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Design as a Sequential Decision Process

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Summary

- PSU has developed and evolved a preliminary *Sequential Decision Framework* for Model-Based Design that provides two key contributions:
    - A framework for linking models into a chain of increasing detail
    - An approach for determining an optimal sequential model chain
- Approach is being brought to bear on a number of problems/projects
    - UAV design
    - Rotorcraft NextGenDesign tool development
    - Army investment portfolio management
    - NSF Resilient Buildings Project
- For each, similar steps…
    - Identifying the trade space
    - Identifying the models used in the design process, with a focus on evolving levels detail
    - Looking to build initial test case model chains to support a design process
    - Use the problem to drive extensions to the framework
    - Understanding how the framework changes modeling

Design as a sequential decision process

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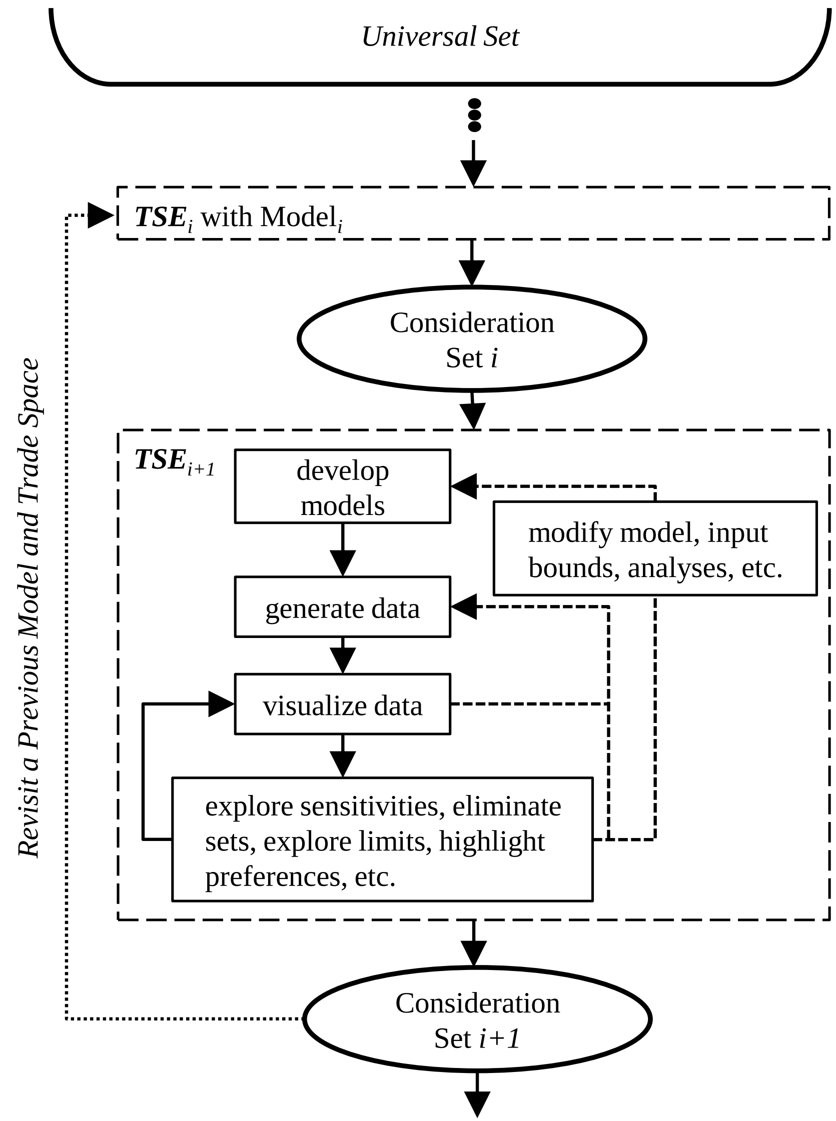
Problem Framing

