Scientific Machine Learning and Mathematical Analysis

ONR and DOD investments

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Cognizant DoD POs

1. ONR
   1. Applied and Computational Analysis
   2. Computational Methods for Decision Making
      1. Automated Image Understanding (Behzad Kamgar-Parsi)
      2. Large scale Distributed Decision-making (Predrag Neskovic)
      3. Resource Allocation (David Phillips)
2. AFOSR
   1. Computational Cognition and Machine Learning (Hal Greenwald)
   2. Computational Mathematics (Fariba Fahroo)
   3. Dynamic Data and Information (Erik Blasch)
   4. Optimization and Discrete Mathematics
3. ARO
   1. Modeling of Complex Systems (Robert Martin)
4. DARPA
   1. Yannis Kevrekidis

Prediction versus Understanding

1. Prediction relies on actionable knowledge – it leads to real-time decision tools for operators. The time-scale is usually on the order of several months or a few years.
2. Understanding relies on acquiring fundamental knowledge – the time scale is on the order of several years or decades.

One of the grand challenges in applied mathematics is how to model dynamics of **interfaces among two or more materials**. This is especially the case for the critical problems Navy faces (climate and weather, additive manufacturing, design of new materials).

Phenomena is **Multiscale** and **Multiphysics**

Basic versus Applied Research (6.1 versus 6.2)

1. Basic Research (6.1): the systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs.
2. Applied Research (6.2): the systematic study to understand the means to meet a recognized and specific need. It is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. It may be oriented, ultimately, toward the design, development, and improvement of prototypes and new processes to meet general mission area requirements. Applied research may translate promising basic research into solutions for broadly defined military needs, short of system development.

Impact of Data: "Classical" versus "Modern" Applied Mathematics

1. "Classical" Applied Mathematics

   "Truth" is embedded in equations (Navier-Stokes, Maxwell's, Elasticity, ...).

2. "Modern" Applied Mathematics

   "Truth" is embedded in Data

   Emphasis has been on

   1. using **equations in support of extracting meaning out of data**
   2. **Statistical Mechanics** – stochastic methods are the main tools, in collaboration with rigorous mathematical theory
   3. **Accuracy in computation** – statistical stability of the numerics is sought, as opposed to precision

3. And now Machine Learning is beginning to take center stage.

Core Program (emphasis is on complex media)

1. **Turbulent dynamical systems**
   1. Climate Science, especially the impact of the Arctic regions and the tropics
   2. Interaction of laser beams with a maritime domain
2. **Extreme events**
3. **Sensing and signal processing**

Complex Media

When modeling complex media one has to deal with the following issues:

1. (Multi-scale nature of modeling) Physical phenomena always have a large number of time and spatial scales: **cracks, nucleation, discontinuities, leads, shock waves, bubbles**
2. (Multi-physics nature of modeling) phenomena often require multi-phase modeling (e.g., bubbles in fluids) or multi-physics (atomistic versus continuum)
3. (Model uncertainty) Unlikely that we know all of the physics involving interfaces (bubbles/fluids, sea ice/ocean, air-sea interface, ...)
4. (Sparsity and heterogeneity of data) All modeling has to be informed by data, but data is almost always very sprase (as in the case of sea ice), given at only few spatial grid points and a few discrete times, and is noisy. Data is often given in terms of quantities that are not directly being modeled.

MURIs

1. **Sea Ice** MURI (Dimitris Giannakis, https://seaicemuri.org/people.html)"
2. **Deep Learning** MURI (Rich Baraniuk, http://deepmuri.rice.edu)
3. **Disparate Data Fusion** MURI (Anne Gelb, https://math.la.asu.edu/ muri/)
4. **Data Driven Closure Relations** (Kaushik Bhattacharya, https://ddcr.caltech.edu)