Data Science and AI Regulatory Applications Workshop Future Focused Initiatives Opening Remarks

November 9, 2021

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Deputy Director, Division of Systems Analysis
Office of Nuclear Regulatory Research

Data Science and Artificial Intelligence

The nuclear industry is investigating and using artificial intelligence applications

The NRC recognizes a need to use data analytics and artificial intelligence for regulatory decisionmaking

The NRC must be prepared to understand and evaluate these technologies

https://www.nrc.gov/public-involve/conference-symposia/data-science-ai-reg-workshops.html

Time (Eastern)	Topic	Presenter
10:00 a.m. – 10:20 a.m.	Introduction and Regulatory Purpose	Theresa Lalain (NRC)
10:20 a.m. – 10:40 a.m.	NRC Future Focused Research Program	Robert Tregoning (NRC)
10:40 a.m. – 11:00 a.m.	INL AI R&D Activities	Chris Ritter (Idaho National Laboratory)
11:00 a.m. – 11:20 a.m.	SNL AI R&D Activities	John Feddema, Stephen Kleban (Sandia National Laboratories)
11:20 a.m. – 11:40 p.m.	ANL AI R&D Activities	Rick Vilim (Argonne National Laboratory)
11:40 a.m. – 12:00 p.m.	Machine Learning for Safeguarding Nuclear Materials	Nathan Shoman (Sandia National Laboratories)
12:00 p.m. – 1:00 p.m.	Break	
1:00 p.m. – 1:20 p.m.	Nuclear Applications of Large Language Models	Jerrold Vincent, Bradley Fox (NuclearN)
1:20 p.m. – 1:40 p.m.	Hybrid Physics-Data Driven Model for Prescriptive Control and Design	Satyan Bhongale (X-Energy)
1:40 p.m. – 2:00 p.m.	CAP Automation and Informed Inspection Preparation Project - Update	Tim Alvey (Exelon Nuclear Innovation Group) Drew Miller (Jensen Hughes) Ahmad Al Rashdan (Idaho National Laboratory)
2:00 p.m. – 2:45 p.m.	Panel Session	Thiago Seuaciuc-Osorio (EPRI) Curtis Smith (INL) James Slider (Nuclear Energy Institute) Luis Betancourt (NRC)
2:45 p.m. – 3:00 p.m.	Executive Summary and Path Forward	

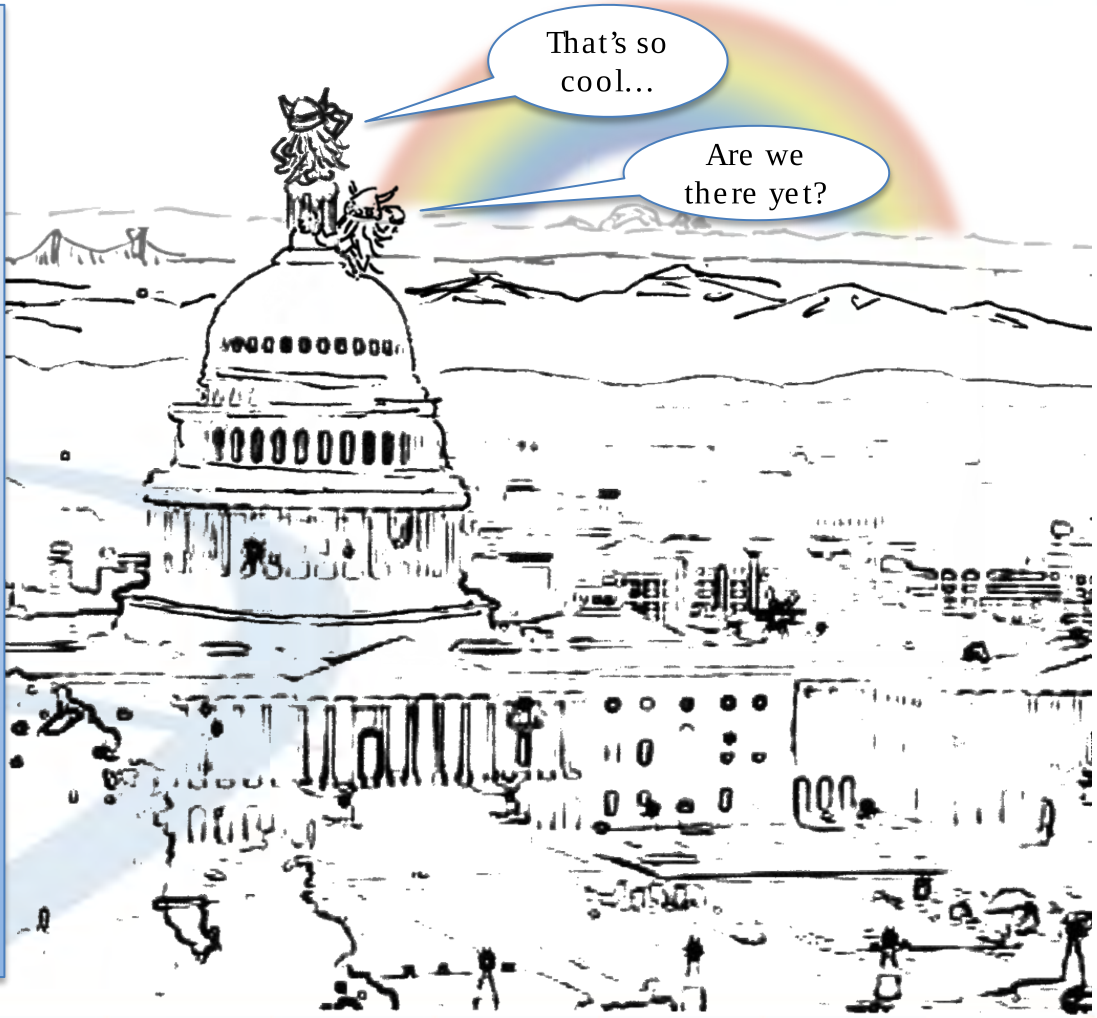
NRC's Future-Focused Research Program

Advisors: R. Tregoning, C. Boyd

Project Manager: J. Steckel

NRC Data Science and AI Workshop III – Future Focused Initiatives

11/9/2021



FFR Program Overview

- Program Concept and Context
- Program Objectives
- Process Considerations
- Activities
  - Artificial Intelligence and Data Science
- Future Directions

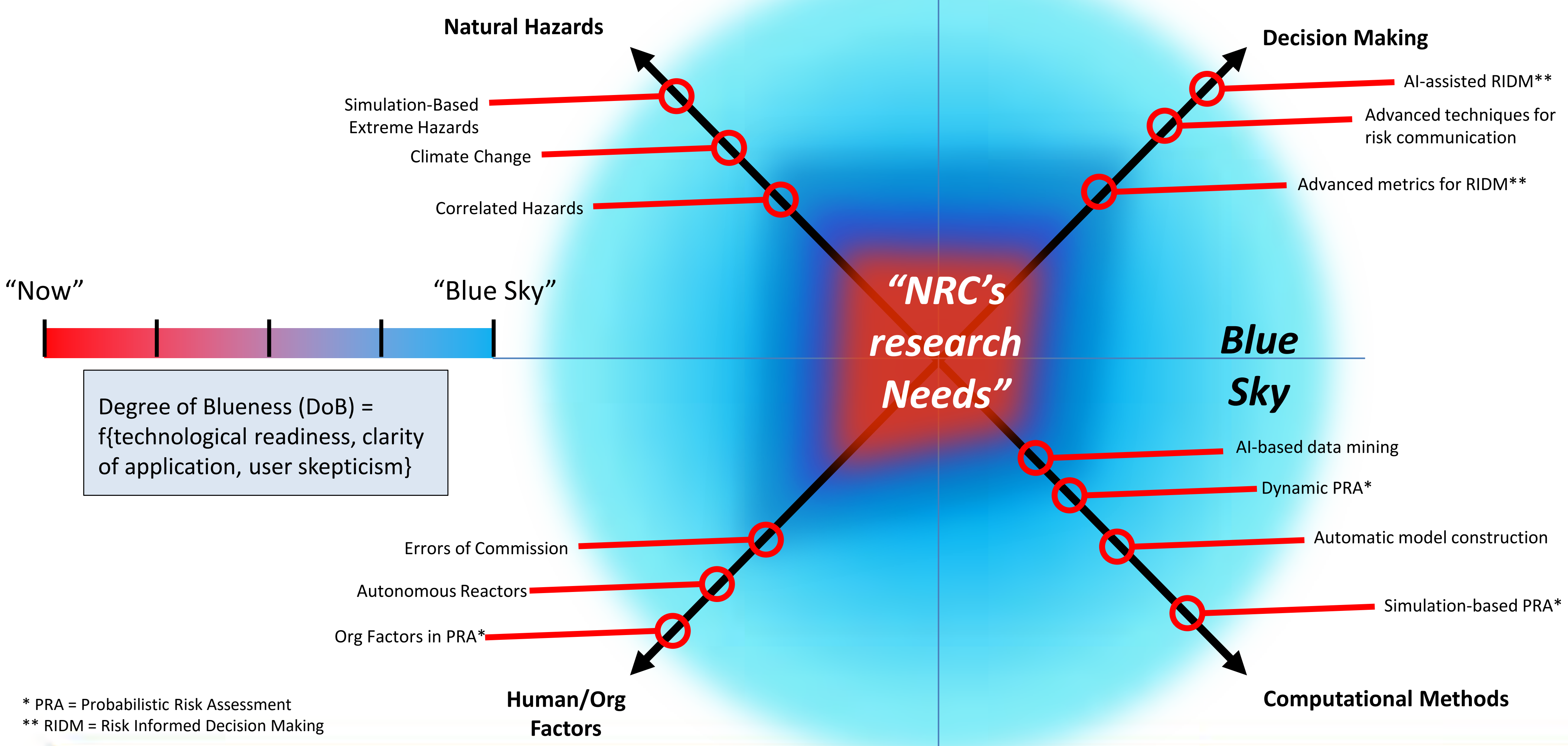
Future-Focused Research (FFR) Program Concept

- Support NRC's need for longer-term (≥ 3 years) R&D activities
- Broad scope: all good ideas considered*
- Funding
  - Dedicated
  - Fully loaded at beginning of project
  - Exploring opportunities to leverage with University R&D Grant Program
- Program management and administration
  - Streamlined submission and review process
  - Low-burden, low-resource implementation
- Start small, grow with success
  - Initiated current program in FY-20
- Mixed project portfolio
  - Time horizons
  - Project risk: ***emphasizing riskier, less-applied ideas for FY-22 and beyond***

- Inspired by national lab "Laboratory-Directed Research and Development" (LDRD) programs
  - Concept
  - Scale
- Includes "blue sky," "risky" projects

*All ideas (including those outside FFR scope) are communicated to NRC management

NRC's Blue Sky



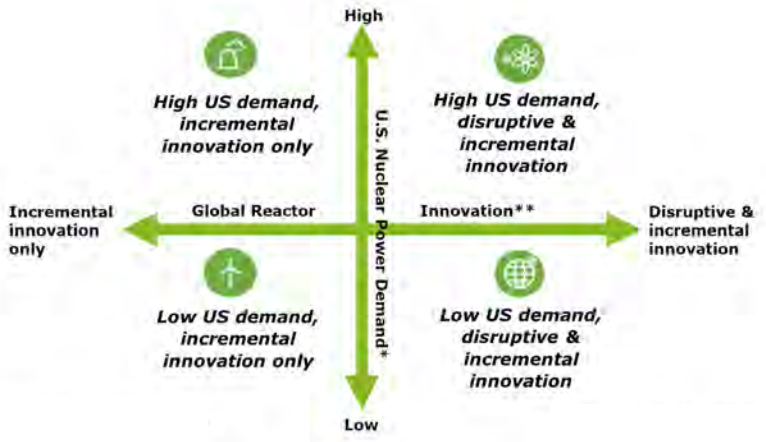
Degree of Blueness (DoB) = f{technological readiness, clarity of application, user skepticism}

* PRA = Probabilistic Risk Assessment
** RIDM = Risk Informed Decision Making

NRC's Horizon: Opportunities and Challenges

"It's tough to make predictions, especially about the future."
- Yogi Berra

- Changing reactor technologies, concepts of operation
- Increasing knowledge base (and means to use)
- Increasing computational capabilities (hardware, software, modeling approaches, …)
- Changing staff and other stakeholders
- Increasing and more challenging regulatory applications



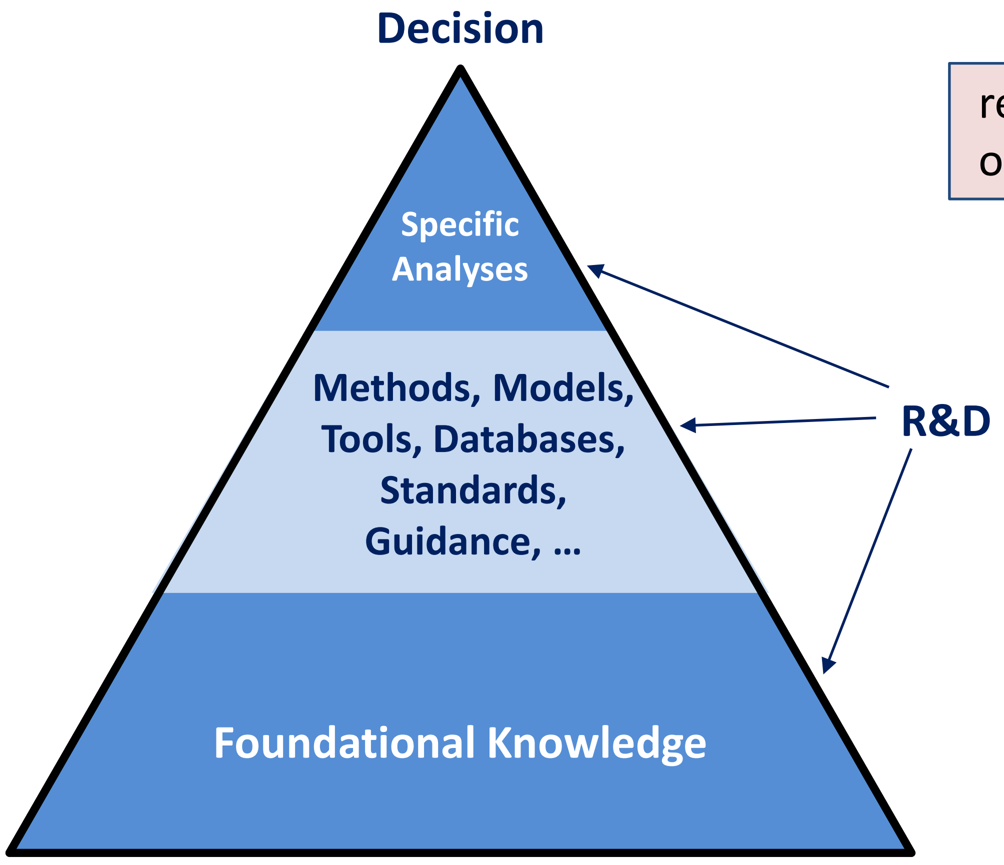
U.S. Nuclear Regulatory Commission, "The Dynamic Futures for NRC Mission Areas," 2019. (ML19022A178)

RES goal: help ensure that NRC is prepared

FFR Objectives

- Provide kickstart (basis, direction, and support) for extended projects (outside the FFR program) on likely important topics
- Promote more robust R&D program to sustain agency
- Energize staff
- Improve (and perhaps even radically change) foundational knowledge on key topics
- Develop useful products and appropriate staff cognizance of same
  - Actionable insights (including dismissal of potential issues)
  - Tools and data for analyses
  - Current status, directions, and likely schedules for potentially important technologies, programs, etc.
- Create synergy with related programs (e.g., University R&D Grants)

Research: providing a basis for decisions



Regulatory Decision Support

re•search, *n.* diligent and systematic inquiry or investigation in order to discover or revise facts, theories, applications, etc.

Typical products (regulatory research)

- Ways to look at and/or approach problems (e.g., frameworks, methodologies)
- Points of comparison (e.g., reference calculations, experimental results)
- Job aids (e.g., computational tools, databases, standards, guidance: best practices, procedures)
- Problem-specific information (e.g., results, insights, uncertainties)

Side benefits

- Education/training of workforce
- Networking with technical community

FFR Process

FFR Program

Idea Generation → Idea Refinement and Selection → Portfolio Monitoring and Reporting → Follow-On Projects (User Needs)

Idea Generation
- Gather ideas – could be individual or crowdsourced
- Open to ideas from across agency

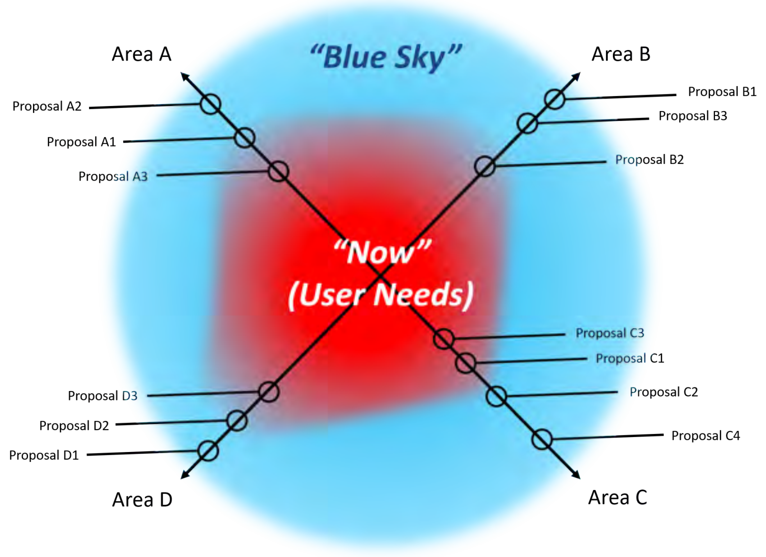
Idea Refinement and Selection
- As needed, work with submitters to refine initial concept
- Advisors recommend and senior RES managers choose projects

Portfolio Monitoring and Reporting
- Communicate and monitor progress through program reviews and seminars

Follow-On Projects (User Needs)
- May identify research for potential future development through user needs

Project Rating Considerations*

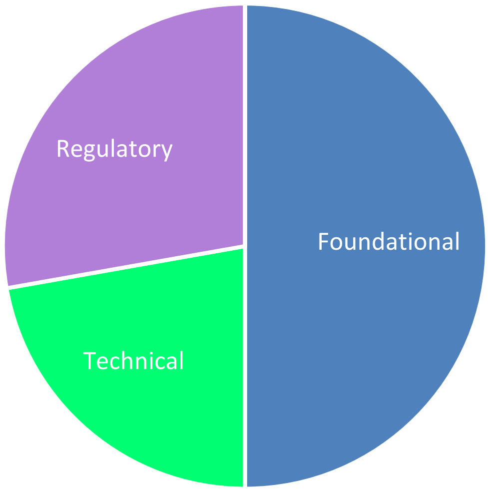
- Agency impact
  - Improves NRC's future capabilities
  - Improves foundational knowledge important to future decision making
  - Addresses recognized gaps
- Resource leveraging
  - Enables NRC's influencing of important external activities
  - Potentially benefits multiple NRC programs
  - Leverages available resources for research
- Staff enrichment
  - Is attractive to individual researchers
  - Is attractive to university research programs



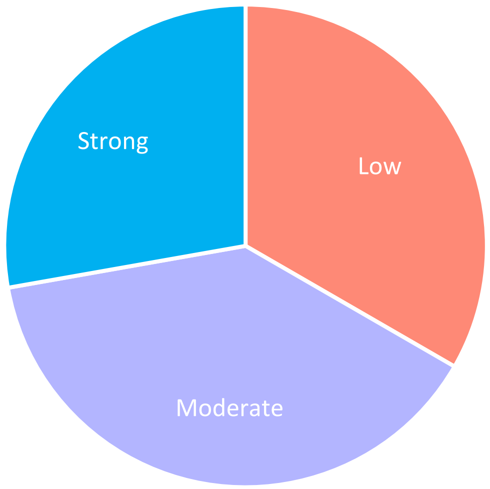
*Notes:
1) Considerations used as guidance.
2) Selection committee also considers the overall portfolio of FFR activities
   a) Risk
   b) Resources

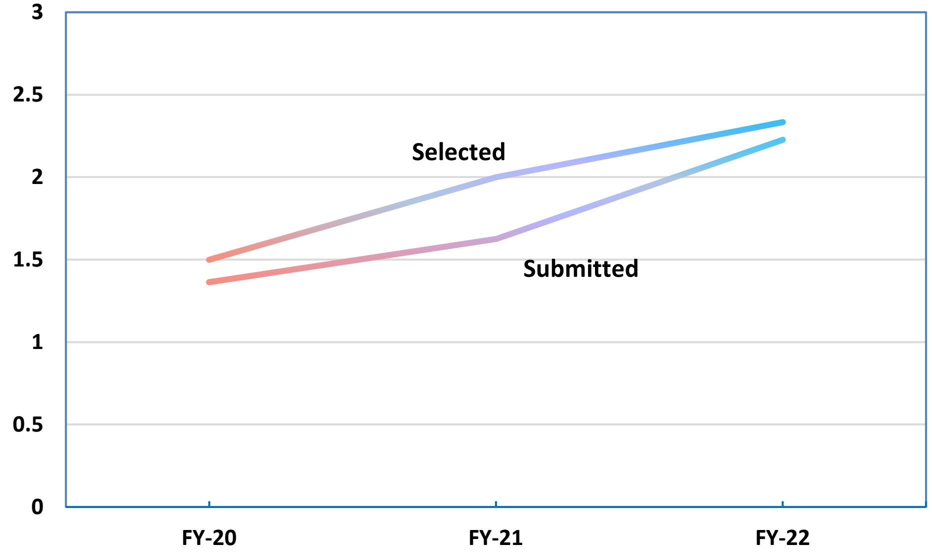
FFR Portfolio

Gap Objectives



Degree of Blueness





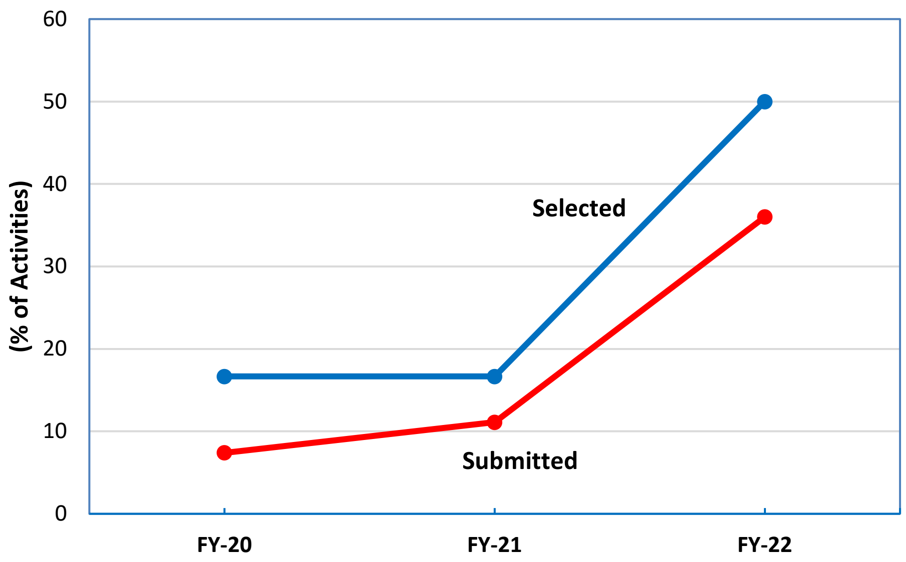
- Appropriate balance among efforts
  - 50% developing foundational knowledge
  - 50% developing more specific technical tools or addressing regulatory framework gaps

- Current portfolio is balanced across risk horizon spectrum.
- Trending toward “bluer sky” activities as FFR program has matured.

