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OPEN-SOURCING SAFETY, RISK, AND RELIABILITY TOOLS

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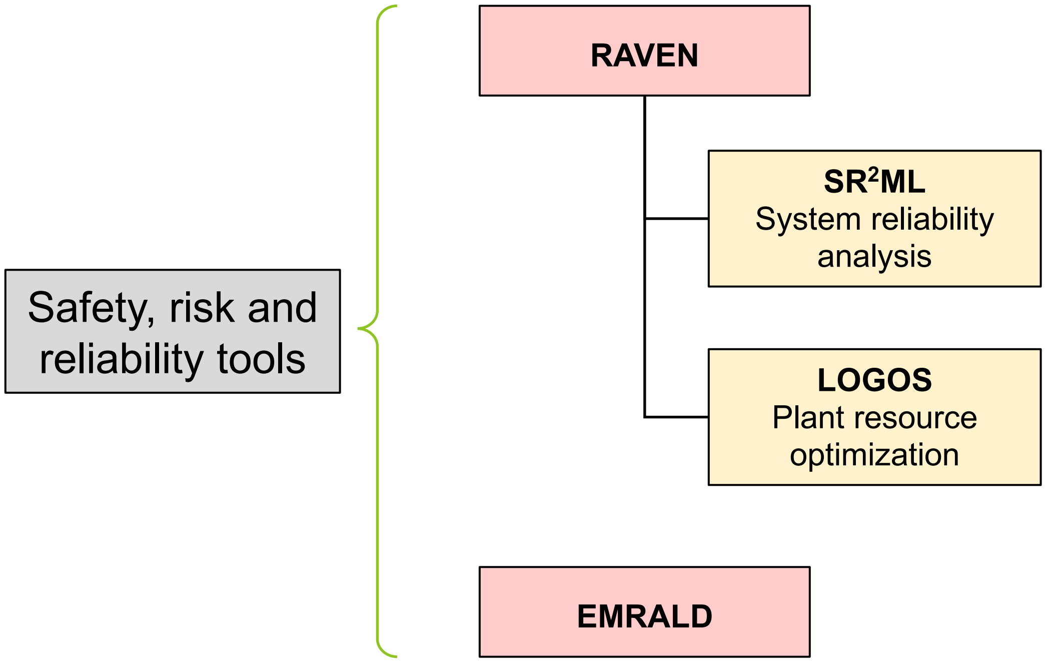
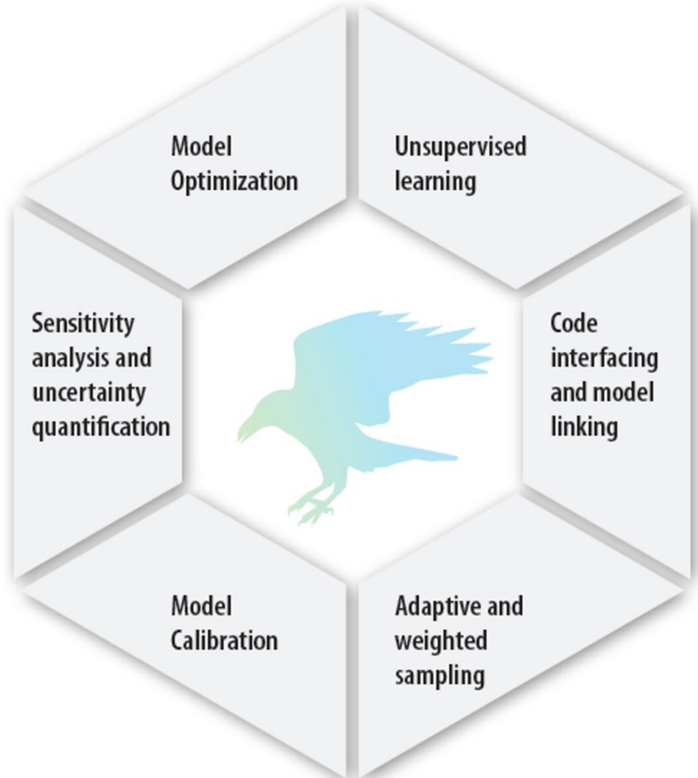
About This Talk

- Goal: provide an overview of INL open-source tools designed for safety, risk and reliability purposes

