Dynamic graphical models for security and safety joint modeling

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CHANGER L'ÉNERGIE ENSEMBLE

Context: pervasive computing

Rail transportation

Aerospace

Automobiles

Energy

Medical

Outline

- Introduction
  - Safety/security convergence
  - Why Petri nets, SAN and BDMP
- Petri nets and SAN
  - Formalism description
  - Use case: security of a metro station
- BDMP
  - Formalism description
  - Use case: a pipeline
- Conclusion

Introduction

Industrial systems are more and more complex and interconnected

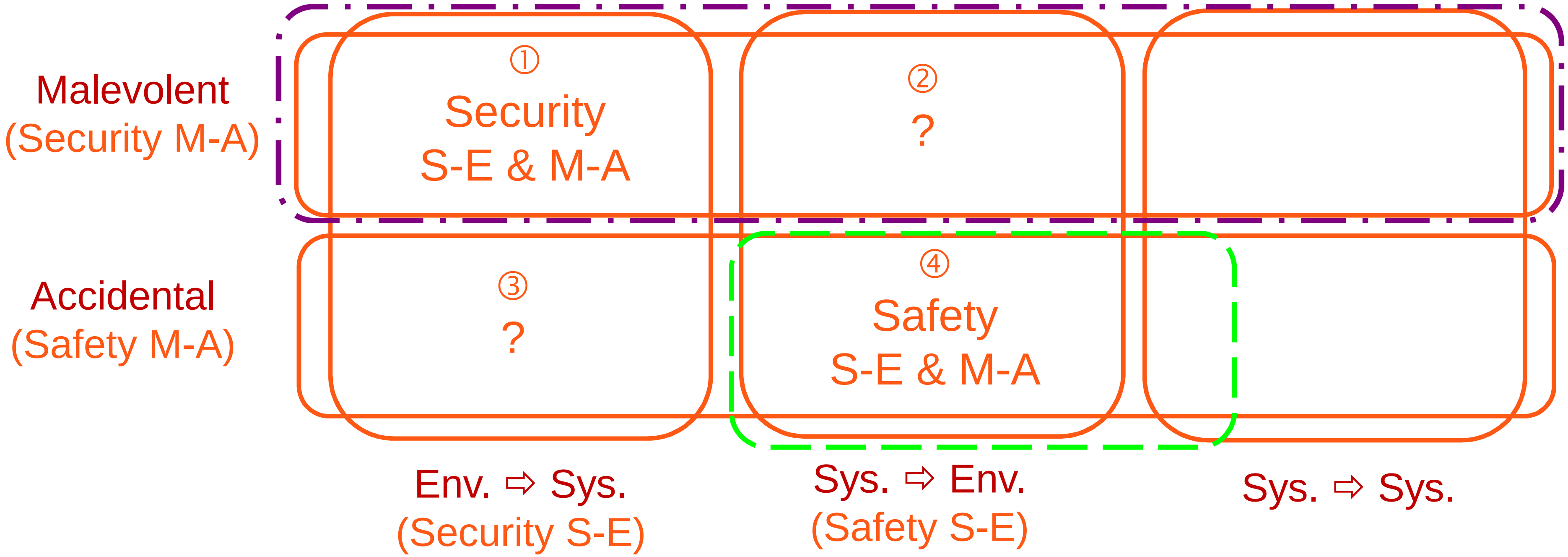
Safety:
accidents, failures

Security:
Cyber-attacks

- Safety and security domains historically separated
- Industrial systems targeted by cyber-attacks
- Large consequences on the system’s environment
- Their requirements converge for complex systems

Terminology

- Safety and security (SEMA referential) [1]



(cyber) Security
in this talk

Safety in
this talk

[1] L. Pietre-Cambacedes and C. Chaudet, "The SEMA referential framework: Avoiding ambiguities in the terms “security” and “safety”," International Journal of Critical Infrastructure Protection, Vol. 3 Issue 2, pp. 55-66, July 2010.

Safety and security

Differences

- Random vs intelligent
- Stability vs evolution
- Access to information
- Vocabulary

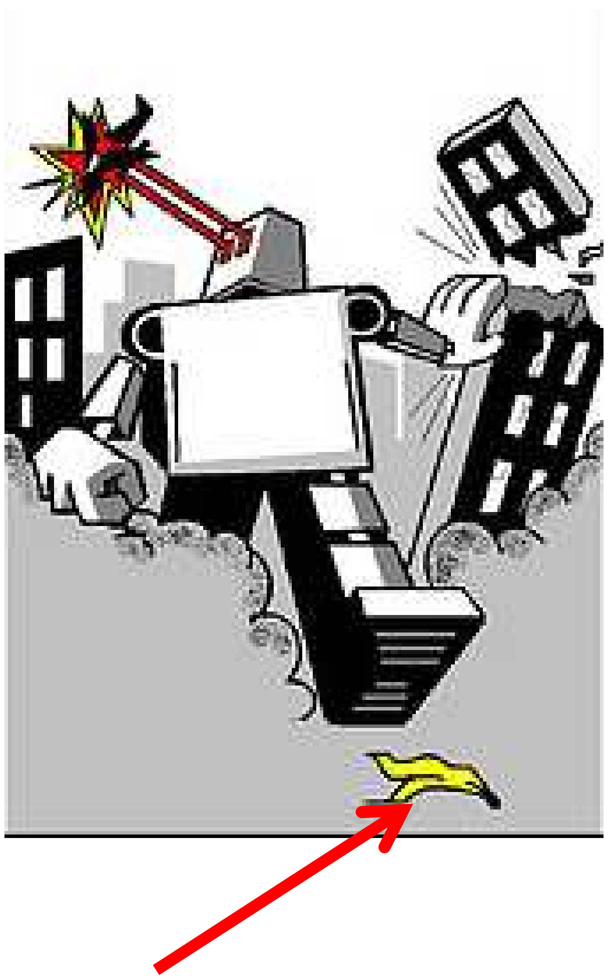
Similarities

- Protection aim
- Risk = fundamental notion
- Not "additive"
- Importance of human factors

Synergy between the two communities: possible & desirable

Interdependences Safety Security

- Interdependences
  - Antagonism
  - Conditional dependence
  - Mutual reinforcement
  - Independence
- Stakes
  - Correct risk evaluation
  - Cost optimization



Dynamic graphical models to study such interdependencies

- We need a holistic approach
- Single model describing both safety and security aspects
- State of the art [2] identified the following **dynamic** graphical formalisms:
  - Stochastic Petri nets and SANs
  - BDMP
  - Dynamic Bayesian nets
- All of them can be simulated and have a probabilistic basis
- Formalisms too specific of one domain have been discarded (e.g. Mobius/ADVISE)

[2] A Survey of Approaches Combining Safety and Security for Industrial Control Systems
Siwar Kriaa, Ludovic Pietre-Cambacedes, Marc Bouissou, and Yoran Halgand

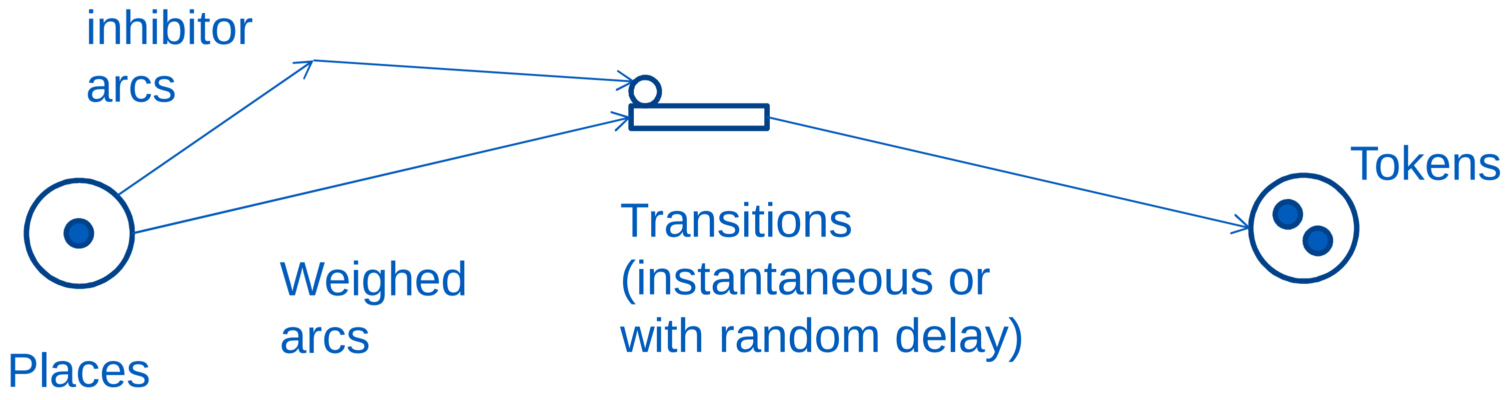
SPN & SAN

Stochastic Petri Nets and
Stochastic Activity networks

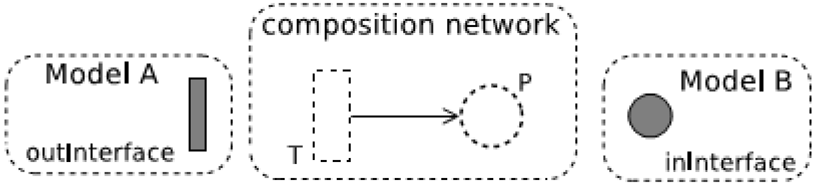
Stochastic Petri nets

- Standard SPN must be used in a bottom-up manner
- Patterns can ease the model construction
- The resulting model is flat and lacks structure
- Assessing methods:
  - Markovian Petri net => all Markov analysis methods
  - Non Markovian => Monte Carlo simulation

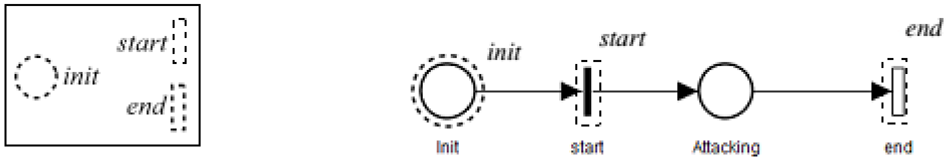
Reminder: "ingredients" of GSPN



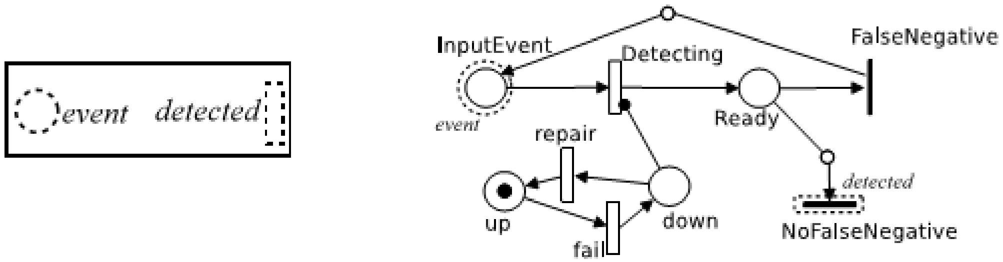
Example taken from [3]



Connecting Model A to Model B
Well suited for describing a sequence



Attack pattern (single phase)



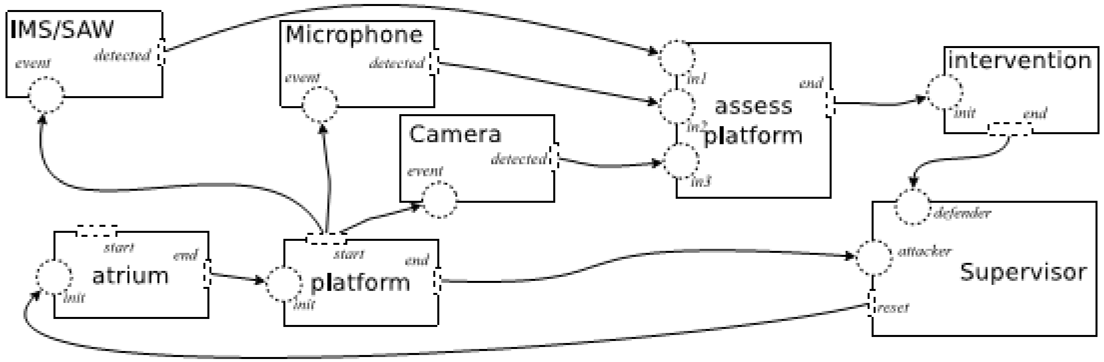
Faulty sensor

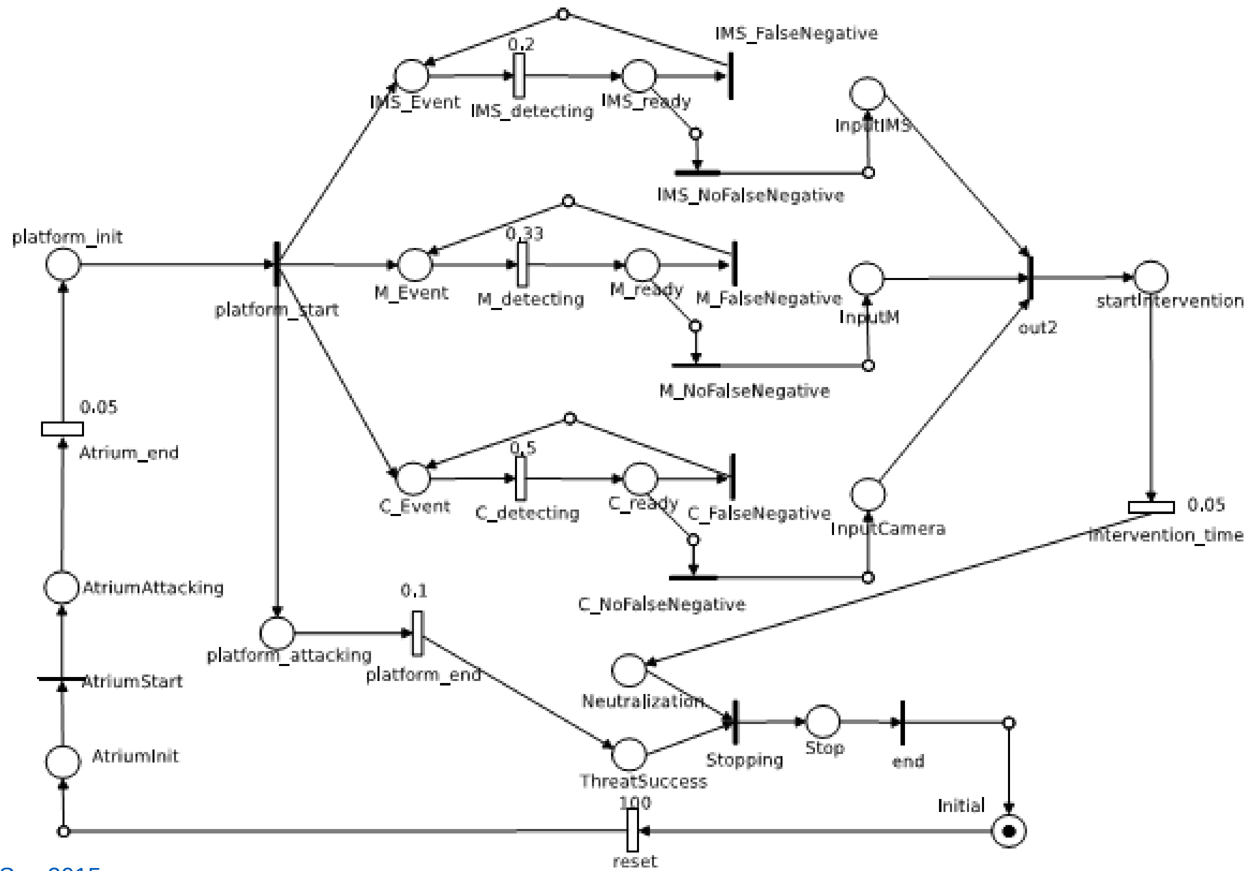
Single phase intervention

[3] Flammini et al. A Petri Net Pattern-Oriented Approach for the Design of Physical Protection Systems. Safecomp 2014

Assembling patterns

Security of a Metro station [3]





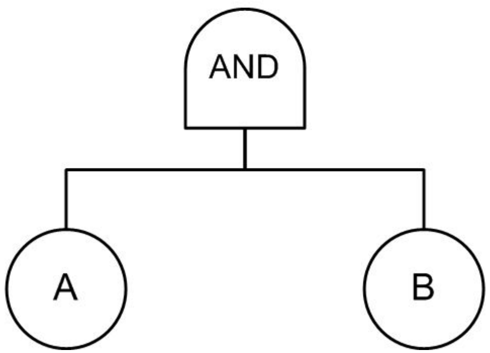
Stochastic Petri nets pros and cons

- Theoretically, unlimited modeling power (Turing machine)

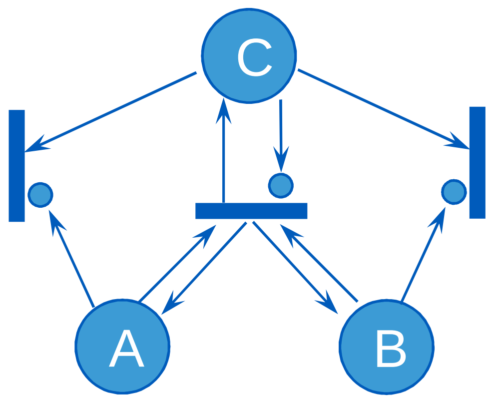
- Not suited for representing structure functions
  (nor instantaneous far reaching interactions)

