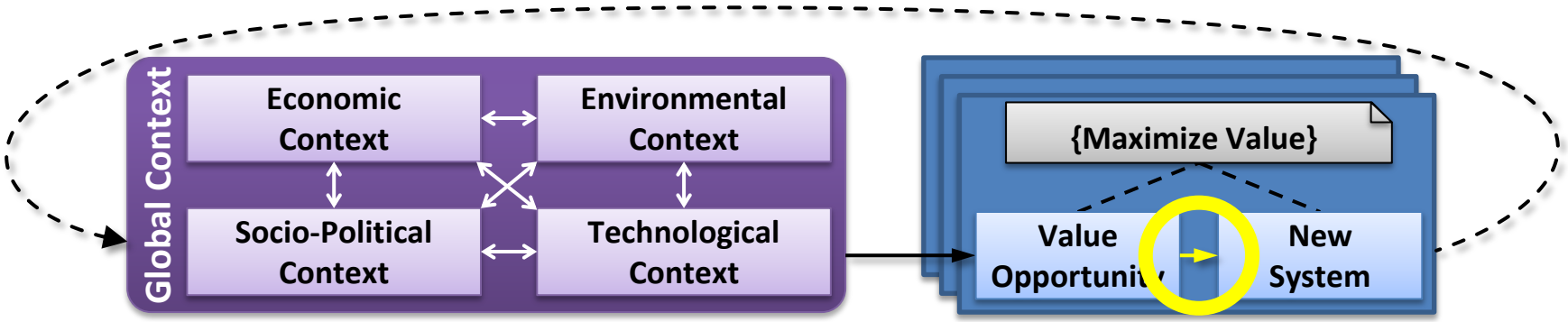
Systems Engineering: Maximizing Value

Value Opportunities are Restricted by SE Capabilities



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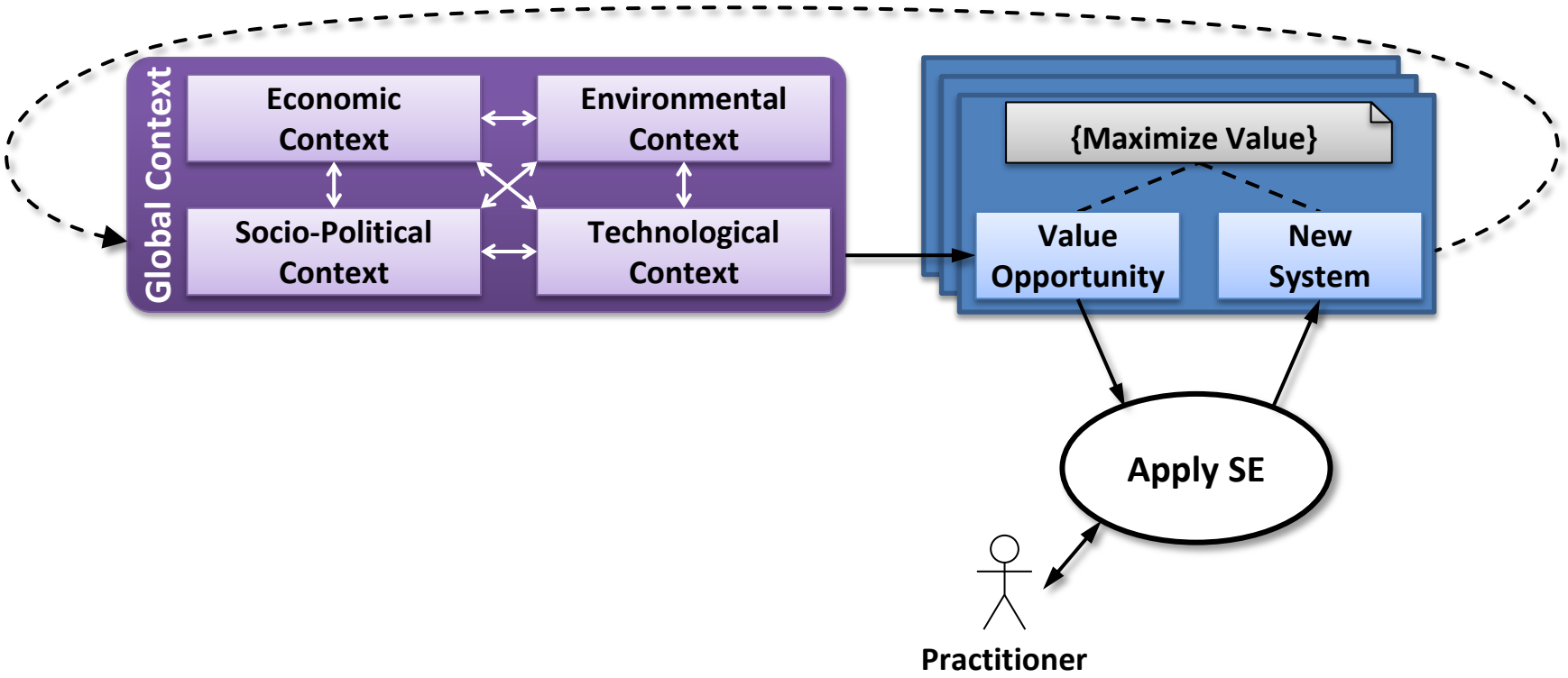

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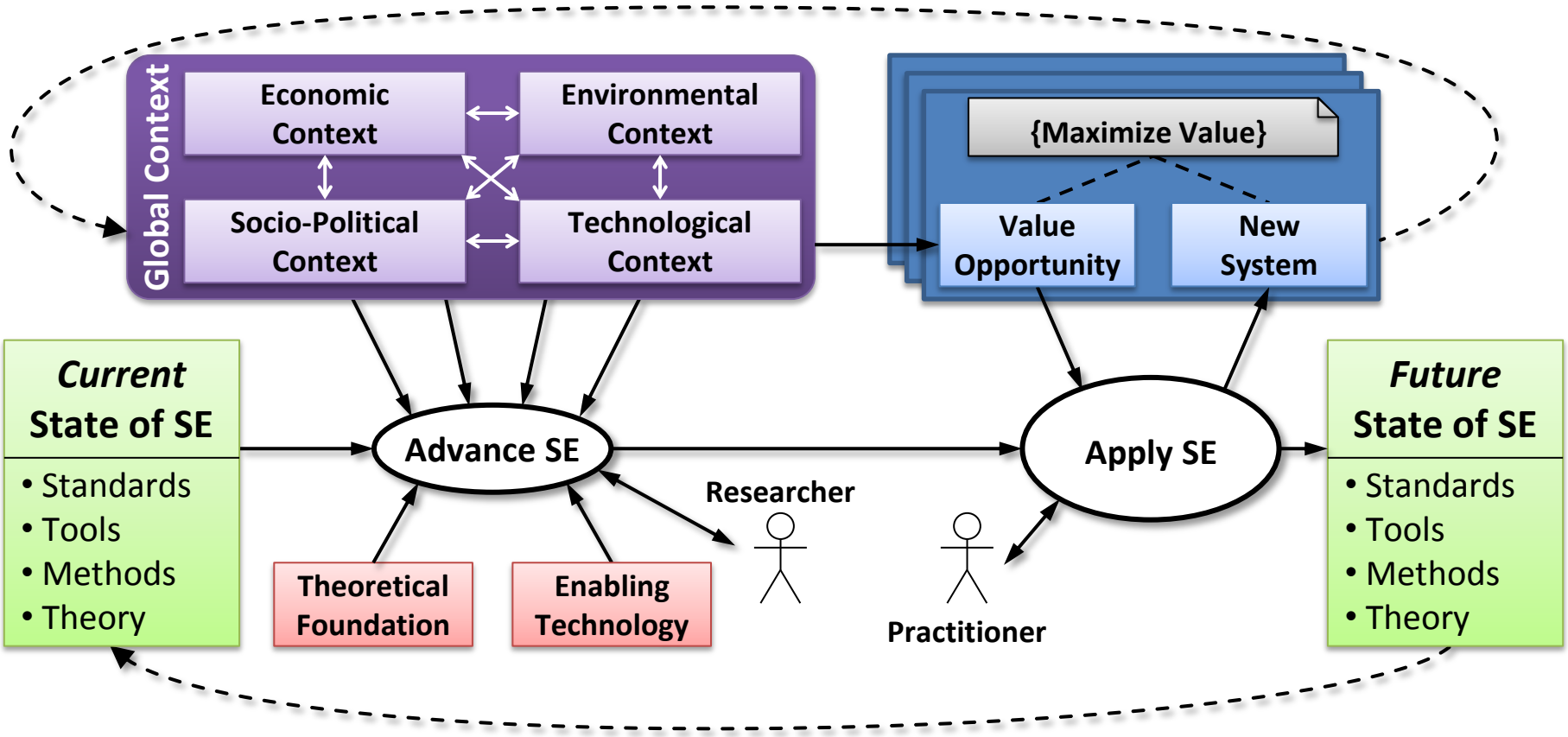
Systems Engineering: Maximizing Value

