Artificial Intelligence Techniques

in Cyber-Security Applications

SUNET Days – SUSEC – Track 03 Security
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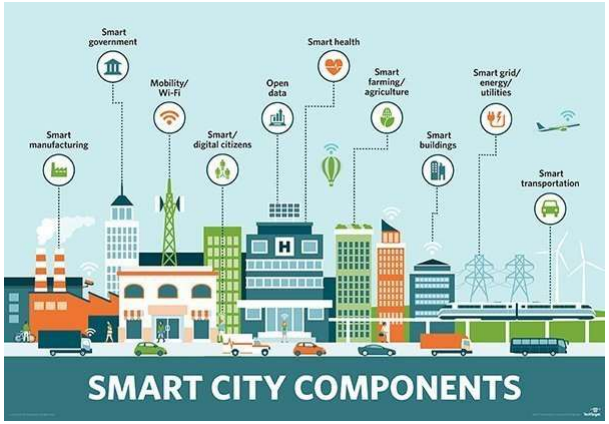
Modern Connected Society

The digital ecosystem is getting increasingly **ubiquitous** and **pervasive**

Growing **complexity** due to size, distribution, and heterogeneity

Growing **criticality** due to safety-related functionalities (e-health, transport, etc.) and evolving **cyber-security threats**

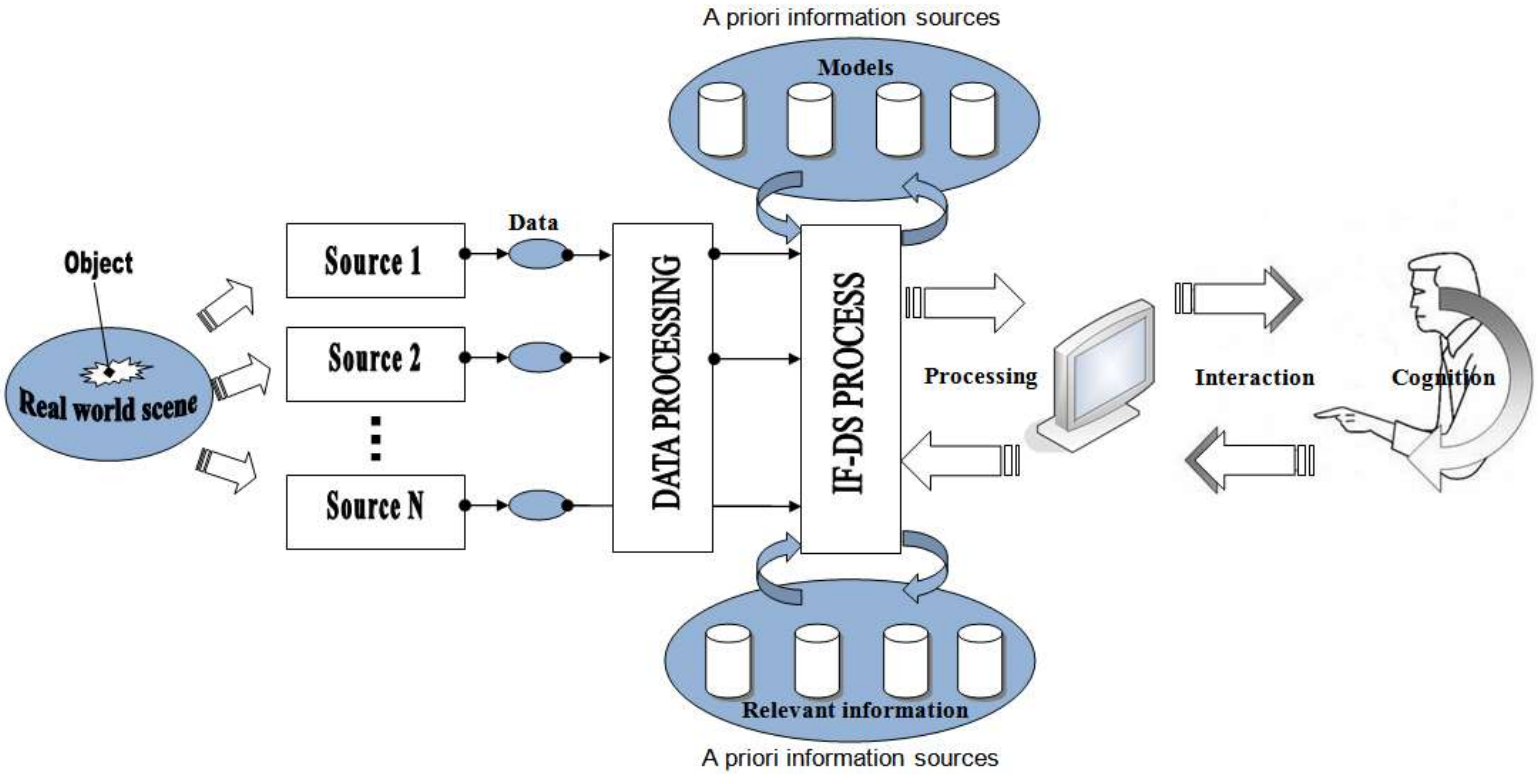


Security Operations Centers

Issues

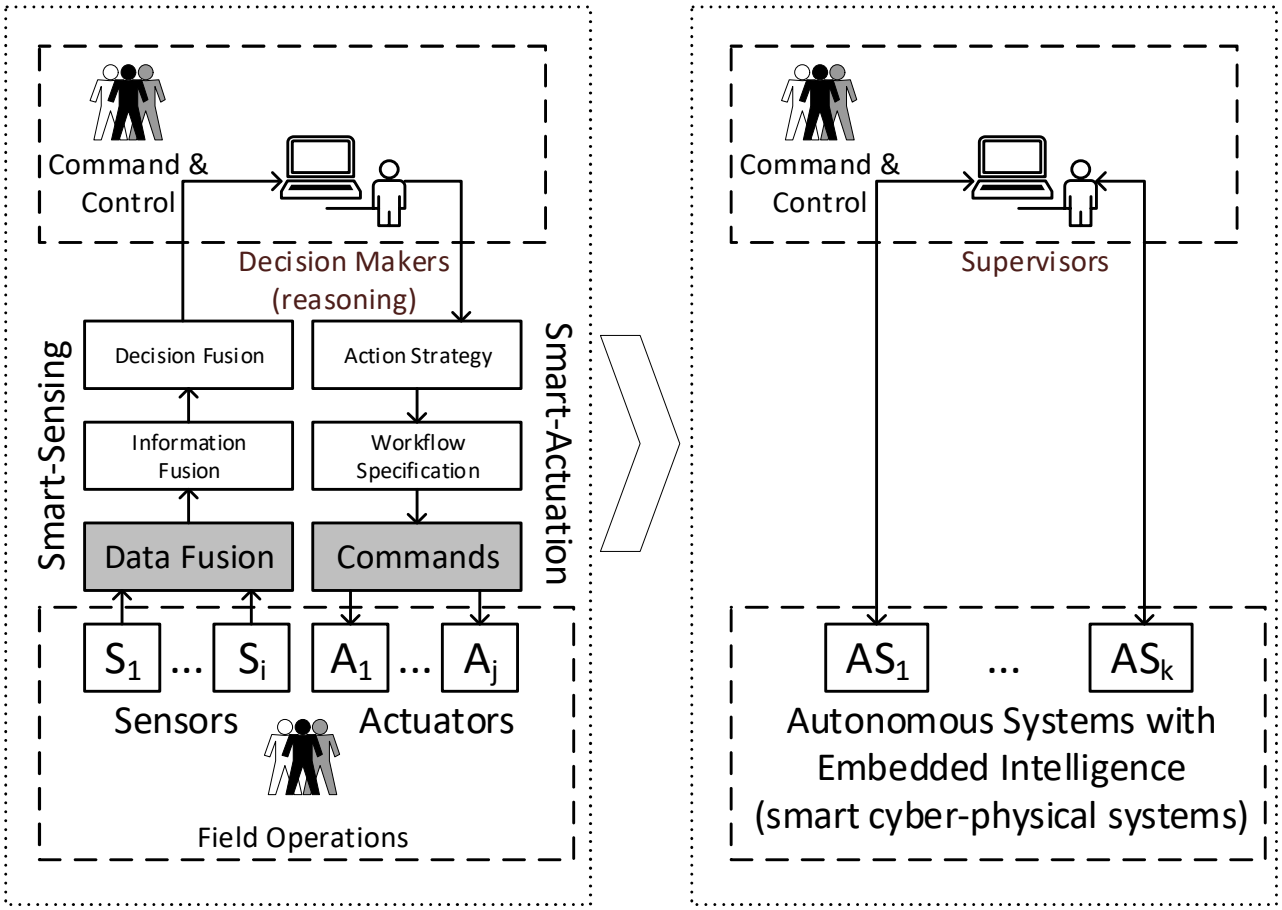
- Too much information for few control room operators
- Operators overwhelmed by signals: events, states, diagnostics, alarms, warnings, etc.
- Software separation between cyber-security and physical security
  - SIEM – Security Information & Event Management
  - PSIM – Physical Security Information Management)
- Many false alarms and nuisance alarms (> 30% => failure)