AI and Data Science in FFR

Related FFR Activities

- **FY-20**
  – Digital Twins - Regulatory Viability
- **FY-21**
  – RESbot - A web-based bot to aid RES Researchers
- **FY-22**
  – Use Machine Learning to Prioritize Inspections
  – Characterizing Cyber Security Using AI/ML
  – Application of Natural Language Processing to NRC Regulatory Documents



- Explosion of AI-DS topics both submitted and selected in latest data call
- General bias in selecting AI-DS topics as FFR activities

Existing AI-DS FFR Activities

- Digital Twins - Regulatory Viability
  - **Objective:** Understand the potential industry applications of reactor digital twins and the regulatory viability of use of digital twins
  - **Approach**: Assess existing technical information, knowledge, tools, and codes and standards to determine state-of-the-art and current gaps; identify regulatory gaps and fundamental infrastructure elements
  - **Status:**
    - Held December 2020 and September 2021 workshops: published December proceedings (ML21083A132)
    - Completed report: ***The State of Technology of Application of Digital Twins*** (ML21160A074)
    - Transitioned out of FFR and is continuing as a follow-on research project
- RESbot - A web-based bot to aid RES Researchers
  - **Objective**: Develop one or more web-based bots, to aid NRC researchers in mining, for example, experimental data, analyses, compilation of field experience, and risk assessments to support decision-making
  - **Approach**: Create NRC use cases and develop RESbot implementation plan to address use cases; executing implementation plan would be a follow-on effort
  - **Status**: Defined use cases on technical document querying, modeling and simulation, and report preparation; currently evaluating use cases using IBM Watson Discovery and Microsoft Azure platforms

FY-22 AI-DS FFR Activities

- Use Machine Learning (ML) to Prioritize Inspections
  - **Objective**: Explore use of commercially available ML applications to prioritize inspections and their associated periodicity during abnormal situations (i.e., pandemics)
  - **Approach**: Define licensees as "customers"; define and build "safety behavior" using data similar to "customer preferences; perform test case using several off-the-shelf ML tools
- Characterizing Cyber Security Using AI/ML
  - **Objective**: Evaluate issues associated with future AI/ML applications used to characterize cyber security system performance and configurations, and detect abnormal system states associated with a cyber attack
  - **Approach**: Identify viable AI/ML technologies; evaluate technologies relative to defined nuclear cyber use case; apply most promising approach to benchmark test case
- Application of Natural Language Processing (NLP) to NRC Regulatory Documents
  - **Objective**: Assess use of existing NLP tools for NRC use to assist review of licensing actions
  - **Approach**: Create licensing benchmark case and collect associated data; apply named entity recognition to data set and subsequently create term-frequency inverse document frequency model; evaluate Google's BERT model to retain semantic meaning for neural network training and implementation

Thoughts for Future: AI/DS

- Nuclear is typically a later adopter of technological innovations
  - Slower pace of innovation
  - Opportunities to build off advancements and investments in other industries
  - **Which AI/DS advancements hold biggest promise and challenges for nuclear application?**
- Nuclear energy landscape is continually changing
  - Future reactors will likely be smaller; may be more widely distributed
  - Bulk of aging LWR fleet may require operation beyond 60 to 80 years to meet nation's energy goals
  - **How can AI/DS be used to both optimize the new design, certification, and approval process?**
  - **How can AI/DS optimize efficiencies of existing plants to retain safety and economic viability?**
  - **How can NRC use AI/DS to evaluate this landscape to better position itself for future regulatory challenges?**
- Continuous pressure to decrease human operations to maximize efficiencies
  - **What are the actions/operations where decreasing human involvement is most beneficial?**
  - **Are there actions/operations that should always retain human involvement/oversight and, if so, how can these be best identified?**

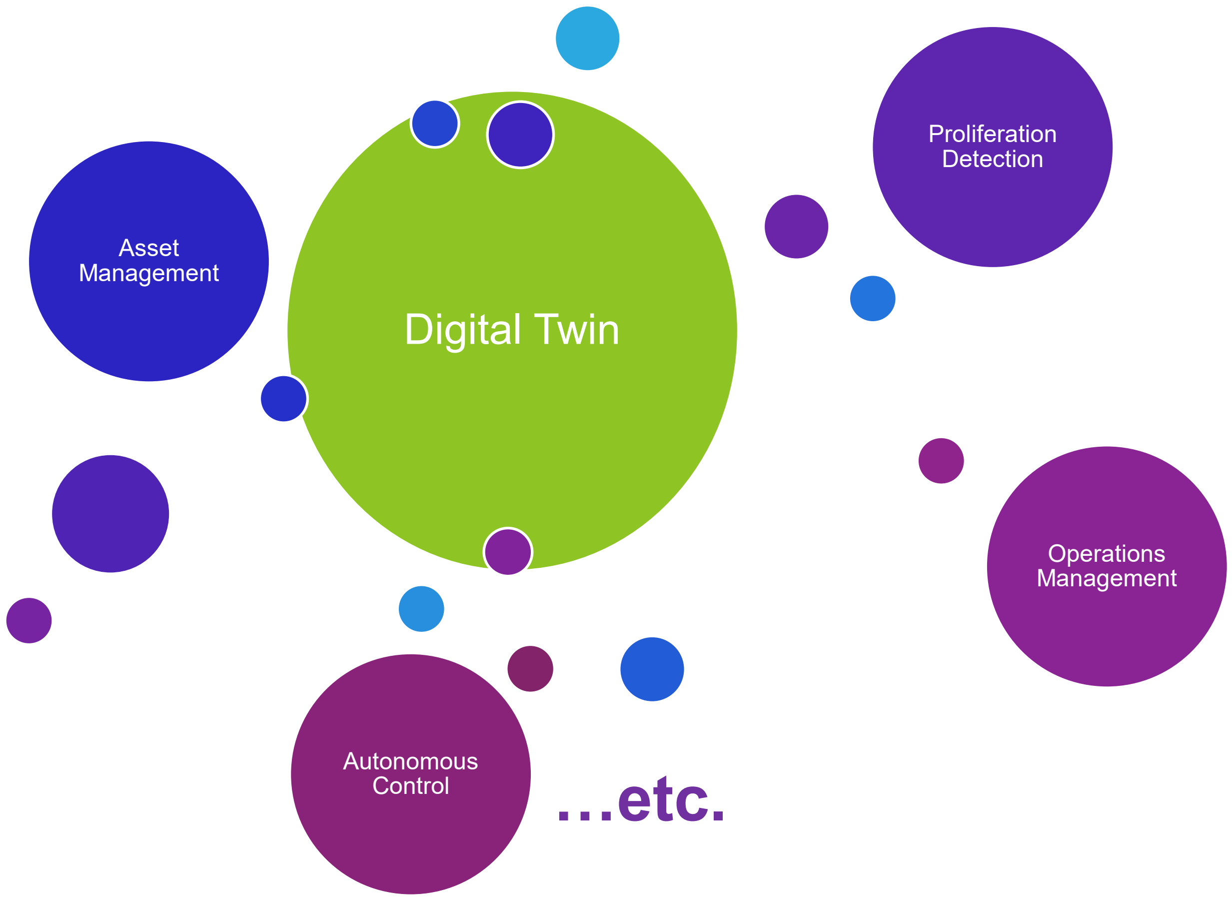
Questions?

Digital Innovation Center of Excellence

Lab Directed Research and Development (LDRD) Digital Twin Overview

Idaho National Laboratory

What is a Digital Twin?



INL definition: Digital Twins represent the merging of integrated and connected data, sensors and instrumentation, artificial intelligence, and online monitoring into a single cohesive unit.

It is a **living virtual model** that mirrors a physical asset to predict future behavior.

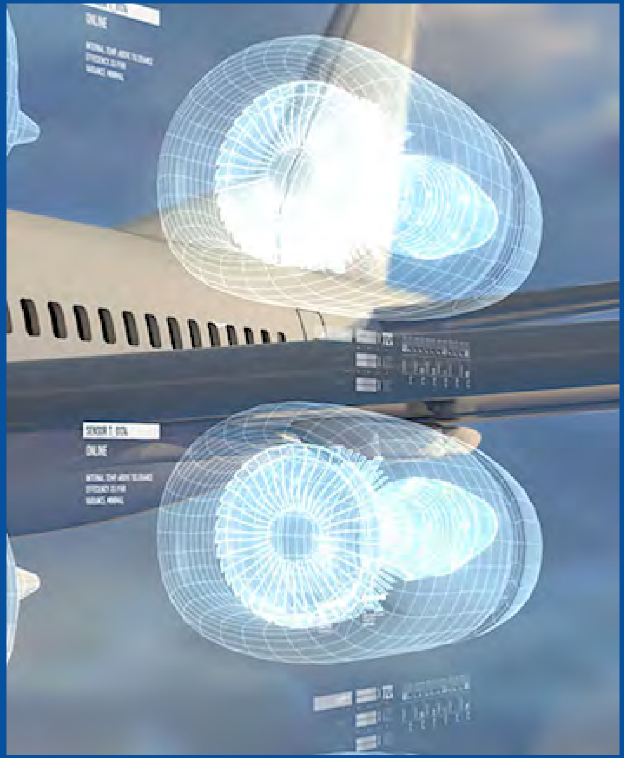
Digital Twins use **real-time bi-directional communication** to track and trend both simulated and measured asset information.

What is different than a traditional simulation?

- Integration of real-time data
- Dynamic model update (AI/ML integration)
- Real-time operator feedback (visualization)
- Accurate predictions with fused (integrated) data
- Ability to enable autonomous control
- Distributed across computing platforms

Digital Twin Proven Opportunity from Industry Applications

- **Operational Cost**
  - **14 - 23%** reduced operations cost (BCG)
  - **$1.05 billion** in cost avoidance (GE)
- **Asset Performance**
  - **40% improvement** in first-time quality (Boeing)
  - **10% improvement** in effectives (Gartner)
- **Growing Market and Technology**
  - Market is **~$3.1 billion** (2020)
  - Market predicted to be **$48.2 billion** by 2026

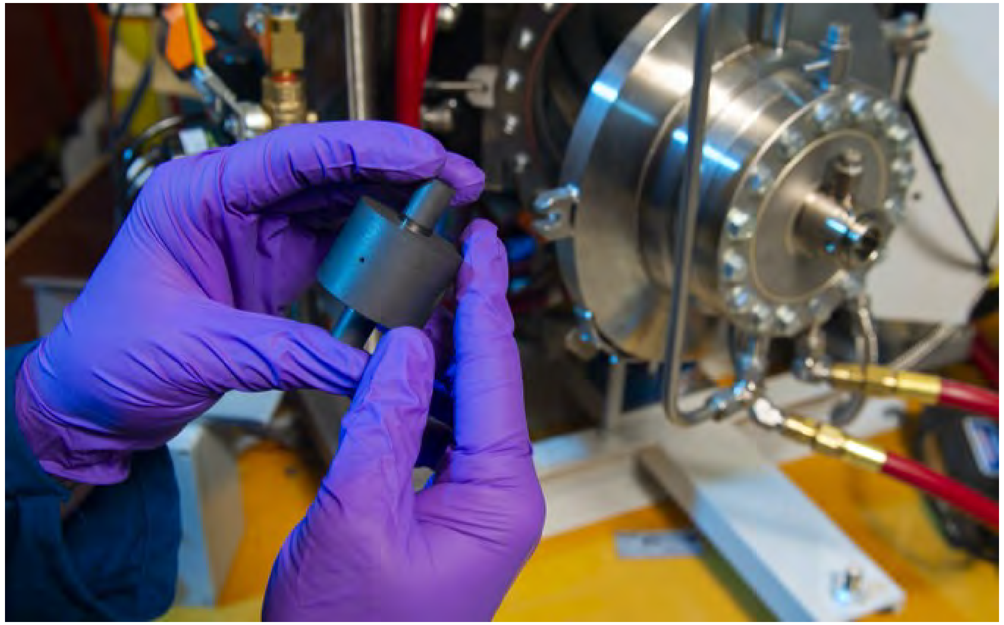


General Electric Aviation has digital replicas of every engine to monitor performance and predict maintenance issues. This approach reduces engine operational costs and increases safety.

Adv. Manufacturing Digital Twin (AM&M Initiative)

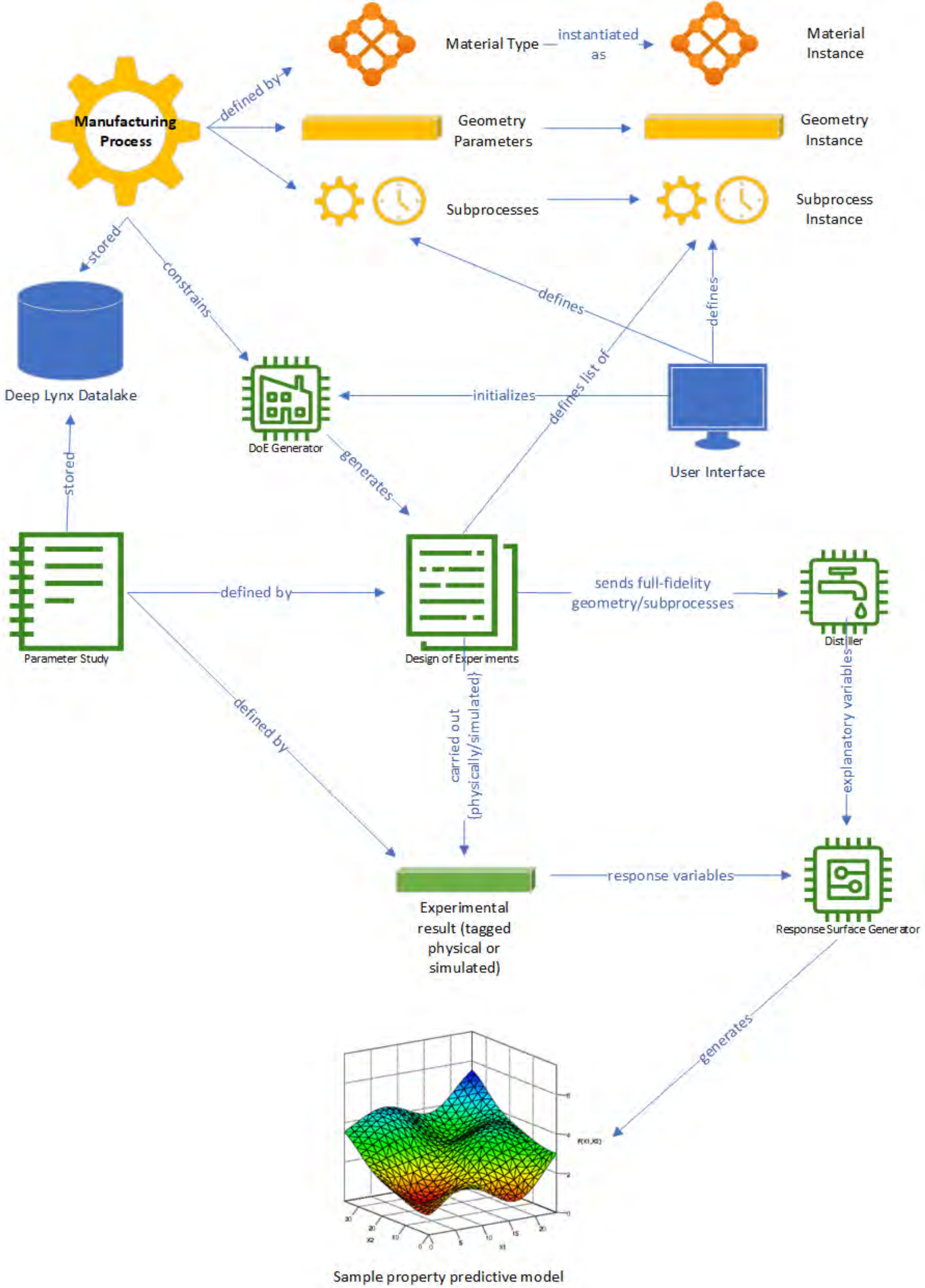
PI: Brennan Harris

- **Manufacturing Processes:**
  - Spark plasma sintering
  - Digital light processing
- **Opportunity:** Predict manufactured sample performance from varied manufacturing input parameters



Results

- **Digital architecture that allows both simulated and physical material properties to be predicted from manufacturing parameters**
  - An open database and interface for INL manufacturing researchers to utilize
  - Manufacturing optima for SPS samples from statistical prediction
- **Potential for follow-on research**
  - Applying the method to processes outside SPS and DLP.



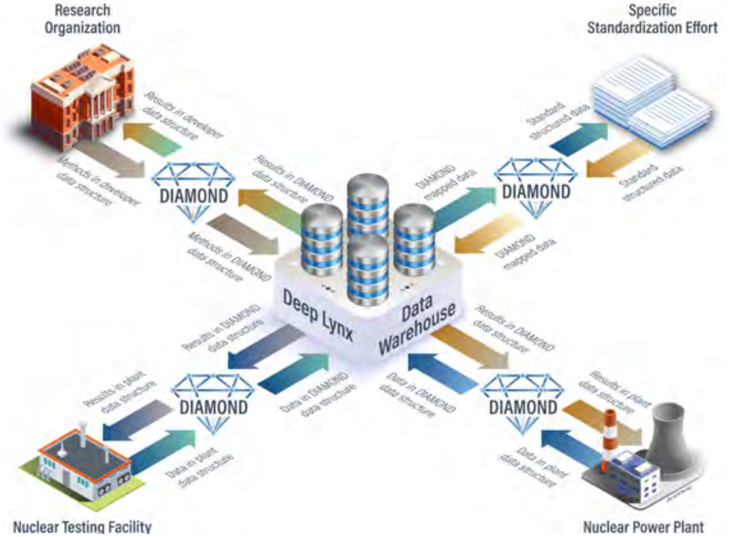
Solvent Extraction Equipment Testing Laboratory Digital Twin

PI: Ashley Shields

- **Facility:**
  - 30-stage annular centrifugal contactor system
  - Binary Metal separations

Centrifugal Contactor Cascade at the Bonneville County Technology Center

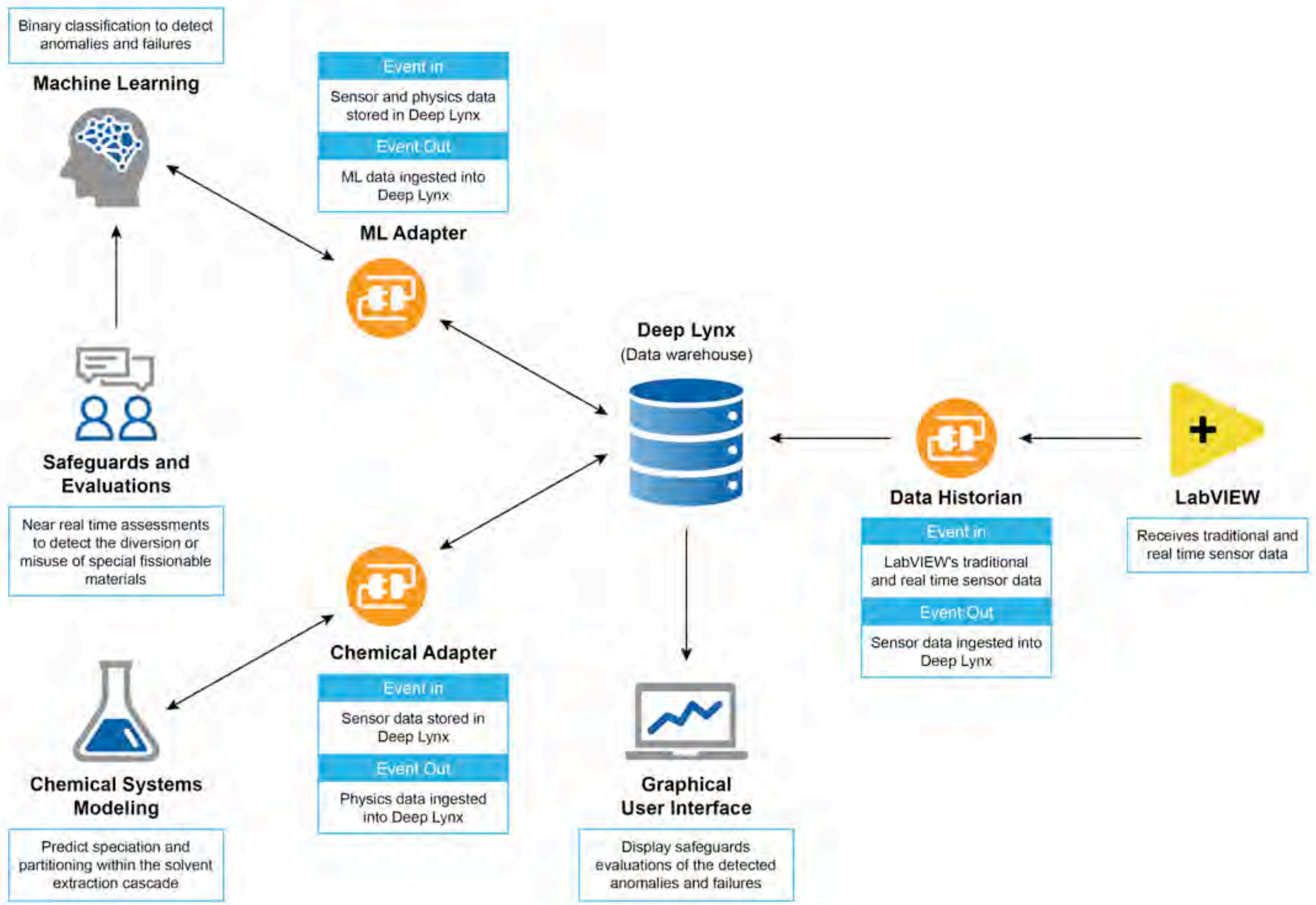
- **Opportunity:**
  - First solvent extraction twin
  - Provide open-source adaptable digital twin components



Leveraging Deep Lynx data warehouse and DIAMOND ontology

Anticipated Results

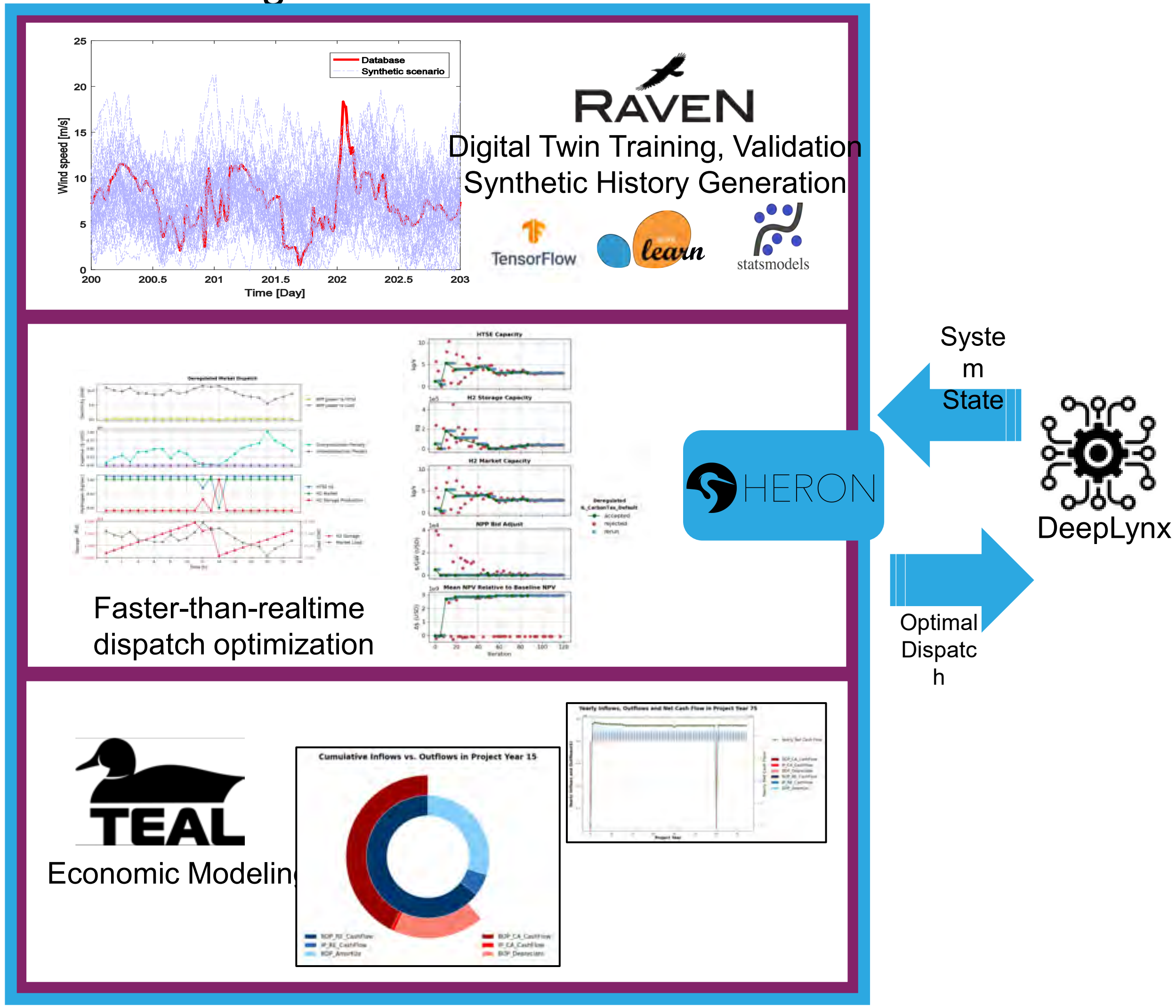
- **Goals: Framework twin for the solvent extraction process**
  - Integrated via the Deep Lynx data warehouse and newly developed warehouse adapters
  - Research advancements in
    - Digital twin infrastructure
    - Sensor integration
    - Chemical modeling
    - Artificial Intelligence
    - Data visualization
    - International Nuclear Safeguards
    - Nuclear Proliferation Detection
- **Potential for follow-on research**
  - Beartooth Testbed Digital Twin



IES Digital Twin Framework

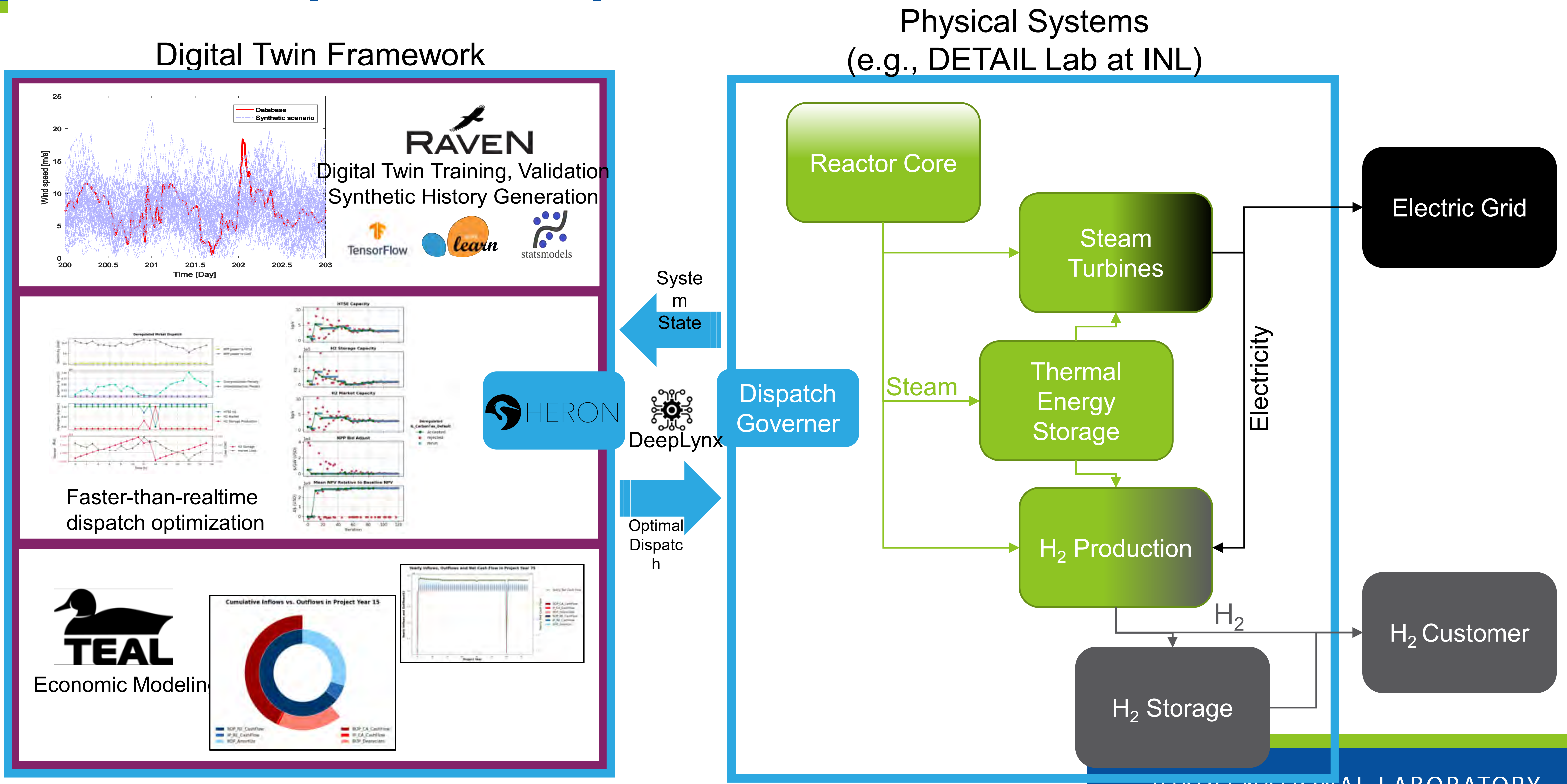
PI: Paul Talbot

Digital Twin Framework



- HERON
  - Dispatch Optimization
  - Uses TEAL for economic analysis
  - Uses system state to optimize operation
- RAVEN
  - MLAI Digital Twins
  - Coupling to Codes, Experiment
  - Validation and Verification
  - Synthetic Histories for Unc. Quant.
  - Enhances trusted libraries

