Risk-based Assessment of Salt Domes as Disposal Sites for Nuclear Waste (RADON)

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Background

Reliability Assesment

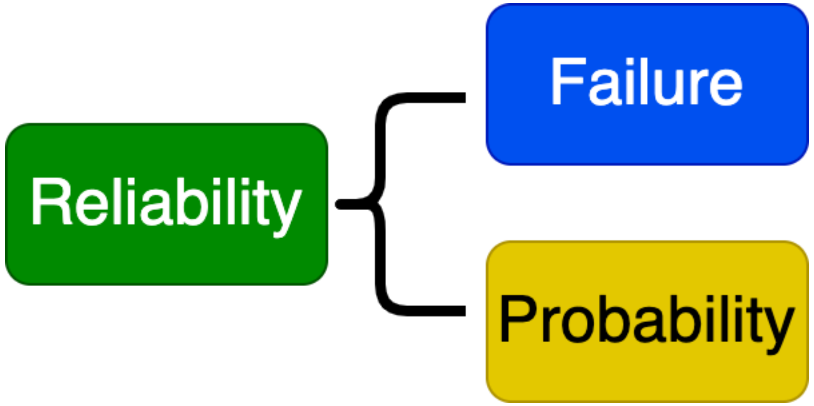
Reliability Assessment of Safety Disposal

*‘A systematic process of identifying **hazards** and evaluating any associated **risks**’ for a given case of study*

(British Safety Councill)

Reliability

- *Ability to perform an assigned task for a “Mission Time” under given environmental and operational conditions*
- ***Probability** that a component (or system) performs its required function for a ”Mission Time” under given environmental and operational conditions*



Terminantion (or loss) of ability of a component (or system) to perform its required function

- Classical
- Frequentistic
- Subjective
- **Assiomatic (Kolmogorov Assioms)**

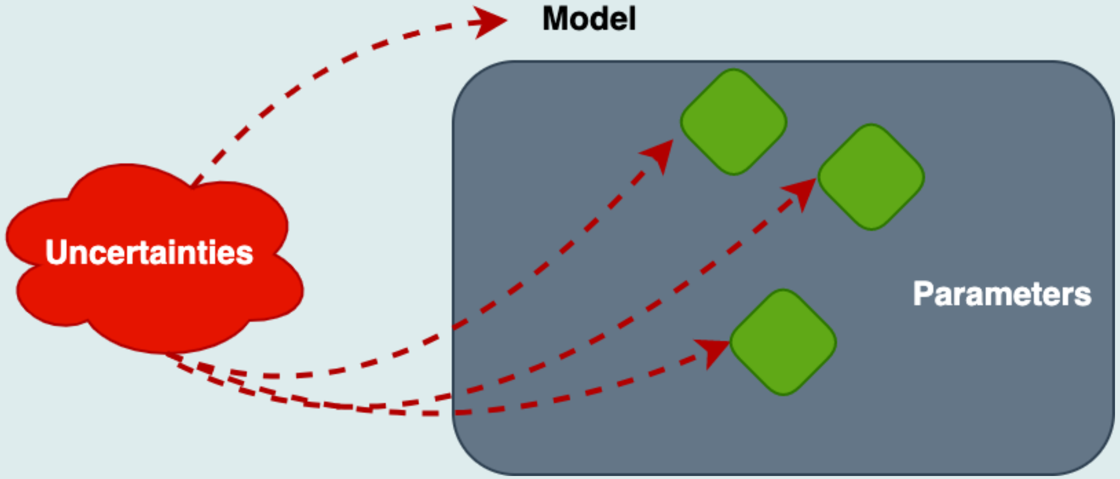
Uncertainties

"There is nothing so wrong with the analysis as believing the answer!" *Richard P. Feynman*

- A result is as good as the assumptions are good
- Uncertainteis evaluation is needed to have a reliable result

