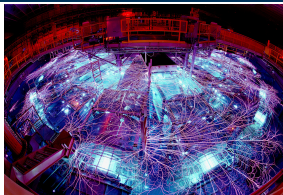


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Conditional Reduction in the ADAPT Framework

Targeting Subsets of a Discrete Dynamic Event Tree

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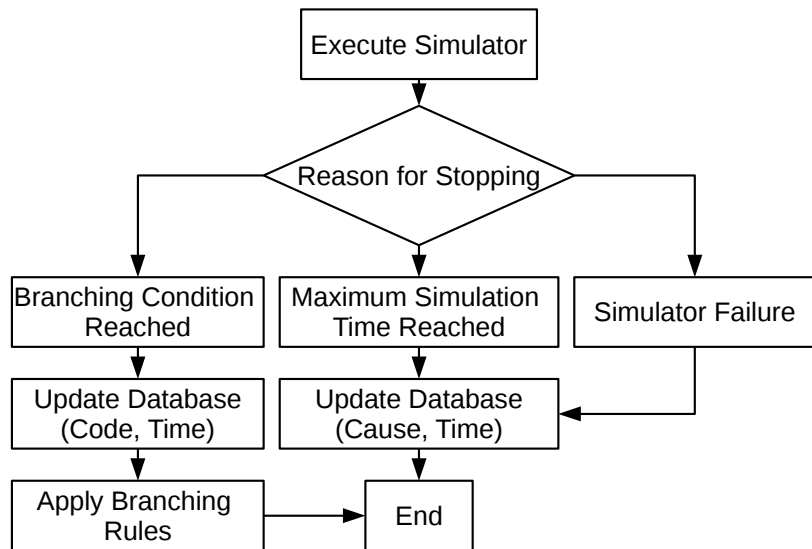
- Background
 - Discrete Dynamic Event Trees (DDETs)
 - DDET Tools
- Motivation
 - Difficulty in Visualization
 - Focus on Key Characteristics
- Code Modifications
 - Gathering Outputs
 - Checking Conditions
- Sample Problem
- Visual Interface
- Comparisons
- Concluding Remarks

- Traditional Probabilistic Risk Assessment (PRA)
 - Combined fault tree / event tree analysis
 - Binary success / failure branching
 - Does not traditionally capture timing effects
 - Prescribed order of events
 - Practitioner may miss important sequences or include non-realistic sequences

- Dynamic PRA (DPRA) using discrete dynamic event trees (DDETs)
 - Begin root branch with simulator plant state file at $t=0$
 - Typically just before initiating event occurs
 - Tree grows according to branching rules, e.g.:
 - Branch on scram success / failure when demanded
 - Branch on number of high pressure injection trains available when demanded
 - Branching triggers set in simulator input (e.g. MELCOR)
 - Simulator programmed to stop either at predetermined time intervals (ADS) or upon reaching a trigger (ADAPT)
 - Branching occurs only when appropriate, and always when appropriate (according to simulator parameter values)

- Accident Dynamic Simulator (ADS), 1996
 - Hard-coded link to RELAP5/TRACE for plant model and
 - Hard-coded link to Information, Decision, and Action in a Crew (IDAC) for operator model
- Reactor Analysis and Virtual Control Environment (RAVEN), INL, 2012
 - Control system for RELAP-7 plant model
 - Also linked to RELAP5-3D, MAAP, MELCOR
 - Single branching code for DDET operation
- Analysis of Dynamic Accident Progression Trees (ADAPT), SNL/OSU 2006
 - Initially linked to MELCOR
 - Intended to be simulator-flexible
 - Subsequently linked to RELAP5, MAAP4, SAS4A
 - Now allows arbitrary number of arbitrary branching codes

ADAPT Branch Behavior



- Visualization of a full DDET may not be feasible
 - 2006: *...the number of branches may reach several hundreds or even thousands.*
 - 2011: *...can produce hundreds of thousands of scenarios which is extremely cumbersome to post-process without some method of filtering the results.*
- Focus on key characteristics
 - Filter down to sequences that meet a set of arbitrary condition-at-time rules
 - Example rule set, return sequences where:
 - "primary pressure below 12MPa at any time before t=1hr"
and
 - "any fuel damage at any time after t=12hr"

Slicing Rule Parameters

Input Field	Sample Input
Name	<i>Low primary pressure early</i>
File	<i>plot_CVH-P_520</i>
Parameter Value	<i>12 MPa</i>
Parameter Operator	<i>2</i>
Time Value	<i>3600 s</i>
Time Operator	<i>2</i>

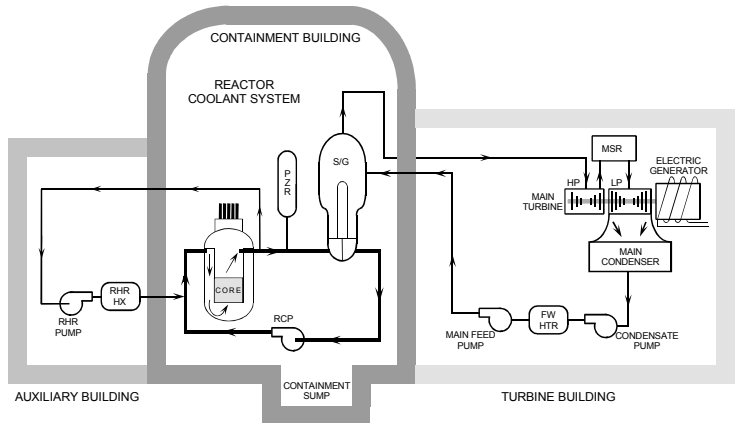
- Gathering condition data
 - Nuclear system code outputs (e.g. MELCOR) generally binary, require specialized extraction tools to translate to plain text
 - Modify branch execution script to extract data after simulator finishes
 - Interface will allow extraction of additional data after DDET has finished
 - Creates time series files for each variable in a standard format
 - Allows filtering on both input and output parameters