Value Maximization Drives Advances in SE



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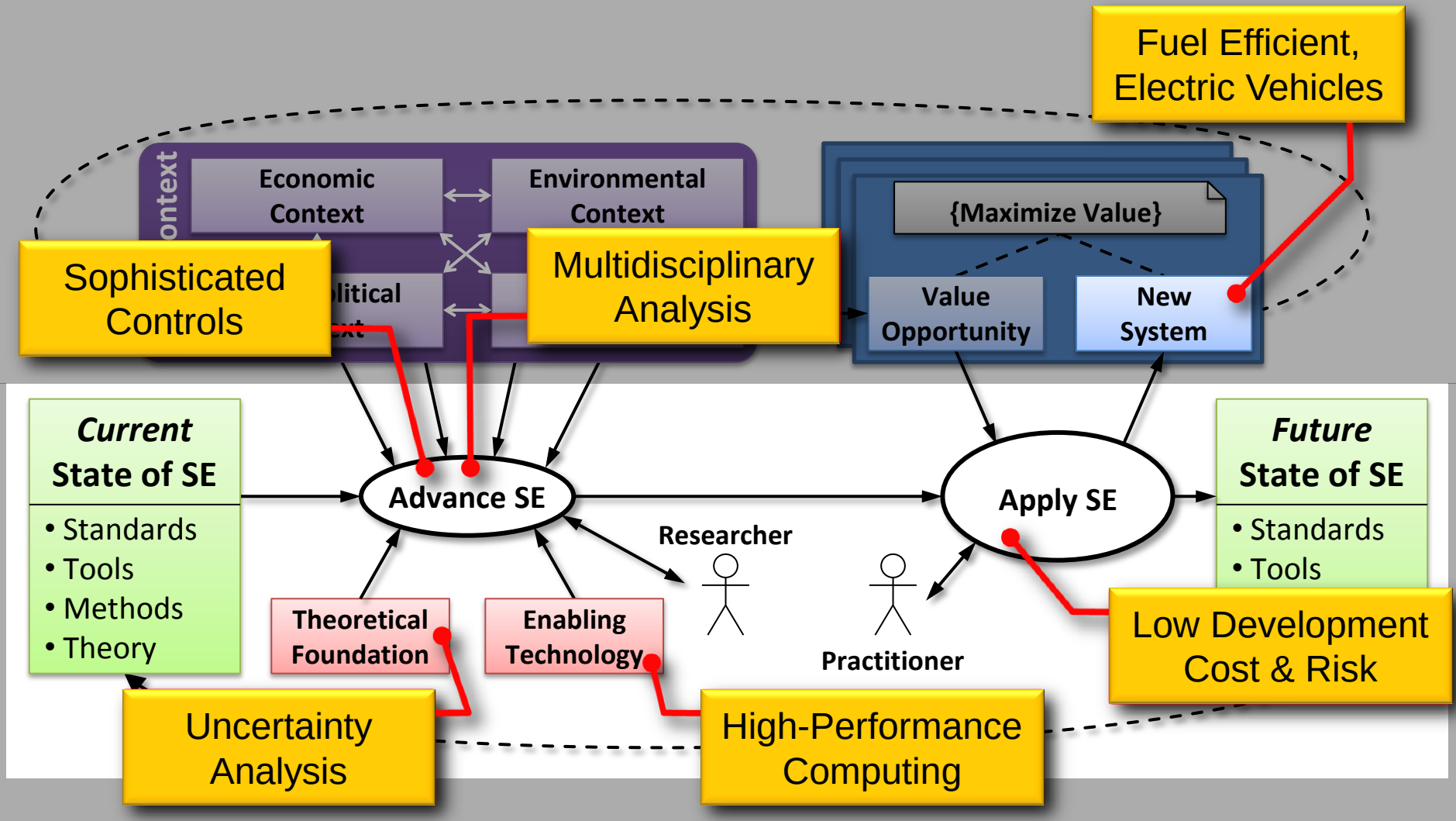

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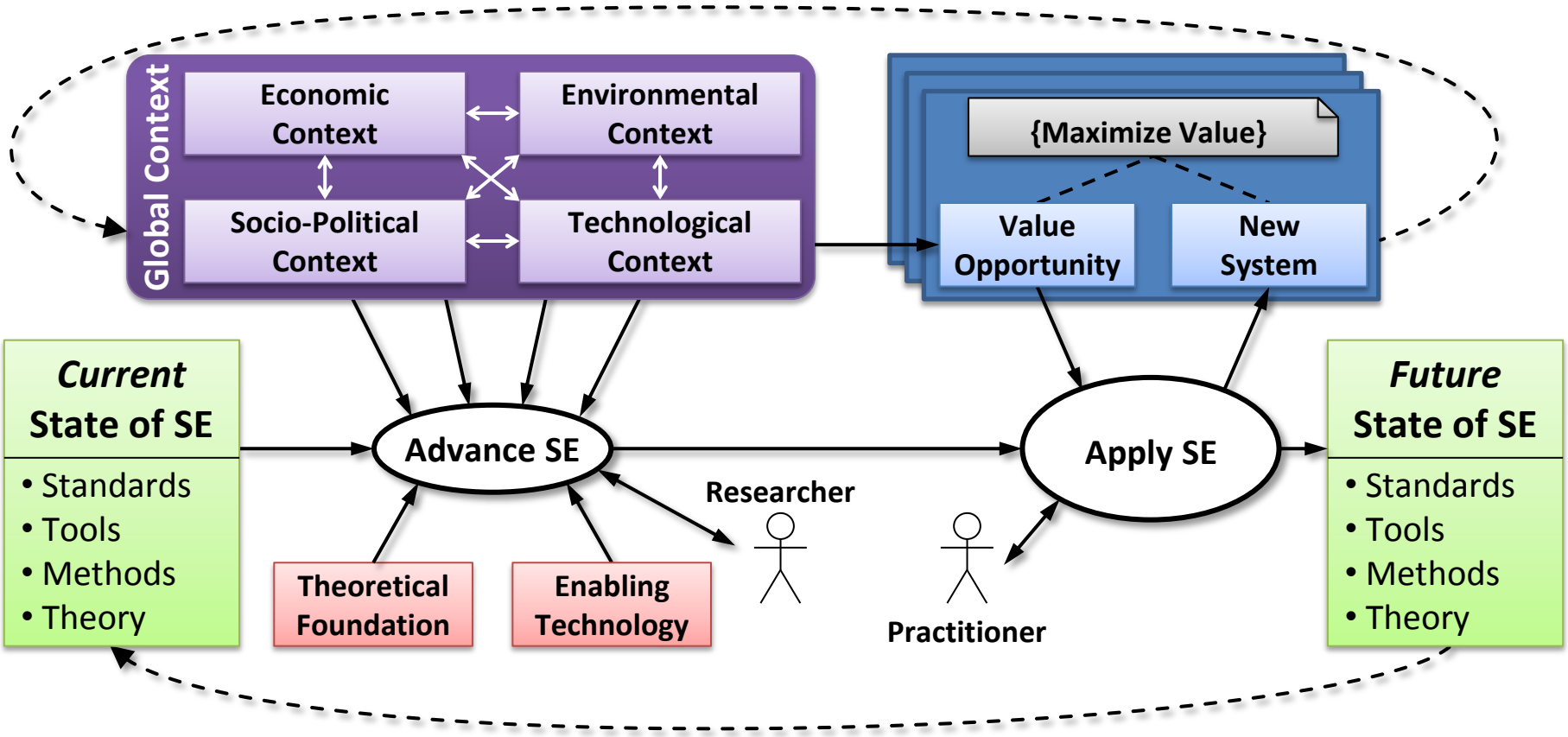
Systems Engineering: Maximizing Value

Research and Education in SE



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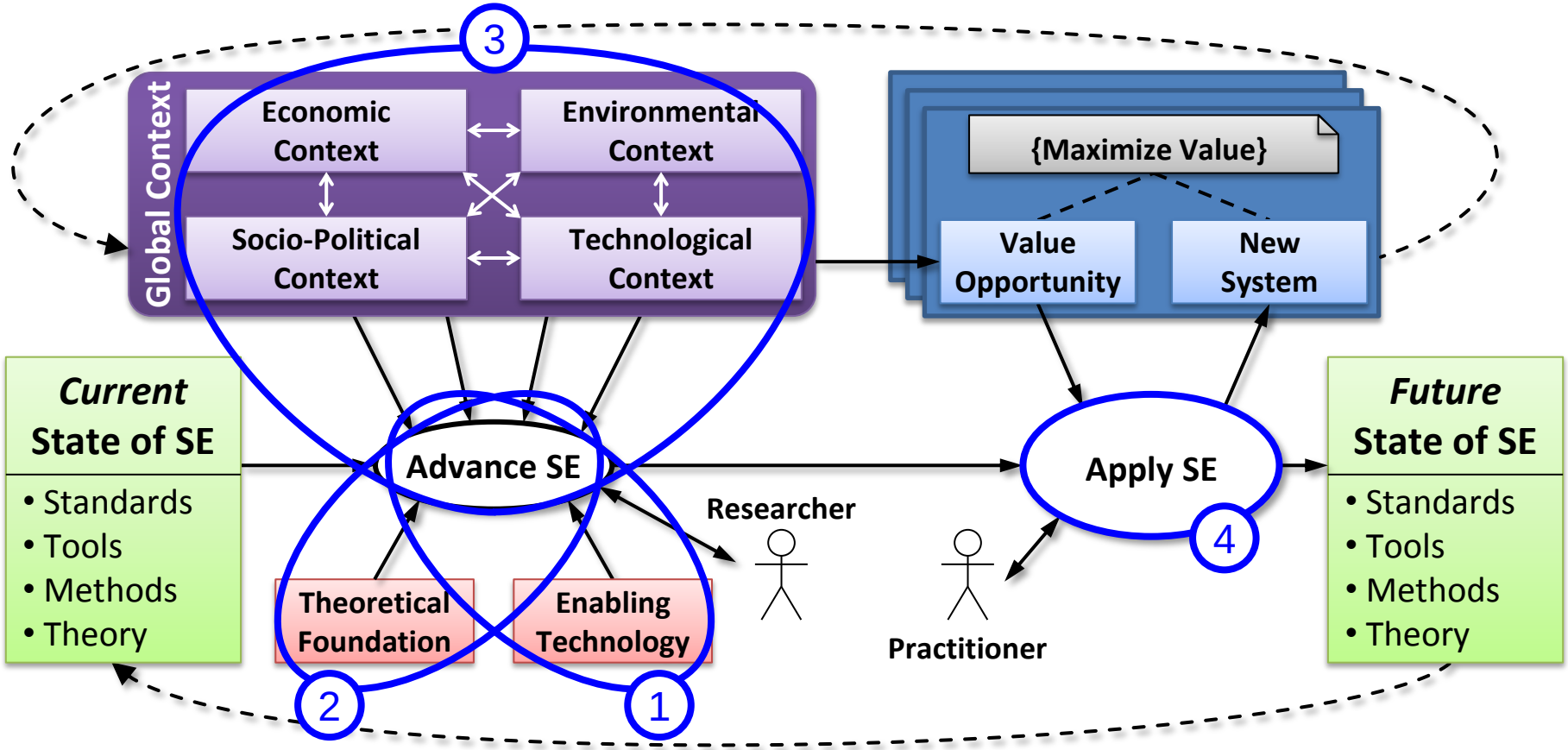

