Decision Superiority

Applying integrable systems-based planning to help the U.S. achieve competitive advantages through better management of real-time decision applications.

Introduction

Institutional Initiatives reflect Lawrence Livermore National Laboratory's (LLNL's) "team science" approach and support a focus on a single institutional mission by anticipating issues of national importance. LLNL's Decision Superiority Institutional Initiative was recently created to build on mathematical advances in dynamical systems to foster scalable, stable, and robust modeling and forecasting capabilities that can resolve complex decision tasks given only limited information.

Simply put, the Decision Superiority Initiative helps meet the pressing national need for decision support tools.

Coupling streaming data with simulations enables playing out future scenarios and optimizing action choices to achieve a desired long-term objective, all in near-real-time. To help build these capabilities, LLNL investments in decision superiority are focused on three technical pillars:

1. Data brokering to provide necessary information for decision-making

2. Algorithmic innovations to meet speed, scale, and computing platform requirements for decision modeling

3. Verification and validation approaches to help identify capability gaps and build trust with users.
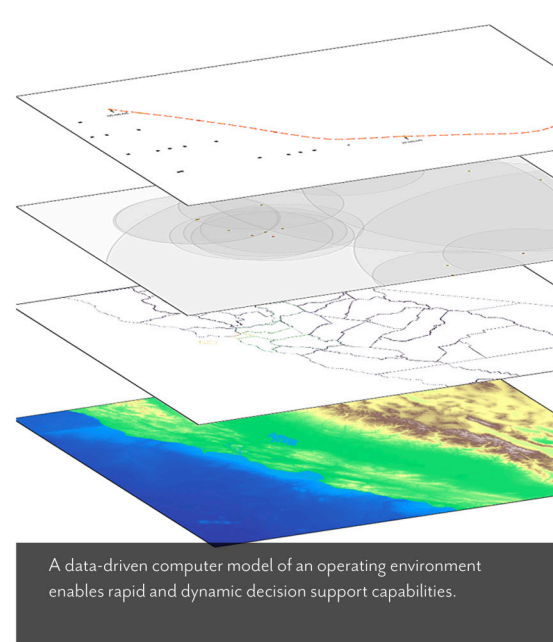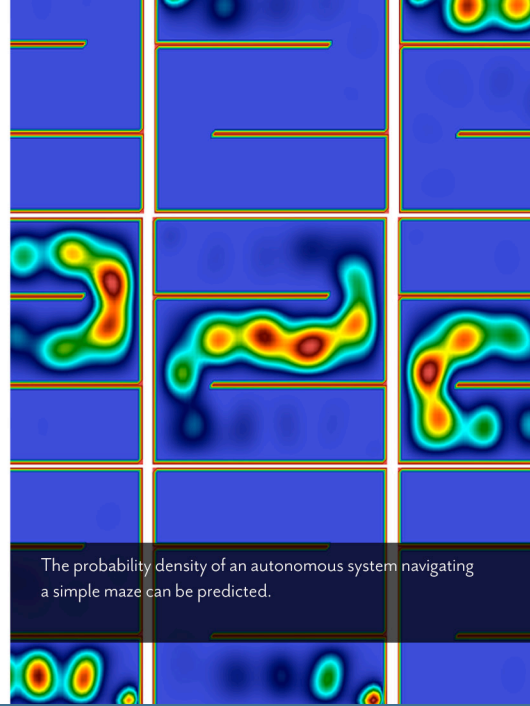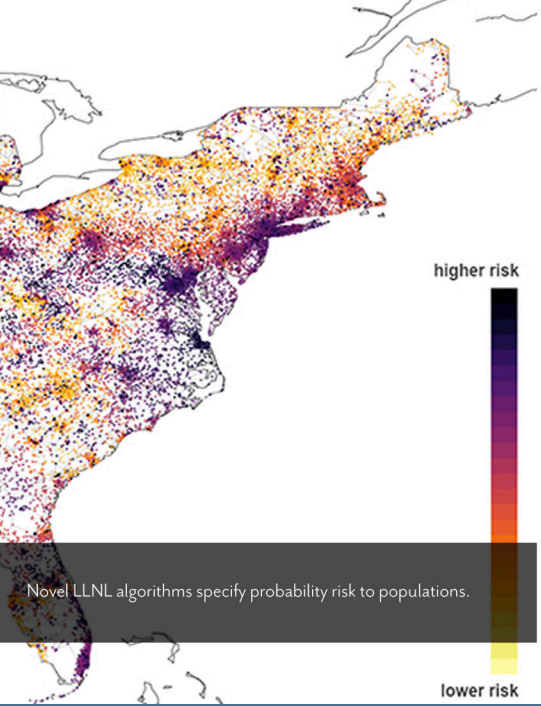
Applications

