



The Value of Modeling in Systems Engineering and Design

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Presentation Outline



Context: Framing SE&D

A normative perspective:

Can we understand and explain why engineers use models and argue for how they should use models?

- What is a model?
- Why do engineers model?
- What kinds of models do engineers use?
- Which models should engineers use?

Framing Systems Engineering & Design

SE&D is a Process with a Purpose... Maximizing Value

- “Everyone designs who devises courses of action aimed at **changing existing situations into preferred ones**”
 - Herbert Simon, *The Sciences of the Artificial*
- How do engineers change existing situations?
 - **By creating or improving artifacts...**
- Value is a measure of preference
 - The most preferred outcome is assigned the largest value
 - Aim to maximize value

SE&D is a purposeful search for value

Models Add Value in SE&D

Models Enable Efficient Search for Valuable Artifacts

Vision

Reality

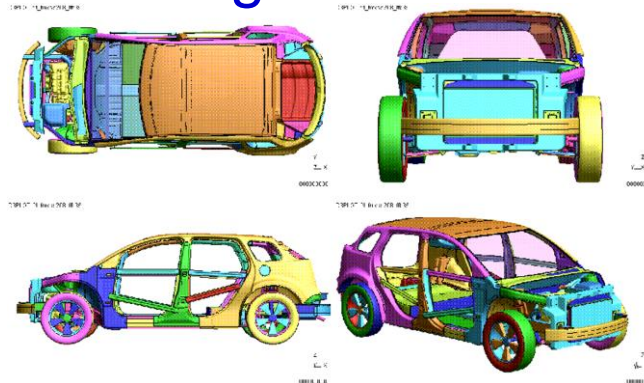
If you fail to plan, you are planning to fail!

Benjamin Franklin

Potential
Value Opportunity



Models for
Planning & Prediction



<https://lotusproactive.wordpress.com/2013/01/15/determining-the-crashworthiness-of-a-lightweight-vehicle/>

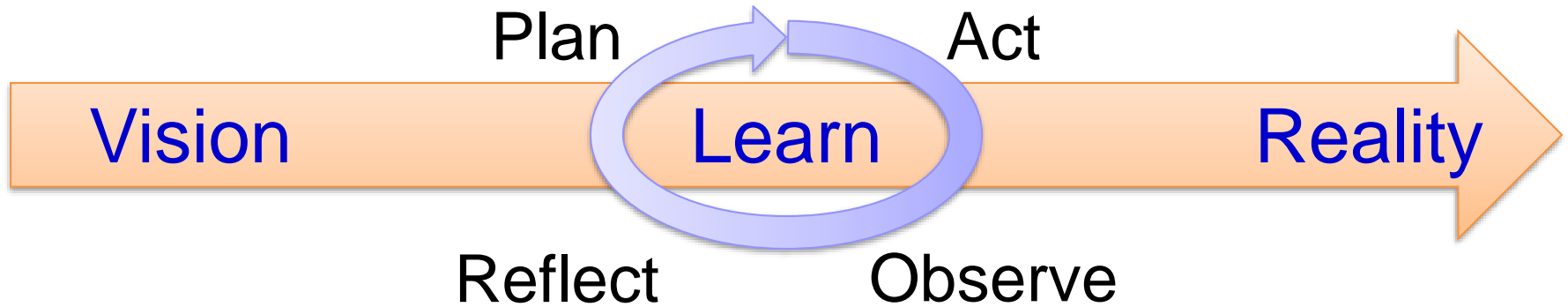
Valuable
Artifact



<http://cuicardeeporange.com/project/do4/>

SE&D as Learning

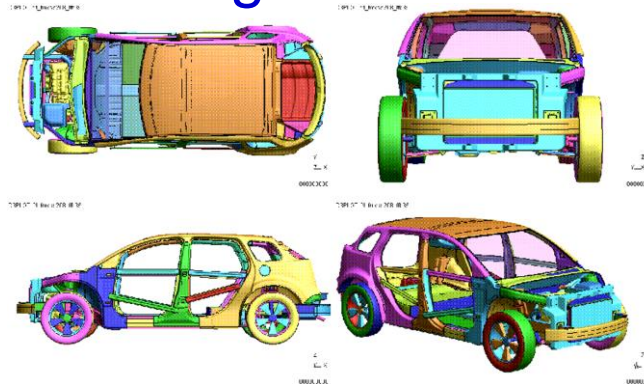
Strategy: Incremental Refinement & Uncertainty Reduction



