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[Mercury: An Integrated Environment for Performance and Dependability Evaluation of General Systems.](#)

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# Mercury: an Integrated Environment for Performance and Dependability Evaluation

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UNIVERSIDADE  
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DE PERNAMBUCO



MoDCS  
Research Group

# Aims

- depicting Mercury tool,
- reasons for proposing another tool,
- functionalities supported,
- current constraints, and
- briefly mentioning next planned supported functionalities.

# Agenda

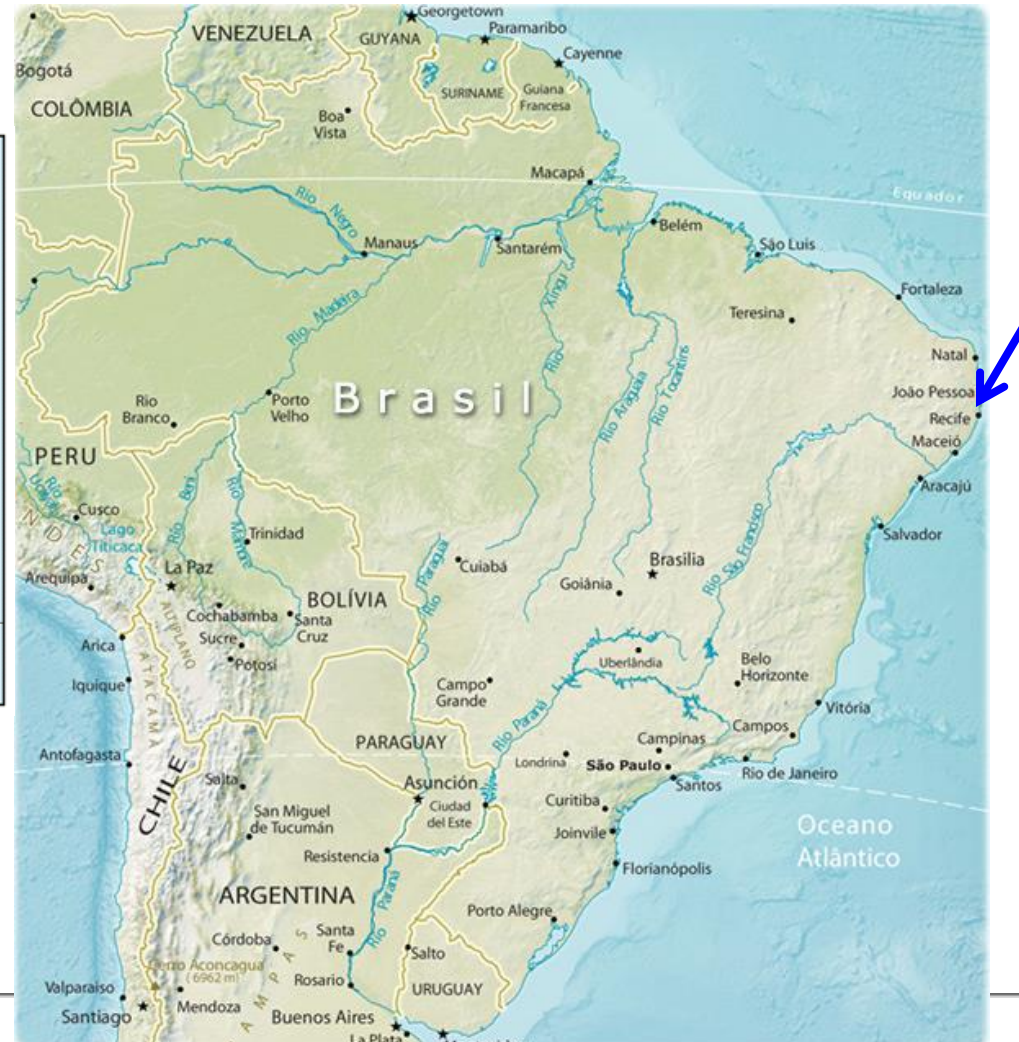
- **Context**
- **Motivation**
- **Architecture: an overview**
- **Brief description of models' functionalities supported**
- **Additional supported functionalities**

**But, before...**

# where we are located

Our research group is part of Centro de Informática at UFPE.

UFPE is located at state of Pernambuco at northeast region.



# Context

Research in the group: our main research interest is devoted to formal timing modeling and evaluation of systems:

performance,  
dependability and  
energy consumption

# Context

We have devoted our efforts to study many practical domain problem, encompassing:

- cloud computing
- sustainable data centers
- mobile system
- workload generation for capacity planning of servers
- fault injection and monitoring in cloud computing
- energy consumption in embedded system
- convergent networks
- logistic distribution
- production systems
- policies of emergency call center systems