- Preferences are constructed during the process
  - Different strategies used at different times
  - Noncompensatory versus compensatory
    - Payne et al, (Psychology)
    - Balling (Design engineering)
- Choice is a sequential process of reducing the size of sets and increasing detail
  - Universal, consideration(s) and choice sets
  - Shocker (Marketing)
- Conceptual design is a Sequential Decision Process
  - Customer and provider both gain knowledge throughout the process
  - Defer commitment to best use knowledge
  - Explicitly acknowledge it
    - Singer, Doerry (Set-based Design…Naval Arch)
    - Frye (Pugh Controlled Convergence…Engineering Design)
    - ARL/Penn State
- How decision posed significantly affects choice
  - Prospect theory, framing effects
    - Kahneman, Tversky



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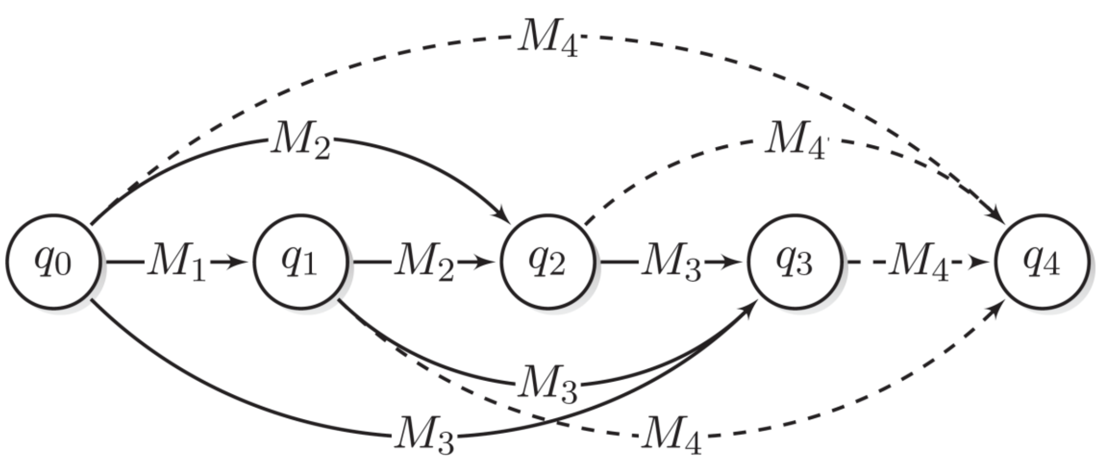
Many potential paths through the design/modeling process

- Lots of models to potentially use
- Low fidelity employed initially, help focus effort
  - models provide rapid feedback at reduced cost
- As a design progresses, the model fidelity increases
  - More accuracy – asymptotically approaches reality
  - Cost increases superlinearly
  - Higher fidelity = more inputs and outputs and more variable interactions
- Space to be considered decreases in breadth
- Questions
  - how should models link together?
  - What is the “best” modeling path?



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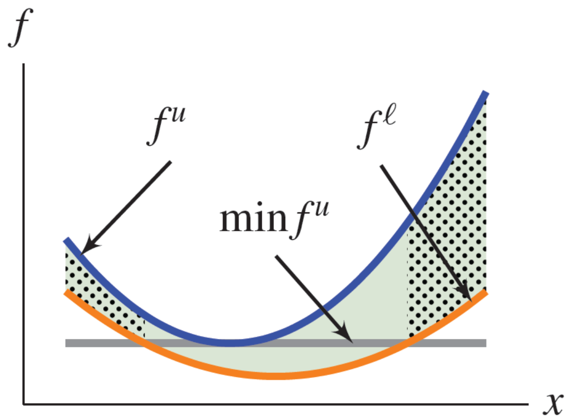
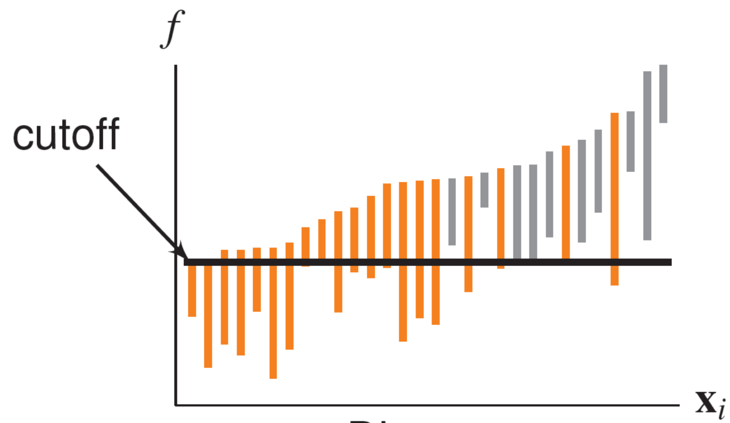
Formal Model of Connection

