The Open-PSA Initiative

Standard Representation Format for Probabilistic Safety Analyses

Towards a New Generation of Models and Tools

Credits

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- Report Layer

Where Are We?

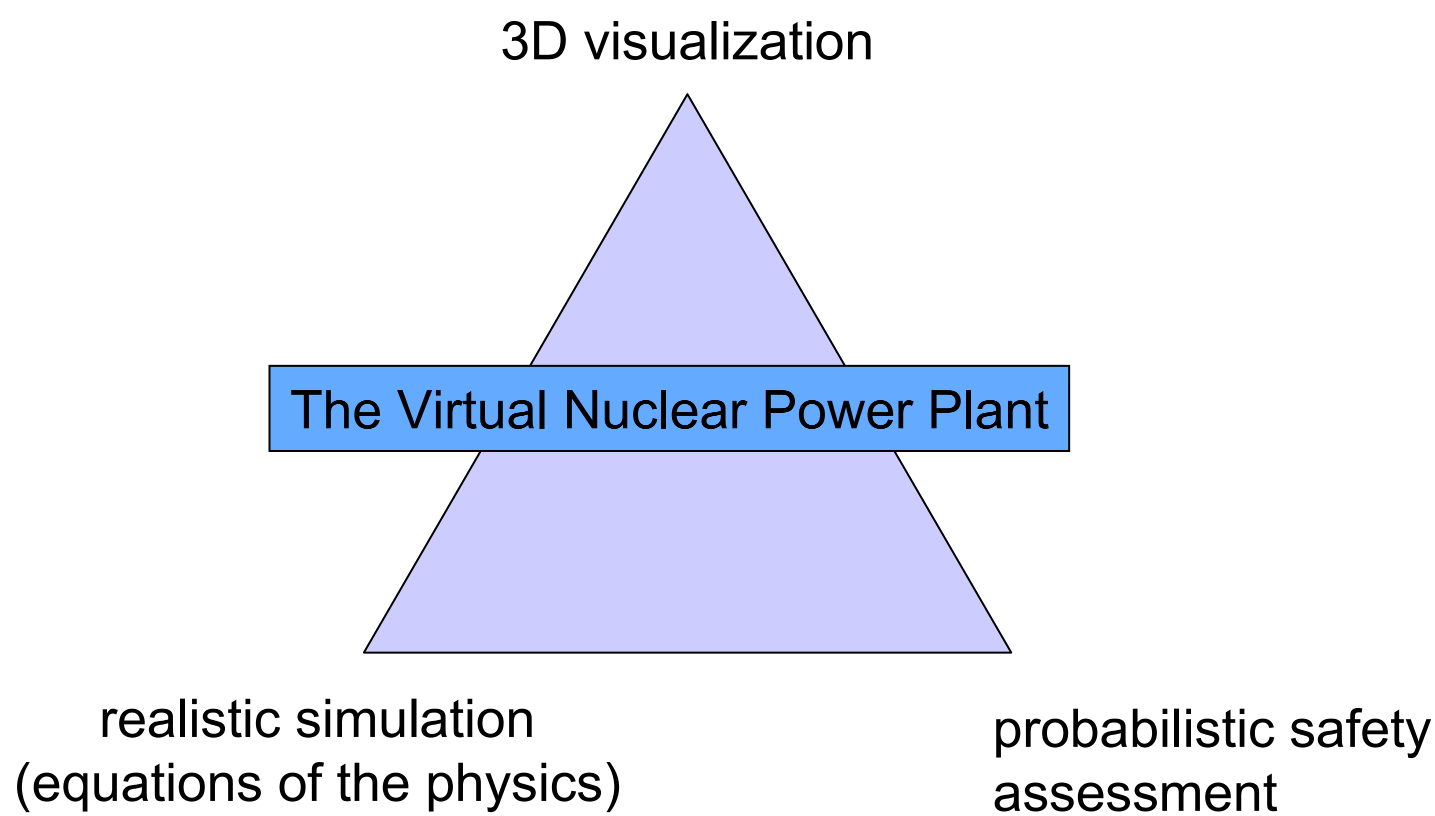
- Detailed models have been developed for level 1 and level 2 PSA
- Good tools have been developed to design and assess models

... but

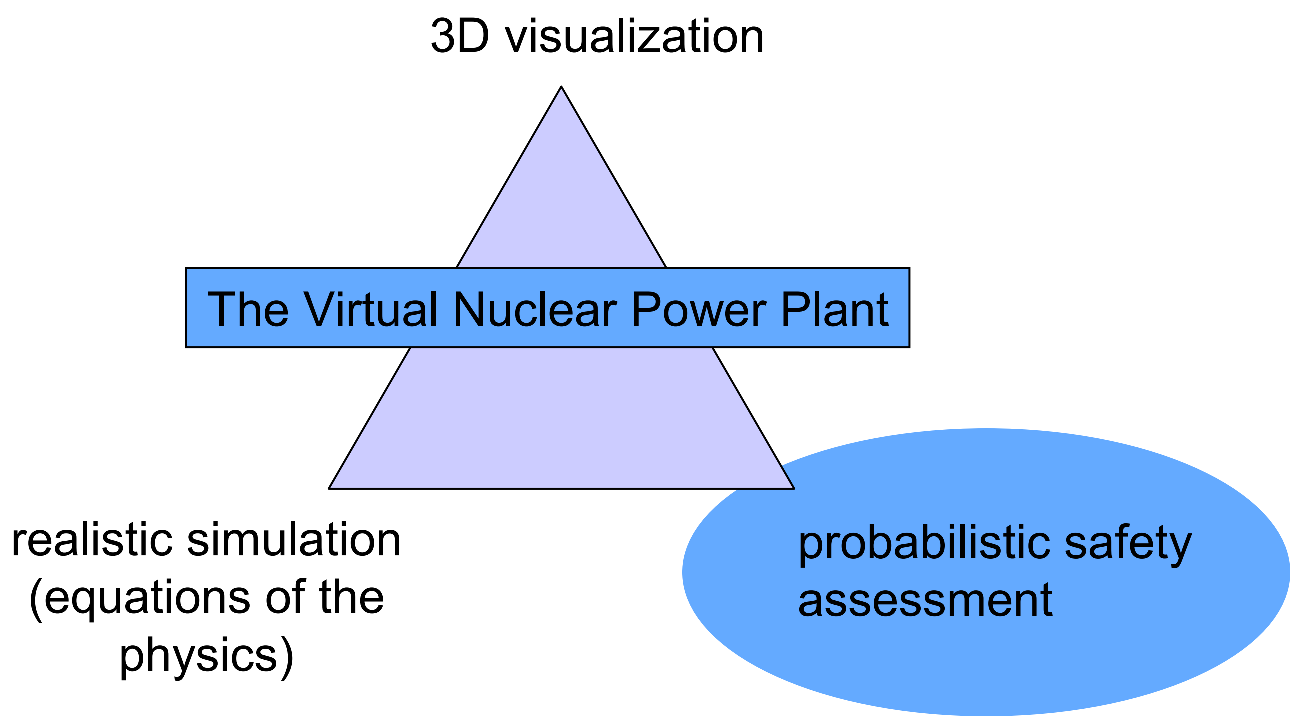
- Models are hard to master, to check for completeness, to maintain...
- Models are tool-dependent
- Calculation engines have flaws