- Spaghetti plate syndrome => validation is very hard

C = A and B



5 objects

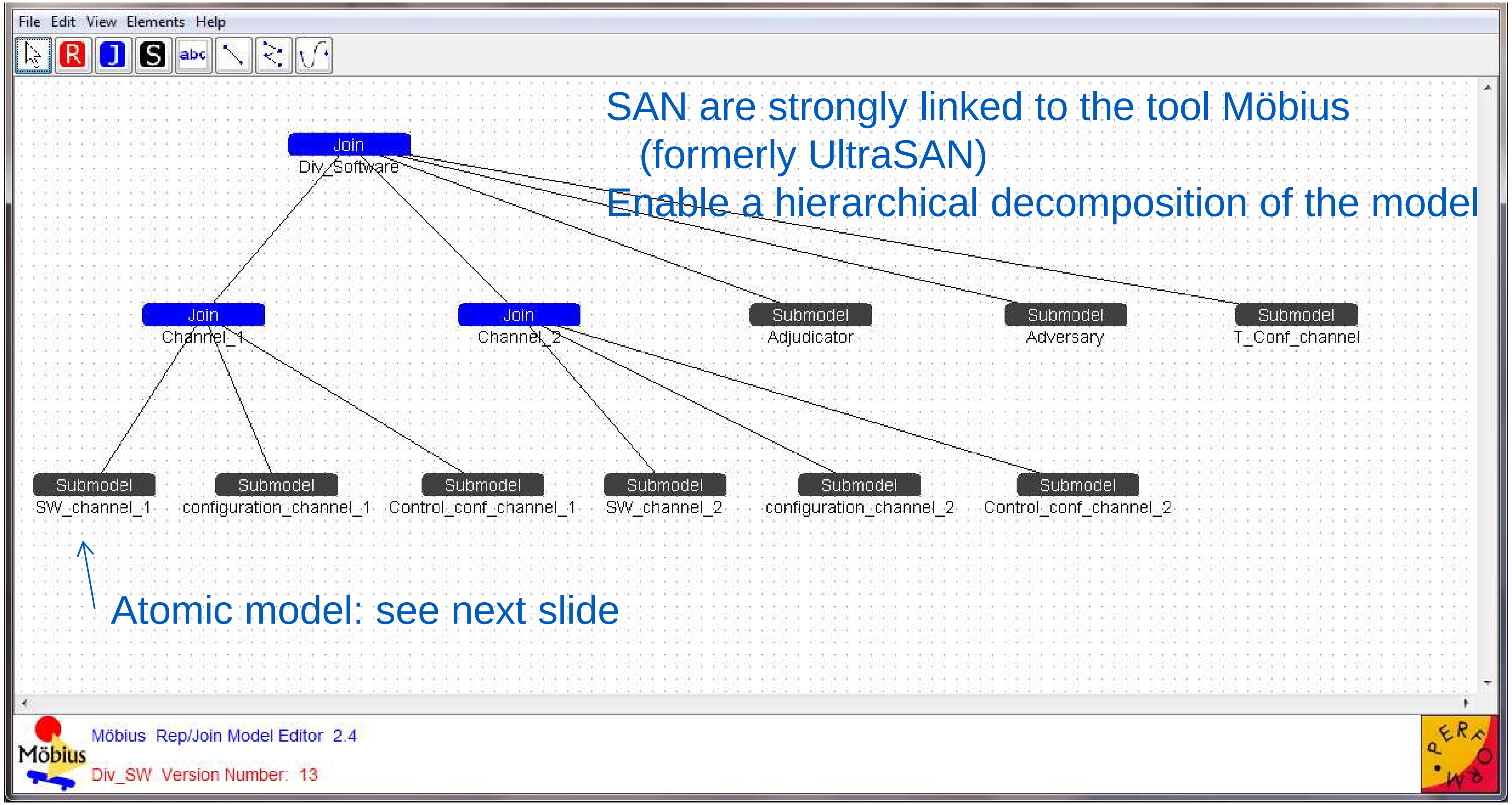


16 objects

Stochastic Activity Networks [4]

SAN are strongly linked to the tool Möbius (formerly UltraSAN)

Enable a hierarchical decomposition of the model

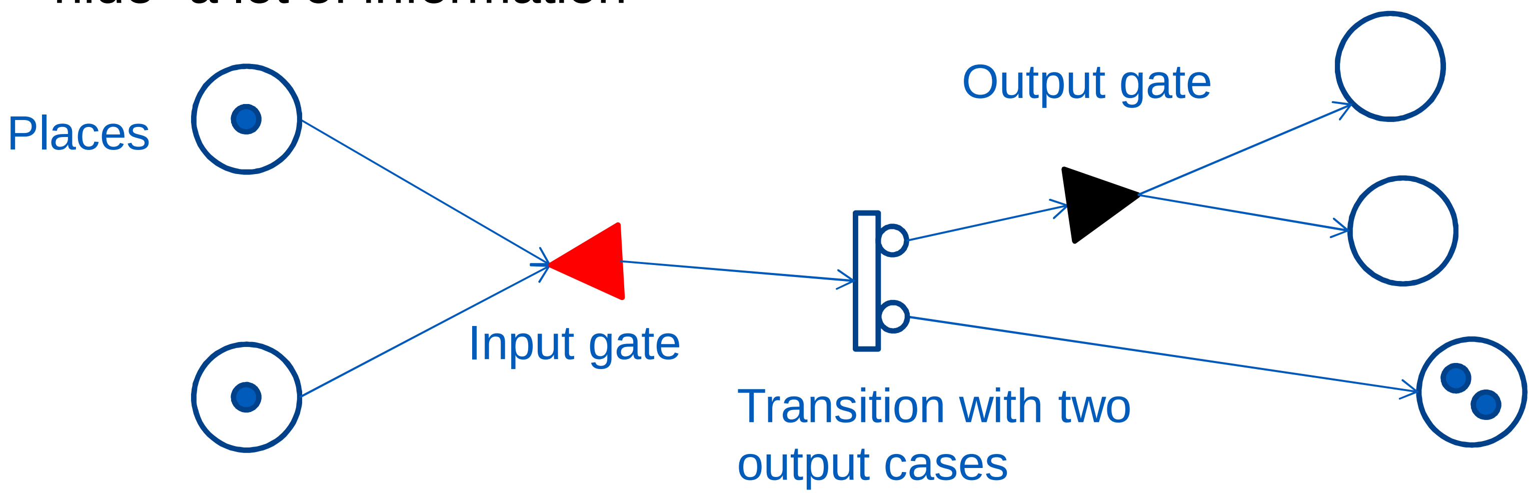


Atomic model: see next slide

[4] W. H. Sanders and J. F. Meyer, "Stochastic Activity Networks: Formal Definitions and Concepts" Lecture Notes in Computer Science no. 2090, pp. 315-343. Berlin: Springer, 2001.

SAN atomic model = Stochastic Petri net + following extensions

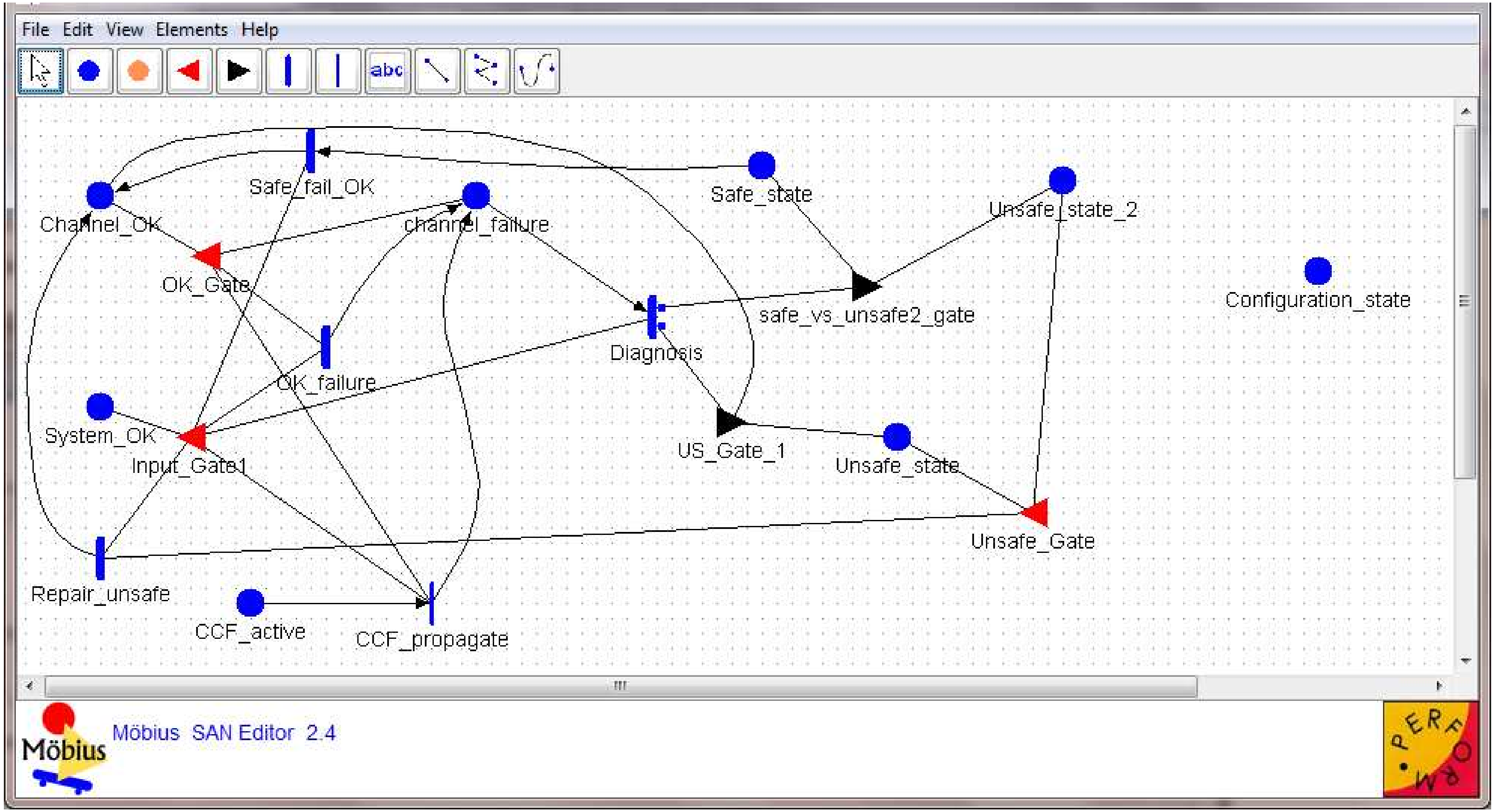
- Activities (= transitions) can have several outputs (probabilistically chosen)
- Input gates: contain the definition of a Boolean function of the input places marking that defines the enabling of the activity, and the modification of the input places marking when the transition fires
- Output gates: contain a set of actions to perform on output places when the transition fires
- Input and output gates are defined using C++ syntax => the graph can "hide" a lot of information



Communication between submodels

- Shared places
- Shared variables

(not apparent on the GUI)



SAN pros and cons

- Can solve the problem of structure function representation (but not graphically)

- Instantaneous far reaching interactions? Maybe, with very complicated input and output gate functions

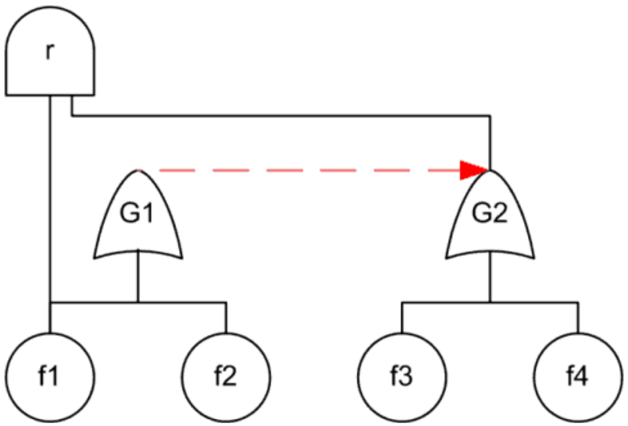
- In a "normal" use
  - Lots of small spaghetti plates with sauce  => validation is still very hard
  - Sauce can be hot chili! (input and output functions, shared variables are hidden)

BDMP

Boolean logic Driven Markov Processes

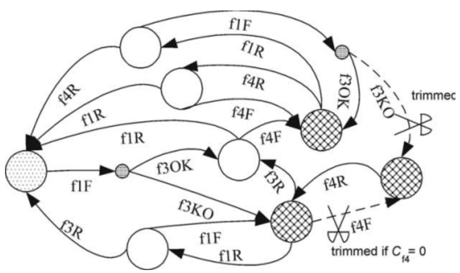
BDMP CV

- Since 2002, Interest proven in reliability and safety engineering



- ✓ Dynamic
- ✓ Readable
- ✓ Tractable

A new formalism that combines advantages of fault-trees and Markov models: Boolean logic Driven Markov Processes
Reliability Engineering and System Safety, Vol. 82, Issue 2, Nov. 2003, pp.149-163



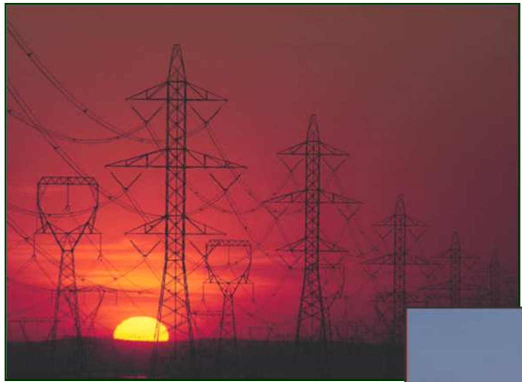
- Invented and used at EDF (NPP safety, substations, data centers reliability,…)
- Complete theory and software framework

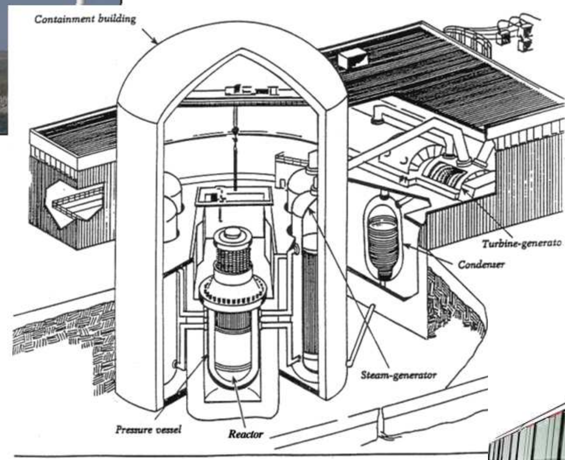
⇒ Adapted to attack and defense modeling [5]

[5] L. Pietre-Cambacedes, M. Bouissou, Attack and defense dynamic modeling with BDMP. MMM-ACNS 2010, St Petersbourg, September 2010.

BDMP can be used to model any kind of system…

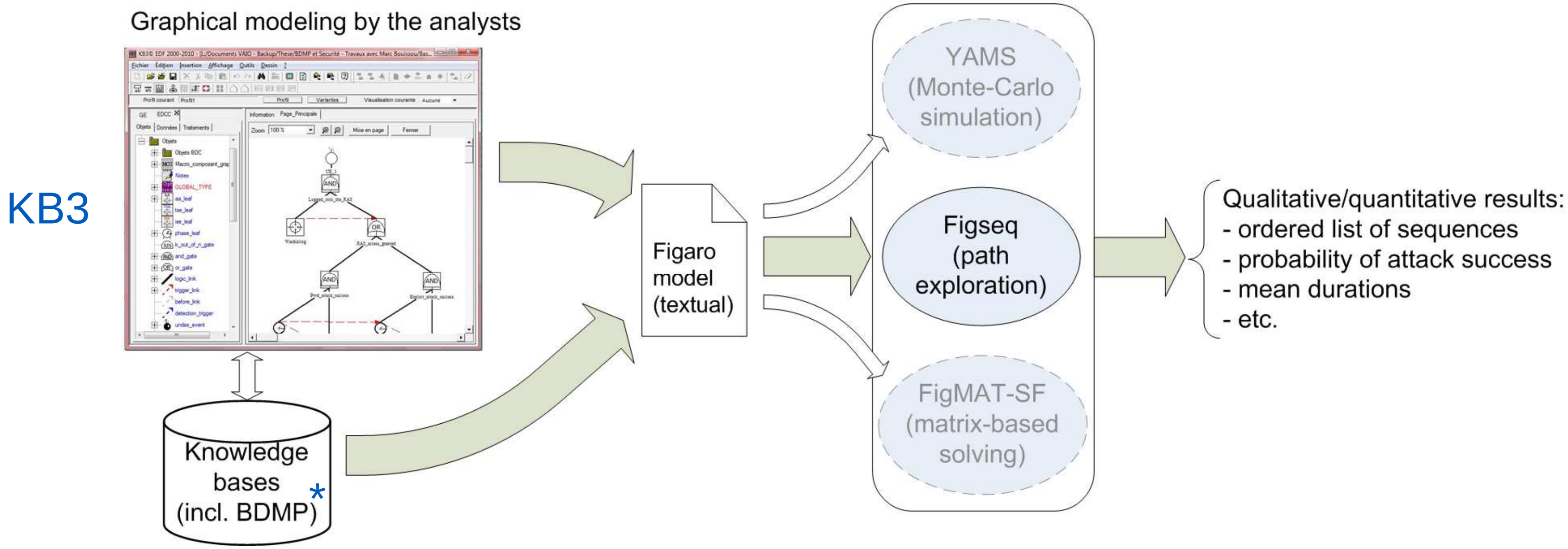
Repairable or not
Multiphase
Multistate
…





2 major parts of a nuclear powerplant work together to produce electricity.

