Towards Quantitative Security Evaluation ?

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Fault forecasting

- Evaluation:
  - Gain confidence that system dependability is satisfactory
  - Select architecture/components to achieve the best dependability-performance-cost trade-off
- Quantitative measures
  - Reliability: MTFF = mean time to first failure,
    $R(t) = \text{prob}_{\text{continuous service}}(t)$
  - Availability: MTBF/(MTBF+MTTR),
    $A(t) = \text{prob}_{\text{correct service provided when needed}}(t)$

Basic assumption

- Faults = elementary component failures
  (or other rare physical phenomena)
  Model = independent stochastic processes
  with known distributions

- OK for physical H/W faults
  and most environmental faults

- ~OK for most S/W design faults (bugs)

- Not OK for attacks or malicious design faults

Security Evaluation

- Usual techniques
  - Evaluation criteria (TCSEC, ITSEC, CC, ...):
    ~ qualitative evaluation
  - Risk assessment: subjective evaluation of vulnerabilities, threats, consequences
  - These are static analyses rather than dynamic:
    "*How the system has been built?*" rather than "*How is it operated?*"

Quantitative security evaluation

- Measure = effort needed for a possible attacker to defeat the security policy

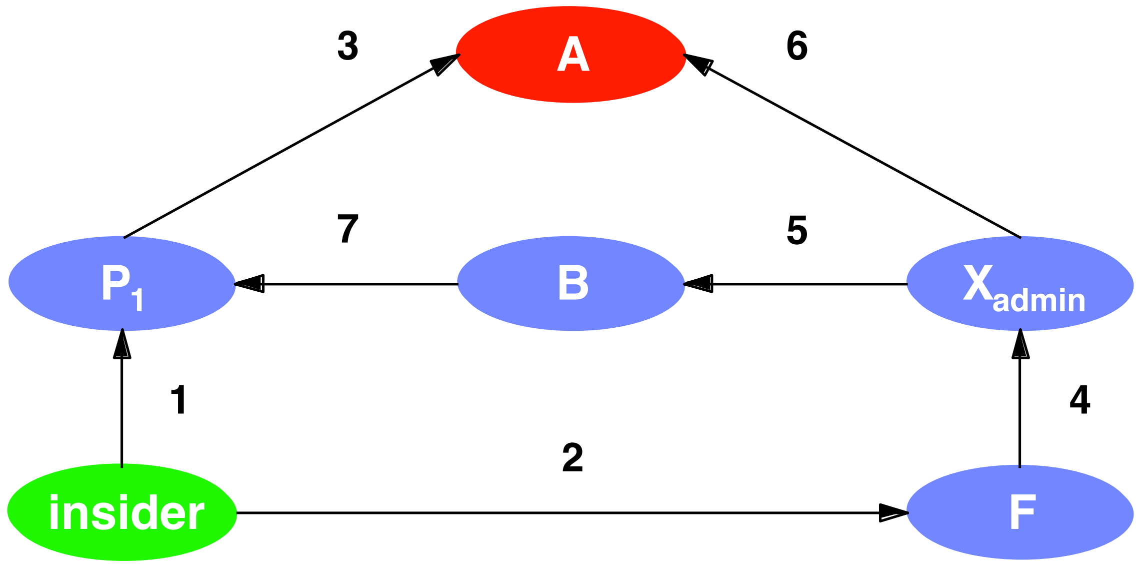
- Objectives:
  - Take into account security/usability trade-offs
  - Monitor security evolutions according to configuration and use changes
  - Identify the best security improvement for the least usability change

ESOPE: General approach

- Identify security objectives: security policy
- Model (operational) system vulnerabilities
- Model the attack processes
- Compute significant measures