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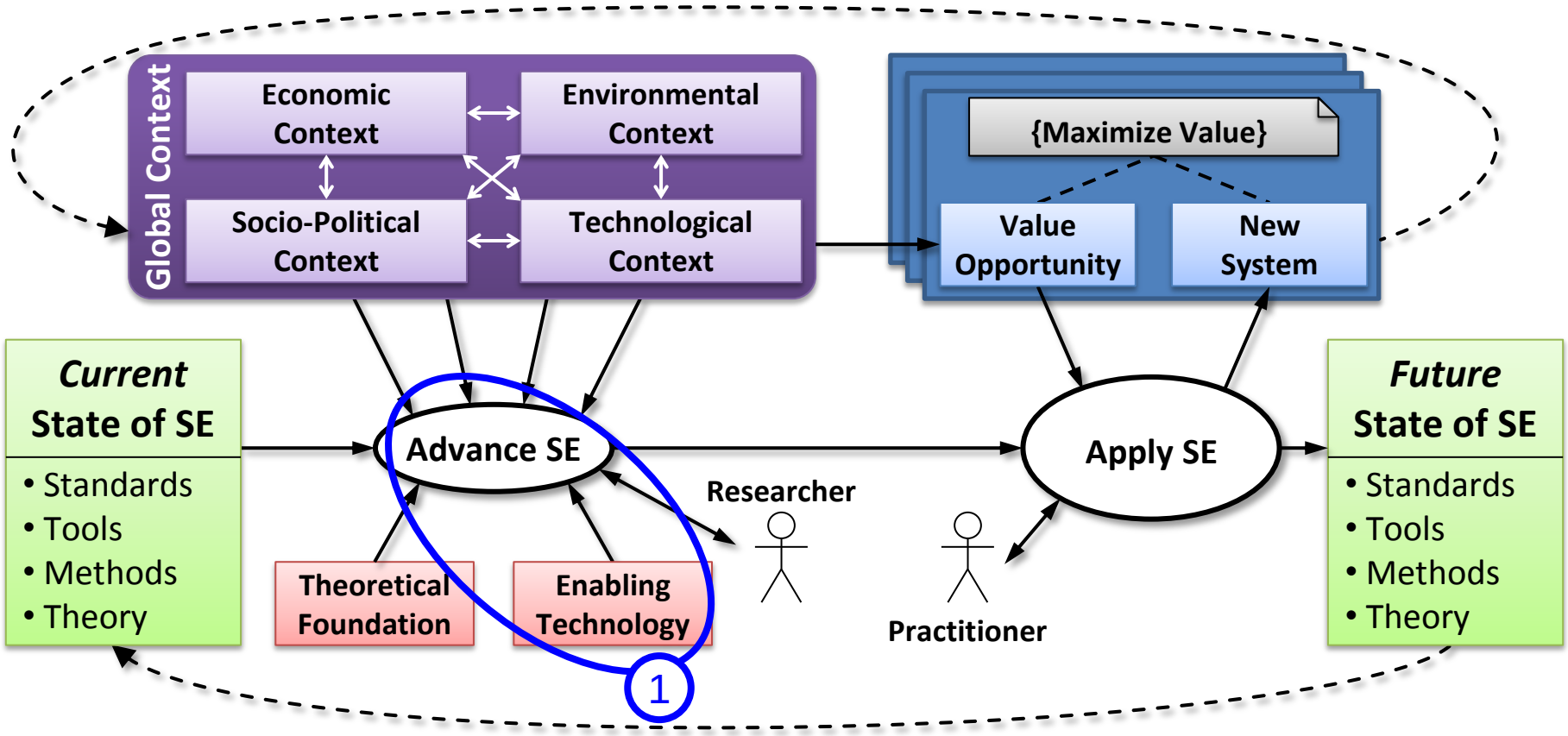
Systems Engineering: Maximizing Value

SE Methods and Tools for Novel Enabling Technologies



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MBSE Based on Novel Enabling Technologies

Primary SE Activities: Work with Information and Knowledge

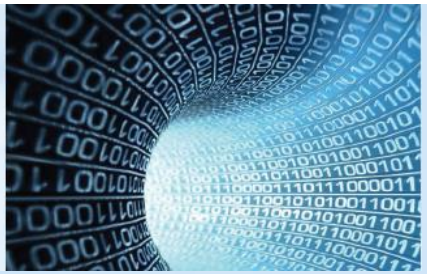
- Collect and store information
- Express information and knowledge formally
- Create new information and knowledge
- Share and manage information and knowledge
- Process information and knowledge
- Access information and knowledge
- Interpret information

Transforming Systems Engineering

Leveraging Technology for Systems Engineering Tools

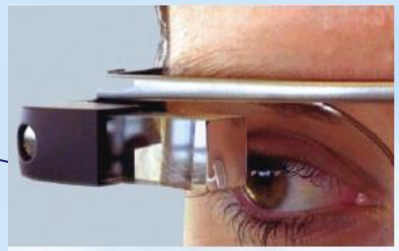
(Source: SE Vision 2025)

Cloud-based high performance computing support high fidelity system simulation



Advanced search query, and analytical methods support reasoning about systems

Immersive technologies support data visualization



Net-enabled tools support collaboration

MBSE Based on Novel Enabling Technologies

Some Research Challenges

- Model Integration – Inconsistency Management
  - Avoiding and resolving inconsistencies in federated models
- Computation
  - Model-based formal verification
  - Computing with uncertain information
- Big Data
  - Data-driven prediction → better, holistic system models
  - Mine the MBSE model repositories
- Visualization — but why stop there?
  - Visual, auditory, tactile, olfactory,…, direct neural interface

MBSE Based on Novel Enabling Technologies

Some Research Challenges

- Model Integration – Inconsistency Management
  - Avoiding and resolving inconsistencies in federated models
- Co
  -
  -
- Bi
  -
  - Mine the MBSE model repositories
- Visualization — but why stop there?
  - Visual, auditory, tactile, olfactory,…, direct neural interface

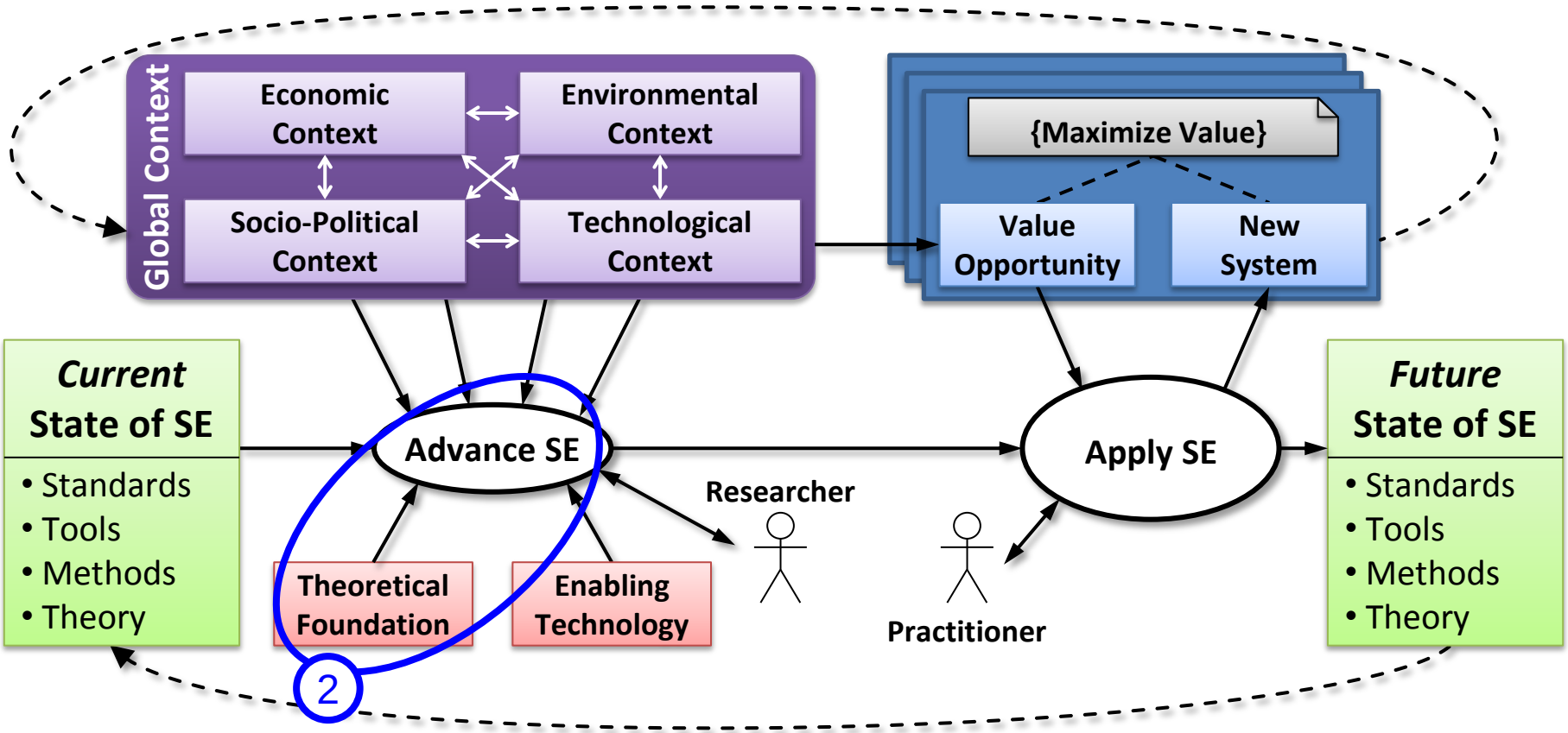
Ultimate Goal: Better Decisions

Methods and tools must be based on sound decision theory. Else…

Tools that help us make poor decision more quickly and cheaply

Systems Engineering: Maximizing Value

The Theoretical Foundation of SE



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Theoretical Foundation for SE