Where We Want to Go?

The future ...



A First Step...

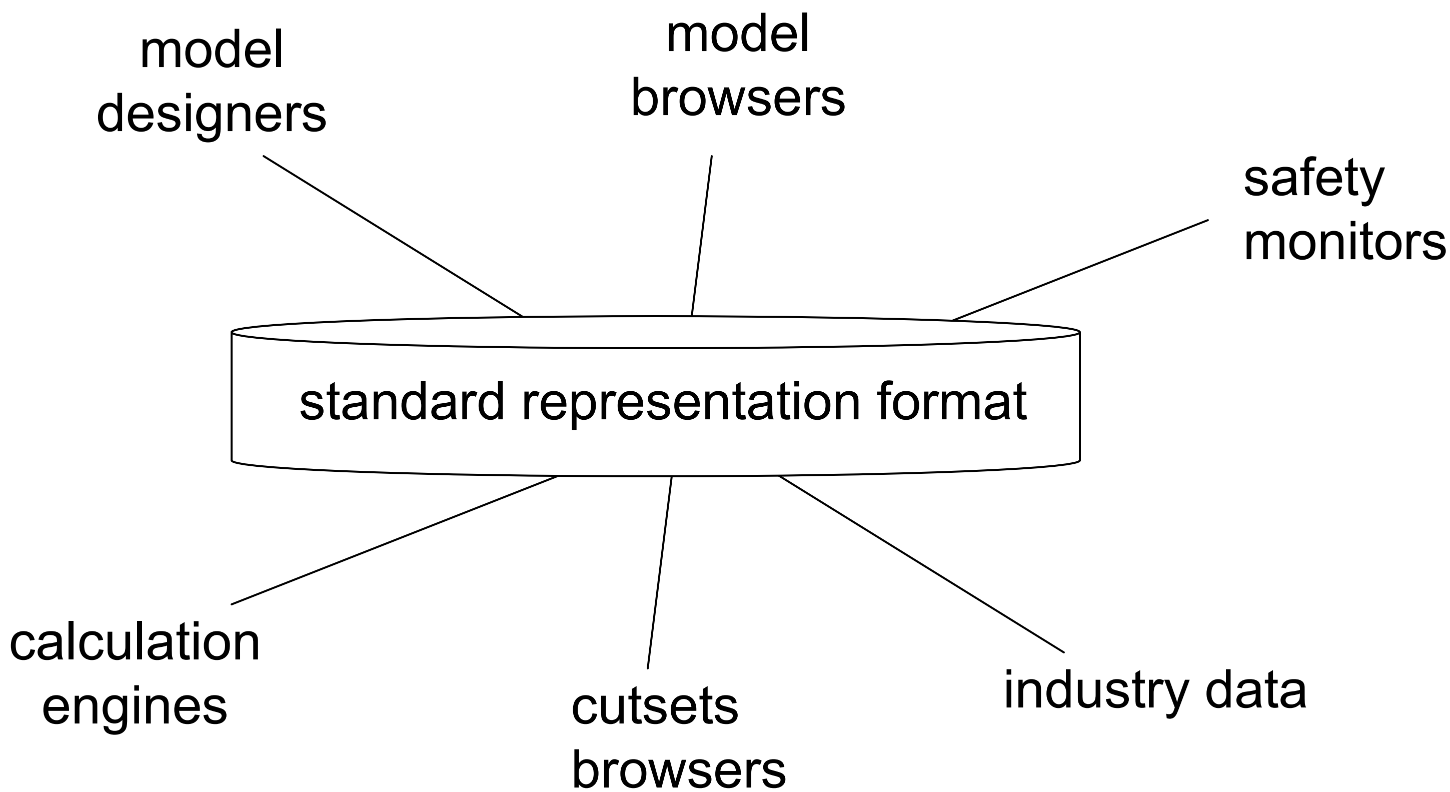


An International Standard Representation Format for PSA Models

Why Do We Need a Standard?