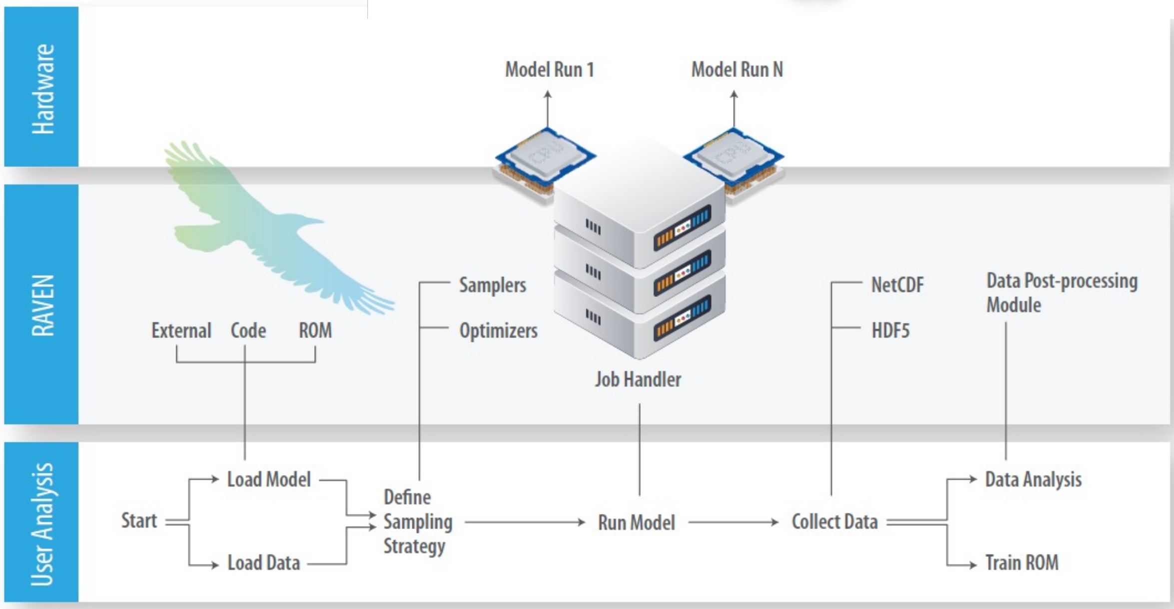


RAVEN: Overview

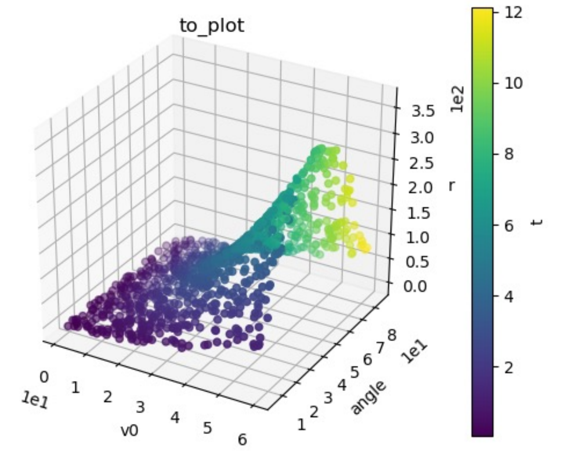
- RAVEN: multi-purpose stochastic platform
- **Methods/capabilities**
  - Uncertainty propagation
  - Machine learning
  - Optimization
  - Data analysis
- **Language:** designed to apply these methods and capabilities to user-provided simulation models



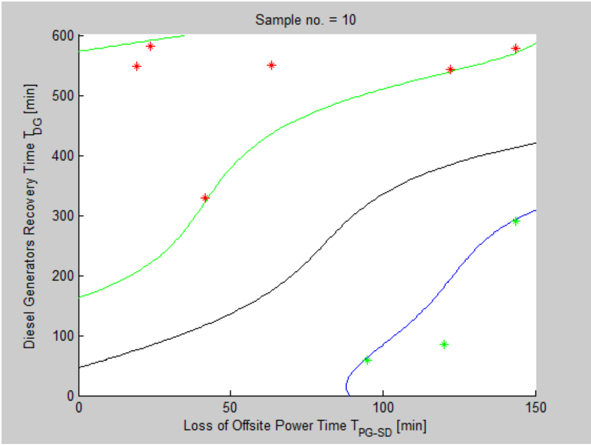
- RAVEN entities are combined to create analysis steps
- RAVEN executes user-specified sequence of steps, e.g.
  - Job dispatch on HPC system
  - Collect model output data
-

