Engineering Resilient Space Systems
Introduction to Short Course

Co-Leads
Leonard Reder, John Day, Mitch Ingham – JPL/Caltech
Richard Murray – Caltech
Brian Williams – MIT

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How to conceive, develop and operate a future class of spacecraft that will require unprecedented resilience?

1. Ability to execute a mission with changing science objectives
2. Adaptability to unexpected changes in spacecraft health, performance, and/or the environment

- Study integrates concepts from another proposed study entitled “New Space Exploration Concepts Enabled by Revolutionary Flight Software Architectures”
- Question: What will spacecraft flight software look like in 25 years and why?
What is a resilient control system?

- From Wikipedia (**Resilient Control Systems**):
  - "Resilient control systems are those that tolerate fluctuations via their structure, design parameters, control structure and control parameters”
  - “… is one that maintains state awareness and an accepted level of operational normalcy in response to disturbances, including threats of an unexpected and malicious nature”
Resilience Engineering

• “Resilience engineering is concerned with building systems that are able to circumvent accidents through anticipation, survive disruption through recovery, and grow through adaptation”
  – Failures represent inability to adapt
  – Opposite of resilience is “brittleness”
    • A system unsuitable to adapt to the unexpected is brittle!
  – Resilience implies “elasticity”
    • Systems with capability to return to original stable state after being bent, compressed or stretched by unexpected change

“Towards a Conceptual Framework for Resilience Engineering”
Azad M. Madni and Scott Jackson
Autonomy is important

- Targets have diverse morphologies, compositions
- Closest approach may pass quickly (sub-hour flyby timescales)
- Target locations are not known in advance
- Geometry and illumination constraints
- Features of interest are highly localized
- Surface activity varies on scales shorter than RTLT

Images: Tempel 1 (Deep Impact) PIA 02142, NASA/JPL/UMD
• Resilient space systems engineering is inherently multidisciplinary!!

• Short course talks do not present resilient systems discussions, but rather, provide the context and background information to enable productive discussion of the topic

• Topics:
  1. Principled System Architecture - Rasmussen
  2. Capturing FSW Architectures Using DSLs - Gostelow
  3. Control Theory and Methods - Murray
  4. Autonomy Practices - Williams
  5. Ultra-Reliability for Interstellar Missions - Garrett
<table>
<thead>
<tr>
<th>Time</th>
<th>Short Course - Open to All Interested Parties</th>
<th>Speaker</th>
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</thead>
<tbody>
<tr>
<td>8:00 - 8:30</td>
<td>Coffee and refreshments</td>
<td>Team Leads; Short Courses Moderated By: Len Reder</td>
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<tr>
<td>8:30 - 8:45</td>
<td>Introduction to Short Courses - What is a resilient system?</td>
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<tr>
<td>8:45 - 10:00</td>
<td>Principled System Architecture (includes 15 minutes for Q+A)</td>
<td>Robert Rasmussen</td>
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<td>10:00-10:30</td>
<td>Break (Coffee, Discussion)</td>
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<tr>
<td>10:30-11:45</td>
<td>Capturing Flight Software Architecture using DSLs (includes 15 minute for Q+A)</td>
<td>Kim Gostelow</td>
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<td>11:45 - 12:45</td>
<td>On site, informal lunch provided by KISS for all short course attendees</td>
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<td>12:45 - 2:00</td>
<td>Control Theory and Methods (includes 15 minutes for Q+A)</td>
<td>Richard Murray</td>
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<td>2:00 - 2:30</td>
<td>Break (Coffee, Discussion)</td>
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<td>2:30-3:45</td>
<td>Autonomy Practices (includes 15 minutes for Q+A)</td>
<td>Brian Williams</td>
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<td>3:45-5:00</td>
<td>Ultra-Reliability for Interstellar Missions (includes 15 minutes for Q+A)</td>
<td>Henry Garrett</td>
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<td>5:00</td>
<td>SHORT COURSE CONCLUDES</td>
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