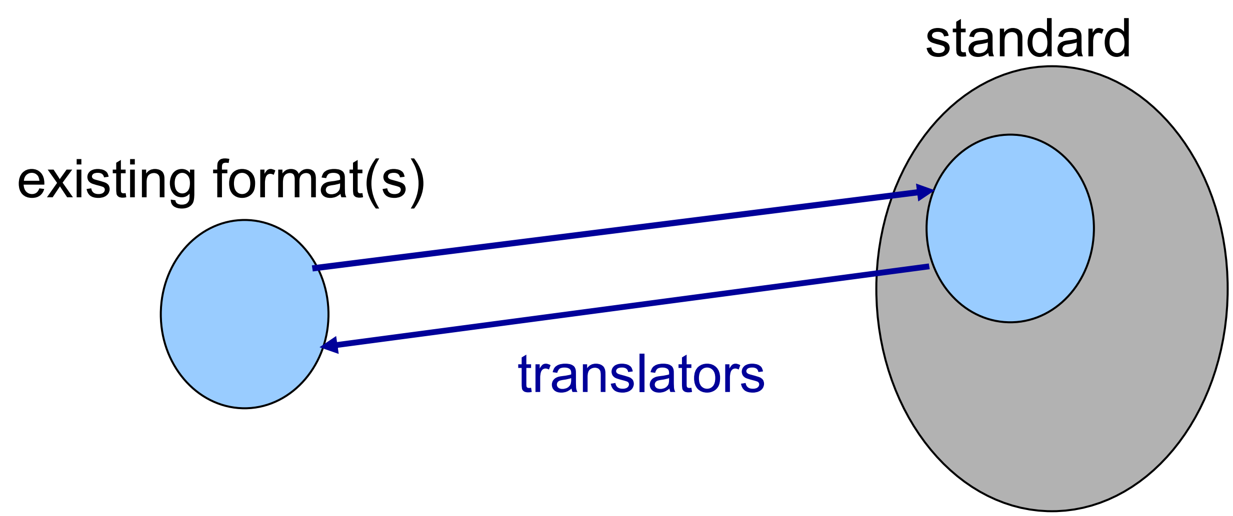
- Reduce tool dependency
- Have a better confidence in approximations (quality insurance)
- Cross check calculations
- Develop new calculation engines
- Design new model browsers and safety monitors
- Review and document (existing) models
- Clarify (unify?) modeling methodologies
- Call external tools (Level 2 PSA)
- Extend fault trees/events trees formalism
- …

The Open-PSA Architecture



Requirements

- It should be possible to cast any existing model



- The role of each element should be clearly identified and have an unambiguous semantics
- The standard should be easy to embed in existing tools and easy to extend

… XML format

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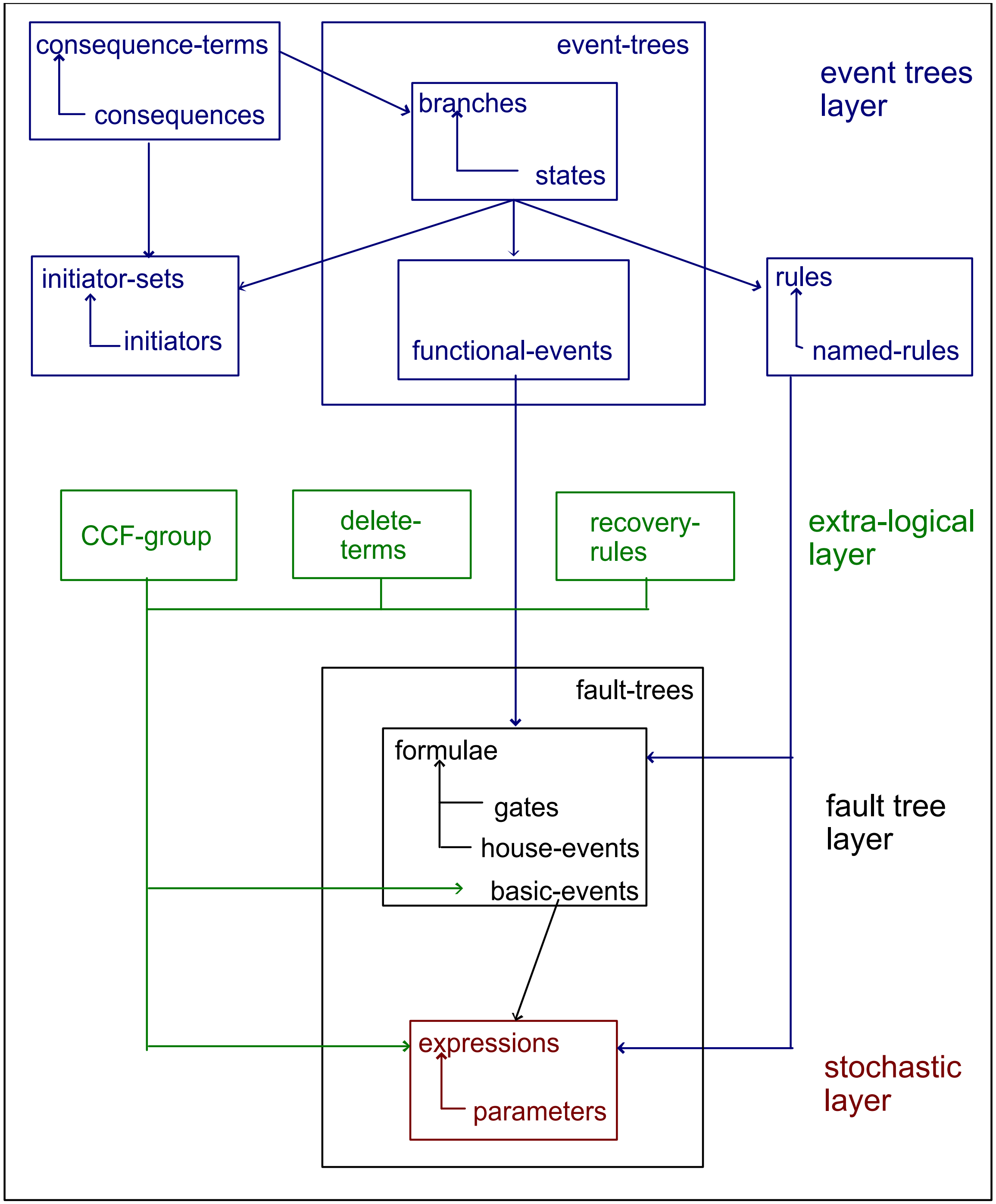
Anatomy of the Standard