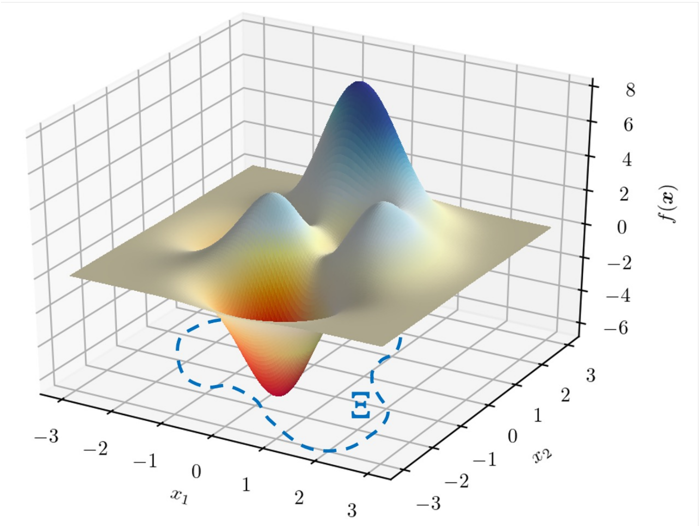


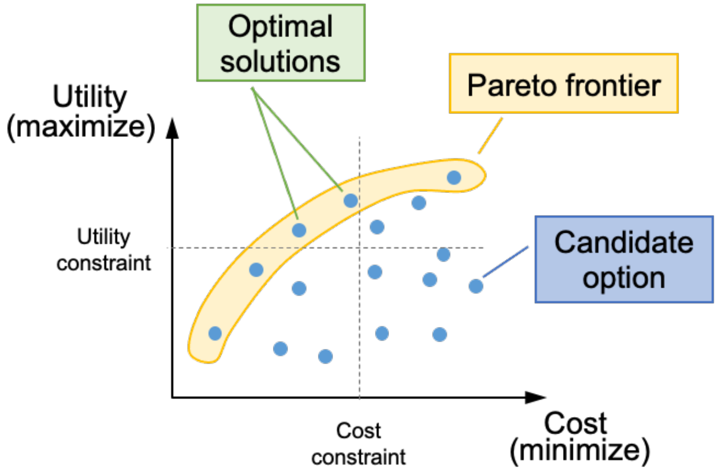
RAVEN: Model Sampling



- Generate data by evaluating model response according to a specific sampling scheme
- **Samplers**
  - Forwards samplers (e.g., Monte-Carlo, grid, ensemble sampling, stratified)
  - Adaptive samplers including Markov Chain Monte Carlo (MCMC)
- **Optimizers:** Gradient descent, genetic algorithms, Pareto frontier analysis
  - Reliability application: determine optimal reliability values for system components

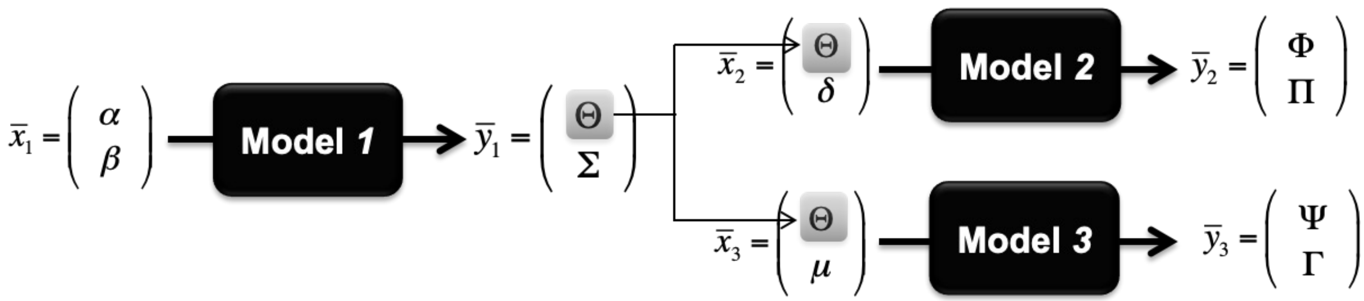




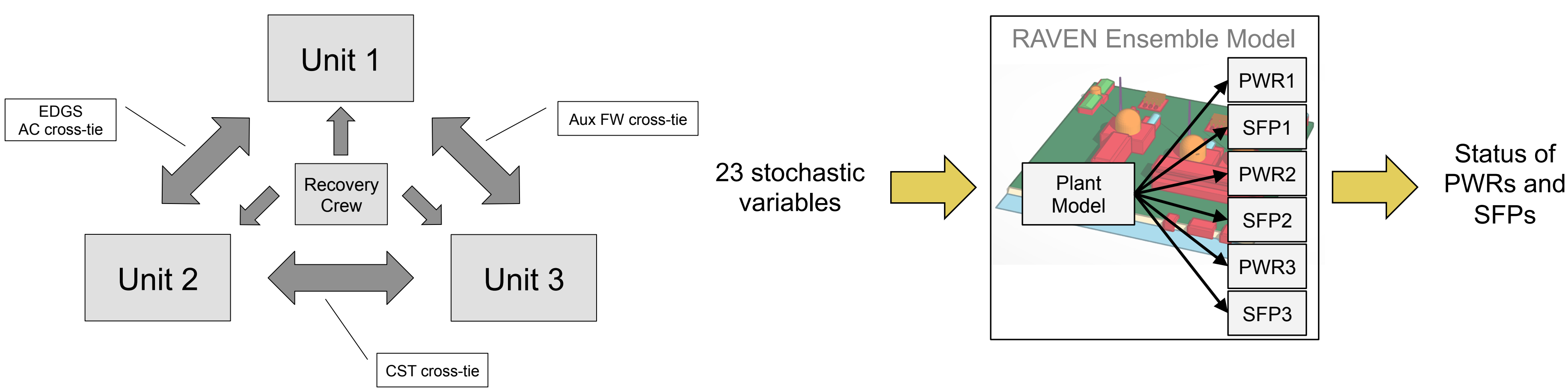


RAVEN: Model Architecture

- **Ensemble Models:** link models together in a linear fashion (i.e., parallel, serial)