Flexible Operation Optimization



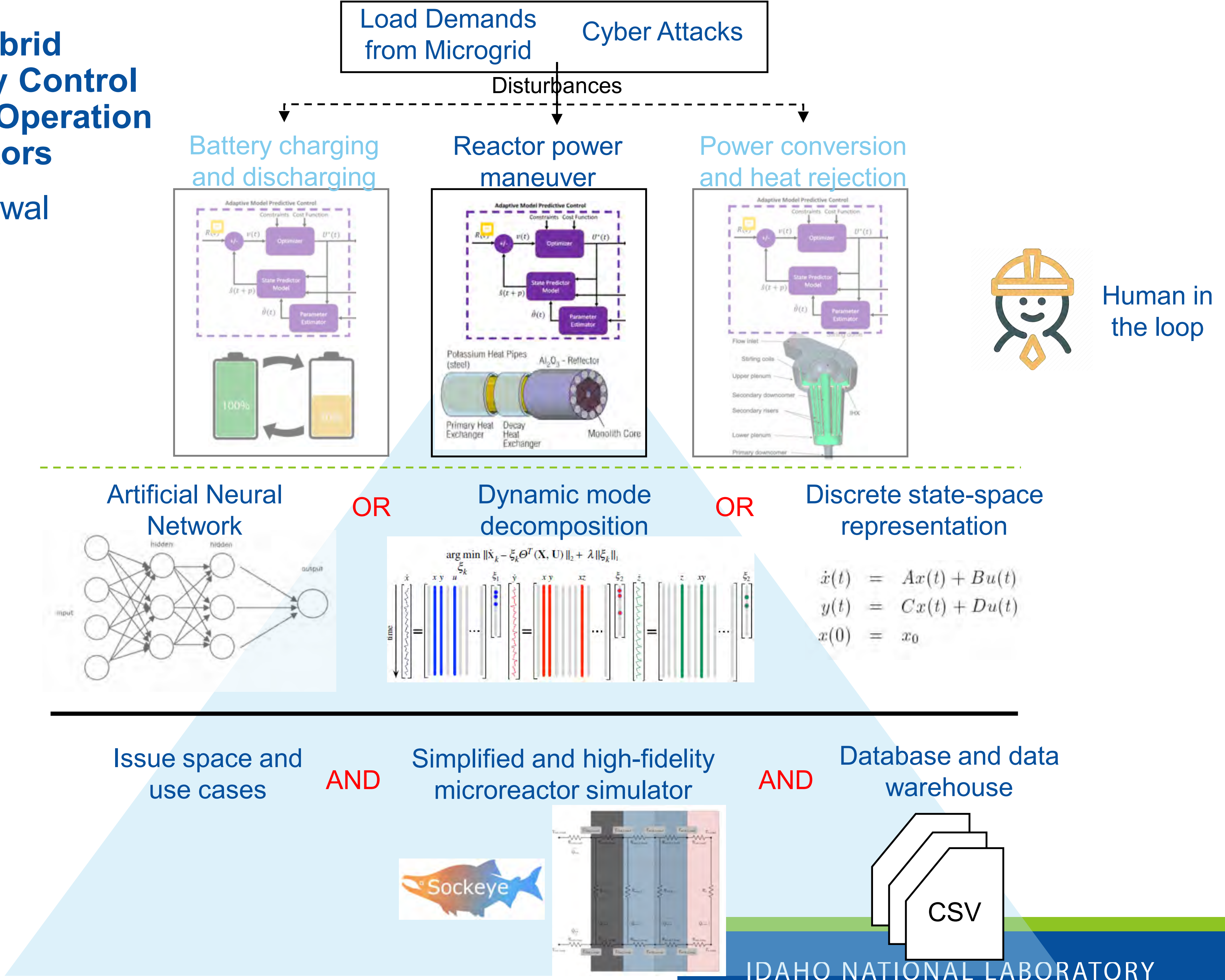
Scalable Framework of Hybrid Modeling with Anticipatory Control Strategy for Autonomous Operation of Modular and Microreactors

PI: Linyu Lin and Vivek Agarwal

Anticipatory controller demonstration

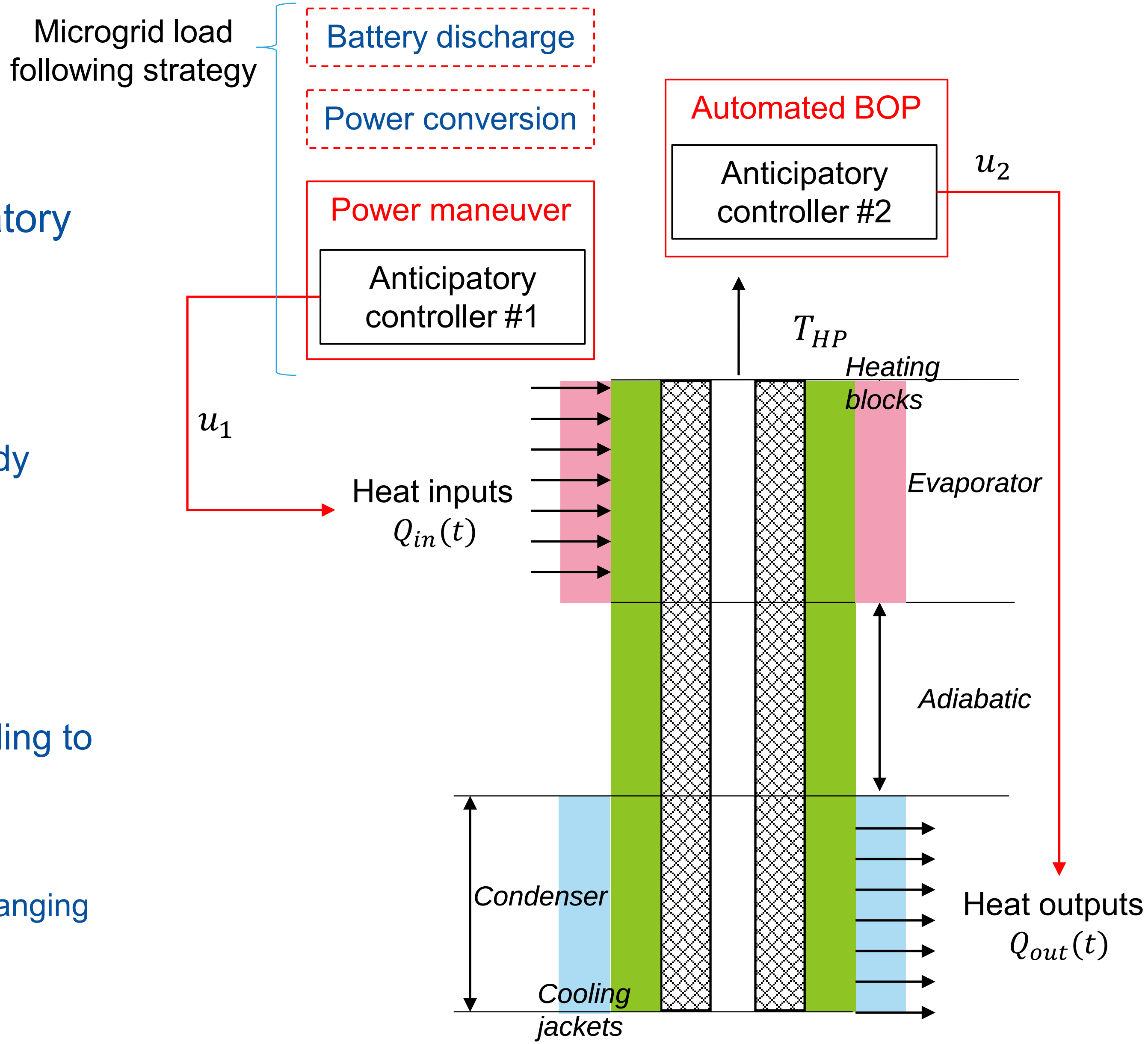
Anticipatory controller development

Knowledge Base



Current Progress

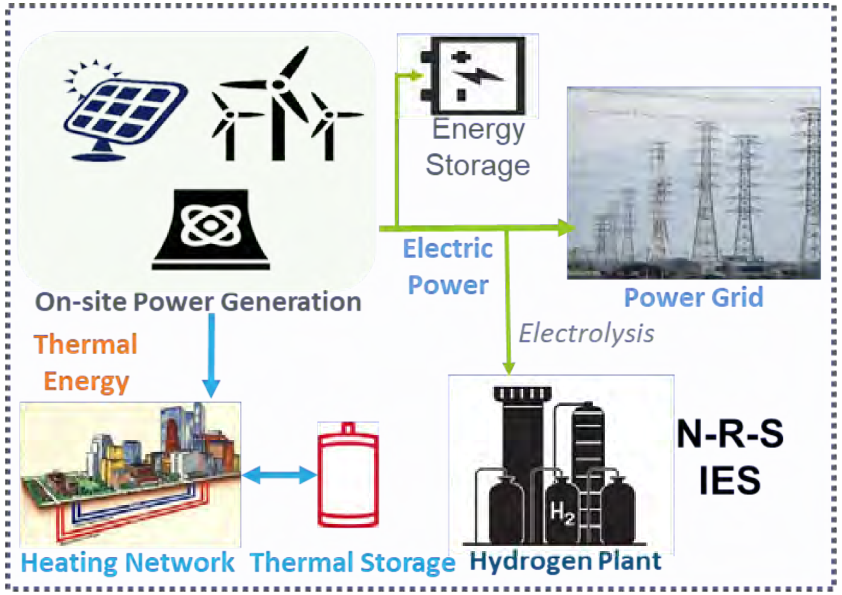
- Model predictive controllers for the anticipatory control of a single heat pipe
  - Assumption
    - Simplified modeling
    - Distributed controllers
  - Initial condition: normal operation at a steady power input to the evaporator
  - Load following through
    - Power maneuver by controller #1
    - Power conversion
    - Battery
  - Automated balance of plant (BOP) responding to the disturbances due to power maneuver:
    - Controller #2 alters heat removal rates from condenser
    - Controller #2 maintains magnitudes and changing rates of heat-pipe internal temperatures



Nuclear-Renewable-Storage Digital Twin

PI: Binghui Li

- Goal: Improve system **economy**, **security**, and **reliability** of Nuclear-Renewable-Storage Integrated Energy Systems (N-R-S IES)
- Innovation
  - Integrated **high-fidelity physics model** to inform the operation of IES
  - Deep reinforced learning based (**DRL-based**) methods to enable faster-than-real-time simulation
- Impact
  - A collection of DRL-based tools: Reliability Enhancement and System Operation Tool (**RESORT**)
  - Can be extended for future research grants

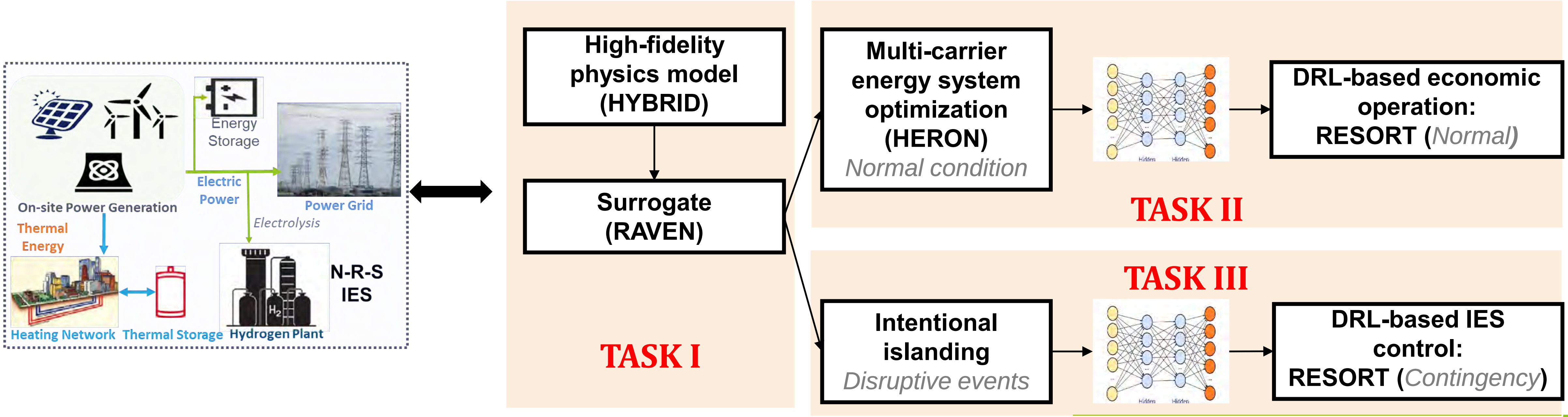


Why N-R-S IES?

- Electricity and heat → **Multi-carrier** energy system
- Nuclear → Carbon-free **baseload**
- Renewable + short-term storage → flexible **peaking** capability
- Long-term storage → **resilience** against disruptive events

Project Tasks

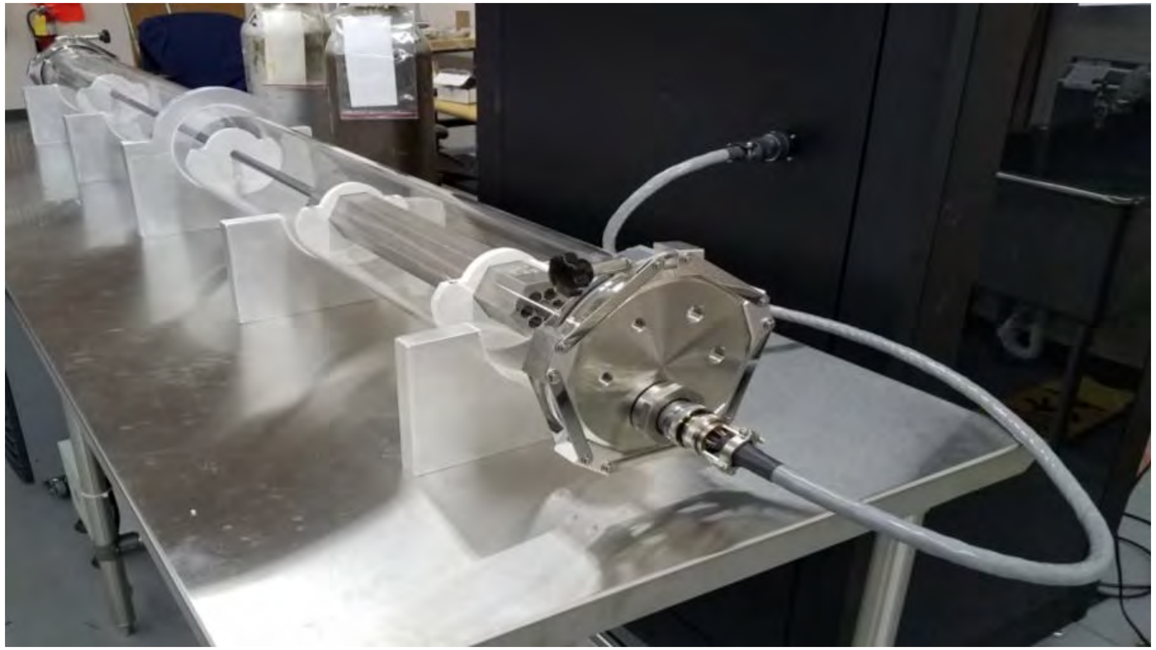
- Tasks
  - I: Learning-enhanced modeling of complex electric-thermal coupled systems using high-fidelity physics-based models
  - II: Learning-based steady-state IES economic operations
  - III: Risk mitigation through intentional islanding and optimal IES control



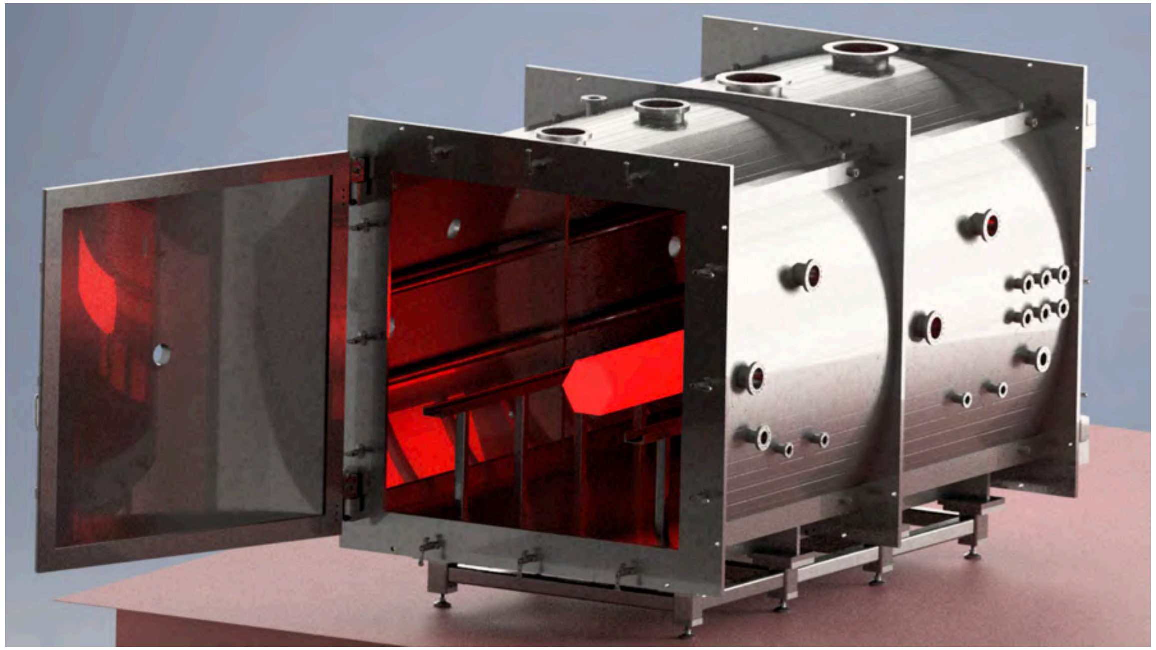
MAGNET Digital Twin (Fission Battery Initiative)

PI: Jeren Browning

- **Test Beds:**
  - SPHERE (single heat pipe)
  - MAGNET (37 heat pipes)
- **Opportunity:** Remote and autonomous control of a heat pipe



SPHERE



MAGNET

Results

- **Proven Digital Twin capability and repeatable roadmap**
  - Integrated via the Deep Lynx data warehouse
  - Open-source, reusable components
  - Research advancements in economic benefit, cyber security, and Artificial Intelligence

- **Potential for follow-on research**
  - MARVEL Microreactor Test Bed

References

1. http://futureofconstruction.org/content/uploads/2016/09/BCG-Digital-in-Engineering-and-Construction-Mar-2016.pdf
2. https://www.ge.com/digital/blog/industrial-digital-twins-real-products-driving-1b-loss-avoidance
3. https://www.foxnews.com/tech/air-force-flies-6th-gen-stealth-fighter-super-fast-with-digital-engineering

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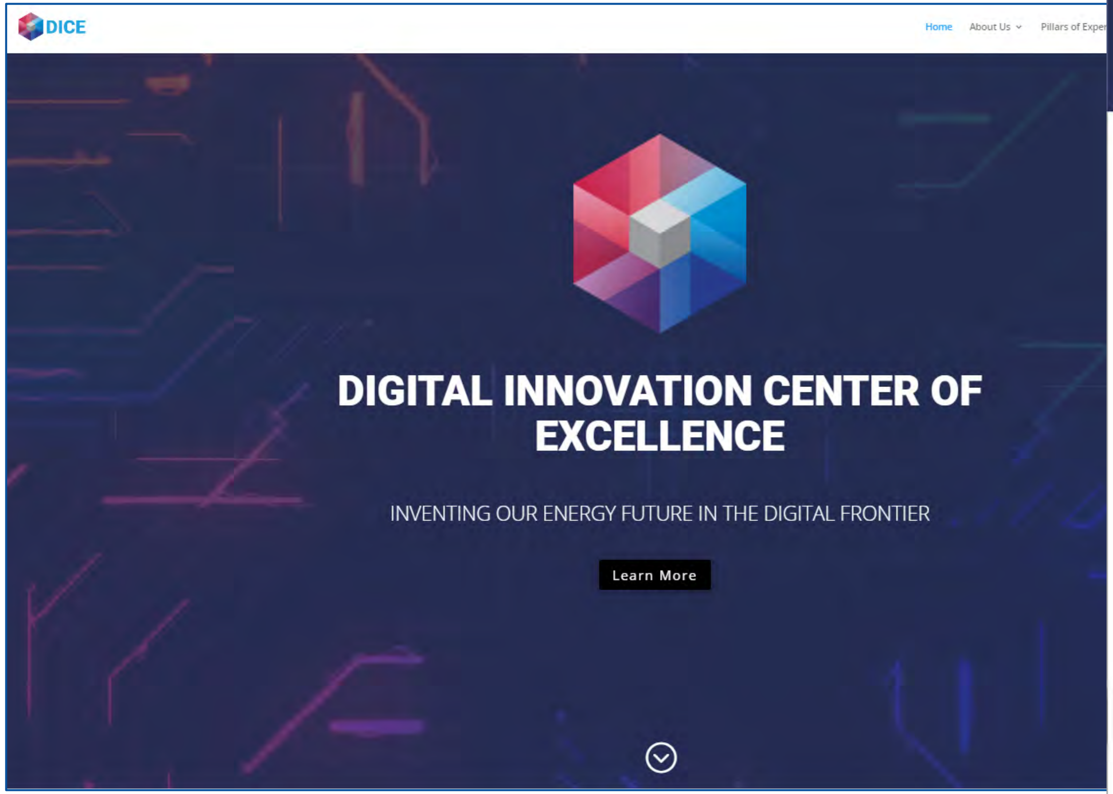
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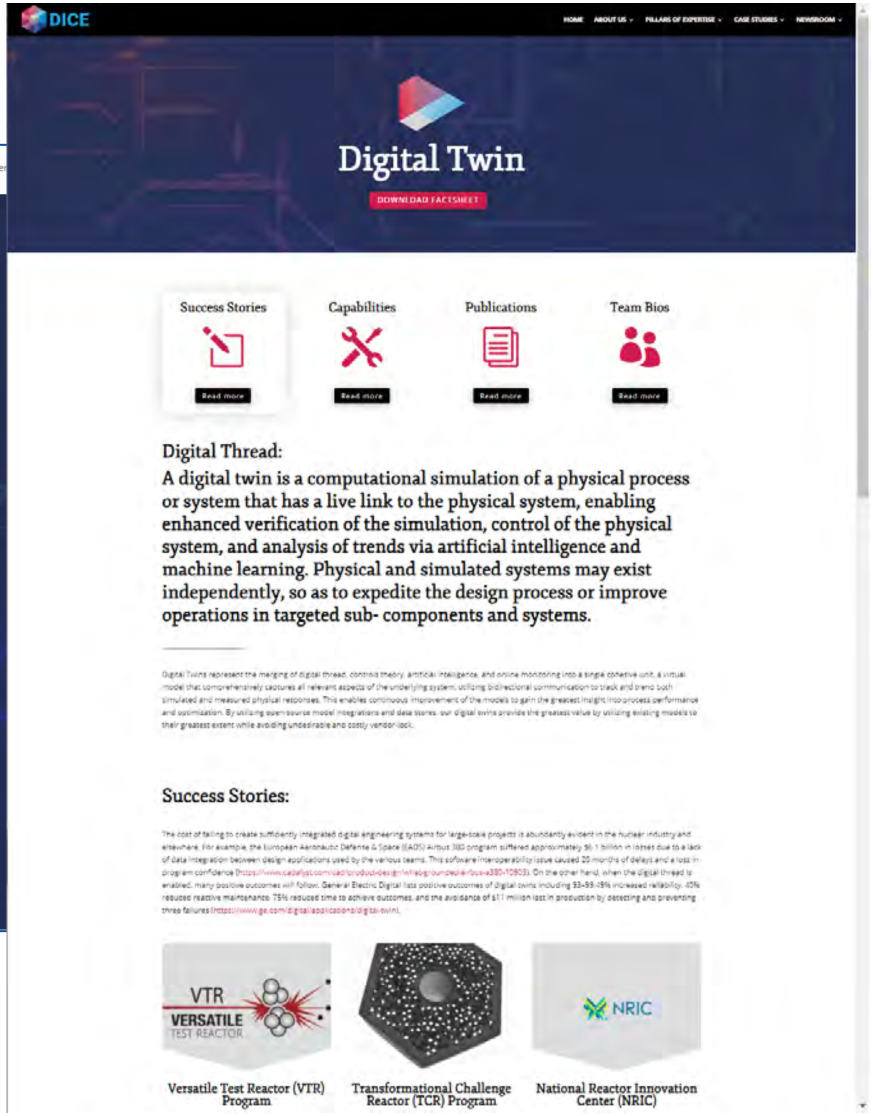
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Success Stories
Capabilities
Publications
Team Bios
Digital Thread:
A digital twin is a computational simulation of a physical process or system that has a live link to the physical system, enabling enhanced verification of the simulation, control of the physical system, and analysis of trends via artificial intelligence and machine learning. Physical and simulated systems may exist independently, so as to expedite the design process or improve operations in targeted sub- components and systems.
Success Stories:
VTR
VERSATILE
TEST REACTOR
NRIC
Versatile Test Reactor (VTR) Program
Transformational Challenge Reactor (TCR) Program
National Reactor Innovation Center (NRIC)

Questions

Any Questions?