Methodology

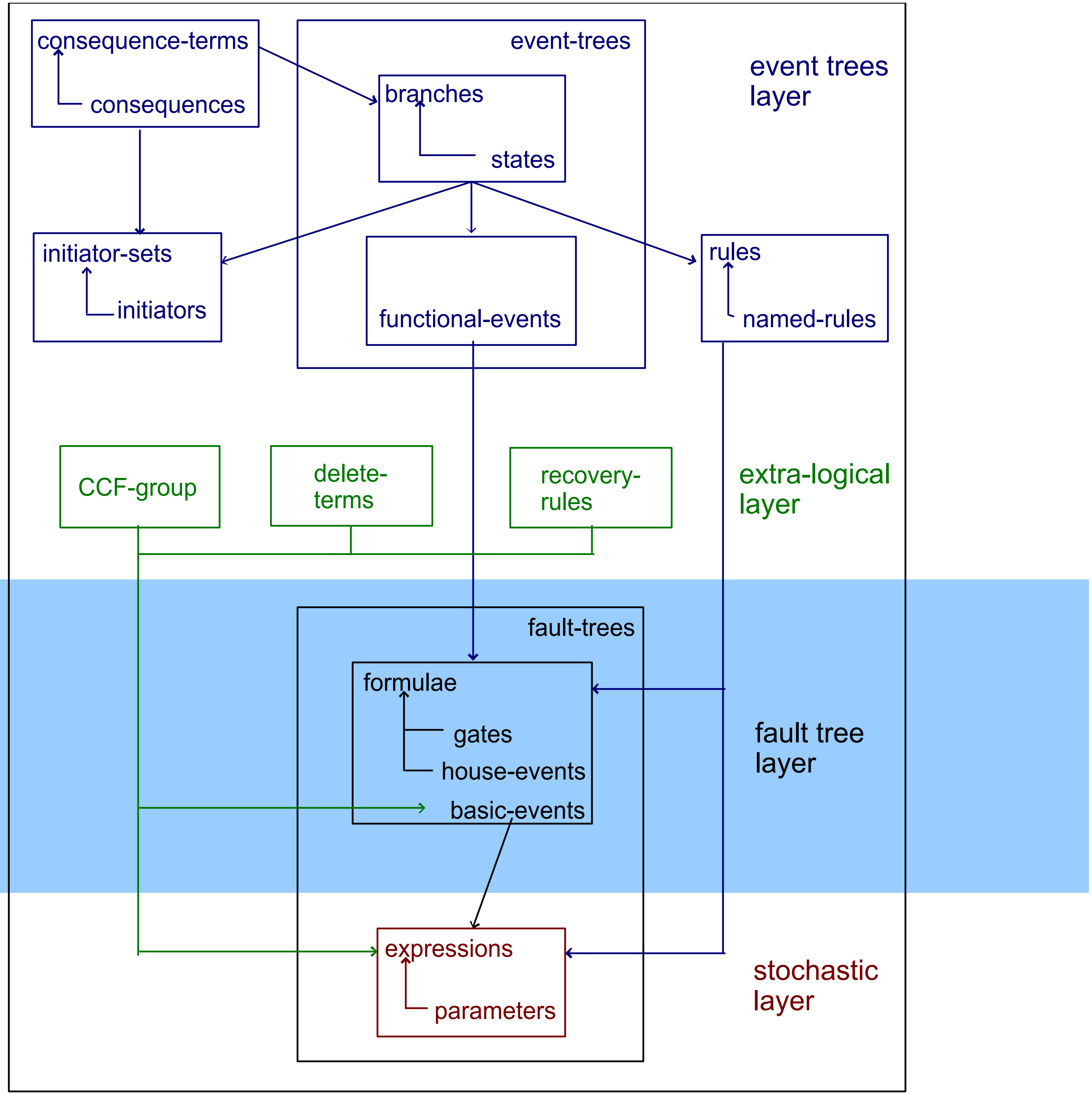
- We considered models built with the main tools available on the market
  - Cafta, Saphire, RiskSpectrum, Riskman, Fault Tree free...
  - US, Japanese and European PSA
- We made of taxonomy of all syntactic categories we found in these models
  - Gates, basic events, house events, sequences...
- We gave to each category a formal operational semantics
- We designed a XML representation of categories

Five Layers Architecture

- Report Layer
  - Results of calculation...
- Event Tree Layer
  - Event trees, initiators, sequences, consequences
- Extra-Logical Layer
  - CCF-groups, delete terms, exchange events...
- Fault Tree Layer
  - Fault Trees, gates, basic events, house events
- Stochastic Layer
  - Probability distributions, parameters


consequence-terms
consequences
event-trees
branches
states
event trees layer
initiator-sets
initiators
functional-events
rules
named-rules
CCF-group
delete-terms
recovery-rules
extra-logical layer
fault-trees
formulae
gates
house-events
basic-events
fault tree layer
expressions
parameters
stochastic layer

Fault Tree Layer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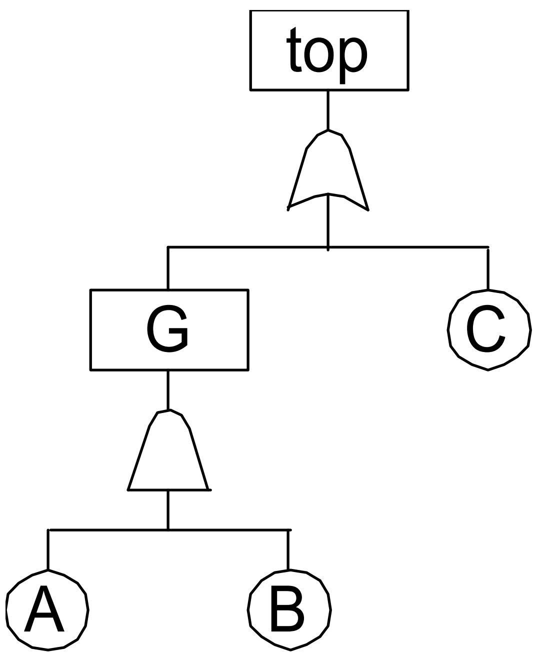
Declarations of Fault Trees




```xml
<define-fault-tree name="FT1" >
  <define-gate name="top" >
    <or>
      <gate name="G" />
      <basic-event name="C" />
    </or>
  </define-gate>
  <define-gate name="G" >
    <and>
      <basic-event name="A" />
      <basic-event name="B" />
    </and>
  </define-gate>
</define-fault-tree>
```