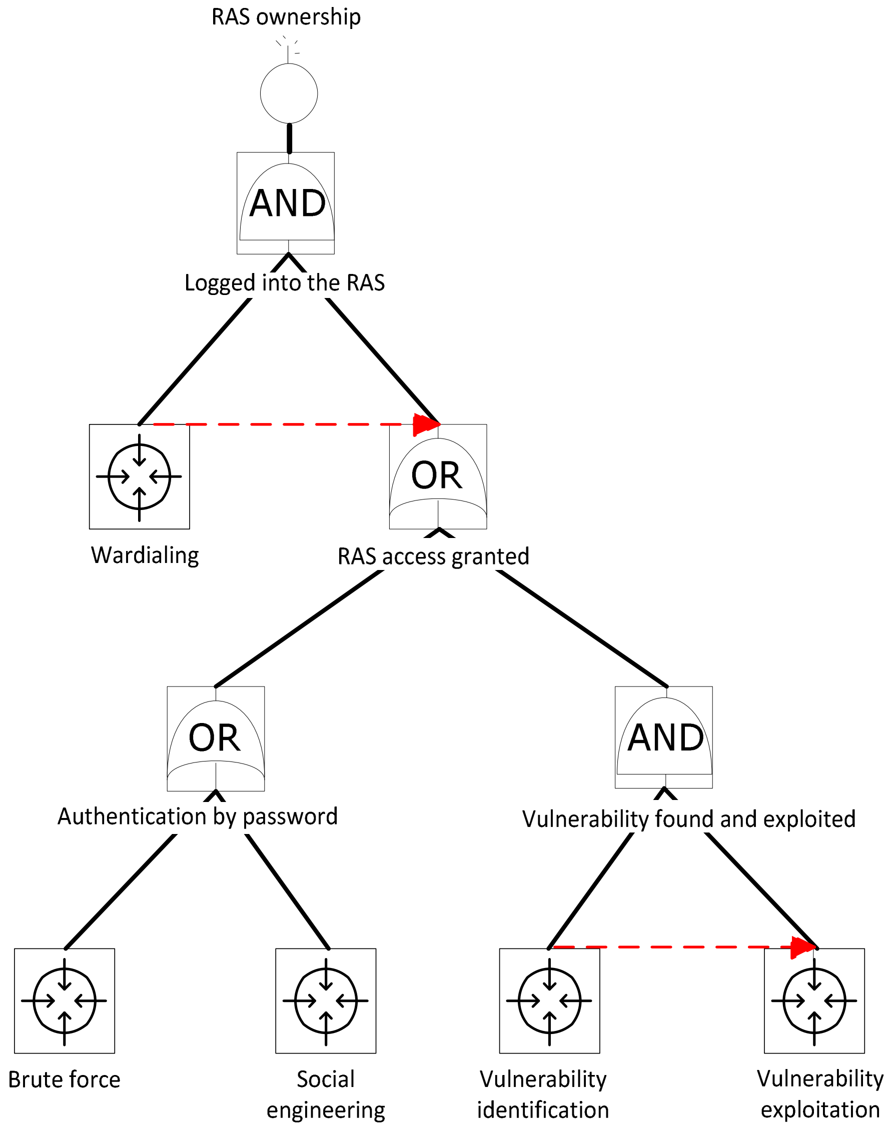
Tools associated to BDMP formalism



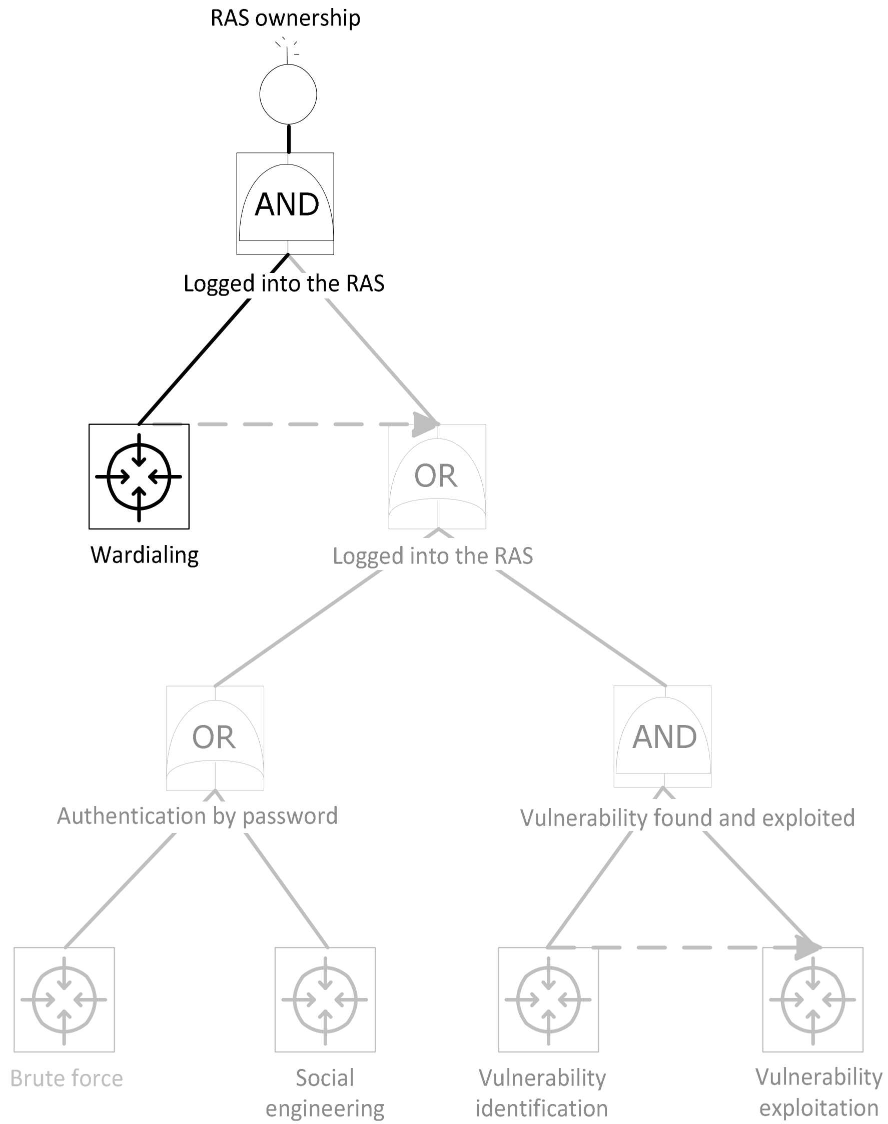
* And Petri nets!

Download: http://sourceforge.net/projects/visualfigaro/

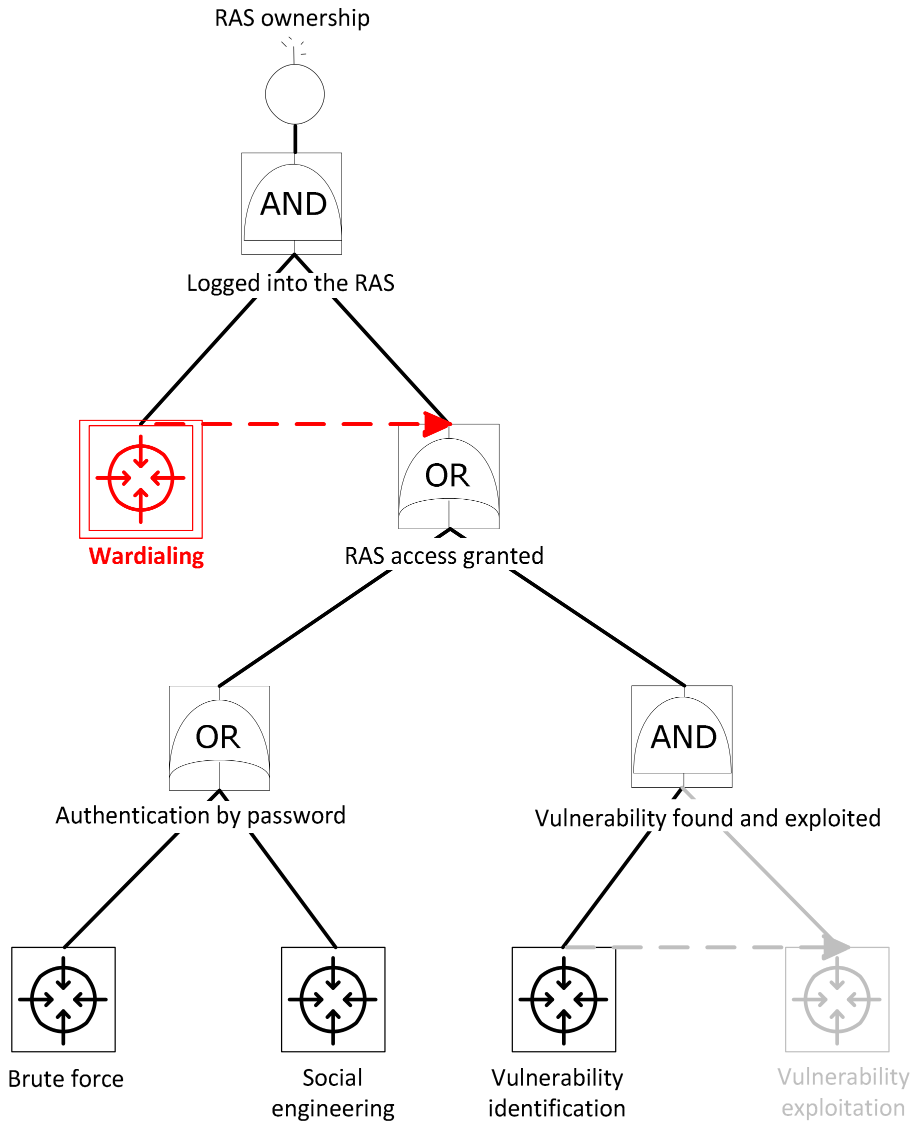
An example of BDMP in security: attack of a remote access server



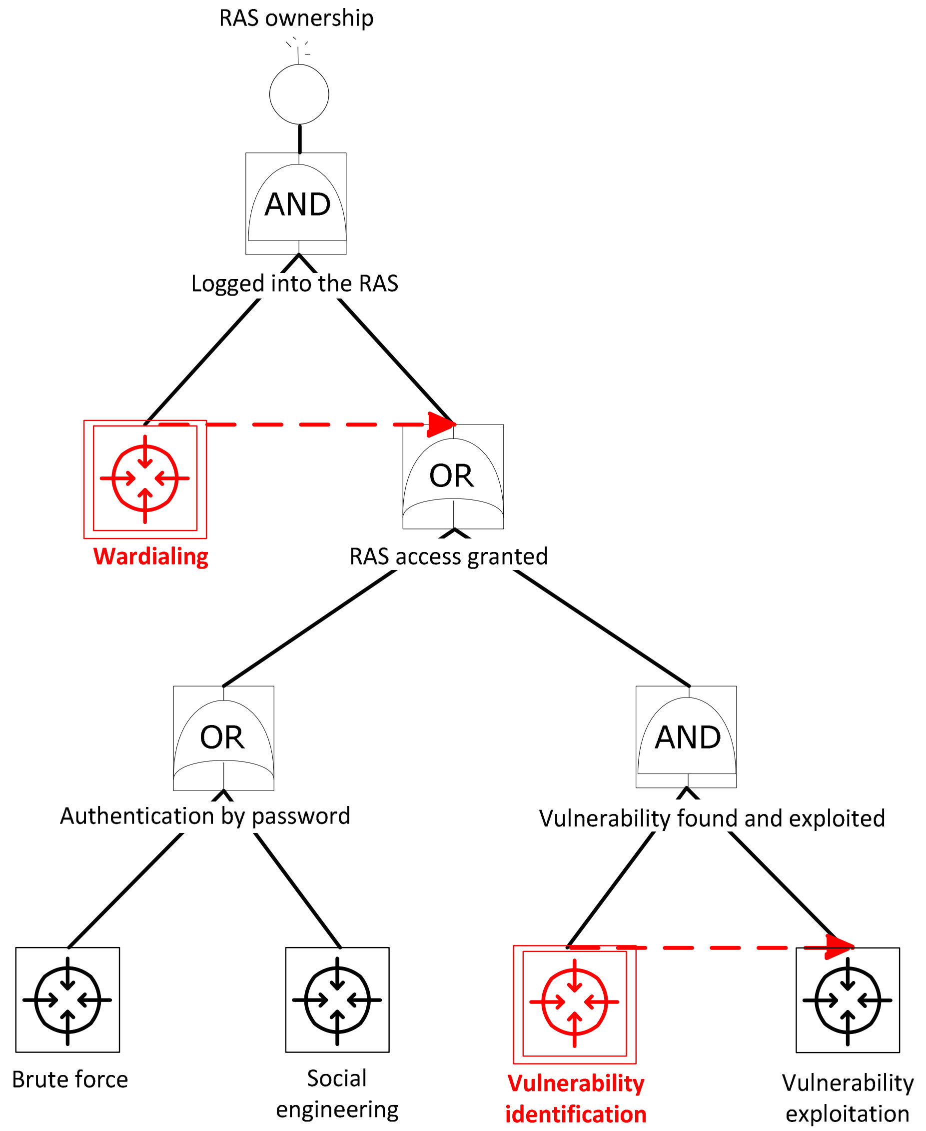
RAS attack BDMP – Step 0 (attack just started)



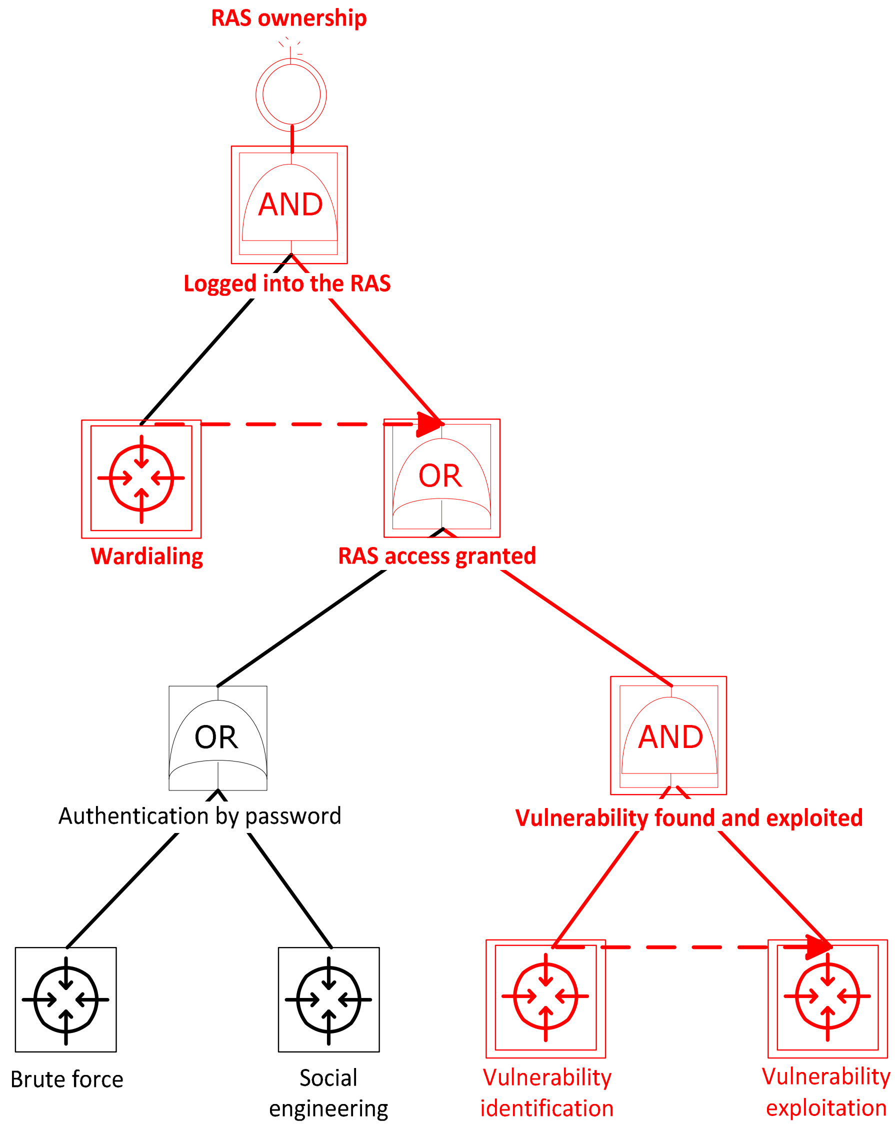
RAS attack BDMP – Step 1



RAS attack BDMP – Step 2

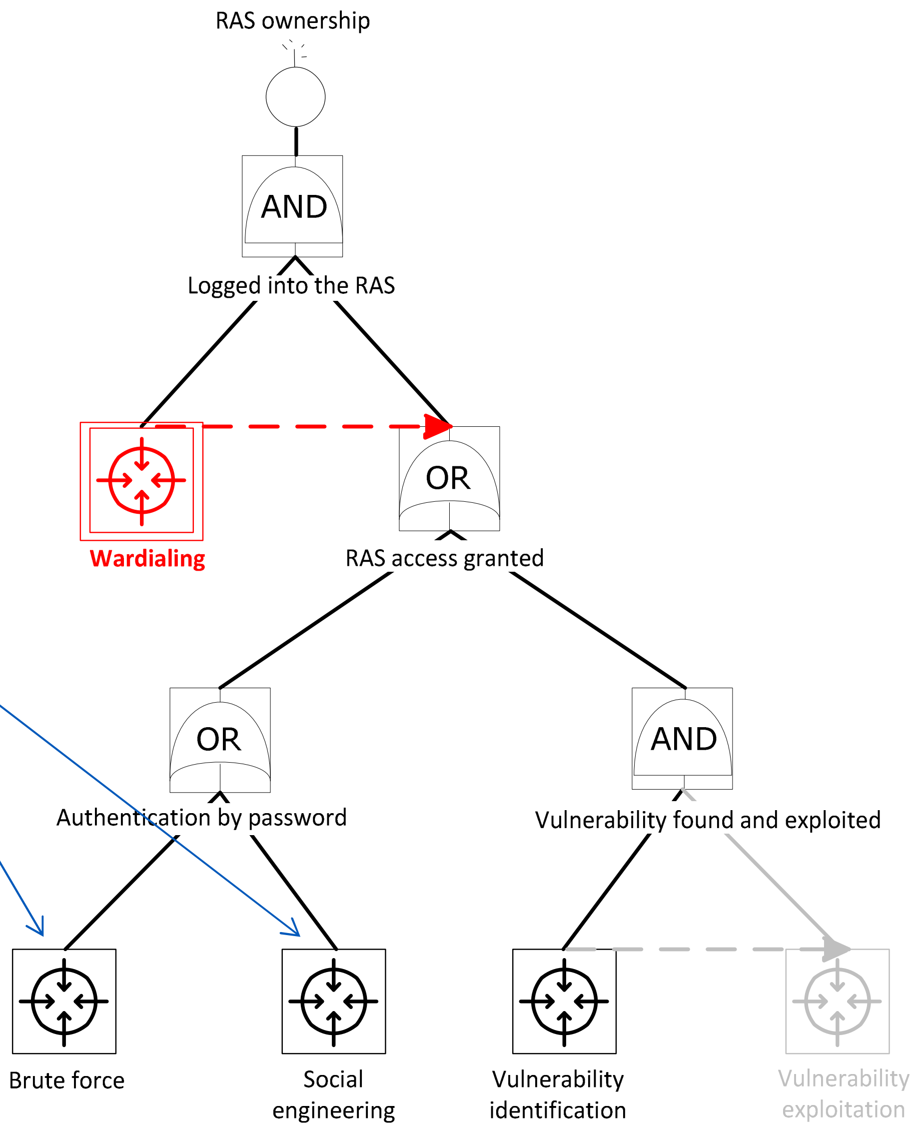


RAS attack BDMP – Attacker's objective reached

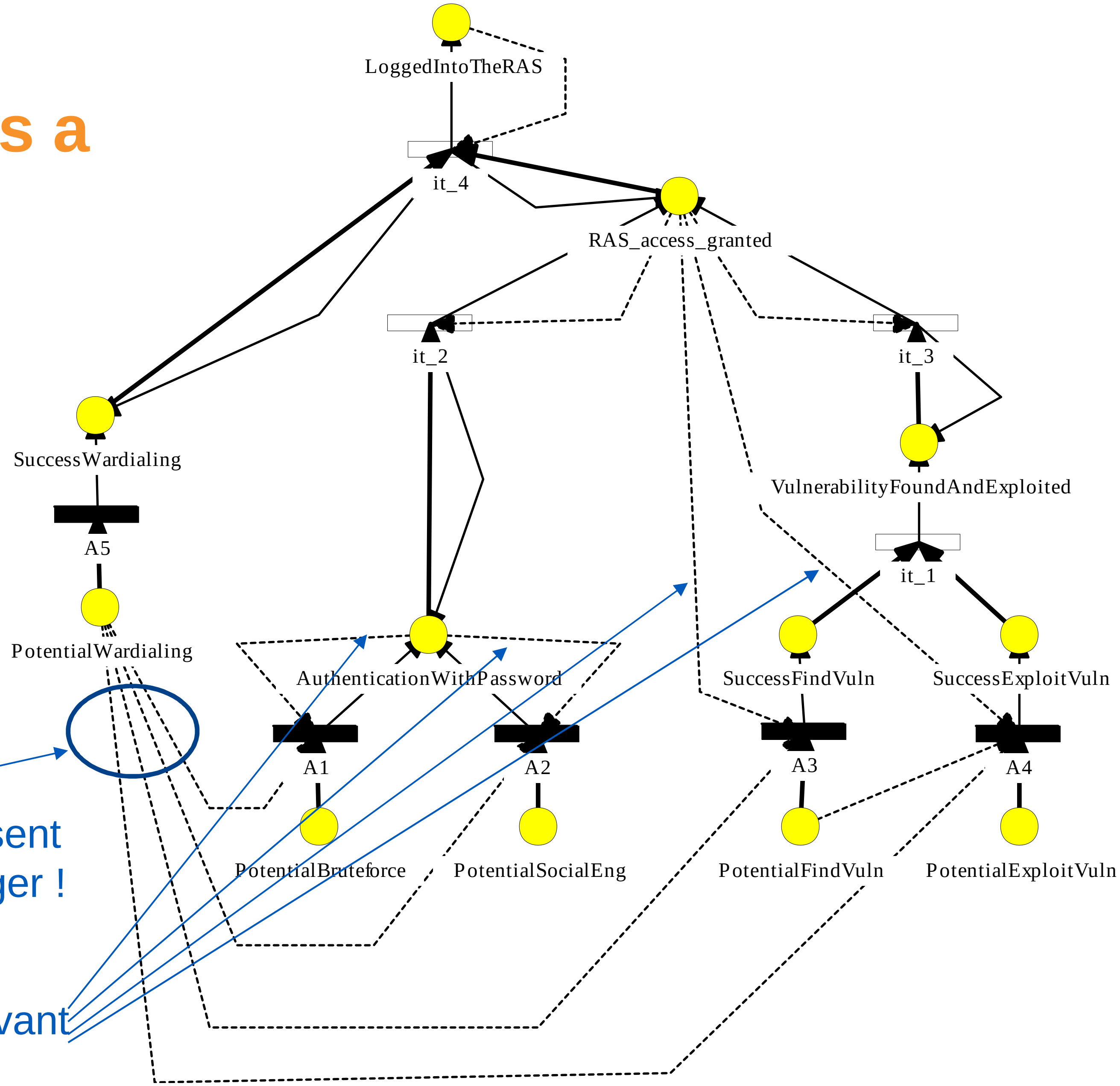


An important mechanism of BDMP: filtering of relevant events

If one of these leaves is realized, it makes the other one irrelevant and thus inhibited