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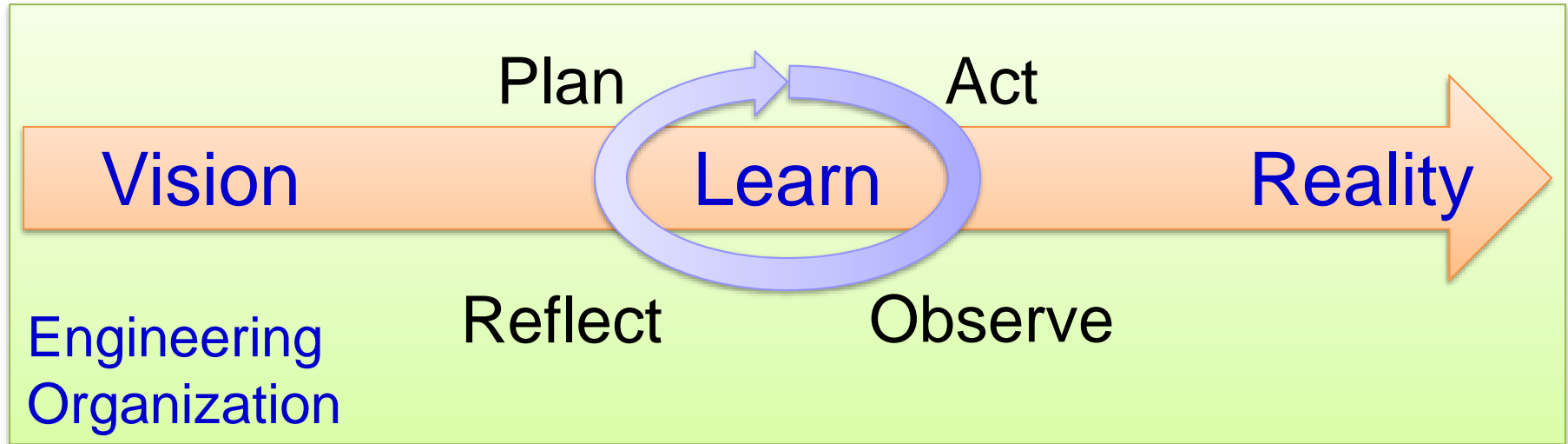
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SE&D in an Organizational Context

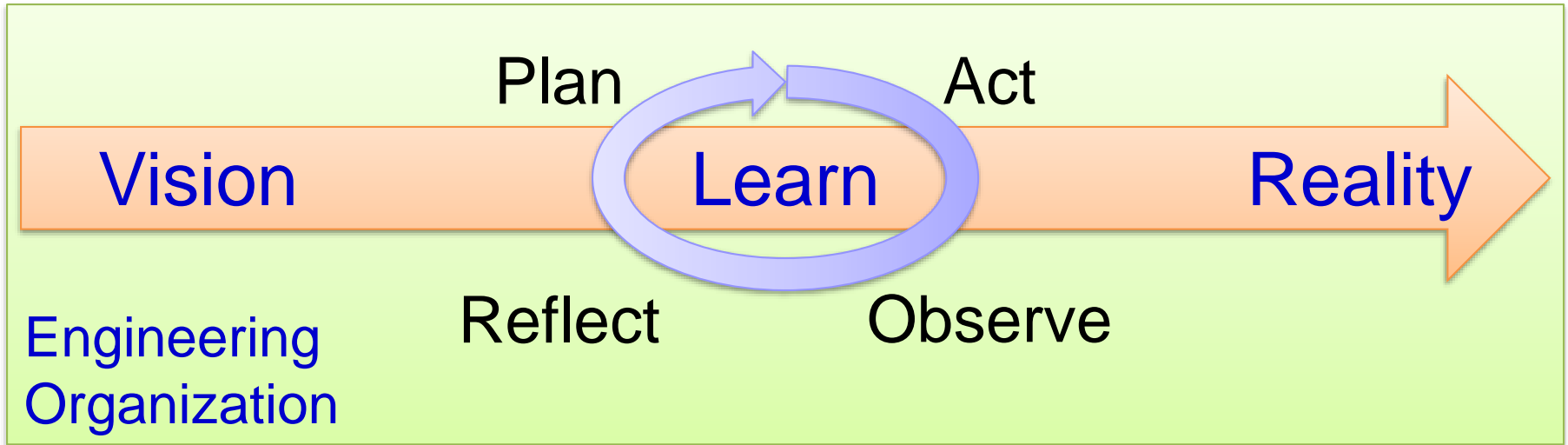
Strategy: Divide & Conquer through Decomposition & Delegation



