

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

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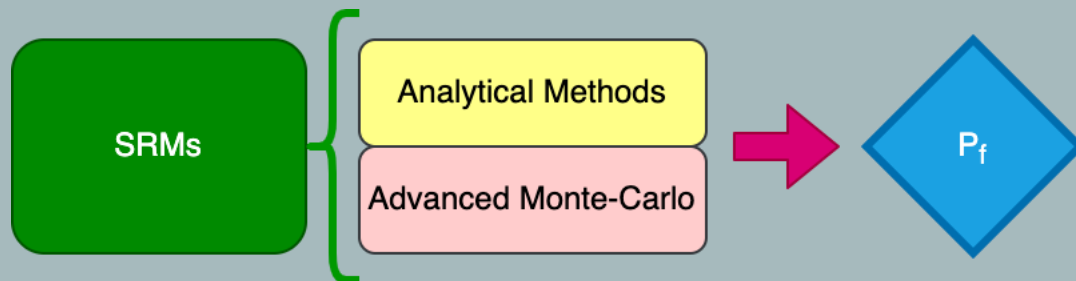
- Enhanced Bayesian Network (EBN) General Concepts
 - Callbacks
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- EBN Implementation
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- Surrogate Modeling
 - Artificial Neural Network (ANN)
- Next Step

EBN Presentation

EBN Presentation – Callbacks

Structural Reliability Methods

- System's state can be:
 - **'safe'** with a given set of parameters
 - **'not safe'** with a **slightly changed** set of parameters
- When one (or more) parameter/s of the system are **affected by uncertainties**:
 - *Parameter/s becomes random variable/s 'X'*
 - *System state became **dependent** on this random variable/s*

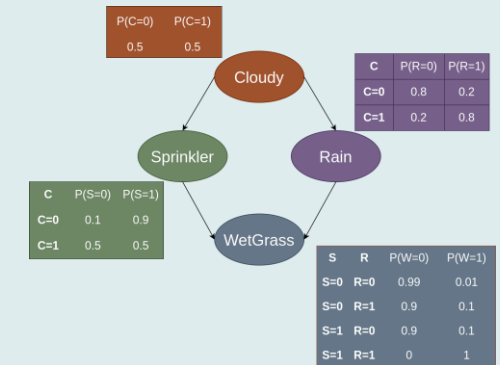


Bayesian Networks

- For evaluating the reliability of a system in **different scenarios**

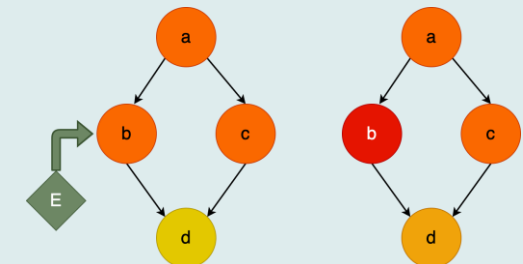
- General features:

- *multidisciplinary-usability*
- *Human-readability*
- *Compact-representation*



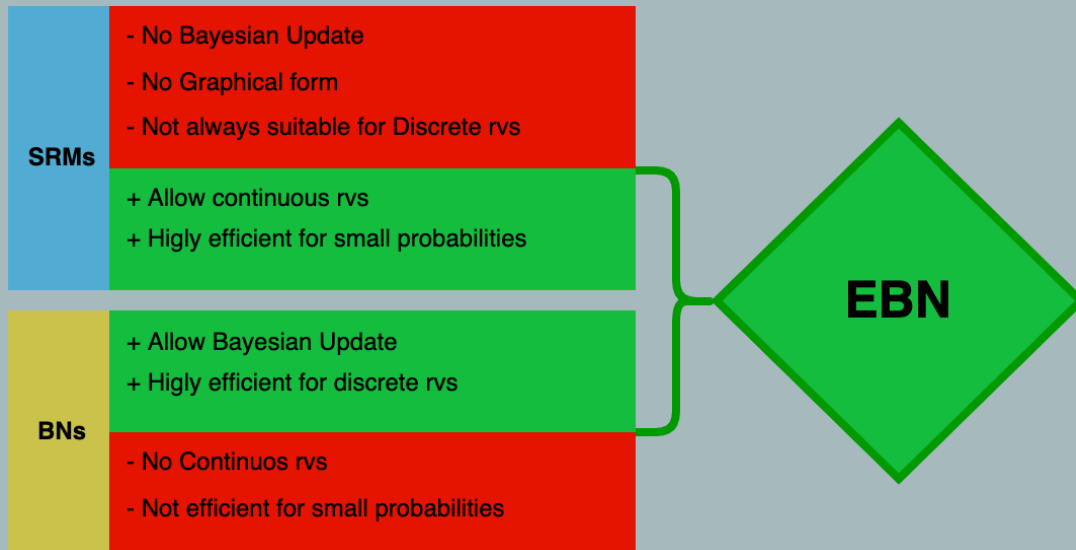
- Specific feature:

- **Bayesian Update** of marginal probabilities (once new data 'E' becomes available)
- **what-if analysis**
- **propagation of the information on the direction of interest**



EBN Presentation – EBN properties

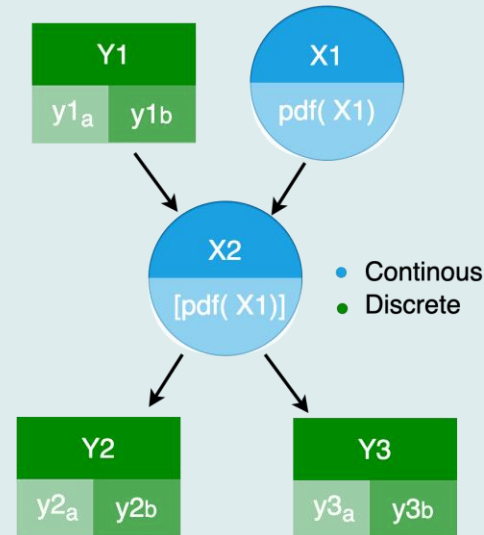
IDEA



eBNs (BNs Enhanced with SRM) are a tool able to:

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

HOW



Formally

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

System pdf:
$$f(\mathbf{Z}) = \prod_{Y_i \in \mathcal{Y}} f(y_i | pa[Y_i]) + \prod_{X_i \in \mathcal{X}} f(x_i | pa[X_i])$$

The problem of the evaluation of discrete probabilities (or pdf) of each node with at least one continuous parent has the same mathematical form of a System Reliability Problem!

EBN Implementation

EBN Implementation

WIP!

- Developing a **general purposes library for exploiting eBN in any application**
- Under development in [Julia](#)
- Based on [UQ.jl](#) Library (SRM part)

EBN Implementation

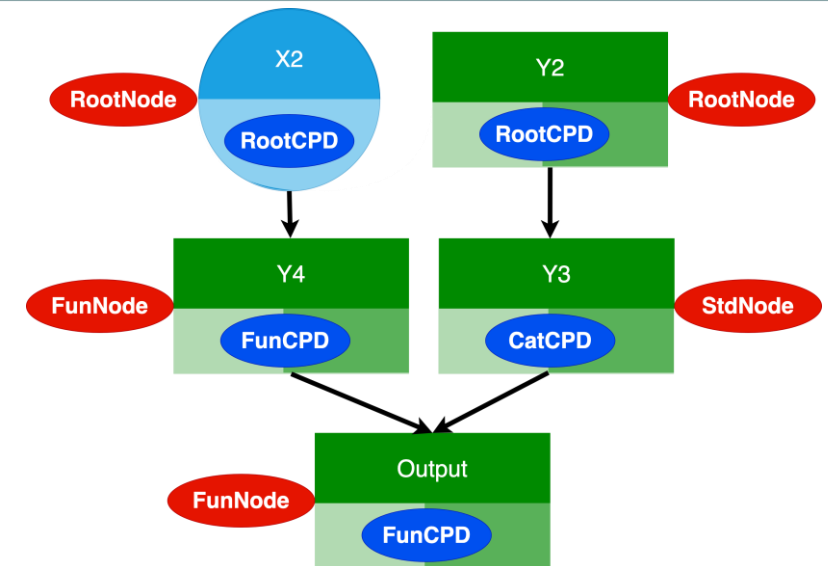
Implemented so far

➤ CPDs

- Structure to define the Conditional Probability Distribution (Discrete or Continuous) as:
 - 1) RootCPD
 - 2) NamedCategoricalCPD
 - 3) FunctionalCPD

