Statistics at Sandia National Laboratories

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SANDIA'S HISTORY IS TRACED TO THE MANHATTAN PROJECT

- July 1945: Los Alamos creates Z Division
- Nonnuclear component engineering
- November 1, 1949: Sandia Laboratory established
- AT&T: 1949–1993
- Lockheed Martin: 1995–2017
- Honeywell: 2017–present
WE HAVE FACILITIES ACROSS THE NATION

Main sites
• Albuquerque, New Mexico
• Livermore, California

Activity locations
• Kauai, Hawaii
• Waste Isolation Pilot Plant, Carlsbad, New Mexico
• Pantex Plant, Amarillo, Texas
• Tonopah, Nevada
OUR MULTIMISSION ROLE HAS EXPANDED OVER THE DECADES

1950s
- NUCLEAR WEAPONS ENGINEERING AND TESTING
  - Arms race

1960s
- NW STOCKPILE DIVERSITY AND BUILD-UP
  - Cuban missile crisis & Vietnam War

1970s
- NW + ENERGY: MULTIPROGRAM LABORATORY
  - Energy crisis

1980s
- DOE MULTIPROGRAM + MISSILE DEFENSE AND OTHER DoD WORK
  - End of Cold War

1990s
- DOE MULTIPROGRAM + DoD, ECONOMIC COMPETITIVENESS
  - Stockpile stewardship

2000s
- EXPANDED NATIONAL SECURITY ROLE POST 9/11
  - Broader national security

Today
- MULTIMISSION LAB: LEPs, CYBER, BIO, SPACE, TERRORISM
  - Evolving national security challenges
SANDIA HAS FIVE MAJOR PROGRAM PORTFOLIOS

- Advanced Science & Technology
- Nuclear Deterrence
- Global Security
- National Security Programs
- Energy & Homeland Security
Nuclear Deterrence

• Sandia is responsible for the non-nuclear components of US stockpile.

  • Each weapon must work immediately if authorized by the President.
  • Each weapon must never go off if not authorized.
  • Weapons remain for decades in complex conditions and survive harsh environments.

• We want to say that we are X% confident that Y% of components will meet a requirement.

• We can’t solely rely on experts state of knowledge.

• Many sources of uncertainty that cannot be straightforwardly quantified.

• Provide statistical modeling for weapons lifecycle decision support.
Global security – Nuclear forensics

Since the 1960’s, Sandia has been involved in treaty verification
- Sensors are deployed on Earth, in orbit, and seismically to detect foreign nuclear activities
- Sandia statisticians play an important role in developing the detection and classification algorithms for the processing of sensing signatures.

Nuclear Forensics.
- Suppose a piece of interdicted material is found. We would like to know where it came from.
- Sandia statisticians are developing inverse prediction techniques for chemometrics, based on measured physical, chemical, and scanning electron microscope (SEM) features of materials, to detect signature characteristics associated with the pedigree of the material based on a statistically designed experiment.
- Sample SEM images of particles. What conditions created it?

Figure 1. SEM image from MAMA software. The blue shapes are the particles from which measurements such as vector area and pixel area are calculated.
Advanced Science and Technology – Z- machine

• Sandia’s Z machine is Earth’s most powerful pulsed-power facility and X-ray generator. Z compresses energy in time and space to achieve extreme power and intensity found nowhere else on Earth. The Z accelerator is an integral part of Sandia’s Pulsed Power Program.

• Many different applications across the laboratory.
Analysis with the Z Machine

Material sciences

- Statisticians had been involved in the development of *uncertainty quantification* methods to predict important physical characteristics in material sciences by coupling experimental data and computer simulations.
Statistical research for detecting climate pathways

Data Fusion

Pulling together the multi-resolution data from varying sources to create a near-global picture of relevant processes.

Spatial Statistics Methods

Quantifying the spatio-temporal evolution of aerosols and climate impacts with interpretable approaches.

Deep Learning

Deep learning will add computational efficiency and account for complex dynamics that lead to long-term climate impacts.