- No individual has all the knowledge about the system... instead, many individuals have deep knowledge about different, specialized aspects of the system
 - How do we integrate all the knowledge such that we develop successful, valuable systems?
 - distributed cognition, decomposition, delegation

Summary: Framing SE&D

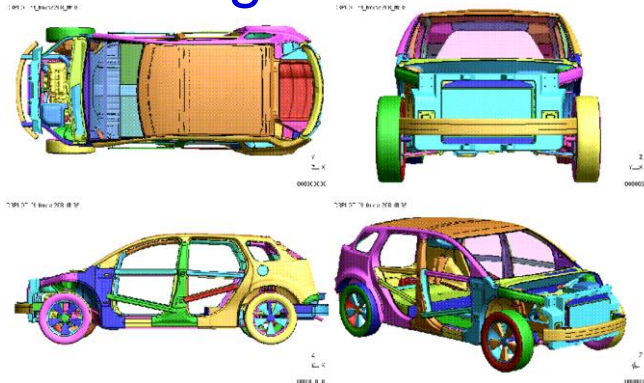
Efficient Learning in an Organizational Context



Potential
Value Opportunity



Models for
Planning & Prediction



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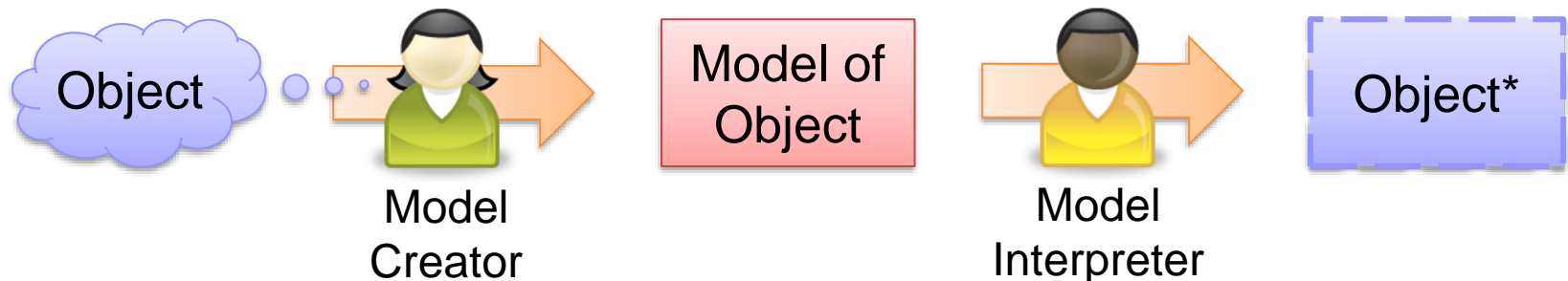


What is a model?

- Why do engineers model?
- What kinds of models do engineers use?
- Which models should engineers use?

What is a Model?