- **Christopher Ritter**
- Director, Digital Innovation Center of Excellence
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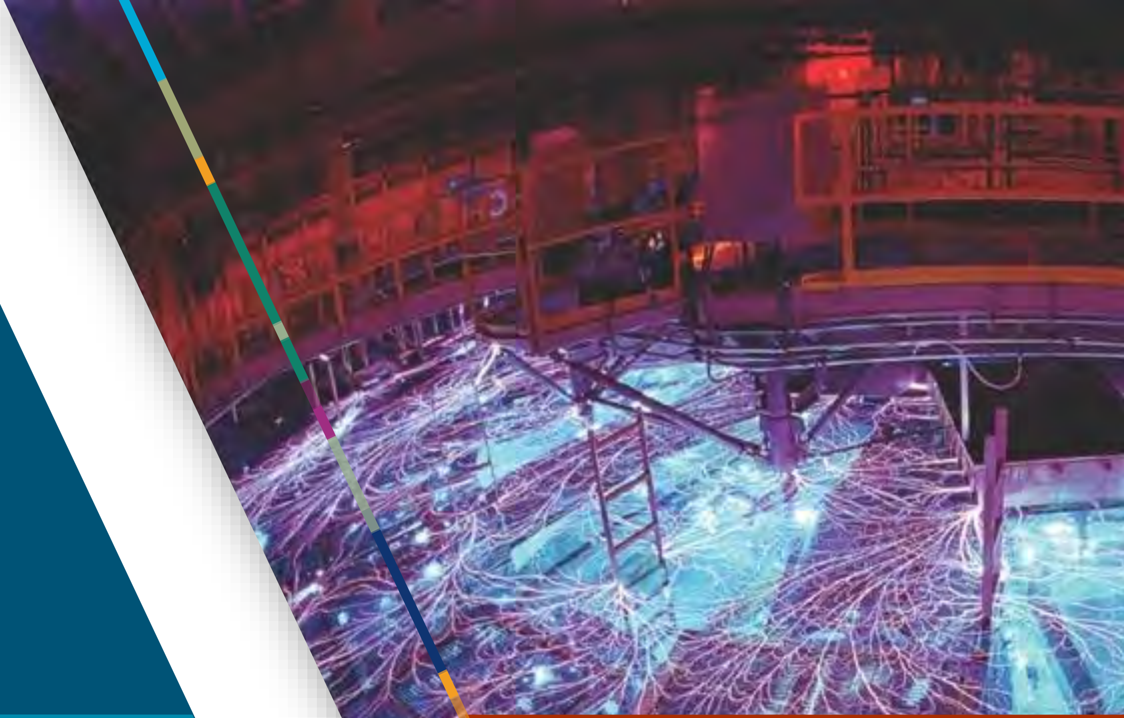


Sandia's Trusted Artificial Intelligence Strategic Initiative

John Feddema, Sr. Manager, Enhanced Decision Making Group

Center for Computing Research

ENERGY NNSA

ASC U.S. DEPARTMENT OF ENERGY Office of Science

NRC Data Science and AI Workshop

Tuesday, November 9, 2021

SAND2021-7619 PE

Sandia's ***<u>Trusted AI Strategic Initiative</u>*** is coordinating a series of fundamental R&D projects to lay the foundation necessary for Sandia's scientific and national security applications

Desire to deploy AI/ML technologies are increasing rapidly

- FY20 – 80 LDRD projects (roughly 20%) had a significant AI focus
- FY21 – 126 projects (28%) had a significant focus in AI or were significantly utilizing AI technologies
- FY21 – 9 DOE SC Advanced Scientific Computing Research projects
- FY21 – 7 NNSA Advance Simulation & Computing (ASC) Advanced Machine Learning (AML) projects

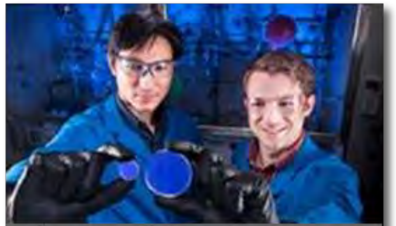
Sandia's unique mission needs set us apart from industry

- High-consequence applications require high-confidence decisions
- Solutions require extrapolation beyond the space of available data
- Many national security applications have low volume, incomplete data
- Deployed AI solutions are often in environments under extreme size, weight, and power constraints
- Decisions may need to be made in very short timeframes
- Need to account for potential adversarial issues

Sandia's history of excellence in core capabilities such as UQ, V&V, optimization, graphs, tensors, and discrete math will enable AI/ML


Space


Military Systems


Nonproliferation


Weaponeering


Infrastructure Resilience

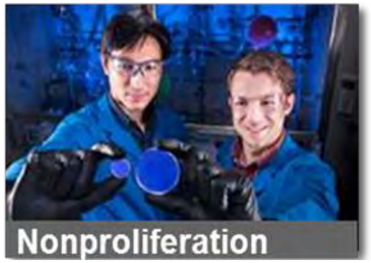

Homeland Security


Research

Sandia Mission Needs for Machine Learning and Artificial Intelligence

Program	Mission Problem	Characteristics
Global Security	Proliferation Detection and Characterization	• Multi-modal sensors, distributed sensors, and real-time behavior • How to extrapolate to cases where we do not have ground truth • Physical models may not exist • Real time monitoring with streaming data
Global Security	Automatic Target Recognition for Military Applications	• Limited data that is likely modified or disguised - extrapolation of models is necessary • Desire to reduce or remove human in the loop • Data available at multiple levels of sensitivity • Adversary withholds differentiating capabilities and tactics exclusively for war
Nuclear Deterrence	Counterfeit and Aging Detection	• Many sources of variation - limits to what can be learned from data are unknown • Lack of a mathematical foundation and physical models • Volume of data is very low
DOE Office of Science	Large Scale Physics Experiments	• Rich but sparse data - can be expensive to obtain • Multi-instrument, multi-experiment, multi-measurement experimental observations • Uncertainty present in experiments and physics models
National Security Programs	Analyst Support for Cyber and Intelligence Operations	• Need to introduce AI into a mature system without disrupting current operations • Very high consequence, very rapid transactions (many per minute) • Streaming data with very dynamic environment
Energy & Homeland Security	Bioscience and Biosecurity	• Multiple types of data requires data fusion • Data collection is often destructive and multiple measurements depend on replication • Theoretical models often don't exist
Advanced Science & Technology	HPC System Management and Operations	• Operations staff don't know much about performance/failure mechanisms • Thousands of instrumentation points but unknown if data provide useful insights • Experiments are typically one-offs due to how resources are allocated and used

Sandia's Trusted AI LDRD Research Campaign Thrusts



AI Usability and Trust

- Generalizability of AI Research to High-Consequence National Security Environments
- Trustworthiness Characteristics of Analytics
- Domain-Informed AI
- Adversarial Impact on User Trust
- Determining Whether to Automate Functionality and to What Level

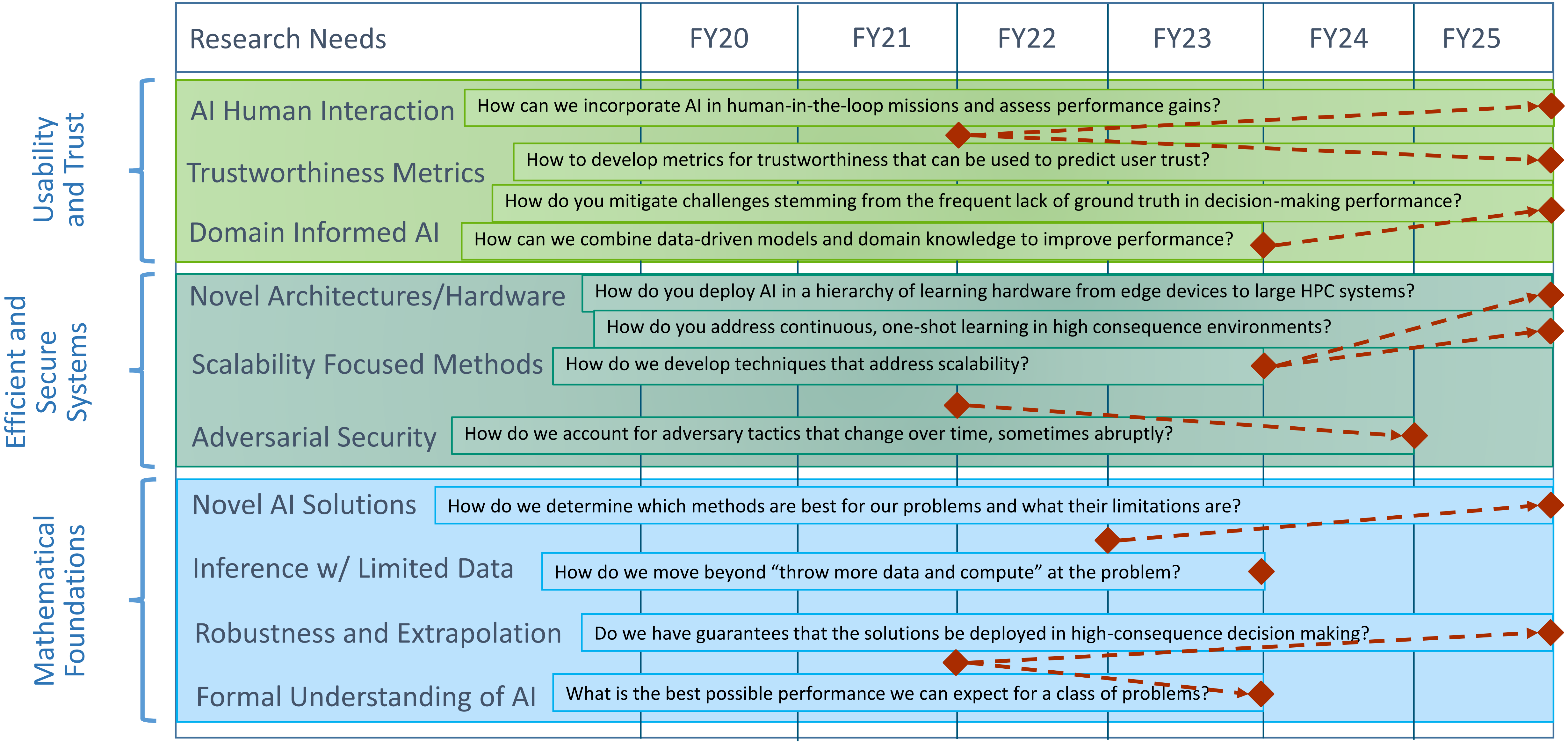
Efficient and Secure AI System

- Novel AI Architectures and Hardware
- Adversarial/Counter-Adversarial Security
- Scalability of AI Methods
- AI Software
- Domain/Architecture Aware AI Methods and Algorithms

Mathematical Foundations of AI

- Mathematical analysis and Directed Improvement of AI Methods
- Acceleration of Training and Hyperparameter Tuning
- Novel AI Solutions
- Robustness & Extrapolation
- Statistical Inference, Especially with Limited Data
- Randomized Methods with Rigorous Probabilistic Guarantees

Successes in Trusted AI will enable Sandia and its mission partners to think differently about current and future mission problems

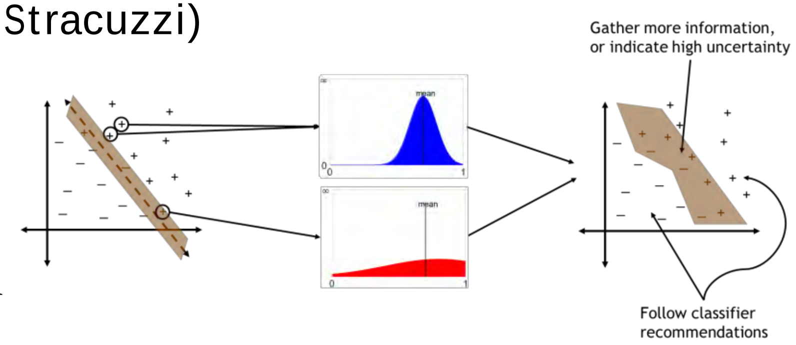


FY21 Trusted AI LDRD Highlights

Usability & Trust

Optimizing Machine Learning Decisions with Prediction Uncertainty (PI: David Stracuzzi)

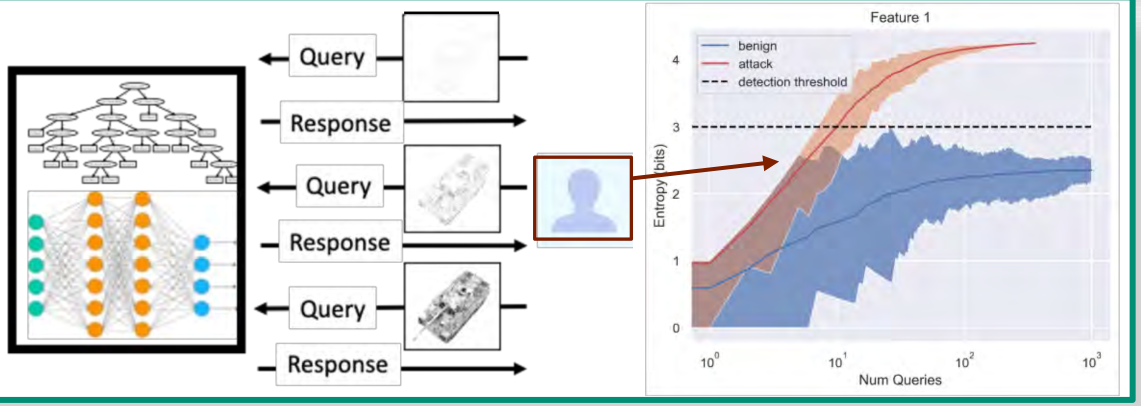
- **Challenge:** The ML prediction problem is often confounded with the decision problem
- **Goal:** Incorporate decision science into ML-based decision making
  - Develop rigorous methods for incorporating prediction uncertainty, error costs, and opportunities to gather additional information to minimize decision errors and costs.
- **Proposed Solution**: Draw on decision science, uncertainty quantification, and information theory to account for possible outcomes and their associated probabilities.



Efficient & Secure Systems

Monitoring Online Adversarial Tampering (PI: Gary Saavedra)

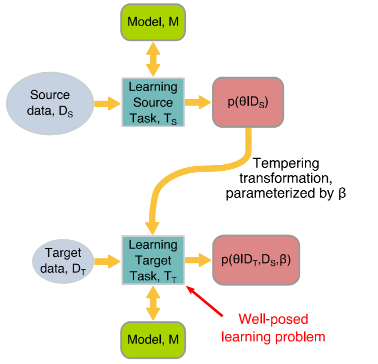
- **Challenge:** Defend against adversarial attacks
  - Little work on detection and less for streaming models
- **Proposed Solution**: Distinguishing factors of our work:
  - Detection rather than model alteration
  - Stream information provides more insight than lone examples
  - Unifies several different attacks into one mathematical framework



Mathematical Foundations

Trust-Enhancing Probabilistic Transfer Learning for Sparse and Noisy Data (PI: Mohammad Khalil)

- **Challenge**: Many Sandia mission domains are defined by a lack of reliable data, effectively precluding the use of many modern deep learning/machine learning techniques for predictive modeling
- **Goal**: Enhance the trust in machine learning (ML) model predictions within sparse & noisy data settings
- **Proposed Solution**: Novel probabilistic transfer learning (TL) framework:
  - Determine when to apply TL, which model to use, and how much (uncertain) knowledge to transfer using new techniques inspired by Bayesian hierarchical modeling, sequential data assimilation, and uncertainty quantification



Thank you for your attention!

For more information, please contact:

John Feddema, 505-844-0827, jtfedde@sandia.gov

Sandia
National
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Sandia National Laboratories

Sandia Information Sciences Initiative

PRESENTED BY

Steve Kleban

Manager, Complex Systems for National Security

U.S. DEPARTMENT OF ENERGY NNSA

COMPUTING CONVERGENCE

The Nation is asking for a computing convergence to enable the ability to address increasingly complex questions at the "speed of mission."

National-Level Strategies Emphasize Paradigm Shift in Information Sciences

Pioneering The Future Advanced Computing Ecosystem: A Strategic Plan

National Strategic Computing Initiative Update: Pioneering The Future Of Computing

Earth System Predictability Research And Development Strategic Framework And Roadmap

DOE Strategies and Budget Justifications Reiterate this Shift

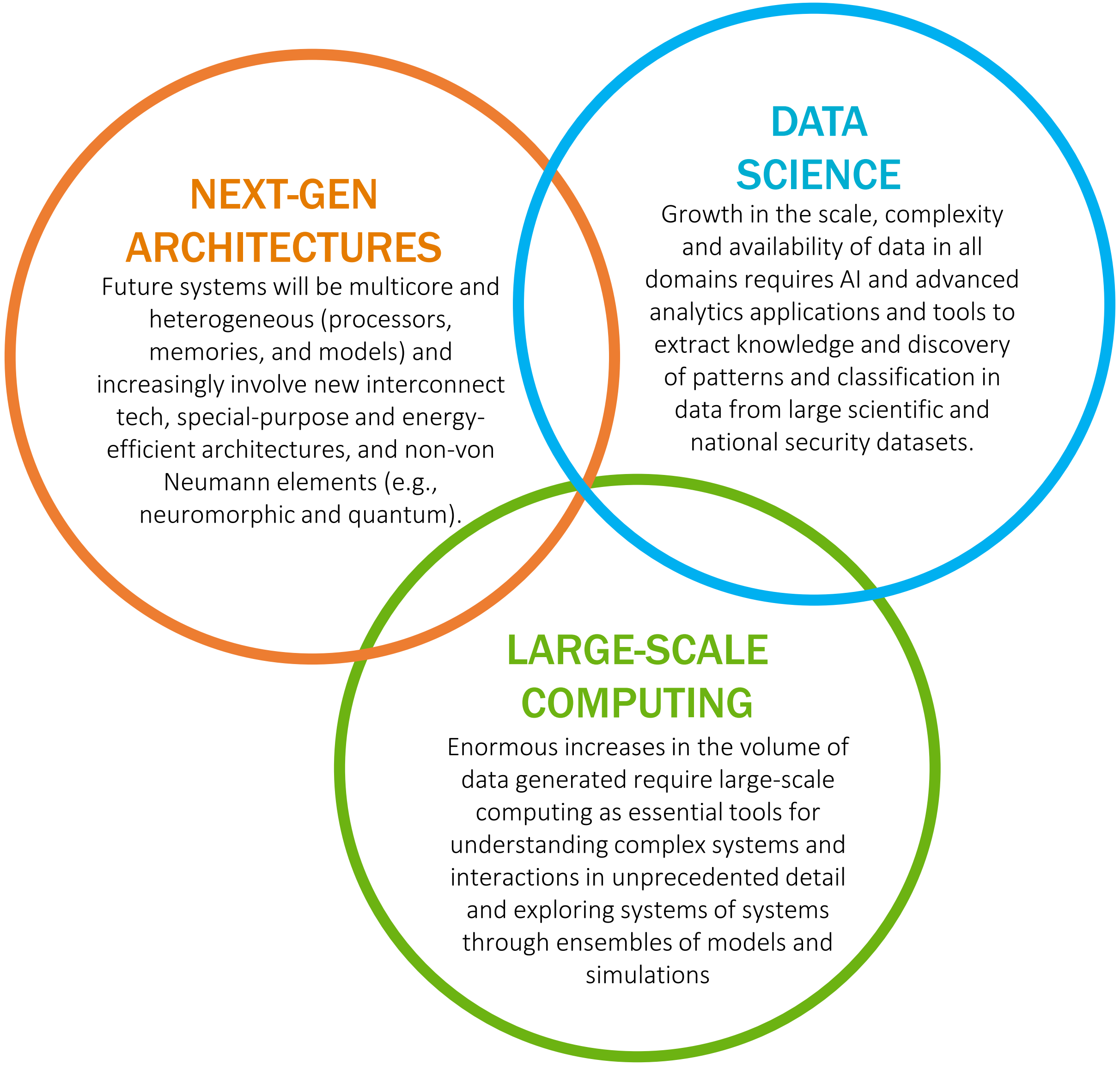
SEAB Report on AI and Machine Learning
"With the given existing and planned investment…
Opportunities range from AI-designed workflow…
to AI-enabled scientific 'comprehension'…"

Office of Science… **NNSA…**

All Agencies Have a Need to Capitalize on Future Advanced Computing and AI

DOE, NASA, NIH, NNSA, DoD, IC, DHS

Strategic computing could address
Unprecedented scale, reducing cost & schedule, increased complexity, real-time data and decision making



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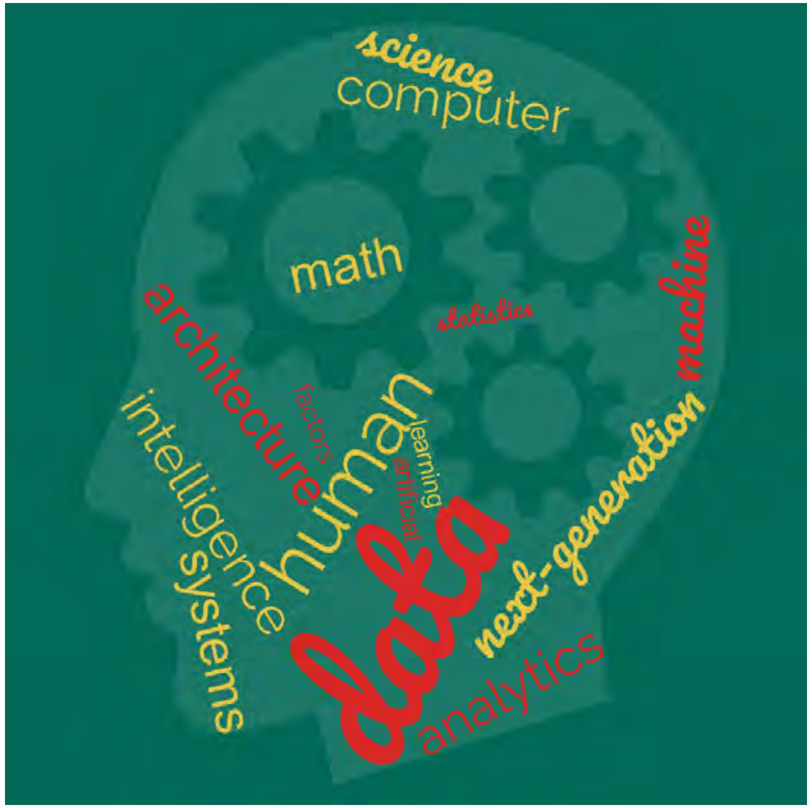
Unprecedented scale, reducing cost & schedule, increased complexity, real-time data and decision making

Applied Information Sciences Center, 5500

SANDIA DEFINITION OF INFORMATION SCIENCE

The integration of:

- data science/analytics
- artificial intelligence
- machine learning
- associated math and statistics
- human systems/human factors
- next-generation computer architecture



INFORMATION SCIENCES INITIATIVE

Initial Objectives

- Bridging fundamental IS research to high consequence applications
- Creating new IS programmatic opportunities to develop and apply IS techniques, tools, workforce, and infrastructure
- Enhancing Sandia's IS capabilities to:
  - benefit of NNSA and other clients
  - increasing Sandia's IS leadership
  - attracting and retaining critical skills in the workforce

APPLIED INFORMATION SCIENCES (AIS) CENTER

- Develop a new Laboratory Directed Research and Development (LDRD) area
  - National Security Information Science & Technology (NSIST)
- Facilitate bridging between fundamental R&D and application
- Focus on institutional technical road mapping, planning, and investments
- Identify critical skills and needed *infostructure*
- Assist existing mission areas in the development of new program opportunities

ALPHAGRID PROJECT OVERVIEW AND OBJECTIVE

When a power grid becomes unstable there are currently no methods to walk it back to a stable state. Can Machine Learning assist grid operators to restore the system to a safe condition in real-time?

- There are six Stability Margins which create a six dimensional space that is too computationally expensive to navigate in real-time using traditional methods
- Reinforcement Learning has shown itself to perform well on similar problems and through LDRD funds, Sandia demonstrated Reinforcement Learning is a strong candidate for this problem, which led to the DOE/OE funding
- Three year project funded by DOE Office of Electricity, Advanced Grid Modeling Program

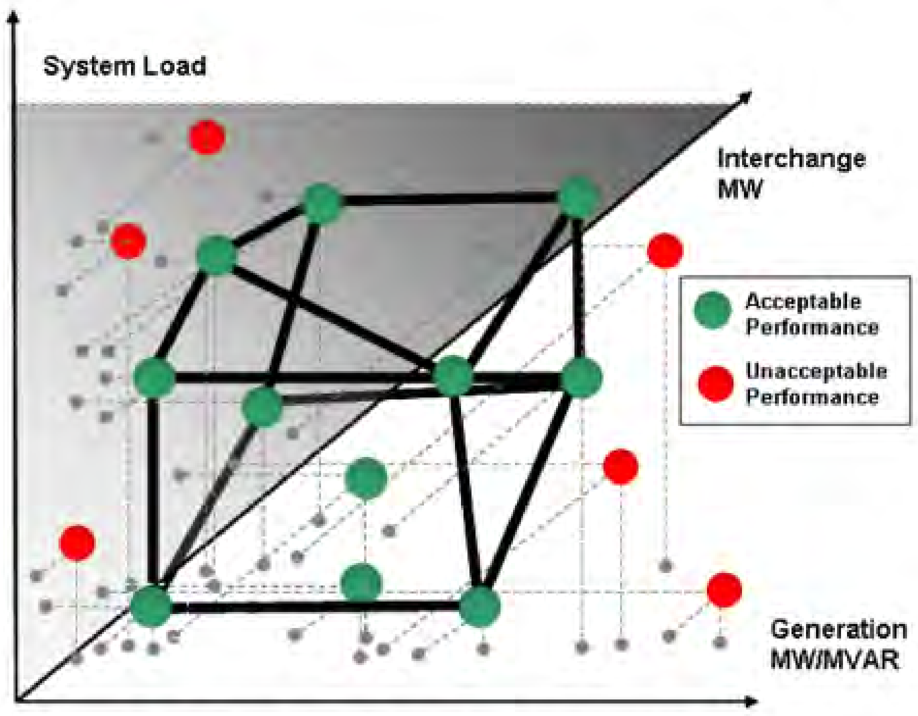


Figure 9 - "Scatter" plot of planning scenarios.

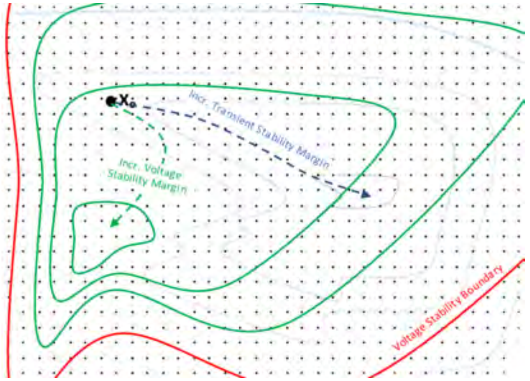
Image from North American Electric Reliability Corporation (NERC), Reliability Concepts document, pg 40.

