Complex Systems Design Research

Design Engineering Lab

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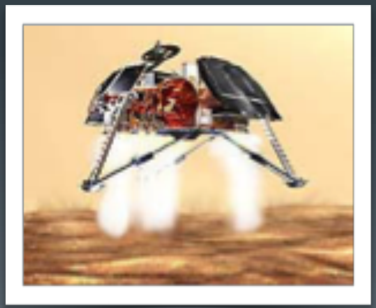

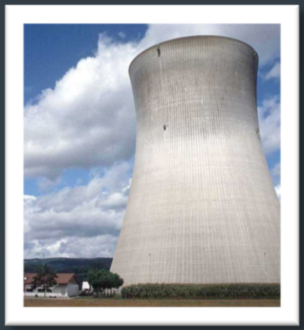

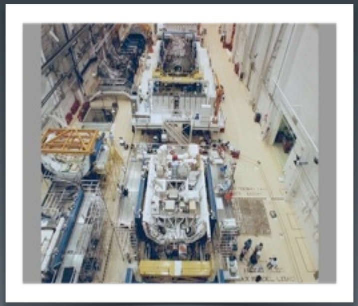

Complex Systems are everywhere!

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Why Study Complex Systems?

- System Design Challenge:
  - Increasingly complex systems that are software intensive
  - Increasingly high expectations of safety and reliability
  - Systems commonly suffer from cost overruns and costly failures

  Need to Understand Tradeoffs between Complexity, Cost, Competitiveness

- Key Questions:
  - Will they perform as specified?
  - Will they fail? If so, when, how, and at what cost?
  - Can failure be prevented?

  Need new design methods & validation processes

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Why Study Safety and Reliability?

Systems still fail in costly and catastrophic ways

Mars Polar Lander
Software-hardware interaction

B-2 Crash
Sensor-control fault

Deepwater Horizon
Systemic failure

Goal: Safety and Reliability Analysis Earlier in the Design Process

Cheapest and best stage to catch potential failures and include mitigation functions in the design

Safety and reliability as the principal drivers for design: enabled by model-based analysis and risk-based decision making

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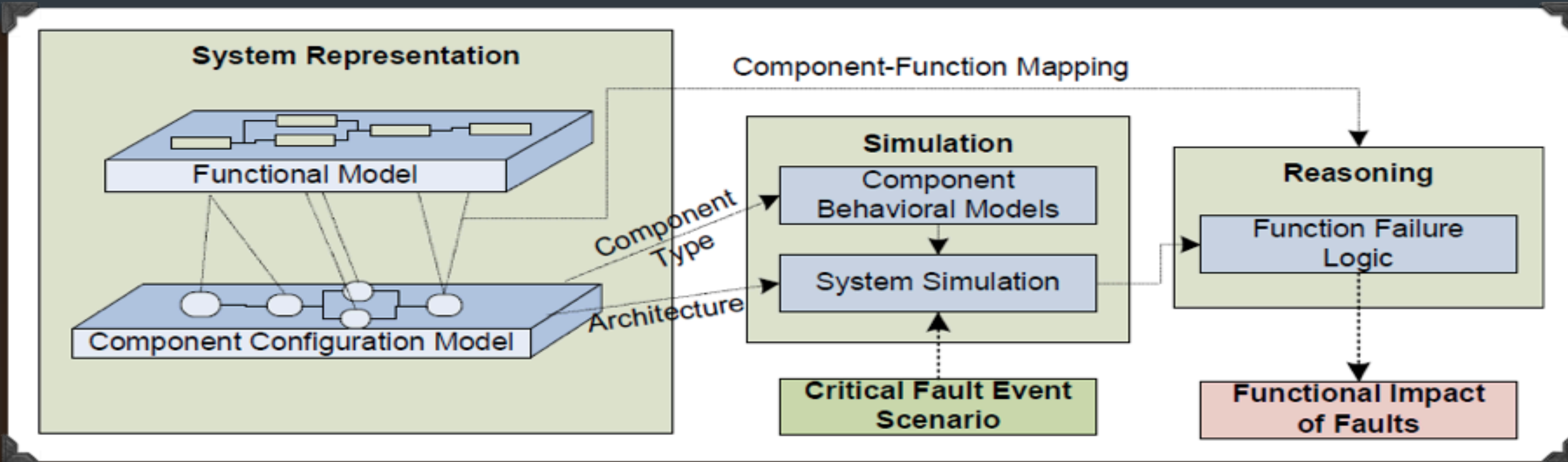
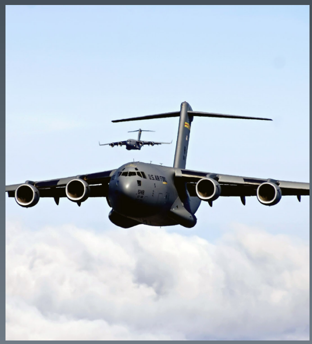
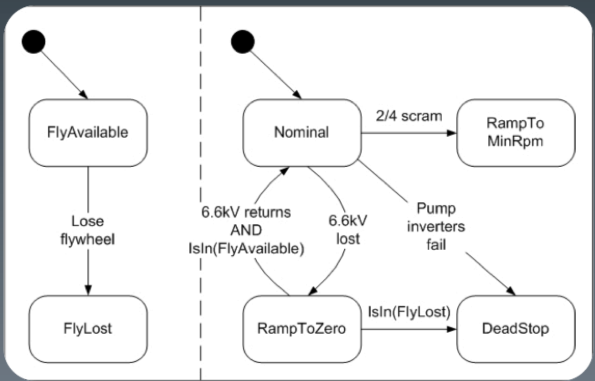
Design Stage Simulation of Behavior