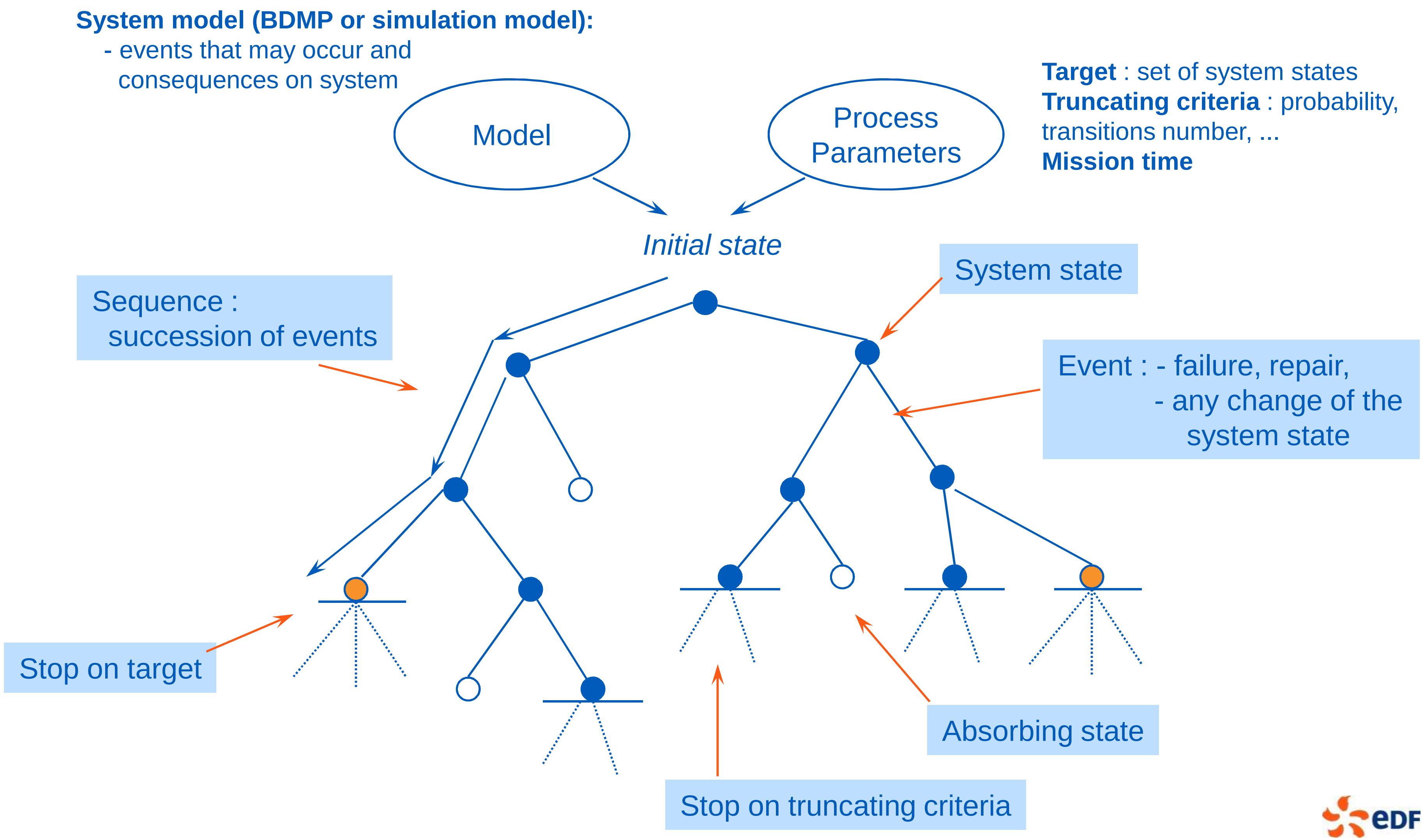
The same example as a Petri Net



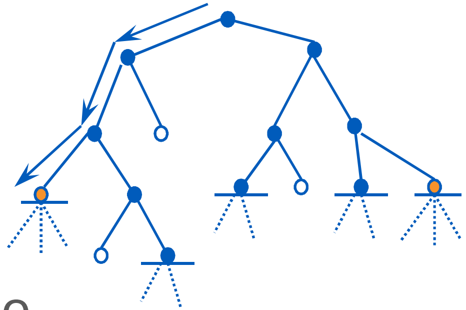
Inhibitor arcs needed to represent the top level trigger !

Inhibitor arcs needed for irrelevant event filtering

Principles of sequences exploration in a locally defined Markov chain (Figseq)



Quantification (1/2) – Time-domain analysis



- Taking advantage of the BDMP framework
  - Efficient sequence exploration with trimming
    - Probability to reach the objective in a given time
    - Overall mean time to the attack success
    - Probability of each explored sequence
    - Ordered list of sequences

0.55
1.07 x 10^5 s
Cf. hereunder

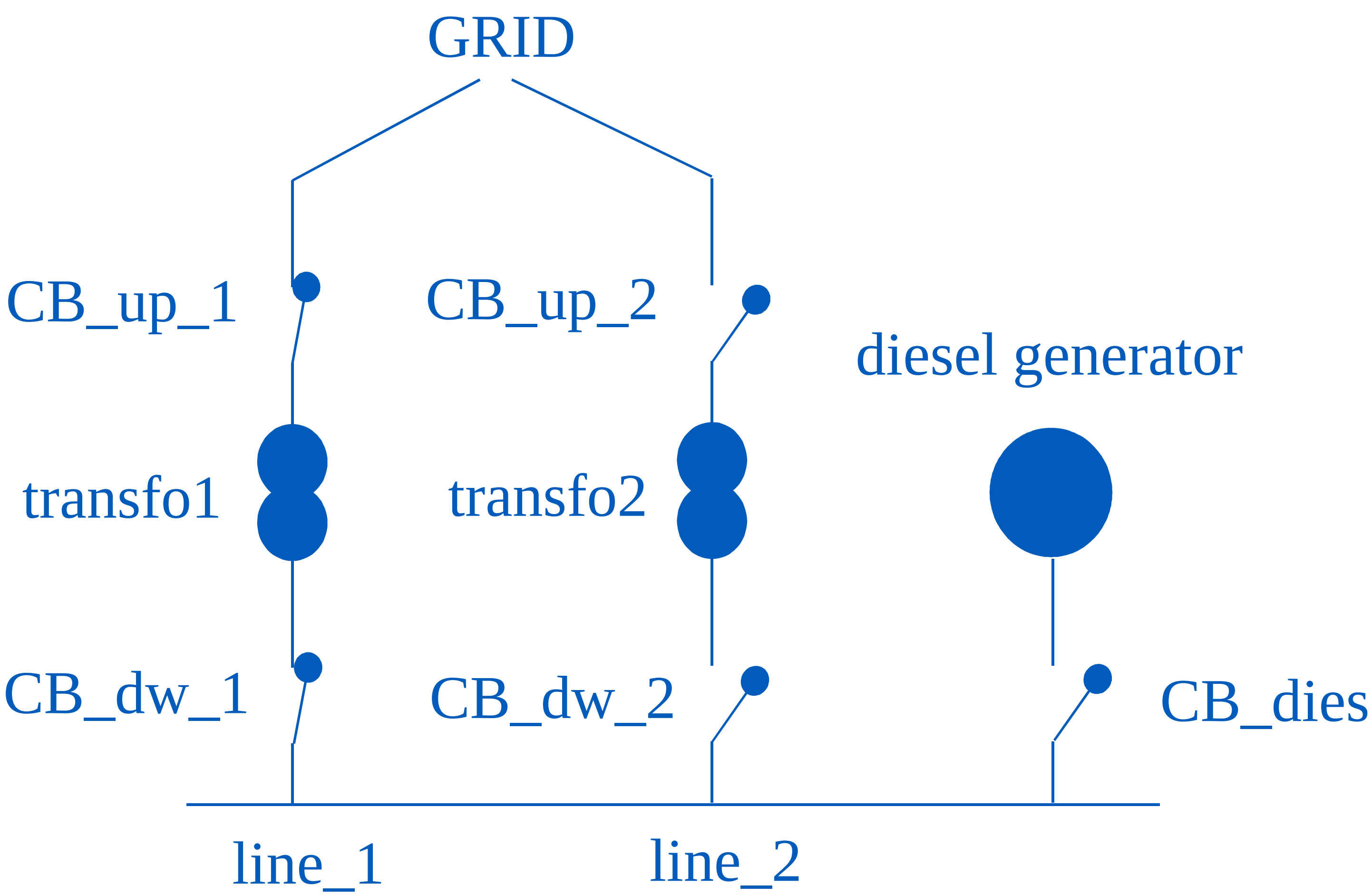
Sequences *Attack steps*	Probability in mission time	Average duration after init.	Contribution
[Wardialing, Bruteforce]	0.2717	4.878×10^3	0.4877
[Wardialing, Find_vuln, Bruteforce]	0.1272	9.7561×10^3	0.2329
[Wardialing, Find_vuln, Exploit_vuln]	0.1272	9.7561×10^3	0.2329
[Wardialing, Social_eng.]	0.0136	4.8780×10^3	0.0249
[Wardialing, Find_vuln, Social_eng.]	0.0064	9.7561×10^3	0.0116

Quantification (2/2) – Time-independent

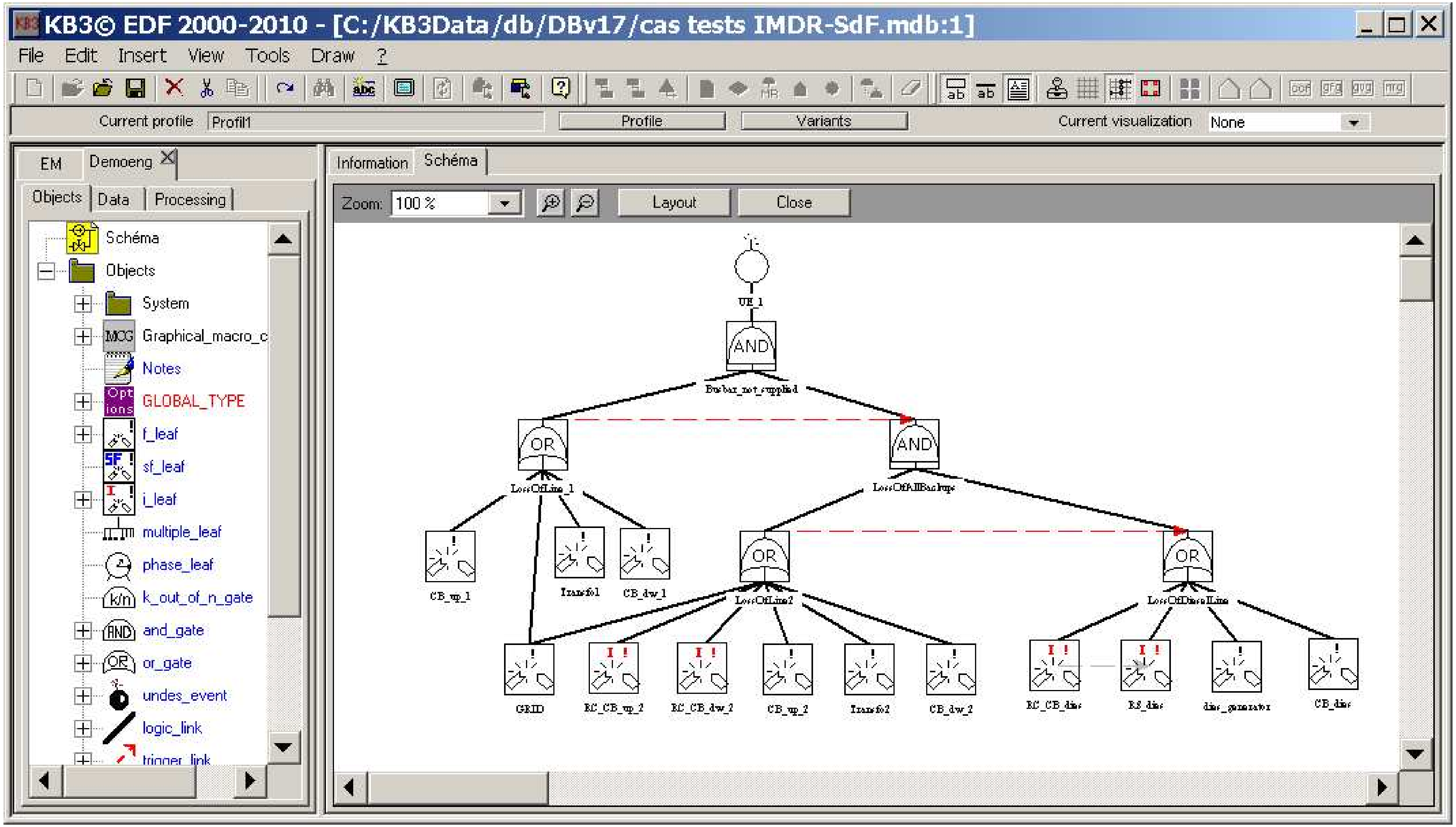
- Classical values attributed to attack tree leaves
  - Fixed probabilities → (dynamically) covered by stochastic processes
  - Monetary cost → scenario cost, average attack cost
  - Boolean indicators (specific requirements, properties)
    - Need of internal knowledge, internal support
    - Need of specific tool, piece of information

    → Characterization of selected scenarios
  - Minimum attacker skills
- (Generalization) Continuous, Boolean, Discrete attributes
  - All computable thanks to the Attack tree structure

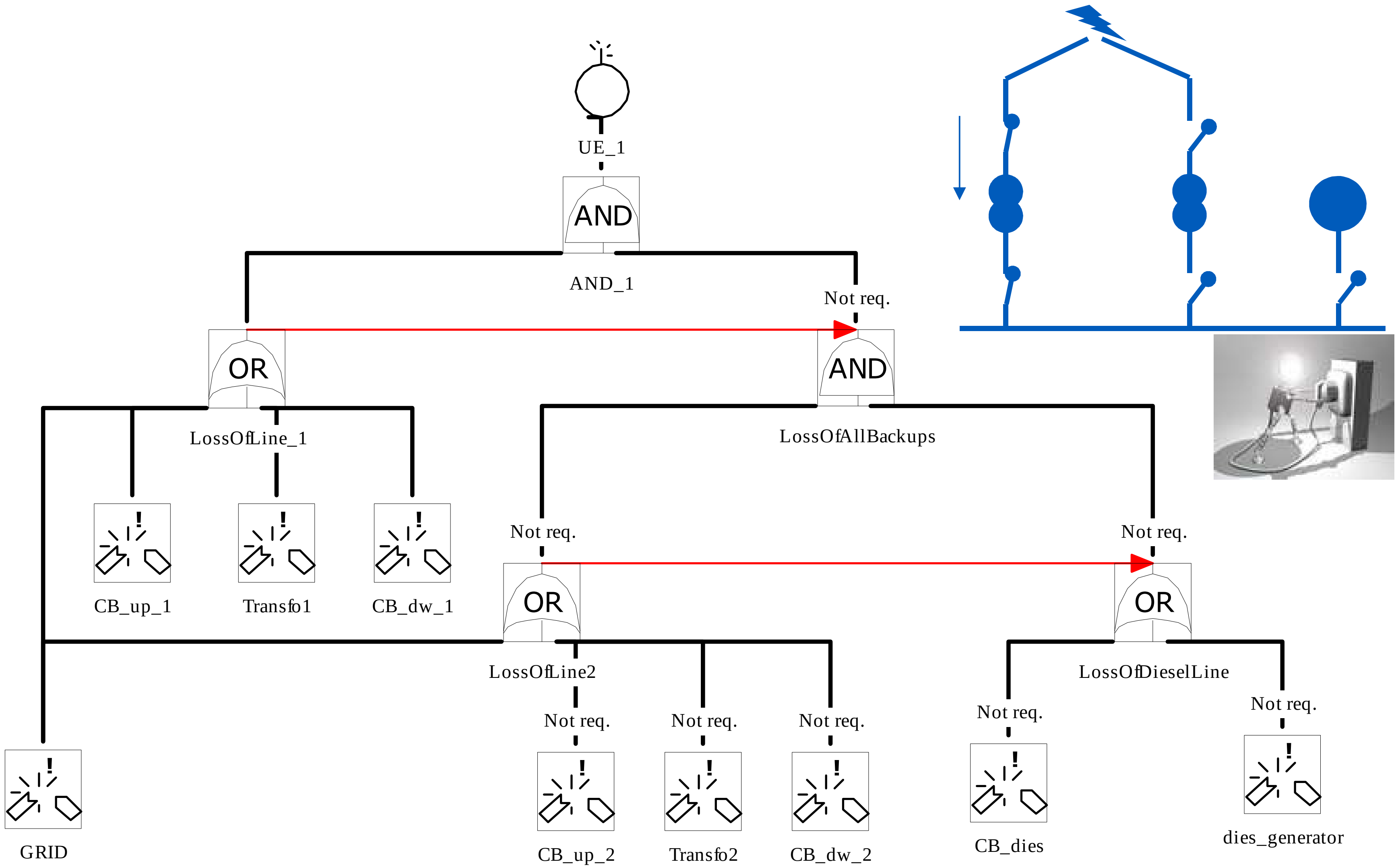
An example in safety: system to be modeled