Vulnerability modeling

Privilege graph



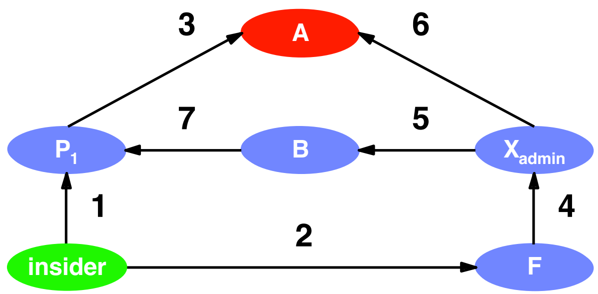
1) X can guess Y's password
2) X can install a Trojan horse that Y can activate
3) X can exploit a flaw in Y's mailer
4) Y is a subset of X
5) Y uses a program that X can modify
6) X can modify a "s-uid" program owned by Y
7) X is in Y's `.rhosts`

- Node = a set of privileges (user, group, rôle, …)
- Arc = a method to transfer privileges = vulnerability
- Path = set of vulnerabilities usable by a possible attacker to reach a target
- Weight = for each arc, effort to exploit the arc's vulnerability

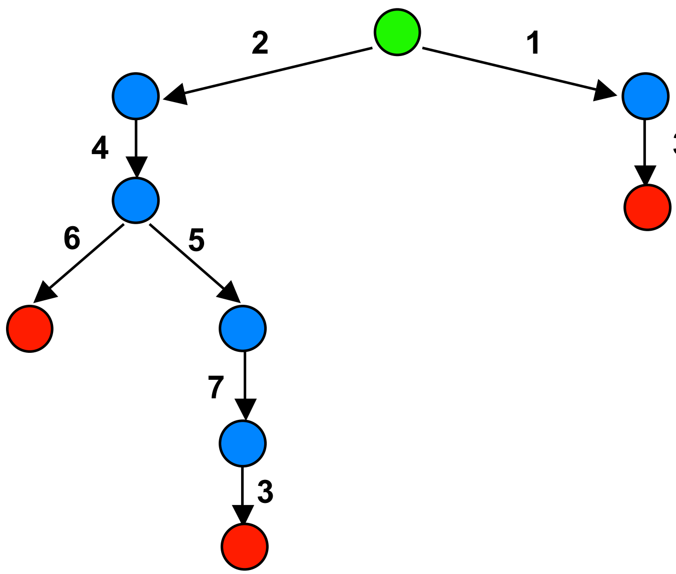
Assumptions on the attack process

- Attack process = all possible successful attack scenarios
- Reasonable assumptions
  - The attacker knows only the vulnerabilities that can be exploited with the privileges he already owns.
  - The attacker will not exploit vulnerabilities which would give him privileges he already owns.
- Plus one out of the two following assumptions:
  - *Total Memory (TM)*: the attacker remembers all the vulnerabilities he did not exploited in the previous steps, and he can "back-track".
  - *Memory-Less (ML)*: the attacker considers only the vulnerabilities that can be exploited with the new privileges he just acquired.