Simulate critical failure scenarios to determine system impact

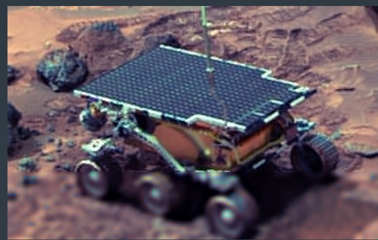
Qualitative behavior simulation based on state machines

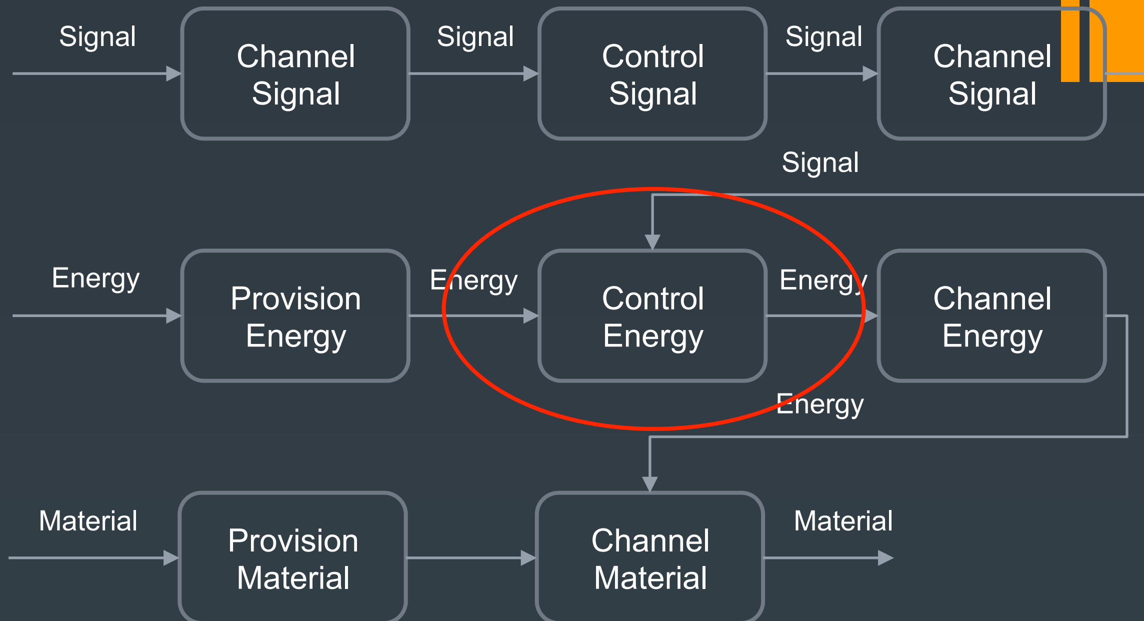




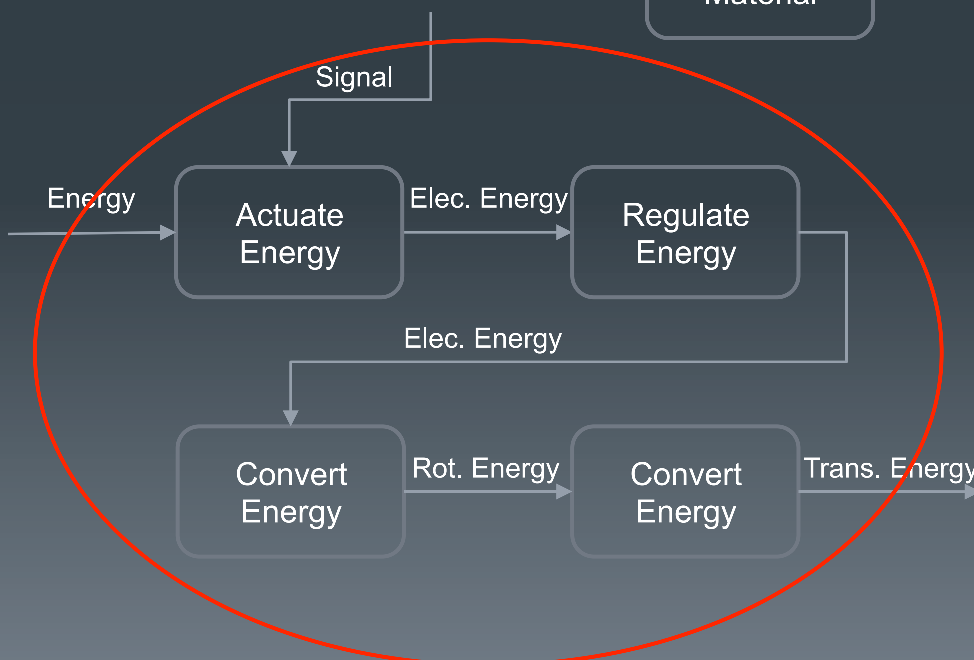
Function Health	Description
Healthy	Function affects flow as intended
Degraded	Function affects flow differently than intended
Lost	Function does not act on the flow
No Flow	There is no flow present

Impact of Abstraction on Behavior



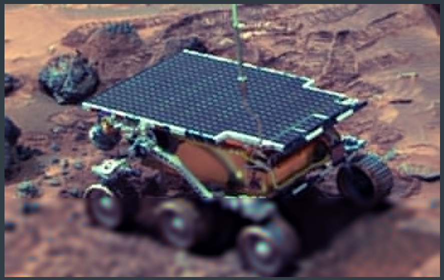


- **Different fidelity functional and behavioral models**



Tradeoff between rapidity, fidelity, and accuracy of models!