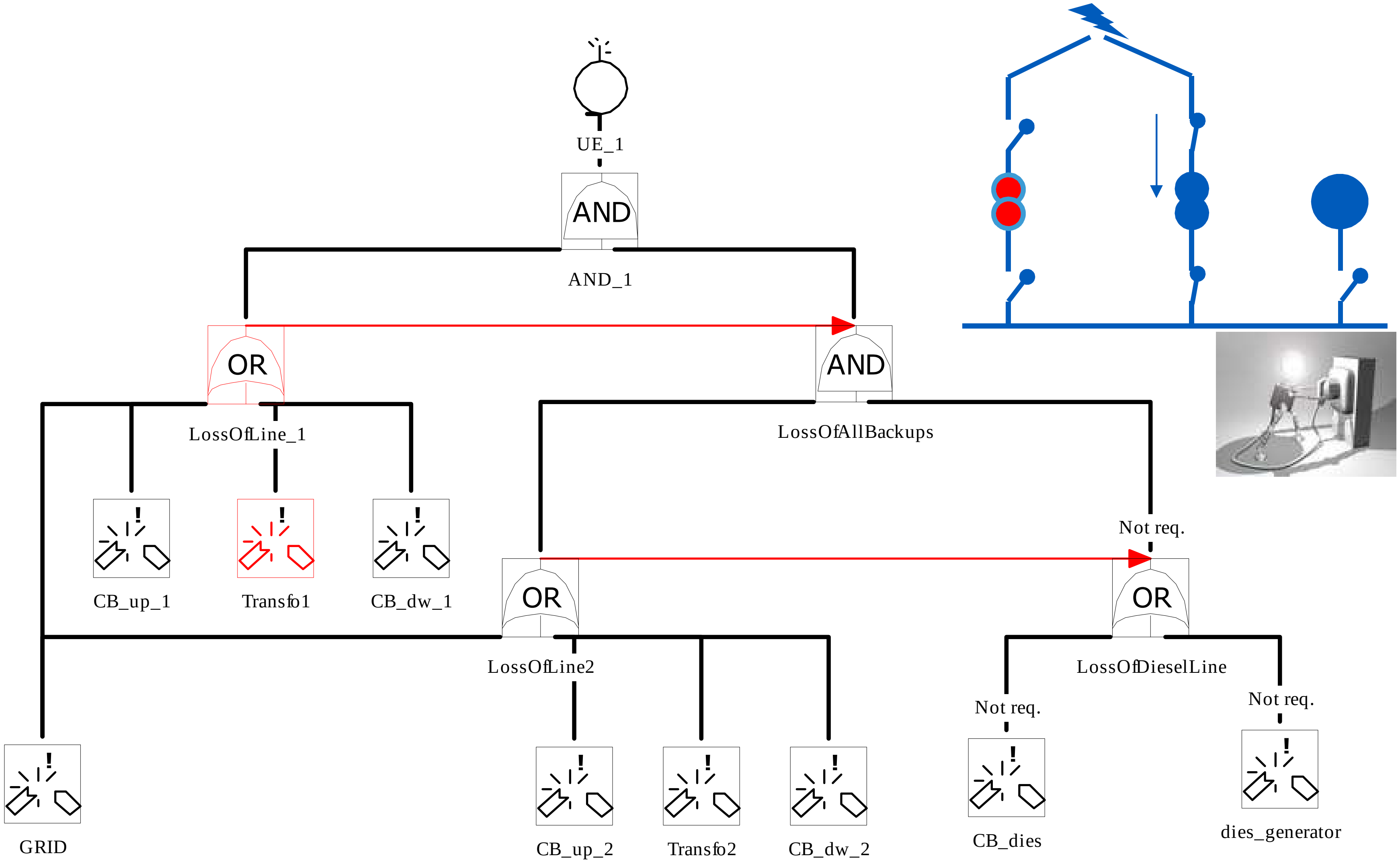
The BDMP in KB3



Simulation of a sequence of events

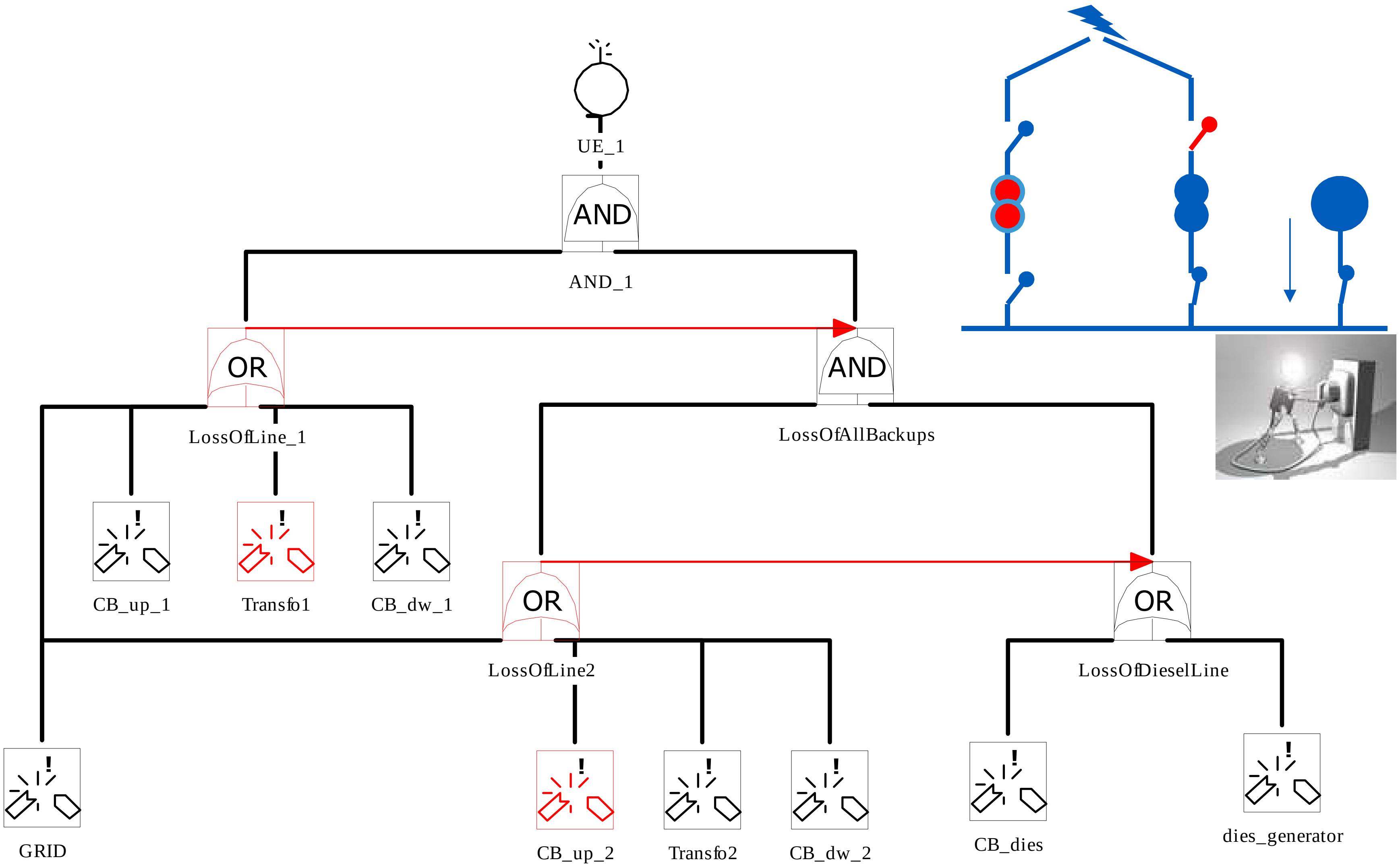


Simulation of a sequence of events

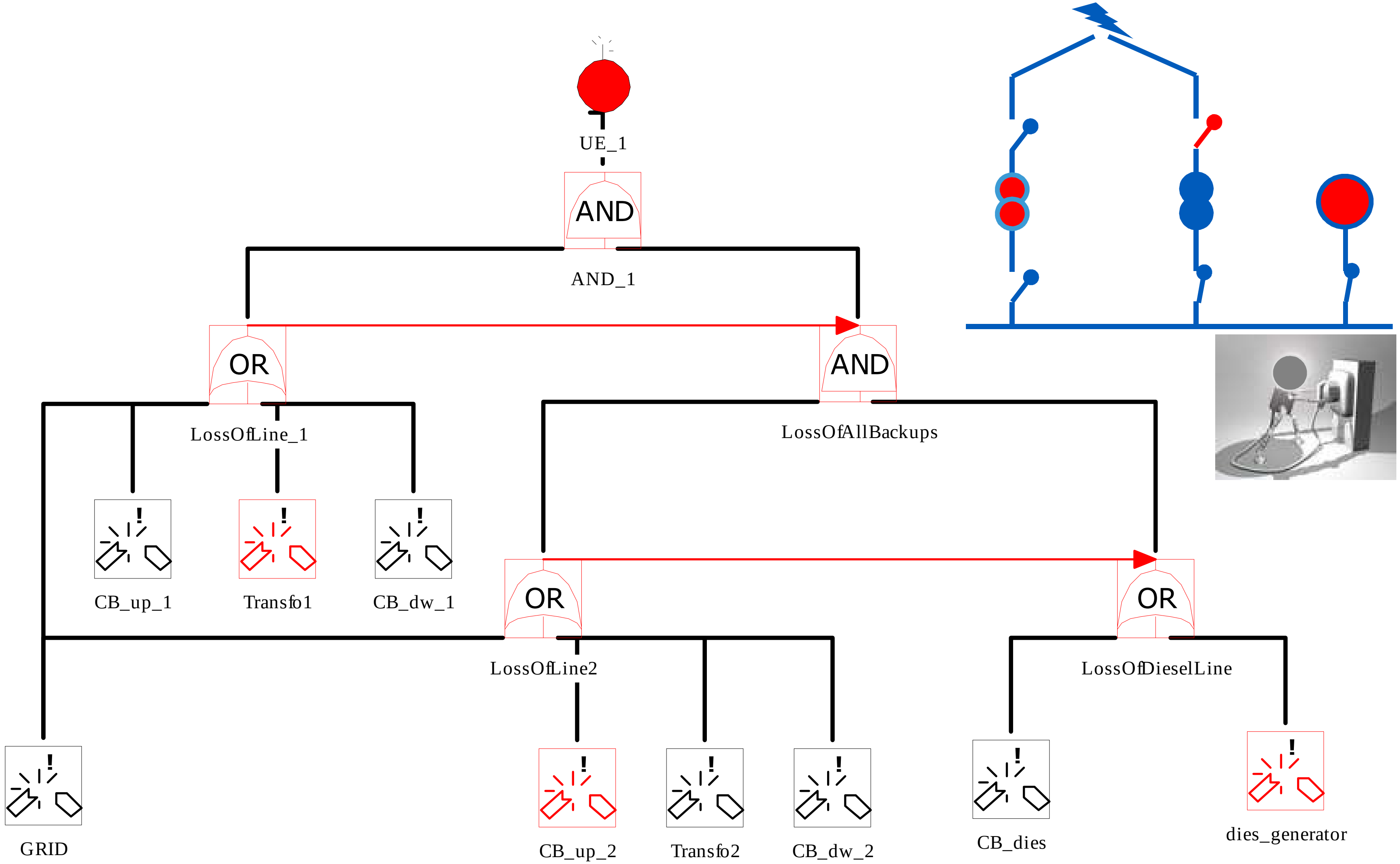


On demand failures are not modeled (here)

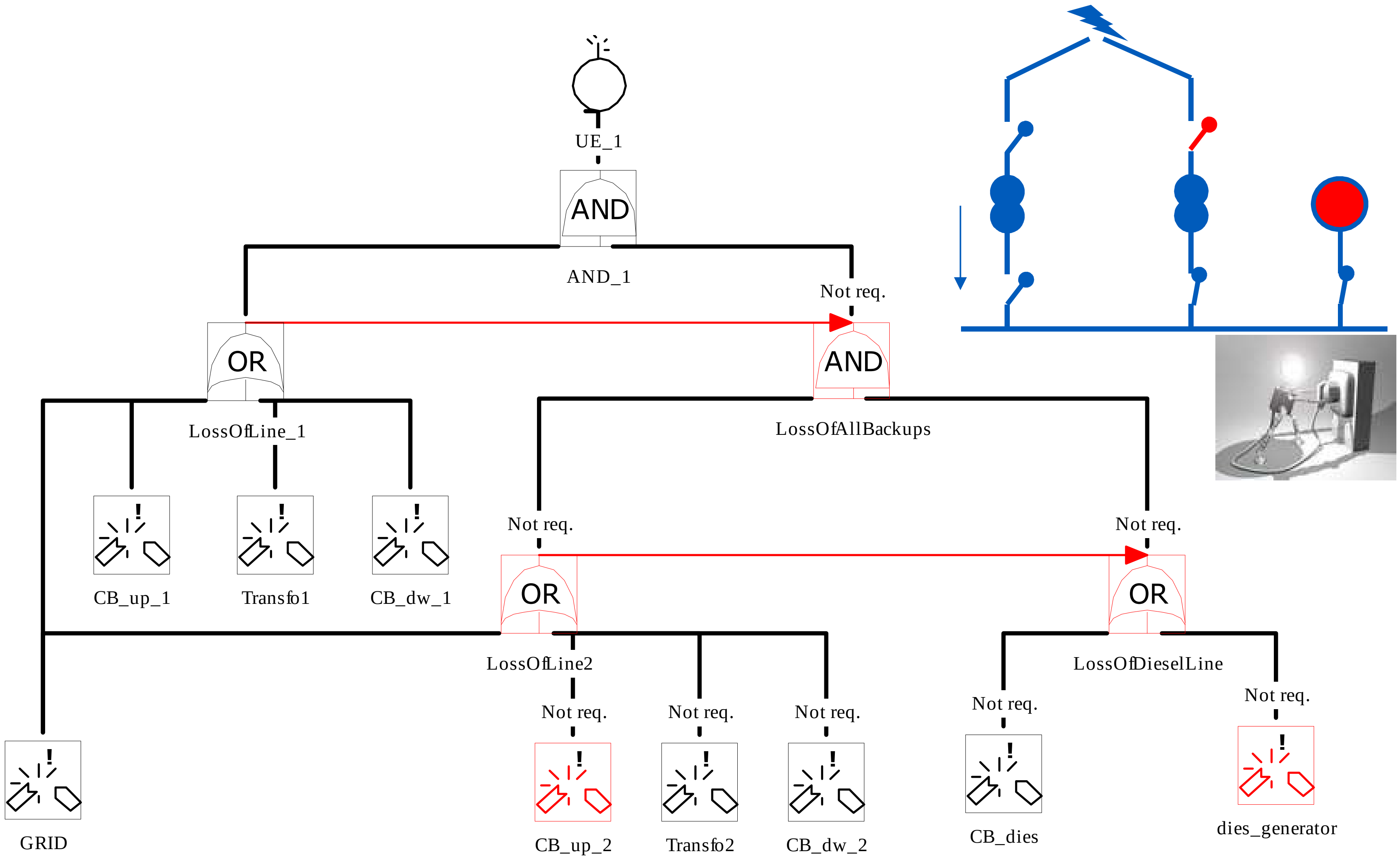
Simulation of a sequence of events



Simulation of a sequence of events



Simulation of a sequence of events

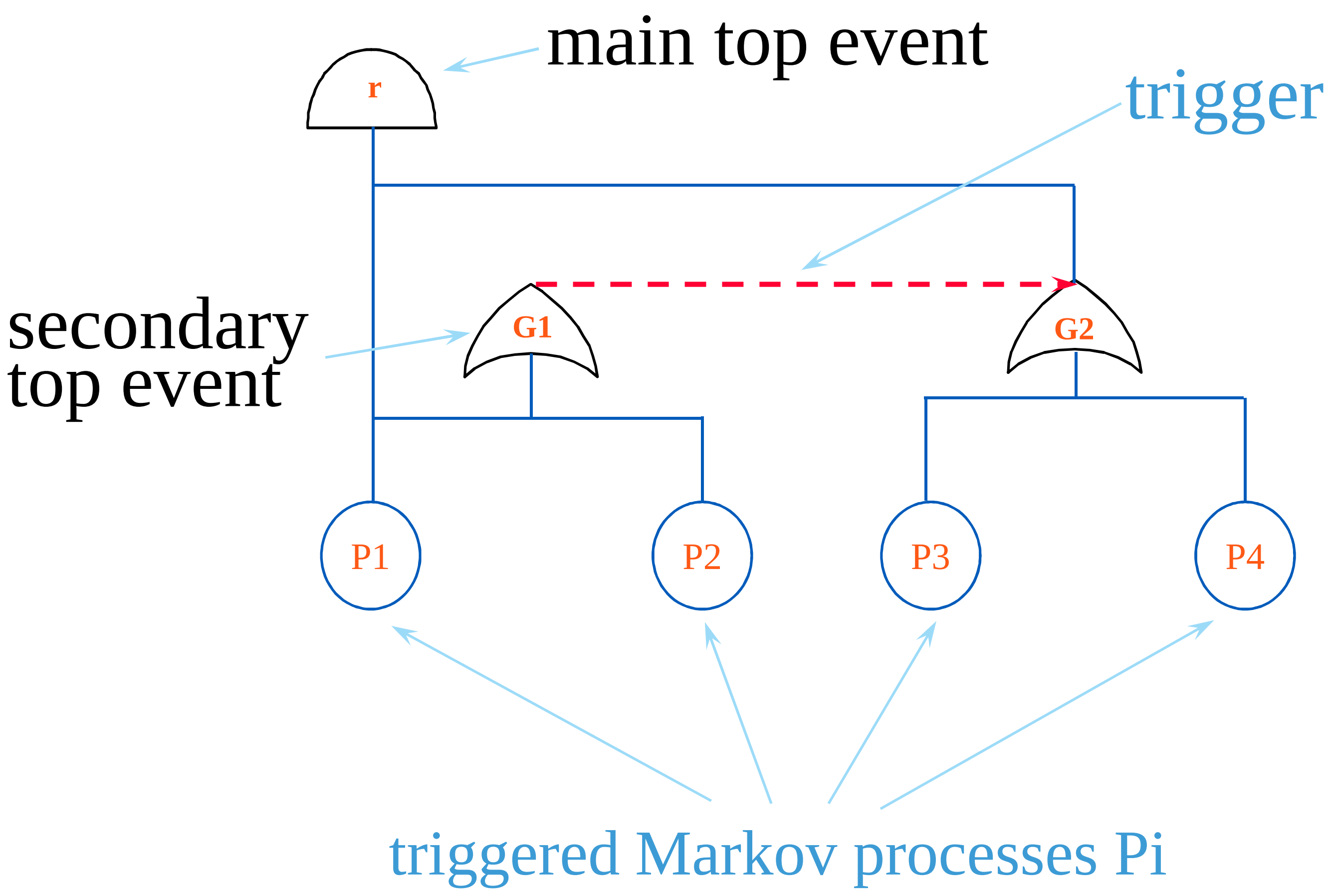


BDMP main ideas

- The total independence of leaves of a fault-tree is replaced by simple dependencies.
  Each leaf has **two modes**:
  required/active (1) and not required/idle (0).
  Transitions between those two modes define instantaneous states in which probabilistic choices can be triggered.
- **Any** Markov process can be associated to each mode of a leaf

Formalism
"Boolean logic Driven Markov Process"
(BDMP)