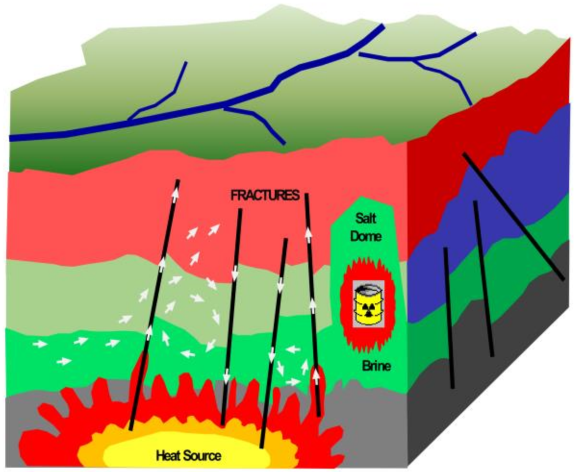
Type of Uncertainties

- **Epistemic** is the uncertainties related to lack of knowledge (can be reduced)
- **Aleatory** is the uncertainty related the intrinsic randomness of the considered phenomena (cannot be reduced)



- We can potentially associate a random variable to each physical parameter of the model (inefficient)
- **Sensitivity analysis** is performed to identify the important parameters

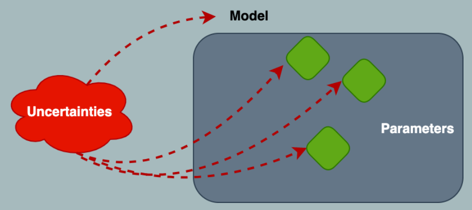
RADoN Project



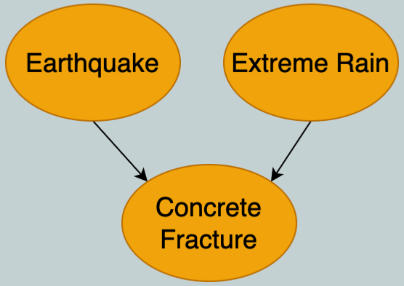
Quantitative *risk assessment* which takes into account the combined effect of

All relevant **sources of uncertainty**

e.g.
- subsurface structure
- material properties
- BCs



Hazardous events with their probability and dependencies



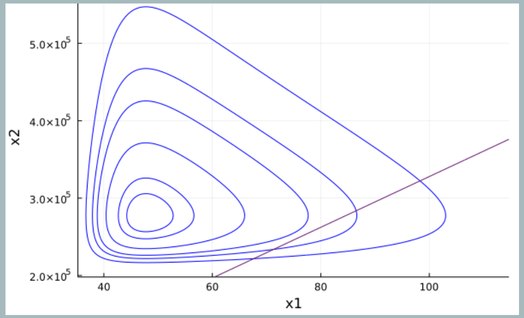
- One of the most *challenging* part is to identify **the hazardous (and not hazardous) events** and describe their relationships (CDFs).
- This process is **expert-knowledge based.**
- The model must be *able to update* all the assumptions on hazardous events CDFs whenever data became available.

Reliability Methods

Evaluation of a system state can be ‘safe’ with a given set of parameters and ‘not safe’ with a slightly changed set of parameters

Concepts

- The aim of all Reliability Methods is to identy the Failure Probability p_f of a system.
- When one (or more) parameter of the system are random variable (/s) ‘X’ the system state became dependent on this random variable(/s).
- Performance function g(X) is the expression of this dependency



