# Breakout Session 7: Learning, Modeling and Modulating Complex Dynamic Systems

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DSO Proposers Day

June 22-23, 2016

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# Goals of the Session

- Have an interactive session to share the DARPA/DSO approach to generating program ideas and capture percolating ideas from the audience

- Below are an overarching idea and question that may stimulate your thinking:

  - Meeting the challenges in mathematical modeling of complex dynamical systems from materials and physical systems to engineered systems of systems, to natural systems such as climate, to biological systems, to social-economic systems
  - What are the new ideas to optimally fuse model-driven and data-driven approaches to better understand and model such systems, possibly leveraging new techniques in mathematics, statistical physics, information science, control theory, deep learning and other fields of endeavor?

- DARPA can bring different communities together. The amount of funding could be large relative to existing basic research funds from other agencies. But DARPA programs aim to answer key focused questions within a relatively short period of time (no open-ended program areas).

# Key Scientific Questions

- **New Paradigms for Modeling, Simulation and Design of Complex Systems meeting these Challenges:**
  - Uncertainty in Models, Parameters, Operating Environments for Complex Systems
  - Curse of Dimensionality – high dimensional parameter/phase/state space
  - Truly Multiscale (spatial and temporal) Models and Approaches
  - Nonlinearity of the underlying dynamics
- **Shortcomings of SOA:**
  - Data-driven techniques don't make good use of prior knowledge, known physics, symmetries
  - Model-driven approaches don't scale well across phase transition boundaries, become computationally intractable
- **Possible Solutions?:**
  - Interplay of Models and Data
  - New topological math that better maps to dynamic and possibly stochastic systems
  - Stochastic modal/spectral models/renormalization group theory
  - New approaches to deep learning that leverage known physics/chemistry/biology/engineering – can we force deep learning to learn useful reduced representations that have physical meaning?

# How to Formulate a Program Idea While Answering These Questions: Heilmeier Catechism

To help bring rigor and formality to the program-development process, DARPA Director George Heilmeier developed a set of questions that every program manager was required to address when formulating or proposing a new program.

**Dr. George H. Heilmeier**
**Director DARPA 1975-1977**

- **What are you trying to do?** *Articulate your objectives using absolutely no jargon.*
- **How is it done today, and what are the limits of current practice?**
- **What's new in your approach and why do you think it will be successful?**
- **Who cares?**
- **If you're successful, what difference will it make?**
- **What are the risks and the payoffs?**
- **How much will it cost?**
- **How long will it take?**
- **What are the midterm and final "exams" to check for success?**

This formalism has become known as “The Heilmeier Catechism.”
It is the program-definition formalism still in use at DARPA today.