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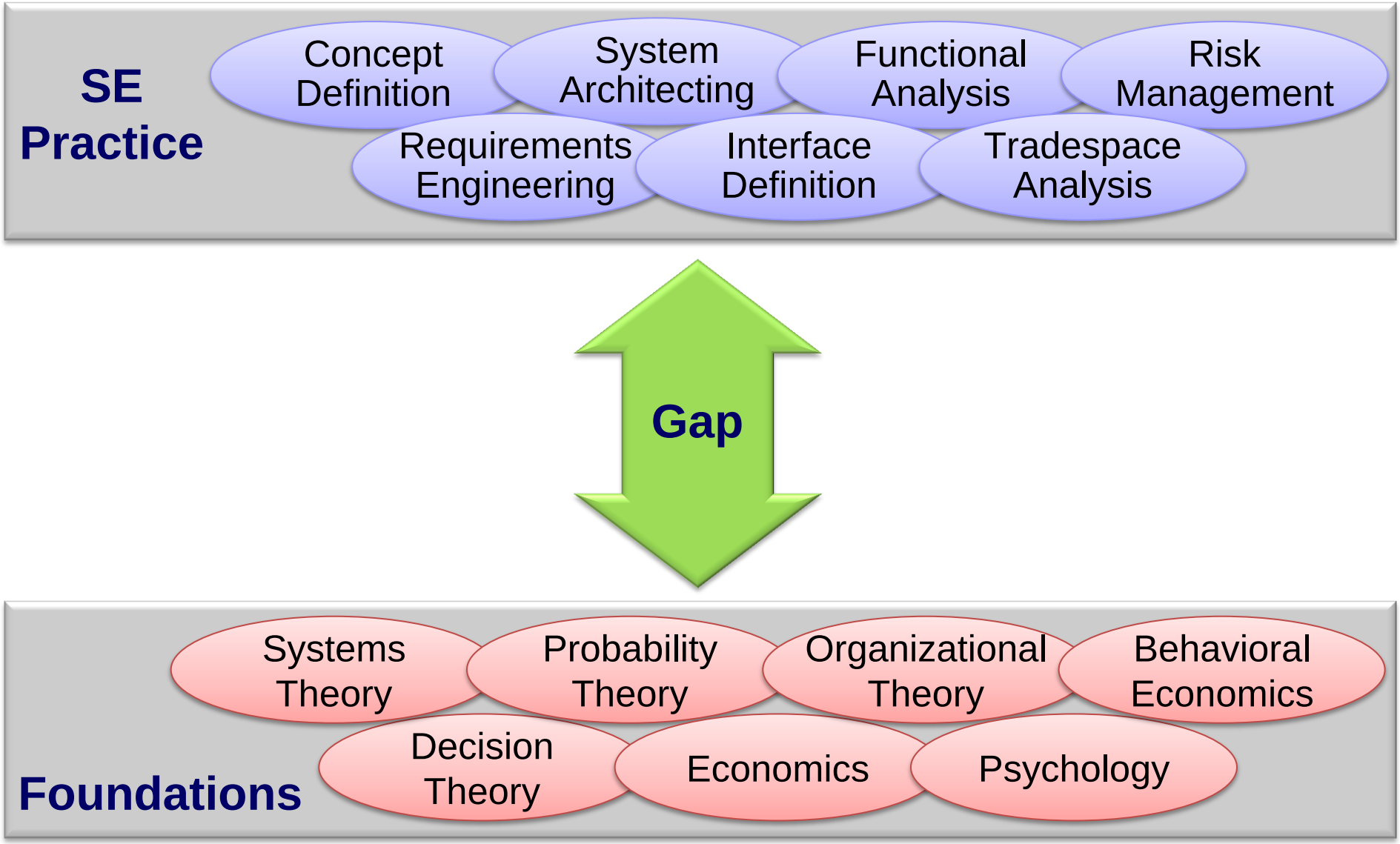

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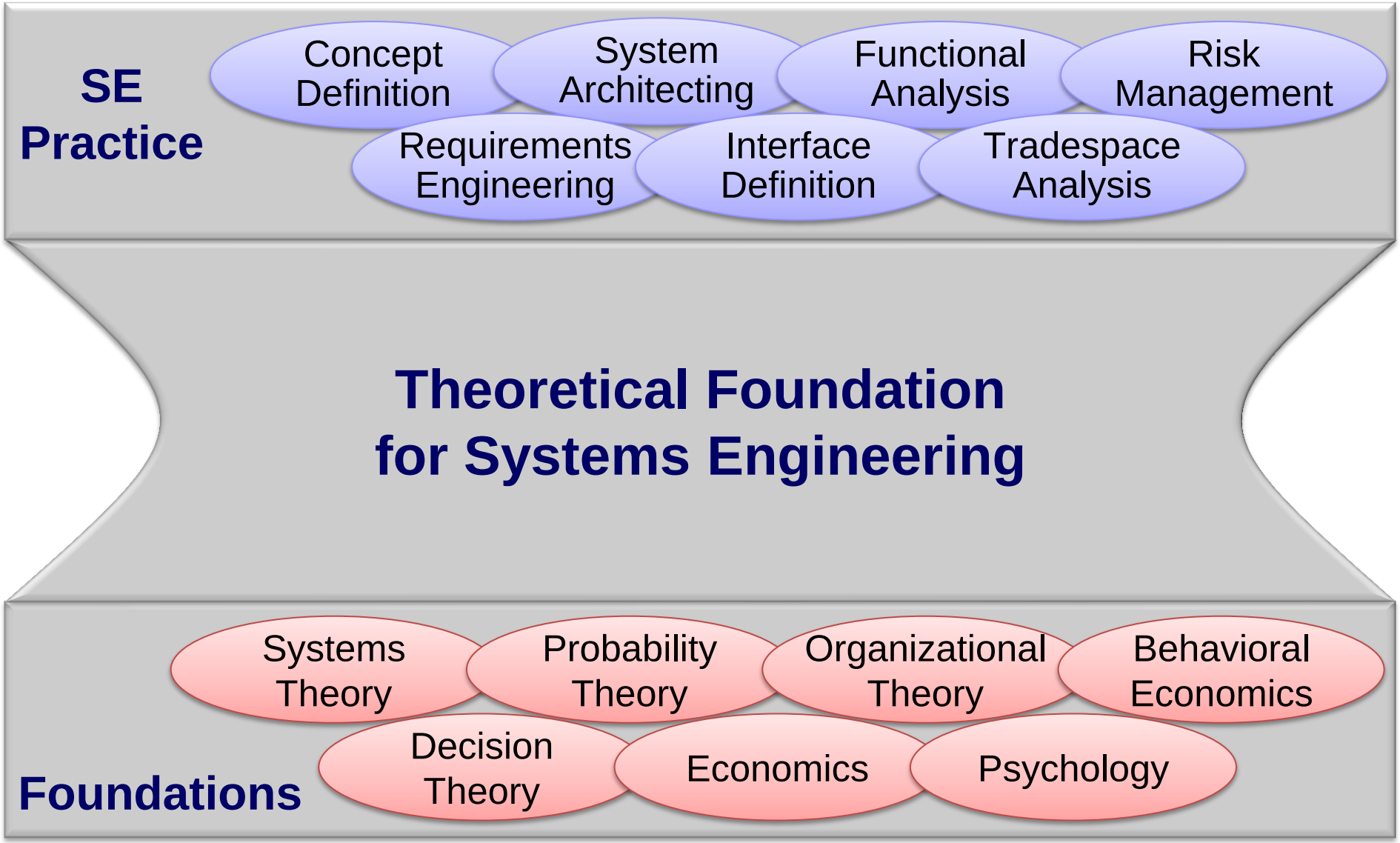