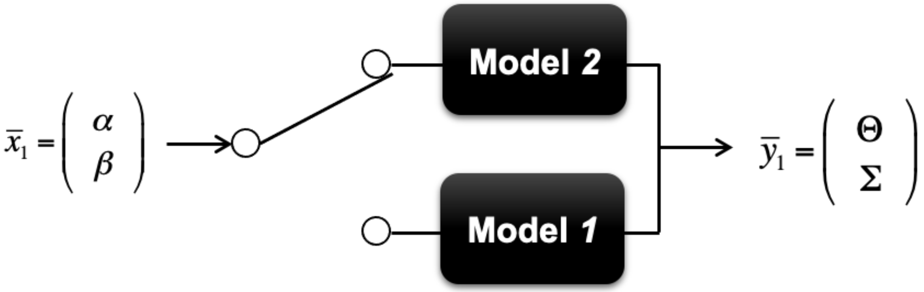


- **Example:** Dynamic probabilistic risk analysis of multi-unit power plant

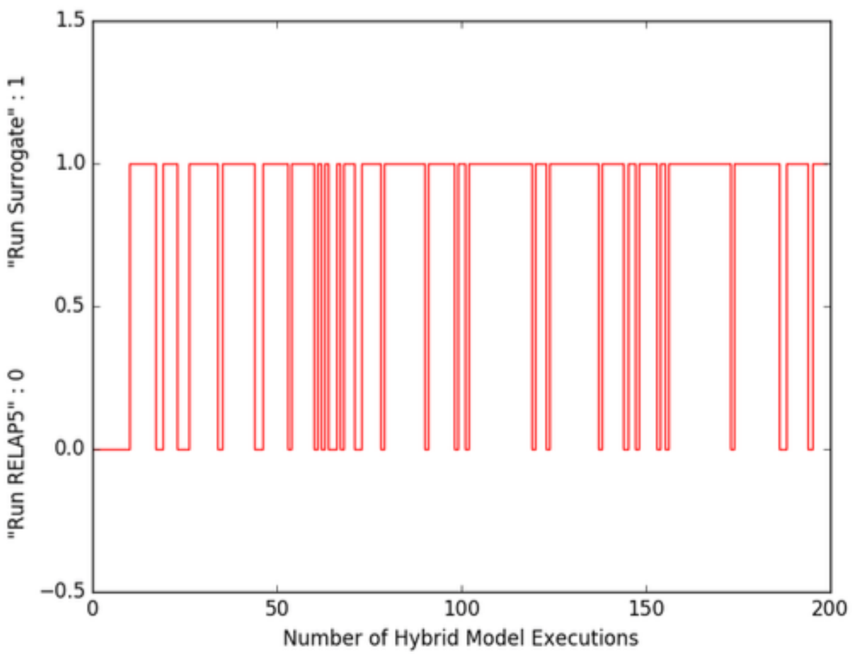


RAVEN: Model Architecture

- **Logical/Hybrid Models:** the execution of a model is dictated by a provided decision function, e.g.
  - System logic controlled
  - Choice between high vs. low fidelity models

