Georgia Institute of Technology

Systems Realization Laboratory

Model-Based Systems Design

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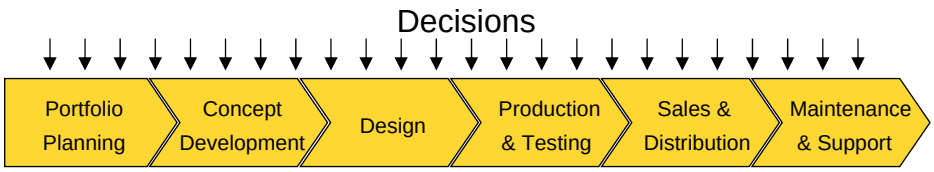
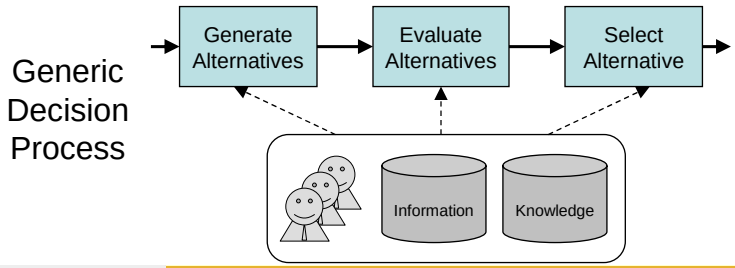
Presentation Overview

- Context
  - A Foundation in Decision Theory
  - Information Economics
- The Systems Design Problem
  - The problem & the challenges
  - Characteristics of a solution approach
- Solution Approach
  - Multi-aspect modeling
  - Model Composition
  - Graph transformations

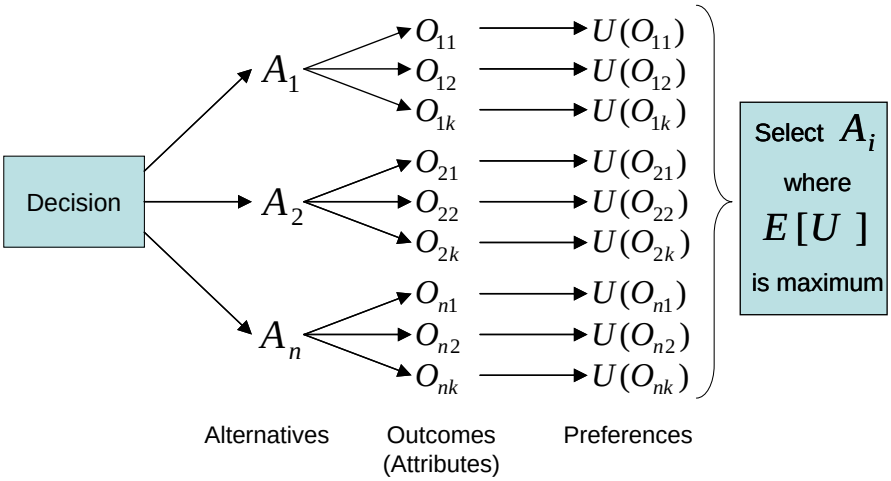
Product Development: A Decision-Based Perspective



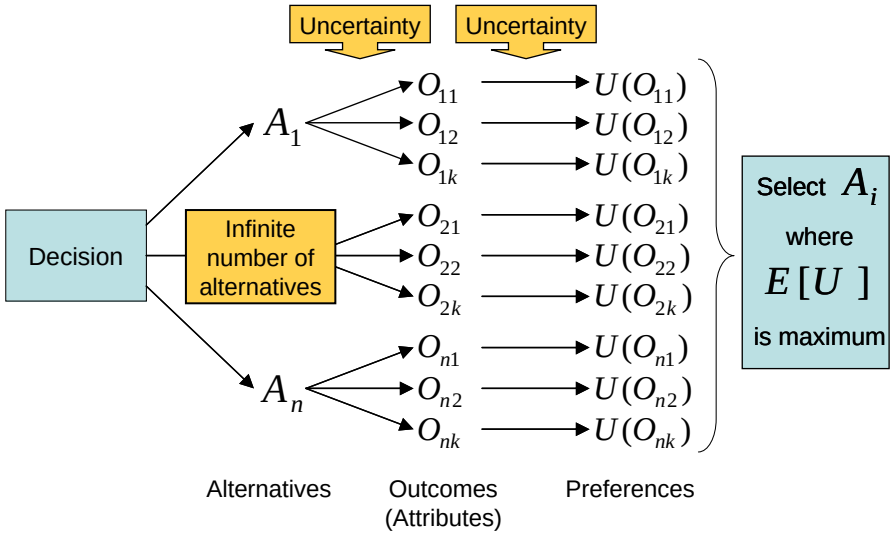
Modeling and Simulation Provides Information in Support of Decisions



Normative Decision Theory



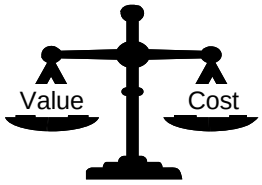
Why are Design Decisions Difficult?