Validating Functionality with Testbeds



How do you validate that models and simulations match reality?

Nominal Mode: Standard

Failure Mode: Flat Tire

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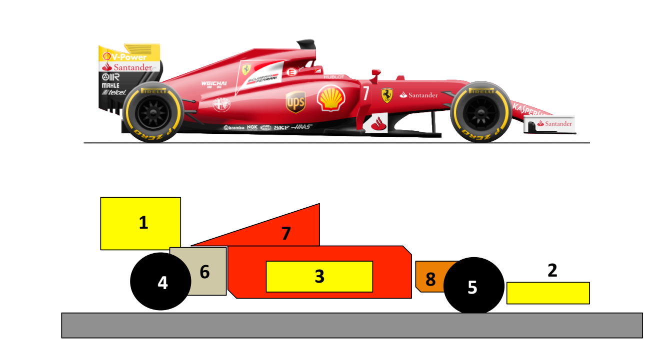
Automation of Distributed Design

Design Process → Design System Level Objectives → Concept Evaluation CCEA → Select Best Concept

Constraints → Design System Level Objectives

Representing the Design of Systems as Coordination among Different Agents



DESIGN TEAMS :

- 1 Rear wing
- 2 Front Wing
- 3 Side Wing
- 4 Rear tire
- 5 Front tire
- 6 Engine
- 7 Cabin
- 8 Impact Attenuator