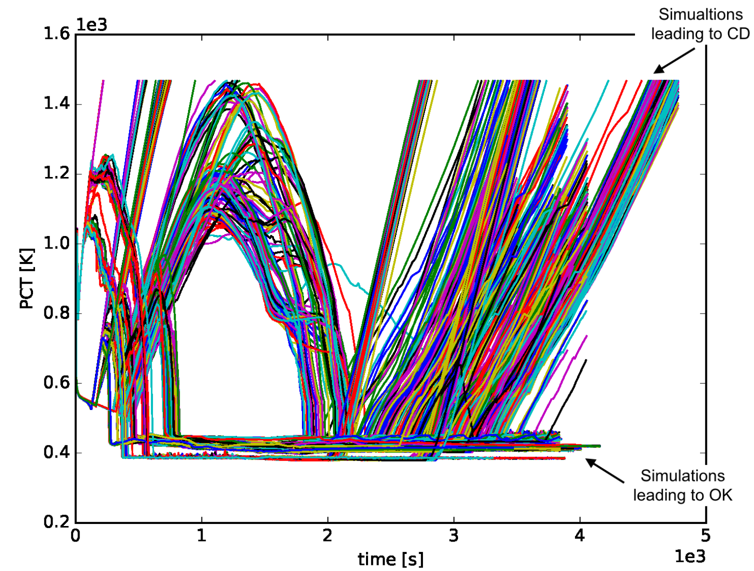


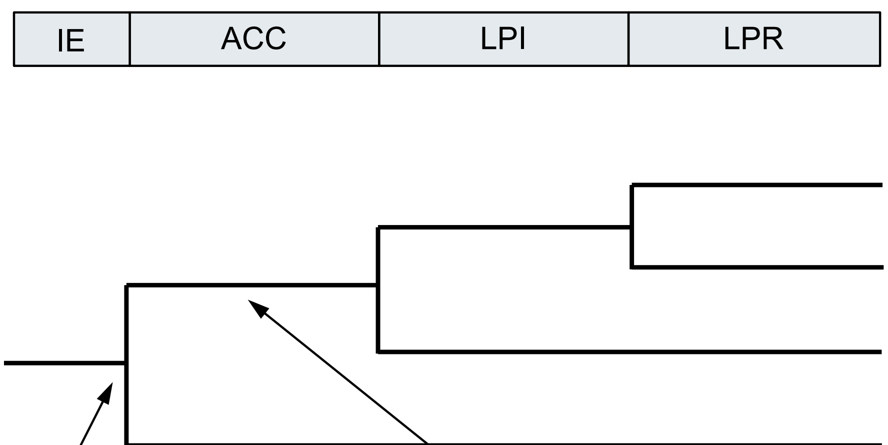
- **Example:** automatic model selection for a PWR SBO sequence using RELAP5-3D and SVM surrogate model
  - Out of the 1000 Monte Carlo samples
  - 200 were run using the RELAP5-3D model
  - Computational time reduction of 800*4 = 3200 CPU-hrs



SR²ML: Dynamic PRA

- **Goal:** Tools and methods to perform safety risk and reliability analyses
- **Application:** Models to perform simulation-based risk modeling (dynamic PRA)
  - Integration of classical PRA models to simulation models
  - Compare classical and dynamic PRA results
  - Integration of dynamic PRA data into classical PRA models





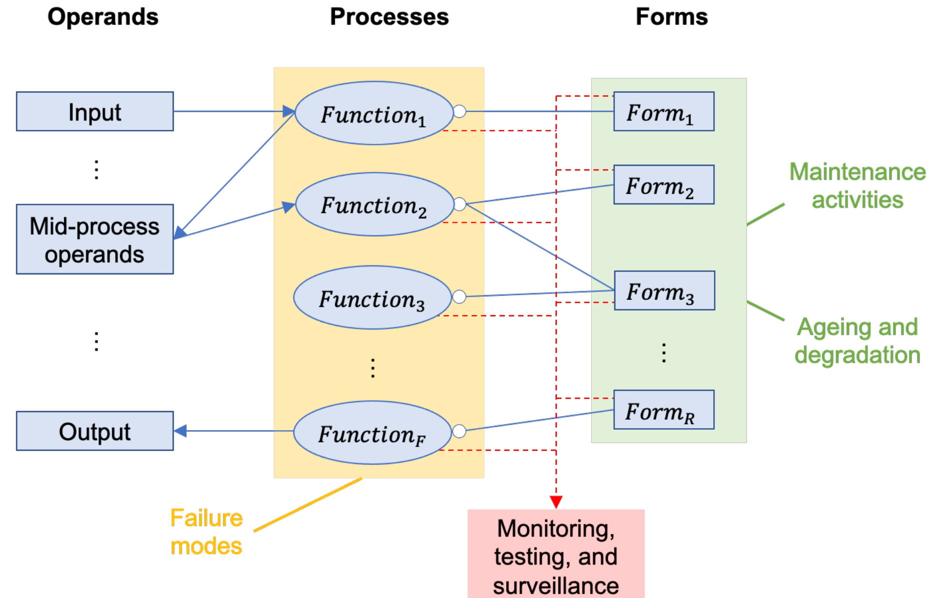
ID	Out	Branch Probability: SAPHIRE	Branch Probability: RAVEN
1	OK	0.99187	0.99176
2	CD	7.27 E-3	7.365 E-3
3	CD	8.12 E-4	8.744 E-4
4	CD	4.80 E-5	5.76 E-10

Original success criteria require 2 out of 2 ACCs to function

However, data shows 1 ACC is actually sufficient

SR^{2}ML: ER Data Analytics

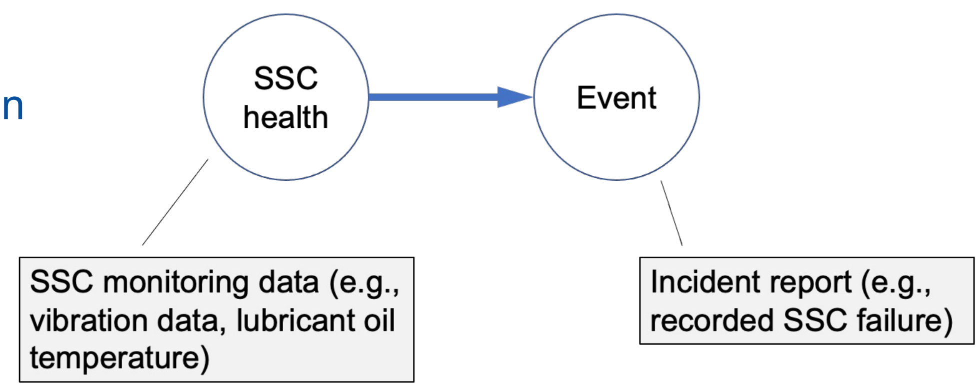
- **Data elements:** Heterogenous plant ER data format: text (events, logs) and numeric
- **Our work:** Find <u>causal</u> patterns from data
  - We need to use data along with models
- **System engineer view:** MBSE represen-tation of a component (e.g., OPM diagrams)
  - Understand "what a text is talking about"
  - Emulate system engineer knowledge about SSC/system architecture
- **Data scientist view:** natural language processing (NLP) methods
  - Discover causal relationship between data elements
  - Integrate numeric and text data