# Motivation

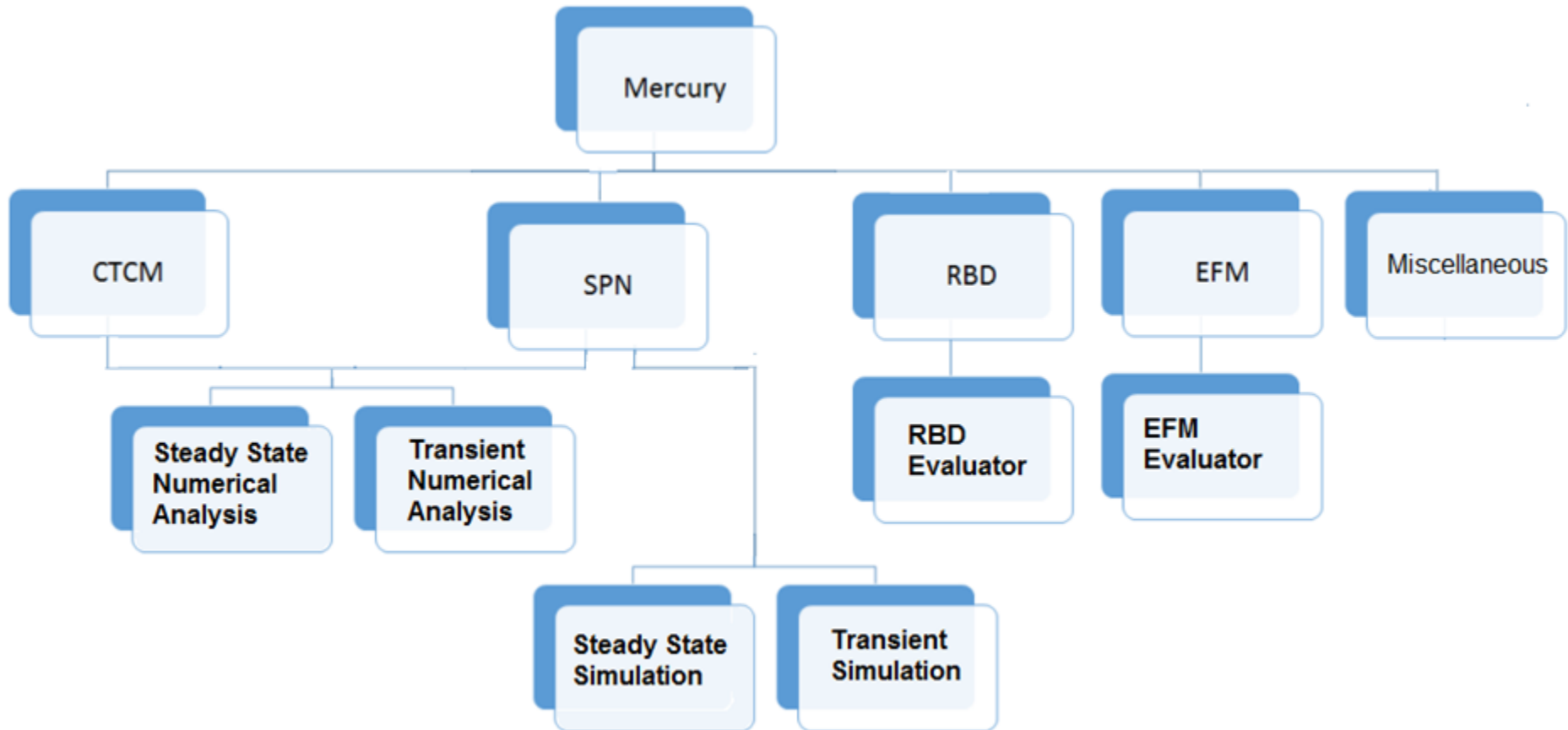
- **Over the years, our group has used many academic and commercial tools.**
  - Some academic tools we have adopted in our group:  
INA, Design CPN and CPN tools, Great SPN, TimeNet, SHARPE ...
- **If there are so many tools, why should I implement another tool?**
  - Cons. (some) :
    - There are many good tools already available
    - It is likely the your (“first”) results should be worse than those provided by these established tools
  - Pros:
    - It is an objective mean for keeping your previous reseach results “alive”
    - Allow practical/real connection between consecutive reseach works
    - Having control over the products (software, models, methods etc) conceived and implemented in the group by graduate students, that, after finishing their respective research projects, start a new phase in their lives,
    - Learning (in depth) of the respective methods.

# Motivation

- My decision was:  
to **implement it**.
- So we began implementing the tool in 2008 by conceiving, specifying and coding a simulation kernel for SPN.
- From then on many functionalities and models have been included and are now supported by the tool.



# Architecture: an overview



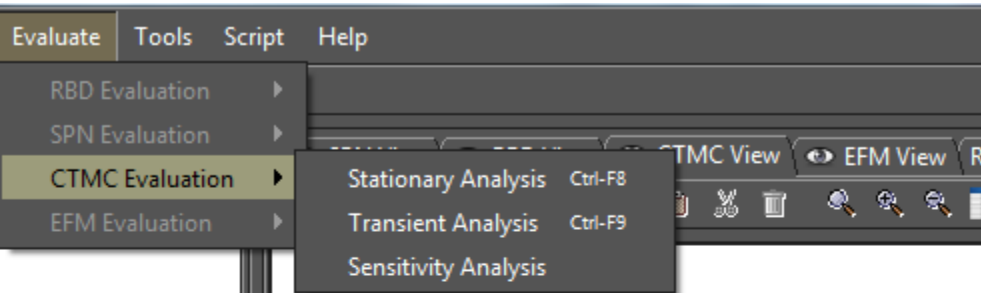
# Markov Chain view

The image displays a software interface for Markov Chain analysis. The top menu bar includes 'SPN View', 'RBD View', 'CTMC View', 'EFM View', and 'Results'. A toolbar below the menu contains various icons for navigation and editing. A 'Metrics' panel on the left shows 'A: P{S0}' with a value of 0.990099. The main workspace shows a Markov Chain diagram with two states, S0 and S1, and two transitions:  $\lambda$  (top) and  $\mu$  (bottom). The diagram is annotated with  $\lambda: 1$  and  $\mu: 100$ . A red box labeled 'Editing' points to the toolbar. A red box labeled 'Analysis' points to the 'Evaluate' menu, which is open and shows options: 'RBD Evaluation', 'SPN Evaluation', 'CTMC Evaluation', and 'EFM Evaluation'. The 'CTMC Evaluation' sub-menu is open, showing 'Stationary Analysis Ctrl-F8', 'Transient Analysis Ctrl-F9', and 'Sensitivity Analysis'. Below the diagram, the value 'A: 0.990099' is displayed. The diagram is repeated below the menu bar.



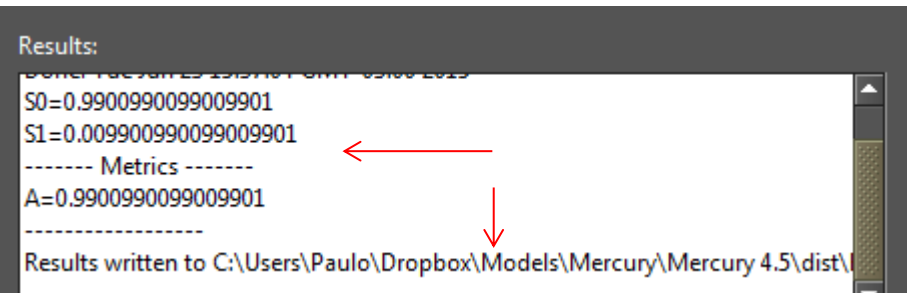
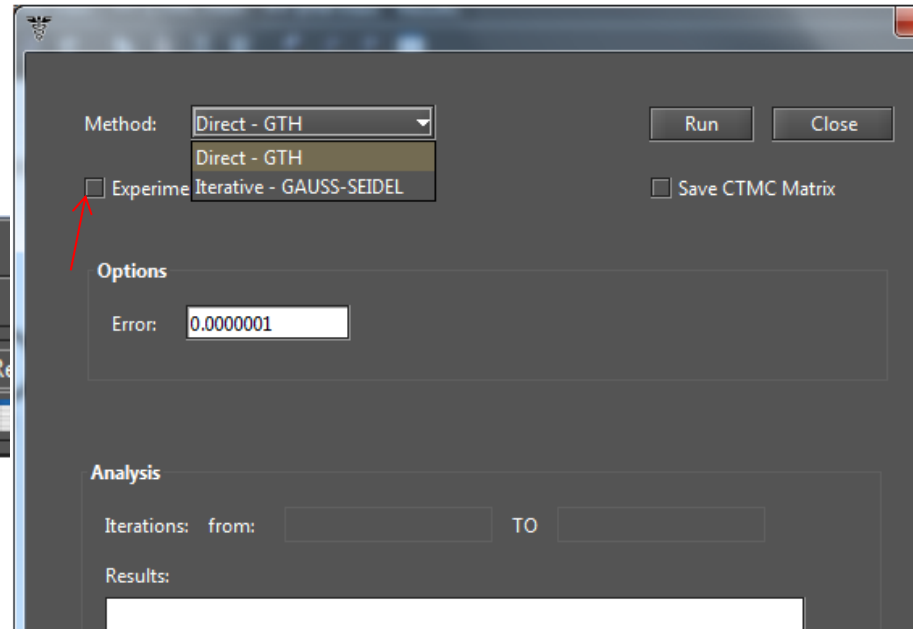
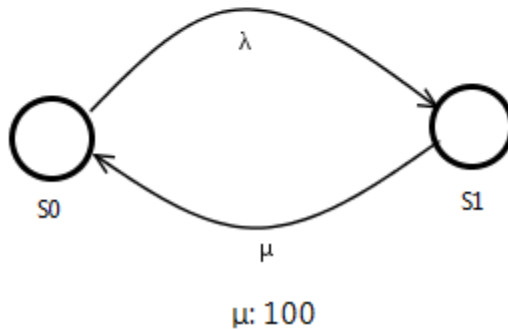
# Steady State Analysis