- Assume a *detailed* and a *conceptual* model
  - Detailed (high fidelity): $v=g_d(x,y)$
  - Conceptual (low fidelity): $v=g_c(x)$
- Goal is to
  - Find x^* and y^* that minimize v
  - Use the cheaper concept model to cull the space first
- Define g_c to return bounds on detailed model



Continuous



Discrete

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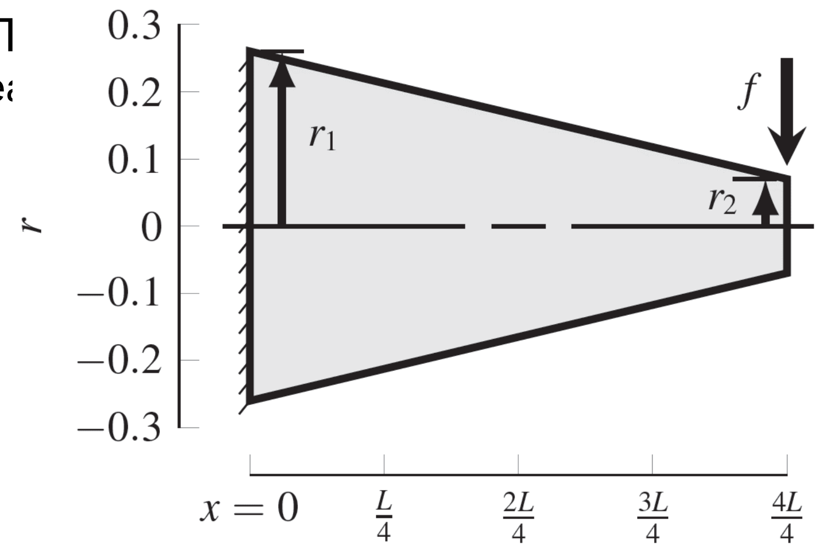
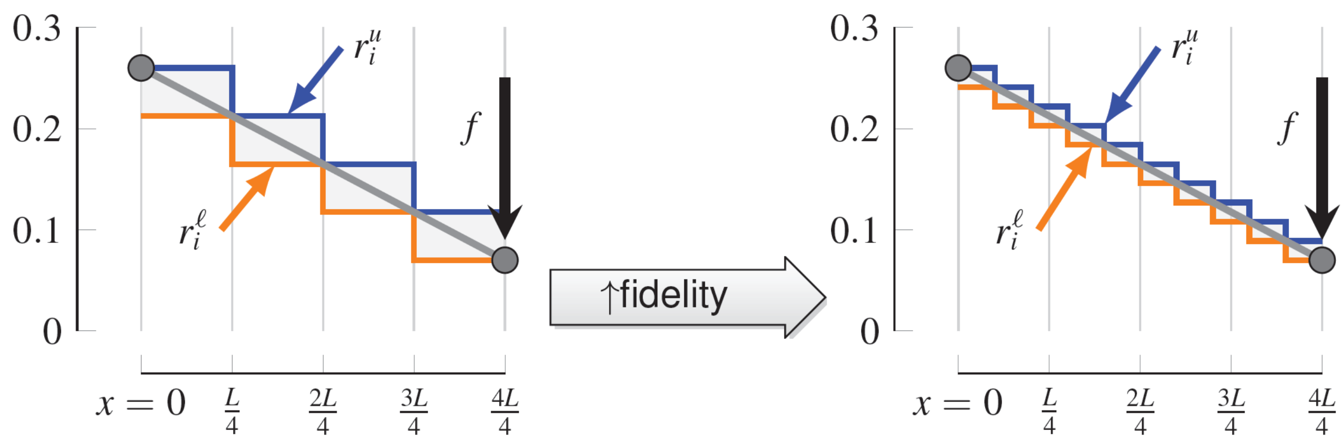
An example problem: cantilevered beam