Limited Resources

Integration of Design Product & Design Process

- Goal: maximize **overall** utility
  - Must consider process in utility assessment
- Value trade-offs between product and process
  - Decrease expected utility of product to reduce expected cost of process
  - "Optimal" solution is guaranteed not to be optimal from a pure product perspective
- Information Economics
  - Meta-level decision: How to frame your design problem?

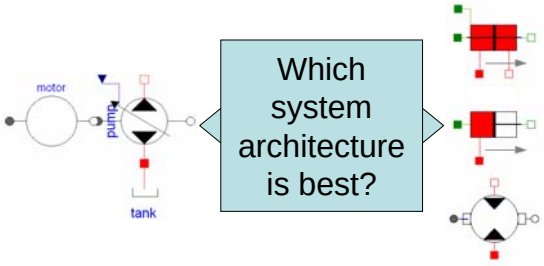


Systems Approach to Product Development

- The ***systems approach*** provides a balanced trade-off between product and process objectives
- Systematic decomposition
  - Large, flexible, yet manageable design space
- Decoupling
  - Limit the risk due to unexpected interactions
  - Enable collaborative engineering
- Helps us deal with complexity

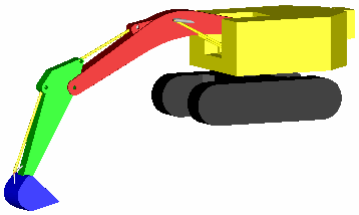
Example: Design of Fluid-Power Systems

- Many system architectures
  - User interfaces with haptic feedback
  - Independent metering control
  - Throttle-less control
  - …

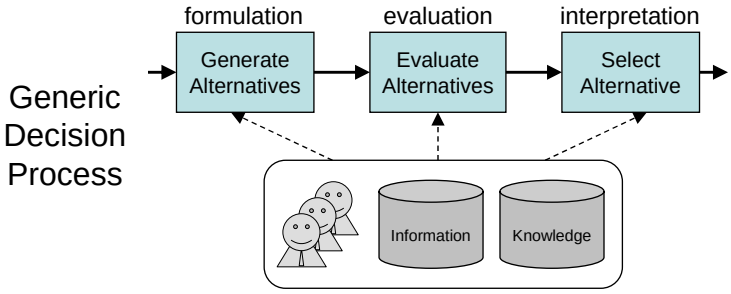


- Challenge:

How can one explore this large space of system architectures efficiently and effectively?



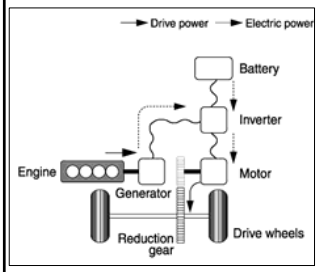
A Decision-Theoretic Perspective



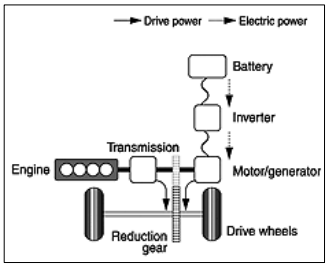
- Challenges for Systems Design
  - The *structure* (architecture) of the alternatives *varies*
  - The evaluation of the alternatives involves *multiple disciplines*
  - In the selection of the most preferred alternative, one should consider *multiple attributes under uncertainty*

Variable Topology Design Space

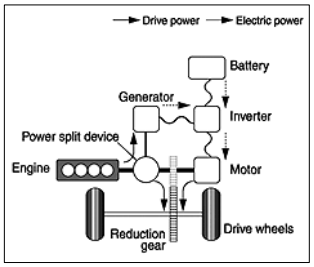
- Different architecture topologies
  - → different parameters
  - → different structure of objectives and constraints