Declarations of Gates

```
<define-gate name="valve-failed-closed">
    <or>
        <basic-event name="valve-hardware-failure" />
        <gate name="valve-human-failure" />
        <basic-event name="valve-test-failure" />
    </or>
</define-gate>
```

the standard provides a complete set of logical connectives

Declarations of Basic Events

```
<define-basic-event name="valve-hardware-failure" >
    <exponential>
        <parameter name="failure-rate-valves" />
        <mission-time />
    </exponential>
</define-basic-event>
```

Stochastic Layer

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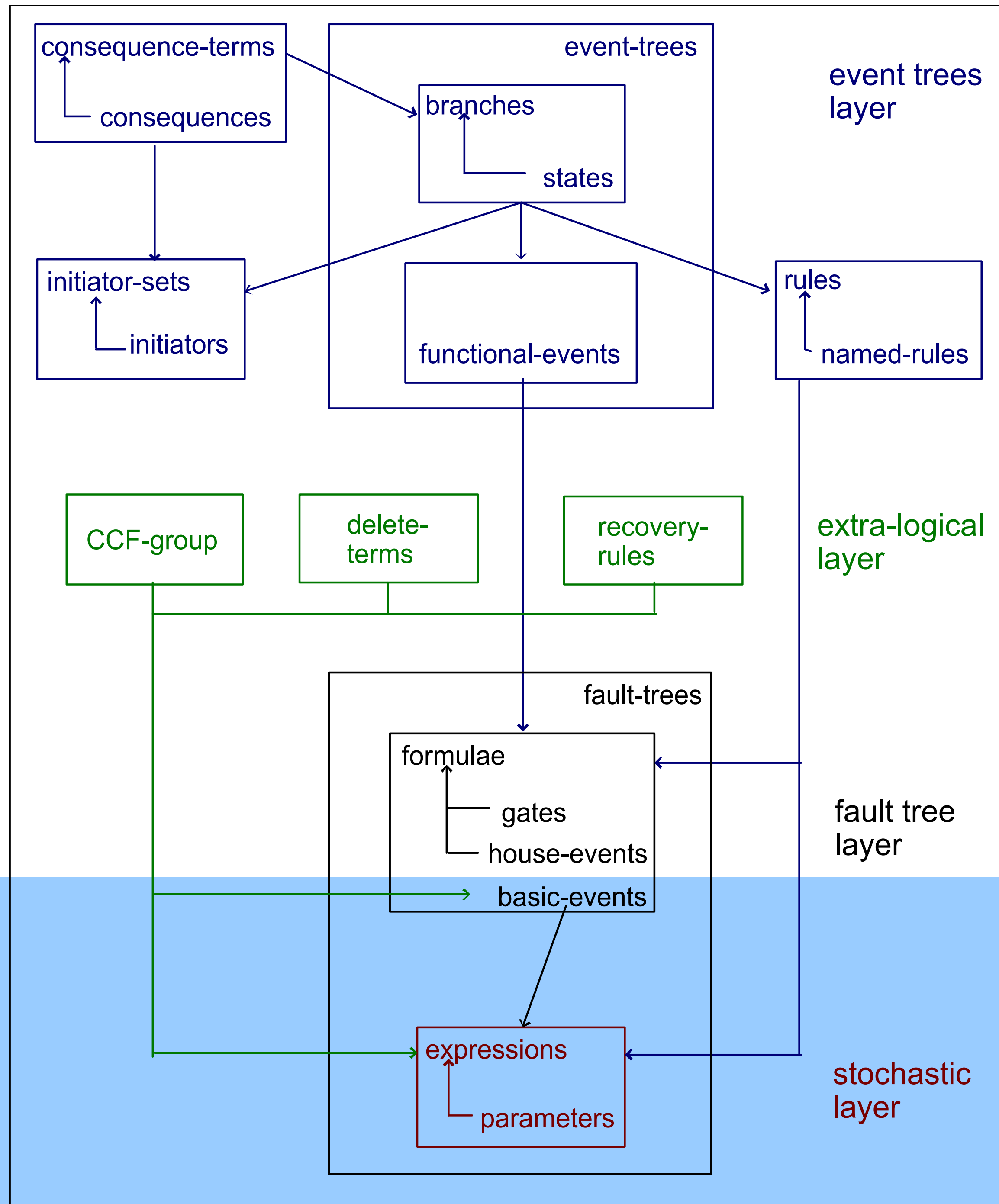
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parameters
stochastic layer

Stochastic Layer (Content)

1. Stochastic expression and parameters
   role and definition
2. Operations
   Arithmetic operations, logical operations, conditional operations
3. Built-ins
   usual time-dependent distributions
4. Random Deviates
   uniform, normal, lognormal deviates, histograms

Role of Stochastic Expressions

1. Associate (possibly time-dependent) probabilities with basic events. E.g.

```
<define-basic-event name="BE">
   <exponential>                          negative exponential distribution
      <parameter name="lambda" />         failure rate
      <mission-time />                    mission time
   </exponential>
</define-basic-event>
```

2. Define distributions for these probabilities (and more generally for parameters). E.g.

```
<define-basic-event name="BE2">
   <uniform-deviate>                      uniform random deviate
      <float value="1.0e-4" />            lower bound
      <float value="2.0e-4" />            upper bound
   </uniform-deviate>
</define-basic-event>
```

Built-ins

Set of predefined function to describe time-dependent distributions. E.g.