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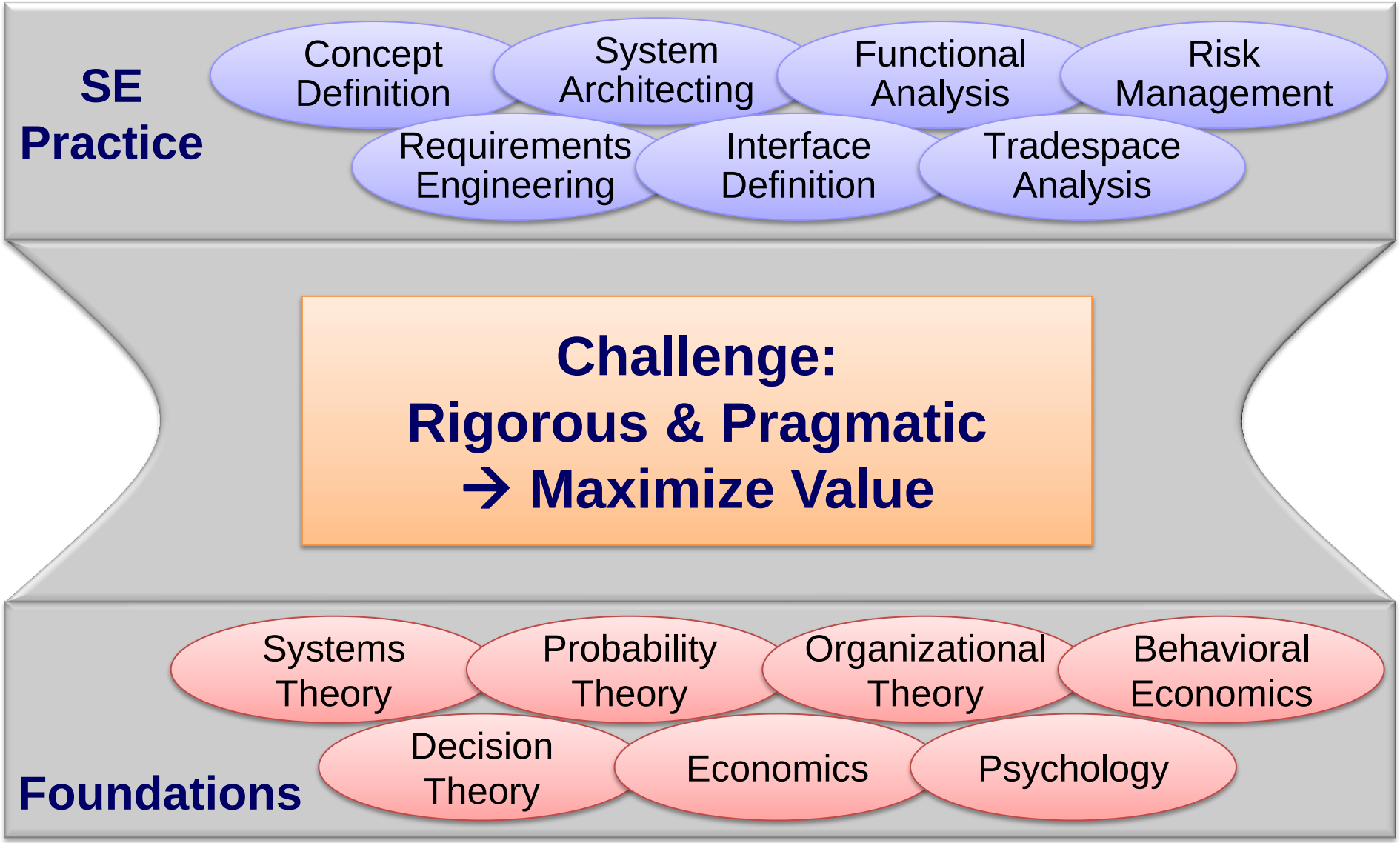
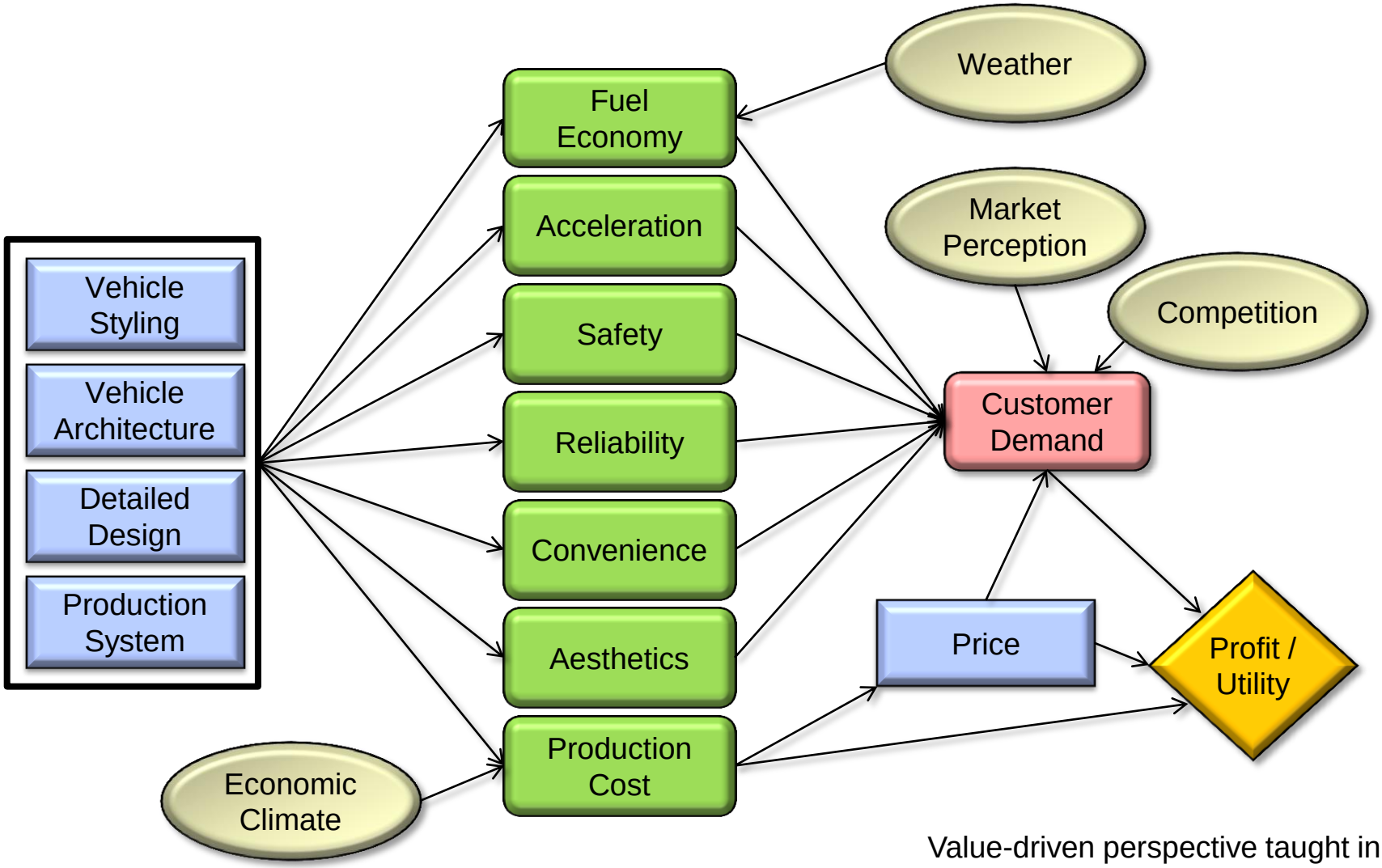


Value-Driven Systems Engineering

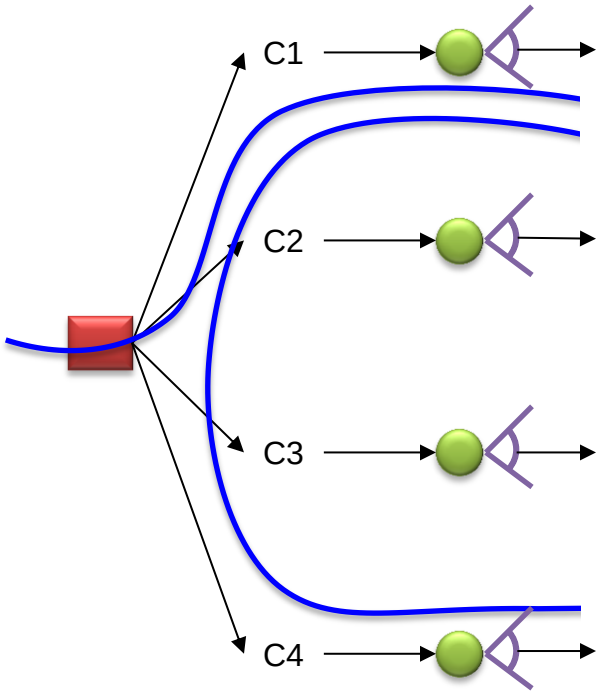
Product-focused Decision Making: Maximizing Profit