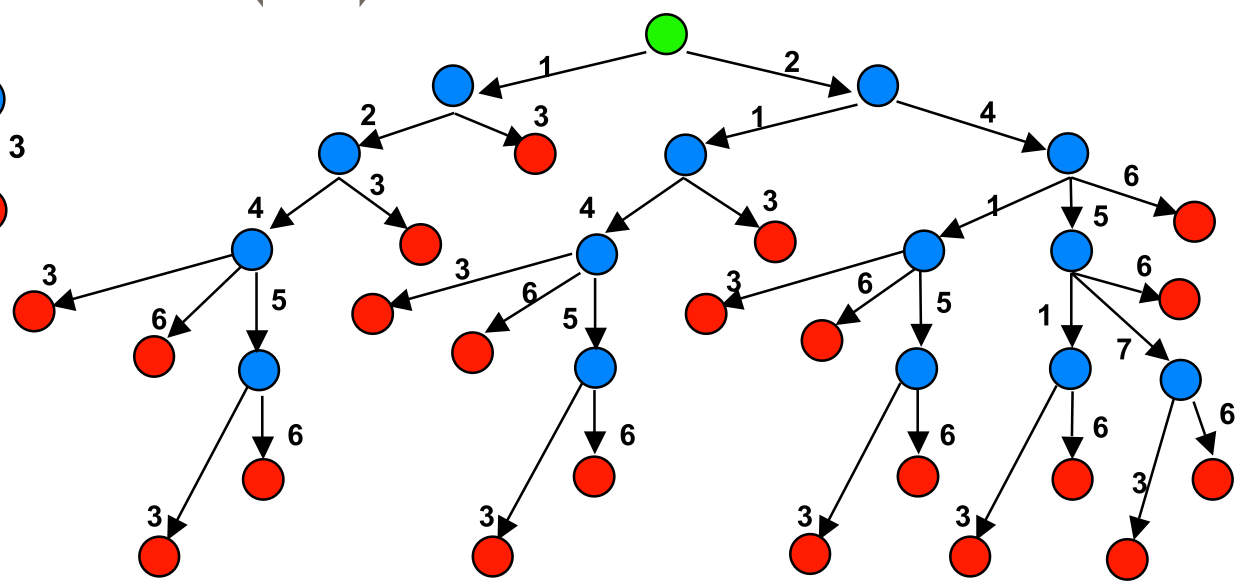
Attack Process Examples



ML Assumption



TM Assumption



Measure computation

① Identify the attacker-target couples

② For each couple, compute:

METF-ML: Mean Effort To security Failure (i.e. to reach the target) with ML assumption.

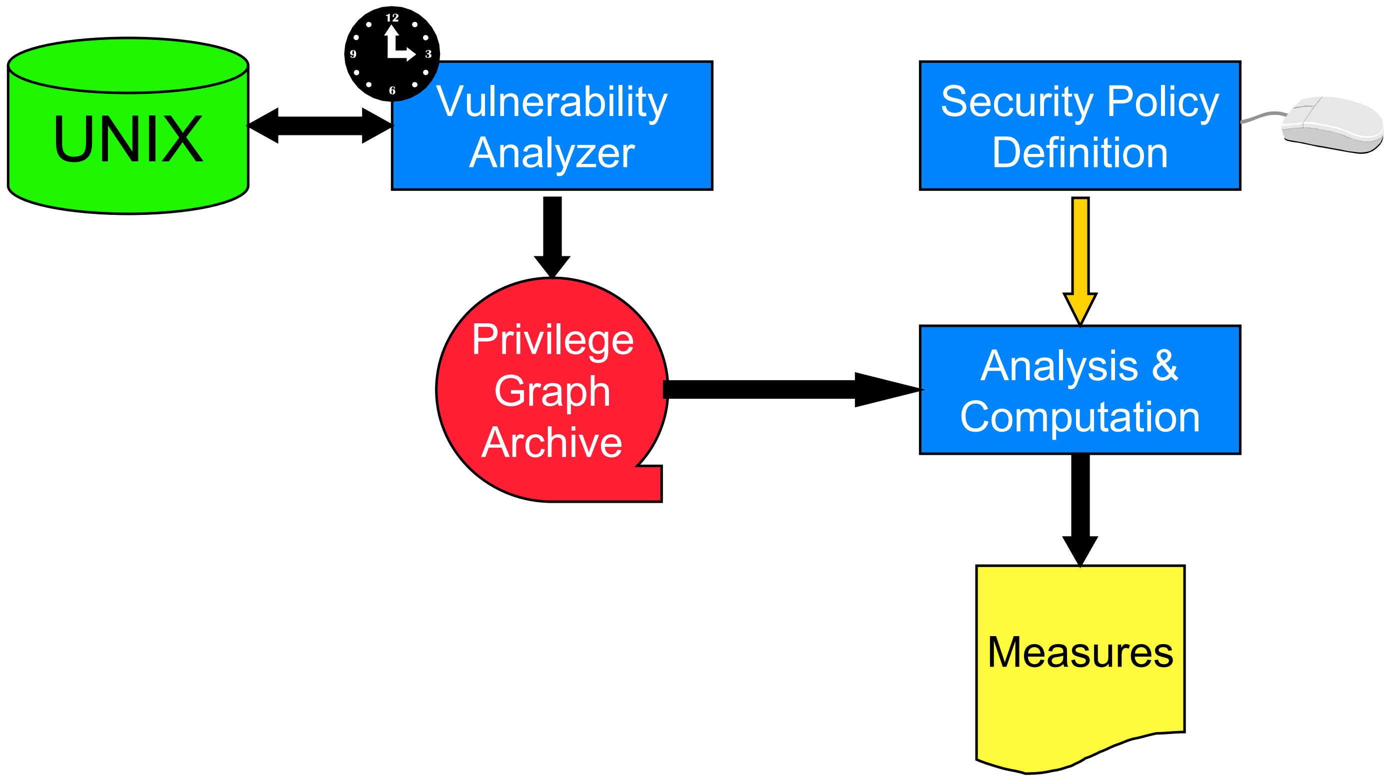
METF-TM: Mean Effort To security Failure with TM assumption.