- 1D FEA of a Cantilevered Beam with T
  - Inputs: root and tip radii of the conical bea
  - Outputs: mass, tip displacement
- Formulation:
  - Single Objective:
    $\min_X (0.2\ \text{mass} + 0.8\ \delta_{tip})$
  - Multi-Objective:
    $\min_X (\text{mass}, \delta_{tip})$
- Model Fidelity = #finite elements





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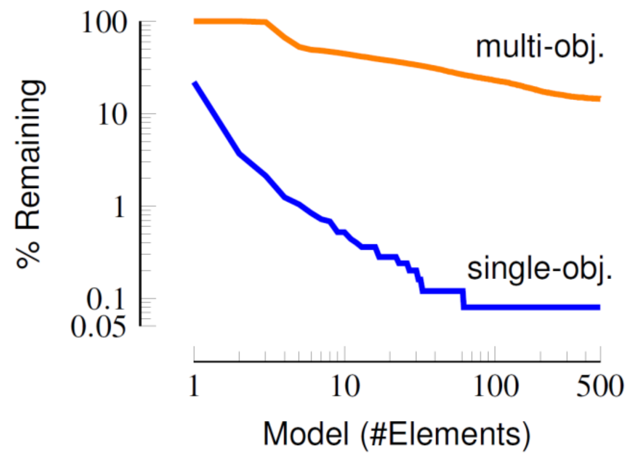
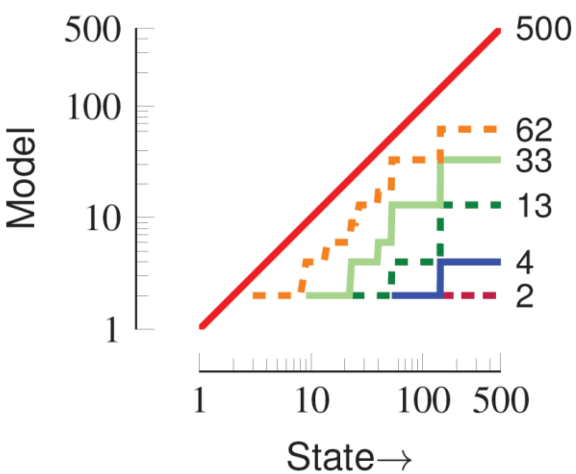
Optimal Modeling Policies

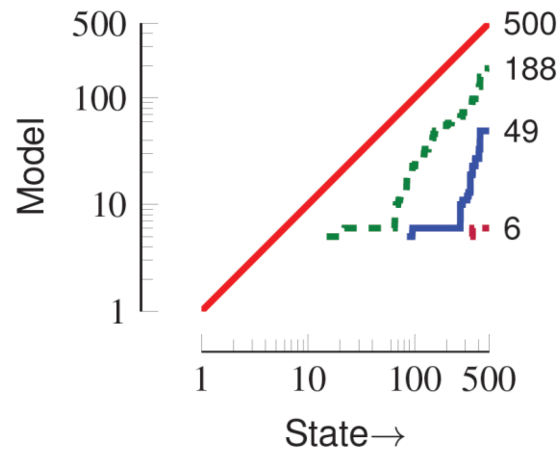
- Discriminatory power approaches the analytic result asymptotically
  - SO yields 1 solution
  - MO yields 327 alternatives



- SO Formulation: $P_{500}=\{2,4,13,33,62,500\}$
  - 100-fold reduction in cost



- MO Formulation: $P_{500}=\{6,49,188,500\}$
  - 4-fold reduction in cost



General Observations

- Sequential model
  - Neatly aligns with set-based design
  - Decision-makers already implicitly make these decisions
  - Attempting to place formalism on the process
- Concept-Detailed Modeling Connection
  - ***Key piece*** to the sequential model process
  - Building good bounding models requires understanding of the physics of the problem
  - ***The value function plays a core role***
    - Must trace bounds to values
    - Multiple objectives greatly reduces discriminatory power of models
- Broadly Applicable, e.g.
  - Equations that can be discretized
  - Cost modeling strategies
  - Rapid heuristics solvers to NP-hard problems
  - Time step simulations