- Checking data values against rules
 1. Initialize matrices:
 - A: rule parameters [$n_rules \times 6$], use input data
 - B: branch rule compliance [$n_branches \times n_rules$], initially *True*
 - C: branch retention [$n_branches$], initially *False*
 2. For each rule in A, read time series file of variable of interest for each branch
 - If no points meeting a rule are found for a branch, mark cell in B with *False*
 3. For each branch, if all columns in B are *True*, mark entry in C *True*
 - Mark parents up to root branch *True*
 - Mark children down to end branches *True*
 4. Delete branches marked *False* in C

- DDET reduction added to ADAPT visual interface
 - Copy of base experiment created in database
 - Links to data files of base experiment
 - Deletion of copied experiment does not delete base experiment files
 - Sequences meeting all rules marked to retain, others discarded
 - (future) Branch probabilities recalculated conditional on rules
 - (future) Extracting additional data
- Sliced version of DDET viewable with same tools as base DDET

Sample Problem (1/3)

- MELCOR Model Split:
 - Containment / Turbine Buildings
 - Auxiliary Building



- Residual Heat Removal System (RHR) Interfacing System Loss of Coolant Accident (ISLOCA)
 - Both isolation motor-operated valves (MOVs) held open in cyber-induced controller failure
 - May lead to large pipe break outside containment
 - May lead to RHR heat exchanger tube rupture, introducing reactor coolant system (RCS) water into component cooling water (CCW)
 - Possibility of failing CCW, upon which many engineered safety features depend
 - May lose safety injection (SI) pumps

Sample Problem (3/3)

- MELCOR model split to allow flexibility in handling possible contamination of auxiliary building
 - Hydrogen combustion may lead to building failure
- For sample analysis, allowing only one-way transfer of control
 - Containment / Turbine model runs to maximum simulation time, then Auxiliary model runs
 - Disregards potential feedback of RHR leak on systems in other model
 - In some scenarios, this may be appropriate
 - Contamination may impede operator actions to isolate and mitigate ISLOCA
- Final analysis will support two-way transfer of control
 - Single MELCOR model
 - Linked habitability model (RADTRAD)

Results (1/3)

- 851 branches, 384 unique sequences
- Difficult to visualize



- Return sequences meeting:

Input Field	Rule 1	Rule 2
Name	<i>Low pressure early</i>	<i>Late core damage</i>
File	<i>plot_CVH-P_520</i>	<i>plot_CFVALU_85009</i>
Parameter Value	<i>12 MPa</i>	<i>0.01</i>
Parameter Operator	<i>2</i>	<i>1</i>
Time Value	<i>3600 s</i>	<i>43200 s</i>
Time Operator	<i>2</i>	<i>1</i>

- Returned 328 sequences out of 384 total
 - $1 - (5.2 * 10^{-8})$ of total probability of sequences retained
 - Only sequences with very small probabilities were removed
 - Early depressurization and fuel damage are likely in this large break ISLOCA (normalized to initiating event probability of 1)
- Reduced experiment behaves identically to base experiment
 - Visualization
 - Dynamic importance measures

- Recent Expansion of ADAPT
 - Multi-simulator support
 - Dynamic importance measures
 - **Slicing of DDET conditional on user-input rules**
- Enabling better visualization with ADAPT will expand the insights that may be gained using DPRA
- Addresses advanced PRA objectives*:
 - *Reduces reliance on unnecessary modeling simplifications and surrogates (i.e., more phenomenological)*
 - *Makes process and results more scrutable*
 - *Leverages advances in computational capabilities and technology developments, but is computationally tractable*
 - *Allows for ready production of uncertainty characterization*

* Don Helton, *Scoping Study on Advancing Modeling Techniques for Level 2/3 PRA*, USNRC, May 2009

- Tuesday - Current Topics in Probabilistic Risk Analysis I
 - 1:00p: N. Martin, Pruning of Discrete Dynamic Event Trees Using Density Peaks and Dynamic Time Warping
 - 1:25p: M. Denman, Preliminary Cyber Informed Dynamic Branch Conditions for Analysis with the Dynamic Simplified Cyber MELCOR Model
 - 2:40p: Z. Jankovsky, Dynamic Importance Measures in the ADAPT Framework
- Wednesday - Computational Methods
 - 10:05a: Z. Jankovsky, Conditional Tree Reduction in the ADAPT Framework
 - 10:30a: Z. Jankovsky, Extension of the ADAPT Framework for Multiple Simulators
- Wednesday - Nuclear Installations Safety: General I
 - 1:00p: J. Cardoni, Severe Accident Modeling for Cyber Scenarios