reasoning

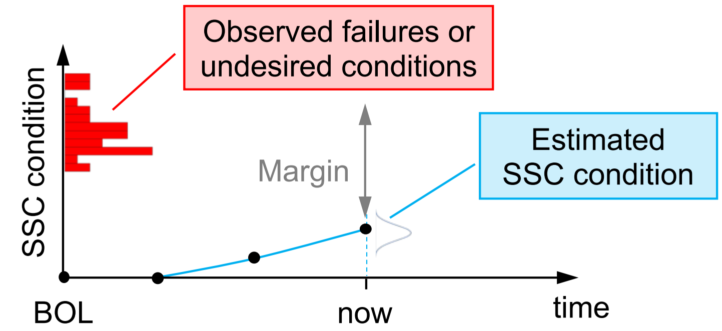
~~Machine learning~~

Create a story out of data



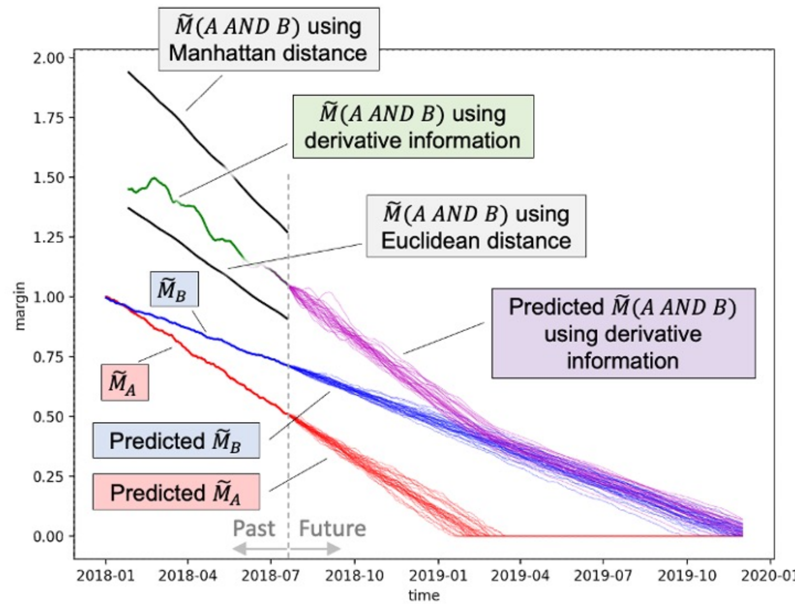
SR²ML: Reliability Modeling

- Reliability modeling based on margin rather than probability of failure
- Margin: "**distance**" between actual status and an undesired status for a component
- This change implies a **redefinition of risk**



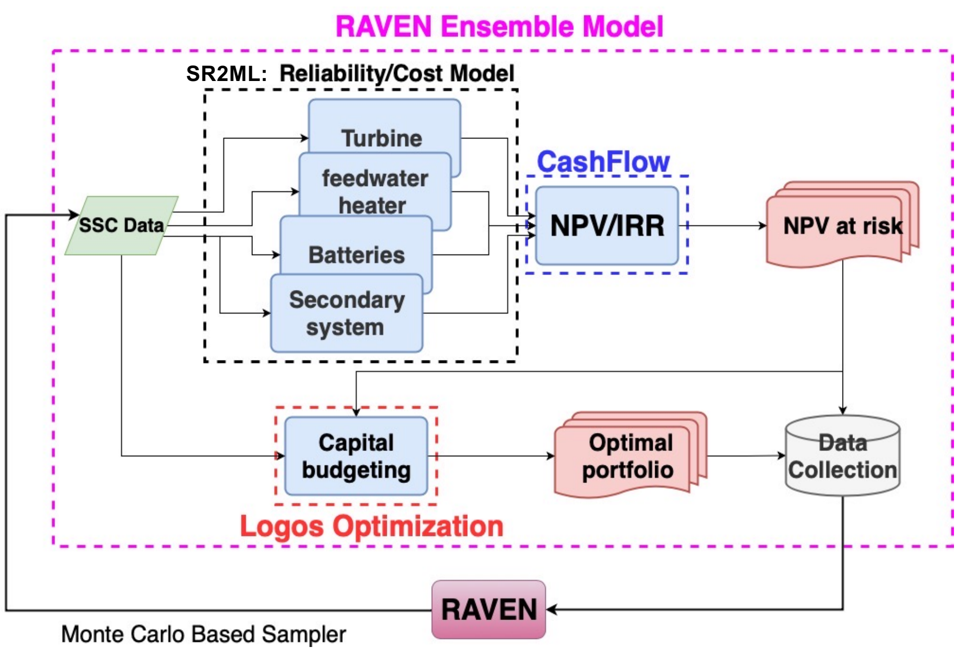
Regulatory definition	System engineer definition
What can go wrong What are its consequences **How likely it is**	What can go wrong What are its consequences **How distant it is**