ALPHAGRID: RESULTS TO DATE

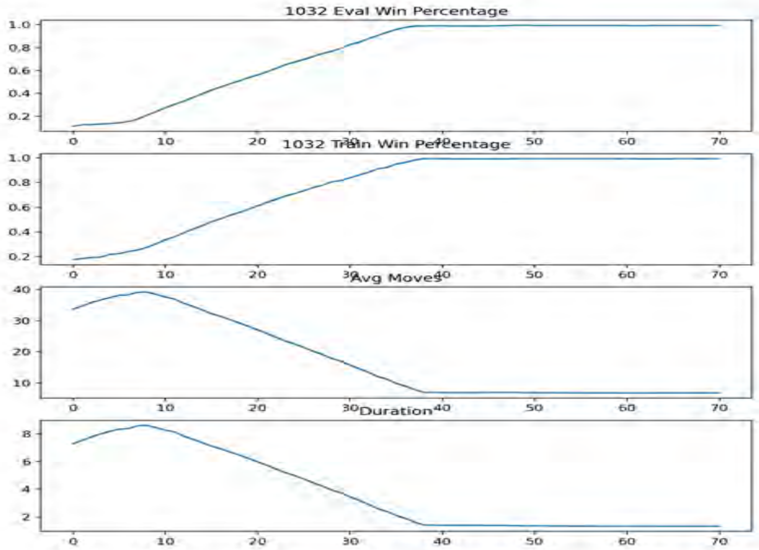
- First year
  - Developed mini-WECC grid model with 20 control dimension to navigate stability space
  - Understand how to navigate stability space using static data from the mini-WECC model
  - Sponsor funding result of LDRD investment

- Second year
  - Implemented Reinforcement Learning (RL) approach to navigate stability space on a <u>simple</u> grid, random player safely navigates ~8%, RL ~100%

- Third year (current year)
  - Advanced RL to navigate stability space on a <u>complex</u> grid, random player safely navigates ~.01%, RL converging towards 100%
  - Apply RL to navigate space, not memorize, dynamic grid
  - Publish results
  - Follow-on funding anticipated



Transient Stability and Voltage Stability Level Curves
(Plot Sandia generated)



Reinforcement Learning plots
(All plot Sandia generated)

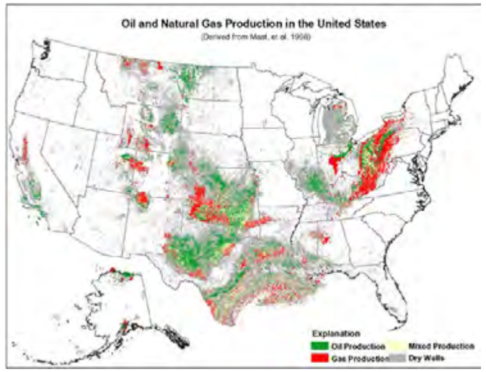
Machine Learning for Early Wellbore Failure Detection

- Problem: 93% of US total energy supply is dependent on wellbores in some form. Current approaches to evaluating wellbore risk focus on manual grading and site specific physics-based models. Need an automated approach.

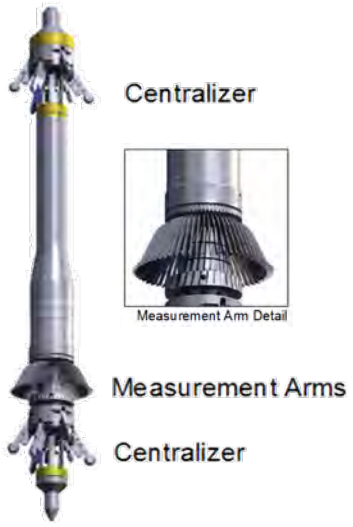
- Sponsor: Geosciences LDRD

- Approach: Use Deep Neural Networks and Random Forests

- Outcome: Good results in automating wellbore failure detection, pursuing follow-on sponsors



https://www.usgs.gov/media/images/map-united-states-oil-and-gas-wells-2017



Weatherford Multi Sensor Caliper Tool Pamphlet 3725.01

NLP for Document Classification

- Problem: Large quantities of documents need to be categorized with rational, effectively and efficiently, with limited human resources.

- Sponsor: DOE Office of Classification (in collaboration with LLNL, ORNL, PNNL, Y-12)

- Approach: Ontologies, Machine Learning, Bayesian Networks

- Outcome: Developing a suite of NLP tools that aid derivative classifiers.

https://www.dreamstime.com/photos-images/messy-file-storage.html

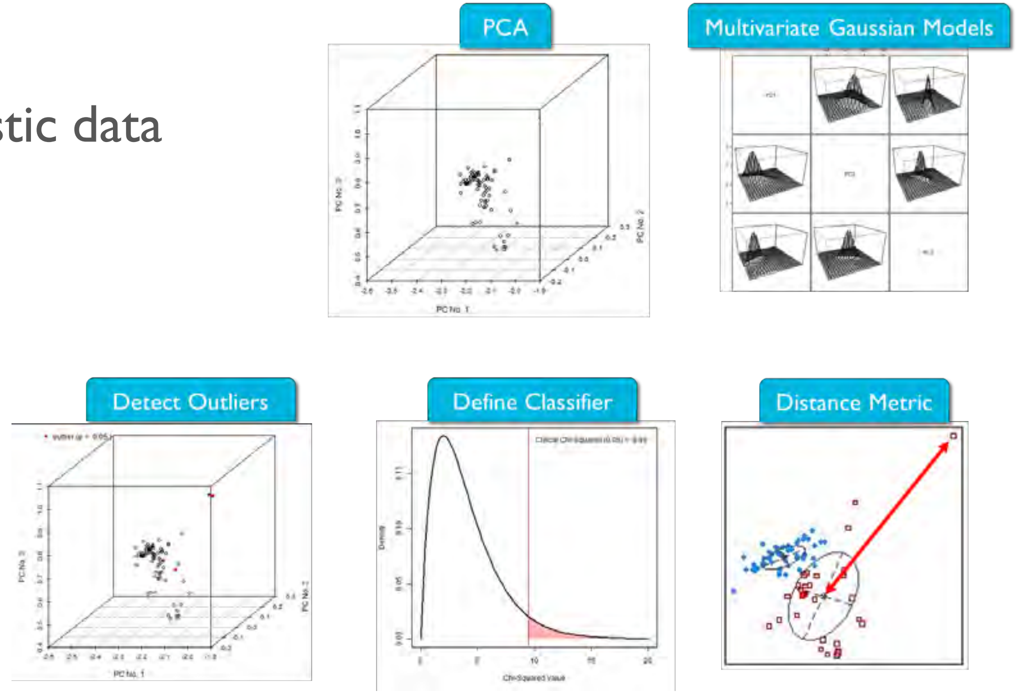
Machine Learning for Outlier Detection

Problem: Develop a method of detecting outliers in the acoustic data from electromechanical devices that produce a sound

Sponsor: NNSA/ND Program

Approach: Statistical machine learning

Outcome: Deployed tool to Component Engineers for testing



(All plot Sandia generated)

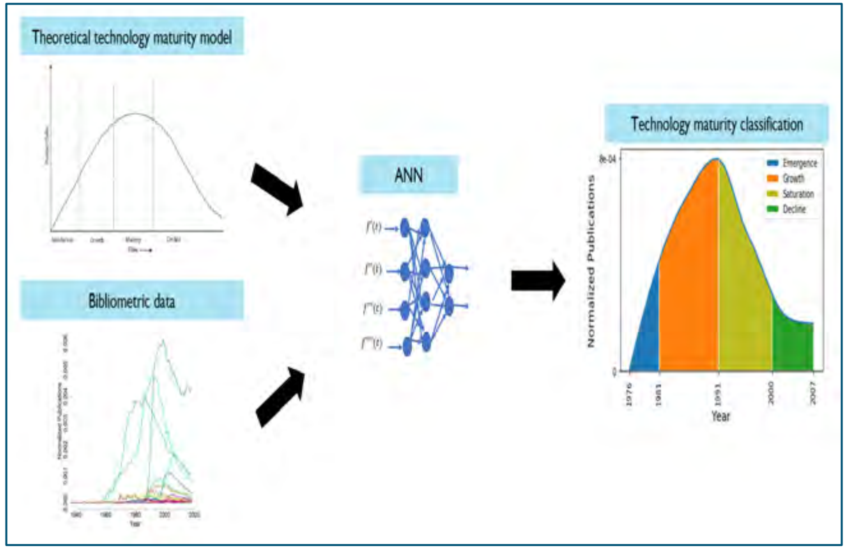
Machine Learning for Detecting Technological Maturity

- Problem: Identifying emergent technologies based on open source indicators (publications, new releases, patents, etc.)

- Sponsor: Airforce Research Lab

- Approach: Artificial Neural Networks, Data Augmentation

- Outcome: Performs with 90.4% accuracy, can be scaled, can be automated

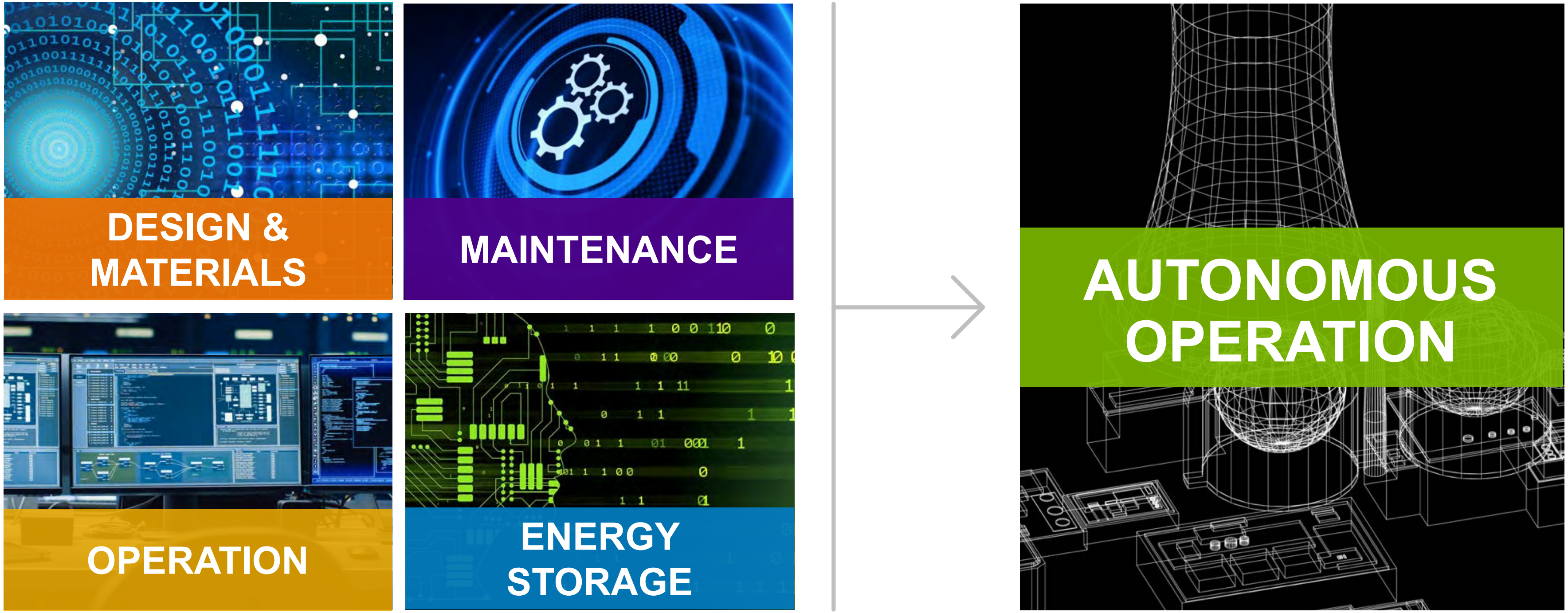


ANL R&D ACTIVITIES

A. DAVE, A. HEIFETZ, R. HUI, M. LI, T. NGUYEN, R. PONCIROLI, S. MOHANTY, R. VILIM, H. WANG, L. YACOUT
Nuclear Science and Engineering Division

Virtual presentation to NRC on AI/ML
November 9, 2021

ANL AI/ML CAPABILITIES ENABLING FUTURE AUTONOMOUS OPERATION



DESIGN & MATERIALS

2.2
3.3
4.4
5.5

AI FOR DESIGN SPACE CHARACTERIZATION

Design and Materials

1. NEED

Facilitate the development and deployment of advanced reactors by improving economics (through accurate safety margin predictions) and reducing the licensing burden (through improved uncertainty quantification).

2. CAPABILITY DEVELOPED

Method to develop ML-based closure models to capture complex spatial-temporal reactor transients, with uncertainty quantifications.

Integration of ML-based closure model into reactor system transient simulation tool SAM.

3. ACCOMPLISHMENTS

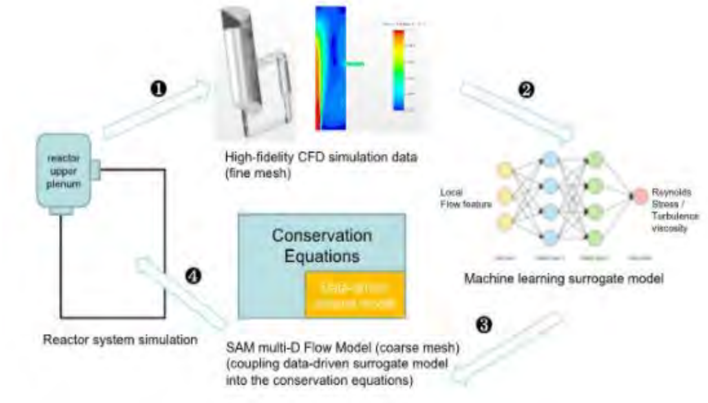
Development and application of data-driven turbulence closure model for thermal mixing and stratification modeling.

Developed a system approach on the optimization and uncertainty quantification of the data-driven ML models

4. FUTURE DEVELOPMENT

Incorporate more domain knowledge into machine learning-based closure for advanced reactor safety modeling;

Develop deep learning-based multi-physics online simulator to support autonomous operations in advanced reactors



Reduction of high dimensional data using ML to yield fast running low-order surrogate models

ML FOR MATERIALS DEVELOPMENT

Design and Materials

1. NEED

AI-enhanced radiation damage assessment to shorten material development and qualification cycle.

2. CAPABILITY DEVELOPED

Deep learning-based radiation defect analysis tools were developed for automated detection, tracking and analysis of voids and dislocation loops produced during in situ ion irradiation at Argonne's IVEM-Tandem Facility.

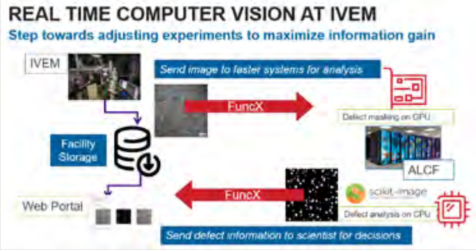
3. ACCOMPLISHMENTS

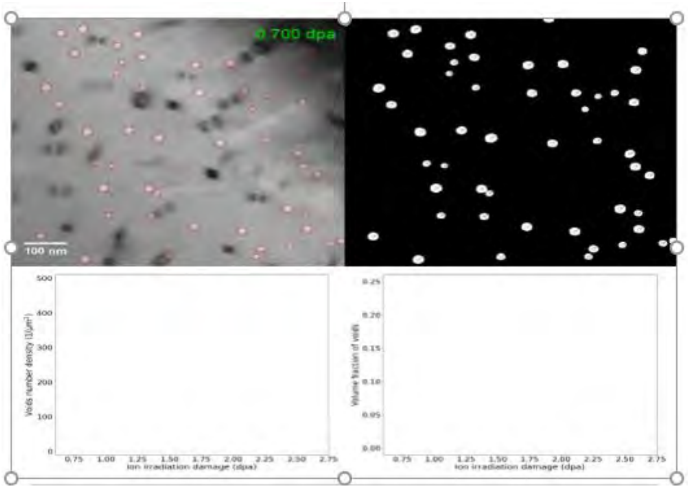
Developed multi-object tracking model to measure the lifetime of individual dislocation loops.

Developed an automated void detection and analysis tool using computer vision and deep learning.

Developed machine-learned dynamical equations.

4. FUTURE DEVELOPMENT





Processed a video recorded during in situ ion irradiation to measure the size and number of voids as a function of irradiation dose produced in pure Nickel irradiated with 1 MeV Kr ions at 600℃.

ML FOR MATERIALS INSPECTION

Design and Materials

1. NEED

Imaging of internal microscopic material defects in additively manufactured metallic structures (SS316 and IN718) for nuclear applications

2. CAPABILITY DEVELOPED

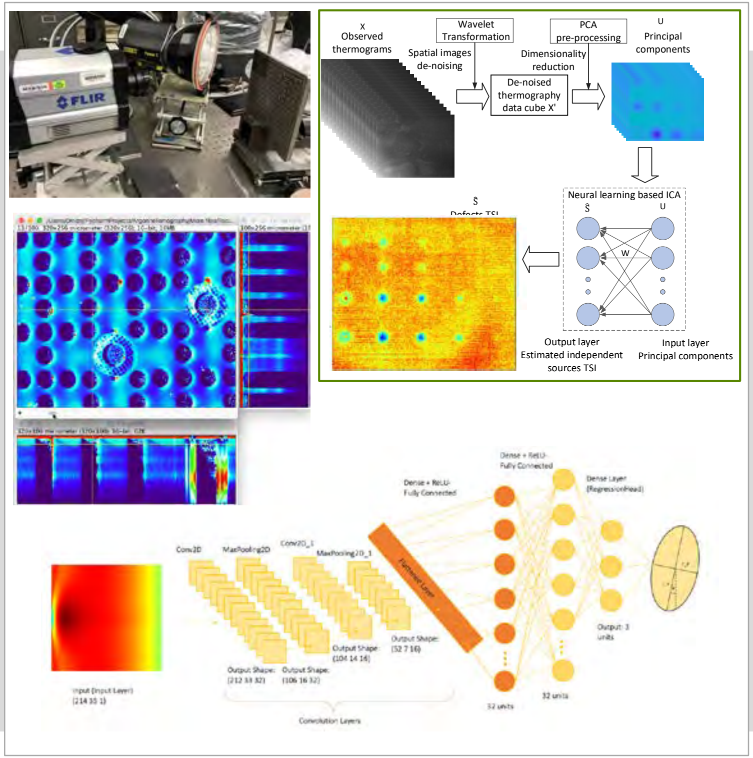
- Imaging hardware (FLIR X8501, flash lamp, optics)
- Machine learning image processing algorithms
- Thermal tomography depth reconstruction and defect classification algorithms

3. ACCOMPLISHMENTS

- Detection of calibrated subsurface microscopic defects in SS316 (down to 100µm size) with unsupervised learning of thermography images
- Classification of defects aspect ratio and orientation in thermal tomography images with convolutional neural network

4. FUTURE DEVELOPMENT

- Further reducing threshold of detected defect size (target 50µm)
- Rapid data processing for in-situ monitoring applications



OPERATION

HEALTH MONITORING: PHYSICS-BASED

Operation

1. NEED

Advanced heath monitoring of equipment for O&M

Inclusion of domain knowledge to deliver diagnoses with greater specificity and reliability

2. CAPABILITY DEVELOPED

Diagnoses both equipment and sensor faults within an engineered system

Requires no *a priori* values for equipment design parameters

Incorporates automated reasoning to facilitate ease of use by non-SMEs

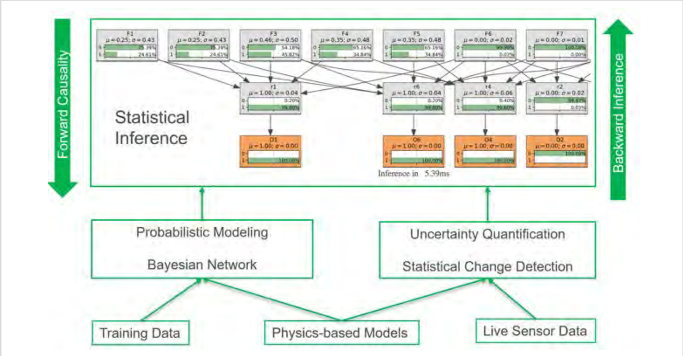
Derives real-time equipment performance from physics-based models

3. ACCOMPLISHMENTS

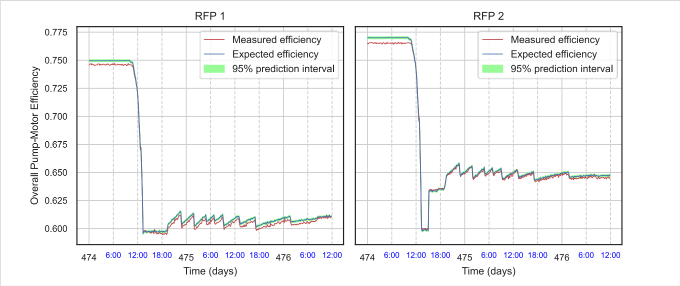
Blind detection and diagnosis of Monticello NPP reactor feed pump fault, North Anna NPP feedwater heater fault

4. FUTURE DEVELOPMENT

Subsume data-driven methods into the existing Bayesian setting for an integrated diagnostic tool utilities have deemed valuable



PRO-AID Code Architecture



PRO-AID Feed Pump Diagnosis: Efficiency Loss Attributed to Bearing Degradation

HEALTH PREDICTION: MECHANISTIC

Operation

1. NEED

High temperature operation can lead to material damage

Need real-time prediction of component health to reduce inspection cost

2. CAPABILITY DEVELOPED

System level structural mechanics model of the physical twin

Real time AI/ML nonlinear material damage prediction from sensors and structural state prediction

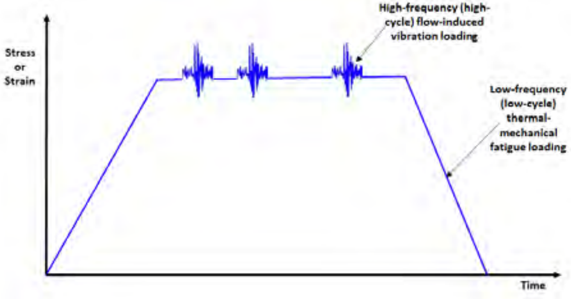
3. ACCOMPLISHMENTS

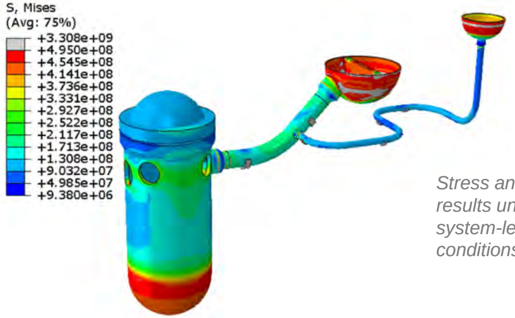
Prediction of component interior system-level stress analysis from AI/ML-digital-twin model during load following based on a few measurements

4. FUTURE DEVELOPMENT

Real-time benchmarking and concept validation using ANL METL or similar facility

Stress experienced over a fuel cycle





Stress analysis results under system-level conditions

PERFORMANCE OPTIMIZATION: OPEN-LOOP

Operation

1. NEED

A capability to learn complex relationships between sensed process variables and performance metrics, such as integrated thermal power and spatial peaking factors

2. CAPABILITY DEVELOPED

Machine learning models that can identify through physics and engineering principles the key process variables inputs

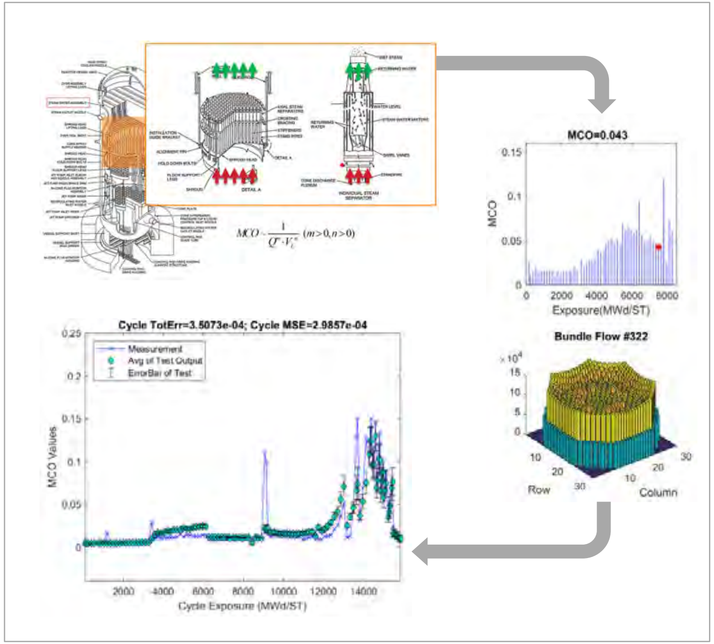
Supervised machine learning algorithms for predicting performance measures from sensor and digital twin virtual sensor inputs

3. ACCOMPLISHMENTS

IN-USE – A physics-informed neural network model developed for optimizing BWR reactor fuel loading and operation mid-cycle

4. FUTURE DEVELOPMENT

Identification and development of ML predictive models for estimation of important performance metrics for advanced reactors



Predictive model developed for a BWR from archived operating history – In use at a US utility

PERFORMANCE OPTIMIZATION: CLOSED-LOOP

Operation

1. NEED

Optimal control policies that avoid the *curse of dimensionality*

Ability to handle nonlinear phenomena (e.g., material degradation, dynamics during load-following)

2. CAPABILITY DEVELOPED

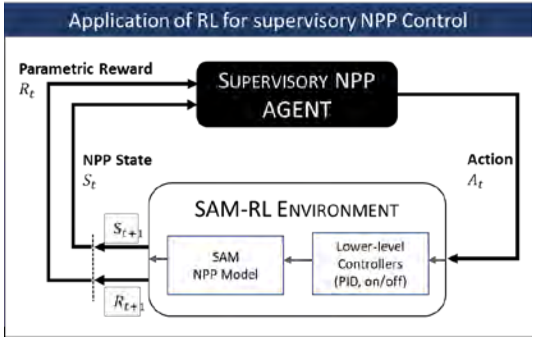
A reinforcement learning (RL) approach that is a data-driven having the potential to learn control policies whose performance surpasses that of humans.

RL agents that learn from a physics-constrained environment via the SAM code – a best-estimate system level code for advanced reactors

A design development framework that generates RL environments that is reactor design agnostic (MSRs, SFRs, HTGRs).