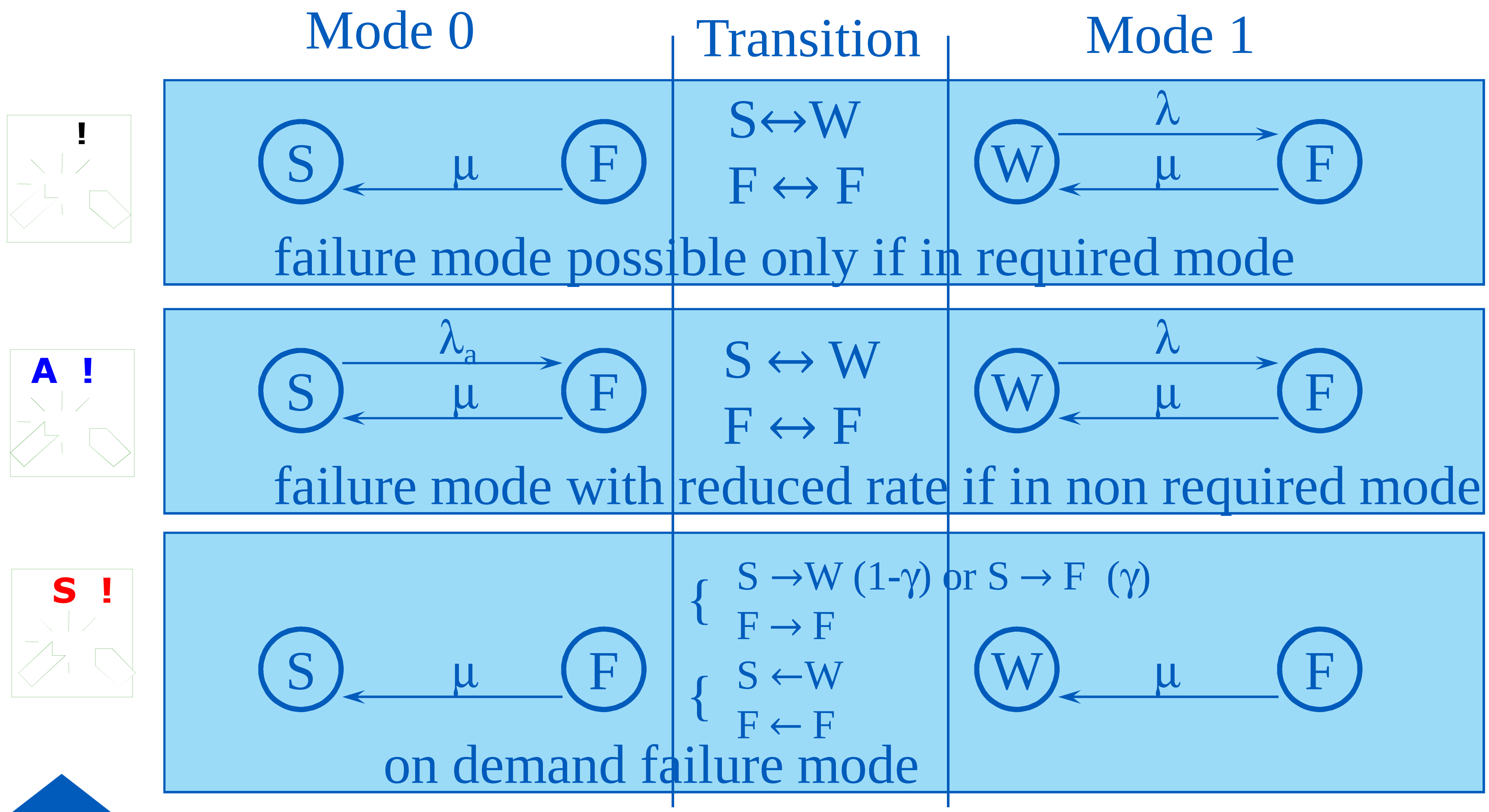
Graphical representation of a BDMP



A gate/basic event is TRUE when:

- a failure is present (for safety related parts)
- an attack is successful (for security related parts)

Examples of leaves behaviors (safety)

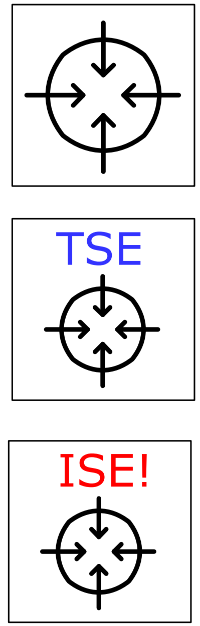


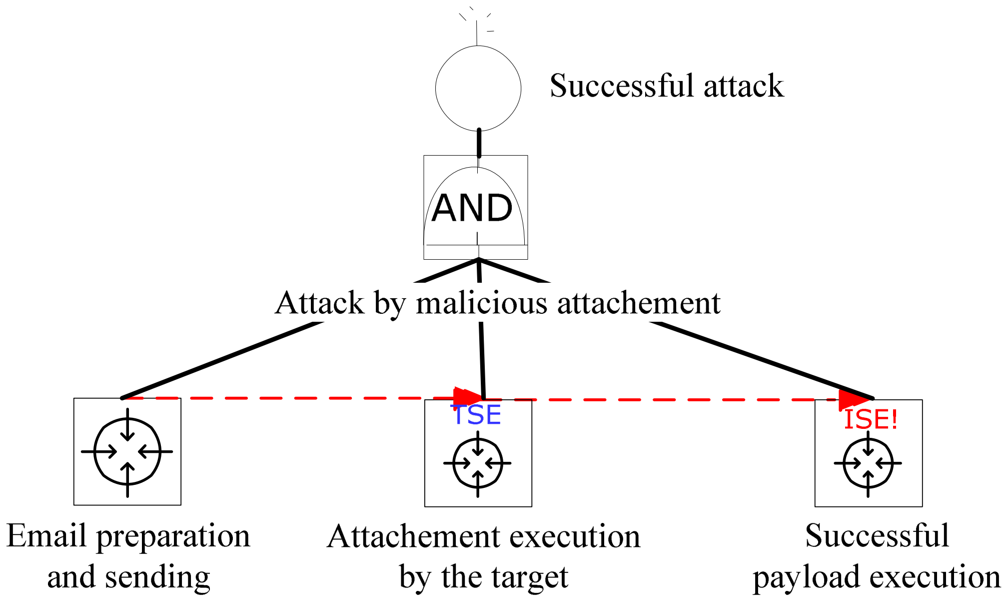
Graphical representation
in the tool KB3-BDMP

Working, **F**ailed, **S**tandby

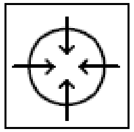
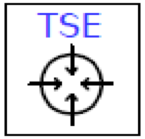
BDMP for attack modeling – Types of leaves

- Attack scenarios ⇒ 3 kinds of security leaves
  - Modeling of attacker's actions
    - AA (*Attacker Action*) leaves, timed leaves (1/ λ = MTTS)
  - Modeling of security events
    - TSE (*Timed Security Event*) leaves, timed as well
    - ISE (*Instantaneous Security Event*) leaves, instantaneous (γ)





Examples of leaves behaviors (security)

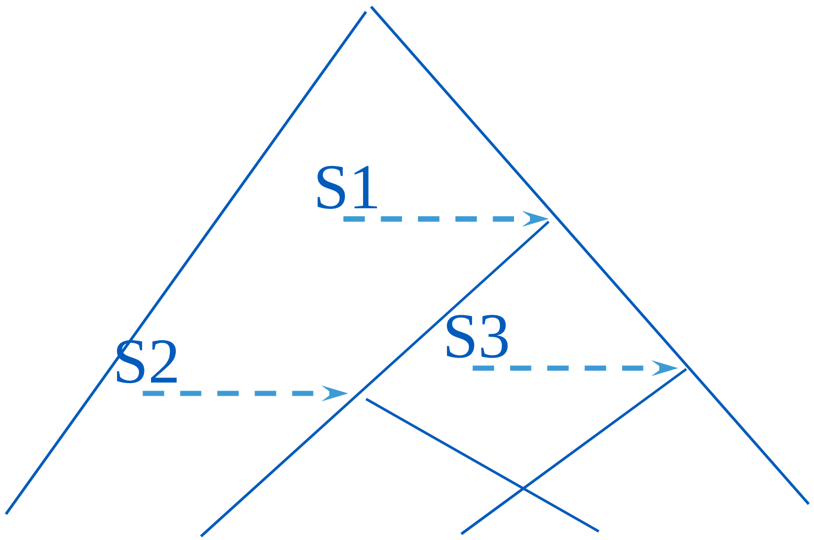
	Mode 0 - idle	Transition	Mode 1 - active
	P, S	$P \leftrightarrow O$ $S \leftrightarrow S$	$O \xrightarrow{\lambda} S$
	Attack that will succeed after going On some time		
	P $NR \xrightarrow{\lambda'} R$	$P \rightarrow NR$ $NR \leftrightarrow NR$ $R \leftrightarrow R$	$NR \xrightarrow{\lambda} R$
	Timed security event, not under attacker control		
	P, R	$\{ P \rightarrow NR\ (1-\gamma)$ or $P \rightarrow R\ (\gamma)$; $R \rightarrow R$ $\{ P \leftarrow NR$; $R \leftarrow R$	NR, R
	Attack that may succeed at the mode change $(0 \rightarrow 1)$		

Graphical representation
in the tool KB3-BDMP

Potential, **S**uccess, **O**n-going
Not **R**ealized, **R**ealized

Definition of required/active mode in a BDMP (1)

- Very powerful concept, because it is hierarchical
- Requirement signal transmitted by the branches of the fault-tree

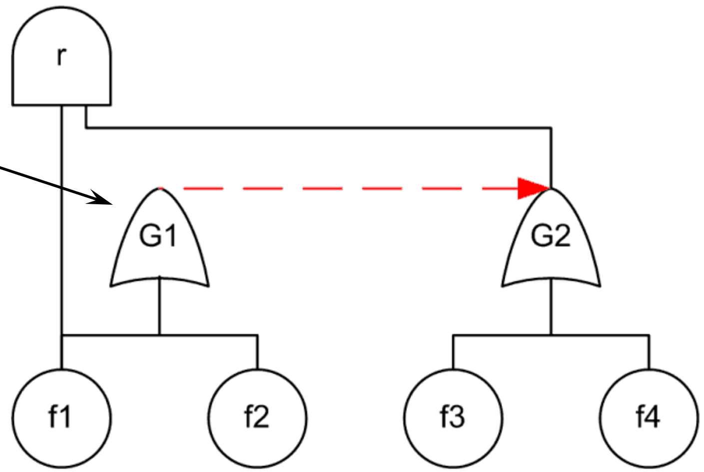


a gate or leaf is in mode 1
except if it receives a
signal of mode 0 from :
all its fathers or
directly via a trigger

Makes it easy to model cascade
standby redundancies/hierarchy
of attack steps

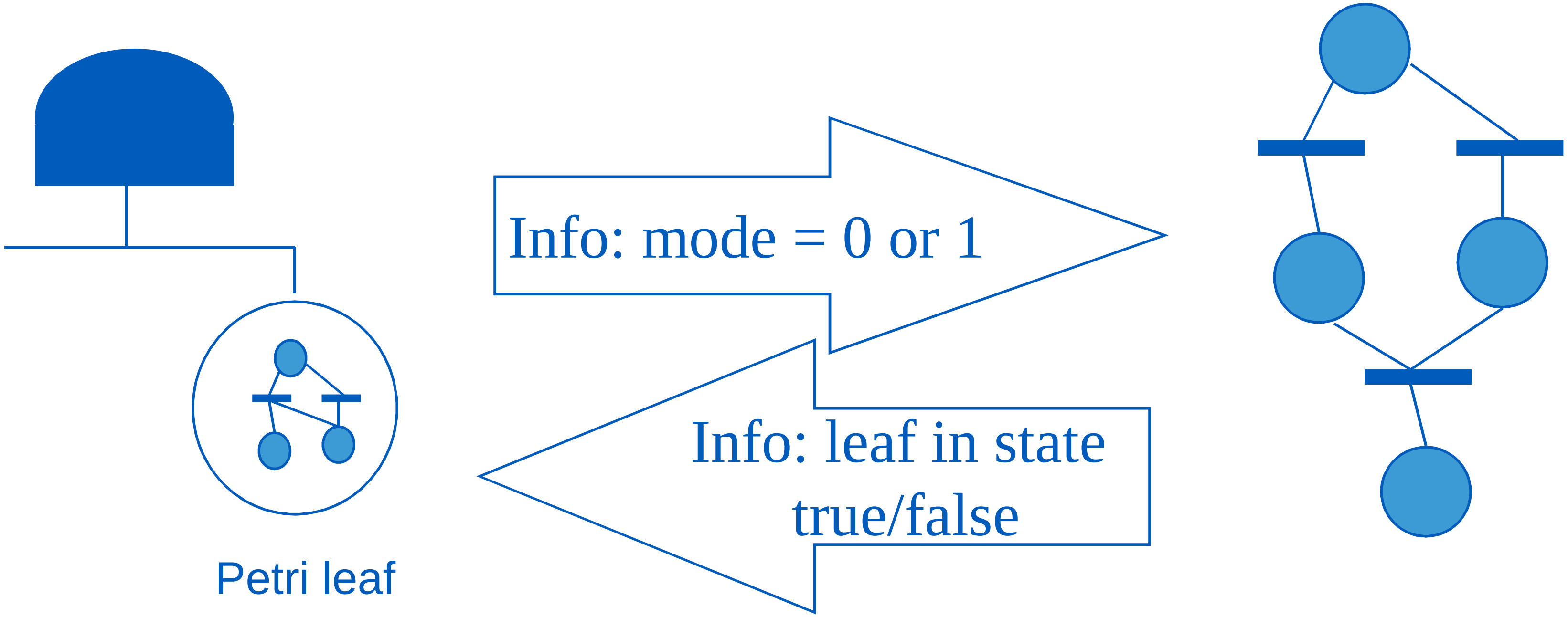
Definition of required/active mode in a BDMP (2)

- The origin of a trigger can be any Boolean function of the states (true or false) of the leaves
- This origin is often a gate corresponding to a sub-tree of the fault-tree defining the structure function of the system, but it is not compulsory

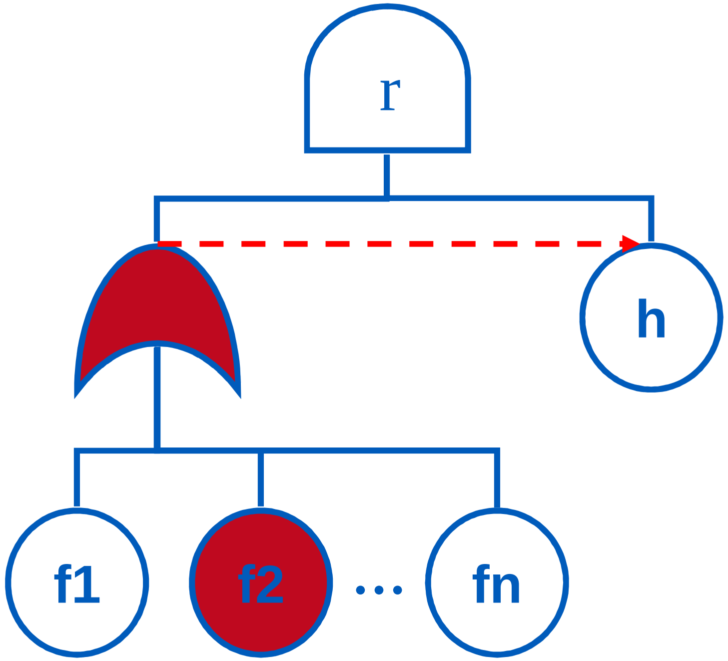


What if a non standard model is needed for a leaf?

Use a «Petri leaf», associated to an arbitrary Petri net, the transitions of which are enabled/disabled according to the mode (required or not required) of the leaf



Definition of irrelevant events



- After a failure of f2, all others fi become irrelevant
- An event is said to be irrelevant if the propagation of the effects of its fulfillment in the fault-tree only concerns gates which are already in the «true» state

Number of sequences leading to top event r

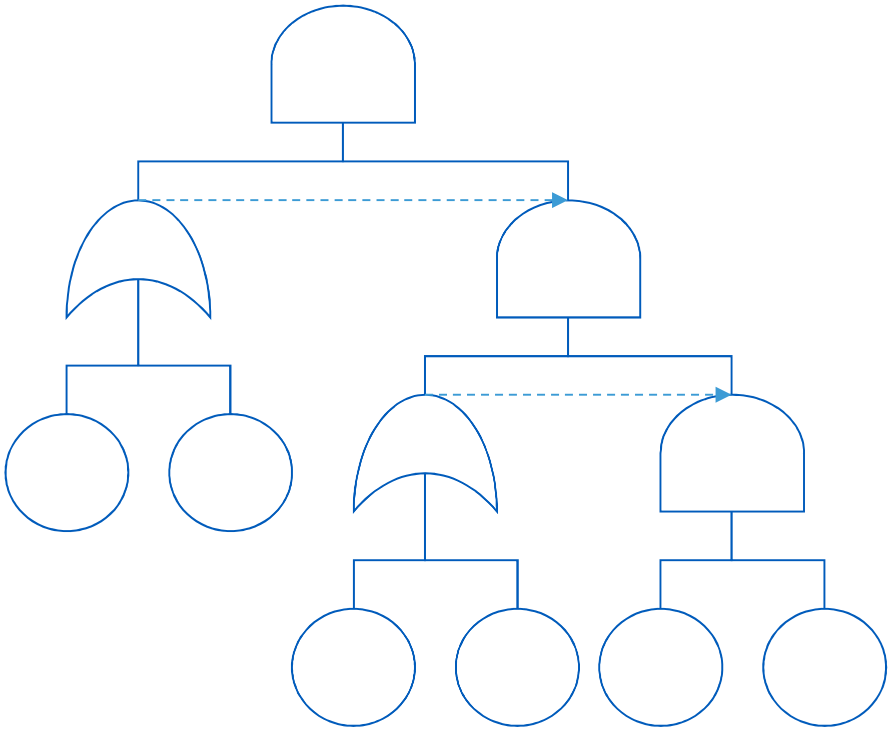
= n if irrelevant events are trimmed: (f1,h ; f2,h…)

Exponential function K(n) if they are not trimmed: (f1,h ; f1,f2,h ; f1,f3,h…)

$K(n) = n + n\, K(n-1)$.

