Detecting Anomalous Behaviors in Computer Infrastructures

Dipartimento di Elettronica e Informazione
Politecnico di Milano
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Feb 25, 2010

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- **Google** estimates more than 1 trillion unique URLs,
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- (Mar 2008) **YouTube** stores more than 70 million videos and the most popular video has been viewed 112,486,327 times.

...unfortunately...

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Note: these only refer to the facts that have been **detected** and **reported**.

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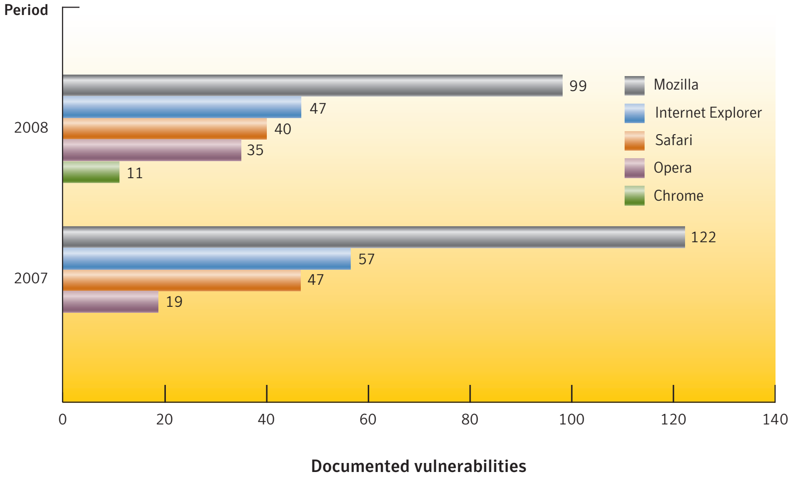
This is actually a “lethal cocktail”: let's see why.

The most popular software tool is flawed

BTW, looks like MS IE is more secure than Mozilla :)



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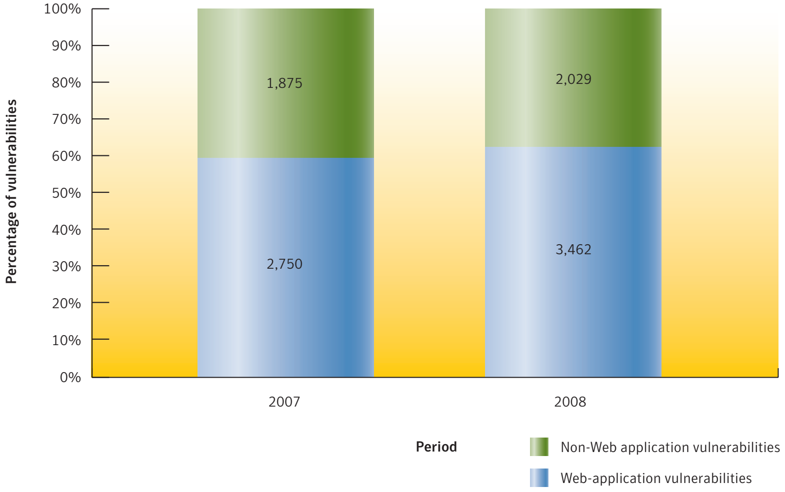
Plug-in	2008 Top Category	2007 Top Category
Adobe Acrobat Reader	Memory corruption	Memory corruption/content injection/ command execution
Adobe Flash Player	Memory corruption/origin validation/ elevated security context	Elevated security context
ActiveX	Memory corruption	Memory corruption
Java	Elevated security context	Elevated security context
Mozilla Extensions	Content injection	Content injection
QuickTime	Memory corruption	Memory corruption
Windows Media Player	Memory corruption	Memory corruption/DoS

The most accessible applications are flawed too



Overview of a modern exploitation work-flow

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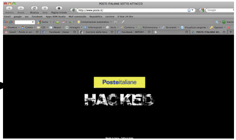
Automated Attacker

Malware



Vulnerable

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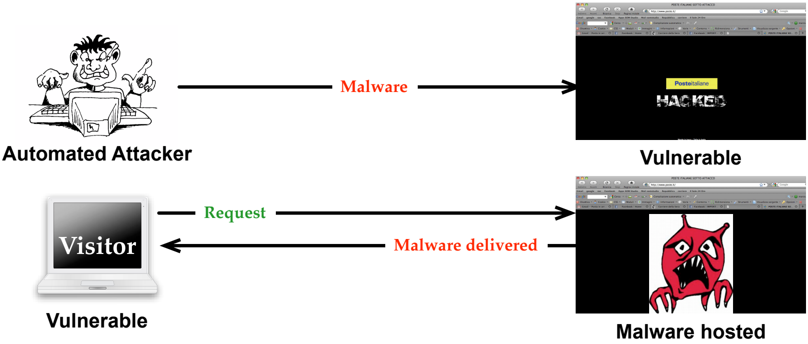

