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Development and Application of the Dynamic System Doctor to Nuclear Reactor Probabilistic Risk Assessment

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Other Study Participants

- Sandia
  - Sean Dunagan
  - Jason Zuffranieri
- Ohio State University
  - Tunc Aldemir
    - Professor Nuclear Engineering
  - Richard Denning
    - Adjunct Professor
    - Retired Battelle Technical Manager of Reactor Safety
    - Member Advisory Committee on Reactor Safeguards
  - Three graduate students
    - Two nuclear engineering
    - One computer science

Background

- NNSA labs have supported the Nuclear Regulatory Commission for 30+ years
- Methods developed for analyzing nuclear reactor safety have also been used in
  - Nuclear weapon safety, security, and use control analyses
  - Nuclear weapon transportation work
  - Space mission studies
  - Other investigations of complex systems, e.g.,
    - Electric power grid
    - Nuclear waste repositories
    - Liquified natural gas facilities

Probabilistic Risk Assessment (PRA)

- A method used in all those applications is probabilistic risk assessment
  - What is the likelihood of something bad happening?
  - How bad is it?
- An element of a PRA is the analysis of the accident progression (Accident Progression Event Tree)
  - 1985-1991 a great leap forward in APET methods
    - Number of questions could be several hundred
    - Not limited to binary answers
    - Questions could be linked to small programs
    - Multiple dependencies among questions explicit

PRA (continued)

- But, applications of the APET approach stalled
  - *Extremely resource intensive to create, review, and apply*
  - Hundreds of million of sequences could be generated
  - Static—not linked to an severe accident computer code
    - Must make timing assumptions in advance, or
    - Must continually re-ask the same questions in light of different events
- NRC has reverted to a simpler approach
  - OK for reactor types for which we have much test data and analysis
  - But for newer generation of reactors, we lack the knowledge base

Problem

- Can we make the PRA APET analysis more efficient?
- Our organization within Sandia had asked universities for ideas concerning nuclear reactor safety research
- Ohio State University proposed using their “dynamic system driver” to support APET construction using state space analysis
  - Driver is a computer code that directs other codes
  - Several had used a similar approach on very small problems (only several percent of whole sequence)
  - But, they were imbedding the driver into the other codes (had not included computer expertise on their teams)

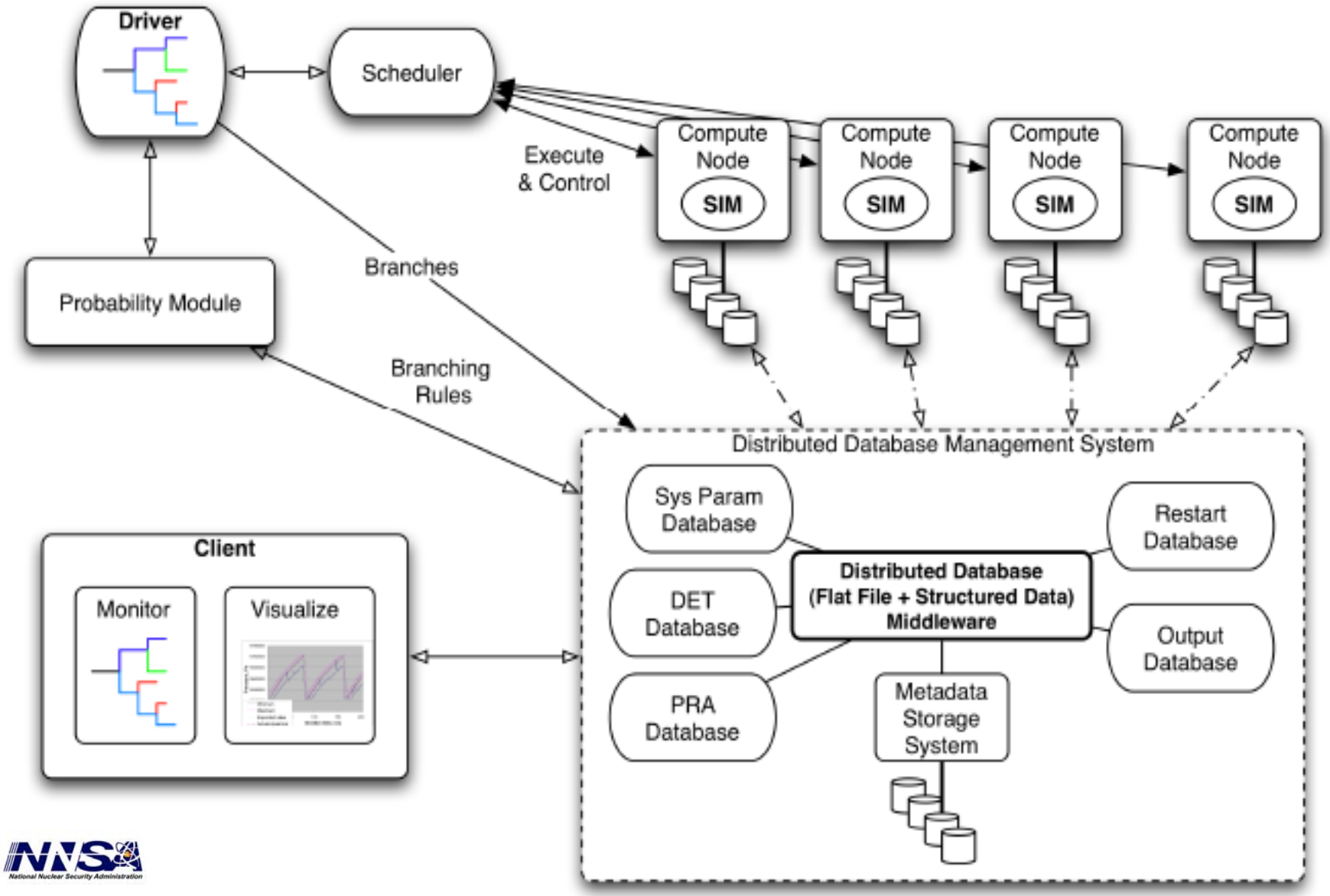
Problem (continued)