Shortest Path: Mean effort to go through the shortest path.

Number of Paths: Number of possible paths from the attacker to the target nodes.

ESOPE Tool Set

(Évaluation de la Sécurité OPErationnelle)



Experiment report

- Objectives:
  - Validate the approach:
    - *Assess* the measure pertinence wrt. system changes (configuration, users, …)
    - Feasibility of a full-size system evaluation.
  - *Was not aimed*:
    - Correct the identified vulnerabilities

Experiment context

Target system:

- Unix
- 700 users - 300 machines - LAN
- 13 months (June 1995 - July 1996)

13 types of vulnerabilities
(files `.rhosts`, `.*rc`, passwords, etc.)

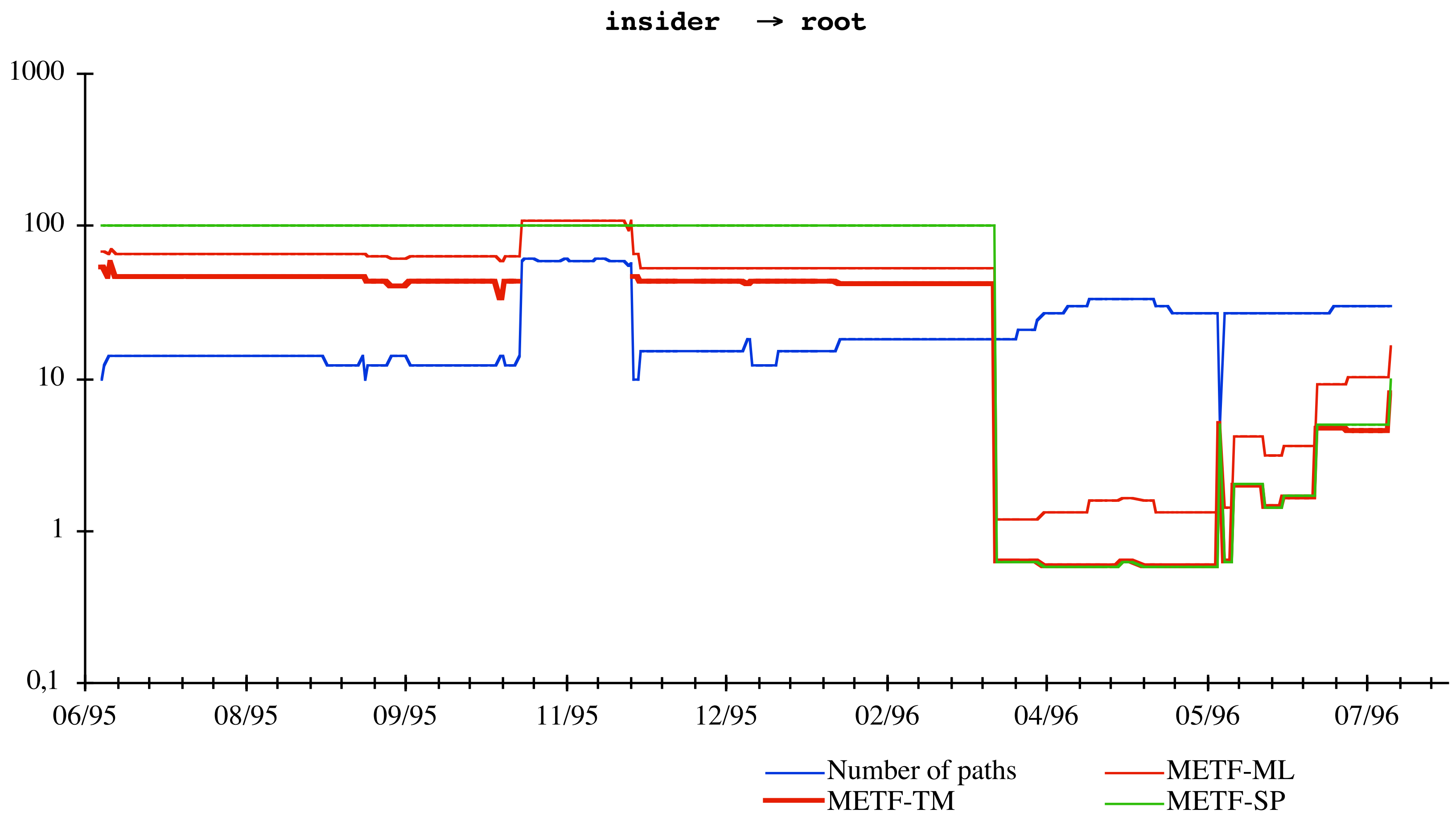
4 difficulty levels:

Type	Weight
immediate	10
easy	10^2
difficult	10^3
very difficult	10^4

Security objectives:

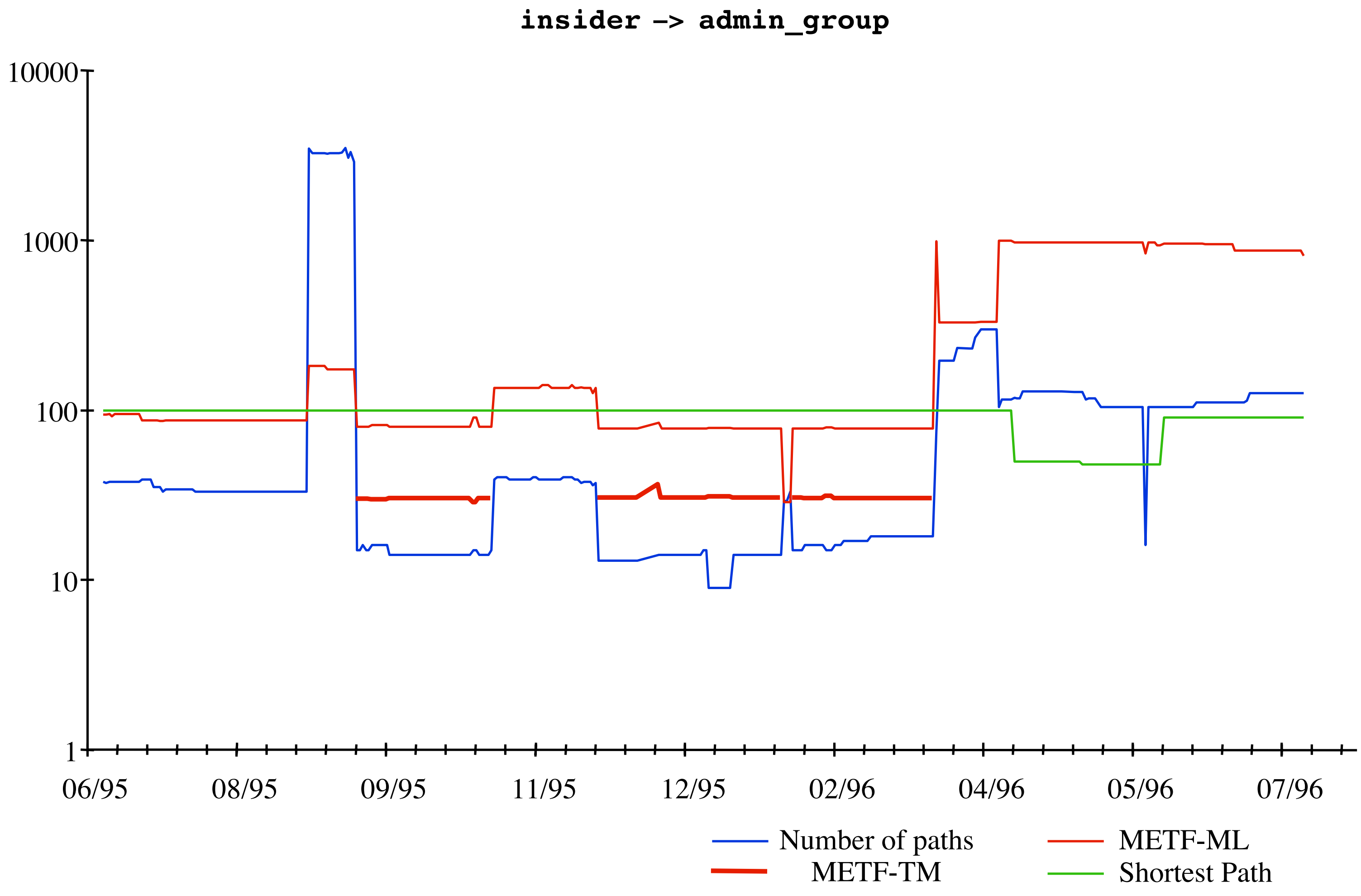
	Attacker	Target
Objective 1	insider	root
Objective 2	insider	admin_group