- Margin is defined over actual and past ER data
  - Direct integration of ER data
- **Margin values change with time**
  - New SSC condition data are observed
  - ER operations are performed
- **Margin values can be propagated through system/plant reliability models**
  - Solved using distance-based operators
  - Quantitative measure of system health
  - Health importance of components



LOGOS: Simulation-Based Optimization

- **Goal:** provide plant resources optimization tools
  - Integration of reliability and economic factors into the decision process
- **Models interfaced to RAVEN (for model-based optimization)**
  - Determine optimal set of maintenance activities
  - Evaluate optimal alternatives for maintenance posture
  - Determine system optimal monitoring configuration
- **Stand-alone tools (for data-based optimization)**
  - Deterministic budgeting
  - Stochastic budgeting
  - Risk-based budgeting
  - Distributionally robust budgeting
  - Job scheduling optimization



LOGOS: Project Prioritization

- **Goal:** Select optimal set of projects and actuation schedule that maximizes overall NPV
- **Input data:** Candidate projects
  - Options for each project (timing, duration, and costs)
  - Budget constraints per year and per resource (e.g., capital funds, O&M funds)
  - Consequences of stochastic events (e.g., SSC failure)

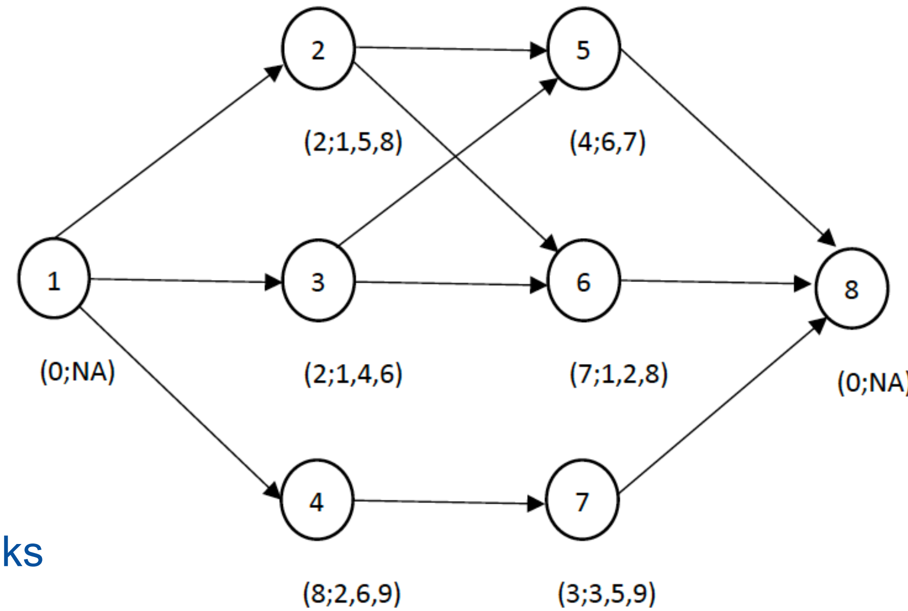
	T1	T2	T3	T4	T5	T6	MTTR [h]	Power Loss	Failure Probability	Risk
Component-scenario	$ 50K	$ 90K	$ 90K	$ 90K	$ 70K	$ 40K				
M1-A	$ 40K						10	10%	0.2	0.2
M1-B		$ 40K					10	10%	0.25	0.25
M1-C			$ 40K				10	10%	0.3	0.3
M1-DontDo							10	10%	1	1

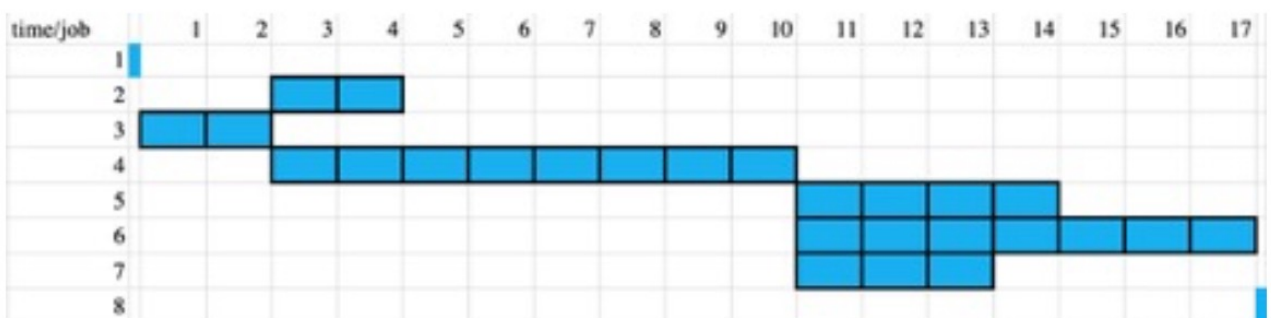
- **Output data:** Selected projects and prioritization and optimal project schedule