➤ Nodes

- Structure to define the nodes of the eBN (Discrete or Continuous) as:
 - 1) RootNODE
 - 2) StdNODE
 - 3) FunctionalNODE



Bayesian Networks

- Structure to define the the Bayesian Network as Direct Acyclic Graph and perform the evaluation of each JointCPD given any evidence, as:
 - 1) StdBayesianNetwork
 - 2) EnhancedBayesianNetwork (WIP)

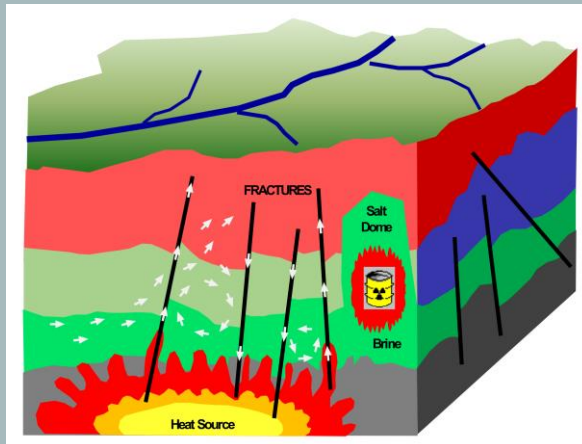
THC Model PoV

TH Model PoV

Case of Study

Risk Assessment

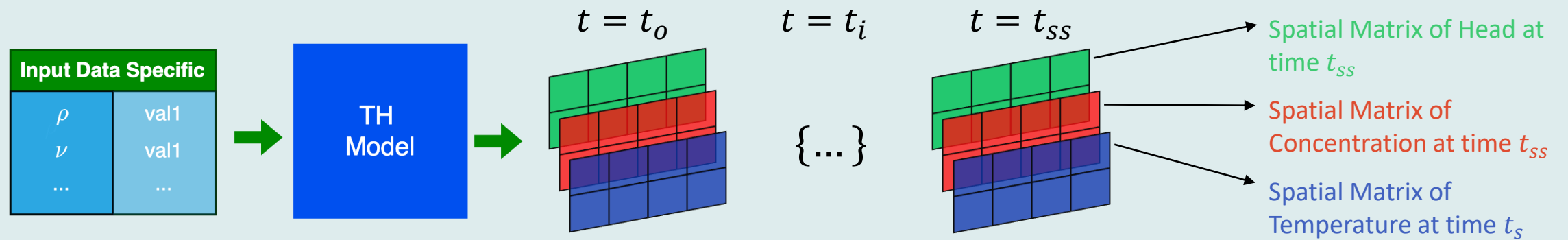
- **The Salt Dome Problem:**
 - Transport of solute (radioactive contaminant) due to groundwater flow within a salt dome (salt dissolution affects flow velocity and vice-versa)
- FE model (smoker.exe) is used to obtain matrices of head, temperature and concentration values at different time.



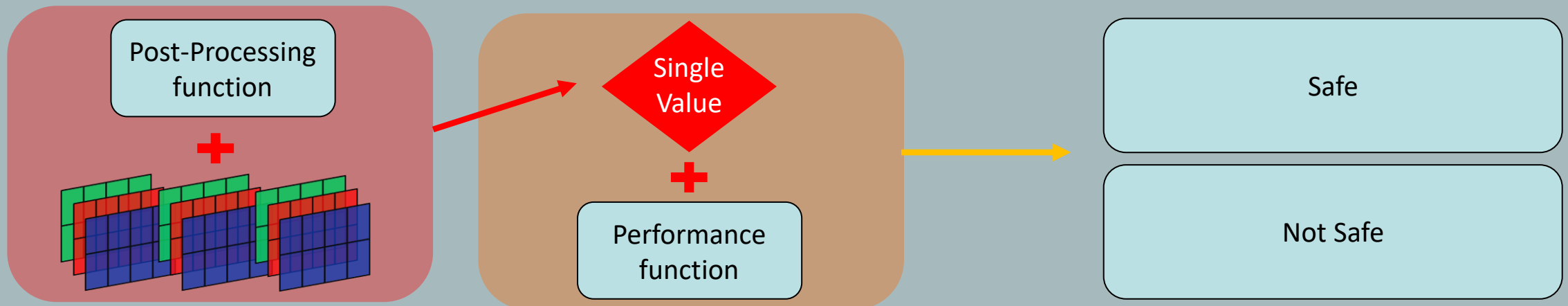
- Identification of the scenarios that affects FE model's inputs, and evaluation of the consequent outputs to determine if the final state is safe or not
- In order to distinguish between safe/not-safe salt dome's final state the FE output (matrices) needs to be
 - Post-Processed to obtain single values
 - Evaluated through a Performance Function to obtain a boolean output