## Markov Chain view

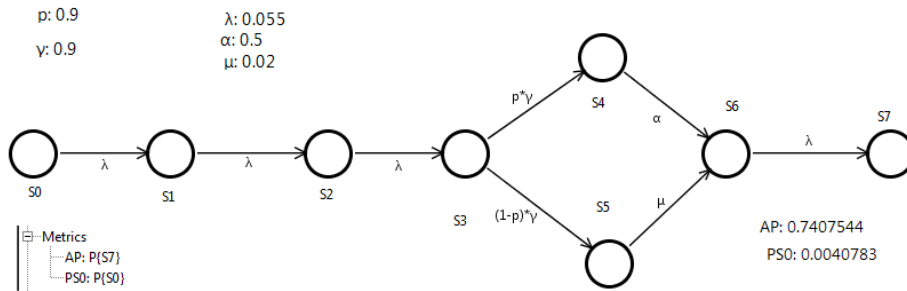
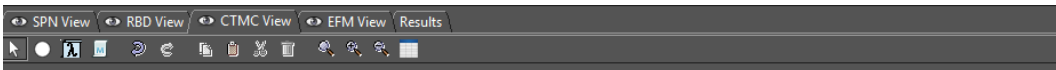


A: 0.990099

$\lambda: 1$



# Markov Chain view



Transient Analysis

Results:

```

S4=0.0068317
S5=0.0360542
S6=0.1240858
S7=0.7407543999999999
----- Metrics -----
AP=0.7407543999999999
PSO=0.0040783
-----
Absorption probability: 0.7407543999999999
Mean Time to Absorption (MTTA): 80.6383838
  
```

Analysis

Method:

Save CTMC Matrix   
 Mean Time to Absorption (failure)   
 Absorption Probability

Options

Time:       Internal Step:

Precision:      

Output:  Point     Curve

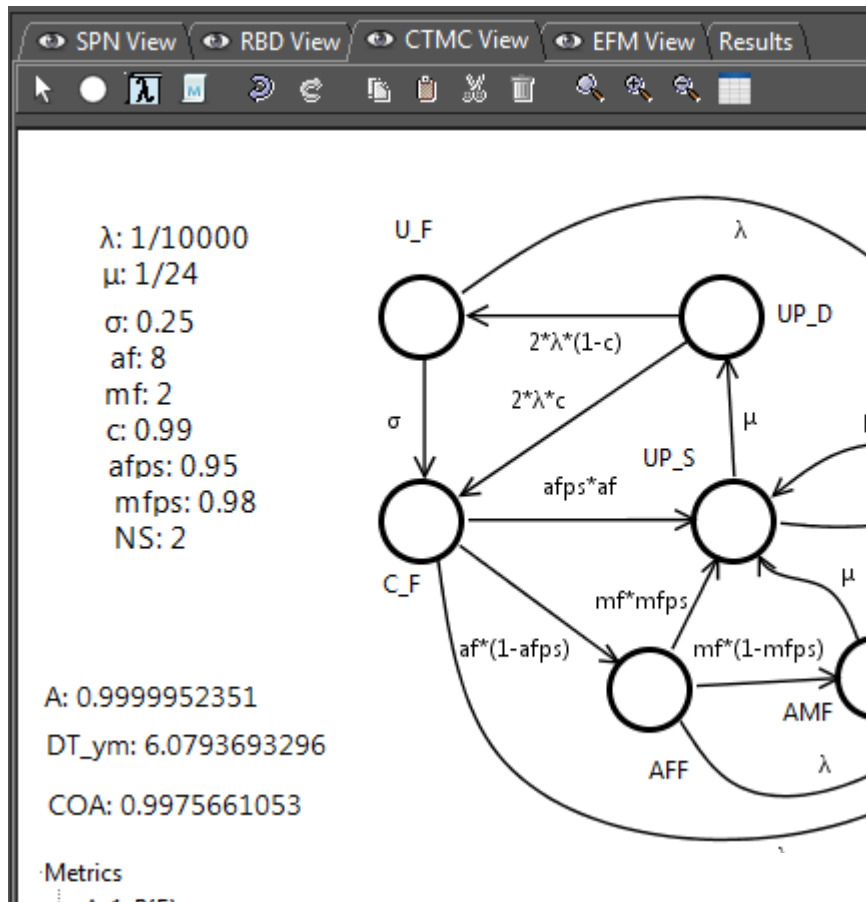
Analysis

Current Time:       N. of iteratios for a step:

Results:

# Sensitivity Analysis

## Markov Chain view



Sensitivity analysis of CTMC

Type of sensitivity index	Type of ranking
<input checked="" type="radio"/> Scaled <input type="radio"/> Unscaled	<input checked="" type="radio"/> Ordered <input type="radio"/> Unordered
Measure of interest	Parameter of interest
All measures ▼	All parameters ▼



# Markov Chain view

Script

The screenshot shows the main application window with the 'Script' menu open. The menu items are:

- RVG (Ctrl-R)
- Moment Matching (Ctrl+Shift-L)
- MTTR/F Calc (Ctrl-M)
- Evaluate External RBDs (Ctrl+Alt-E)
- Evaluate External Model (Ctrl+Alt-M)
- Remote SPN Evaluation (Ctrl+Alt-R)
- Generate Random Numbers (Ctrl+Shift-G)
- Export model to Mathematica (Ctrl+Alt-X)