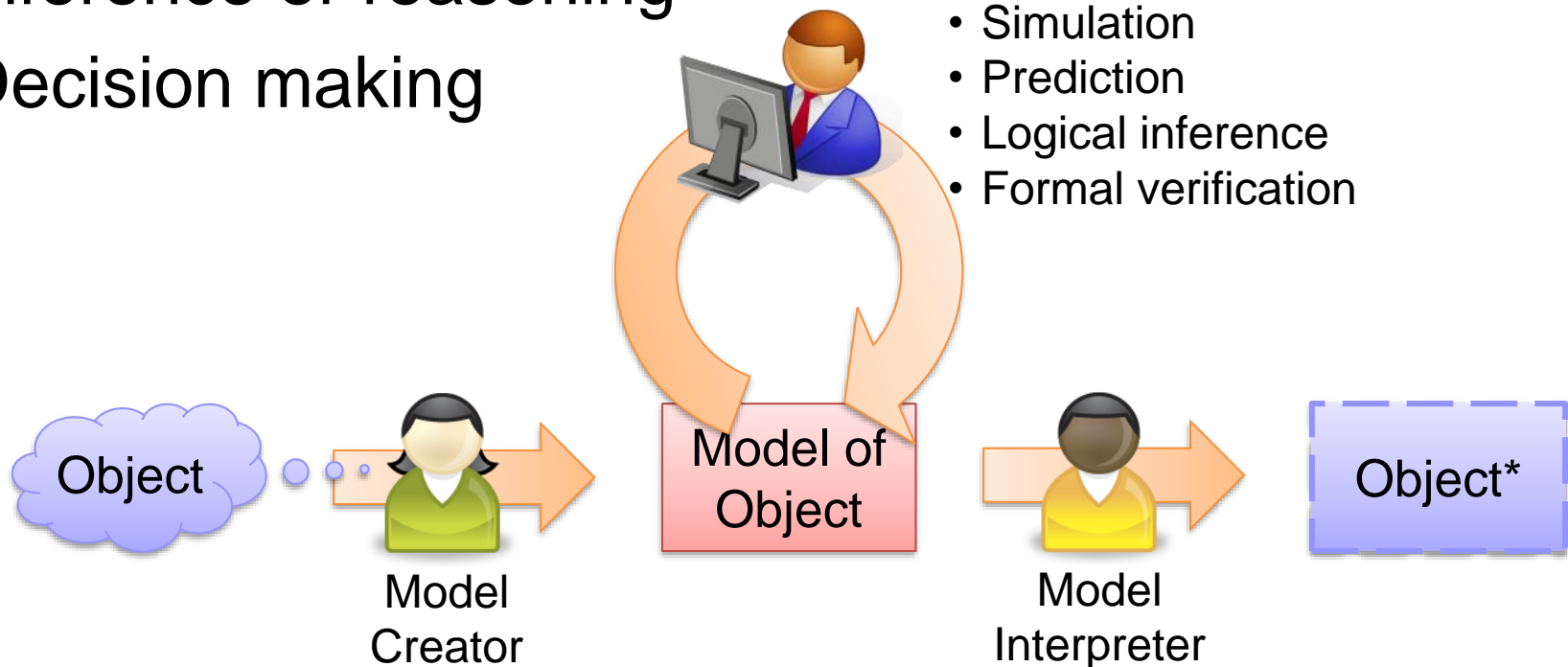
- Definition by F. Cellier based on M. Minsky:
A model (M) for a system (S) and an experiment (E) is anything to which E can be applied in order to answer questions about S
- In an SE&D context:
Models are artifacts — expressions of human thought...about the artifacts being engineered, most commonly in a (formal) modeling language



Why Do Engineers Model?

Formally expressing and representing thoughts help with...

