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Development of an Online Operator Tool to Support Real-Time Emergency Planning Based on the Use of Dynamic Event Trees and Deep Learning

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Outline

- Objectives
- PRA/PSA
- Limitation of static PRA
- Software and accident model
- Deep Learning
- Data preparation
- Results
- Conclusions

Objectives

- To support the declaration of site emergency

- To provide technical guidance to the State

What is PRA/PSA?

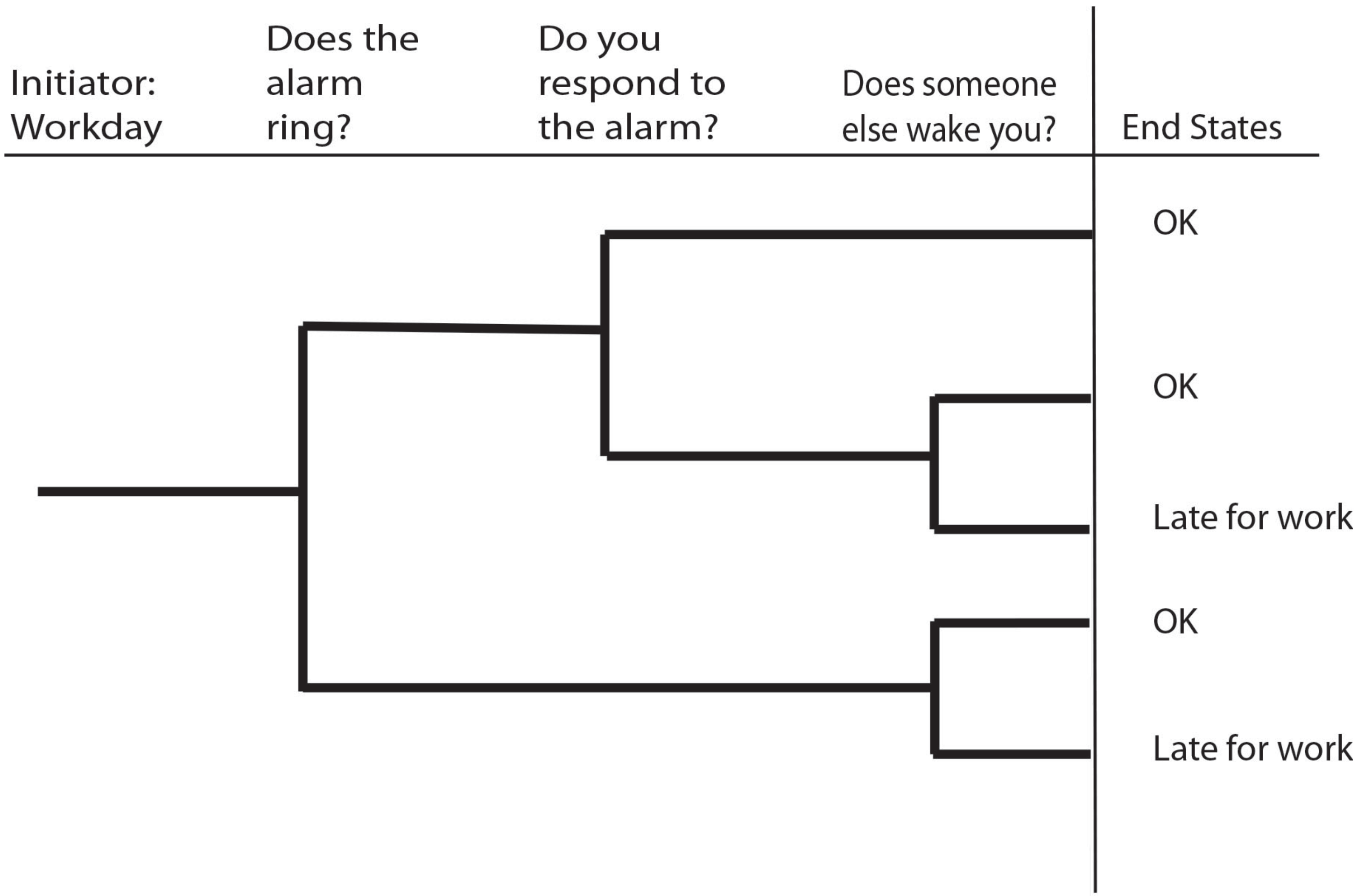
PRA/PSA: Probabilistic Risk/Safety Assessment