Results (1)



insider → root
1000
100
10
1
0,1
06/95
08/95
09/95
11/95
12/95
02/96
04/96
05/96
07/96
Number of paths
METF-ML
METF-TM
METF-SP

Results (2)



insider -> admin_group
10000
1000
100
10
1
06/95
08/95
09/95
11/95
12/95
02/96
04/96
05/96
07/96
Number of paths
METF-TM
METF-ML
Shortest Path

Comparison between measures

- The shortest path (**SP**) is not sensitive enough to identify important events
- The number of paths (**NP**) changes too often and would produce a large number of false alarms.
- **METF-ML** presents a good sensitivity to important events.
- **METF-TM** is easier to interpret, but is sometimes too complex to be computed.

Problems

- Is the model valid in the real world?
- TM and ML are 2 extreme attacker behaviors, but what would be a "real" attacker behavior?
- Weight parameters are assessed arbitrarily (subjective ?)
- Tenacity? Collusion? Attack rates?

→ We need real data!

Validation based on real attack data

- Collect real life data to learn and analyze attackers behaviors, tools and tactics

- Objectives
  - Validate attack assumptions
  - Analyze adequacy of the privilege graph to describe new vulnerabilities and derive attack scenarios
  - Extend security evaluation approach by taking into account distribution of attacks in time, correlation between attacks, etc.