For example, $K(10) = 9.864.100$, and $K(15) > 3.5\ 10^{12}$

Effect of irrelevant events trimming on Markov chain size



64 states
340 transitions

36 states
140 transitions

Supposing all leaves represent repairable components

Exploitation of irrelevant events

- Trimming of irrelevant events:
  - Non repairable system -> dramatic reduction of the Markov chain size, with **exact** calculation of reliability
  - Repairable system -> dramatic reduction of the Markov chain size , with **approximate** calculation of reliability and availability
- Note that in many cases the model with trimming is **more realistic** than without
  (e.g.: electrical components, mutually exclusive failure modes, competition between attack techniques…)

Attack detection Modeling

- Main points
  - The IOFA distinction:
    Initial / **O**n-going / **F**inal / **A** posteriori
  - Changes in the parameters and/or the leaves behavior
  - Introduction of a "Detection status indicator" D_i
    - New Boolean function of the time, associated to each element of the BDMP

Theoretical framework extension - overview

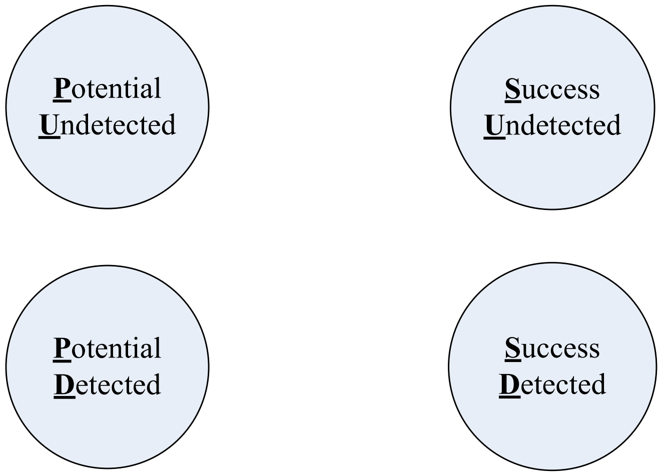
- Introduction of a "Detection status indicator" D_i
- Some change in the modes, related to this new dimension
  - "Active" is divided in "Active Undetected" and "Active Detected"
  - Allows for parameter change, and even leaf cancellation
  - The mode is selected based on X_iD_i

X_iD_i	00	01	10	11
Mode	Idle (I)		Active Undetected (AU)	Active Detected (AD)

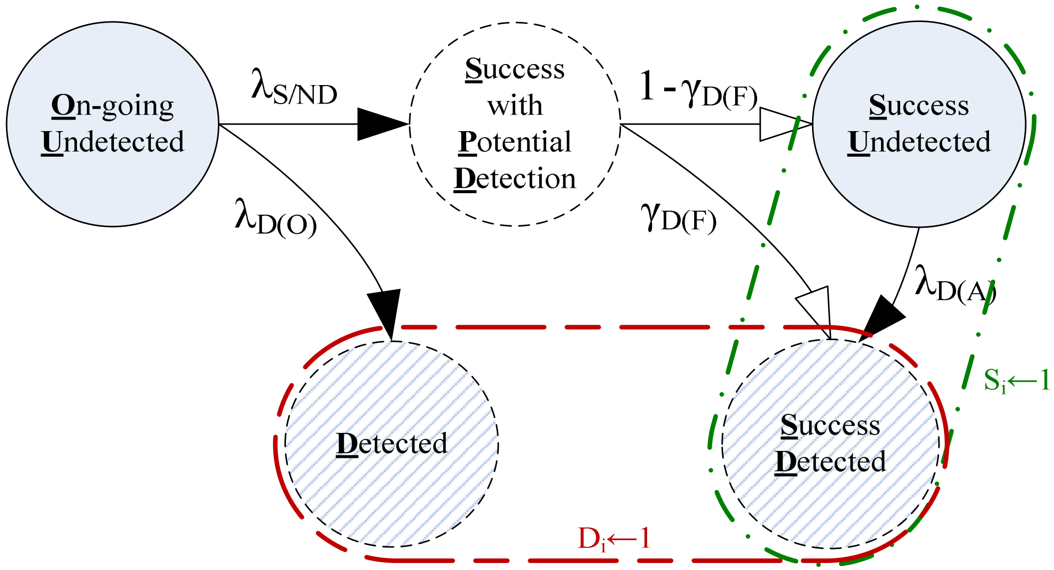
- Extension of the leaves' Markov models
  - New states and transitions, modeling detections & reactions effects
  - New probability transfer functions

Detections/reactions for AA leaves

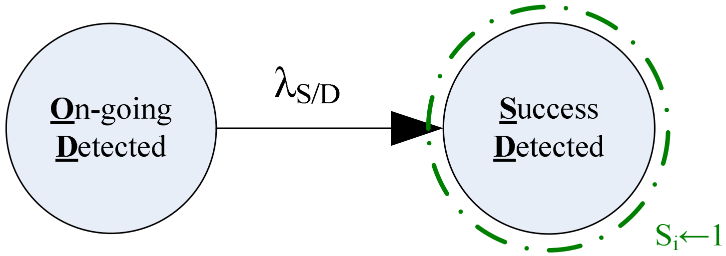
Idle Mode



Active Undetected Mode



Active Detected Mode



Transfer functions

$f^{i}_{0\to 10}(PU)=\{Pr(OU)=1-\gamma_{D(I)},\ Pr(D)=\gamma_{D(I)},\ Pr(SD)=0,\ Pr(SU)=0\}$

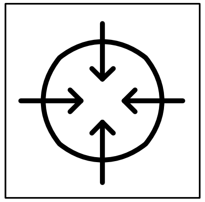
$(PD)=\{Pr(OU)=0,\ Pr(D)=1,\ Pr(SD)=0,\ Pr(SU)=0\}$

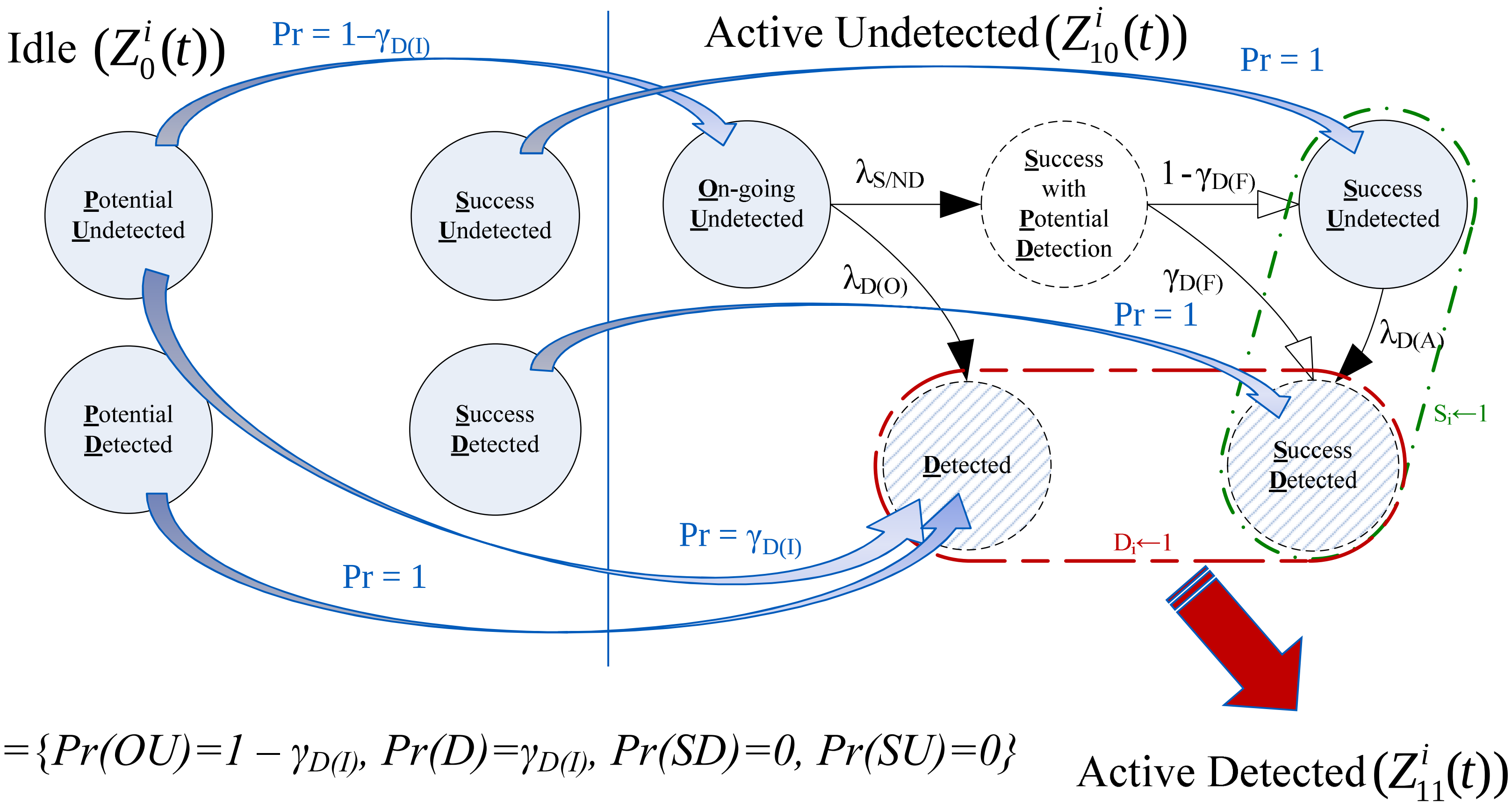
$(SU)=\{Pr(OU)=0,\ Pr(D)=0,\ Pr(SD)=0, Pr(SU)=1\}$

$(SD)=\{Pr(OU)=0,\ Pr(D)=0,\ Pr(SD)=1, Pr(SU)=0\}$

[…]

From Idle to Active Undetected (AU) mode





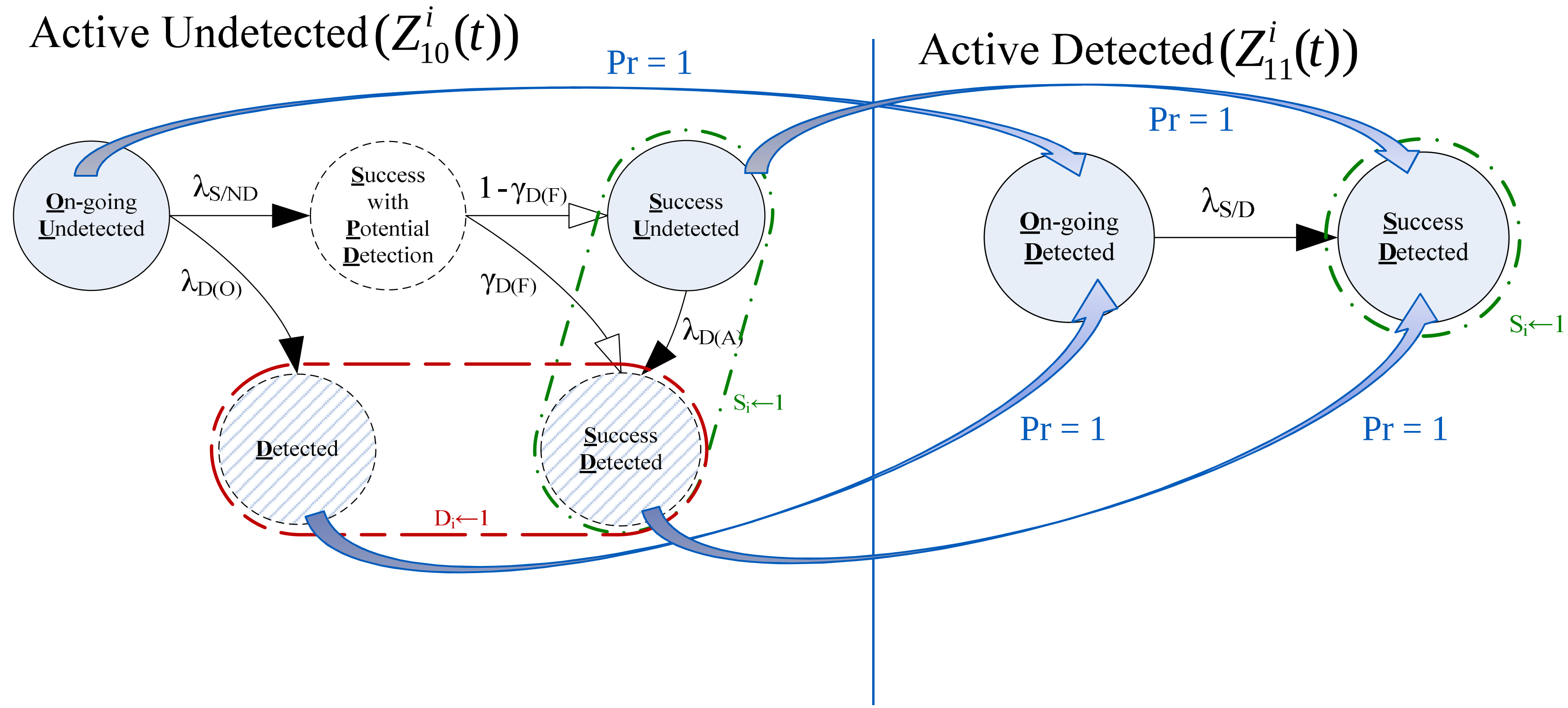
$$f^{\,i}_{0\to 10}(PU)=\{Pr(OU)=1-\gamma_{D(I)},\ Pr(D)=\gamma_{D(I)},\ Pr(SD)=0,\ Pr(SU)=0\}$$

$$(PD)=\{Pr(OU)=0,\ Pr(D)=1,\ Pr(SD)=0,\ Pr(SU)=0\}$$

$$(SU)=\{Pr(OU)=0,\ Pr(D)=0,\ Pr(SD)=0,Pr(SU)=1\}$$

$$(SD)=\{Pr(OU)=0,\ Pr(D)=0,\ Pr(SD)=1,Pr(SU)=0\}$$

From AU mode to Active Detected mode



$$f^i_{10\to 11}(OU) = \{Pr(OD) = 1,\ Pr(SD) = 0\}$$
$$(D) = \{Pr(OD) = 1,\ Pr(SD) = 0\}$$
$$(SD) = \{Pr(OD) = 0,\ Pr(SD) = 1\}$$
$$(SU) = \{Pr(OD) = 0,\ Pr(SD) = 1\}$$

The detection has occurred at a different leaf

Despite D and SD having null durations, these lines are necessary to specify the transfer function, the transfer being potentially triggered by the leaf itself.

And so on…

- Five probability transfer functions…
  - $\left\{f_{0\to10}^{i}, f_{0\to11}^{i}, f_{10\to11}^{i}, f_{10\to0}^{i}, f_{11\to0}^{i}\right\}$
  - $f_{11\to10}^{i}$ is not defined: a detected attack never comes back undetected
- …for each type of leaf
  - Attacker Action (AA)
  - Timed Security Event (TSE)
  - Instantaneous Security Event (ISE)
- With their own Markov chains per mode
- In fact, extension of the triggered Markov process definition

$$\left\{Z_0^i(t), Z_{10}^i(t), Z_{11}^i(t), f_{0\to10}^{i}, f_{0\to11}^{i}, f_{10\to11}^{i}, f_{10\to0}^{i}, f_{11\to0}^{i}\right\}$$

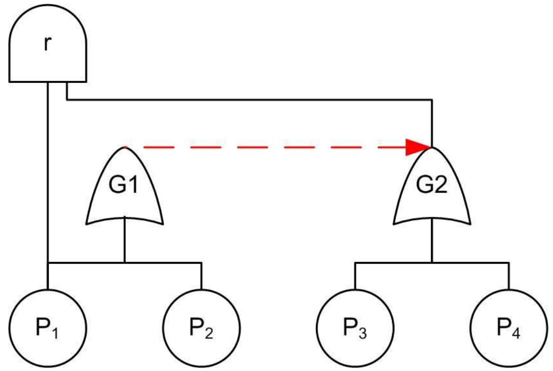
Detection and reaction integration in BDMP

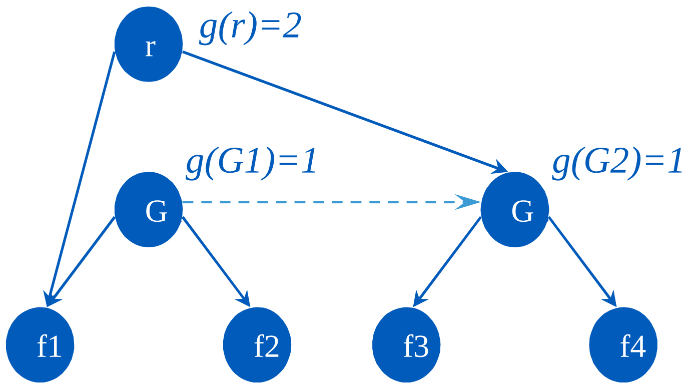
- Three approaches for reaction “propagation” modeling
  - Strictly local incidence: straightforward but not satisfactory
  - Global incidence: meaningful and direct implementation
  - Extended and selective reactions: reaction triggers (not formalized)

Formal foundations – snapshot 1/3

A BDMP $(\mathcal{A}, r, T, P)$ is made of

- A fault/attack tree $\mathcal{A} = \{E, L, g\}$
  - a set $E = G \cup B$, where G is a set of gates and B a set of basic events
  - (E, L) a directed acyclic graph, with L a set of oriented edges (i, j)
  - a function g, defining the gates ($g{:}G \rightarrow N^*$, with $g(i)$ the gate parameter k)





- A main top event r
- Set of triggers T

Formal foundations – snapshot 2/3

- $P = \{P_i\}_{i \in B}$, triggered Markov Processes

$$P_i = \{Z_0^i(t), Z_{10}^i(t), Z_{11}^i(t), f_{0\to10}^i, f_{0\to11}^i, f_{10\to11}^i, f_{10\to0}^i, f_{11\to0}^i\}$$

  - $Z_0^i(t)$, $Z_{10}^i(t)$ and $Z_{11}^i(t)$ three homogeneous Markov processes
    - For k in $\{0, 1\}$ (modes), A_k^i state-space of $Z_k^i(t)$
    - $S_k^i \subset A_k^i$, subset of states for which the leaf is true
    - $D_k^i \subset A_k^i$, subset of detected states
  - $f_{0\to10}^i(x)$ […] $f_{11\to0}^i(x)$ "probability transfer functions" with
    - $\forall x \in A_0^i$, $f_{0\to10}^i(x)$ is a probability distribution on A_{10}^i such that

$$x \in S_{10}^i \Rightarrow \sum_{j \in S_1^i} (f_{0\to10}^i(x))(j) = 1 \text{ and } x \in D_{10}^i \Rightarrow \sum_{j \in D_1^i} (f_{0\to10}^i(x))(j) = 1$$

    - […] x 5 $\{f_{0\to11}^i, f_{10\to11}^i, f_{10\to0}^i, f_{11\to0}^i\}$

Formal foundations – snapshot 3/3

- Four families of Boolean functions of the time
  - Structure functions $(S_i)_{i \in E}$

$$\forall i \in G, \quad S_i \equiv \sum_{j \in sons(i)} S_j \geq g(i)$$

$$\forall j \in B, \quad S_j \equiv Z^j_{X_j} \in S^j_{X_j},$$ with $X_j = 0$ or 1, indicating the mode in which P_j is at time t

  - Process selectors $(X_i)_{i \in E}$

If i is a root of $\mathcal{A}$, then $X_i = 1$ else

$$X_i \equiv \neg\left[\left(\forall x \in E, (x,i) \in L \Rightarrow X_x = 0\right) \vee \left(\exists x \in E / (x,i) \in T \wedge S_x = 0\right)\right]$$

  - Relevance indicators $(Y_i)_{i \in E}$

If $i = r$ (final objective), then $X_i = 1$ else

$$Y_i \equiv \left(\exists x \in E / (x,i) \in L \wedge Y_x \wedge S_x = 0\right) \vee \left(\exists y \in E / (i,y) \in T \wedge S_y = 0\right)$$

  - Detection status indicators $(D_i)_{i \in E}$

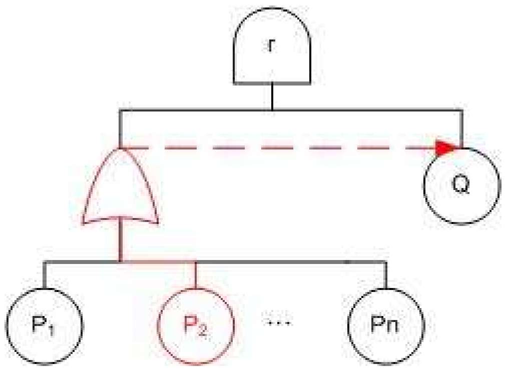
$$\forall i \in B, \; D_i \equiv \left(Z^i_{X_i} \in D^i_{X_i}\right) \vee \left(\exists j \in B / \; j \neq i \wedge D_j = 1\right) \quad \forall j \in G, \; D_j \equiv \left(\exists i \in B / D_i = 1\right)$$