Information fusion

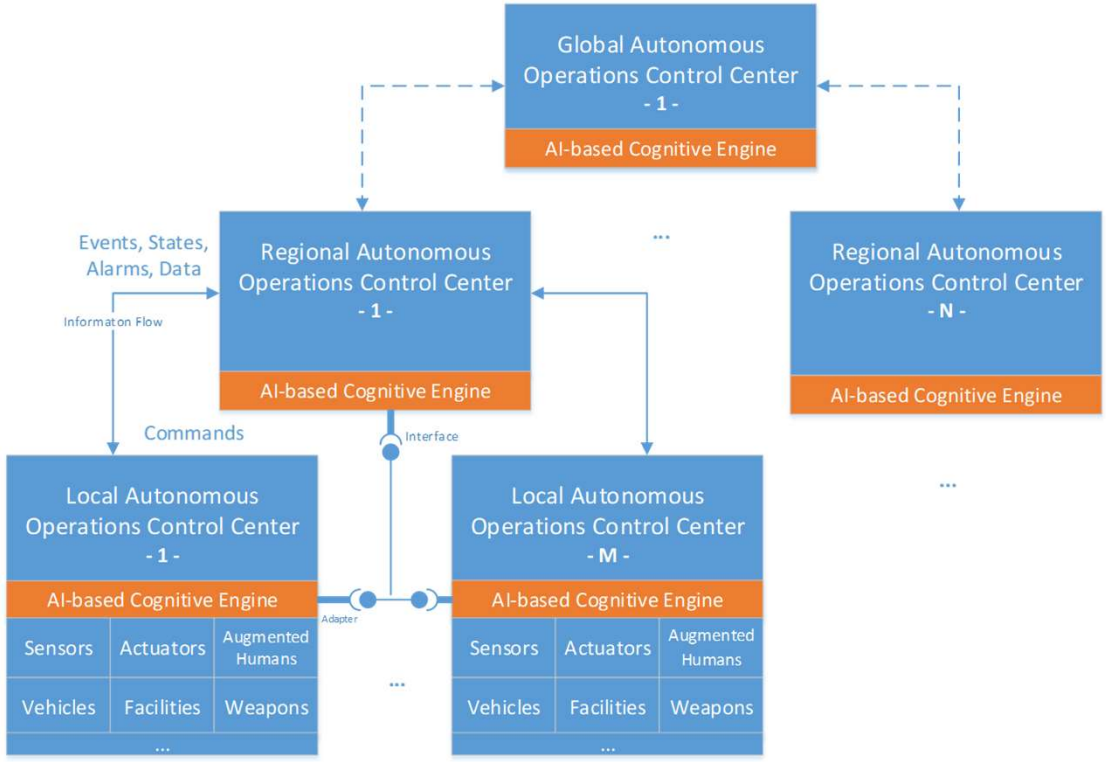


FLAMMINI F., Pappalardo A, Vittorini V (2013). Challenges and Emerging Paradigms for Augmented Surveillance. Effective Surveillance for Homeland Security: Balancing Technology and Social Issues. p. 169-198, BOCA RATON, FL: Chapman & Hall/CRC Taylor & Francis Group, ISBN/ISSN: 9781439883242, doi: 10.1201/b14839-11

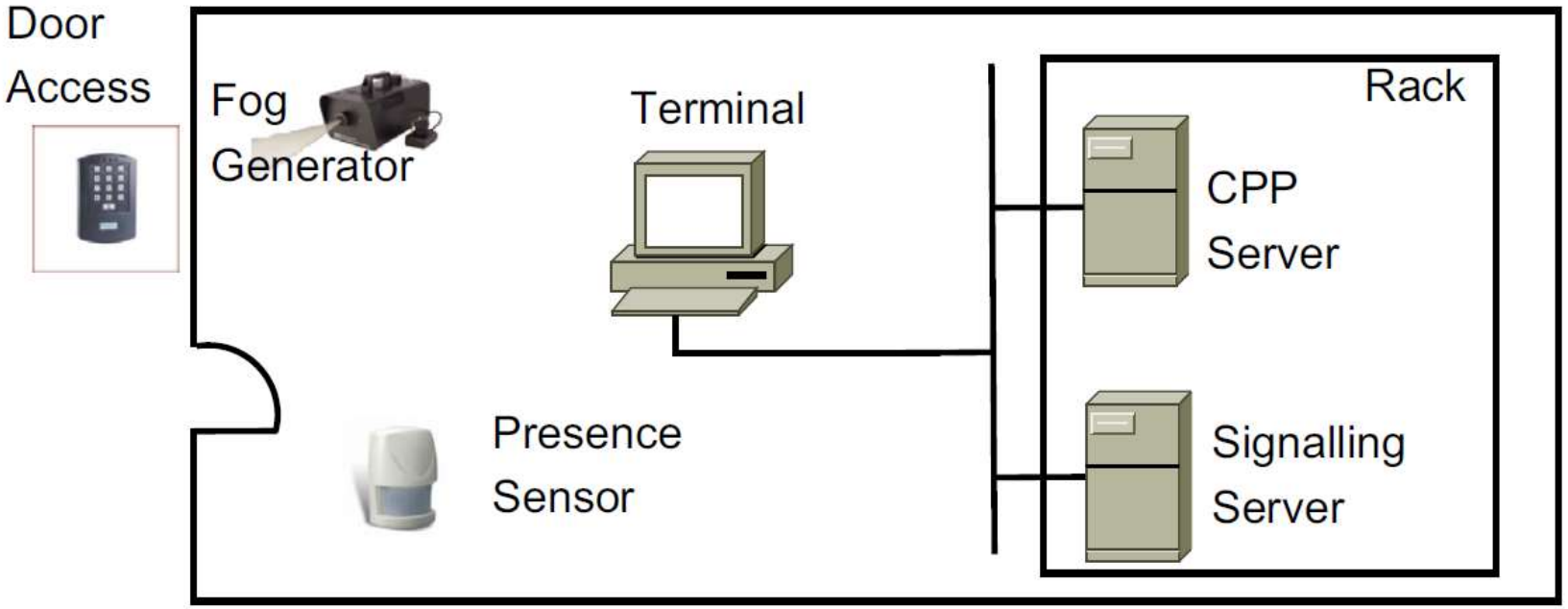
From smart-systems to autonomous systems