Global Formula Racing

Team Goal

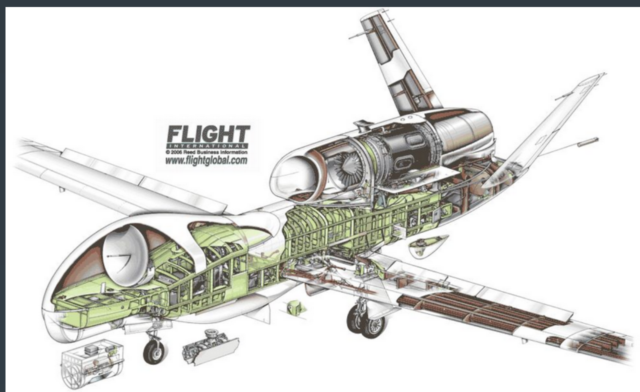
Win competitions

Focus on the areas to which points are *most sensitive*

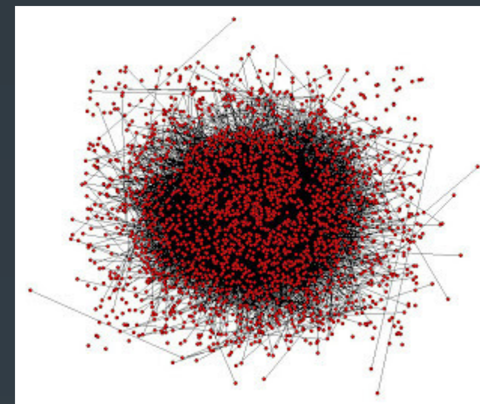
- Simplicity
- Easier to Manufacture
- Easier to repair
- Cheaper
- More reliable
- Lighter

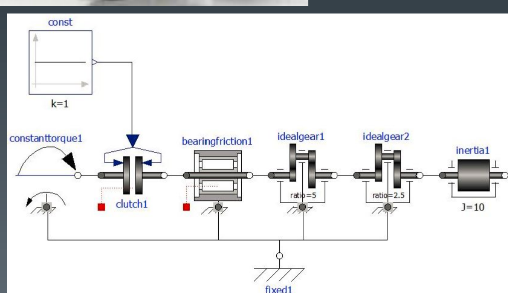
PROJECT 3

Modeling Systems as Networks



Explore similarity





$$F1 : Clutch_{fric} = mu * cgeo * Fn$$

$$F2 : cgeo = N * 1/2 * (r_o + r_i)$$

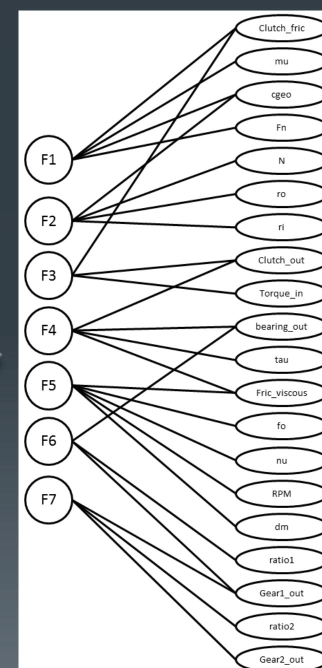
$$F3 : Clutch_{out} = Torque_{in} - Clutch_{fric}$$

$$F4 : 0 = Clutch_{out} + bearing_{out} - tau$$

$$F5 : fric_{viscous} = 10^{-7} * f_o * (nu * RPM)^{2/3} * dm^3$$

$$F6 : 0 = ratio1 * bearing_{out} + gear1_{out}$$

$$F7 : 0 = ratio2 * gear1_{out} + gear2_{out}$$



Representing systems as a network to quantify robustness without requiring complete simulation