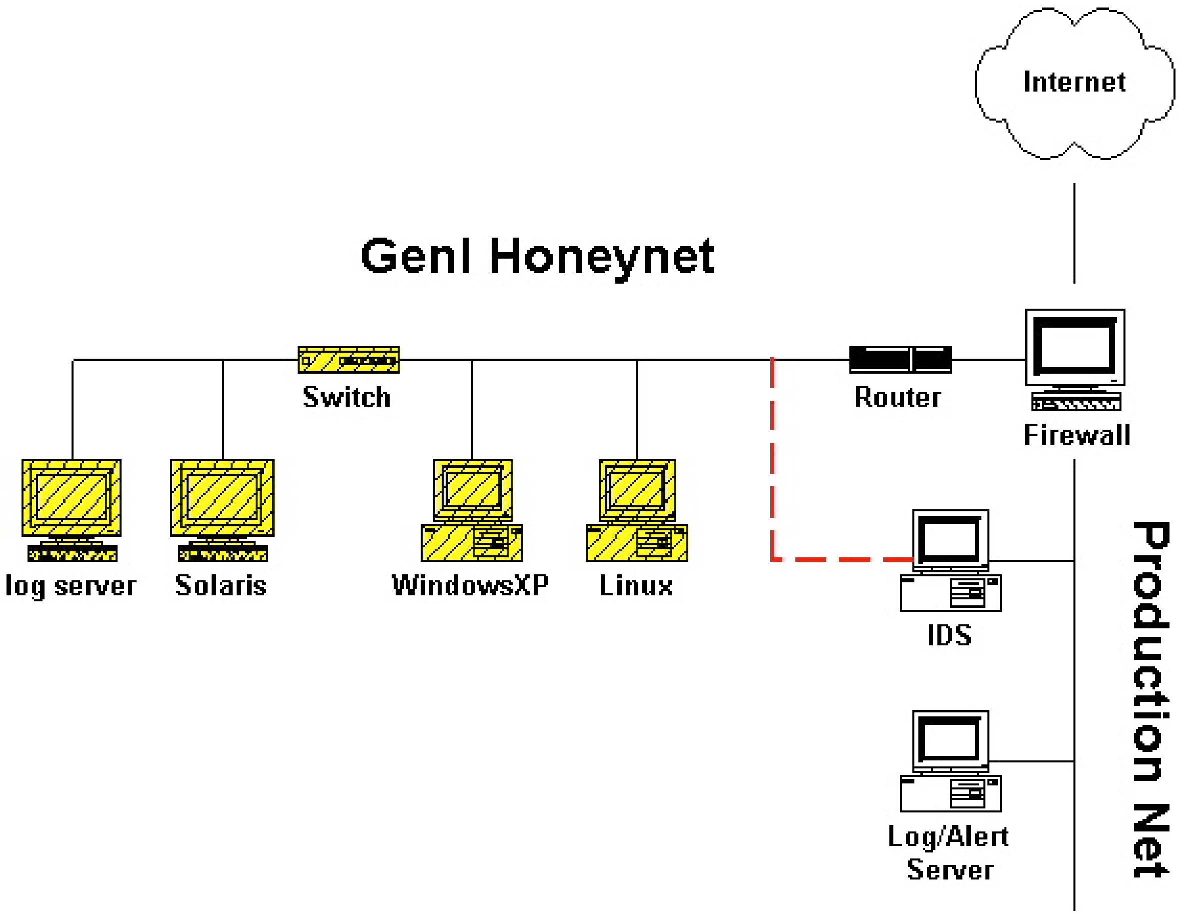
Honeypots and Honeynets

- Honeypot
  - A security resource whose value lies in being probed, attacked or compromised
  - Anything going to or from a honeypot is likely a probe, attack or compromise

- Honeynet
  - A network of honeypots
  - All systems placed within the Honeynet are production systems : Solaris, Windows, Linux

http://www.honeynet.org/alliance/

Example of Honeynet



The threat is real!

- Computers scanned dozens of times a day
- Fastest time a honeypot manually compromised: 15 minutes (automatic, 92 seconds)
- Time before a default Linux Red Hat 6.2 successfully hacked is 72 hours
- 100% - 900% increase of activity from 2000 to 2001
- Its only getting worse

http://www.honeynet.org/papers/stats

Perspectives

- Data collection
  - Several honeynets (different domains, locations, etc.)
  - Need to analyze if data collected from different locations (e.g., .com vs. .edu) exhibit similar or different statistical patterns
- Data Analysis
  - Identify attacks and characterize their distribution in space and time
    - known and new vulnerabilities
    - attack scenarios
    - trend analysis
- Security modeling and evaluation
  - Take into account the lessons learnt from data
  - Analyze how results are useful for designers/administrators

What we do NOT expect :

- Plausible attack rates / effort distribution

… necessary for "reliability / availability" measures

References

- L. Spitzner, *Honeypots: Tracking hackers*, 480p., ISBN 0321108957, Addison Wesley Professional, 2002. *(http://www.tracking-hackers.com/)*

- The Honeynet project (Ed.), *Know your enemy*, 352p., ISBN 0201746131, Addison-Wesley Pub Co, 2002. *(http://www.honeynet.org/)*

- R. Ortalo, Y. Deswarte, M. Kaâniche, "Experimenting with Quantitative Evaluation Tools for Monitoring Operational Security", *IEEE Transactions on Software Engineering*, Vol.25, N°5, pp.633-650, Sept./Oct. 1999.

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