AI hierarchy



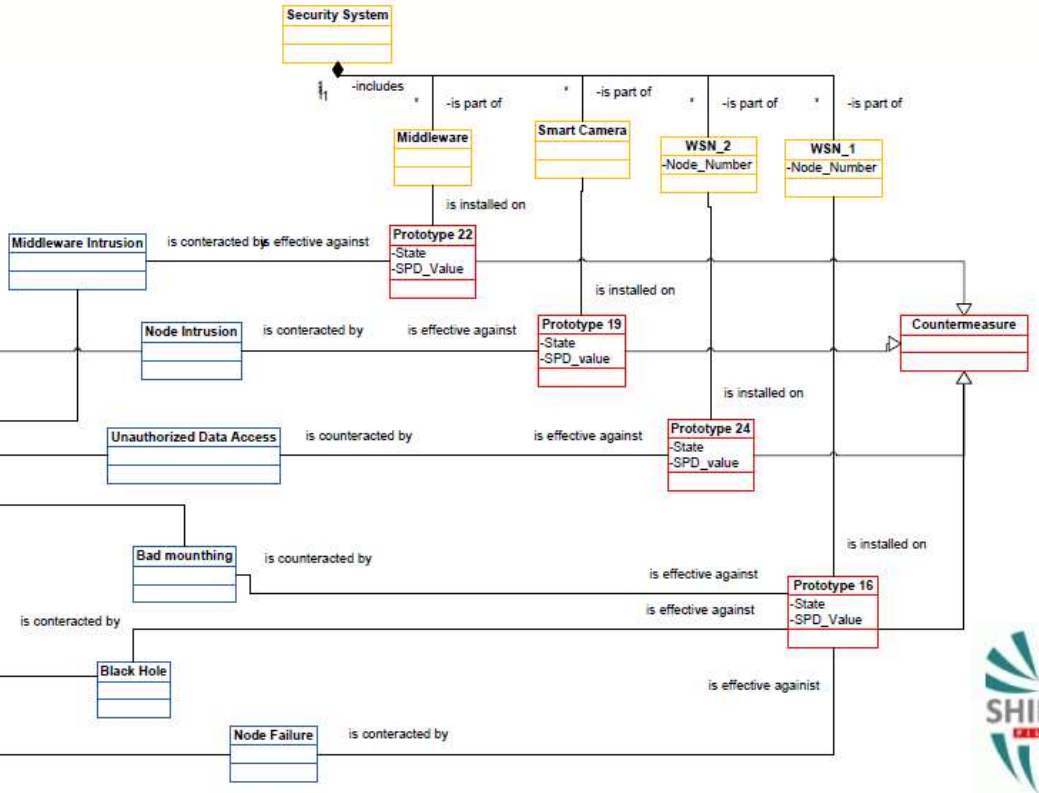
Cyber-Physical Threat Detection



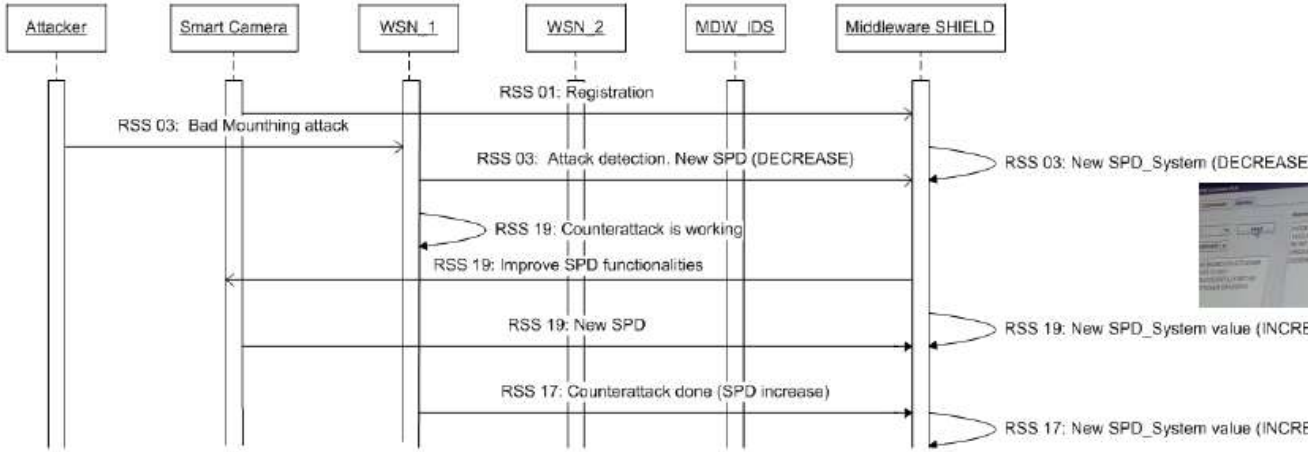
Flammini F, Marrone S, Rodríguez R J, Nardone R, Vittorini V (2015). On synergies of cyber and physical security modelling in vulnerability assessment of railway systems. COMPUTERS & ELECTRICAL ENGINEERING, p. 275-285, ISSN: 0045-7906, doi: doi:10.1016/j.compeleceng.2015.07.011

Example scenario (1/2)

Protot. number	Prototype name
16	Reputation-Based Secure Routing
19	Policy Based Management Framework
20	Control Algorithms
22	Middleware Intrusion Detection System
24	Network Layer Security
25	OSGI Middleware
26	Semantic Model
32	Secure Discovery
33	Security Agent



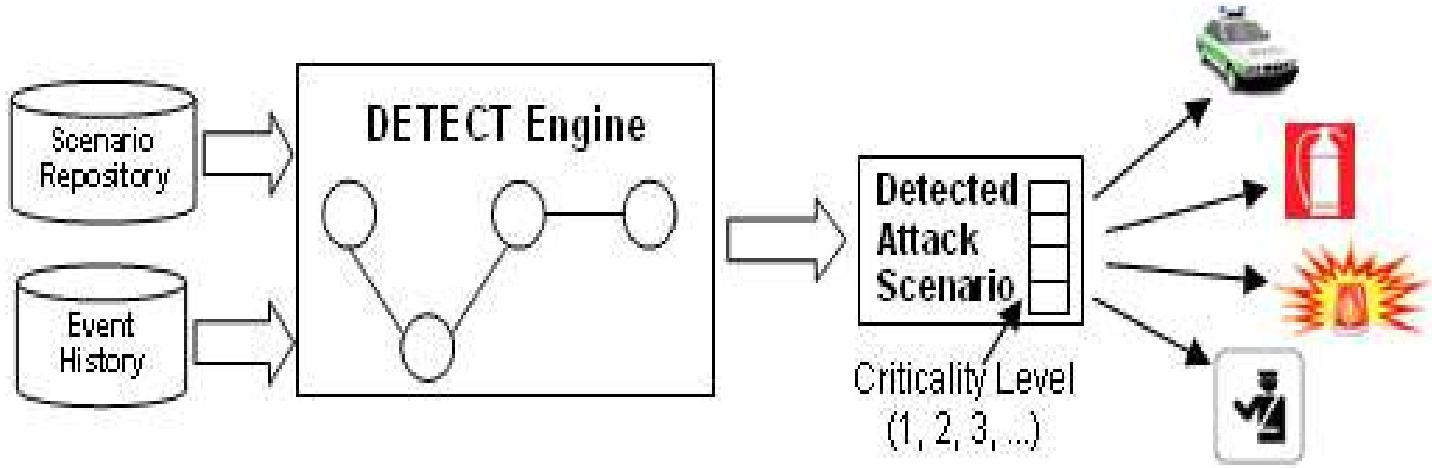
Example scenario (2/2)



STEP	Description	System Status	SPD norm	Level
2	In WSN_1 a bad mouthing attack has occurred. The middleware is informed that an attack is occurring and it sends a command to the smart camera to activate its security mechanisms. The SPD level decreases. **WSN_1: Bad mouthing attack** **WSN_2: Encryption 64 bits** **Smart Camera: Messaging - no protection** **MDW_IDS: Normal**	State_03	0	VERY LOW
3	The smart camera improves its SPD functionality and SPD level increases. **WSN_1: Bad mouthing attack** **WSN_2: Encryption 64 bits** **Smart Camera: Messaging - Authentication & Integrity** **MDW_IDS: Normal**	State_19	0,3	LOW