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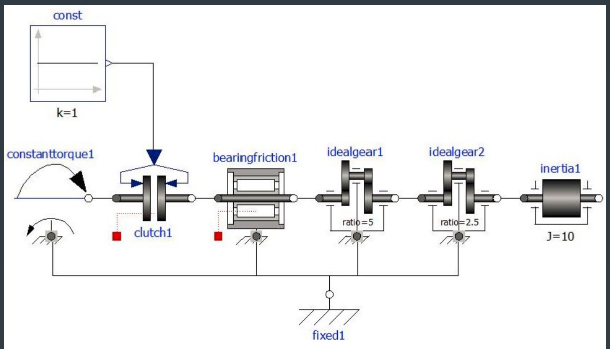
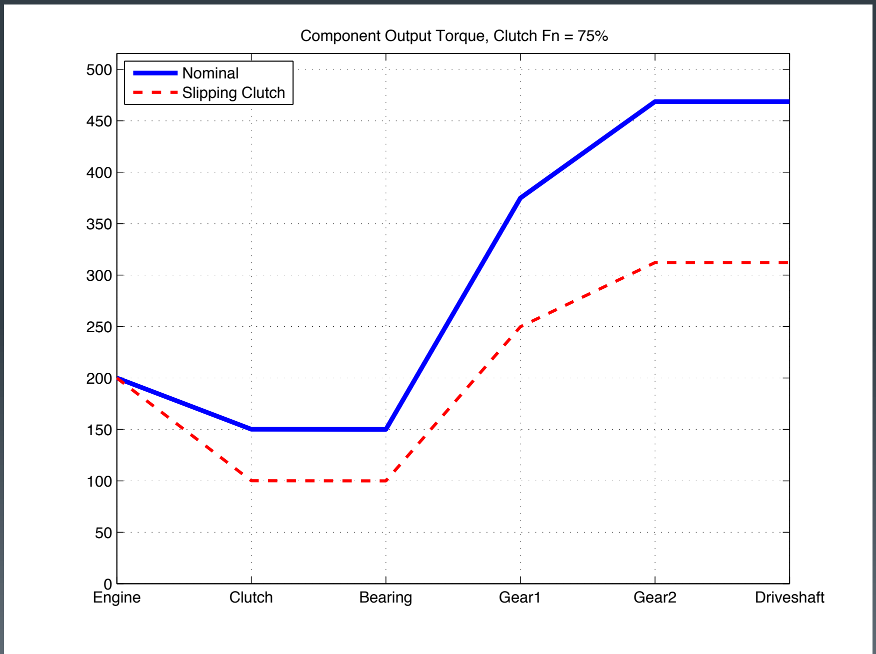
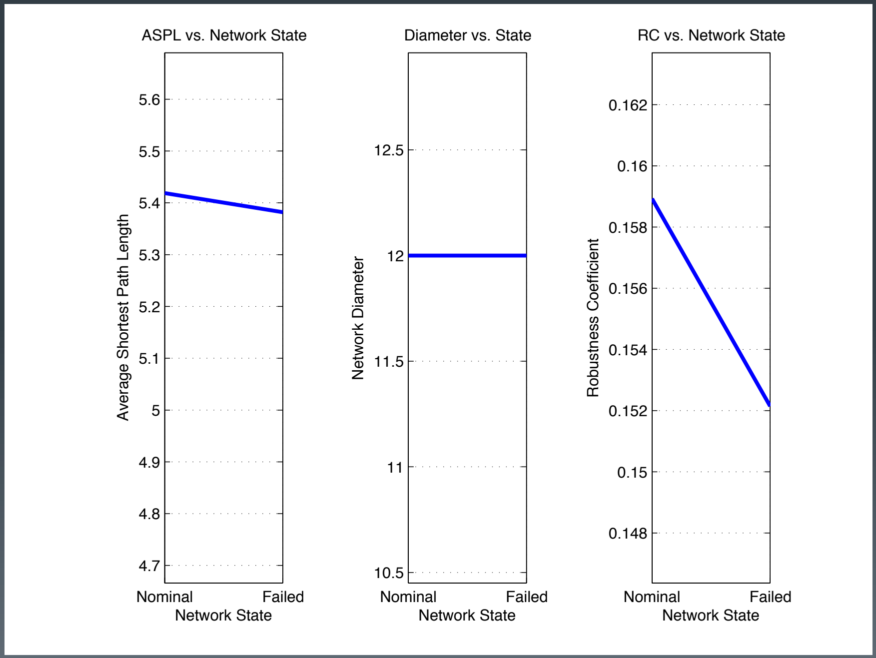
Quantification of Robustness