The code editor contains the following Markov chain definitions:

```
2 markov CTMCMODEL{
3
4 state UP_D;
5 state U_F;
6 state C_F;
7 state UP_S;
8 state AFF;
9 state F;
10 state AMF;
11
12 transition UP_D -> U_F( rate = 2*lambda*(1-c));
13 transition UP_D -> C_F( rate = 2*lambda*c);
14 transition U_F -> C_F( rate = sigma);
15 transition U_F -> F( rate = lambda);
16 transition C_F -> UP_S( rate = afps*af);
17 transition C_F -> AFF( rate = af*(1-afps));
18 transition C_F -> F( rate = lambda);
19 transition UP_S -> UP_D( rate = mu);
20 transition UP_S -> F( rate = lambda);
21 transition AFF -> UP_S( rate = mf*mfps);
22 transition AFF -> F( rate = lambda);
23 transition AFF -> AMF( rate = mf*(1-mfps));
```

Mathematica file generation

The dialog box shows the following options:

- Select output directory: C:\Users\Paulo
- Select output format:
  - Mathematica 9/10 output format
  - StateDiagrams.m package output format ([link to homepage](#))
  - Generate linear system
- Buttons: Generate, Exit

# SPN view

Editing

Token game

Structural Analysis

The screenshot displays the Modcs software interface. At the top, there are tabs for 'SPN View', 'RBD View', 'CTMC View', 'EFM View', and 'Results'. Below the tabs is a toolbar with various icons. The main workspace shows a Petri Net (PN) and a Stochastic Petri Net (SPN) diagram. The PN diagram includes places P0, CA, P1, BI, B, S, and P3, and transitions AT, CA, BI, and BSM. The SPN diagram includes places NS, SR, SD, and SF, and transitions TR and TF. A 'Place Properties' window is open, showing 'Place Name: SU' and 'Marking: NS'. A 'Transition Properties' window is open, showing 'Transition Name: CA', 'Guard Expression', 'Server Type: Single Server', 'Probability Distribution: Exponential', and 'Mean delay: AT'. A 'Structural Analysis' window is open, showing a table of classification results. A menu is open, showing options for 'Stationary Simulation', 'Transient Simulation', 'Stationary Analysis', 'Transient Analysis', 'Structural Analysis', and 'Convert to Mercury Script'. The 'Structural Analysis' window shows the following classification results:

Property	Value
State Machine	false
Marked Graph	true
Free Choice Net	true
Extended Free Choice Net	true
Simple Net	true

Additional text in the interface includes: ASS: 1.6398943392274319, TP: 0.28152974717797474, A: 0.9882356340618874, COA: 0.917647513545558, and BSM: 30.

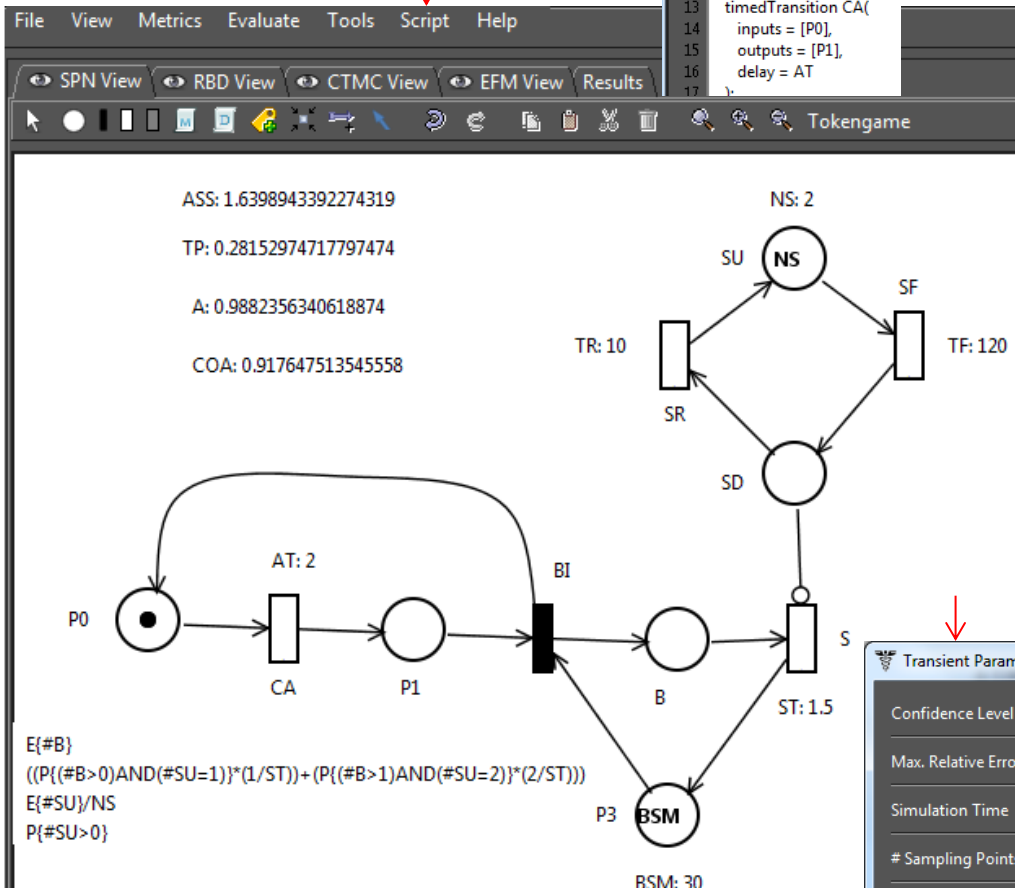
# SPN view

```

Run script
2
3 SPN Petri{
4
5 place P0(tokens= 1);
6 place P1;
7 place B;
8 place P3(tokens= BSM);
9 place SD;
10 place SU(tokens= NS);
11
12
13 timedTransition CA(
14 inputs = [P0],
15 outputs = [P1],
16 delay = AT
17 );

```

## Evaluation



Menu: Evaluate Tools Script Help

- RBD Evaluation
- SPN Evaluation
  - Stationary Simulation Ctrl-F5
  - Transient Simulation
  - Stationary Analysis Ctrl-F7
  - Transient Analysis Ctrl-F8
  - Structural Analysis
  - Convert to Mercury Script
- CTMC Evaluation
- EFM Evaluation

Stationary Simulation

Confidence Level %: 95  
 Max. Relative Error %: 10  
 Min. # of firing for each Transition: 50  
 Warm-up period (simulation time): 50  
 Run Size (# of firing): 1000  
 Max simulation real time (sec): 0  
 Batch Size (simulation time): 50000  
 Estimate Batch Size:   
 Experiment:

Run Cancel

Transient Parameters

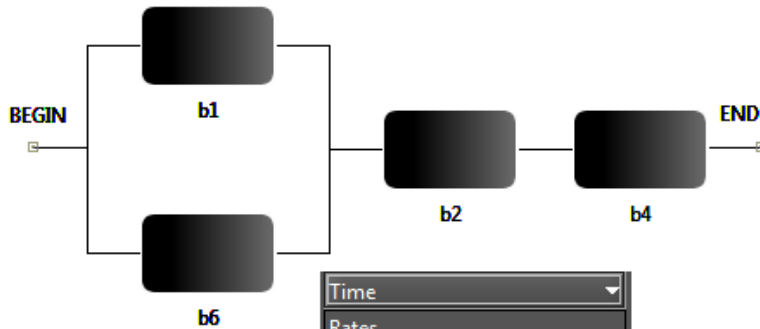
Confidence Level %: 95  
 Max. Relative Error %: 10  
 Simulation Time: 50000  
 # Sampling Points: 30  
 Max simulation real time (sec): 0  
 File Containing Results: ...