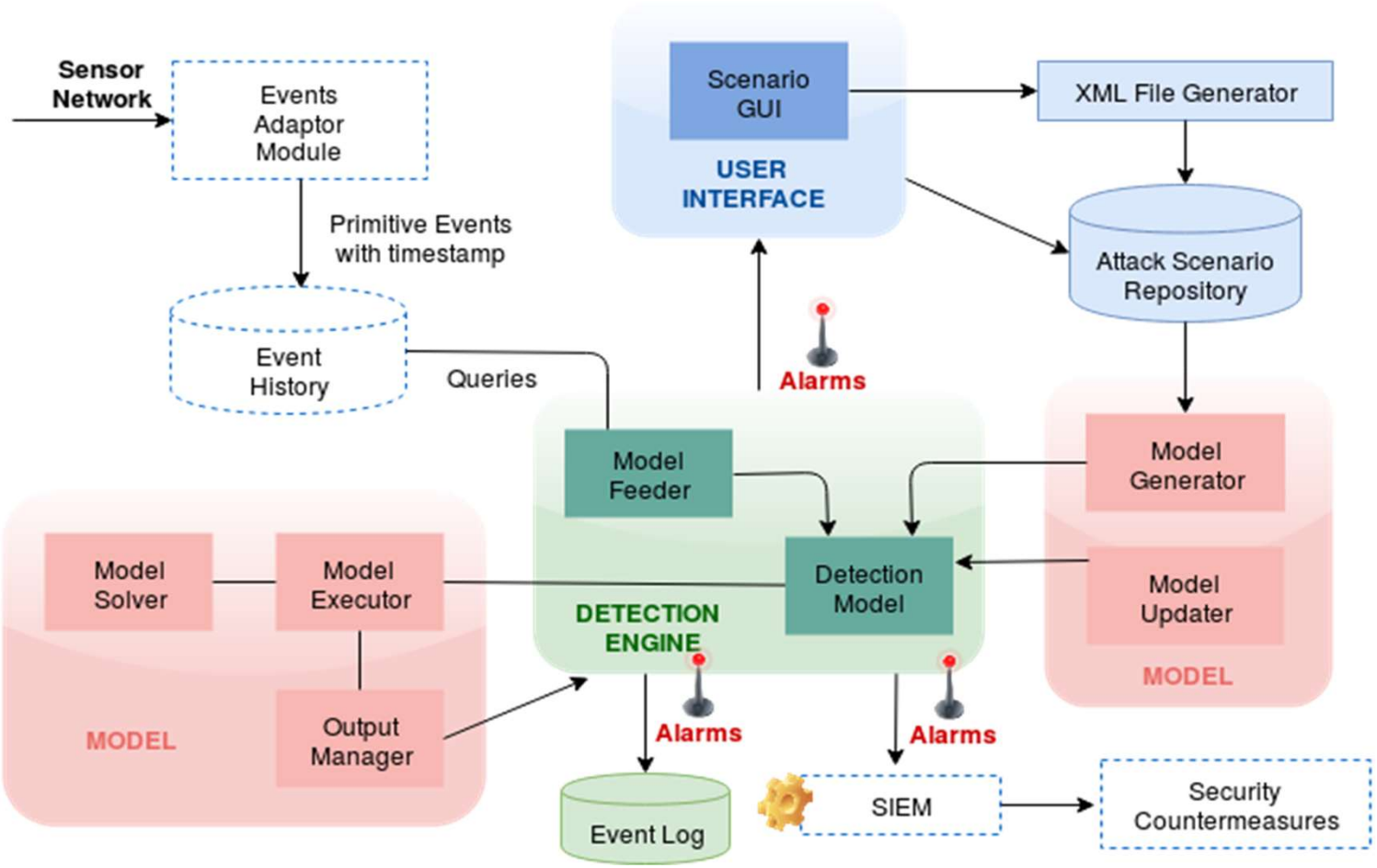
Delli Priscoli F, Di Giorgio A, Esposito M, Fiaschetti A, Flammini F, Mignanti S, Pragliola C (2017). Ensuring Cyber-Security in Smart Railway Surveillance with SHIELD. INTERNATIONAL JOURNAL OF CRITICAL COMPUTER-BASED SYSTEMS, p. 138-170, ISSN: 1757-8779

DETECT
Decision Triggering Event Composer & Tracker



FLAMMINI F., Mazzocca N, Pappalardo A, Pragliola C, Vittorini V (2011). Augmenting surveillance system capabilities by exploiting event correlation and distributed attack detection. In: Availability, Reliability and Security for Business, Enterprise and Health Information Systems. Vienna, Austria, 22-26 August 2011, BERLIN HEIDELBERG: Springer-Verlag, vol. 6908, p. 191-204, ISBN/ISSN: 978-364223299-2, doi: 10.1007/978-3-642-23300-5_15

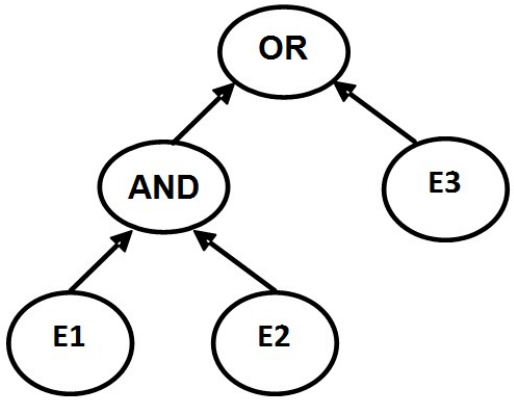
The DETECT framework architecture



Event Trees

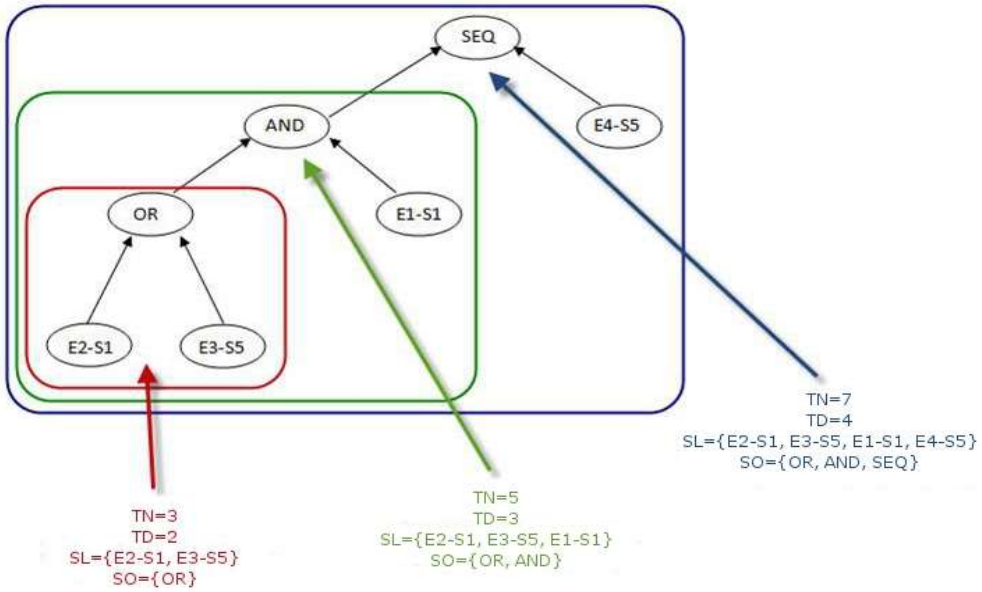
EDL based on the *Snoop* event algebra, considering the following operators:
OR, AND, ANY, SEQ

Example Event Tree: (E1 AND E2) OR E3



Problem: non determinism

First solution: distance metrics



$$D = \left|TN_A - TN_B\right| + \left|TD_A - TD_B\right| + \left|TW_A - TW_B\right| + DSL_{AB} + DSO_{AB}$$

TN: total number of nodes
TD: tree depth, that is the number of levels from leaves to the top node
TW: tree width, that is the max number of operators at the same level
SL: set of leaf nodes *SO*: set of operator nodes

$$DSL_{AB} = card(SL_A \cup SL_B) - card(SL_A \cap SL_B)$$

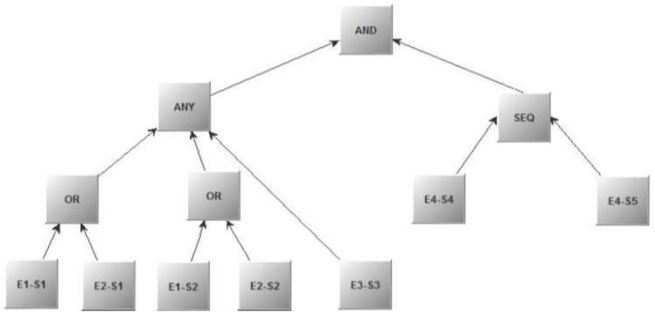
$$DSO_{AB} = card(SO_A \cup SO_B) - card(SO_A \cap SO_B)$$