- Communication
- Memorization
- Ideation
- Inference or reasoning
- Decision making
- Understanding, explaining & theorizing
- Learning



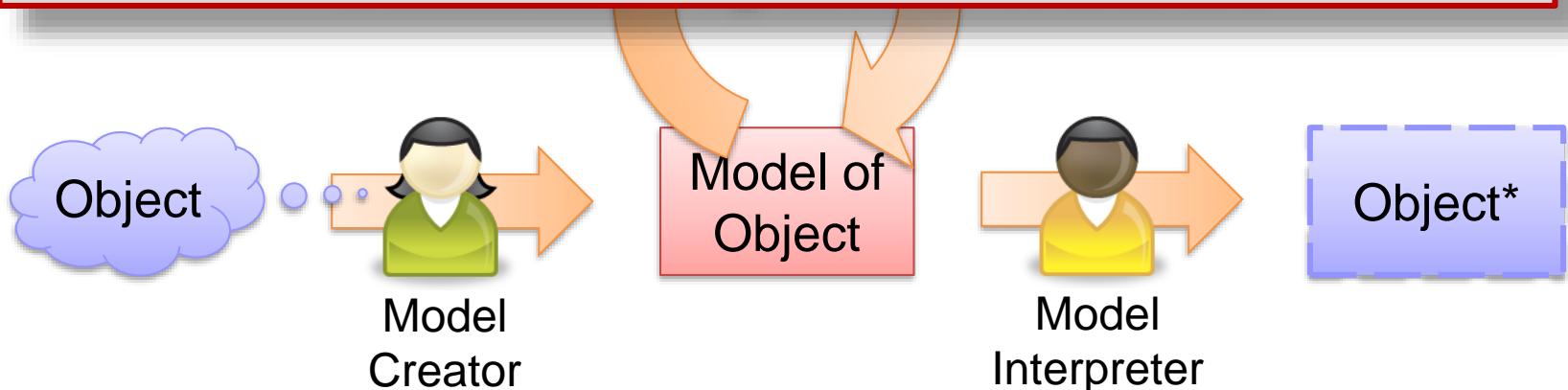
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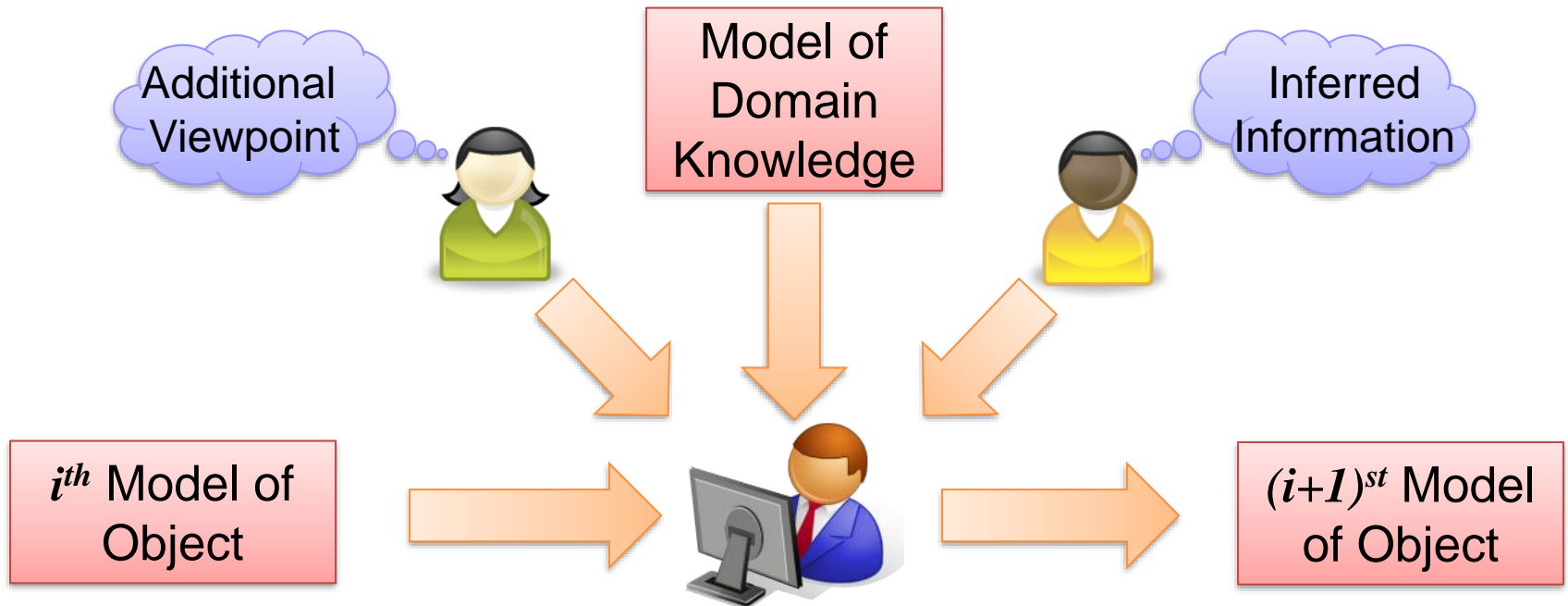
Models expand the cognitive abilities of engineers