TH Model PoV

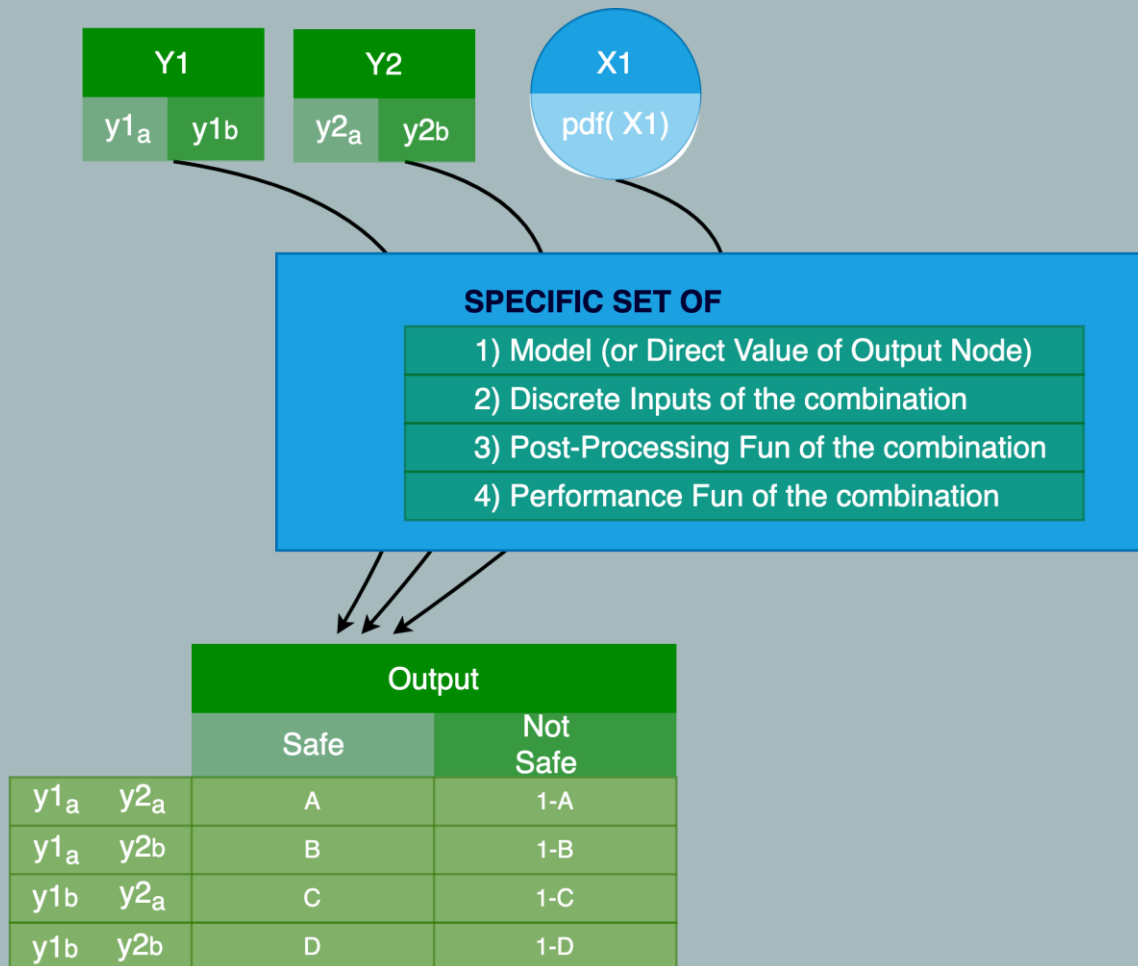
Model's output



Post-Processing + Performance Function



TH Model PoV



- This eBN general structure requires to define (for **each** discrete parents combination):
 - Whether or not the Model's simulation needs to be run
 - All discrete inputs
 - A post processing function
 - A performance function