Series



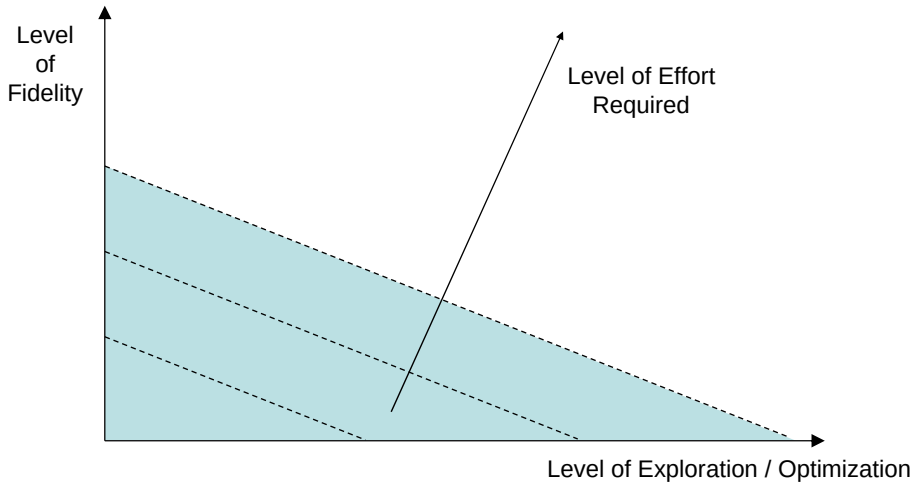
Parallel



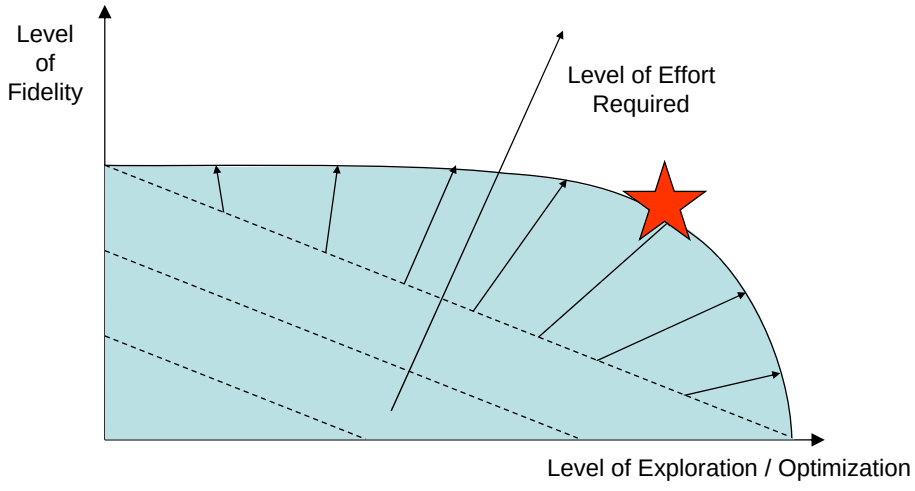
Series/Parallel

(Source: http://www.toyota.co.jp/en/tech/environment/ths2/what.html)

The Information Economic Challenge

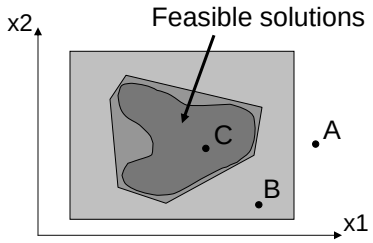


The Information Economic Challenge

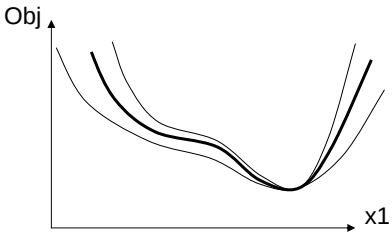


Variable Fidelity Modeling

- Low fidelity for broad exploration
  →identify promising regions of design space
- High fidelity for detailed optimization



Variable Fidelity
Constraints



Variable Fidelity
Objective Function

A Model-Based Approach

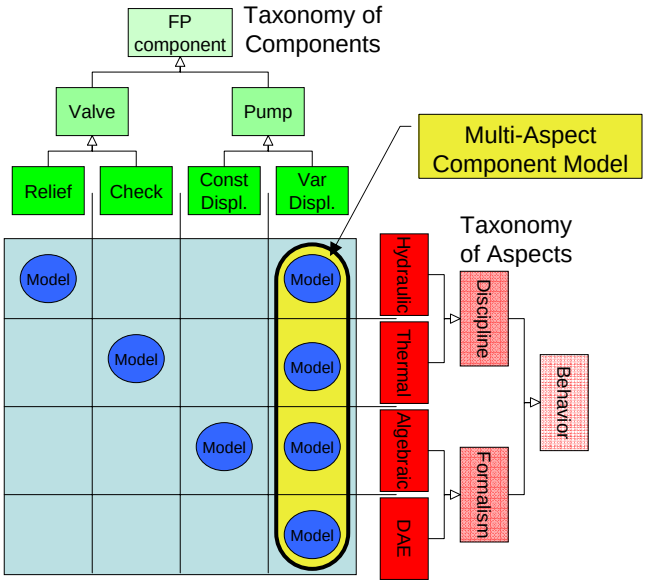
Traditional Mathematical Modeling	Variable Topology & Multi-Fidelity
$\max_{x \in D} f(x)$	$\max_{x \in D} \{f_1(x), \ldots, f_n(x)\}$
$s.t. \quad g(x) \geq 0$	$s.t. \quad \{g_1(x), \ldots, g_m(x)\} \geq 0$

How to Generate Models Dynamically?