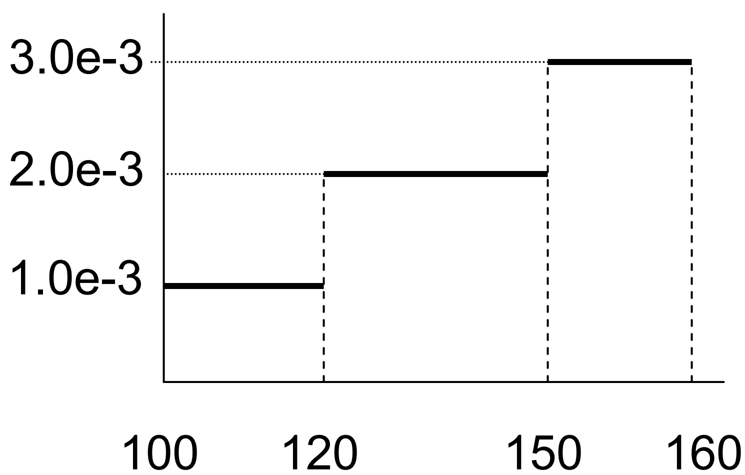
- <exponential>
    <parameter name="failure-rate-pump" />
    <mission-time />
</exponential>
- <Weibull>
    <parameter name="shape1" />
    <parameter name="scale1" />
    _{
        <mission-time />
        <parameter name="locality1" />
}
</Weibull>
- ...

Random-Deviates

To perform sensitivity analyses. E.g.

- <uniform>
  <float value="1.0e-3" /> *lower-bound*
  <float value="2.0e-3" /> *upper-bound*
  </uniform>
- <lognormal>
  <float value="1.23e-4" /> *mean*
  <int value="3" /> *error-factor*
  <float value="0.90" /> *confidence*
  </lognormal>
- ...

Histograms




```
<histogram lower-bound="100" >
   <bin upper-bound="120" >
      <float value="1.0e-3 />
   </bin>
   <bin upper-bound="150" >
      <float value="2.0e-3 />
   </bin>
   <bin upper-bound="160">
      <float value="3.0e-3 />
   </bin>
</histogram>
```

Extra-Logical Layer

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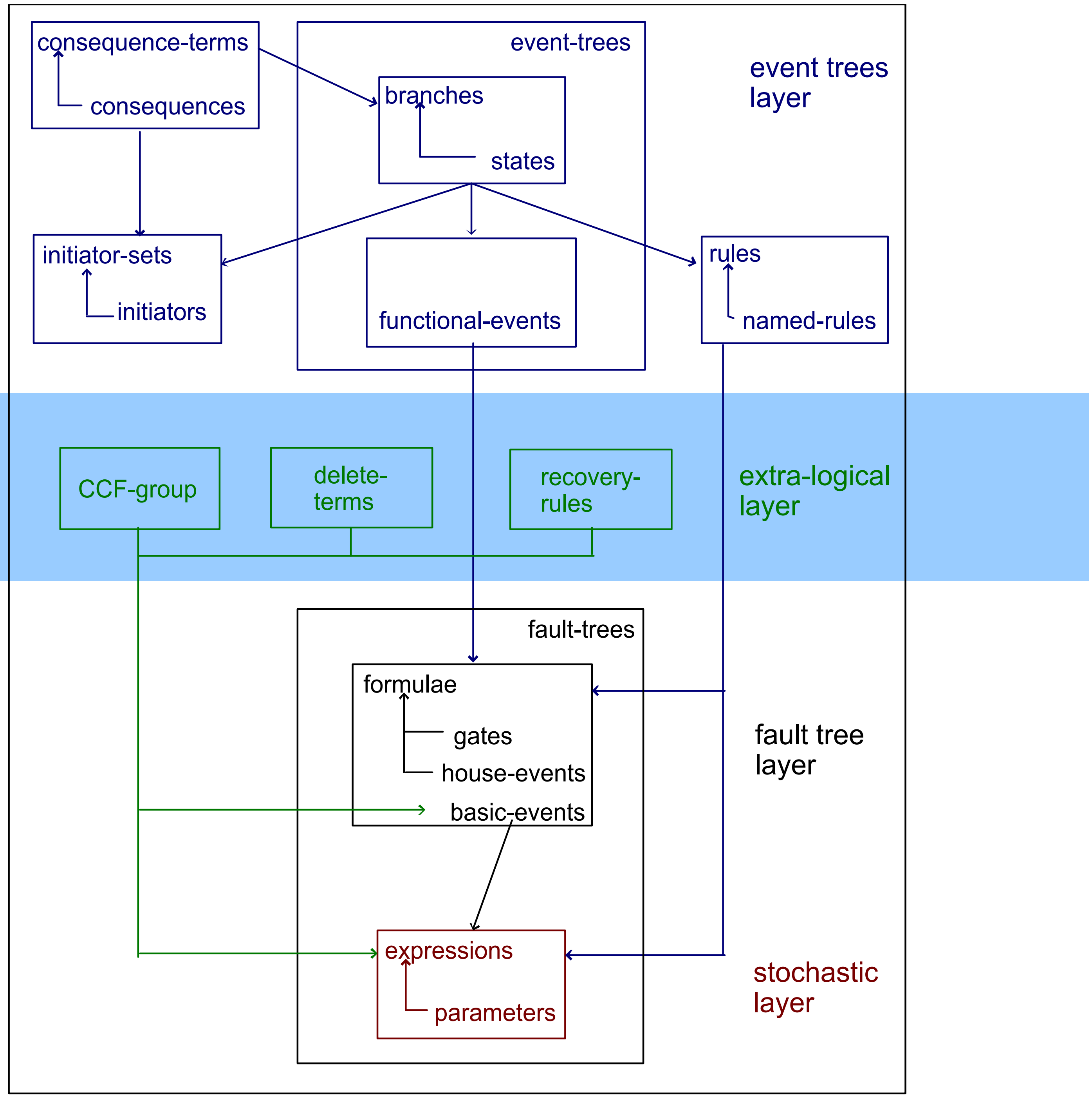

Extra-Logical Layer (Content)

1. Common Cause Failures
   - models, declarations
2. Exclusive events (delete terms)
   - model, declaration
3. Recovery rules
   - model, declaration

Delete Terms

Delete terms are groups of exclusive (basic) events.