	T1	T2	T3	T4	T5	T6	Risk
	$ 50K	$ 90K	$ 90K	$ 90K	$ 70K	$ 40K	
M1-B		$ 40K					0.25
M2-B			$ 50K				0.36
M3-B				$ 35K			0.18
M4-A				$ 40K			0.18
M5-A		$ 45K					0.2
M6-A	$ 25K						0.168
M7-A			$ 30K				0.72
Total	$ 25K	$ 85K	$ 80K	$ 75K	0	0	2.058

LOGOS: Schedule Optimization

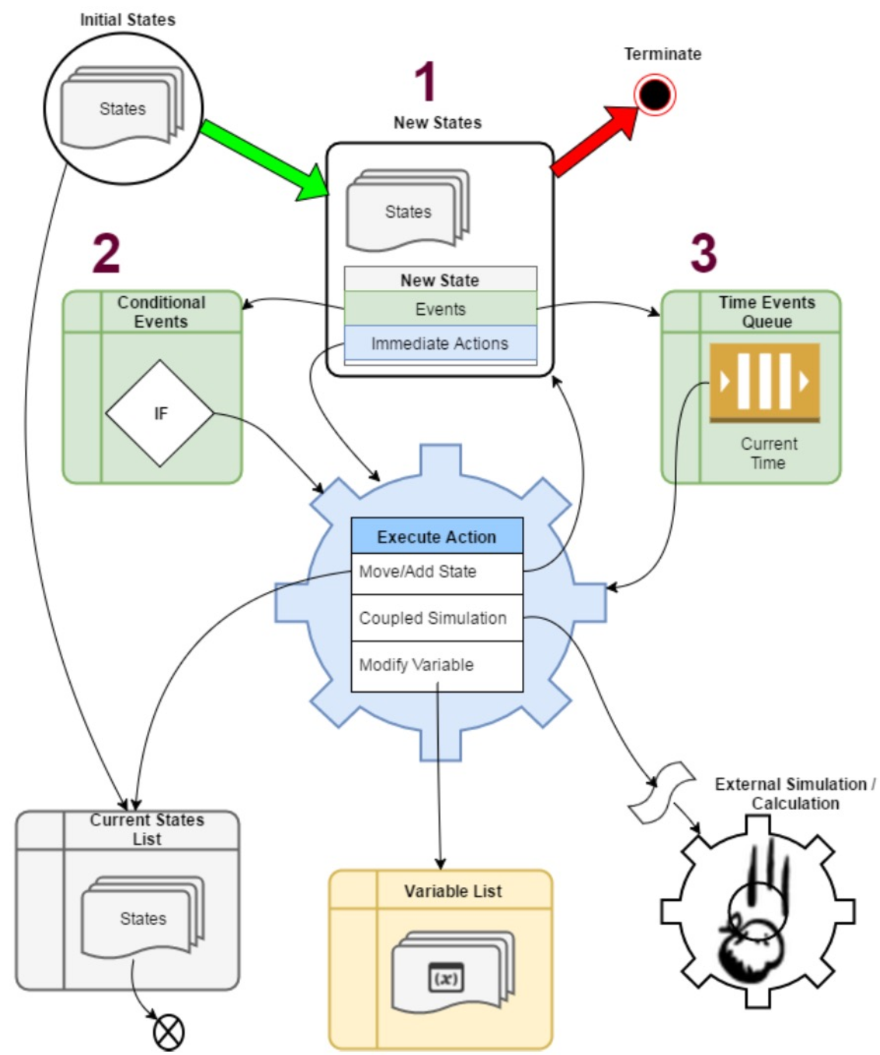
- **Applications**
  - Scheduling of maintenance and surveillance activities
  - Scheduling of outage activities
- **Input data**
  - Crews (skill set, availability)
  - Tasks (duration, dependencies, skills)
- **Objective:** minimize time to perform all tasks
- **Methods:** Mixed integer linear optimization
- **Output data**
  - Task schedule assigned to each crew





EMRALD

- Event Modeling Risk Assessment using Linked Diagrams (EMRALD)
- Dynamic PRA model based on a three-phased discrete event simulation
- To begin, add initial start states to Current and New States List
  1. While there are States in the New Sates list, for each State:
     - Add the Events to the Time Queue or Conditional List
     - Execute any Immediate Actions
  2. If any Conditional Events criteria is met
     - Execute that events action
     - (Go to Step 1)
  3. Jump to the next chronological event
     - Process that event's actions.
     - (Go to Step 1)



Conclusions