Run Cancel



# RBD view

Editing



Edit Block

Block Name: **b2**

Parameters Type: **Time** State: **Default**

Parameters

MTTF: 8760.019272042398  From Submodel

MTTR: 48.0  From Submodel

Price (\$) 0.0

Block Name: **b4**

Parameters Type: **Rates** State: **Default**

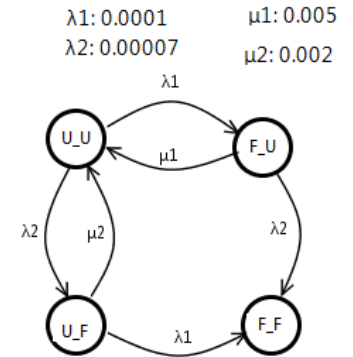
Parameters

Failure Rate: 0.0  From Submodel

Metric: **MTTF** Analysis Type: **Transient**

Repair Rate: 0.25  From Submodel

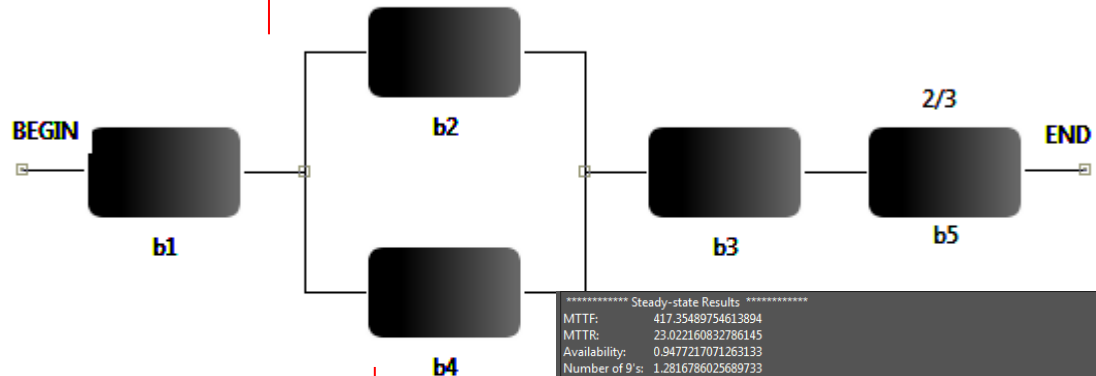
Price (\$) 0.0



MTTF: 223389.1213334  
 R: 0.9982874  
 A: 0.9982873  
 R:  $1 - P\{F_F\}$   
 A:  $P\{U_U\} + P\{F_U\} + P\{U_F\}$   
 MTTF: MTTA

# RBD view

## Evaluation



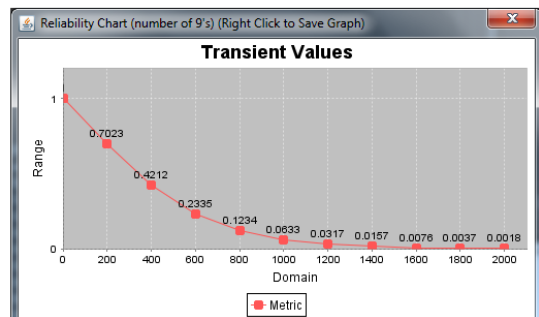
Evaluate Tools Script Help  
 RBD Evaluation ▶ Exact Evaluation  
 SPN Evaluation ▶ Bounds Evaluation  
 CTMC Evaluation ▶ Importance Measure  
 EFM Evaluation ▶ Experiment  
 Get Functions  
 Sensitivity Analysis

\*\*\*\*\* Steady-state Results \*\*\*\*\*

MTTF: 417.35489754613894  
 MTTR: 23.022160832786145  
 Availability: 0.9477217071263133  
 Number of 9's: 1.2816786025689733  
 Uptime: 8307.551042734038 hours  
 Downtime: 458.26172726596275 hours

\*\*\*\*\* Instantaneous Results \*\*\*\*\*

Time	Reliability	(9's)	Unreliability	Inst. availability
0.0000	1.0000	∞	0.0000	1.0000
200.0000	0.702261866875	0.526165539068	0.297738133125	0.948387921145
400.0000	0.421236308077	0.237498721665	0.578763691923	0.947730709945



Reliability Analysis

Calculation Type: Sum of Disjoint Products

Standard Calculation

Sum of Disjoint Products

Mean Time to Failure  
 Mean Time to Repair  
 Uptime  
 Steady-State Availability  
 Instantaneous Availability  
 Downtime  
 Reliability  
 Unreliability  
 Time unit: hours