1. How likely is the core damage? (Level 1 PRA)
2. How likely is radioactive material release to the environment? (Level 2 PRA)
3. What levels of radiation are people estimated to be exposed to? (Level 3 PRA)

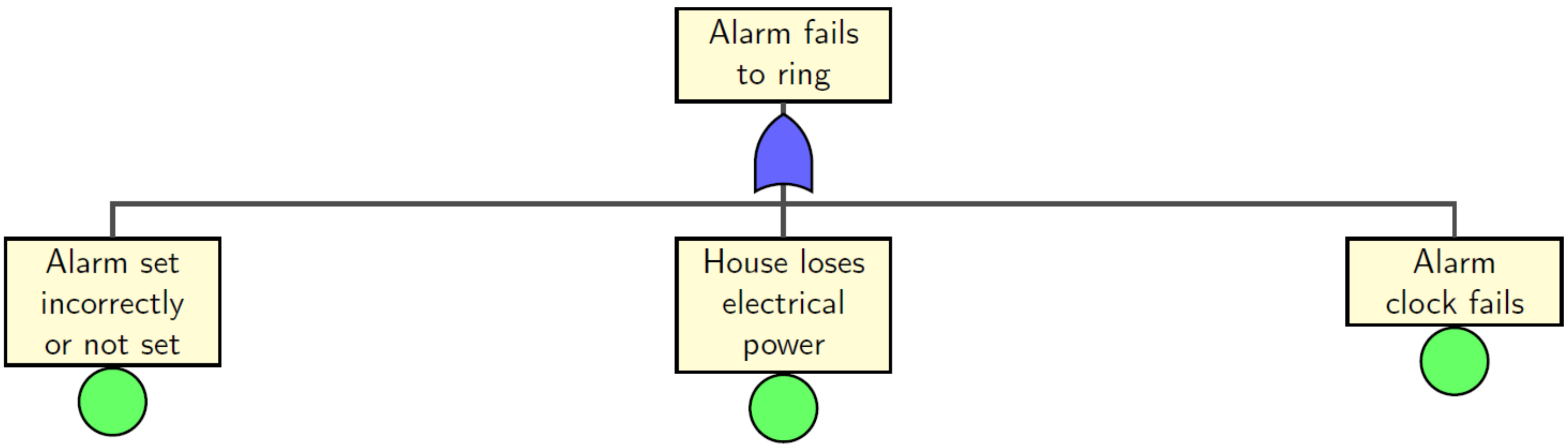
Basic PRA

- Event trees
- Fault trees

Event tree [1]


Initiator: Workday
Does the alarm ring?
Do you respond to the alarm?
Does someone else wake you?
End States
OK
OK
Late for work
OK
Late for work

Fault tree [1]


Alarm fails to ring
Alarm set incorrectly or not set
House loses electrical power
Alarm clock fails

Limitations of basic PRA [2]

- Time of occurrence of each event is not explicitly modeled
- Interaction among hardware/software/process/human behavior is not explicitly taken into account
- Order of event is preset by the analyst
- Often relies on the use of expert judgement

Simulation data used in this work

Seamless Level 2/3 probabilistic risk assessment using dynamic event tree (DET) analysis [3]