- Used to model physically impossible configurations such as simultaneous maintenance

Three possible interpretations/uses of the exclusive group g={e1,e2}

1. Post-processing of cutsets
   - (e1 and e2 and ...) deleted
2. Global constraint
   - NewTopEvent = TopEvent and [not (e1 and e2)]
3. Local subsitution
   - e1 $\rightarrow$ ge1 = (e1 and not e2)
   - e2 $\rightarrow$ ge2 = (e2 and not e1)

Delete Terms (continued)

XML representation

```
<define-exclusive-group name="g1" >
    <basic-event name="e1" />
    <basic-event name="e2" />
    <basic-event name="e3" />
</define-exclusive-group>
```

Event Tree Layer

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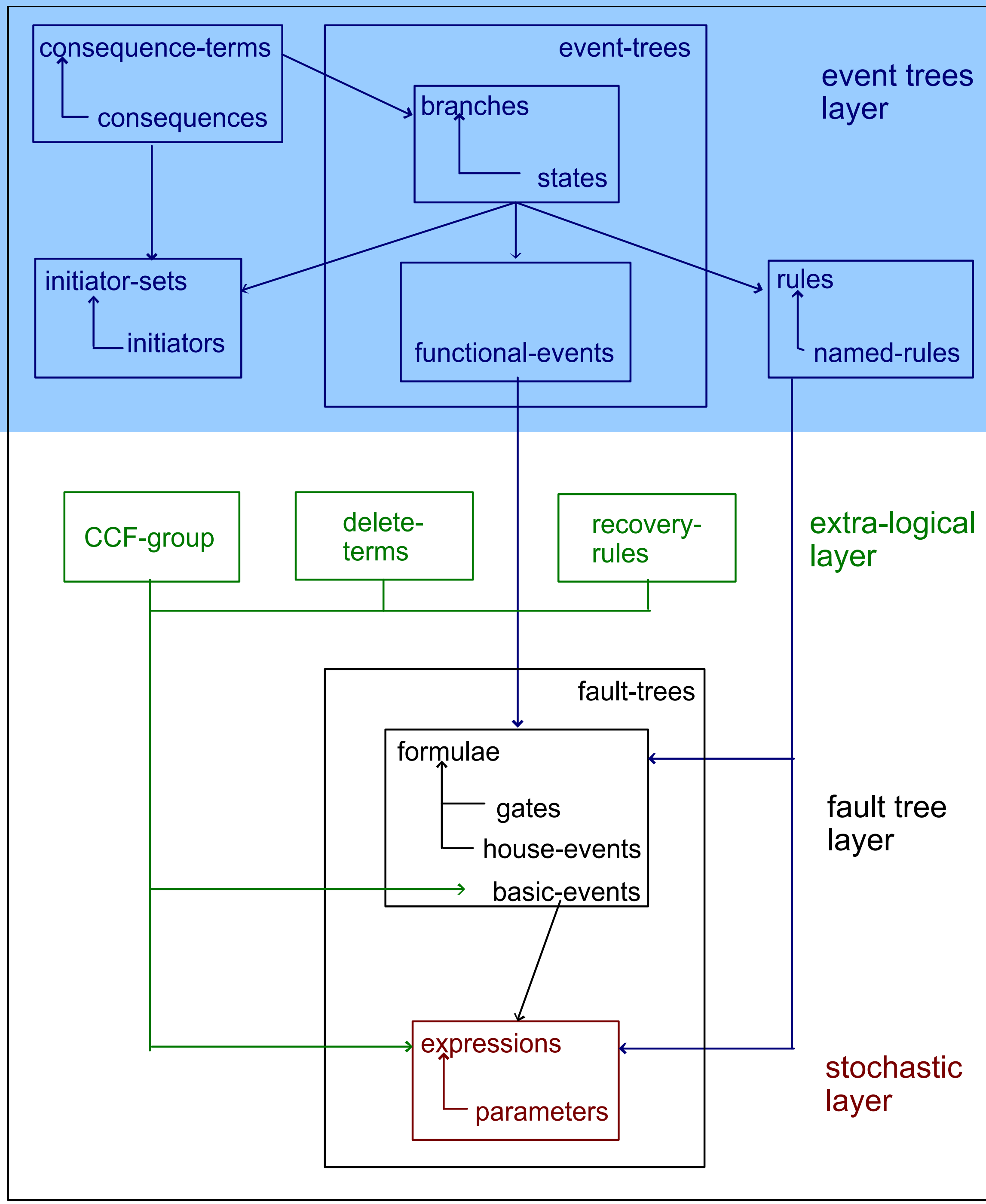
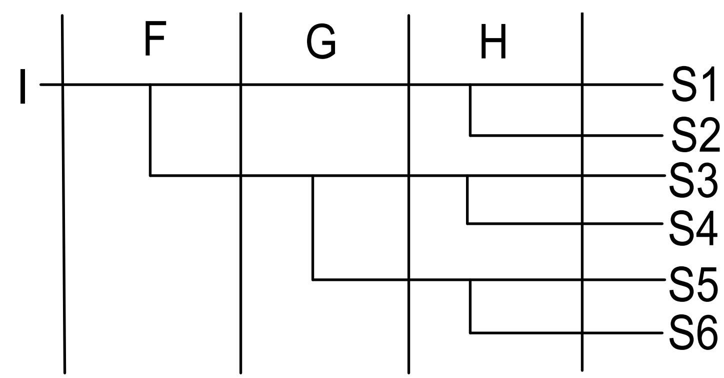


Preliminaries (1)

Graphical presentation of Event Trees



Interpretation

S1 = I and not F and not H
S2 = I and not F and H
S3 = I and F and not G and not H
S4 = I and F and not G and H
S5 = I and F and G and not F
S6 = I and F and G and H