Models used by Teams =
Distributed Cognitive Environment



Modeling as a Transformation Process

Incrementally and collaboratively refining a plan



Transform Model

- Inference or Reasoning
- Abstraction, Elaboration
- Augmentation, Integration

Enabling More Efficient Search for Value

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What Kinds of Models Do Engineers Use?

Descriptive Models — Describe What Is

- Examples
 - Describe what is measured or observed
 - Describe what is preferred
- Purpose of descriptive models
 - To “change existing situations into preferred ones,” it is important to be able to describe the situation as-is
 - To enable communication among stakeholders
 - To provide context for reasoning about to-be states
- Nature
 - Reflects what is observed
 - Requires a conceptualization, ontology — language & vocabulary
 - Propositions — could be true or false

What Kinds of Models Do Engineers Use?

Prescriptive Models — Prescribe What Shall Be

- Examples
 - Requirement models
 - Functional models
 - CAD models — prescribe geometry
 - Behavior specification models
- Purpose of prescriptive models
 - Specification of a plan for how to move from the current situation to a different/improved situation
- Nature
 - Reflects what is imagined — not observed
 - Reflects a choice — not a true/false proposition
 - Constrains, directs, and guides future SE&D actions

What Kinds of Models Do Engineers Use?

Predictive Models — Predict What Will Be

- Example
 - Predict the cost or performance of an artifact
 - Predict how the state of a system will evolve over time
- Purpose of predictive models
 - To reason consistently about the consequences of a prescribed plan executed in a described context
 - Is indispensable for efficient search
- Nature
 - Reflects a believe
 - Is inherently uncertain — we are not clairvoyant
 - But should be coherent — internally consistent, but also externally consistent with scientific knowledge
 - Engineers rely on the generality of scientific knowledge to predict future situations in new contexts
 - But engineers don't necessarily care about making (the most) accurate predictions — good enough to make a good choice

What Kinds of Models Do Engineers Use?

Models of Heuristics — Suggest How to Get There

- Example
 - When designing an outer-planets spacecraft, rely on nuclear energy rather than solar
 - When designing a consumer-product, first aim to understand the value proposition to the user — empathize
- Purpose
 - To provide guidance — based on previous experience, it suggests how to act in particular context
- Nature
 - Reflects learning — engineering knowledge
 - When engineers search, they capture knowledge about the search space and about how to search efficiently
 - Often suggests how to use scientific models to achieve engineering goals
 - Could become prescriptive – e.g., a handbook of best practices

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Which Models **Should** Engineers Use?

The Models that Add the Most Valuable

- Goal of engineering is to add value — to arrive at more preferred situations efficiently
 - A good engineering model supports the addition of value efficiently
- Do we care whether it is “right” or “valid”?
- In the end, I care whether it “works,” i.e., “adds value”
- Difficult to know in advance which models add most value → rely on heuristic

Summary

- It is human nature to aim to improve one's situation
- Since the resources needed to improve a situation are valuable themselves, engineers aim to arrive at improved situations efficiently
- Models add value by allowing engineers to expand their cognitive abilities (as a team), and hence to search for improved situation more systematically and efficiently
- Models serve different purposes in search for value
 - Descriptive models — describe existing situations
 - Prescriptive models — specify plans for future situations
 - Predictive models — predict the consequences of the plans
 - Models of heuristics — capture what we have learned