3. PROPOSED FUTURE DEVELOPMENTS

Numerical demonstration of RL-agent providing supervisory control for a Fluoride-cooled High-temperature Pebble-bed Reactor in FY22



Framework to train supervisory NPP agents using next-generation AR best-estimate system code SAM

MAINTENANCE

DECISION MAKING

Maintenance

1. NEED

Explainable diagnoses for decision making

Confirmatory diagnostic traceback via the conservation equations to an accountable set of sensors

2. CAPABILITY DEVELOPED

Physics-based fault symptoms from model residuals

Automated backward chaining reasoning

Fault diagnoses can be explained in the forward causality direction

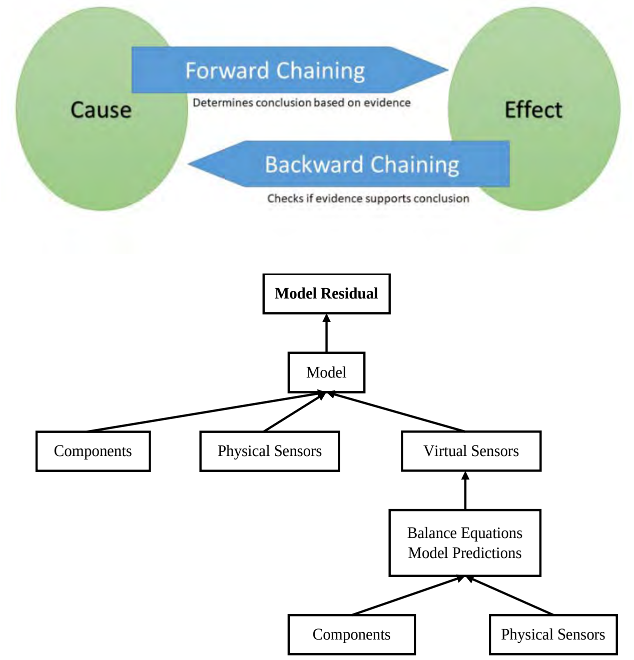
3. ACCOMPLISHMENTS

Conducted assessment tests with NPP operators on full scope simulator

Received confirmation of the utility and value of the approach

4. FUTURE DEVELOPMENT

Improve reasoning engine efficiency



Physics-Based Model Residual Generation: A Basis for Explainable Diagnoses

SCHEDULING

Maintenance

1. NEED

Cost optimization of O&M for increased economic competitiveness

2. CAPABILITY DEVELOPED

Sensor network design algorithm to provide for monitoring/diagnosing faults and component degradation over plant lifetime

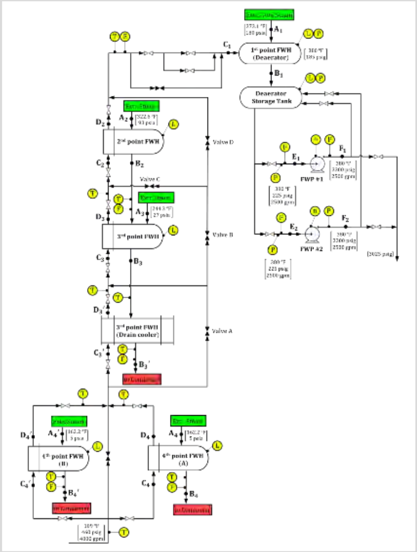
Maintenance and asset management approach that integrates online monitoring with plant risk profile

3. ACCOMPLISHMENTS

In-progress demonstration for the feedwater and condensate system of the MHTGR design

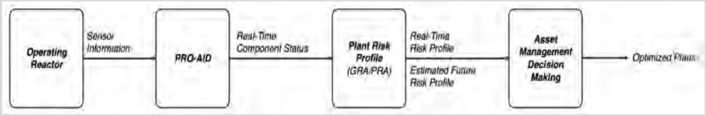
4. FUTURE DEVELOPMENT

Application of Markov Decision Process method for asset-management decision-making



P&ID of the feedwater system used as test-case

Overview of Operational Decision-Making Process



ENERGY STORAGE AND THE GRID

ENFORCING STORAGE CAPACITY CONSTRAINTS

Energy Storage and the Grid

1. NEED

Control strategies for improved regulation wrt to structure operating limits for margin recovery

2. CAPABILITY DEVELOPED

Algorithm for translating process variables constraints into power set-points limits

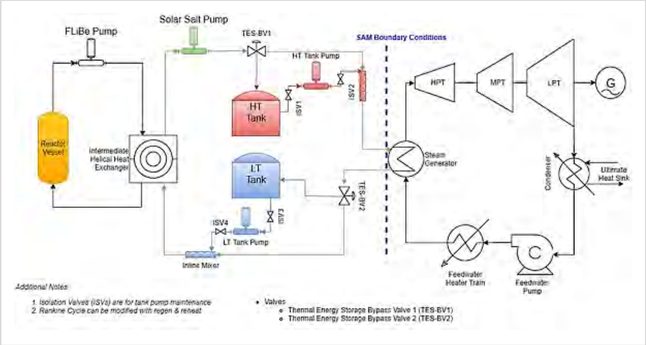
Satisfies n-dimensional envelope as set by constraints on important process variables

3. ACCOMPLISHMENTS

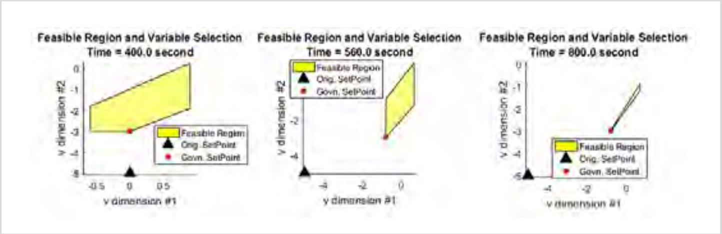
Preliminary implementation completed for representative integrated energy system

4. FUTURE DEVELOPMENT

Integrate with diagnostics and decision-making algorithms for semi-autonomous operation



Reactor with Thermal Storage



Time Evolution of Acceptable Region of Operation during a Transient

REDUCED ORDER ON-LINE LEARNING

Energy Storage and the Grid

1. NEED

Accurate mathematical representation of power systems at various power level and operational mode for efficient control

2. CAPABILITY DEVELOPED

Algorithm to update the state-space representation of power systems at various power level and mode using on-line simulation data

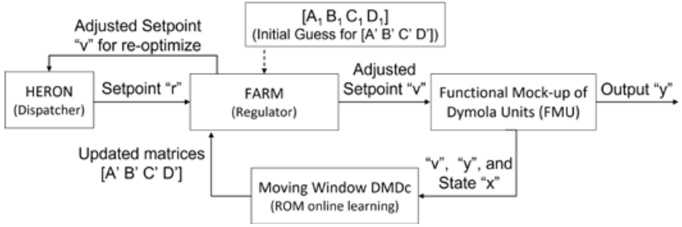
On-line updated mathematical models helped avoiding constraint violations, actuation oscillation and over-shooting

3. ACCOMPLISHMENTS

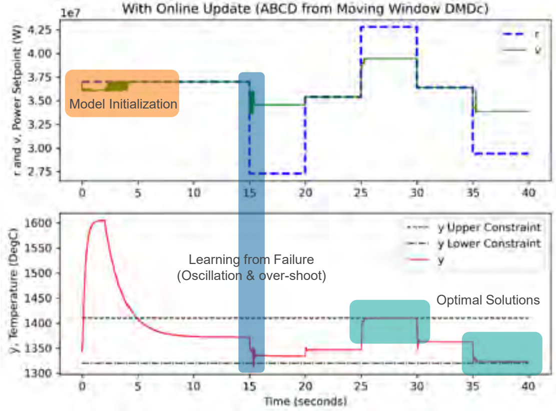
Preliminary implementation completed for representative power systems

4. FUTURE DEVELOPMENT

Improve the robustness of on-line learning algorithm to learn from noisy data



Block Diagram Schematic of Algorithms



On-line ROM learning and solution improvement example

AUTONOMOUS OPERATION

AUTONOMOUS OPERATION AS AN INTEGRATED PROCESS

Autonomous Operation

1. NEED

O&M cost reduction in deregulated markets through more efficient human resource allocation

2. CAPABILITY DEVELOPED

Diagnostics – Discrimination of sensor and component faults via PRO-AID algorithm

Control – Automation of constraint enforcement via Reference Governor algorithm

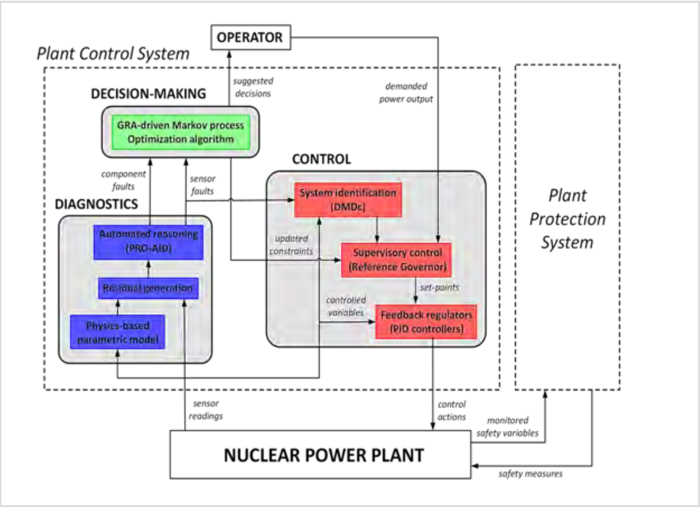
Decision-Making – Optimal operating and maintenance procedures via Markov process

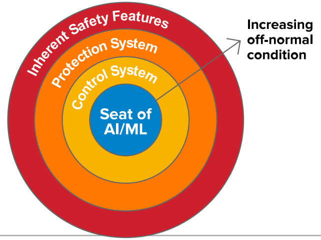
3. ACCOMPLISHMENTS

Developed a control-oriented simulator of KP-FHR coupled with thermal energy storage

4. FUTURE DEVELOPMENT

Integration of diagnostics, control, and decision-making for seamless autonomous operation





Advanced Reactor - Layers of Protection

Argonne
NATIONAL LABORATORY

Sandia National Laboratories

Exceptional service in the national interest

New Approaches Utilizing Process Monitoring Data and Machine Learning

Nathan Shoman & Ben Cipiti

Data Science and Artificial Intelligence Regulatory Applications: Workshop #3: Future Focused Initiatives

November, 2021

SAND2021-5699 PE

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Motivation

- Process monitoring data (such as bulk mass, flow, temperature, current, voltage, etc.) and additional measures (such as surveillance) are part of the overall safeguards systems—but how can we make more efficient use of this data?
- One motivation for the application of data analytics like machine learning is to reduce the cost and burden associated with safeguards:
  - Reduction of sampling and DA could significantly reduce the burden of IAEA safeguards. More use of unattended monitoring systems instead of DA (on-site laboratory) would free up IAEA resources.
  - Reduction of sampling and DA can also be useful for domestic safeguards to reduce cost for the operator.
- A second motivation is to improve plant monitoring for facilities or areas that have difficulties achieving materials accountancy goals:
  - In pyroprocessing for example where there are materials accountancy challenges, can we make more use of plant monitoring data to verify operations?

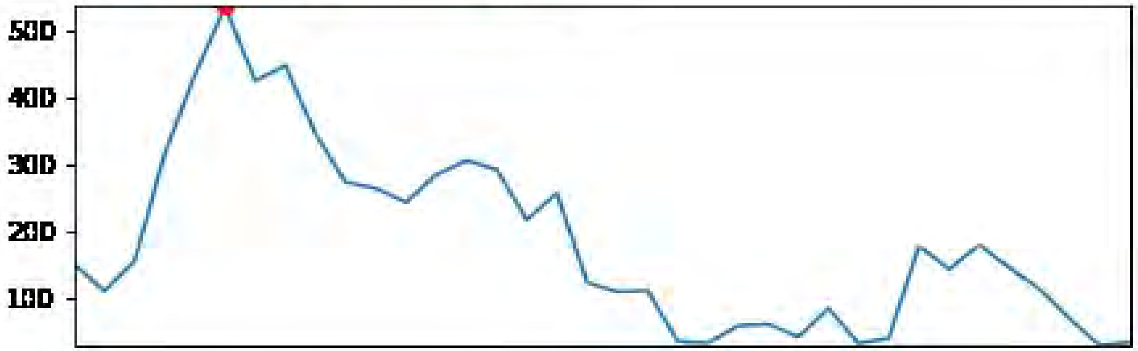
Machine Learning: The Answer to All Our Problems

- Machine learning is broadly defined as approaches that can learn and adapt without explicit instructions.
- Potential Benefits:
  - ML can automate tedious tasks and reduce chance for human error.
  - ML can aggregate large amounts of data and disparate data sources to learn “normal” operation, potentially making it easier to detect abnormal operation.
  - Can automate monitoring to help reduce costs.
- Potential Downsides:
  - ML algorithms will only be as good as the data used to train it.
  - Developing useful algorithms potentially require a large amount of training data which may not be available.
  - A “black box” algorithm may not be suitable for safeguards where transparency is important (how much can we trust the results?)

Example 1: Video Surveillance (NNSA Funded)

- Generates massive quantities of data with few segments of interest.
- Tedious for human review, however, image recognition is a well understood problem.

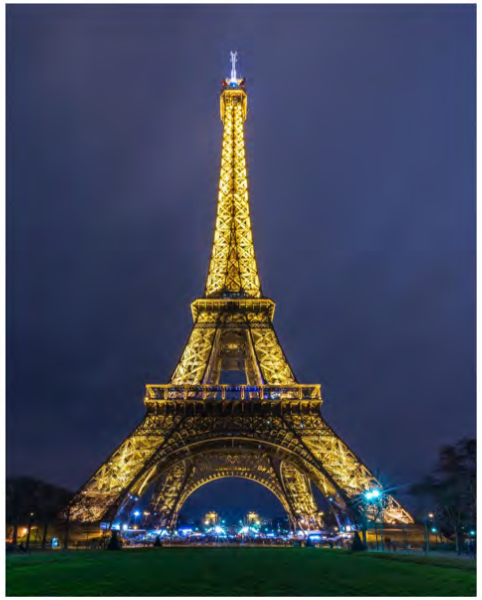
UCSD anomaly dataset:
http://www.svcl.ucsd.edu/projects/anomaly/dataset.html



Anomalous behavior identification in video sequences.

Spatio-Temporal Anomaly Detection in Video. Smith, Rutkowski, and Hamel.

Deep Learning to Predict Operational Status (NNSA)



Not a power plant

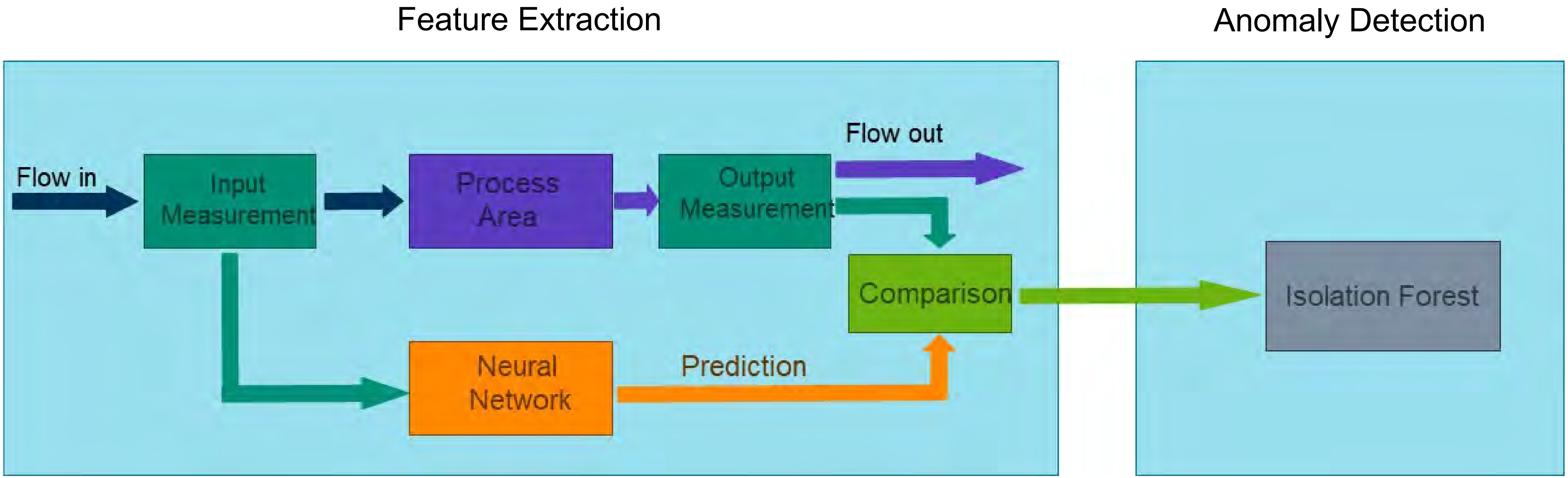
Plant not operating

Plant operating

	Signature Precision	Operationalized Precision	Signature Recall	Operationalized Precision
Plant not operating	0.89	0.66	0.91	0.87
Plant operating	0.96	0.95	0.95	0.84

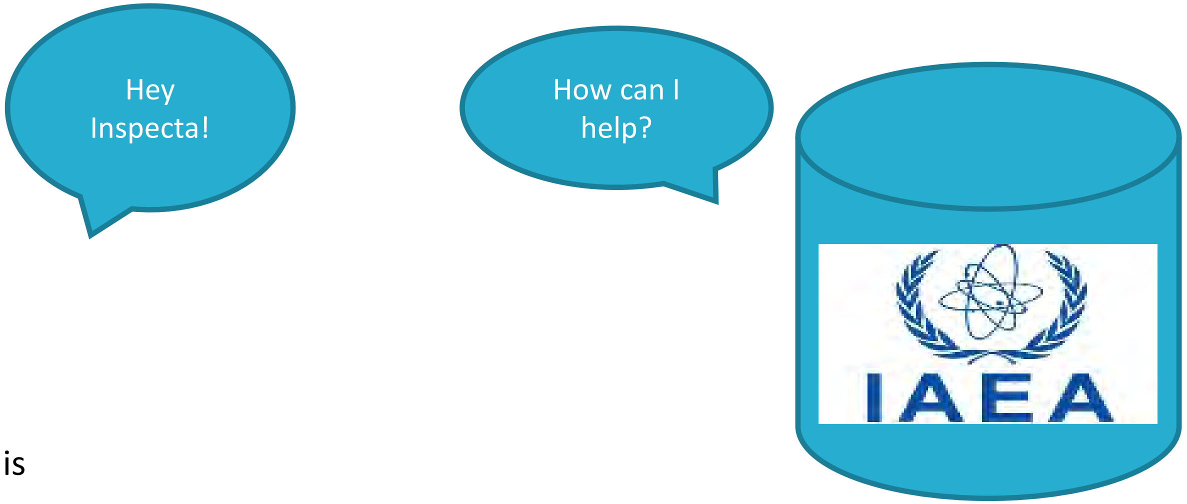
Example 2: Anomaly Detection in Heterogeneous Safeguards Data Streams (NNSA funded)

- Neural approaches should be able to learn normal rhythm of facility operations.
- Deviations from normal might indicate anomalous behavior.



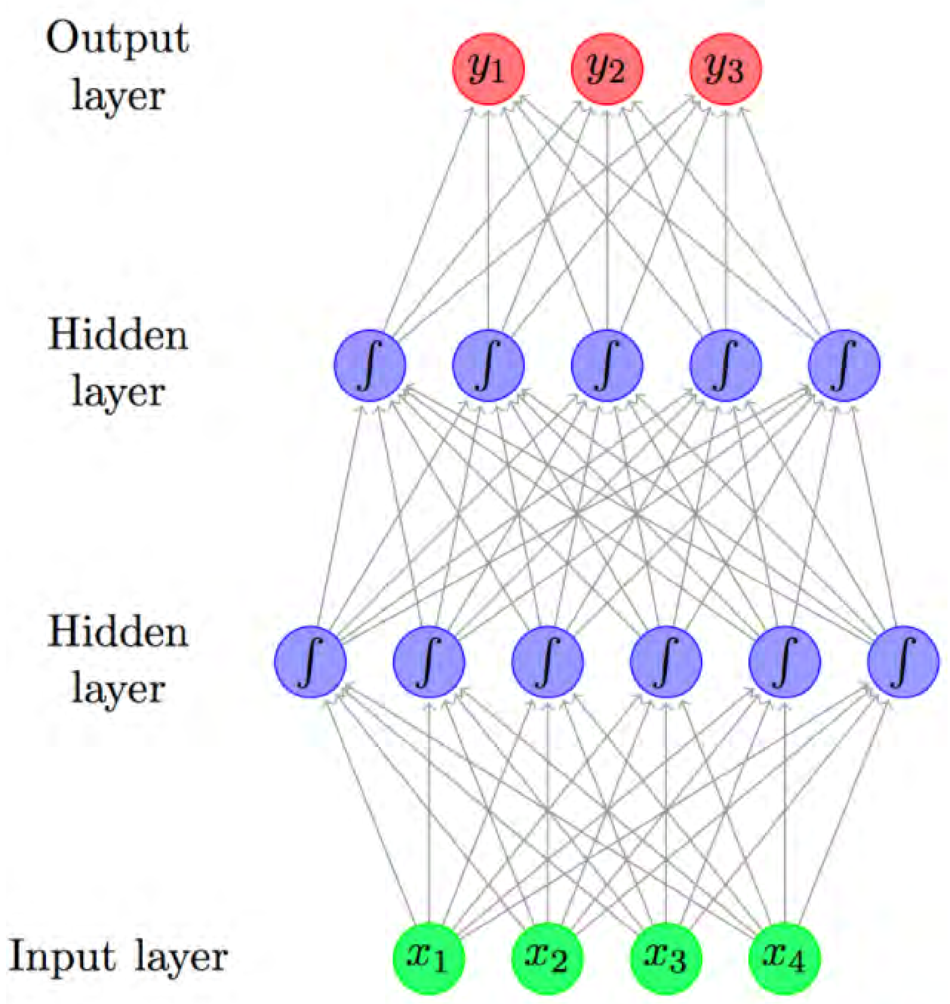
Example 3: Hey Inspecta! (NNSA Funded)

- Smart assistant to improve effectiveness of international nuclear safeguards inspectors.
  - Information recall
  - Measurement system integration
  - Hands-free support
- Incorporates many ML domains from text analytics to image recognition.



Example 4: Neural Networks for Insider Threat Detection

- Can commercial software improve insider threat detection?
  - Changes in facility pattern-of-life
- Many off-the-shelf computing packages exist, and these can be useful in some applications.
- However, some applications in safeguards may require customized solutions.

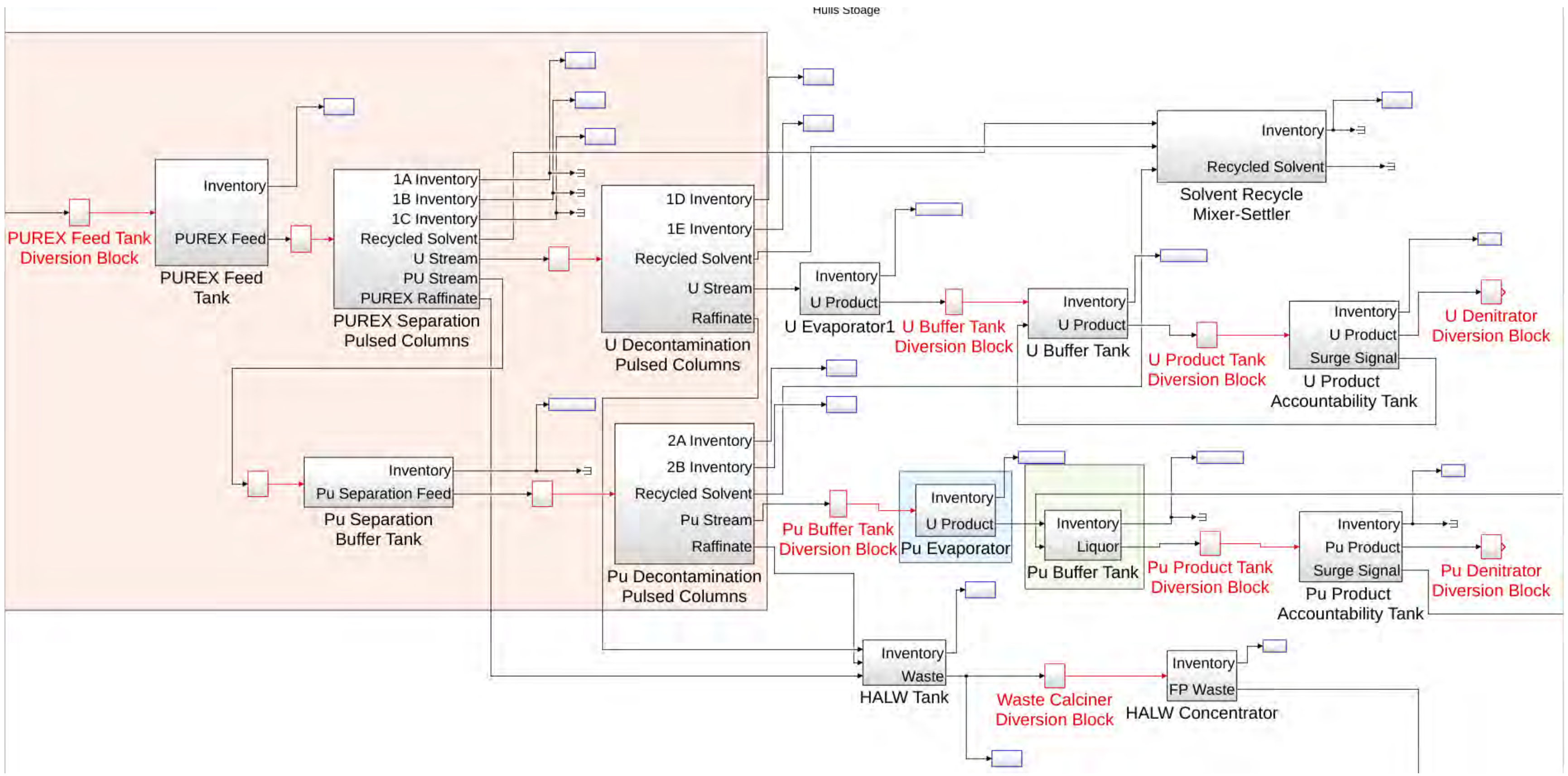


https://tutorials.com/primer-on-neural-network-models-for-natural -language-processing/

Lessons Learned

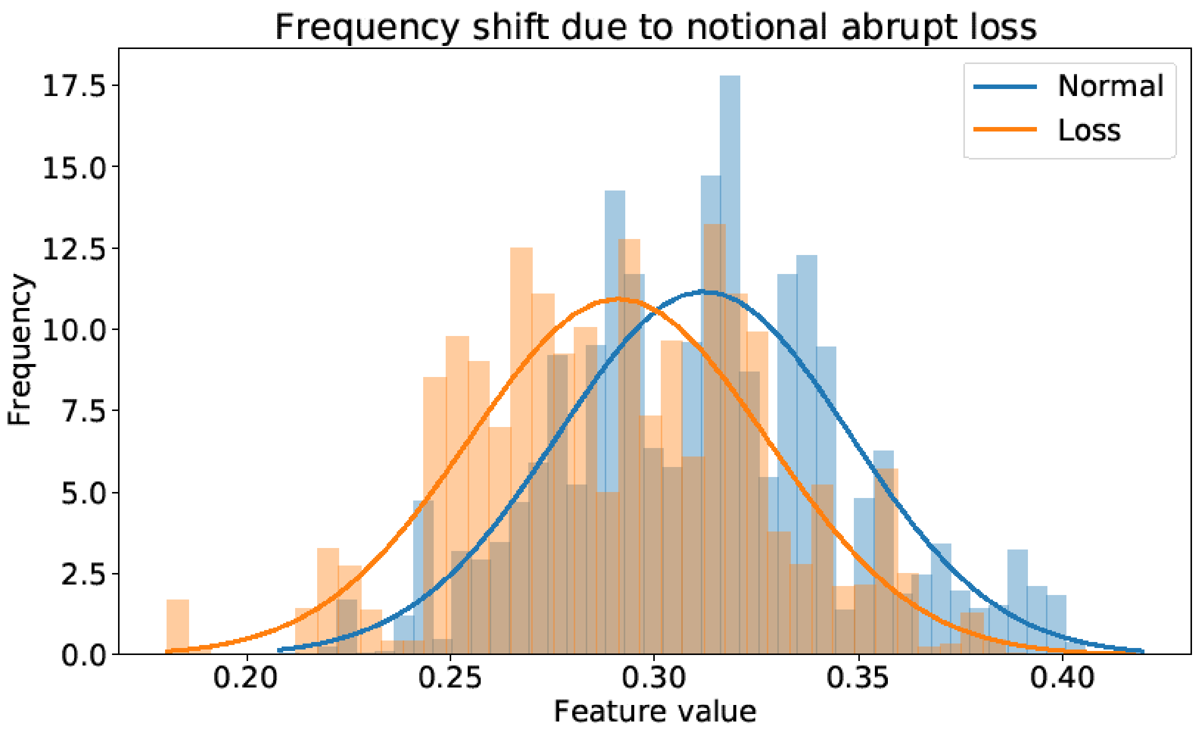
Current and Past Work Has Evaluated the Use of ML to Improve Materials Accountancy for Reprocessing and Enrichment.