A priori simple but …

Preliminaries (2)

- Fault trees may be given flavors (by setting house events)
- These flavors may depend on the current branch
- There may have several initiating events
- Some success branches may be interpreted as a bypass
- There may have multi-states branches
- Branches may be defined as references to other branches
- …

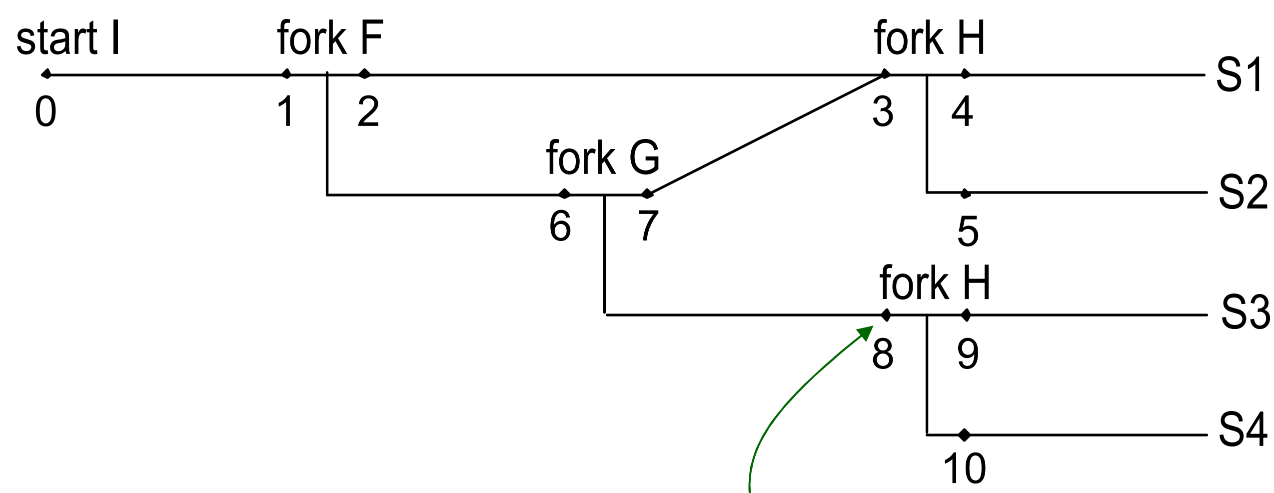
Preliminaries (2)

- Fault trees may be given flavors (by setting house events)
- These flavors may depend on the current branch
- There may have several initiating events
- Some success branches may be interpreted as a bypass
- There may have multi-states branches
- Branches may be defined as references to other branches
- …

Event Trees should be seen as a graphical programming language!

- The graphical view described the structure of the tree, i.e. the different sequences
- Instructions are provided to give flavors to fault trees
- The interpretation of sequences (Boolean formula) is built while walking along the branches

Structure of Event Trees (1)



Walk:

- 0, 1, 2, 3, 4 (S1)
- 0, 1, 2, 3, 5 (S2)
- 0, 1, 6, 7, 3, 4 (S1)
- …

at each point some instructions can be executed in order to set values of house events and parameters and/or to collect functional event

Structure of Event Trees (2)

```
<define-event-tree name="ET1" >
    <define-functional-event name="F">          declarations of functional events
        <fault-tree name="FTF" gate="top" />
    </define-functional-event>
    …
    <define-consequence name="S1" />            declarations of consequences
    …
    <path>                                      definition of the structure
        <fork functional-event="F" >
            <path>
                <collect functional-event="F" polarity="success" />
                <fork functional-event="H" >      ← instruction
                    …
                </fork>
            </path>
            …
        </fork>
    </path>
</define-event-tree>
```

Instructions (1)

Instructions to set parameters/house event values

- <set house-event="H1" >
  <constant value="false" />
  </set-parameter>
- <set parameter="lambda" />
  <float value="0.001" />
  </set-parameter>

Instructions to collect functional events

- <collect functional-event="F" polarity="failure" />

Conditional instructions

- <if>
  <collected functional-event="F" />
  <set house-event="H2"> <constant value="true" /> </set>
  </fi>

Instructions (2)

Blocks

- <block>

  instruction+

  </block>

Rules (named blocks of instructions)

- <define-rule name="R1" >

  <set house-event="H1"> <constant value="false" /> </set>

  <set house-event="H2"> <constant value="true" /> </set>

  <set house-event="H3"> <constant value="true" /> </set>

  …

  </define-rule>

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Report Layer

Report Layer (content)

1. Description of Calculations
   - model, tool, algorithm, mission-time, cutoff...
2. Description of Results
   - minimal cutsets
   - probabilistic measures

Description of Calculations

- Software
  - version, contact organization (editor, vendor)
- Calculation algorithm
  - name
  - limits (number of basic events, cutsets...)
  - preprocessing techniques
  - cutoffs
  - handling of success branches, use of delete terms
  - external routines
  - calculation time
  - ...
- Feedback
  - success, failure

The standard provides examples rather than a strict syntax for these items

Descriptions of Results

```
<sum-of-products name="MCS1" basic-events="3" products="2" >
    <product order="2">
        <basic-event name="A" />
        <basic-event name="B" />
    </product>
    <product order="2">
        <not>
            <basic-event name="A" />
        </not>
        <basic-event name="C" />
    </product>
</sum-of-products>
```

Descriptions of Results

```xml
<measure name="RAW" system="TopEvent" component="BE33" >
  <mean value="0.00149807" />
  <standard-deviation value="0.000385405" />
  <error-factor percentage="90" value="1.00056" />
  <histogram lower-bound="0" >
    <bin upper-bound="0.25"> <float value="0.00112081"> </bin>
    <bin upper-bound="0.50"> <float value="0.00136203"> </bin>
    <bin upper-bound="0.75"> <float value="0.0016188">  </bin>
    <bin upper-bound="1.00"> <float value="0.00186128"> </bin>
  </histogram>
</measure>
```