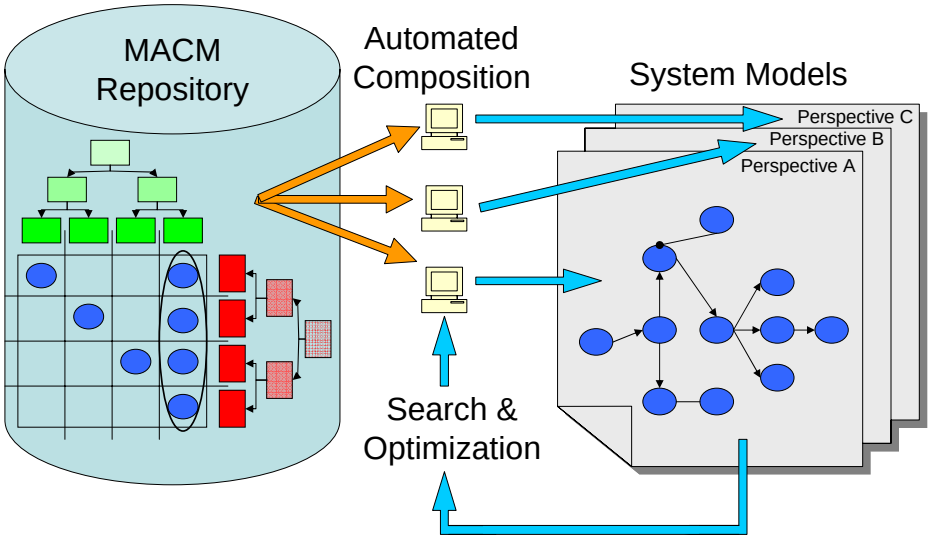
- Approach
  - Rich semantics → Capture meta-information about models
  - Model composition → Enable model reuse
  - Graph transformations → Automatic model generation

Multi-Aspect Component Models

- In OMG SysML™ (Systems Modeling Language)
- Organizes models of components according to *different perspectives* and *levels of fidelity*



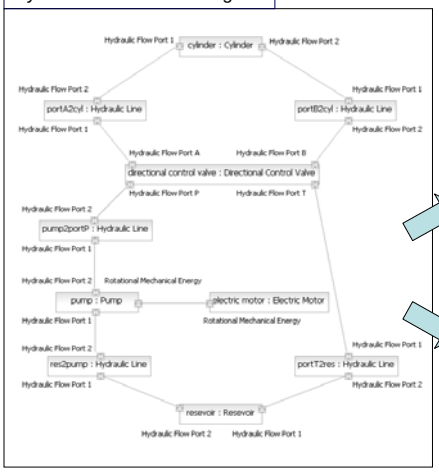
Composition of Multi-Aspect Models

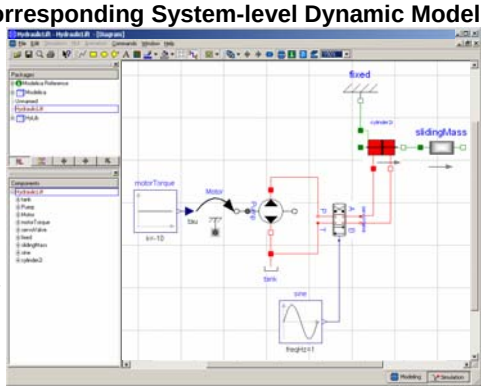


Goal: Automated Composition

Corresponding System-level Dynamic Model

SysML Internal Block Diagram





Corresponding Algebraic Model

slidingMass.vel = vmax;
slidingMass.vel = cylinder.piston.vel;
cylinder.portA.q = cylinder.piston.vel*cylinder.area;
cylinder.portA.q = pump.portP.q;
pump.shaft.omega*pump.displ / (2*pi) = pump.portP.q;
motor.shaft.omega = pump.shaft.omega;

Graph Transformations

- Graph-based generation of models
  - Translation to model formalism
  - Idealization: Design → Analysis
- Graph-based representation of system alternatives
  - Generated automatically through graph grammars
  - Capture synthesis knowledge
- Challenges:
  - Can we predict the fidelity of the model?
  - How can search/optimization take advantage of variable fidelity?

Summary

How to explore and optimize system architectures for complex, multidisciplinary systems?

- Normative Decision Theory
- Information Economics Drives Design Methods
- Systems Design = Variable Topology + Variable Fidelity
- Dynamic Model Generation
  - Capture and reuse (compose) models in SysML
  - Graph transformations to capture composition knowledge

Acknowledgments

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Questions?