Flammini, F., Mazzocca, N., Pappalardo, A., Pragliola, C., Vittorini, V. Improving the dependability of distributed surveillance systems using diverse redundant detectors (2015) Advances in Intelligent Systems and Computing, 307, pp. 35-53

Example (1/3)

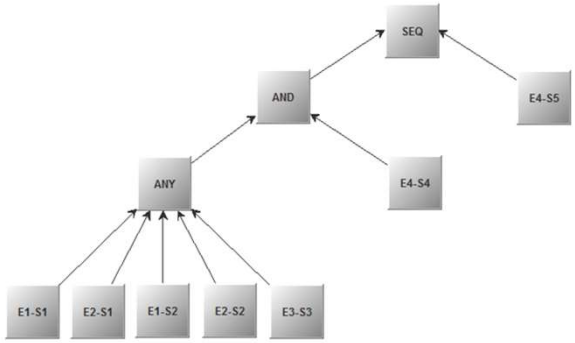
Intelligent Camera (S1) :: Fall of person (E1)
Intelligent Camera (S1) :: Abnormal running (E2)
Intelligent Camera (S2) :: Fall of person (E1)
Intelligent Camera (S2) :: Abnormal running (E2)
Audio sensor (S3) :: Scream (E3)
IMS/SAW detector (S4) :: CWA detection (E4)
IR detector (S5) :: CWA detection (E4)

Scenario A



TN	12	
TD	3	
TW	2	
SL	E1-S1, E2-S1, E1-S2, E2-S2, E3-S3, E4-S4, E4-S5	cardinality=7
SO	AND, ANY, SEQ, OR	cardinality=4

Scenario B

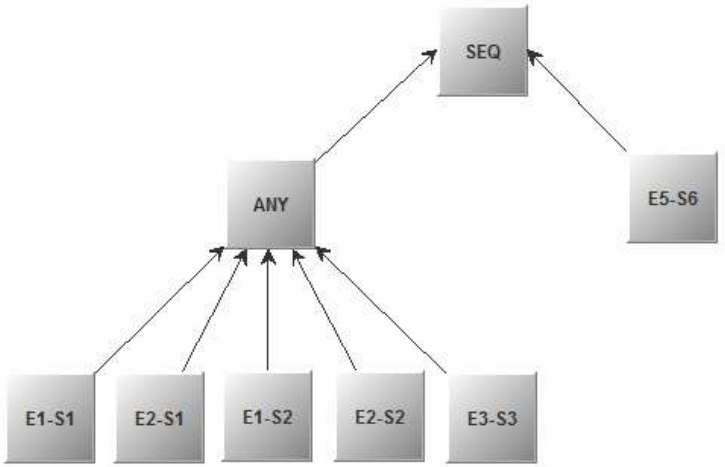


TN	10	
TD	3	
TW	1	
SL	E1-S1, E2-S1, E1-S2, E2-S2, E3-S3, E4-S4, E4-S5	cardinality=7
SO	SEQ, AND, ANY	cardinality=3

$$D = |12-10| + |3-3| + |2-1| + 0 + 1 = 4$$

Example (2/3)

Scenario C (aggression)



TN	8	
TD	2	
TW	1	
SL	E1-S1, E2-S1, E1-S2, E2-S2, E3-S3, E5-S6	cardinality=6
SO	SEQ, ANY	cardinality=2

Off-line distance computation (all trees available)

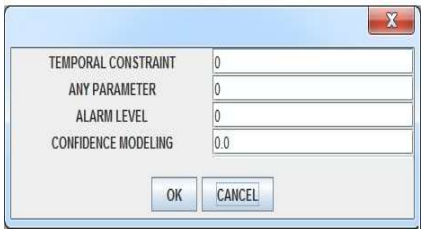
	A-B	A-C	B-C
ΔTN	2	4	2
ΔSL	0	3	3
ΔTD	0	1	1
ΔSO	1	2	1
ΔTW	1	1	0
D	4	11	7

On-line distance computation (only ANY subtree available)

TN	8	
TD	2	
SL	E1-S1, E2-S1, E1-S2, E2-S2, E3-S3	cardinality=5
SO	ANY, OR	cardinality=2

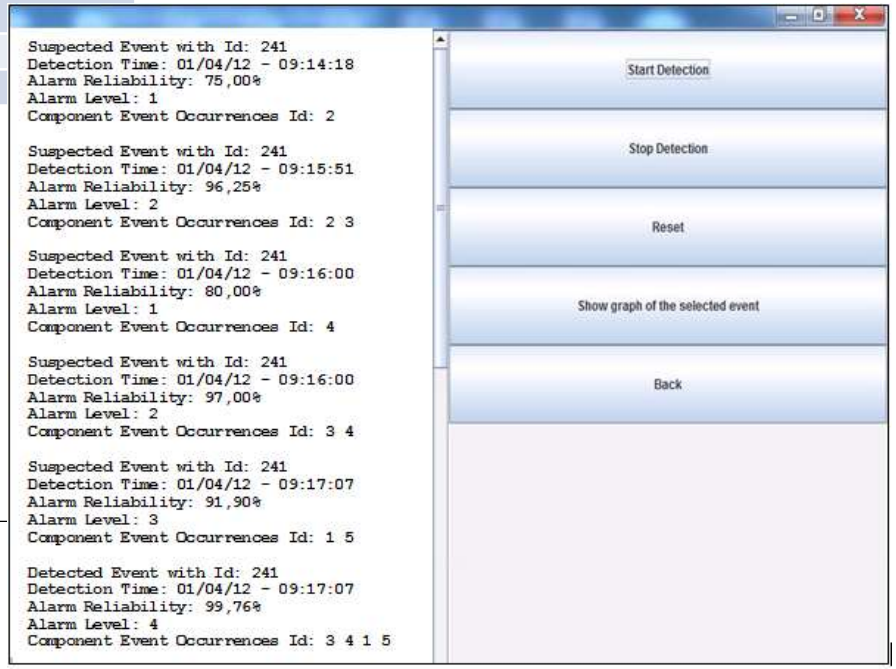
	ANY-A	ANY-B	ANY-C
ΔTN	4	2	0
ΔSL	2	2	1
ΔTD	1	1	0
ΔSO	2	3	1
D	9	8	2

Example (3/3)

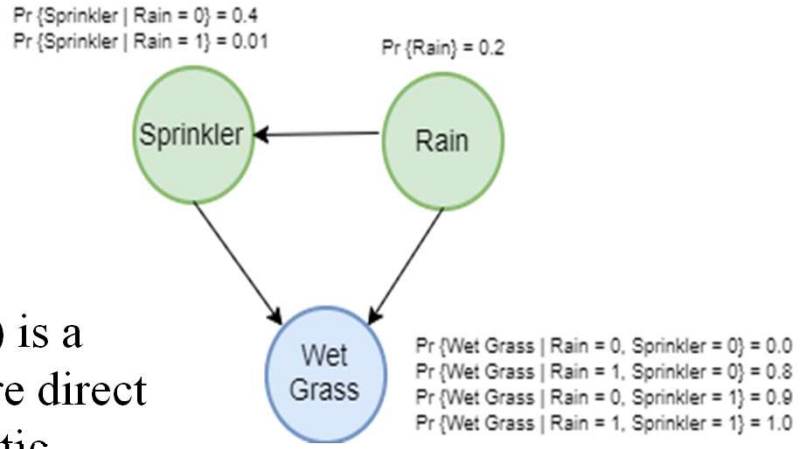


Detector ID	Detector Description	Event ID	Event Description	FAR
S1	Intelligent Camera	E1	Fall of person	0.25
		E2	Abnormal running	0.20
S2	Intelligent Camera	E1	Fall of person	0.25
		E2	Abnormal running	0.20
S3	Audio Sensor	E3	Scream	0.15
S4	IMS/SAW detector	E4	CWA detection	0.30
S5	IR detector	E4	CWA detection	0.27