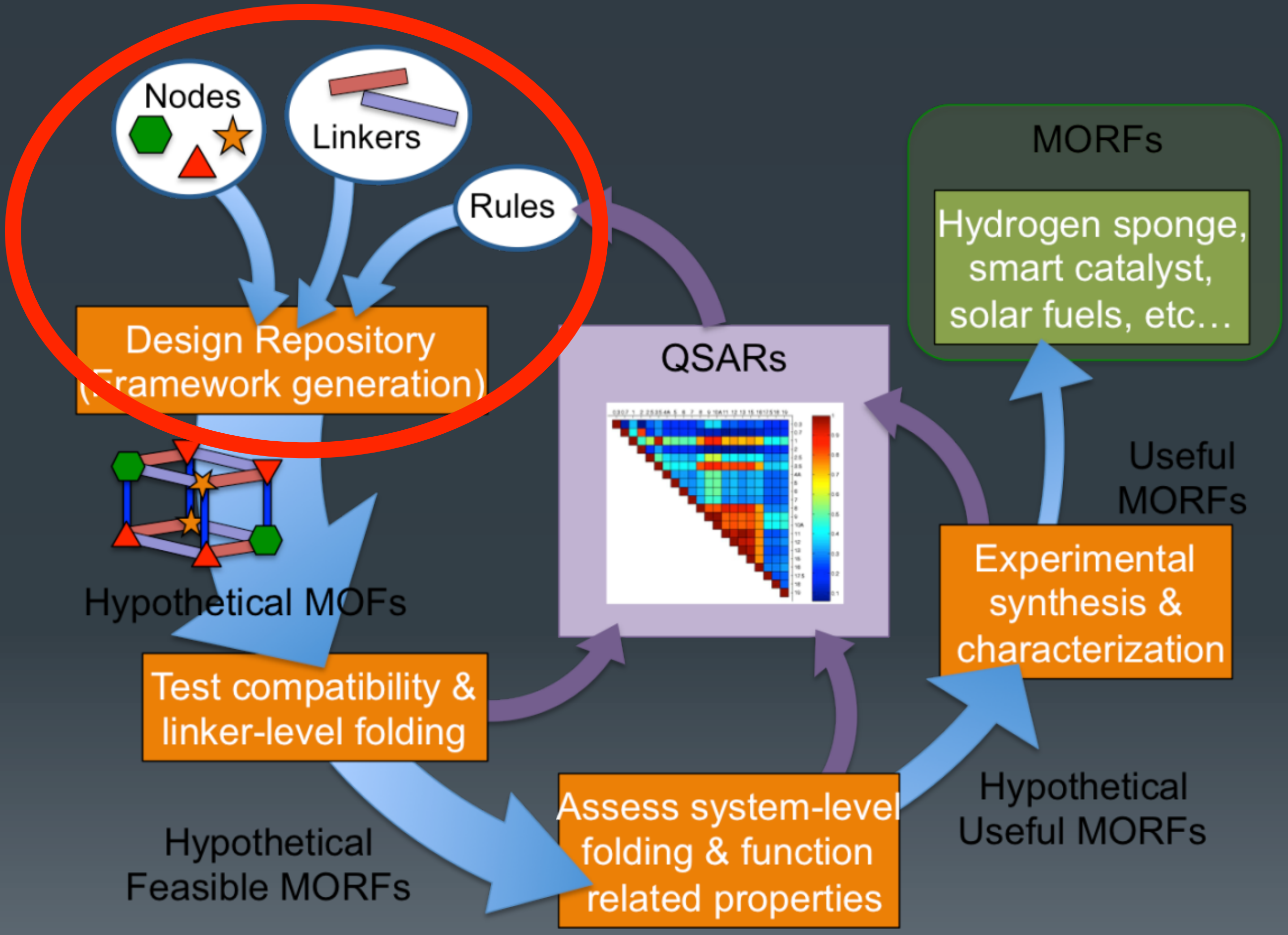




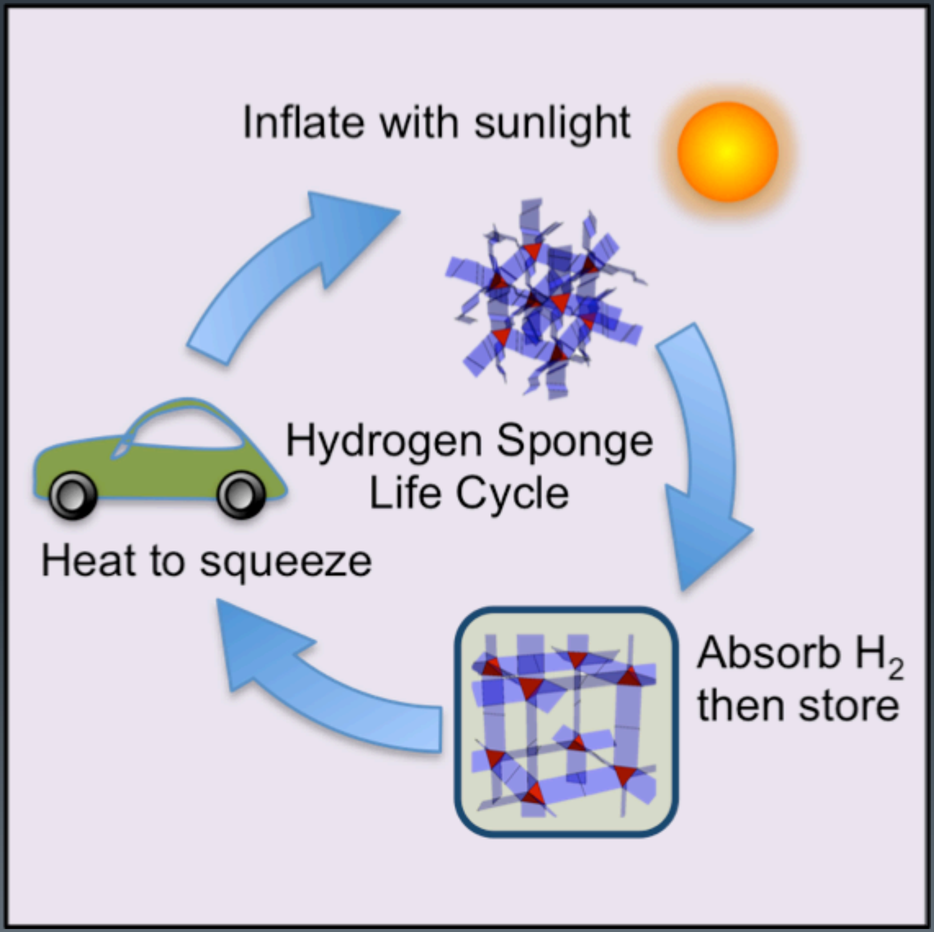


Performance degradation indicated by change in network metrics

Engineering Design Methods to Design Functional Materials



Designing Unique Materials: MORFs



MORF Applications:

- Self-squeezing H_2 sponge
- Self regulating catalysis
- Tunable/active filtration
- Opto-mechanical muscles
- Failsafe seals etc.
- Smart catalysis
- Chemical/environmental sensing
- Solid State Turing Media

CESD Graduate Students

- MS Students
  - Sean Hunter (Current)
  - Brandon Haley (NuScale, Inc.)
  - Brady Gilchrist (Solar City)
  - Joe Piacenza (see PhD)
  - Jesse Grimes (NASA JPL)
  - Bryan O'Halloran (see PhD)
  - Mike Koopmans (Tesla Motors)
  - Blake Giles (Oregon Ironworks)
  - Michael Koch (Cascade Energy)
  - Rudy Hooven (Boeing)
  - Farzaneh Farhangmehr (PhD @ UCSD)
  - Jonathan Mueller (Hanson Prof. Services)
  - Scott Kramer (US Coast Guard)
  - David Jensen (see PhD)
  - Masahiro Kitagawa (in Japan)
- PhD Students
  - Nicolas Soria (Current)
  - Charlie Manion (Current)
  - David Jensen (Faculty, U of Arkansas)
  - Douglas VanBossuyt (Faculty, Colorado School of Mines)
  - Kerry Poppa (CyDesign Labs)
  - Sarah Oman (Faculty, Northern Arizona U.)
  - Joe Piacenza (Faculty, CSU Fullerton)
  - Bryan O'Halloran (Raytheon)
  - Hoda Mehrpouyan (Faculty, Columbus State University)