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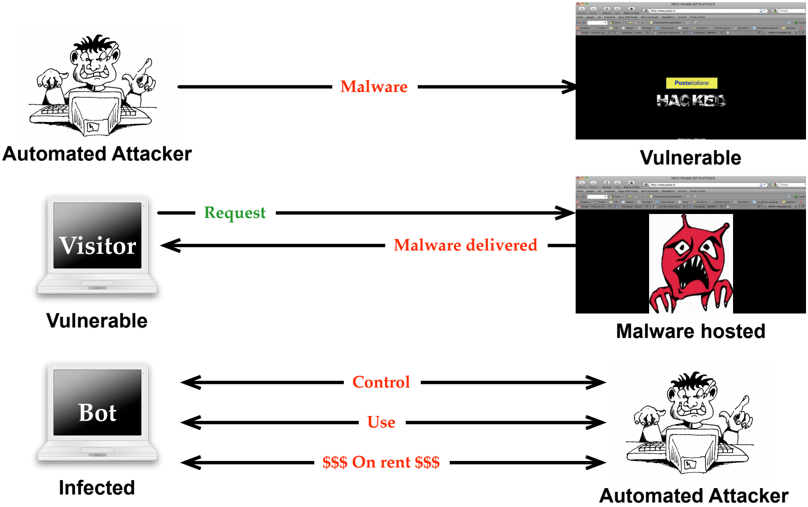

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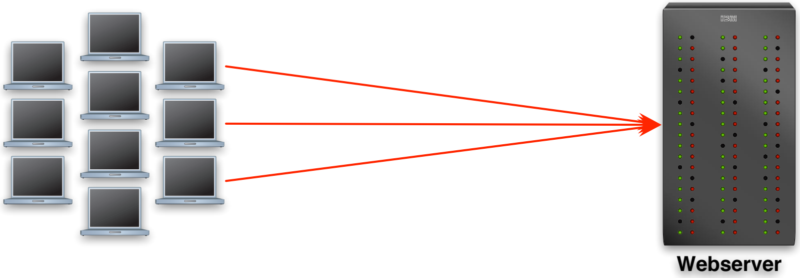
  - DDoS
  - Phishing campaigns
  - Spamming campaigns,
  - Scam web-sites design!

Pick your choice from the attack-as-a-service gourmet menu

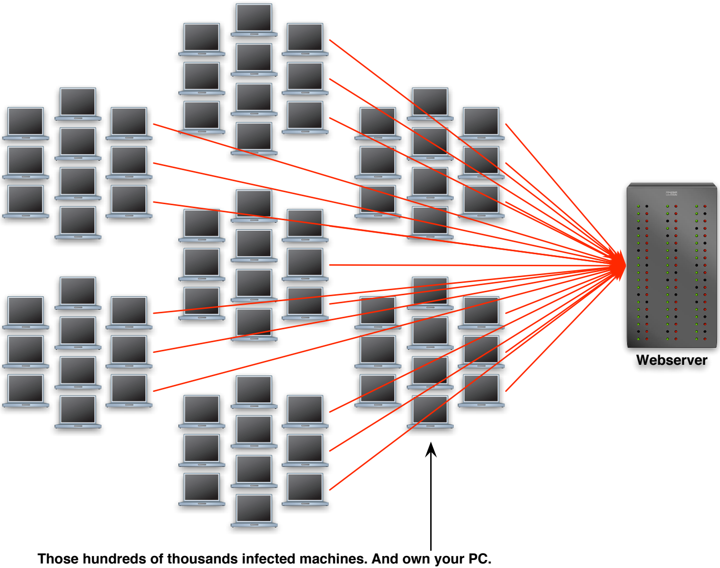
2008 Rank	2007 Rank	Item	2008 Percentage	2007 Percentage	Range of Prices
1	1	Credit card information	32%	21%	\$0.06–\$30
2	2	Bank account credentials	19%	17%	\$10–\$1000
3	9	Email accounts	5%	4%	\$0.10–\$100
4	3	Email addresses	5%	6%	\$0.33/MB–\$100/MB
5	12	Proxies	4%	3%	\$0.16–\$20
6	4	Full identities	4%	6%	\$0.70–\$60
7	6	Mailers	3%	5%	\$2–\$40
8	5	Cash out services	3%	5%	8%–50% or flat rate of \$200–\$2000 per item
9	17	Shell scripts	3%	2%	\$2–\$20
10	8	Scams	3%	5%	\$3–\$40/week for hosting, \$2–\$20 design

A few years ago...