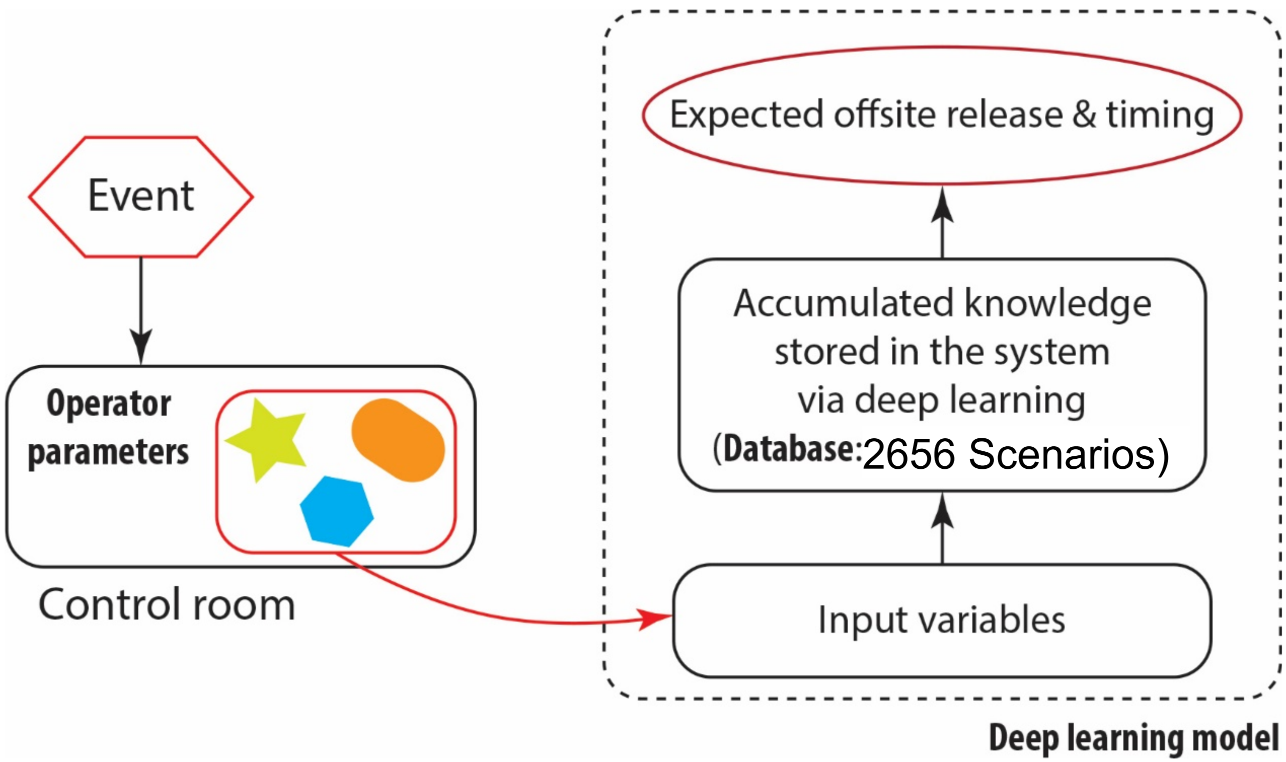
- Objective - to extend the ADAPT methodology to combine Level 2 and Level 3 PRA
- Accident model – PWR experiencing Station Black out
  - Total loss of AC power
  - MELCOR model used is based on state-of-the-art reactor consequence analysis (SOARCA)

Software structure

Deep Learning

- A subset of AI (Artificial Intelligence)
- Inspired by the field of neural networks, which most closely simulates the thought processes of the human brain
  - Can create the efficient network from large-scale unlabeled data sets
  - Applicable to temporally continuous datasets such as video, speech recognition and dynamics which makes it suitable for analyzing temporal characteristics of event evolution in nuclear power plants

Deep Learning model



→ Caffe

Caffe

- Open source computer code - a framework developed by Berkeley Vision and Learning Center (BVLC)
- A primary focus on pattern recognition of visual objects
- Capable of processing over 60 million images per day with a PC equipped with NVIDIA K40 GPU
- Written in C++ and also developed for Matlab and Python

Output Data

- Bin Over 10rem
- Bin 0-10rem

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Data Distribution

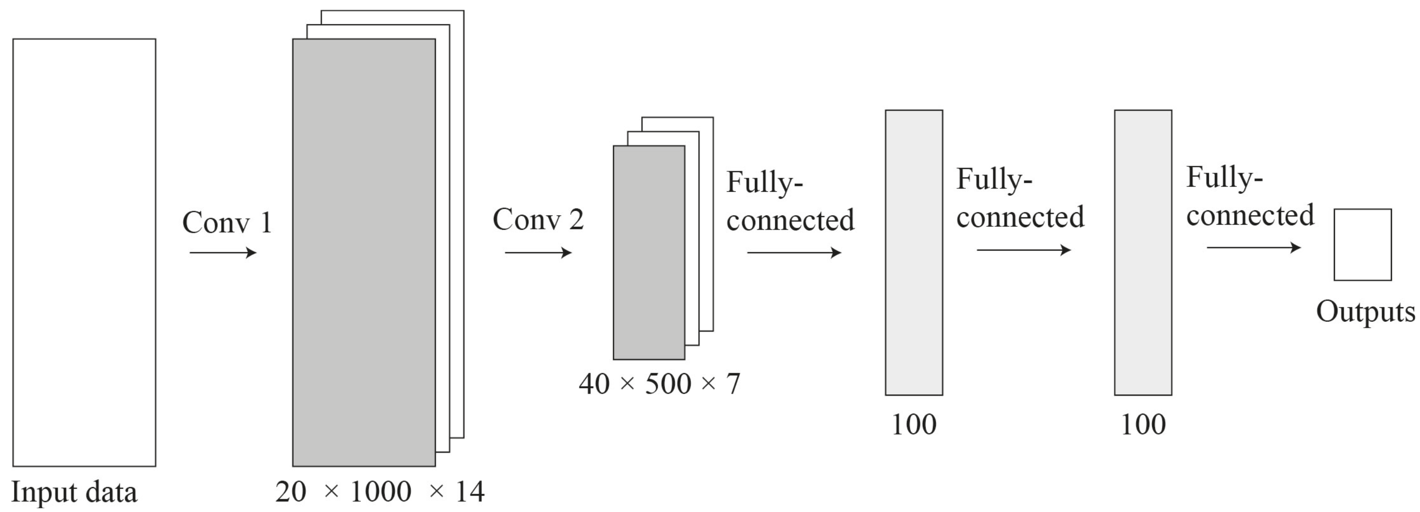
Data distribution of the training, testing, and validation sets (2 miles)