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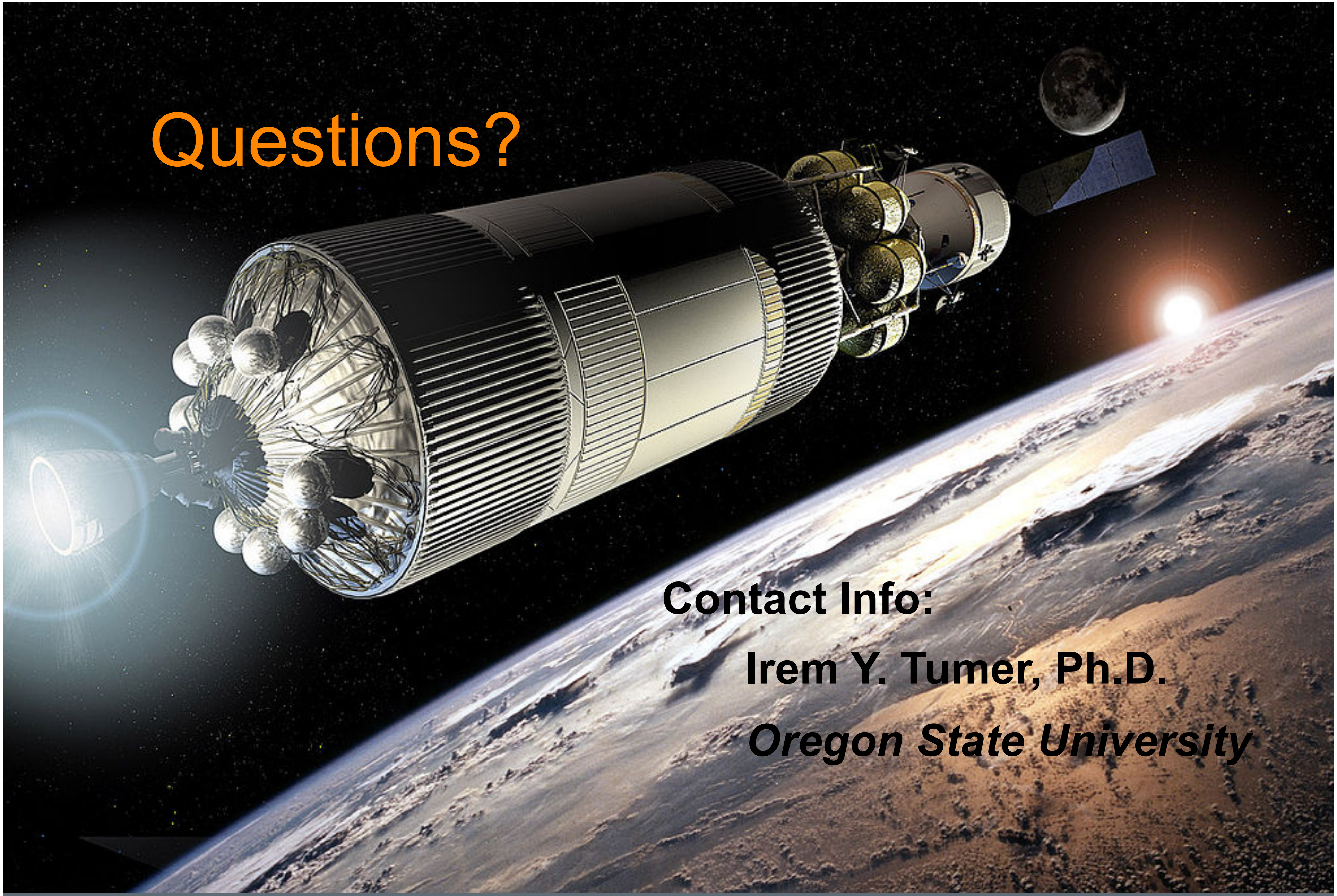
Funding Sources

- National Science Foundation:
  - Science of Design Program
  - Engineering Virtual Organizations Program
  - Engineering Design Program
  - GOALI Program
  - Systems Science Program
  - IUCRC Program
- Airforce Office of Scientific Research (AFOSR)
  - Systems and Software Program
- NASA:
  - JPL, ARC, Marshall
- DARPA:
  - Adaptive Vehicle Make, META Program
  - Adaptive Vehicle Make, C2M2L Program
- Keck Foundation



Questions?

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