Evaluation Time: 4000

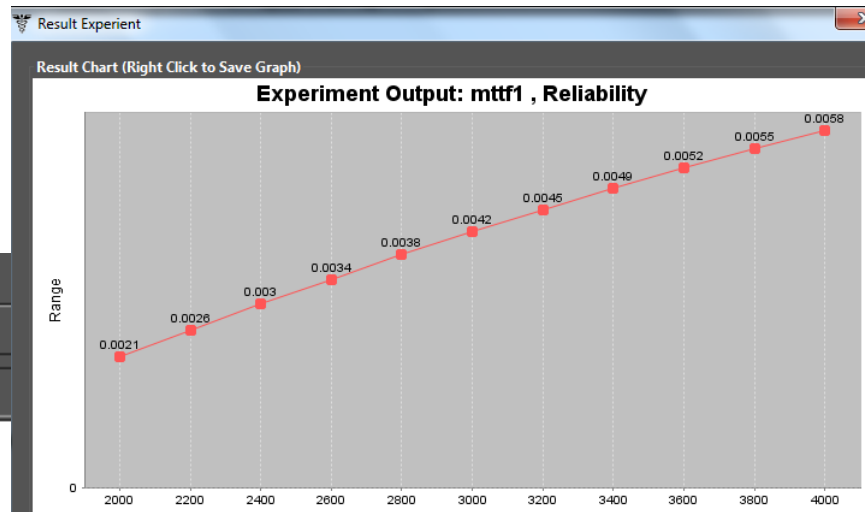
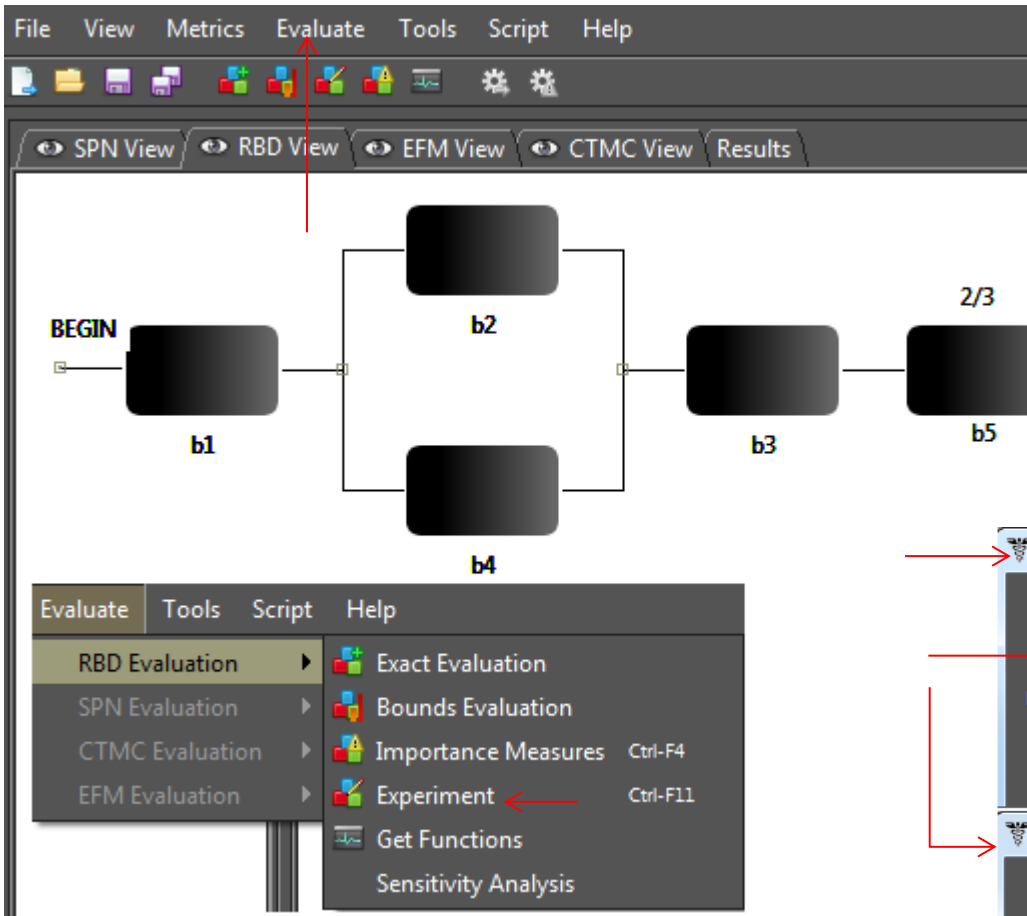
Analyze in multiple time points

Number of sampling points: 10

Run Cancel

# RBD view

Evaluation



Label Name: mttf1: 17520.0  
 Metric: mttf1: 17520.0  
 Range Minimal Value: mttf2: 12000.0  
 Interval: 20  
 Evaluation Time: 4

mttr2: 8.0  
 mtr1: 8.0  
 mttf3: 6000.0  
 mtr3: 24.0  
 mtr3: 24.0  
 mttf4: 1000.0

Experiment RBD

Label Name: mttf1: 17520.0  
 Metric: Reliability  
 Range Minimal Value: 2000 Range Maximum Value: 4000  
 Interval: 200  
 Evaluation Time: 4000

Experiment

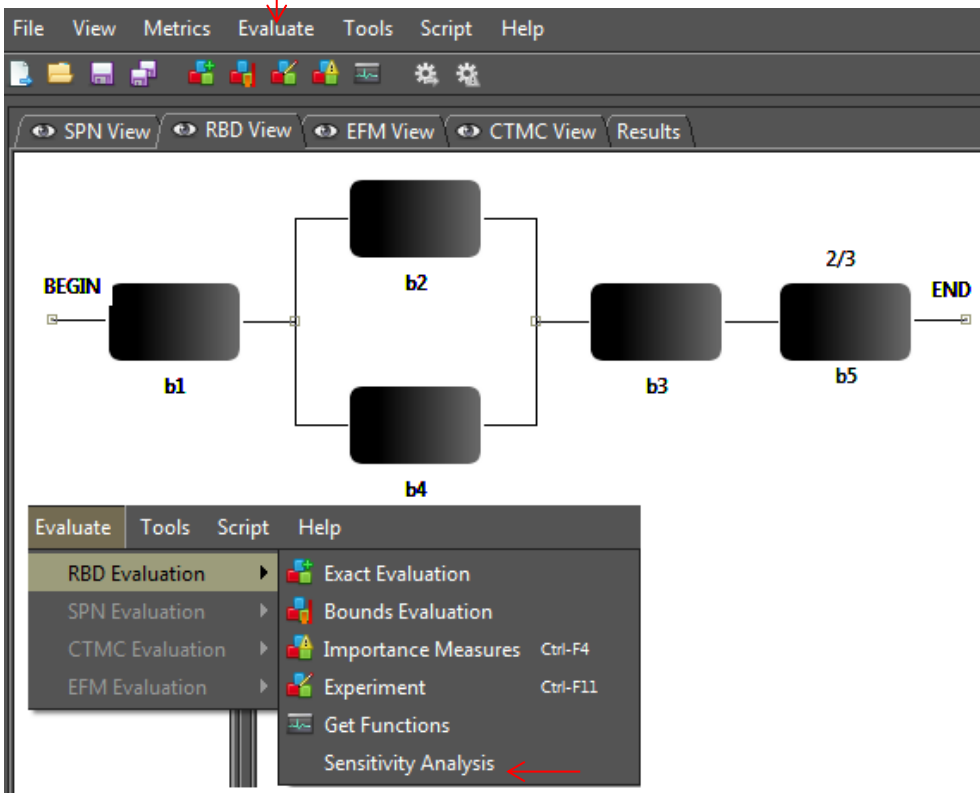
Experiment RBD

Label Name:   
 Metric: Mean Time to Failure  
 Range Minimal Value: Reliability  
 Interval: 0.0  
 Unreliability  
 Instantaneous Availability  
 Mean Time to Failure  
 Mean Time to Repair  
 Steady-State Availability