Date	Time	Event ID	Detector ID	Occurrence Nr
01/04/2012	09:11:11	E4	S4	1
01/04/2012	09:14:18	E1	S2	2
01/04/2012	09:15:51	E3	S3	
01/04/2012	09:16:00	E2	S2	
01/04/2012	09:17:07	E4	S5	



Bayesian Networks



A Bayesian Network (BN) (or "influence diagram") is a formalism suitable to model uncertainty. BNs are direct acyclic graphs in which nodes represent stochastic variables and arcs statistical dependencies between variables, quantified by conditional probabilities (Conditional Probability Tables, CPT)

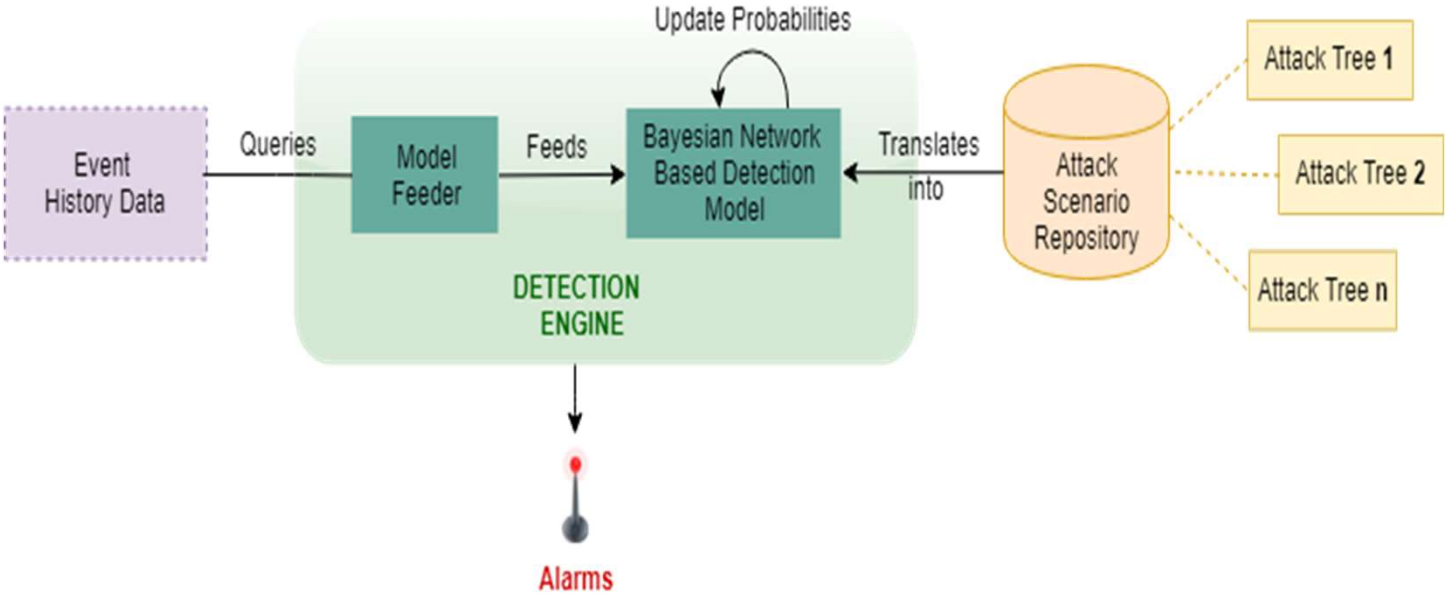
Each node X_i is be associated with a probability distribution given by all its parent nodes through the CPT.

This can be denoted as p(X | parents(x)). Following this simplified explanation, an entire BN can then be represented by a single joined probability distribution:

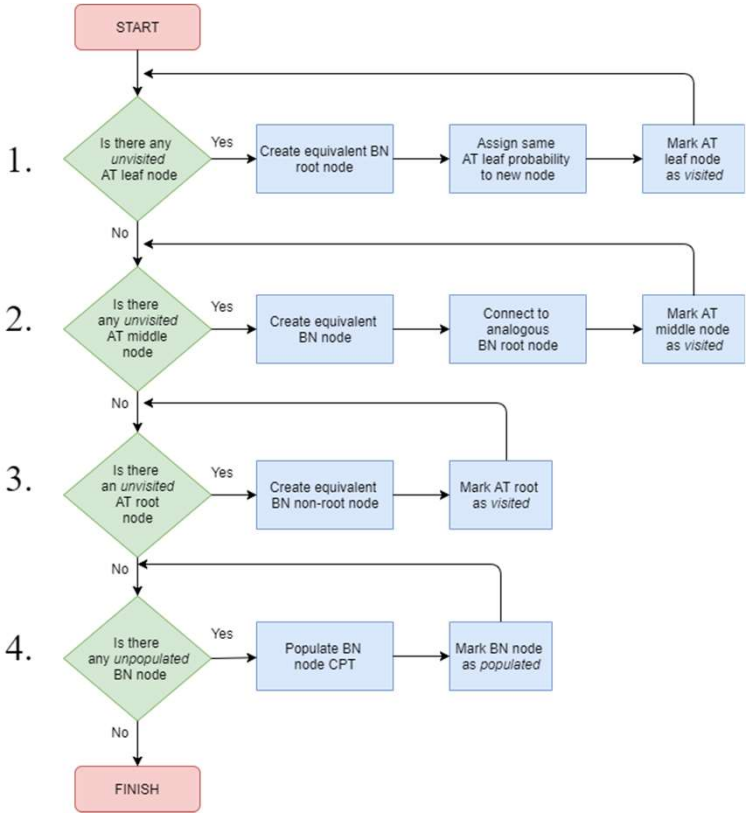
$$p\,(X_1 \ldots X_n) = \prod_{1}^{n} p\,(Xi \,|parents\,(Xi))$$

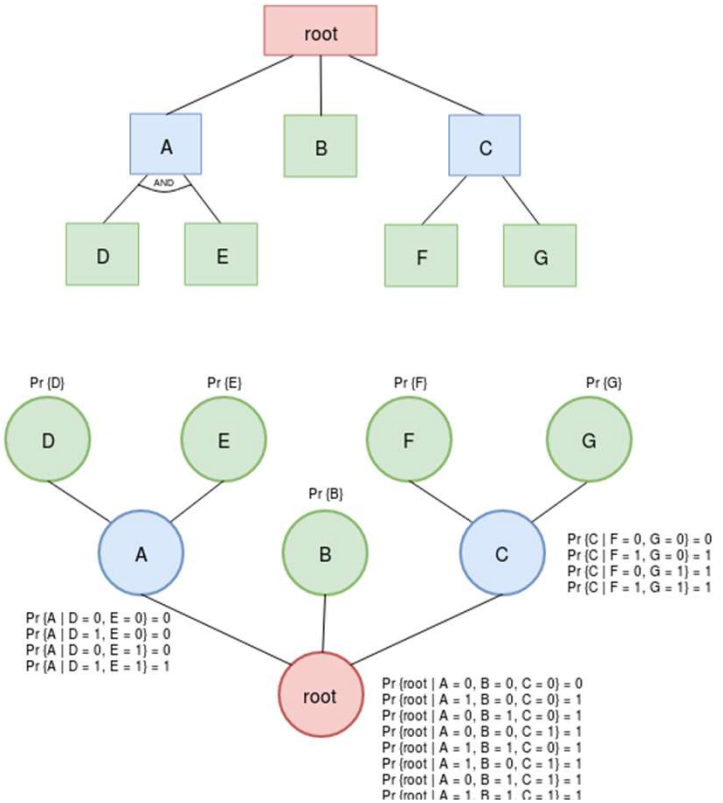
Eugene Charniak (1991), Bayesian networks without tears: making Bayesian networks more accessible to the probabilistically unsophisticated, AI Magazine, v.12 n.4, pp.50-63

BN in DETECT


Update Probabilities
Event History Data
Queries
Model Feeder
Feeds
Bayesian Network Based Detection Model
Translates into
Attack Scenario Repository
Attack Tree 1
Attack Tree 2
Attack Tree n
DETECTION ENGINE
Alarms

From Event/Attack Trees to BN





How to populate BN models

- Data collection on attacks, or other data collection techniques such as honey pots and data harvested from simulations.
- Probabilities are refined as more precise data is collected using ML techniques applied to empirical evidence.
- As an example of using historical data, a study published in 2017 by Symantec Corporation titled the Internet Security Threat Report (ISTR):
  - Email phishing rate is 1 in 2995 emails.
  - Email malware rate is 1 in 412 emails.
  - From more than 1 billion requests analysed every day, 1 in 13 web-requests lead to malware.
  - 76% of websites contain vulnerabilities, out of which 9% are critical vulnerabilities.
  - Out of 8718 vulnerabilities discovered in 2017, 4262 were zero-day vulnerabilities.
- This and similar data can be customized to a specific organization and updated dynamically by counting the number of emails sent, websites accessed, etc.