Value-driven perspective taught in ME6105 and ASE6002

Value-Driven Systems Engineering

Process-focused Decision Making

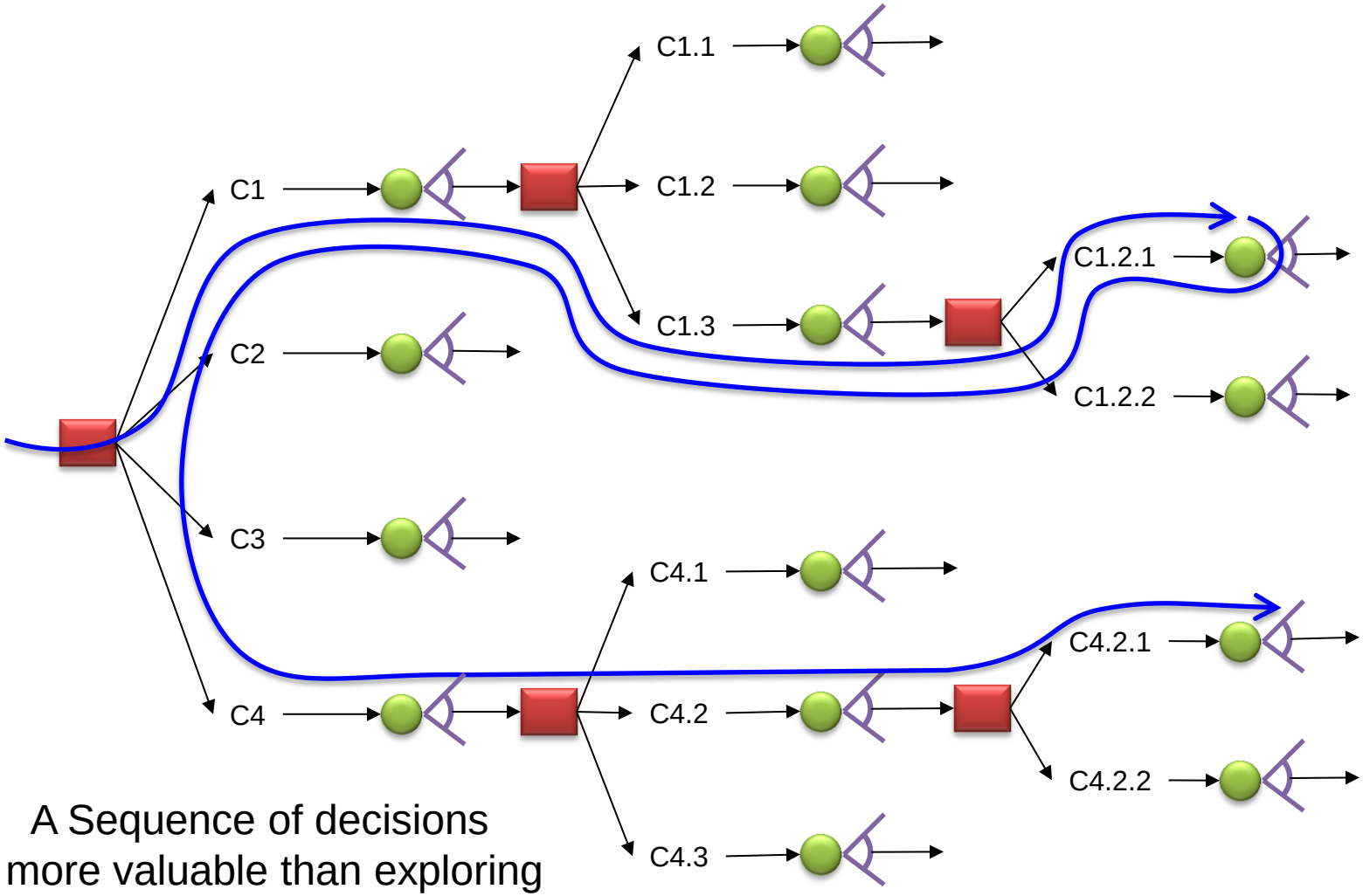


A Sequence of decisions is more valuable than exploring the entire tree at once

Work with former PhD Student Stephanie Thompson

Value-Driven Systems Engineering

Process-focused Decision Making



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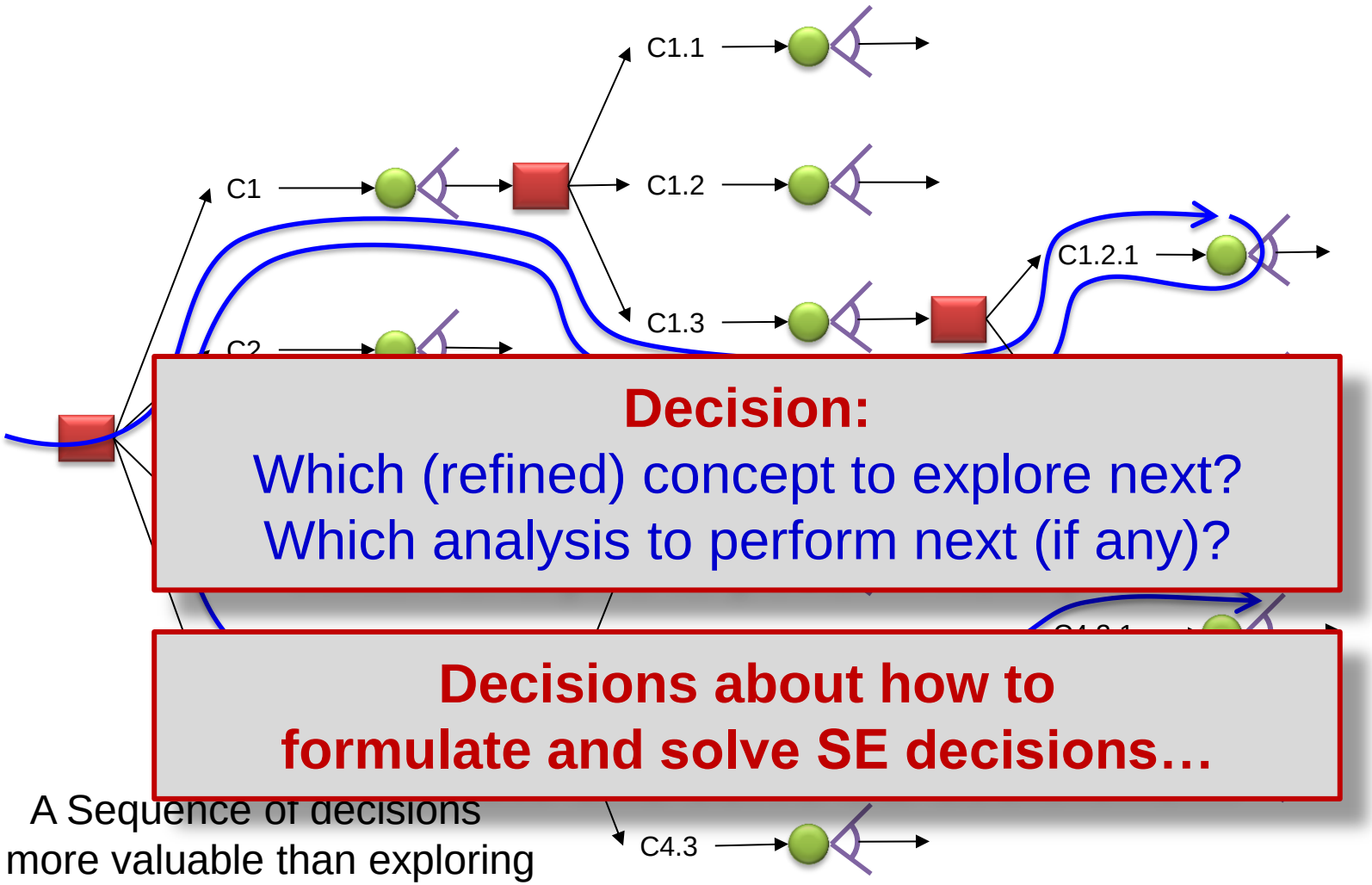

Decision:
Which (refined) concept to explore next?
Which analysis to perform next (if any)?

Decisions about how to formulate and solve SE decisions…

A Sequence of decisions is more valuable than exploring the entire tree at once

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Value-Driven Systems Engineering

Organization-focused Decision Making

Finance

Software

Analysis

Project Management

Manufacturing

CAD

- Power plant
- Transmission
- Brakes
- Chassis
- …

Value-Driven Systems Engineering

Organization-focused Decision Making

Finance

Software

Analysis

Decisions:

To whom to assign which authority & responsibility?

How to measure performance?

How to provide incentives?