Experiment

# RBD view

Evaluation



Sensitivity analysis of RBD

Type of sensitivity index  
 Scaled  Unscaled

Type of ranking  
 Ordered  Unordered

Parameters under analysis  
 Component's availability  Component's MTTF and MTTR

Structural function:  $(b1) * (1 - (1 - b2) * (1 - b3)) * (b4)$

Partial derivative of Availability with respect to

b1:  $b4 * (-(-b2 + 1) * (-b3 + 1) + 1)$   
 b2:  $b1 * b4 * (-b3 + 1)$   
 b3:  $b1 * b4 * (-b2 + 1)$   
 b4:  $b1 * (-(-b2 + 1) * (-b3 + 1) + 1)$

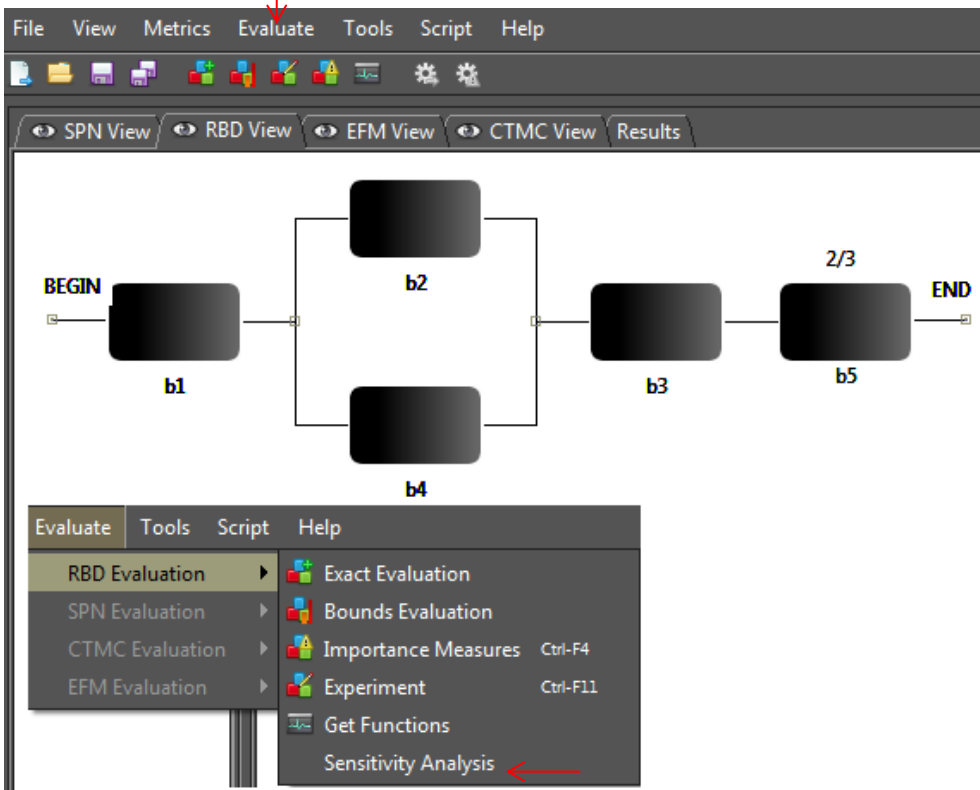
Parameter	Sensitivity value
b1	1.0000000000000013
b4	0.9999999999999889
b2	0.003981420039794288
b3	6.635700063158216E-4

Run Close

Partial derivative  
Sensitivity analysis

# RBD view

Evaluation



Sensitivity analysis of RBD

Type of sensitivity index  
 Scaled  Unscaled

Type of ranking  
 Ordered  Unordered

Parameters under analysis  
 Component's availability  Component's MTTF and MTTR

Structural function:  $(b1) * (1 - (1 - b2) * (1 - b3)) * (b4)$

Partial derivative of Availability with respect to

b1:  $b4 * (-(-b2 + 1) * (-b3 + 1) + 1)$   
b2:  $b1 * b4 * (-b3 + 1)$   
b3:  $b1 * b4 * (-b2 + 1)$   
b4:  $b1 * (-(-b2 + 1) * (-b3 + 1) + 1)$

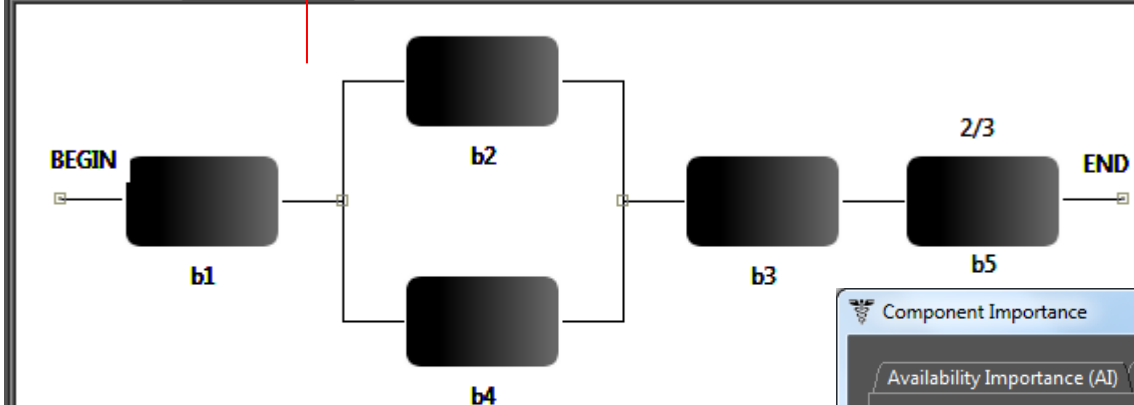
Parameter	Sensitivity value
b1	1.0000000000000013
b4	0.9999999999999889
b2	0.003981420039794288
b3	6.635700063158216E-4

Run Close

Partial derivative  
Sensitivity analysis

# RBD view

Evaluation



Importance measures

Evaluate Tools Script Help

- RBD Evaluation
  - Exact Evaluation
  - Bounds Evaluation
  - Importance Measures **Ctrl-F4**
  - Experiment **Ctrl-F11**
  - Get Functions
  - Sensitivity Analysis
- SPN Evaluation
- CTMC Evaluation
- EFM Evaluation

Component Importance

Availability Importance (AI) | AI x Cost | Reliability Importance (RI) | RI x Cost

Time: 720 Evaluate

Component:	Importance Value
b5 2/3:	0.4384477396461068
b3:	0.2463759103574593
b1:	0.13223206362127476
b2:	0.023179537864145863
b4:	0.02222564741706167

Component:	Normalized Value
b5 2/3:	1.0
b3:	0.5619276554061419
b1:	0.3015913908645211
b2:	0.052867276457748955
b4:	0.050691668373067926