Example data

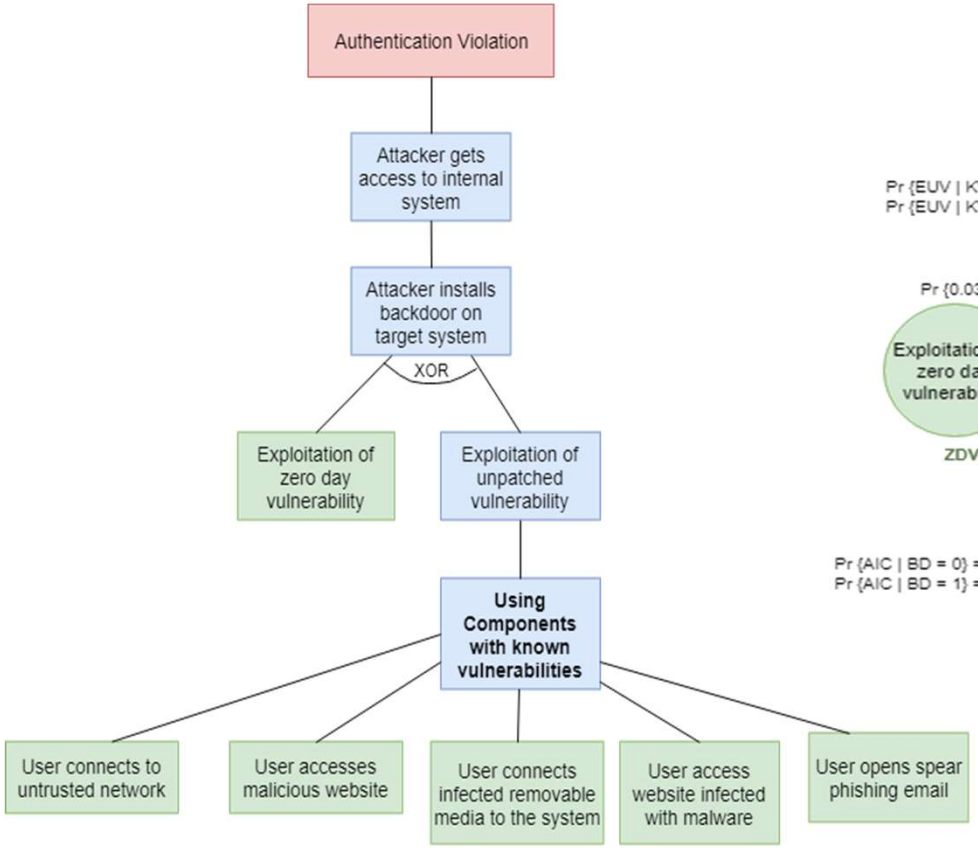
For instance, if you trust the above statement "Email phishing rate is 1 in 2995 emails", and in your organization you have 1200 emails sent at a certain time, then you can get your custom value for the email phishing probability as:

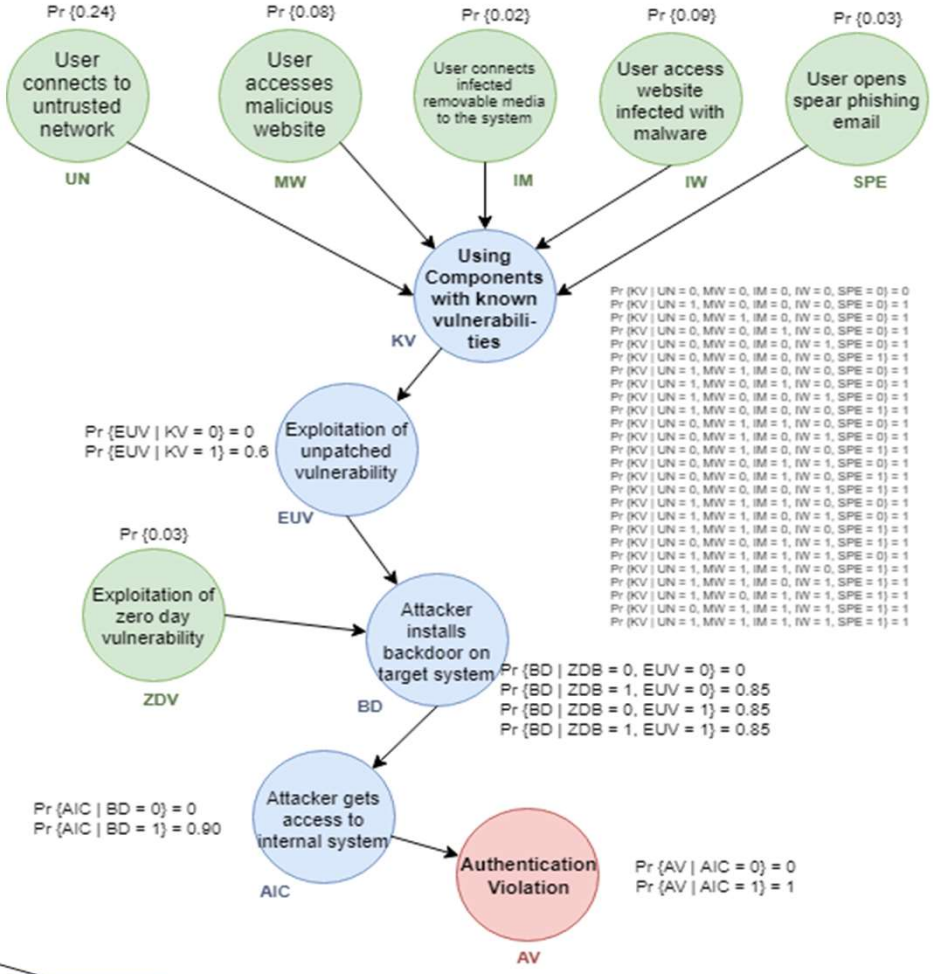
$$1 - \prod_{1}^{1200} \left(1 - \frac{1}{2995}\right)$$

In this formula (1-1/2995) would be the probability of not having phishing in a single email, whereas the production refers to the probability of not having phishing in any of the 1200 emails (assuming they are not correlated). One minus the production is then the probability of having phishing after 1200 emails.

In other words, it is possible to update in real-time that probability by counting the number of emails received in the organization at any time. The same holds for the other parameters like website access. The SIEM system can be configured to monitor those parameters and provide updates to DETECT and hence to the BN detection model.