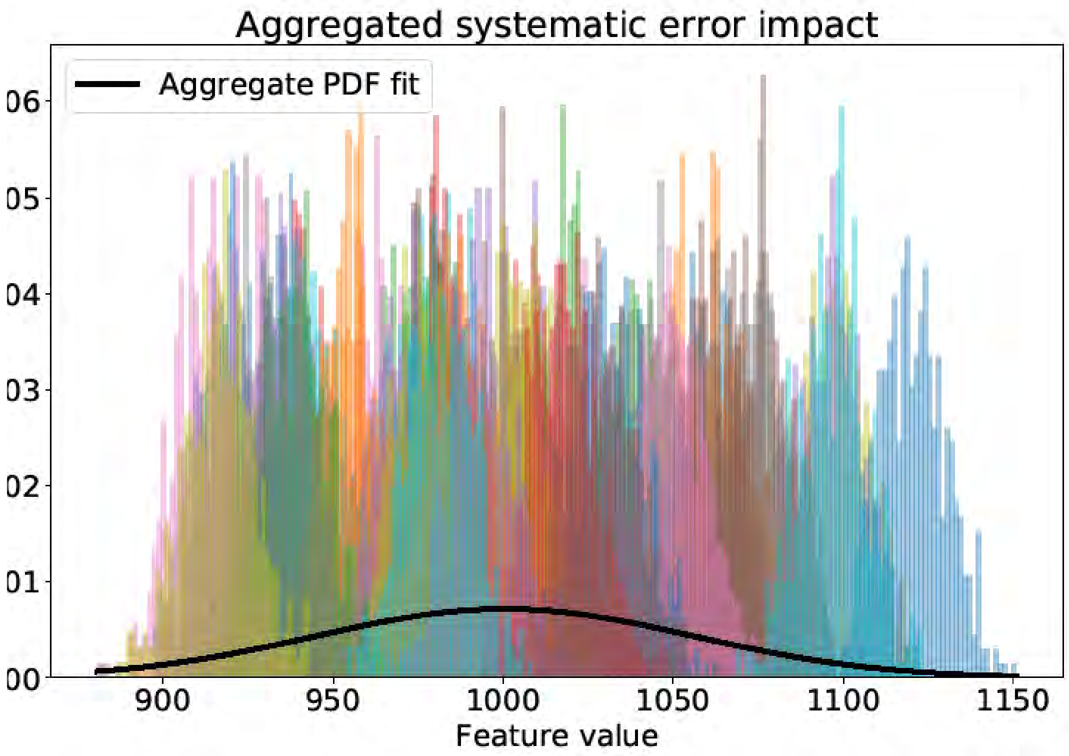
- Process models were used to generate the necessary training data.
- Simulated measurements including both bulk processing monitoring data and nuclear measurements have been used to reduce reliance on DA.



Application of ML to Materials Accountancy

- Application of ML to a material balance (which includes measurement uncertainty) is rather unique in the ML field.
- Large data requirements combined with safeguards errors create a difficult challenge.

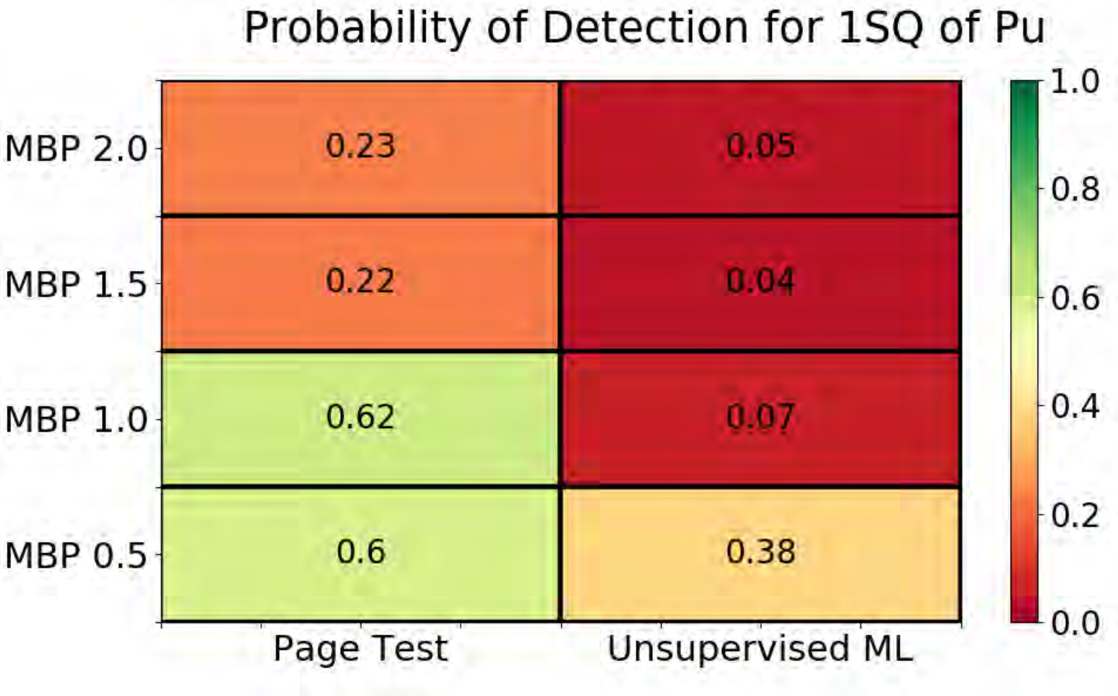




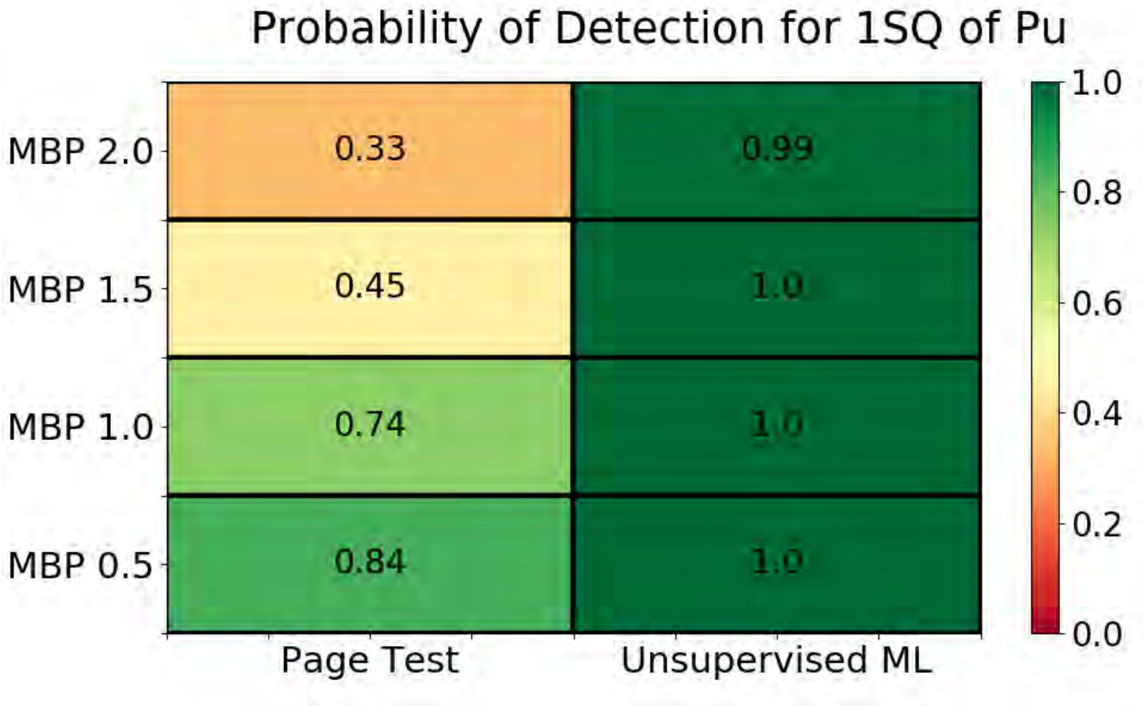
Results

- Initially, the ML results were much worse than a traditional materials accountancy approach, due to the variation in systematic errors.
- Reduction of systematic biases through cross-calibration of sensors led to significantly improved results.

Initial Results



Results with Detector Cross-Calibration



Conclusions

- Machine Learning can work very well in specific domains. **Image and text recognition are proven** uses with many applications. Application to containment and surveillance could provide significant benefit to safeguards.
- **ML is powerful but requires careful application and subject matter expert input**—it needs to be trained, and training can require a lot of data and time to develop the algorithms.
- The application to materials accountancy appears to be less promising—**training with data that has uncertainty is a unique application in the ML community.** More R&D is needed to determine if there are viable approaches.
- There are concerns over the **operational transparency** of using ML approaches.
- **The high consequence** nature of safeguards results in **strict requirements** not often seen in other industries which results in further R&D challenges.

NuclearN

We develop and distribute Nuclear-Ready AI software

https://nuclearn.ai

Roses are red
violets are blue,
the remainder of this poem was generated with Nuclear AI,
and it has been sent to the NRC for review.

Applicability of large language models in Nuclear

NuclearN

Previously started Palo Verde's Data Science Team in 2017

Prior Work at Palo Verde:

Auto PO&C Labeling, Equipment Anomaly Detection, DIANA Network Analysis, CAP AutoScreening, Supply Chain Forecasting & Optimization

Recipients of 2020 Nuclear Energy Institute's <u>Top Innovative Practice Award</u> for *Process Automation using Machine Learning*

Jerrold Vincent

B.S. Business Economics

M.S. Computer Science

10 years in Utility Data Science and Business Intelligence, PVNGS

Bradley Fox

B.S. Materials Science & Engineering

6 years Nuclear Engineering & 6 years Data Science & Software, PVNGS

What are Large Language Models?

Specialized neural networks for modeling general natural language trained on HUGE amounts of data

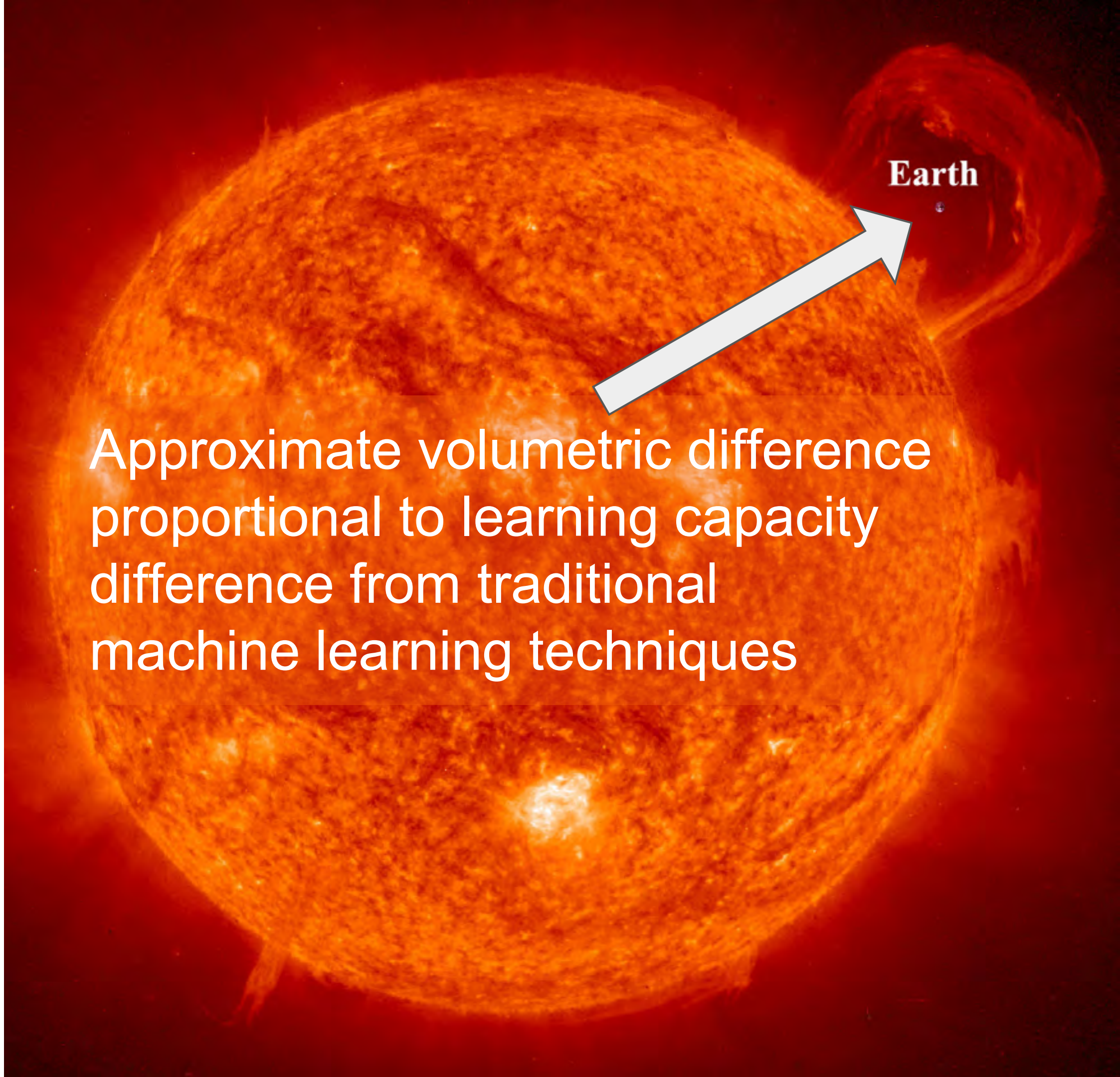
Broad (English), domain specific (Medical) or task specific (Q&A)

Single model can answer questions, generate novel passages, classify text, perform translations, summarize content

$$p(\overbrace{t_1, t_2, \ldots, t_N}^{\text{Token sequence}}) = \prod_{k=1}^{N} p\left(t_k \mid t_1, t_2, \ldots, t_{k-1}\right)$$

Sequence probability

Conditional probabilities

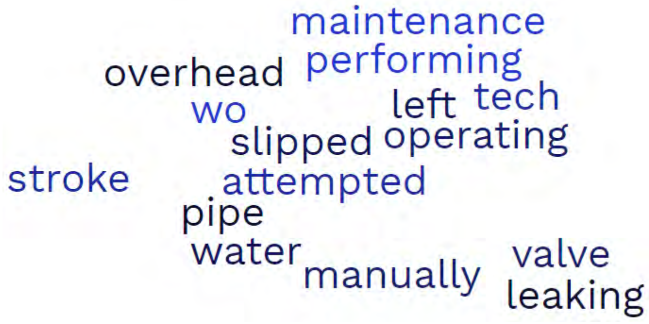


Revolution in Natural Language Approaches

Move data pipeline complexity and feature engineering into the language model

Old School

- Manually clean text to reduce number of extraneous words and identify “phrases” and “keywords” that matter
- Train Naive Bayes/Boosted Tree/Simple Neural Network on features
- Accuracy is lower than humans



Large Language Model Era

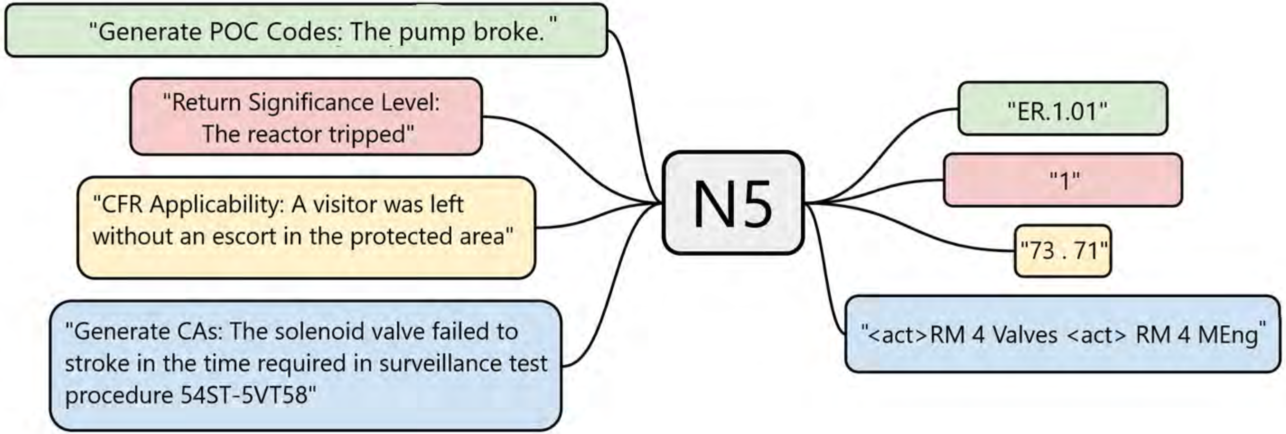
- Pre-trained models can perform many tasks without any additional training
- Models can be “fine-tuned” to specific problems to achieve superior performance
- Models “read” an entire passage, and use the entire context to “understand” the natural language
- 4.3x reduction in number of errors[1]

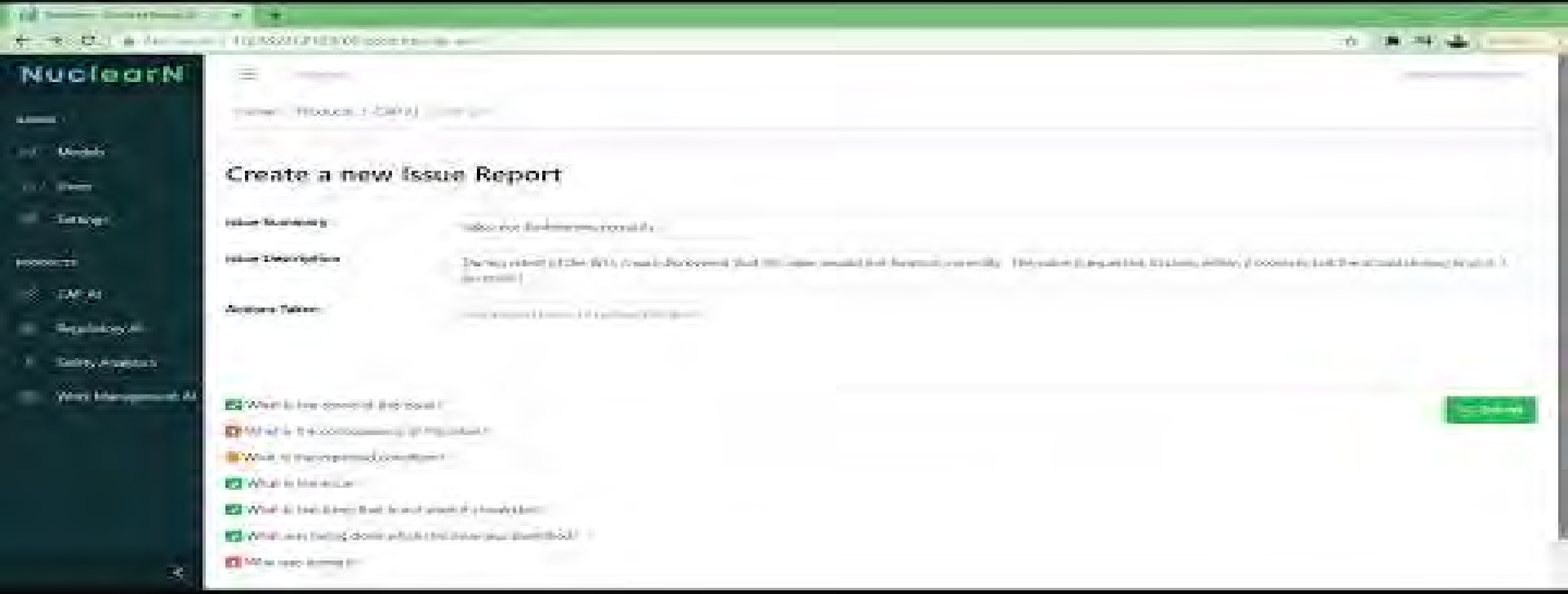
After performing WO 1234567, maintenance tech attempted to stroke the valve. While manually operating the valve, the tech slipped on water left from a leaking overhead pipe.

1.https://gluebenchmark.com/leaderboard

What can we do with these models?

- More accurately auto-screen a higher proportion of issues utilizing improved classification abilities
- Improve the quality of reports using intelligent autocomplete with Nuclear-specific terms and phrases
- Evaluate whether an issue report contains sufficient information as it is being written

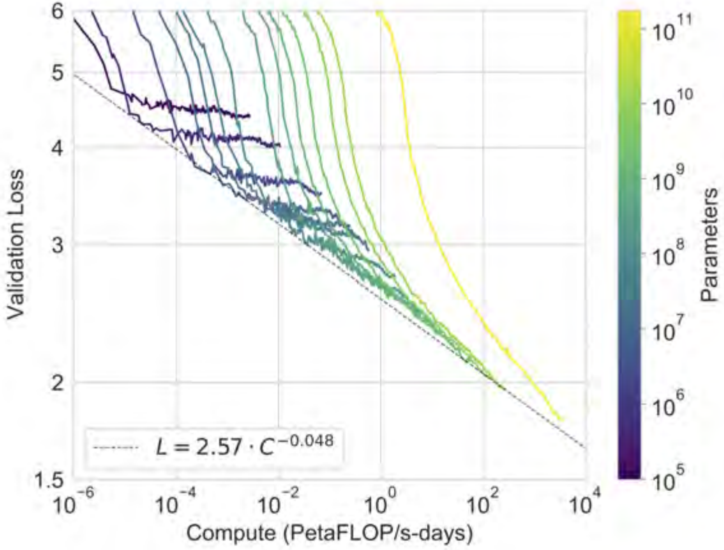




https://www.youtube.com/watch?v=K3SdC909bnc

Large Language Models are still improving.

- Next generation predicted to be 200x size of current generation
- Models will achieve superhuman performance on a broad range of natural language and general AI tasks
- Services such as Github Copilot already leverage advanced auto-complete functionality for millions of users
- Gartner predicts that by 2025 generative AI will account for 10% of all data produced worldwide



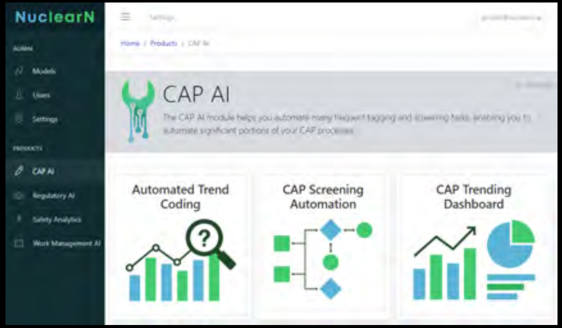
For the first time in the history of Machine Learning, there is no evidence of decreasing returns from increasing model size. The only limiting factor is compute resources.

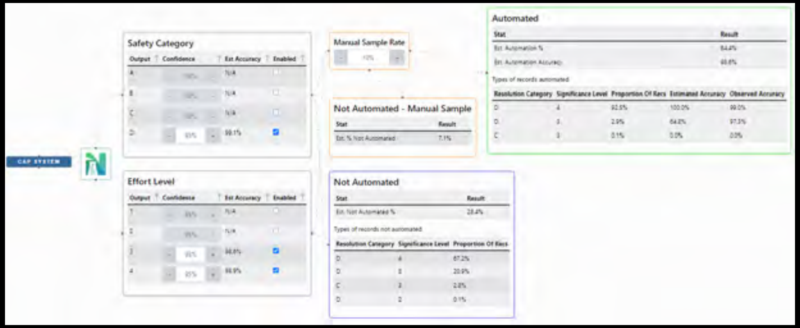
Future Use Cases and Research

- Intelligent auto-completion of procedures and work instructions, including generation of entire work steps
- “Query” large Nuclear texts for answers (e.g. FSAR, design documents, etc.)
- Chatbots for creating Issue Reports, Work Orders, Scheduling
- Automatic summarization of site schedules and daily issues
- We plan to release a Nuclear-specific Large Language Model in the future

Large Language Models are used in Nuclearn platform and products

- CAP Screening Automation
- Automated Trend Coding
- CAP Trending Dashboard
- 10CFR50 Section Applicability





NuclearN

https://nuclearn.ai

Questions?