- We counter-proposed using the dynamic system driver approach to
  - Link directly to a system level severe accident modeling code (MELCOR-- ~ 500,000 lines of code)
  - Have the driver create the event tree for approximately 1/3 of an overall reactor problem
  - Have the driver determine the frequencies of the event tree pathways and their uncertainty
  - Keep the OSU driver flexibility and dynamic approach
- This is the LDRD started the beginning of FY 05
  - Division of work
    - OSU builds the driver for this size of problem and code linkages
    - Sandia provides support for MELCOR and APET/PRA understanding
    - Both provide severe accident knowledge support

Accomplishments

- **We've done it!**
  - **The basic approach has worked**
    - **We can set up the problem, start the driver (now several codes), walk away, and come back (a few days) later and find an event tree drawn and its sequences solved**
    - **ADAPT—Analysis of Dynamic Accident Progression Trees**
  - **But, we have some "minor" work still to do to make it a usable product**
  - **Architecture supports the application of method to many different types of problems**

SCHEMATIC OVERVIEW OF COMPUTATIONAL INFRASTRUCTURE



National Nuclear Security Administration

Computational System Overview

- Plant Simulator SIM (currently, MELCOR code)
  - runs simulation on computer nodes
- Distributed Database Management System
  - provides initiating conditions
  - records the duration of simulation
  - stores Restart and Output databases
- Scheduler
  - receives information from
    - plant simulator on setpoint crossing
    - probability module on branch probabilities
  - decides whether to branch or not

Plans for Completion

- **Between now and the end of March 07, we wish to**
  - **Refine the data base and its linkage**
  - **Optimize scheduler**
  - **Upgrade the incorporation of uncertainties**
  - **Make the graphical user interface more user friendly (less “geek-like”)**
  - **Publicize our work**

Getting the Word Out

- **Papers to date (LDRD did not pay for travel for the third one.)**
  - **"A Graphical Tool for the Analysis of Event Trees", SAND 2006-0319C, presented at ANS Annual Meeting, June 4-8, 2006.**
  - **"Treatment of Uncertainties in Modeling the Failure of Major RCS Components in Severe Accident Analysis", SAND 2006-0318C, presented at ANS Annual Meeting, June 4-8, 2006.**
  - **"Distributed Dynamic Event Tree Generation for Reliability and Risk Assessment", SAND 2006-0807C for CLADE 2006 workshop (Challenges of Large Applications in Distributed Environments), held in conjunction with the 15th International Symposium on High Performance Distributed Computing, Paris, France, June 19, 2006 (the conference itself was June 19-23).**
  - **"Treatment of Uncertainties in Modeling Hydrogen Burning in the Containment during Severe Accidents", to be presented at ANS Winter Meeting, Albuquerque, NM, November 12-16, 2006, SAND 2006-4050C.**
  - **"A Software Tool for the Creation and Analysis of Dynamic Event Trees", to be presented at the ANS Winter Meeting, Albuquerque, NM, November 12-16, 2006, SAND 2006-4049**

Getting the Word Out (continued)

- Several staff members at the NRC have kept abreast of our progress (including senior technical advisors)
  - After the first three papers,
    - We have heard from a number of others at NRC
    - NASA personnel have spoken with us
- Workshop
  - NRC is hosting a severe accident analysis meeting in Albuquerque at the end of September
  - They have asked us to hold a half day workshop on this work then
  - We are inviting analysts from Sandia's nuclear weapon safety and security and nuclear weapon transportation groups to the workshop
    - Over the past six months, we have been telling several what we have been doing
- We shall continue to write papers and are starting the process to produce journal articles

Conclusion

- If you have a complex systems problem amenable to portrayal as an event tree, and
- If you have a computer code you use to provide you with how the events could progress,
- If this code is has event switches or is amenable to adding them,

- See us. We can help.