Example model





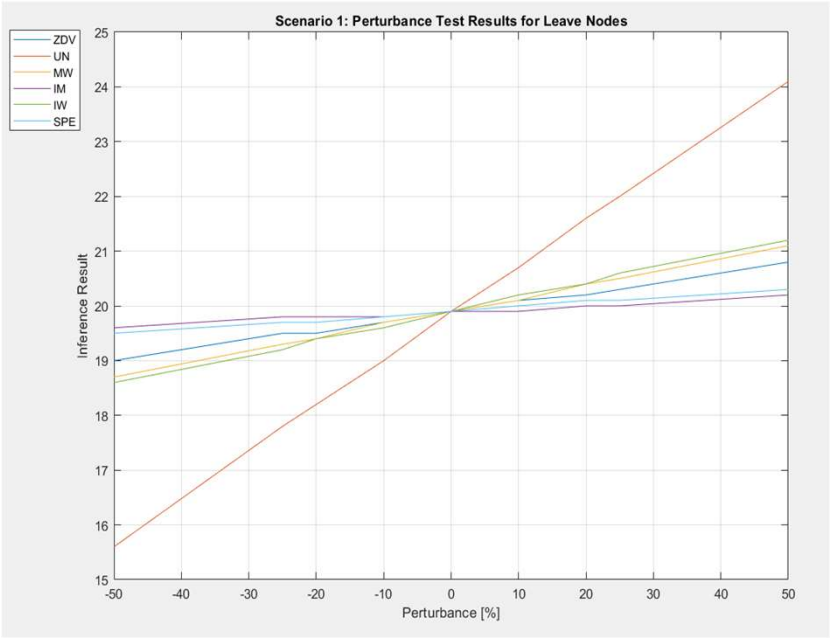
Data for the example model

Leaf node	Identifying Acronym	Estimated probability	Possible Detection Sensors
Exploitation of Zero-Day Vulnerability	ZDV	0.03	-Anomaly detection based IDS -User Level Endpoint Monitoring
User Connects to Untrusted Network	UN	0.24	-IDS -SSL Certificate missing/rejected -Netflow Analysis -Firewall
User Accesses Malicious Website	MW	0.08	-IDS -SSL Certificate missing/rejected -Unexpected flow of data
User Connects Infected Removable Media to the System	IM	0.02	-IDS -Antivirus -System Event Logs
User Accesses Website Infected with Malware	IW	0.09	-IDS -Web Browser Plugin
User Opens Spear Phishing Email	SPE	0.03	-Human -User Level Endpoint Monitoring

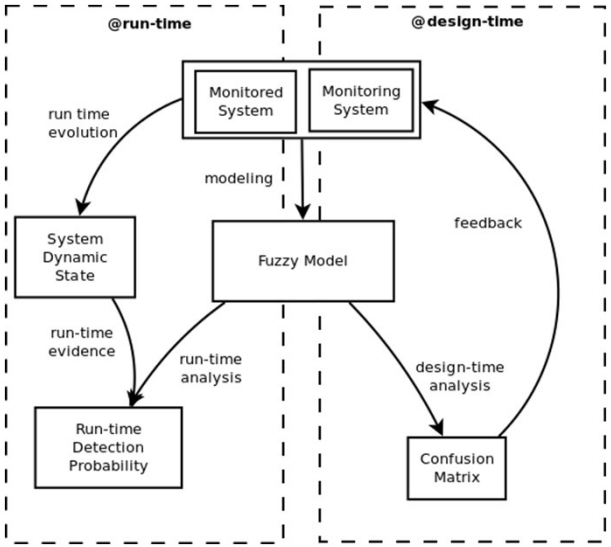
Middle Node	Identifying Acronym	Estimated Probability
Exploitation of unpatched vulnerability	EUV	0.60
Attacker installs backdoor on target system	BD	0.85
Attacker gets access to internal system	AIC	0.90

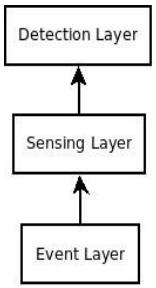
Perturbation tests

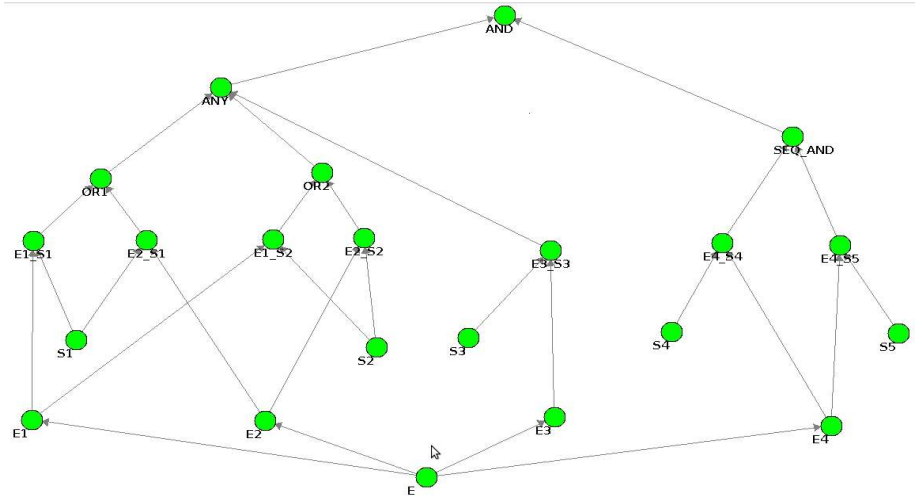
Node	IM		IW		SPE	
Perturbance Percentage	Value	Results	Value	Results	Value	Results
-50%	1	19.6	4.5	18.6	1.5	19.5
-25%	1.5	19.8	6.75	19.2	2.25	19.7
-20%	1.6	19.8	7.2	19.4	2.4	19.7
-10%	1.8	19.8	8.1	19.6	2.7	19.8
0%	2	19.9	9	19.9	3	19.9
10%	2.2	19.9	9.9	20.2	3.3	20
20%	2.4	20	10.8	20.4	3.6	20.1
25%	2.5	20	11.25	20.6	3.75	20.1
50%	3	20.2	13.5	21.2	4.5	20.3



BN: design time vs run time







Value	Meaning	Probability
true	Alarm on	$2.273*10^{-5}$
false	Alarm off	0.999977
unknown	Alarm inactive	$2.7*10^{-7}$

Evidence	Alarm on	Alarm off
True	0.995 (tp)	$0.22*10^{-4}$ (fn)
False	$0.5*10^{-2}$ (fp)	0.999978 (tp)

Unobserved ev.	Alarm on	Alarm off
E1	0.9934	0.0066
E2	0.9941	0.0059
E3	0.9938	0.0062

FLAMMINI F., Marrone S, Mazzocca N, Vittorini V (2016). Fuzzy decision fusion and multiformalism modeling in physical security monitoring. Recent Advances in Computational Intelligence in Defence and Security. vol. 621, p. 71-100, BERLIN: Springer, doi: 10.1007/978-3-319-26450-9_4

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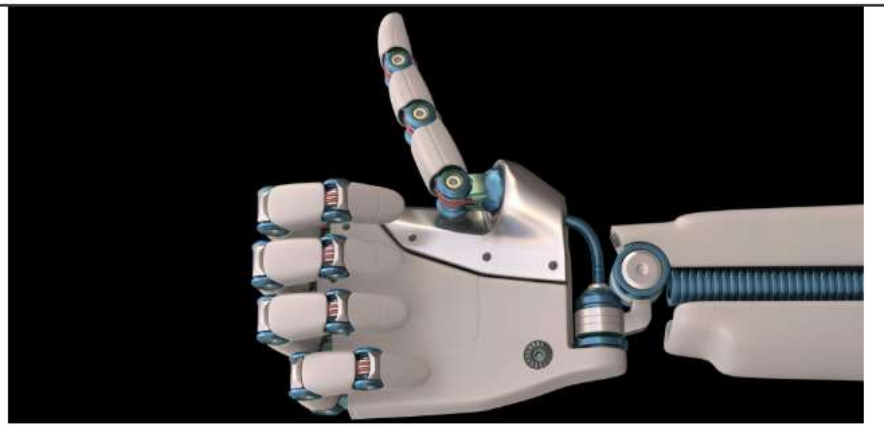

Cyber-Physical Systems (CPS)

The CPS research group is responsible for research, teaching, and outreach activities in the field of Cyber-Physical Systems.

The research of Cyber-Physical Systems addresses the close interactions and feedback loop between the embedded cyber components and the dynamic physical components that involve mechanical components, energy systems, human activities and surrounding environment.

Designing CPS involves the consideration of multiple factors such as timing, energy, reliability, dependability and security. Experts from different disciplines are needed to tackle the challenges on large scale analytical modeling and analysis, efficient simulations, model driven synthesis and verification, real-time data analytics and system control, etc.

The current research focuses on

1. model-based design, synthesis and verification of CPS,
2. CPS dependability, security and privacy,
3. big data analytics for CPS,
4. cross-layer modeling and optimization for CPS, and
5. applications of CPS in smart energy systems and automotive systems, etc.

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Thank you for your kind attention!