Complex Systems Design Research

Design Engineering Lab

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Complex Systems are everywhere!
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*
Why Study Safety and Reliability?

Systems still fail in costly and catastrophic ways

- Mars Polar Lander: $327.6 Million, Software-hardware interaction
- B-2 Crash: $1.4 Billion, Sensor-control fault
- Deepwater Horizon: $700 Million +, 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
Design Stage Simulation of Behavior

Simulate critical failure scenarios to determine system impact
Qualitative behavior simulation based on state machines

<table>
<thead>
<tr>
<th>Function Health</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>Function affects flow as intended</td>
</tr>
<tr>
<td>Degraded</td>
<td>Function affects flow differently than intended</td>
</tr>
<tr>
<td>Lost</td>
<td>Function does not act on the flow</td>
</tr>
<tr>
<td>No Flow</td>
<td>There is no flow present</td>
</tr>
</tbody>
</table>
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
Automation of Distributed Design

Design Process

Design System Level Objectives

Concept Evaluation CCEA

Constraints

Select Best Concept
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

DESIGN TEAMS:
- 1 Rear wing
- 2 Front Wing
- 3 Side Wing
- 4 Rear tire
- 5 Front tire
- 6 Engine
- 7 Cabin
- 8 Impact Attenuator
Modeling Systems as Networks

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

Performance degradation indicated by change in network metrics
Engineering Design Methods to Design Functional Materials

Design Repository (Framework generation)

Nodes

Linkers

Rules

Hypothetical MOFs

Test compatibility & linker-level folding

Hypothetical Feasible MORFs

QSARs

Assess system-level folding & function related properties

Experimental synthesis & characterization

Useful MORFs

MORFs

Hydrogen sponge, smart catalyst, solar fuels, etc...

Useful MORFs

Hypothetical Feasible MORFs
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)
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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