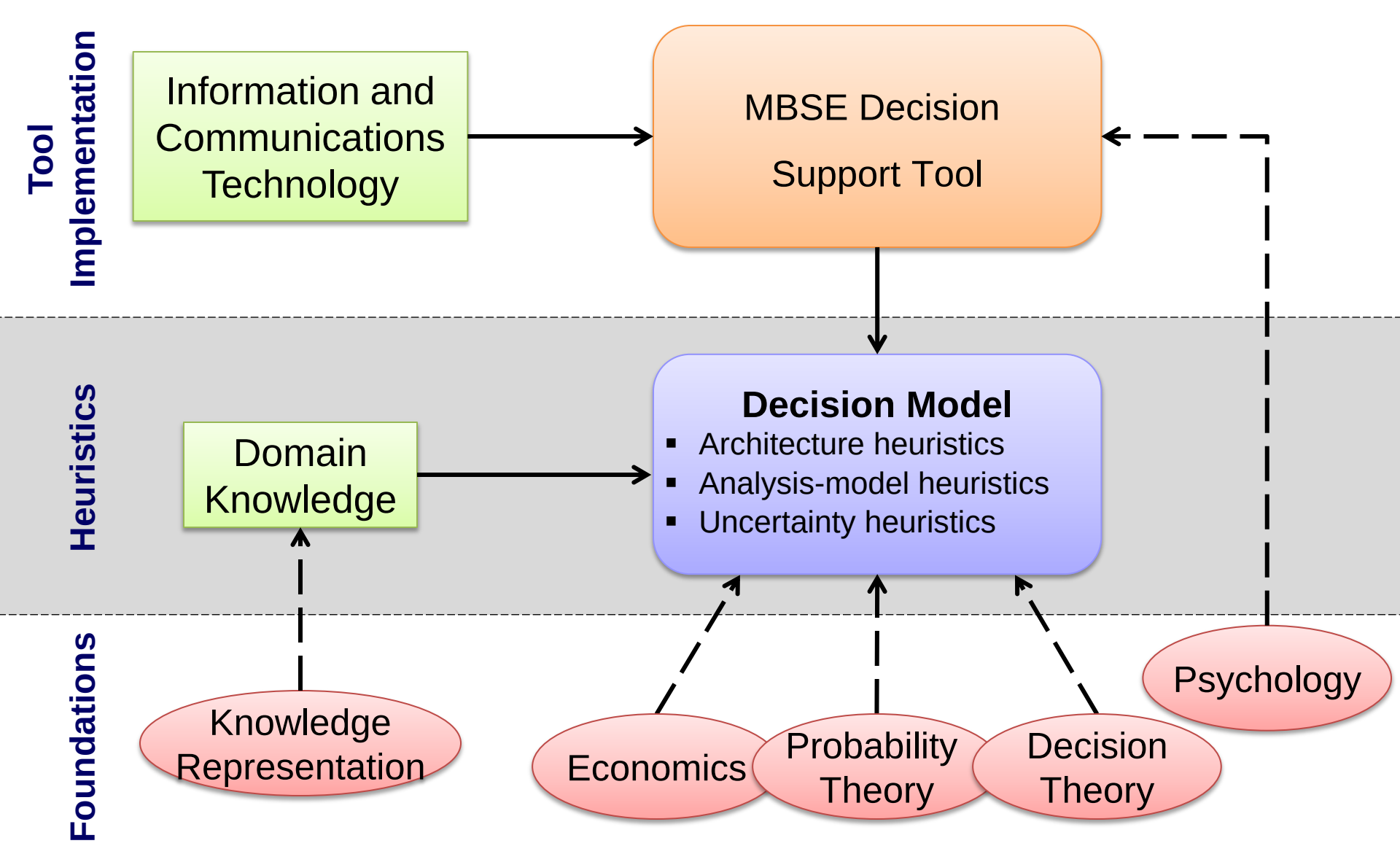
Manufacturing

CAD

- Power plant
- Transmission
- Brakes
- Chassis
- …

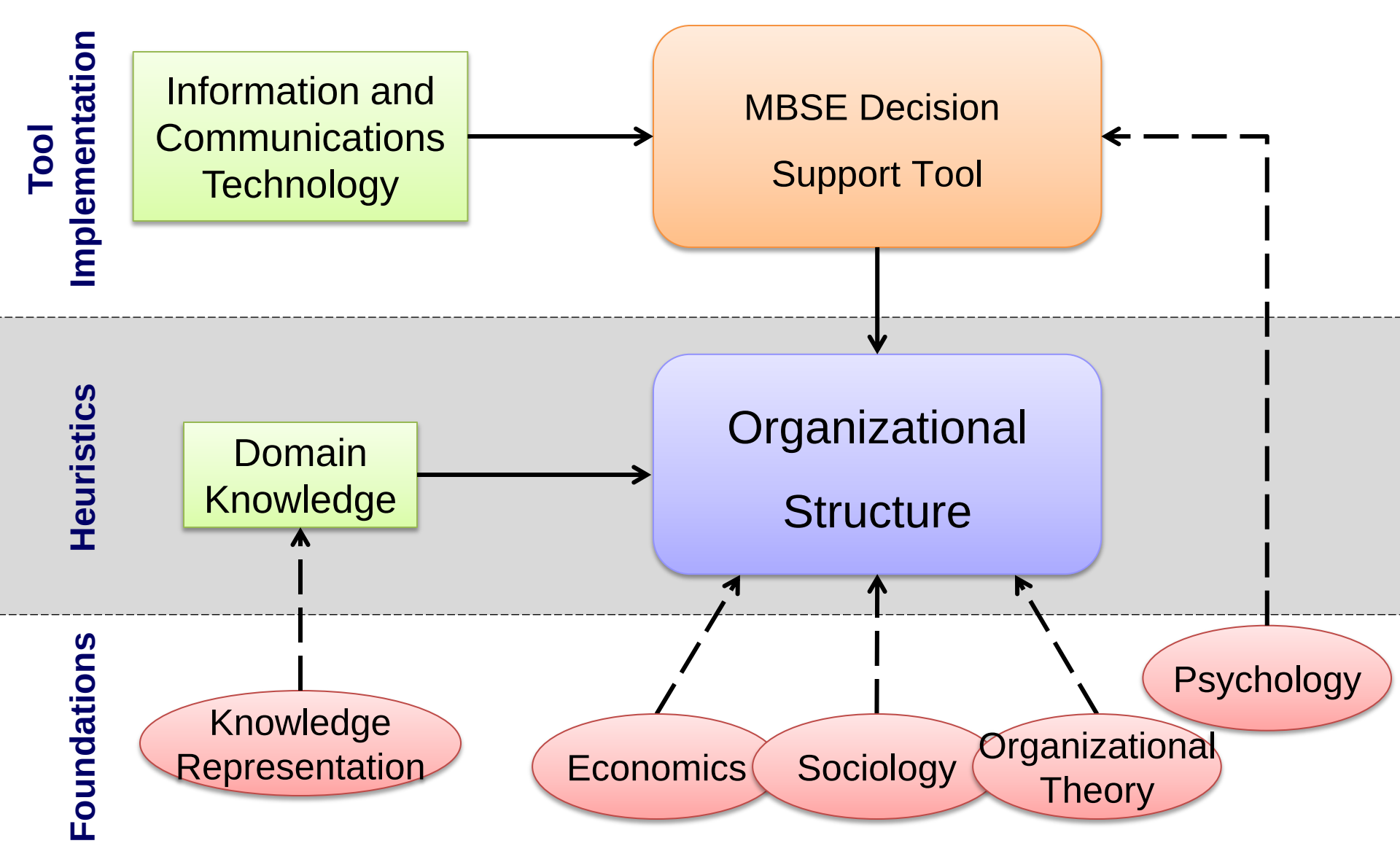
Theoretical Foundation for SE

What Does this Mean for MBSE?



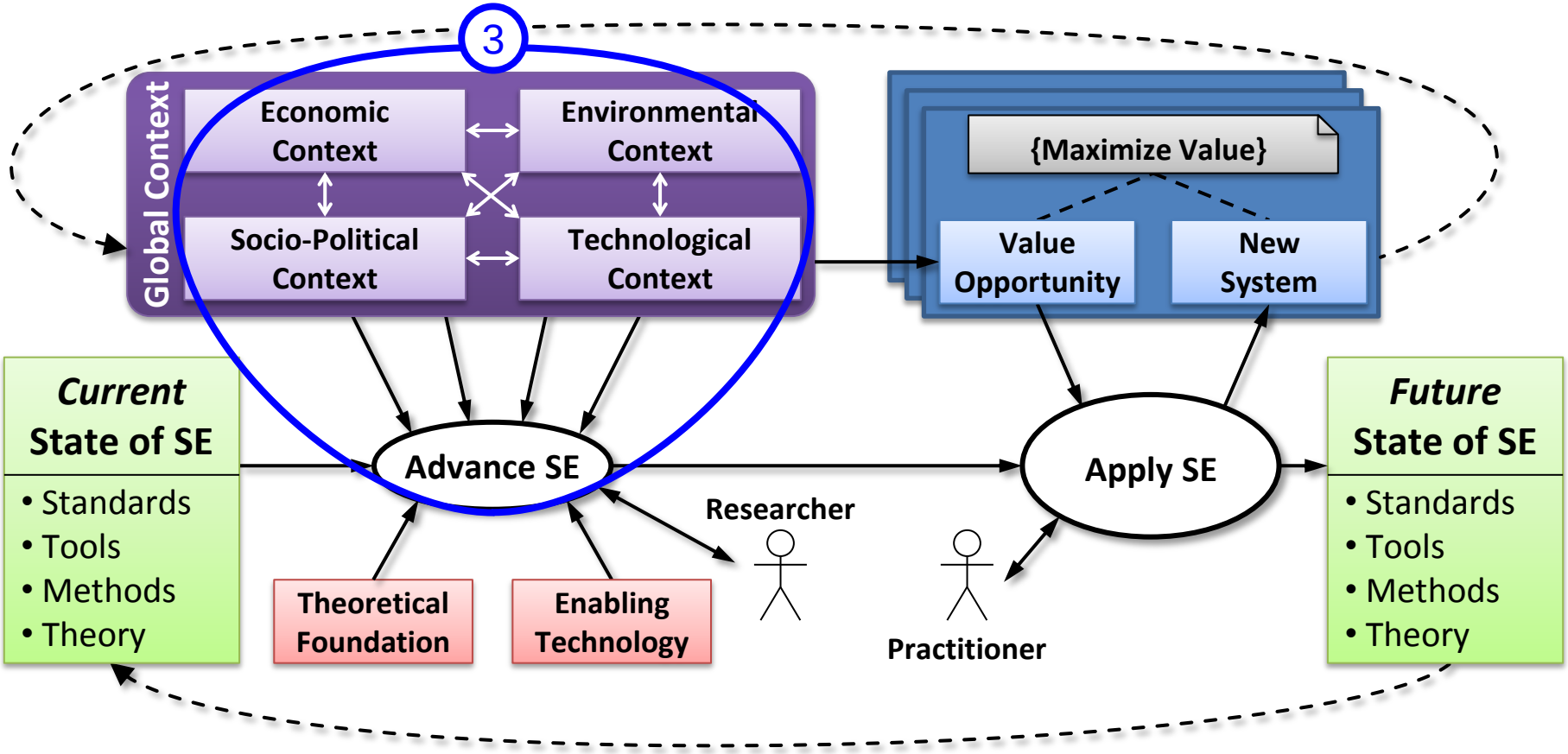
Theoretical Foundation for SE

What Does this Mean for MBSE?



Systems Engineering: Maximizing Value

Research and Education in SE



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MBSE Methods & Tools for a Specific Context

Driven By Value Maximization

- As the global context changes, SE must adapt…

…by operationalizing the theoretical foundation for each specific context

- Increasing complexity
- Shorter lifecycle times
- Decentralization
- Miniaturization
- Mass-customization
- Human-centered
- Systems of Systems
- The Internet of Things
- Dynamic, Data-Driven Application Systems
- Sustainable Systems

MBSE Methods & Tools for a Specific Context

Driven By Value Maximization

- As the global context changes, SE must adapt…

…by operationalizing the theoretical foundation for each specific context

A new context implies new heuristics:

- Synthesis heuristics — which architecture patterns?
- Analysis heuristics — which formalisms, fidelity?
- SE process heuristics — where to allocate resources?
- Organizational structure — who does what?

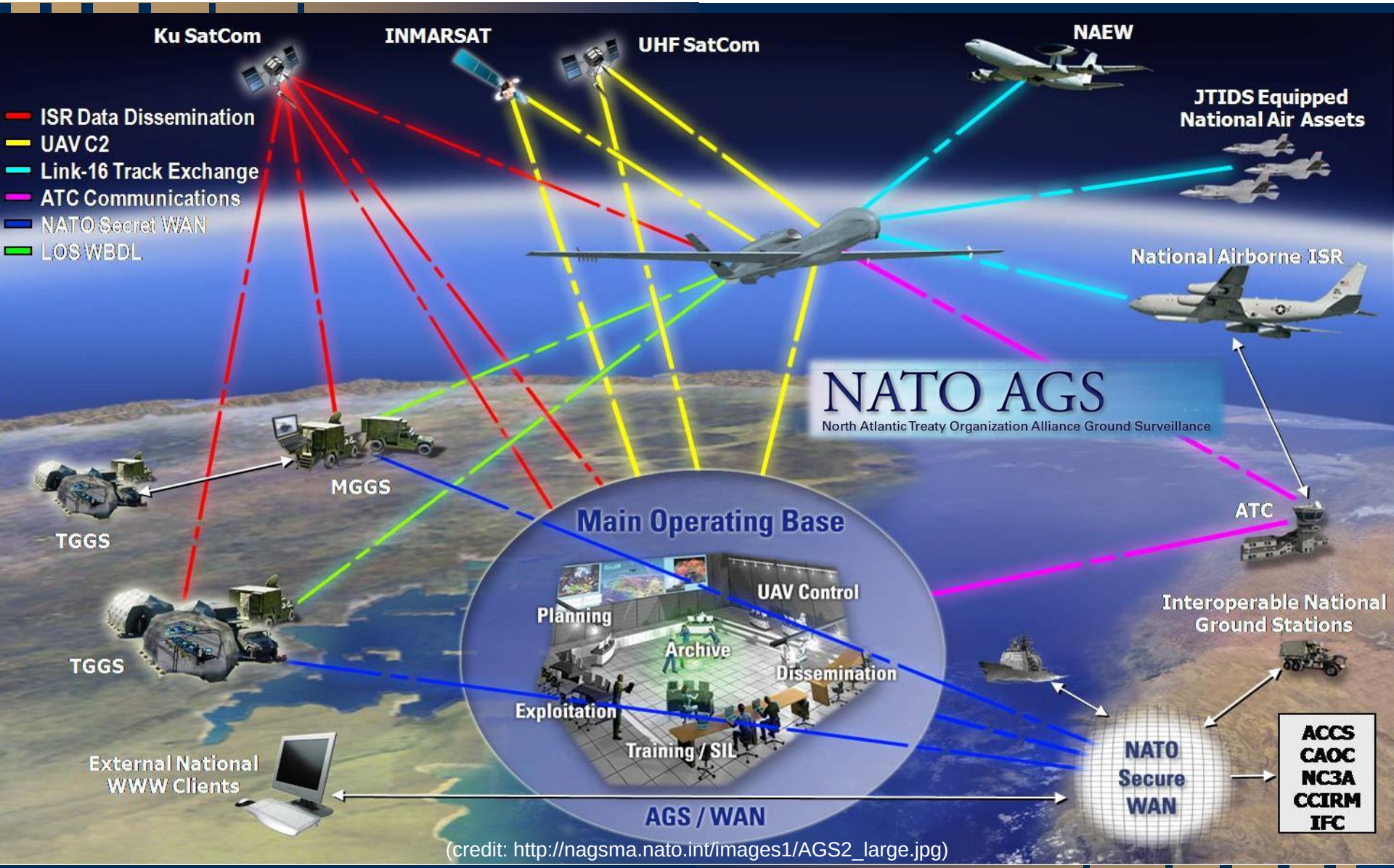
- Miniaturization
- Mass-customization
- Human-centered