Train		Test		Validation	Total
Bin over 10rem	Bin 0-10rem	Bin over 10rem	Bin 0-10rem	Only Bin over 10rem	
96	90	26	26	2418	2656

Data distribution of the training, testing, and validation sets (10 miles)

Train		Test		Validation	Total
Bin over 10rem	Bin 0-10rem	Bin over 10rem	Bin 0-10rem	Only Bin over 10rem	
450	421	69	69	1647	2656

Network - architecture



Results (1/4)

FN: False negative TN: True negative
FP: False positive TP: True positive

- TP, TN, FP, FN
- Precision, Recall, f-measure, Accuracy

$$\text{Precision} = \frac{\#true\ positives}{\#true\ positives + false\ positives}$$

$$\text{Recall} = \frac{\#true\ positives}{\#true\ positives + false\ negatives}$$

$$\text{f} - \text{measure} = 2 \cdot \frac{Precision \times Recall}{Precision + Recall}$$

$$\text{Accuracy} = \frac{\#\text{true positives} + \#true\ negatives}{\#total}$$

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Results (2/4)

FN: False negative TN: True negative
FP: False positive TP: True positive

Contingency table of testing, validation, and testing + validation set

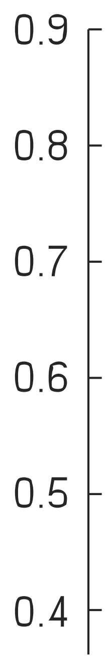
Number of Scenarios

	FN		FP		TN		TP	
	2 mile	10 mile	2 mile	10 mile	2 mile	10 mile	2 mile	10 mile
Testing	0	8	6	10	20	59	26	61
Validation	1	143	0	0	0	0	2417	1504
Testing + Validation	1	151	6	10	20	59	2443	1565

Results (3/4)

FN: False negative TN: True negative
FP: False positive TP: True positive

Contingency table with normalized probability (2 miles)



Contingency table with normalized probability (10 miles)

Results (4/4)

Accuracy, precision, recall, and f-measure of testing and validation set

	Accuracy		Precision		Recall		f-measure	
	2 mile	10 mile	2 mile	10 mile	2 mile	10 mile	2 mile	10 mile
Testing	0.8846	0.8696	0.8125	0.8592	1	0.8841	0.8966	0.8714
Validation	0.9996	0.9132	1	1	0.9996	0.9132	0.9998	0.9546
Testing + Validation	0.9972	0.9098	0.9976	0.9937	0.9996	0.9120	0.9986	0.9511

Conclusion

- A real-time tool to assist NPP operators in predicting the likelihood of future states of the NPP has been developed
- DL techniques are used to project the radiological outcomes to the public
- The data from the simulation of an accident scenario are used to illustrate the approach

References

1. NRC, U.S., Tutorial on Probabilistic Risk Assessment *(PRA).* Risk-Informed Regulation for Technical Staff.
2. Aldemir, T., A survey of dynamic methodologies for probabilistic safety assessment of nuclear power plants. *Annals of Nuclear Energy*, 2013. **52**: p. 113-124.
3. Osborn, D. (2013). Seamless Level 2 / Level 3 Probabilistic Risk Assessment Using Dynamic Event Tree Analysis. (Electronic Thesis or Dissertation). Retrieved from https://etd.ohiolink.edu/