Methods

Approximate Analytical Methods

- First Order Reliability Method
- Second Order Reliability Method

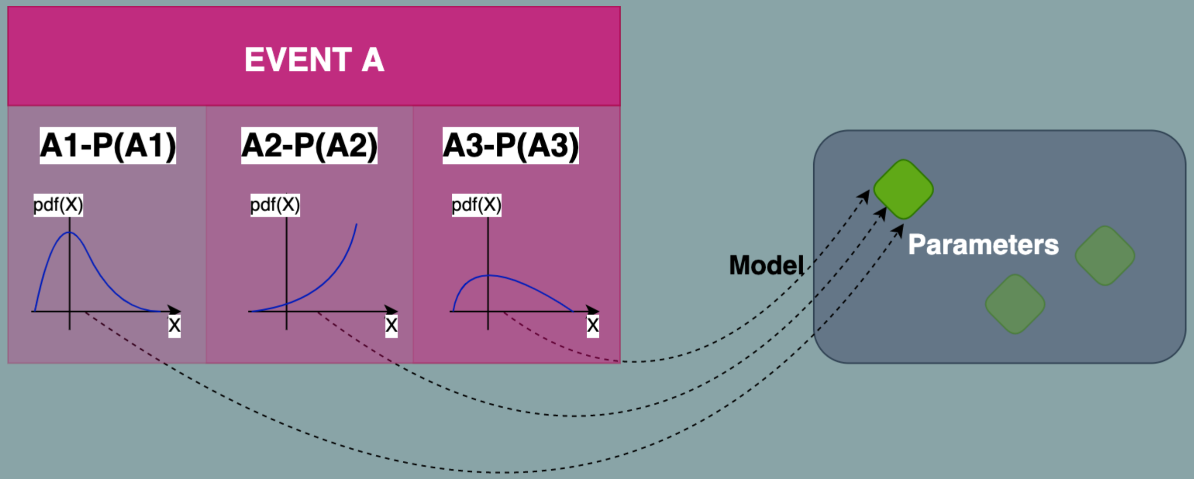
Montecarlo Methods

- Standard Montecarlo Method
- Advanced Montecarlo Methods

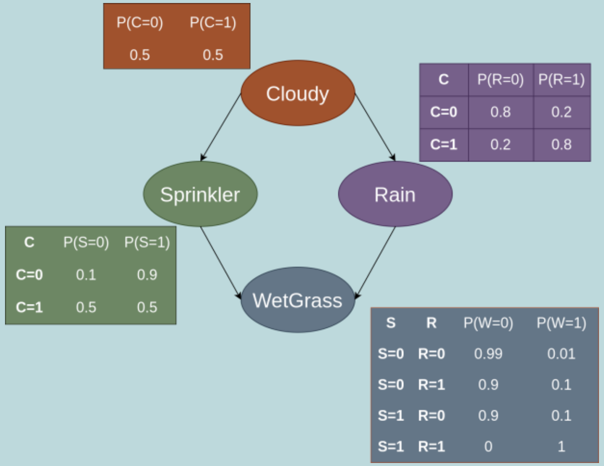
Bayesian Network - Intro

What is the aim of Bayesian Network?

- Reliability Methods are able to deal with system complexity and uncertainties related to models parameter
- An exhaustive reliability assessment have to take into account **different possible scenarios**



- Bayesian Network (BN) (Belief Network) are a statistical framework suitable for dealing with a reliability problem considering different possible scenarios, particularly s.t.
  - *high-impact*
  - *Interdisciplinary*



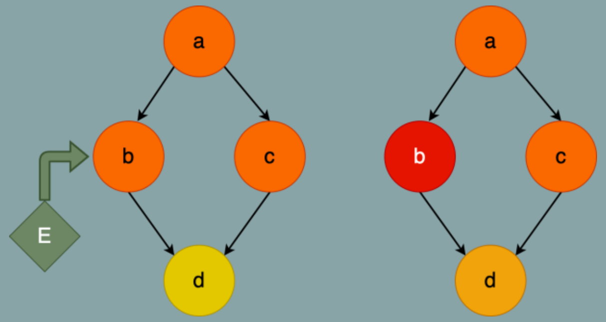
Bayesian Network – Summary

BNs are a tool for evaluating the impact of different scenarios on the reliability of a system

Model Update

BNs enable **Bayesian Update** of marginal probabilities once new data becames available.

*** Once all scenarios are evaluated, the BN works like a container of all the p_f, being computationally super-efficient*



What-if Anlysis & Decision Making

BNs enable the **propagation of the information on the direction of interest**, therefore the evaluation of the p_f related to every specific scenario.

***Once all scenarios are evaluated, the BN works like a "container" of all the p_f, being the TH-model a node of the network => computationally super-efficient*

Through the knowledge of the failure probabilities, is possible to determine the most critical scenarios for a **robust long term decision making** (decisional nodes can be implemented in the network)

Analytical solutions can be obtained only with discrete or Gaussian Random Variable

Enhanced Bayesian Network – Intro

Structural Reliability Methods

Pros:

- Allow **Continuous** rv
- Higly efficient for **small probabilities**

Cons:

- No Bayesian Update
- No graphical form
- Not always suitable for Discrete rvs

Bayesian Networks

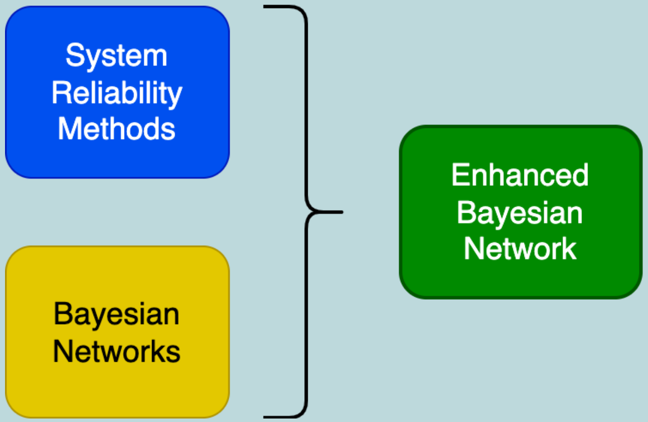
Pros:

- Higly efficient for **Discrete** rv
- Allow **Bayesian Update** therefore *inference*

Cons:

- No Continuous rvs
- Not efficient for small probabilities

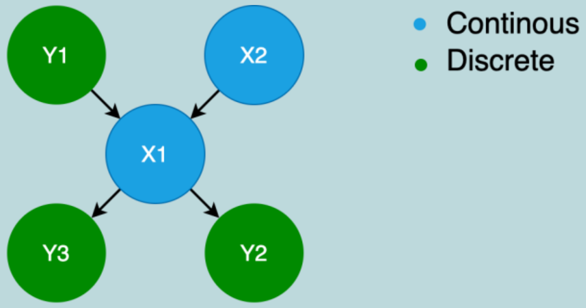
The idea of **enhanced** (with structural reliability methods) **BN**, is to *combine* the pros of the BNs and SRMs



eBNs are a tool able to:

- Implement Discrete and Continuous rvs
- With arbitrary distributions
- And any dependency

Enahnced Bayesian Network – Reduction



Formally

- **Discrete nodes** have a *finite sample space*
- **Continuous nodes** are *vectors of continuous rvs*
- **System pdf** is expressed by the combined effect of continous and discrete rvs

$$f(\boldsymbol{Z}) = \prod_{Yi \in \boldsymbol{Y}} f(yi|pa[Yi]) + \prod_{Xi \in \boldsymbol{X}} f(xi|pa[Xi])$$

** xi, yi are the realizations of Xi, Yi

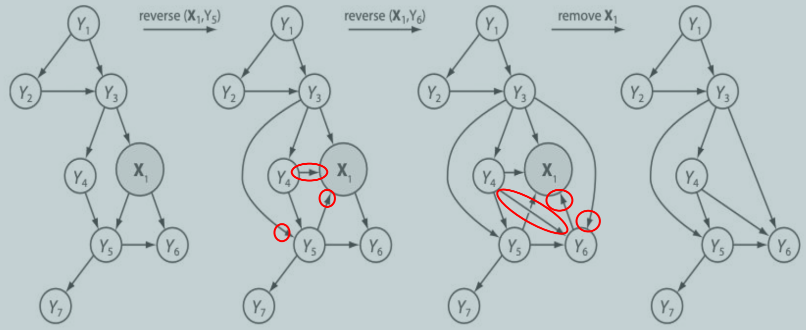
eBN reduction to rBN

In order to perform inference with eBNs using exact inference algorythm is necessary to reduce it into a reduce BN

Nodes Elimination

Continuous nodes have to be eliminated through *Shachter* theorems:

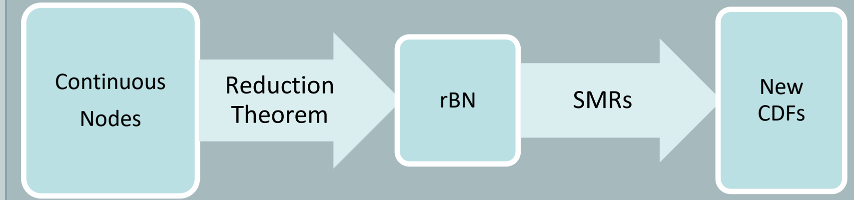
- **Barren nodes** Theorem
- **Reverse Link** Theorem



Potentials Calculation

Once rBN is obtained the conditional probabilities of discrete nodes (potentials) need to be updated

Can be demonstrate this problem has the general mathematical form of a Reliability problem. Therefore can be solved through SRMs.