Change Point Methods

Change Point Detection methods can identify the underlying fundamental shifts in climate processes due to significant events.

Figure: Sulfur Dioxide from TOMS on NOAA Nimbus-7 immediately after eruption

https://earthobservatory.nasa.gov/images/1510/global-effects-of-mount-pinatubo

Figure: Stratospheric Aerosol Optical Depth from AVHRR instrument (Mills et al., 2016).

https://www.ecmwf.int/en/newsletter/159/meteorology/global-reanalysis-goodbye-era-interim-hello-era5
Dynamic spatio-temporal models are intuitive and interpretable ways to represent complex, dependent, physical processes that change across space and time simultaneously.

• Nearest Neighbor Gaussian Process (NNGP) priors can make dynamic models for large data more efficient.

\[ \begin{align*}
\mathbf{y}_t(s) &= \mathbf{X}_t(s)'\beta_t + \mathbf{u}_t(s) + \mathbf{e}_t(s), \quad \mathbf{e}_t(s) \sim N(0, \Sigma) \\
\beta_t &= \beta_{t-1} + \eta_t, \quad \eta_t \sim N(0, \Sigma_\eta), \quad \beta_0 \sim N(m_0, \Sigma_0) \\
\mathbf{u}_t(s) &= \mathbf{u}_{t-1}(s) + \mathbf{w}_t(s), \quad \mathbf{w}_t(s) \sim NNGP(0, C(\cdot, \cdot | \theta_t))
\end{align*} \]

• Baseline trends (e.g. seasonal, ENSO effects) can be captured in \( \mathbf{X}_t(s)'\beta_t \).

• Assuming \( \mathbf{X}_t(s)'\beta_t \) captures our general space-time trends well, \( \mathbf{e}_t(s) \) and \( \mathbf{w}_t(s) \) capture the measurement error and spatial variability, respectively
  • \( \mathbf{e}_t(s) \) will also capture temporal trends outside of \( \mathbf{X}_t(s)'\beta_t \)
  • \( \theta_t \) allows for a temporally varying spatial distribution

Figure: Yearly spatial temperature anomalies from ERA-5 reanalysis in 1992 and 1993 anomalies show clear effects from the 1991 eruption.
National security and intelligence science

- Statisticians are involved in developing space-time marked point processes to study terrorism events globally.


- Extreme spatiotemporal intensities (for attacks that produce at least 20 casualties), integrated over year.
University collaborations and teaching

• Some of the universities Sandia statisticians have ongoing research collaborations with:
  o University of Illinois Urbana-Champaign
  o Ohio State University
  o Brigham Young University
  o Florida State University
  o University of Washington
  o University of New Mexico

• Sandia supports many students from universities all across the USA through internships (summer and year round).

• Teaching activities within Sandia
  o Data Analysis Techniques, Quantification of Margins and Uncertainties, Intro to R, Intro to Measurement Uncertainty, others
Areas of expertise and career path

Some of the areas of emphasis of the Department are

- Experimental design for physical and computer of experiments.
- V&V/UQ studies (validation and verification/uncertainty quantification)
- Bayesian analysis
- Functional data analysis
- Statistical signal processing and time series analysis
- Spatial and spatio-temporal data analysis
- Computational statistics
- Statistical machine learning
- Measurement error, repeatability, and reproducibility plans and analysis
- Data visualization

Staff has varied backgrounds (MsC-Ph.D) and career paths. (student/postdoc $\rightarrow$ staff; staff $\rightarrow$ management; academia $\rightarrow$ staff)

https://sandia.jobs/. Postings for student internships 680151, 680149

Summary

- Statisticians at Sandia support a variety of critical mission areas,
  - Nuclear Deterrence and indirect support of nuclear deterrence
  - Global Security
  - National Security
  - Advanced Science and Technology
  - University Research Collaborations, Internships, and Teaching


Sandia's Statistical Sciences group strives to ensure that all Sandia groups have the statistics support needed to make risk informed and data driven decisions.

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