Mathematical properties

Robustness

- Theorem 1: $(S_i)(X_i)(Y_i)(D_i)_{i \in E}$ are computable whatever the BDMP structure
- Theorem 2 : Any BDMP, defined at time t by the modes and the P_i states, is a valid homogeneous Markov process

Combinatory reduction by “relevant event filtering”



- After attack step P_2, all the others P_i are not relevant anymore: nothing is changed for “r” if we inhibit them
- The number of sequences leading to the top objective is
  - n, if we filter the relevant events $(\{P_1,Q\},\{P_2,Q\},\ldots)$
  - exponential otherwise $(\{P_1,Q\},\{P_1,P_2,Q\}, \{P_1,P_3,Q\},\ldots)$

- Theorem 3: if the P_i are such that $\forall i \in B, \forall t, \forall t' \geq t, S_i(t) = 1 \Rightarrow S_i(t') = 1$ *
$Pr(S_r(t)=1)$ is unchanged whether irrelevant events ($Y_i=0$) are trimmed or not

* This is always the case in security (~ non-repairable in reliability studies)

BDMP pros and cons

- Concise, hierarchical and powerful formalism
- All dynamic behavior can be inferred from graphical representation => relatively easy validation

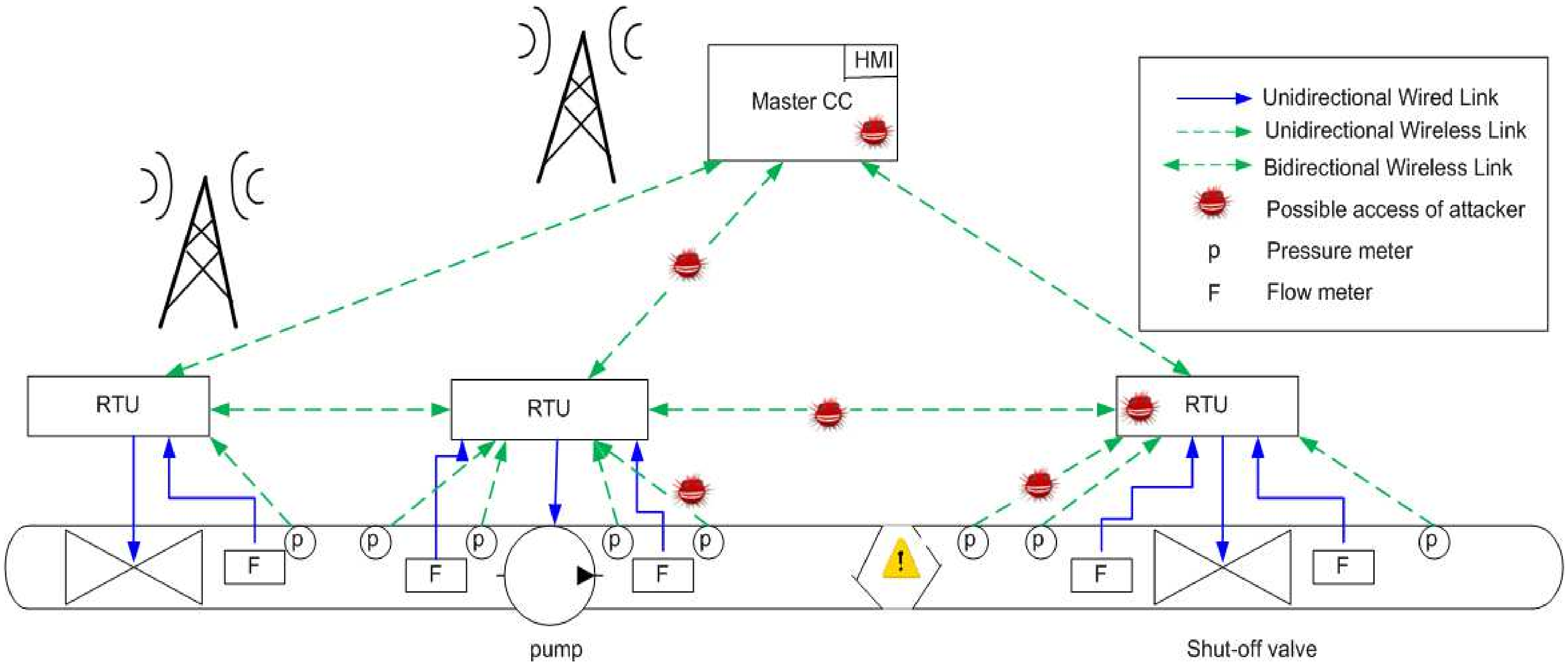
- BDMP (just like fault trees, Petri nets etc.) are difficult to re-use. True re-usability can only be achieved with a tool like KB3 that generates automatically calculation models

- Combinatorial explosion, of course, still exists. The largest BDMP ever processed with sequence exploration had around 300 leaves. With MC simulation, problem of rare events.

- BDMP are not good at all at modeling systems in which objects are created, destroyed, or even simply change places

CASE STUDY

SYSTEM ARCHITECTURE

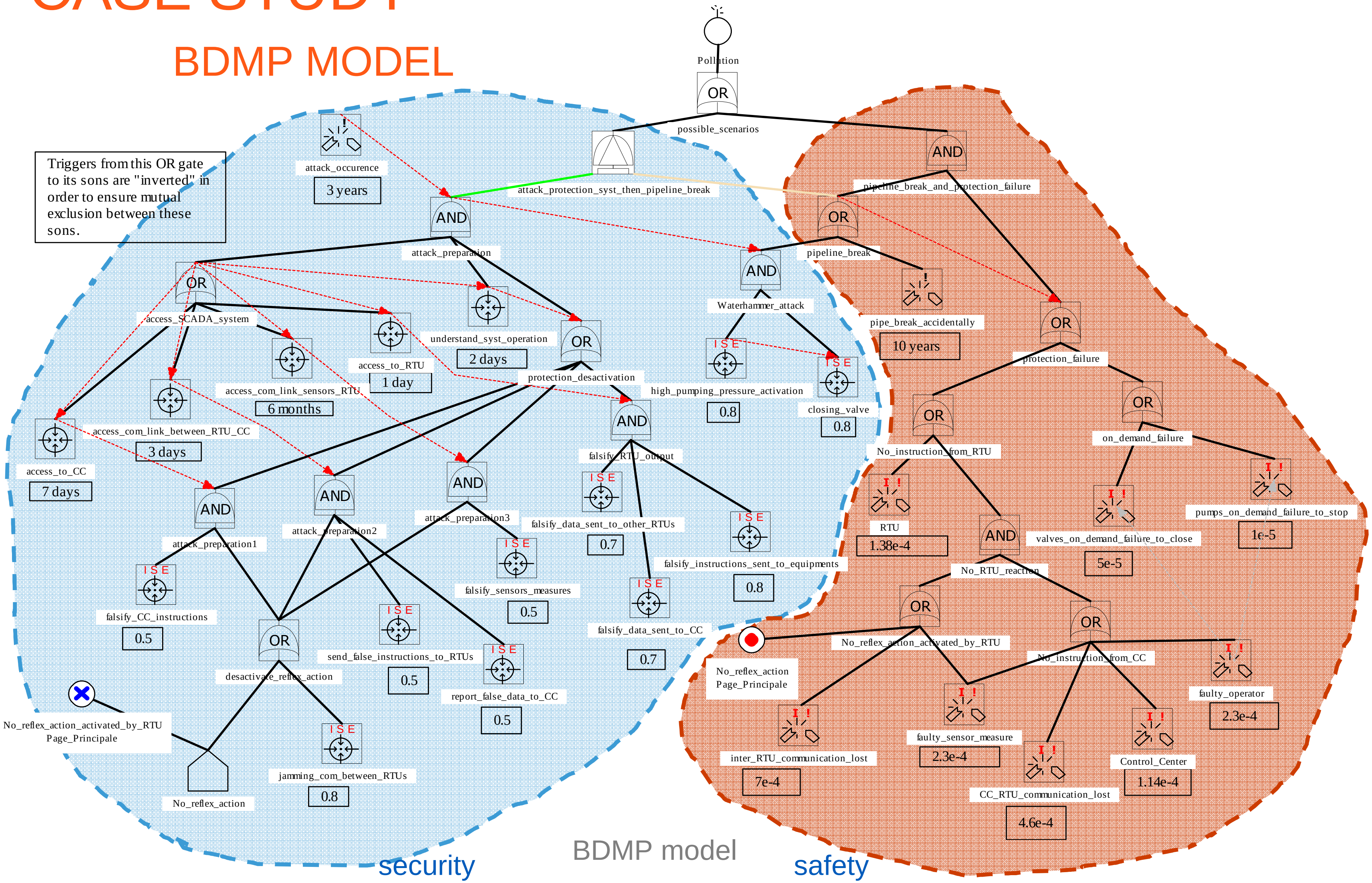


Case study of a pipeline and its control system

Example taken from: S. Kriaa, M. Bouissou et al. Safety and security modeling using the BDMP formalism: case study of a pipeline. SafeComp'2014

CASE STUDY

BDMP MODEL



CASE STUDY

QUANTITATIVE AND QUALITATIVE ANALYSIS

- Model leaves <-> parameters estimated based on assumptions
  - MTTS -> security events
  - MTTF -> safety events
  - Probability -> instantaneous events
- Pollution probability ~ 2e-2 for a mission time of one year
- Attack scenarios are the most likely to happen

CASE STUDY

QUANTITATIVE AND QUALITATIVE ANALYSIS

Transitions		MT proba	Contrib.
Name	**Rate**		
attack_occurrence	2.28e-5	1.31e-2	0.67
access_to_RTU	0.0208		
understand_syst_operation	0.0208		
falsify_data_sent_to_CC falsify_data_sent_to_other_RTUs falsify_instructions_sent_to_equipments	0.6 0.6 0.7		
high_pumping_pressure_activation	0.7		
closing_valve	0.7		

Most probable attack scenario

CASE STUDY

QUANTITATIVE AND QUALITATIVE ANALYSIS

Transitions		MT proba	Contrib.
Name	Rate		
attack_occurrence	2.28e-5	4.03e-4	0.87
access_to_RTU	0.0208		
understand_syst_operation	0.0208		
falsify_data_sent_to_CC falsify_data_sent_to_other_RTUs falsify_instructions_sent_to_equipments	0.6 0.6 0.7		
no_realization(high_pumping_pressure_activation)	0.3		
pipe_breaks_accidentally	1.14e-5		

Most probable hybrid scenario

CASE STUDY

QUANTITATIVE AND QUALITATIVE ANALYSIS

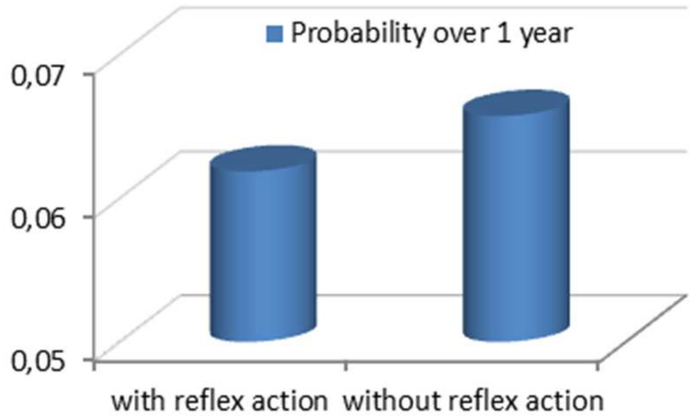
Transitions		MT proba	Contrib.
Name	**Rate**		
pipe_breaks_accidentally	1.14e-5	1.98e-5	1e-3
good(CC_RTU_communication_lost) good(Control_Center) good(RTU) good(faulty_operator) faill(faulty_sensor_measure) good(inter_RTU_communication_lost)	0.99954 0.999886 0.999862 0.99977 0.00023 0.9993		

Most probable accidental scenario

CASE STUDY

SAFETY AND SECURITY INTERDEPENDENCIES

- Mutual reinforcement



Pollution probability with and without reflex action

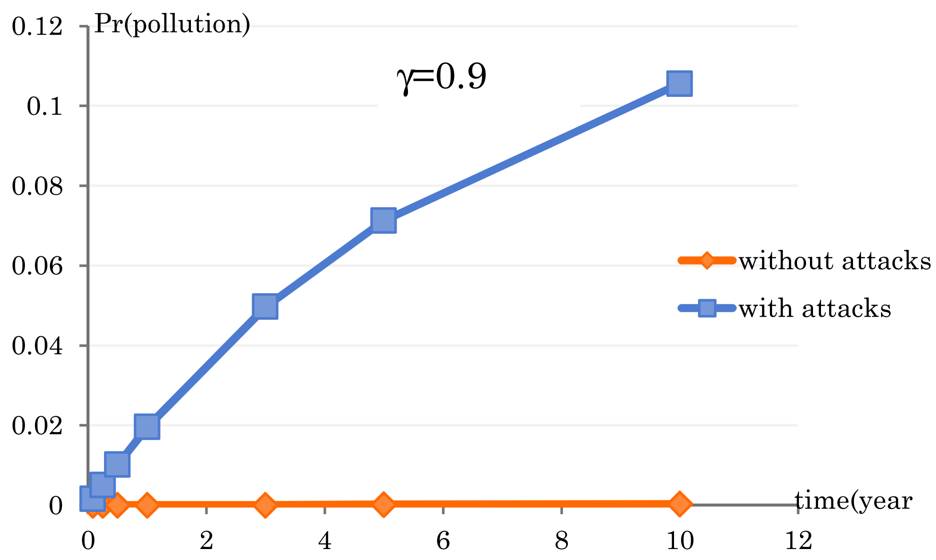
➔The reflex action decreased the pollution probability by 13%

➔ To succeed into causing pollution, the attacker has to deactivate the reflex action.

NB: Reflex action = shutdown decided by the set of RTUs without intervention of the centralized control system

CASE STUDY

SENSITIVITY ANALYSIS



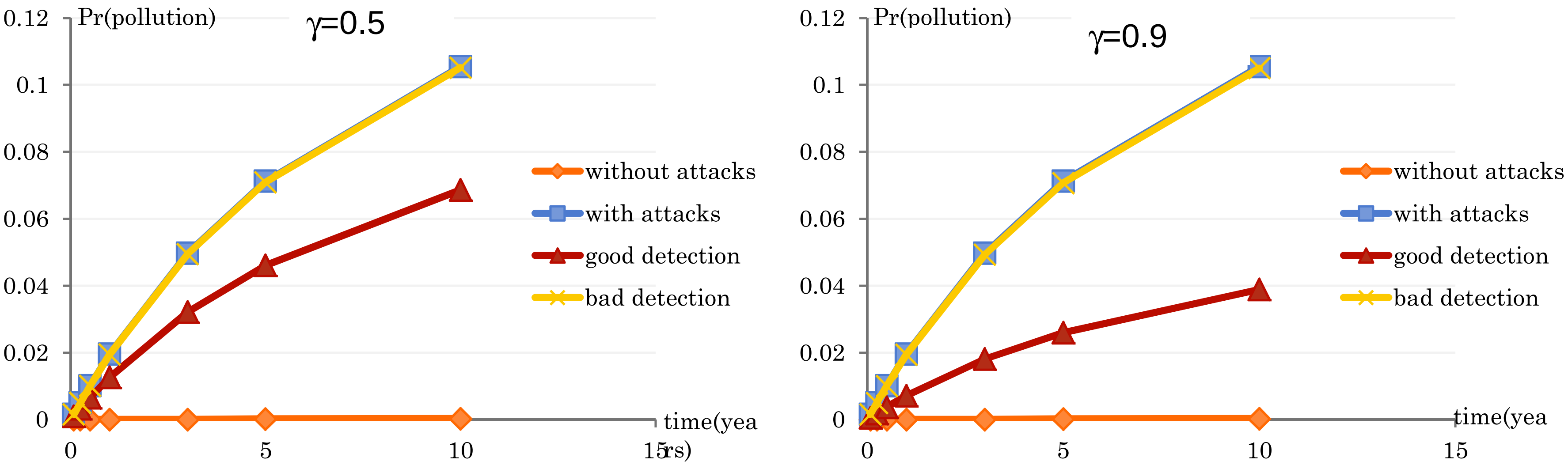
Pollution probability without attacks and with attacks without detection

→Security-related scenarios increase considerably the pollution probability

→Conditional dependency between safety and security

CASE STUDY

SENSITIVITY ANALYSIS



Effect of two detection strategies on pollution probability

bad detection: detection and reaction measures chosen arbitrarily

good detection: detection and reaction measures placed on the elements appearing in the most probable scenarios

γ: detection probability

Conclusion and perspectives

- Importance of considering safety and security together in the risk evaluation and management process

- Petri nets and SAN: unlimited modeling power in theory, but in practice, limits due to validation problems

- BDMP still have a good modeling power, while being easier to use
  - Readability – all essential information is graphically represented
  - Top-down approach, each "refinement" is manageable
  - Qualitative and quantitative analysis
  - Can easily be extended to take different probability distributions into account (requires Monte Carlo simulation). Cf. McQueen *et al.*

- Qualitative and quantitative analysis => identification of:
  - the most probable scenarios
  - the most vulnerable points in the system
  - the best detection and reaction strategies

Conclusion and perspectives

- Common limitation of all these dynamic models
  - Estimation of security metrics (MTTS...)

- Perspectives
  - Robustness of the quantitative results
  - Deal with uncertainties related to security parameters (uncertainty propagation)

Some references

- On BDMP & KB3

  - M. Bouissou, J.L. Bon, “A new formalism that combines advantages of fault-trees and Markov models: Boolean logic Driven Markov Processes,” *Reliability Engineering and System Safety*, Vol. 82, Issue 2, nov. 2003, pp. 149-163

  - M. Bouissou, “Automated Dependability Analysis of Complex Systems with the KB3 Workbench: the Experience of EDF R&D,” *Proceedings of CIEM 2005*, Bucharest, Romania, oct. 2005

  Marc Bouissou’s homepage: http://marc.bouissou.free.fr/

- On BDMP & Security

  - L. Piètre-Cambacédès et M. Bouissou, “Attack and defense dynamic modeling with BDMP,” in *Proc. 5th International Conference on Mathematical Methods, Models, and Architectures for Computer Networks Security (MMM-ACNS-2010)*, St Petersburg, Russia, sept. 2010

  - L. Pietre-Cambacedes, Y. Deflesselle and M. Bouissou, "Security modeling with BDMP: from theory to implementation," in *Proc. 6th IEEE International Conference on Network and Information Systems Security (SAR-SSI 2011)*, La Rochelle, France, may 2011

  - L. Piètre-Cambacédès and M. Bouissou, “Modeling safety and security interdepedencies with BDMP (Boolean logic Driven Markov Processes),” *Proc. IEEE International Conference on Systems, Man, and Cybernetics (SMC 2010*), Istanbul, Turkey, oct. 2010.

  Ludovic Pietre-Cambacedes’ homepage: http://perso.telecom-paristech.fr/~pietreca/

QUESTIONS?

http://marc.bouissou.free.fr/