Decision superiority capabilities help meet the pressing national need for computational tools to create advantages in both speed and insight in international competition and warfighting. LLNL is pursuing an open research frontier in the numerical solution of integrable systems applied to mission-driven models. With advances in numerical speed and accuracy, new problem domains can be solved, including combinatorial optimization, complex systems, and a variety of physical phenomena. Motivation for development of these tools comes from the expressed strategic importance by USSTRATCOM, USNORTHCOM, and other U.S. government agencies.

A breadth of LLNL programs benefit from the fostered capabilities and community around decision superiority. In particular, the Integrated Deterrence and Technology Competition Mission Focus Area (MFA) aims to add computer-driven forward-looking deterrence capabilities to their existing portfolio of activities. The Climate Impacts and Resilience MFA will be able to adapt new modeling capabilities to help inform climate impact mitigation strategies. The LLNL Data Science Institute (DSI) and Artificial Intelligence Innovation Incubator (AI3) share expert staff and tools with the Initiative in technical areas such as data fusion, tracking, anomaly detection, and surrogate modeling of detailed physics simulations.

Additional applications of decision superiority at LLNL include:

- Predictive analytics and dynamic national security scenarios are supported by near-real-time data synthesis tools that ingest open-source data and generate models of operational environments.

- Modeling at the strategic decision-making level helps understand key drivers of integrated deterrence as Laboratory and national leaders consider technology implications under evolving national policy frameworks.

- Classified high-performance computing infrastructure tailored to data analysis and machine learning supports growing defense program activities.

- The science of complex systems in time and space underpinning LLNL's novel decision superiority capabilities helps connect Laboratory competencies and programs in applied mathematics and physics.

Novel LLNL algorithms specify probability risk to populations.

The probability density of an autonomous system navigating a simple maze can be predicted.

higher risk

lower risk

A data-driven computer model of an operating environment enables rapid and dynamic decision support capabilities.

Accomplishments

Meeting the dynamic planning challenges for decision superiority requires new approaches beyond current simulation and machine learning methods, which aren't always available to make timely recommendations for rapidly changing environments.

A recent breakthrough identified new ways to solve optimal control and reinforcement learning problems by casting them as components of completely integrable dynamical systems, which enables efficient solutions via parallel computations. Additional advances in probabilistic machine learning and high-throughput computing methods enable solutions of decision support problems under unique national security mission constraints. Decision superiority researchers are applying these innovations by partnering with experts at LLNL and other national laboratories in defense systems modeling and simulation.

Recent collaborative accomplishments include:

- Understanding the impacts of decisions made by senior leaders has become a complicated problem in the modern geopolitical environment. In partnership with LANL and other national laboratories, LLNL's computational model of decision-making is a first step towards quantifying the follow-on effects of key decisions.

- Developing and demonstrating a prototype data-driven capability for real-time response to emerging threats to friends, allies, and homeland.

- Basing a novel approach to decision superiority on the science of integrable systems, which supports new methods to analyze data and predict possible outcomes of events in near-real-time. The Laboratory's scientific community convenes regularly for a technical lecture series engaging researchers from disparate disciplines in the novel large-scale signal processing and optimal control methods of this initiative.

The Future

Based on mathematical advances in dynamical systems, LLNL is creating scalable, stable, and robust modeling and forecasting capabilities that can resolve complex decisions with limited information. On the horizon for LLNL advances in this area is learning general embeddings of operational data to solve combinatorically hard planning problems. Efficiently representing these embeddings on conventional computing architectures is a gap that will drive evolution in computing architecture designs.

On a three-year timeline, LLNL decision superiority teams expect to demonstrate real-time planning capabilities at scale on LLNL high performance computing systems. This will help expand modeling into social science domains, widely acknowledged as critical for managing future threats. Integrating the developing tools with humans will help build trust in the system.

Within five years, evolving LLNL capabilities will enable delivery of decision support products to users across the U.S. government and will foster transfer of capabilities to a broader LLNL mission set.