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Hybrid Physics-Data Driven Model for Prescriptive Control and Design

Clean • Safe • Secure • Affordable

Satyan Bhongale, *Lead Data Scientist*

November 9, 2021

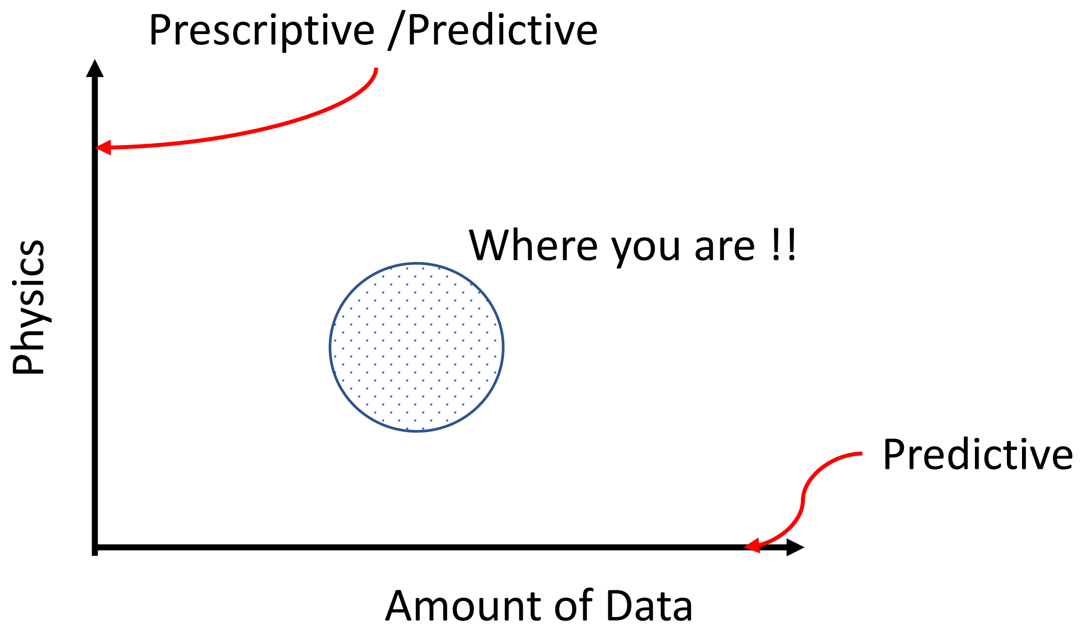
energy

Industrial Data Science Challenges

Industries
- Automotive
- Power /Energy
- Mining
- Semiconductor

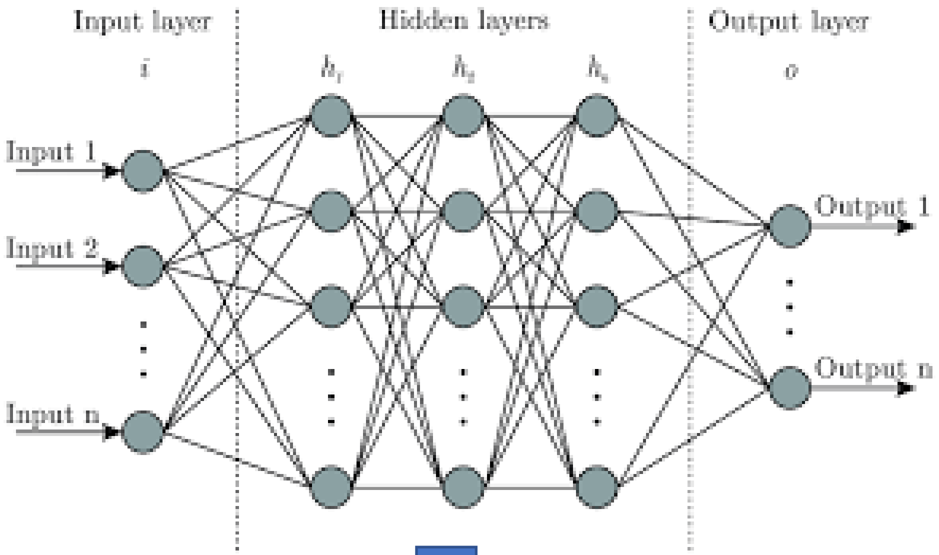
Typical Applications
- Process Optimization
- Predictive Maintenance
- Composite metrology
- Anomaly Detection

Key Challenges
- Lack of Data
- Bad Data Quality
- Lack of Variability
- Multivariant prescriptive control



Predictive vs Prescriptive

Neural Nets / Deep Learning



- One way function and non-invertible
- Lack of physical insight (operational difficulties)

$$Output\ 1 = f_{numerical}(Inpout\ 1, Input\ 2, \ldots Input\ N\ )$$

Symbolic AI / Regression

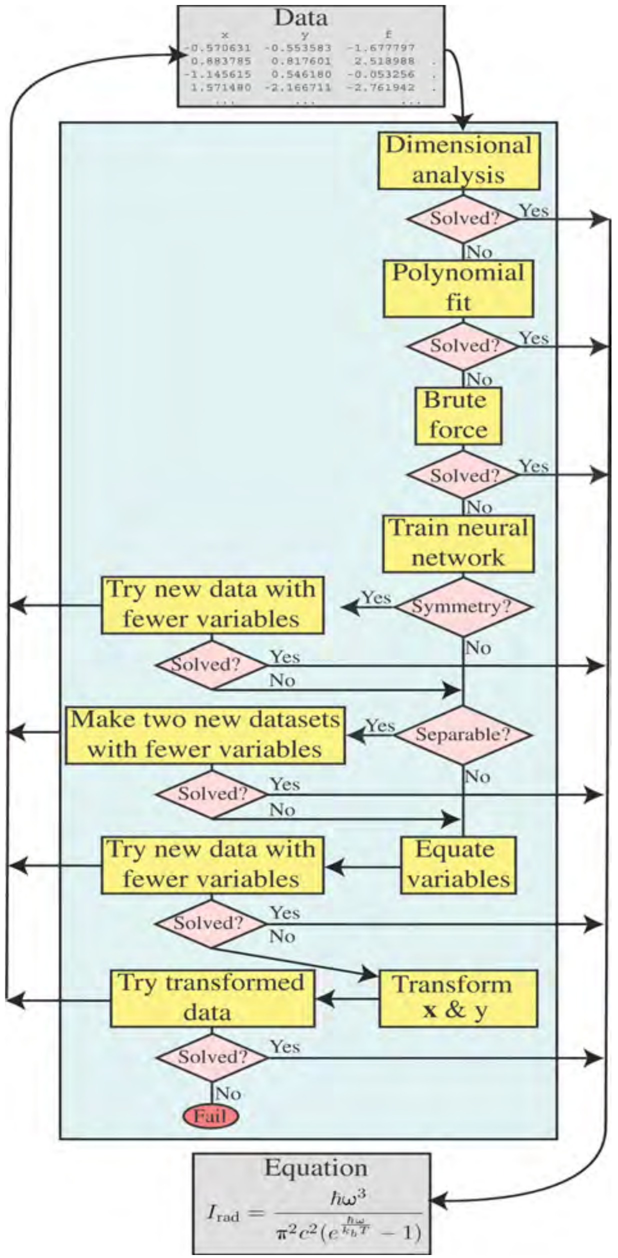
Deriving Physical laws from data

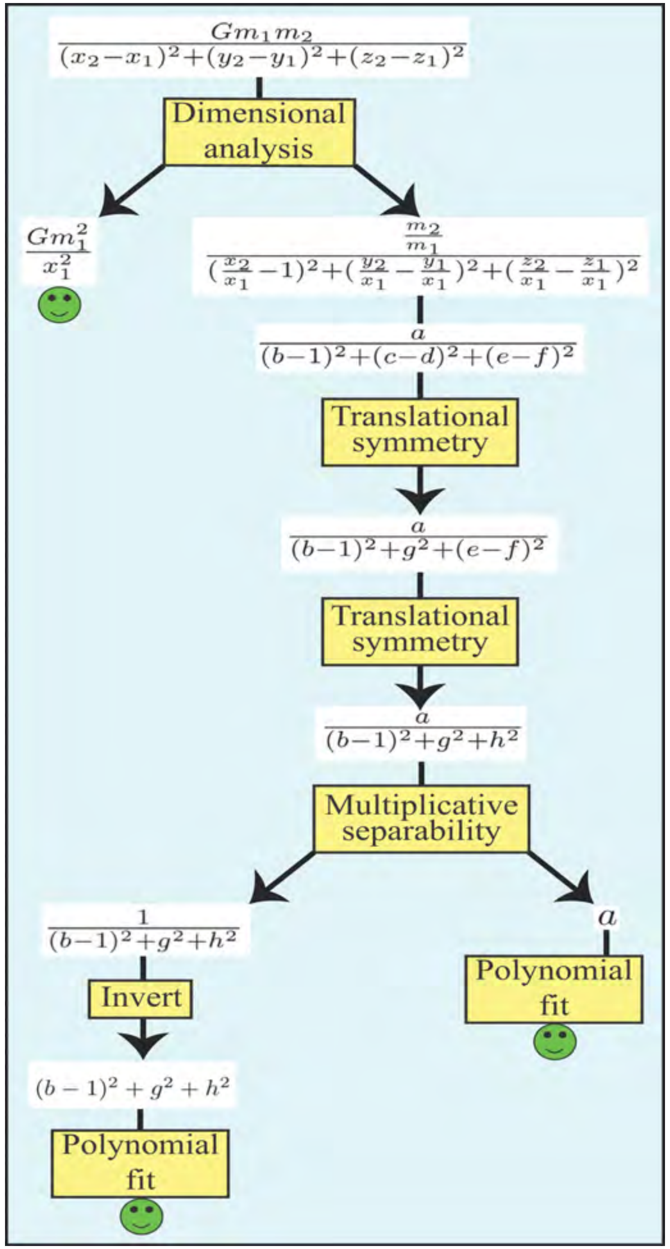
- Data Robot originally Newtonian
- GPLearn (based on genetic algorithm)
- AIFeynman (able to derive over 100 Physics laws from Feynman Lectures

- Most likely invertible (not always)
- Knowledge of gradients and higher derivatives at each point in space

$$Output\ 1 = f_{symbolic}\ \ (Inpout\ 1, Input\ 2, \ldots Input\ N\ )$$

Symbolic AI / Regression





energy

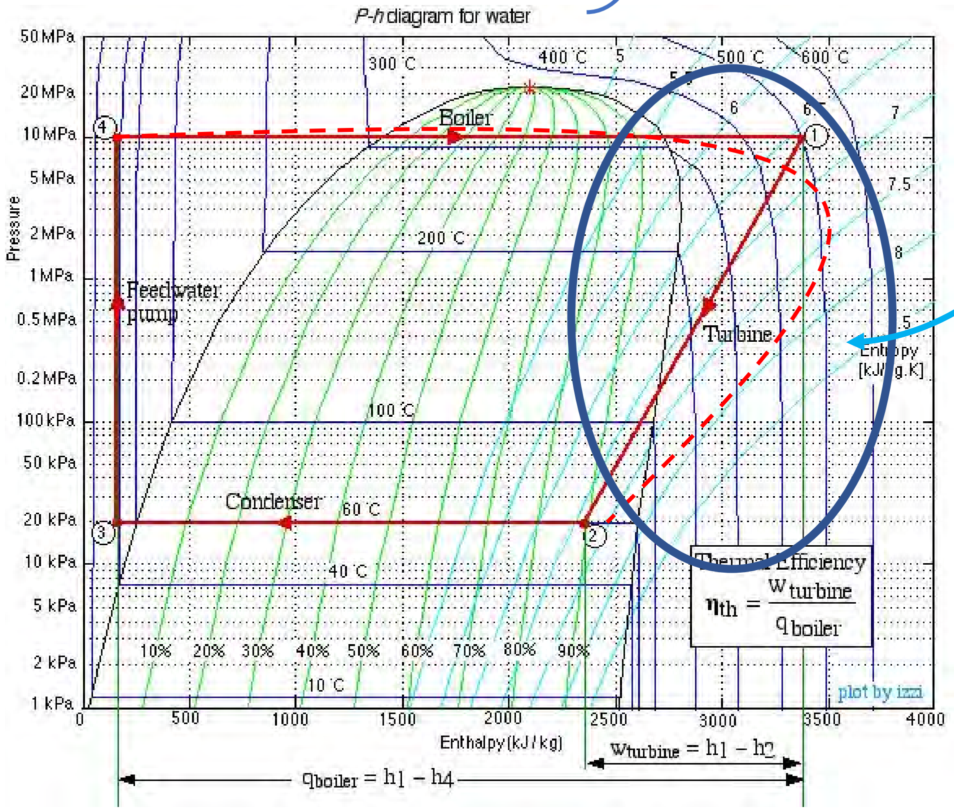
Use case : Condenser – Turbine

$$p_2 = r p_1$$

$$r^{\frac{2}{m}} - r^{1+\frac{1}{m}} = \frac{w^2}{A^2 \rho_1 p_1} \times \frac{m-1}{2\eta m}$$

$$p_2 = NN(p_1, \rho_1, w_1, T_1, .., x_1, x_2, \dots, x_n)$$

$$T \equiv T(h,p) \equiv T = T_0(1 + f(x_1, x_2, .. x_n))$$



Smooth function of variables not captured by the physics equations e.g.

- Vibrations
- Leaks
- Bearing temperature
- Ambient conditions
- Etc.

Symbolic AI

- Prescriptive control
- Extrapolation allowing for design

energy

Summary

- Need to develop Hybrid Physics & Data driven Digital Twins
- Symbolic AI allows for prescriptive control
- Models are extrapolatable beyond their operational regimes

CAP Automation and Informed Inspection Preparation Project - Update

Tim Alvey, Manager, Exelon Nuclear Innovation Group

Drew Miller, Lead Engineer, Risk Informed Engineering, Jensen Hughes

Ahmad Al Rashdan, Ph.D. Senior Research and Development Scientist, Idaho National Laboratory

November 9, 2021, NRC Workshop

Exelon Generation

Agenda

- Project Objectives
- Progress
  - Screening and Automation
  - Inspection Preparation
- Keywords and Trends
  - Topics relevant to P&IR
  - Diverse techniques/approaches
- Next Steps
- Closing Remarks

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Project Objectives

- Explore artificial intelligence and machine learning techniques to improve use of plant information
- Leverage data science technologies and methods
- Identify opportunities to improve utility processes
  - Incident Report Processing
  - Station Ownership Committee
  - Work Week Planning
  - NRC inspection preparation

Project Focus on CAP Data

- Cornerstone of Reactor Oversight Process (ROP)
- Streamlining and strengthening the CAP through use of AI/ML is expected to:
  - Improve consistency in processing, incoming IRs
  - Automate collection of data for inspection preparation
  - Find hidden trends and insights in existing CAP data
- Important Condition reports (CRs) requiring attention
- Software provides a textual comment explaining *why* the decision was made (enhances explainability)

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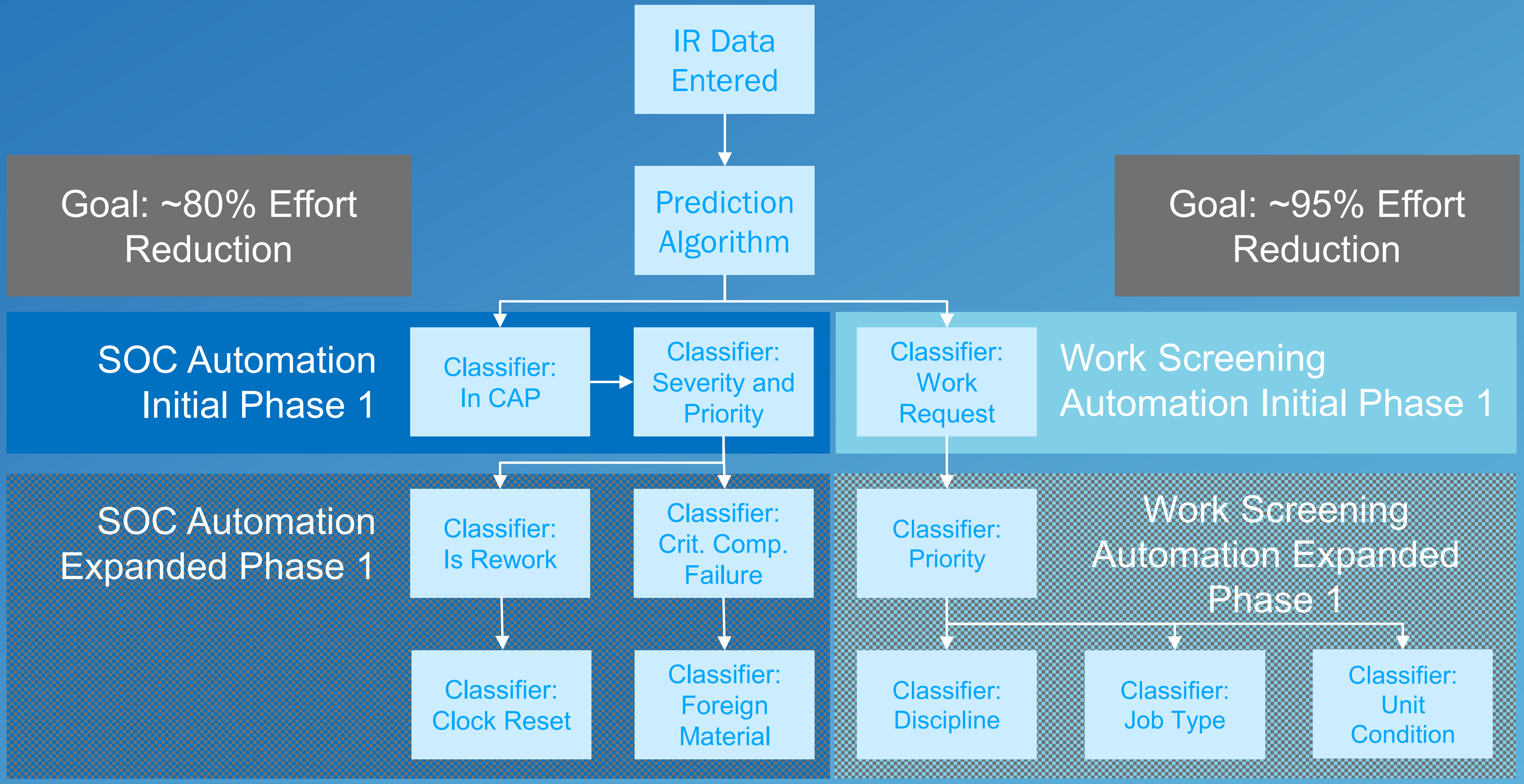
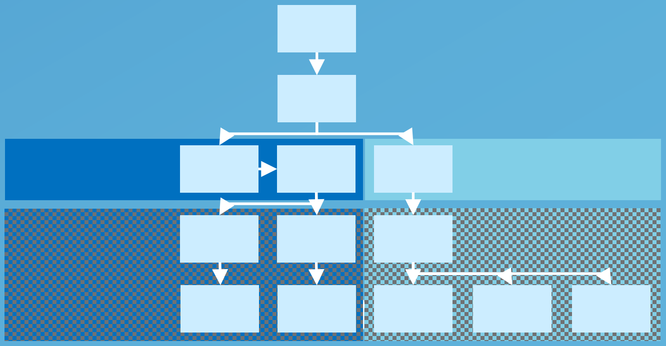
Incident Report Screening Automation Process



Automation Progress

- CAP and New Work Screening stakeholder input
- Areas of automation to reach effort reduction
  - Critical component failures
  - Nondiscretionary clock rests
  - Rework
- Completed models for CR/NCAP items and if they represent a significant condition (SCAQ)
- Develop additional models and results page (i.e., user interface) built into NUCAP 2.0



CAP Statistics (2017 - 2021)

The “significant” conditions that warrant increased attention, investigation and corrective actions comprise about 1% of all CR’s generated

All CRs including NCAP

	Severity 1	Severity 2	Severity 3	Severity 4	Severity 5
Priority A	3	66	25	1	0
Priority B	0	123	372	45	0
Priority D	2	50	3,569	403,231	1,359

CAP (i.e., CAQ)

	Severity 1	Severity 2	Severity 3	Severity 4	Severity 5
Priority A	3	66	25	1	0
Priority B	0	123	371	41	0
Priority D	0	49	3,528	300,364	476

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Informed Inspection Preparation

- Leverage insights from CAP automation and apply these to the identification of relevant inspection trends
- Enhance internal assessments and inform inspections
  - Streamline information sharing through an inspection data portal
  - Develop data-driven metrics to support inspection outcomes
  - Inform these processes though automation
- Develop tools to automate/identify risk contributors
  - Identify and highlight risk-significant information using PRA insights
  - Components and/or operator actions
  - Programmatic and predictive trends

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Topics Relevant to P&IR (from IP 71152)

- Negative trends in human/equipment performance
- Cited or non-cited violations
- Significant conditions (SCAQ)
- ROP cross-cutting themes
- Risk significant issues and trends
- Long-standing degraded conditions
- Reductions in design or operational margin
- Repetitive work orders and equipment failures

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Keyword/Topics

MIRACLE
(Machine Intelligence for Review and Analysis of Condition Logs and Entries)

Topic	Word 0	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10
Alarm	alarm	received	annunciator	reset	alarm received	clear	cleared	unexpected	local	trouble	alarm cleared
Badging	access	lost badge	badge	protected area	lanyard	badging	badge control	oca	visitor	escort	security badge
Battery	battery	voltage	cell	ground	vdc	battery charger	load	amp	charger	volt	battery room
Bolting	bolt	cap	nut	torque	stud	bolting	flange	gasket	ring	hole	fit
Boric acid	boric acid	valve	leak	leakage	boric acid leak	system pressure boundary	pressure boundary	packing	safety related ssc	boric acid	corrosion
Breakers	breaker	mcc	disconnect	cubicle	circuit breaker	bucket	panel	circuit	bkr	trip	tripped
Cable	cable	wire	conduit	box	tb	connection	electrical	wiring	cable tray	ground	connector
Calculation	calculation	analysis	engineering	usar	calc	input	helb	design basis	assumed	assumption	design
Calibration	calibration	instrument	tolerance	setpoint	cal	calibrated	icpm	te	setpoints	instrumentation	found tolerance
Cause evaluation	action	assignment	cause evaluation	apparent cause	grading	assigned	ace	rce	capr	parb	root cause
Chemical control	material	storage	stored	container	chemical	box	bottle	label	cabinet	drum	labelled
Chemistry	sample	chemistry	result	analysis	sampling	lab	ppm	elevated	chem	concentration	ppb
Clearance order	clearance order	isolation	tag	checklist	isolated	clearance	restoration	tagging	tagged	isolate	boundary
Communication equipment	communication	notification	call	phone	radio	called	page	pager	speaker	telephone	cell phone
Configuration management	drawing	field	discrepancy	id	label	labelled	match	shown	print	configuration	labelling
Containment	reactor coolant system	reactor coolant pump	containment	leakage	seal	rc	vault	mode	dw	gpm	reactor coolant pump motor

Hypothetical CR Text	t1	w1	t2	w2	t3	w3	t4	w4	t5	w5
During performance of 'Site Evacuation Alarm Test', the evacuation siren in the EDG Bay did not sound. The evacuation beacon was previously issued under different IRs. Equipment condition appears to be degrading. Test was completed UNSAT due to EDG beacon not lighting.	Emergency planning	19.2	Communication equipment	11.7	Emergency drills	1.5	Diesel generator	1.4	Rad Con instrumentation	0.9

Exelon Generation

Trending

Data-driven keywords with industry data to standardize trending

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Diverse AI/ML Techniques and Approaches

- JH uses a “classifier” algorithm (*CAP Analyzer*) with supervised learning to predict rare events
- INL uses a combination of supervised (*Cortex*) and unsupervised learning (Latent Dirichlet allocation) to create trends
- Integrate and leverage both approaches
- Allows independent validation

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Working … Next steps

Ongoing

- Insights from plant subject matter experts
- Collaboration with Xcel Energy
- Compare Exelon dataset with other utility results and optimize keywords (e.g., specificity)

Future

- Pilot CAP automation – 1st Q 2022
- Explore metrics pertinent to P&IR inspection (and expand to other inspection areas) – 2nd Q 2022
- Deploy open-source tools for broad industry use

Exelon Generation®

Concluding Remarks

- AI/ML techniques have the potential to strengthen the Corrective Action Program
- Overarching goal is to improve Exelon internal governance and oversight
- Stakeholder engagement and input is critical
  “Designers must proactively address their innovation so individuals should decide on long-term use of their product”
- Integration with NRC and industry presents the opportunity for a powerful outcome

Questions?

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Exelon Generation

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE ACTIVITIES

Mr. Luis Betancourt, P.E.
Chief, Accident Analysis Branch
Office of Nuclear Regulatory Research
Division of Safety Analysis

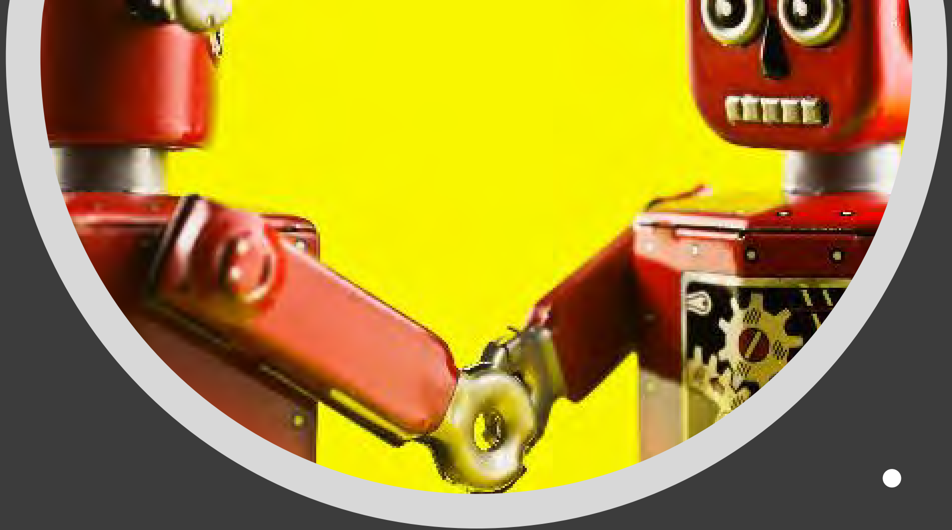
NRC AI Challenges

Current

- Workforce Training
- Traceable and Auditable Evaluation Methodologies
- Internal Challenges: Automating Internal Agency Business Processes
- External Challenges: Understanding Licensee and Applicant AI Usage

Future

- Regulatory Guidance and Decisionmaking Development
- Differentiating AI Usage for Reactor Design Versus Autonomous Control
- Explainable and Trustworthy AI – Reliability and Assurance
- Internal AI Budget Predicated on Emergent Industry Applications



FY 2022 Path Forward

- **Enhance staff knowledge in applications and use of data science and AI**
- **Engage with internal and external stakeholders to seek alignment on the draft Data Science and AI Strategic Plan**
- **Issue Data Science and AI Strategic Plan by Fall 2022**

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