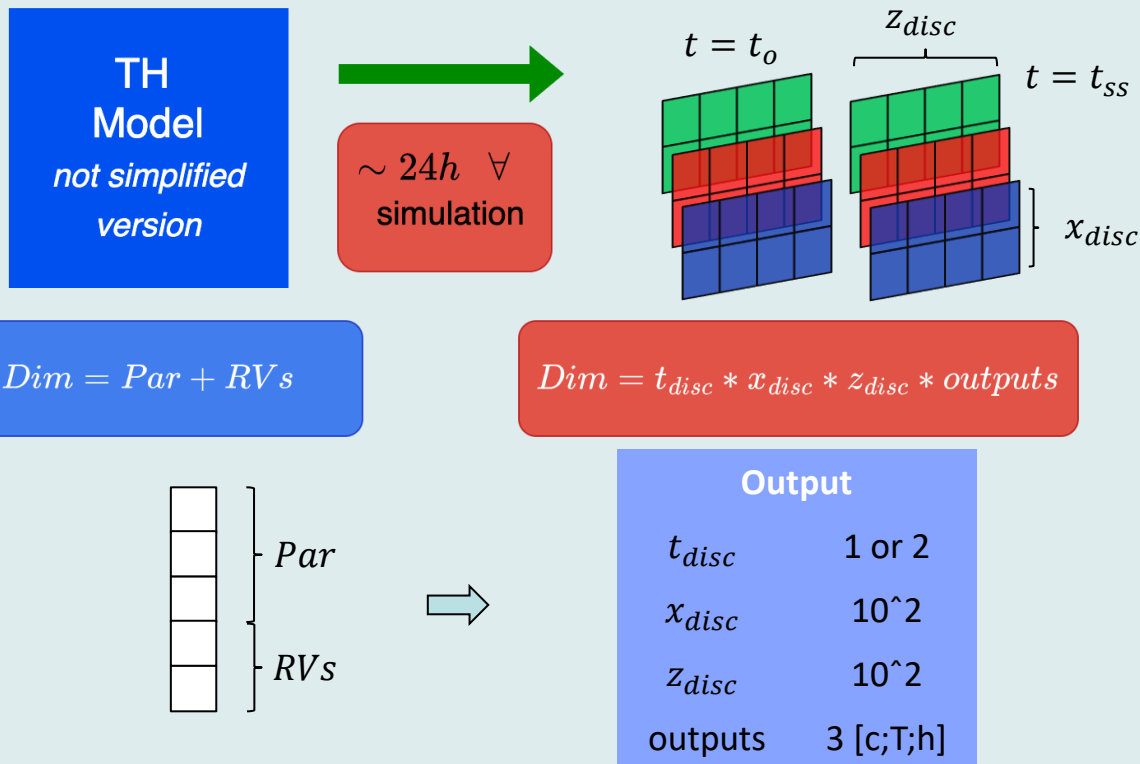
- Continuous random variable/s are not combination-specific and determined uniquely by the continuous node 'X1'.

- Such a structure, with respect to the one where *each node corresponds to a model inputs* is:
 - Less automatize
 - **More general**