Application Systems

- Sustainable Systems

MBSE Methods & Tools for a Specific Context

Example: System of Systems

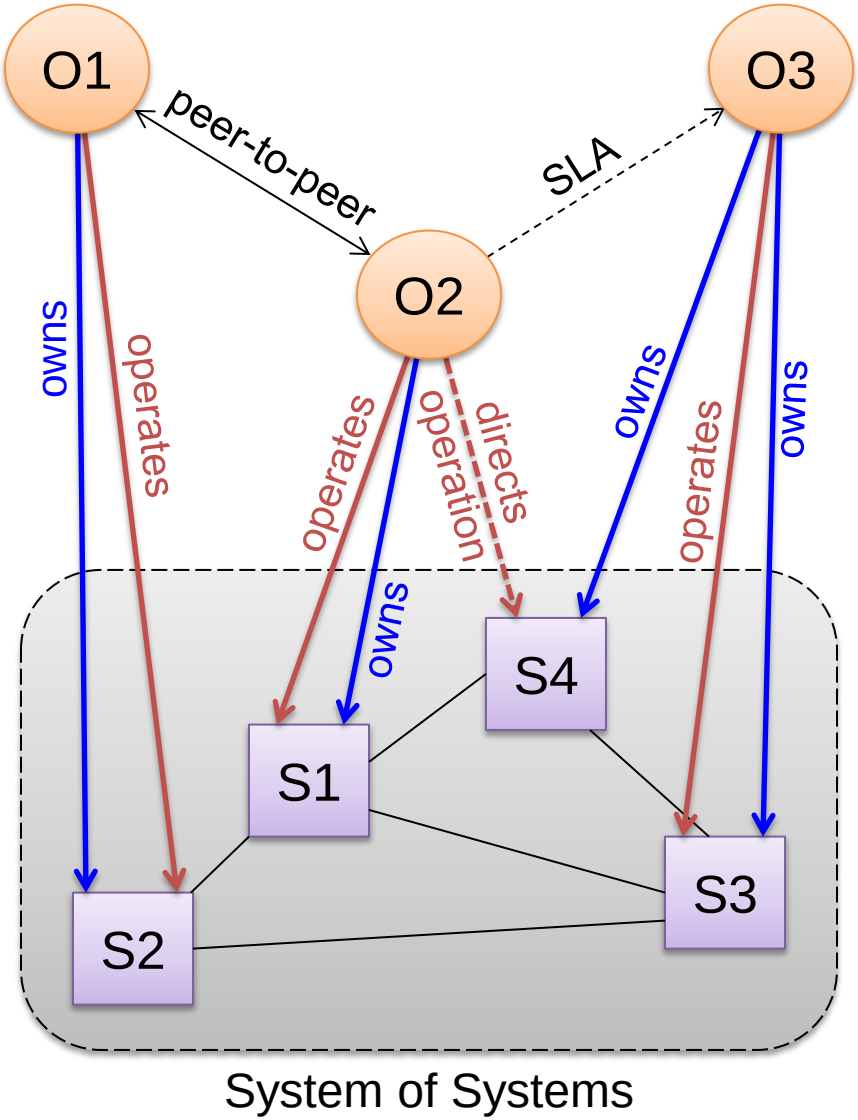


(credit: http://nagsma.nato.int/images1/AGS2_large.jpg)

MBSE Methods & Tools for a Specific Context

Example: System of Systems

- SoS Characteristics
  - Evolving over time
  - Multiple owners
  - Multiple, independent designers
  - Operational and managerial independence
- Challenges
  - Socio-technical problem
  - Uncertain, evolving
  - Requires flexibility, interoperability



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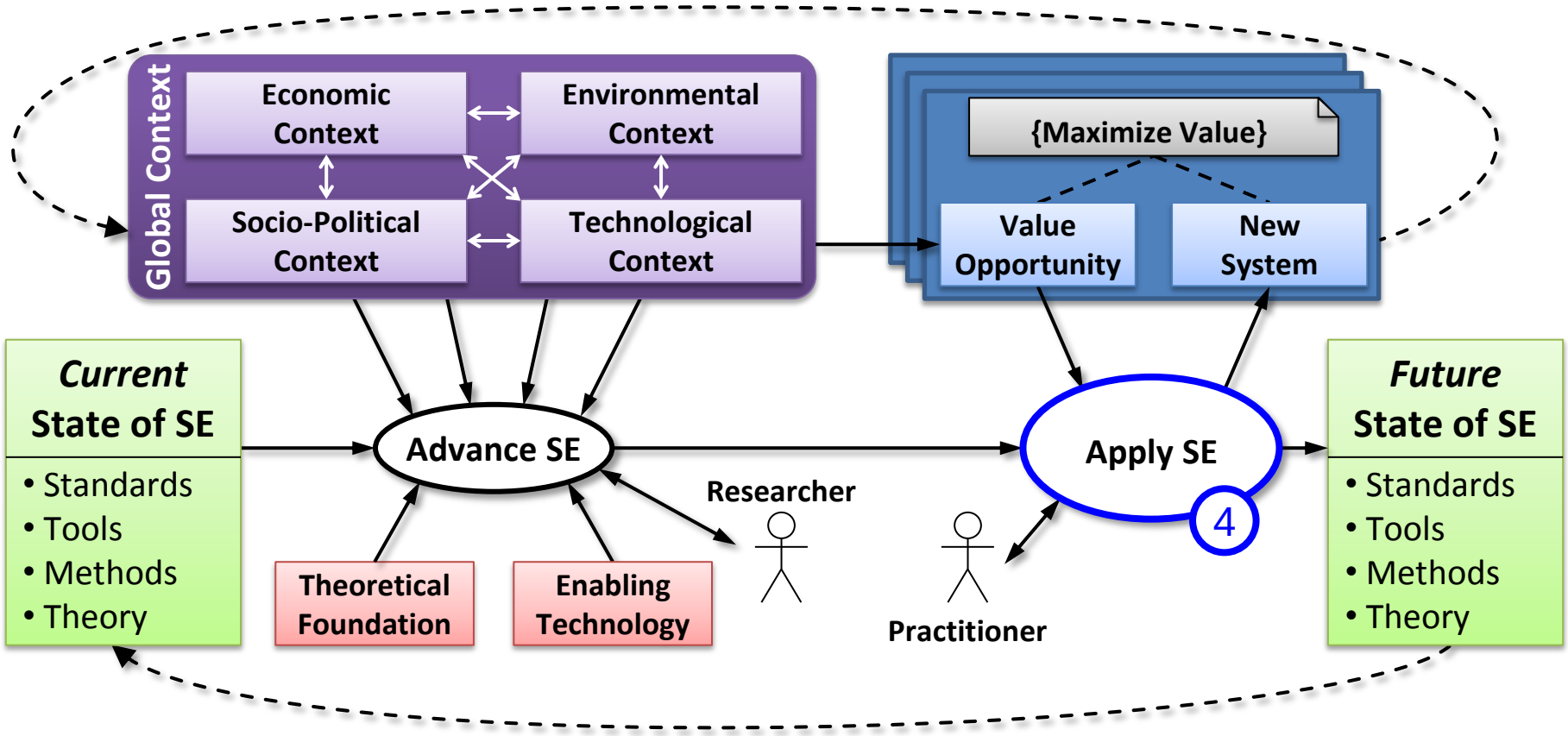

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MBSE in Education

The only Constant is Change

— Heraclitus ca. 500BC

- The context changes very quickly, and at an increasing rate
  - Economic context
  - Environmental context
  - Technological context
  - Socio-political context
  - Enabling technologies

→ We must prepare future systems engineers for constantly changing SE practices

MBSE in Education

Focus on the Foundations — and Start Young…

- Focus on the foundations
  - Modeling = Expressing One's Knowledge Formally
  - Which language or which tool is less important

- Descriptive models
  - Abstraction, object-orientation, formal semantics, ontology
- Analysis models
  - Approximation, uncertainty, mathematical formalisms
- Systems thinking

- We need research on modeling education
  - Which mental models do we use? Meta-cognitive models?
  - At what age do we become capable of modeling?
  - Which practical approaches are most effective for teaching modeling?

Key Take-Aways

1. The Future of SE is Value-Driven and Model-Based
   - The overall objective is to maximize value
2. Systems and Systems Engineering are Changing Constantly
   - Driven by competition — a desire to maximize one's own value
   - Gaining a competitive advantage in SE capabilities is crucial
3. MBSE Must be Based on a Strong Theoretical Foundation
   - Let's avoid helping people make poor decision more quickly and cheaply
4. MBSE Must be Adapted to the Global Context
   - We need to find the best heuristics for each application and for new enabling technologies
5. MBSEC Education
   - Focus on the foundations — and start young…

The Future of MBSE Research and Education:
Value-Driven and Model-Based Methods in the Socio-Technical Context of Organizations