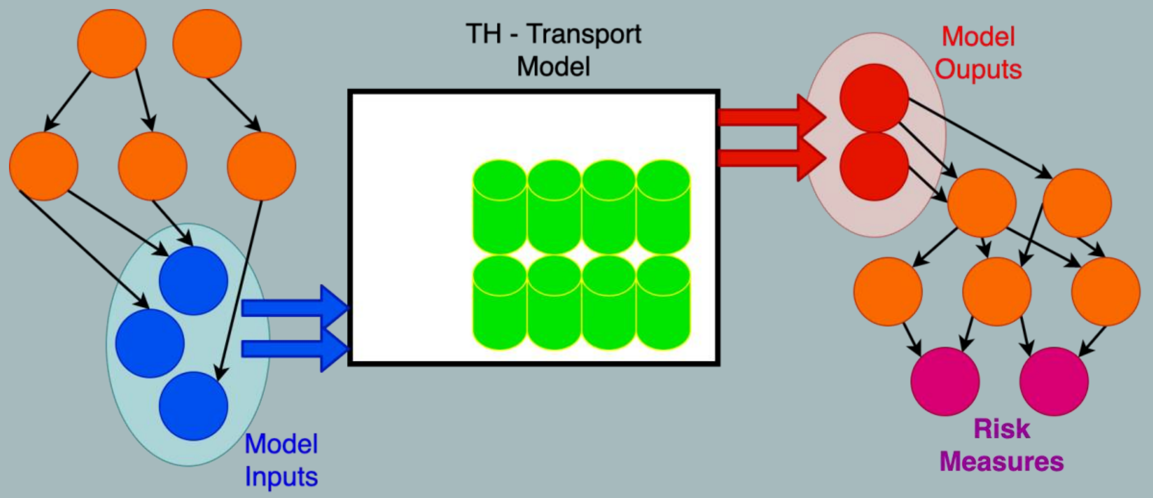
** Discretization of continuous nodes is necessary when evidence is available for them

Application in RADoN Project

Coupling

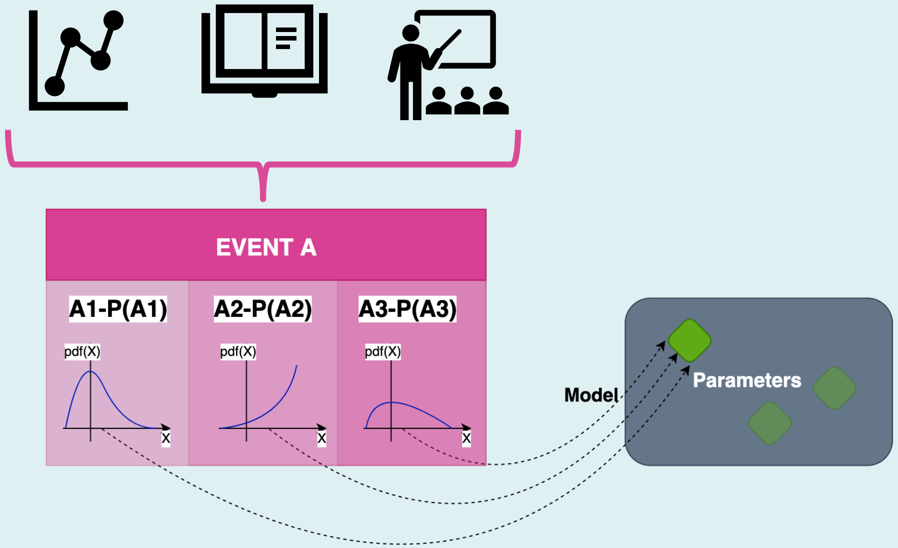
Basic Concepts of models coupling:

- Important parameters of TH models are treated considering their uncertainties and interdependencies (rvs)
- Hazardous events affects affects models parameters and their distributions (eBN)



Probability density functions:

- PDFs (or discrete values) of uncertainties parameter of each node of the eBN represent the most challenging point of the coupling process.
- Definition of distributions (or punctual values) will be addressed in 3 ways:
  - Physical Models or real data
  - Research papers
  - Expert-based knowledge



Up to now

- Toy example
- Sensitivity Analysis and Failure Probability analysis with few expert-based rvs

Still developing the Bayesian framework for both hazardous and not hazardous events, and their consequences over inputs pdfs.