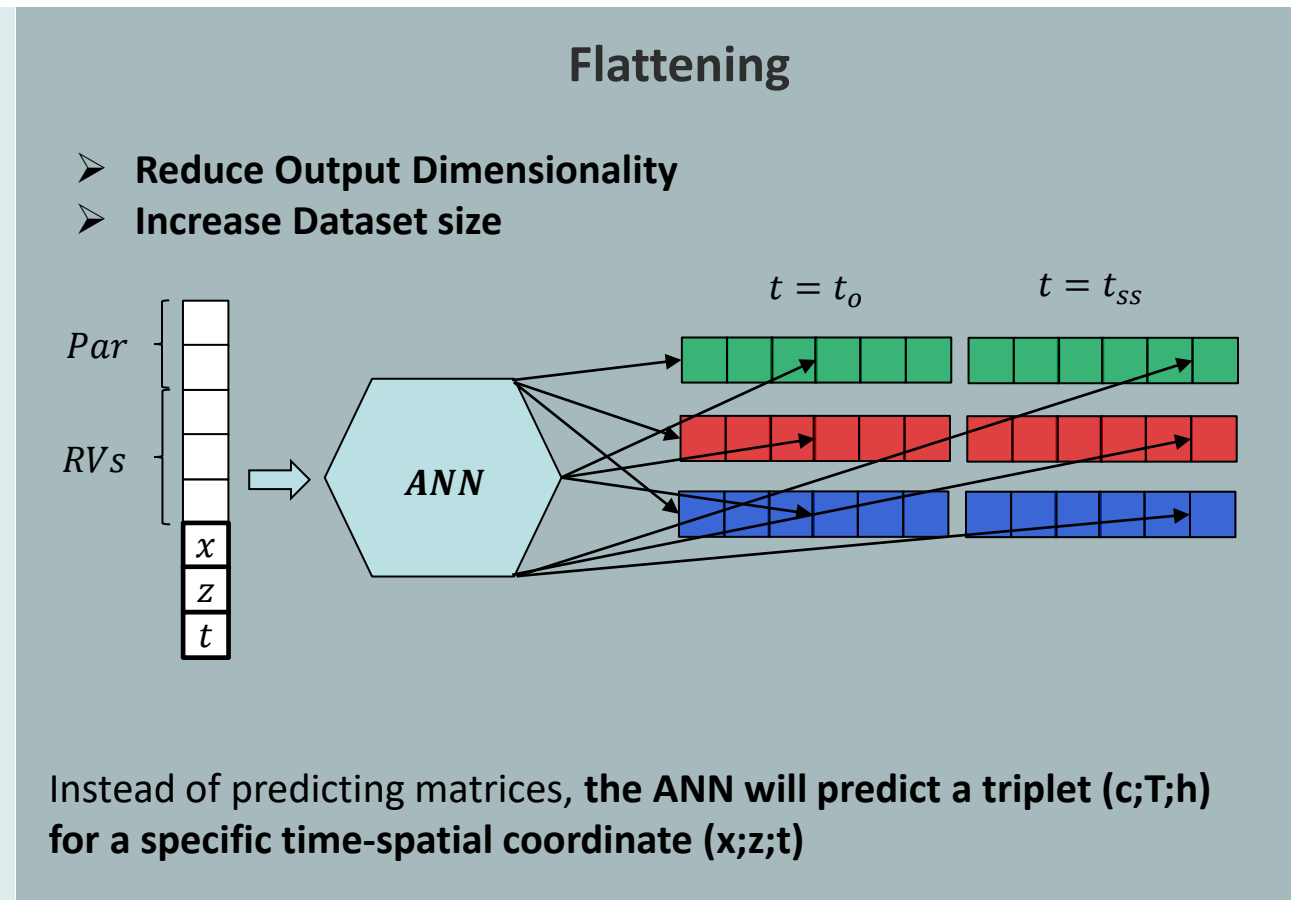
Surrogate Model

Surrogate Model - ANN

FE Models are too computational expensive in a framework where are required to be run several times in different scenarios, especially when low probability of failure have to be established



With a 24h simulation we obtain 1 output sample of 10^4 dimension!



Next Step

Next Step

eBN Library

- Finalise ‘**Enhanced Bayesian Network**’ structures. We are actually working on *node-elimination* algorithm
- Identification and implementation of **test cases** (e.g. *Straub 2019 – Bayesian Network Enhanced with Structural Reliability Methods: Methodology*)

RADON Project

- Identification of the events (eBN nodes) and their influences on THC model’s inputs (e.g. *NEA report - Updating the NEA International FEP List An Integration Group for the Safety Case (IGSC) Technical Note*)
- Implementation of Salt Dome case
- Developing Surrogate Model for TH Model (ANN or PCE or GP)

Possible Upgrade to eBN

- Introduction of ‘Imprecise Probability’ through Interval Variables => Enhanced ‘Credal Networks’