Reliability Importance x Cost

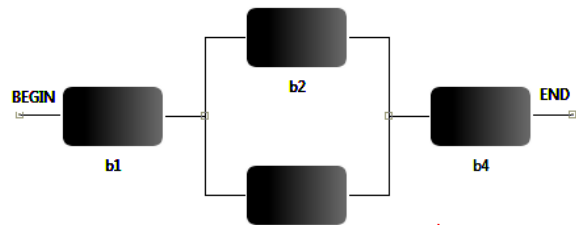
Value

Component name

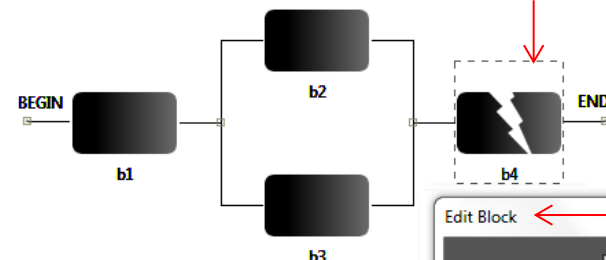
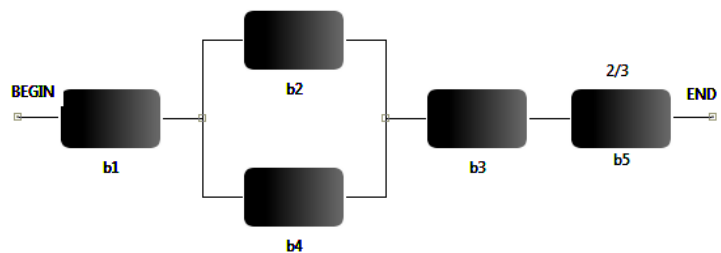
Component

# RBD view

Evaluation



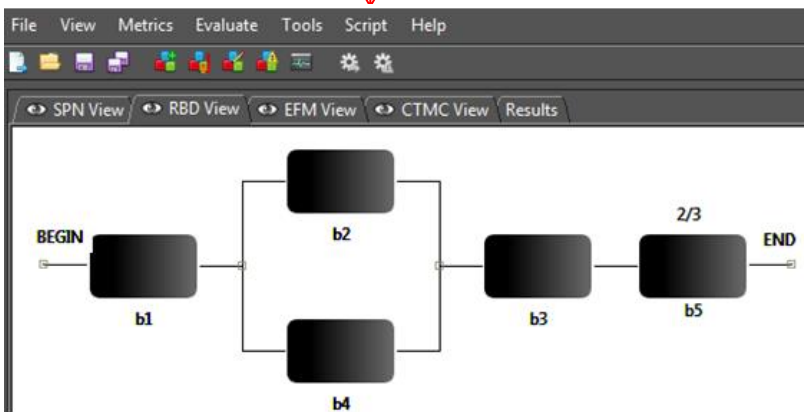
Logic and structural functions



Qualitative analysis

# RBD view

Script generation



```
Run script: DModel{
2
3  block b1( MTTF = 17520.0, MTTR = 8.0);
4  block b2( MTTF = 12000.0, MTTR = 8.0);
5  block b3( MTTF = 6000.0, MTTR = 24.0);
6  parallel p1(b2, b3);
7  block b4( MTTF = 1000.0, MTTR = 24.0);
8  series s0(b1, p1, b4 );
9
10 top s0;
11
12 metric m1 = availability;
13 }
14
15 main{
16 a = solve(model = RBDModel, metric = m1);
17 println(a);
18 }
19
Output
0.9761141936928462
```



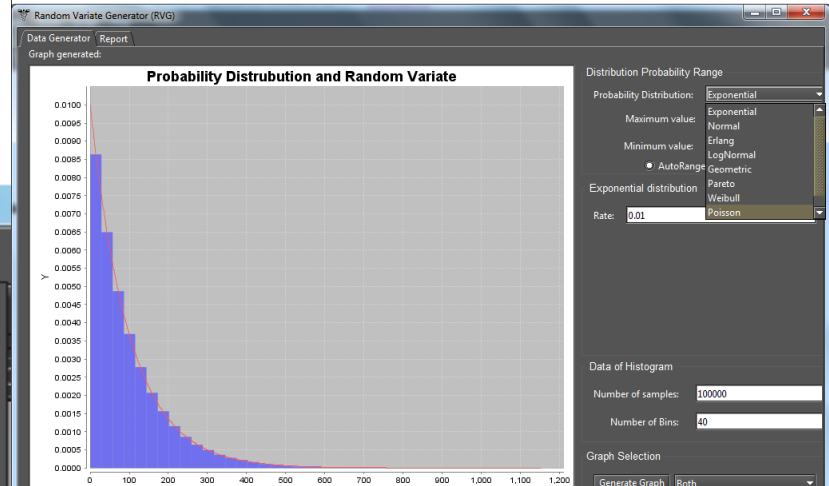
# Miscellaneous

Mercury Tool - RBD29092014.xml

File View Metrics Evaluate Tools Script Help

Project SPN RBD CTMC EFM

- RVG Ctrl-R
- Moment Matching Ctrl+Shift-L
- MTTR/F Calc Ctrl-M
- Evaluate External RBDs Ctrl+Alt-E
- Evaluate External Model Ctrl+Alt-M
- Remote SPN Evaluation Ctrl+Alt-R
- Generate Random Numbers Ctrl+Shift-G
- Export model to Mathematica Ctrl+Alt-X



MTR/F Calculator

TimeInterval: 8760

Availability: 0.99

File Calculate

Result

MTTR = 8672.4

MTTF = 87.6

OK

Moment Matching

File

Input

$\mu$ : 100

$\sigma$ : 50

Show models

Output

tab2

Erlang distribution

CV = 0.5

$CV^2 = 4.0$

$\gamma(n) = 4.0$

Rate (t) = 0.04

Delay (1/t) = 25.0

# Some current constraints and few planned functionalities

- Hierarchical evaluation (at this point) only allows automatically refining one sub-model.
  - This constraint should be removed in next versions.
- Hierarchical multi-model sensitivity analysis not currently supported.
  - On going work
- Enhancing the script language for taking into account other control structures
- Considering other importance measures
- Keep fixing bugs...
- ...

# Final comments

- Mercury is an academic tool.
- The executable code is available for academic use.
- If you would like to try it out, I encourage you to access [www.modcs.org](http://www.modcs.org) and go to Tools. From there, you will get a form, sign it and download it.
- There, you will also find a detailed manual.
- Presently, we have a group of 8 graduated students working on it.
- We very much appreciate if let us know about bugs and improvements, but we cannot guarantee maintenance support.

# Thank you!

**Paulo Maciel**