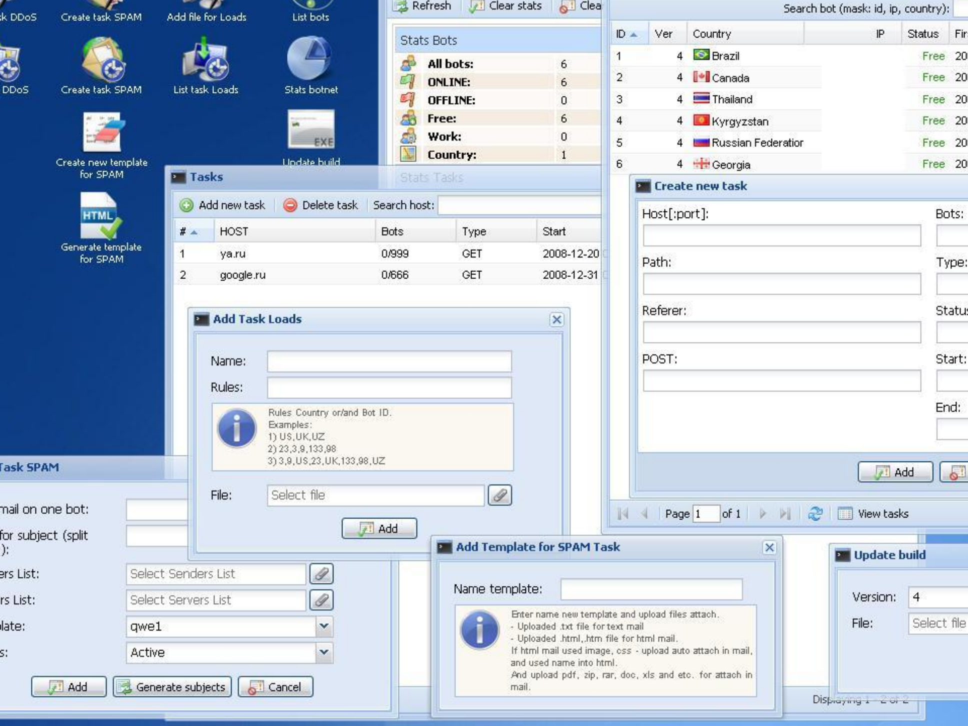


…and nowadays

It's just a multiplication factor but it is damn significant!



...and they come with a sweet graphical user interface...



k DDoS
Create task SPAM
Add file for Loads
List bots
DDoS
Create task SPAM
List task Loads
Stats botnet
Create new template for SPAM
Update build
Generate template for SPAM
Refresh
Clear stats
Stats Bots
All bots: 6
ONLINE: 6
OFFLINE: 0
Free: 6
Work: 0
Country: 1
Stats Tasks
Search bot (mask: id, ip, country):
ID | Ver | Country | IP | Status
1 | 4 | Brazil | | Free
2 | 4 | Canada | | Free
3 | 4 | Thailand | | Free
4 | 4 | Kyrgyzstan | | Free
5 | 4 | Russian Federation | | Free
6 | 4 | Georgia | | Free
Tasks
Add new task
Delete task
Search host:
| HOST | Bots | Type | Start
1 | ya.ru | 0/999 | GET | 2008-12-20
2 | google.ru | 0/666 | GET | 2008-12-31
Create new task
Host[:port]:
Bots:
Path:
Type:
Referer:
POST:
Start:
End:
Add
Page 1 of 1
View tasks
Add Task Loads
Name:
Rules:
Rules Country or/and Bot ID.
Examples:
1) US,UK,UZ
2) 23,3,9,133,98
3) 3,9,US,23,UK,133,98,UZ
File:
Select file
Add
Task SPAM
mail on one bot:
for subject (split
):
ers List:
Select Senders List
rs List:
Select Servers List
late:
qwe1
s:
Active
Add
Generate subjects
Cancel
Add Template for SPAM Task
Name template:
Enter name new template and upload files attach.
- Uploaded .txt file for text mail
- Uploaded .html,.htm file for html mail.
If html mail used image, css - upload auto attach in mail, and used name into html.
And upload pdf, zip, rar, doc, xls and etc. for attach in mail.
Update build
Version:
4
File:
Select file

One possible Mitigation Strategy

Attacks generate anomalous behavior

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Simple example

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/login/<par1>/<par1-val>/<par2>/<par2-val>
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Simple example

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/comment/<par1>/<par1-val>
/login/<par1>/<par1-val>/<par2>/<par2-val>
...
/<component1>/<par1>/<par1-val>/<par2>/<par2-val>
```

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```

Simple example

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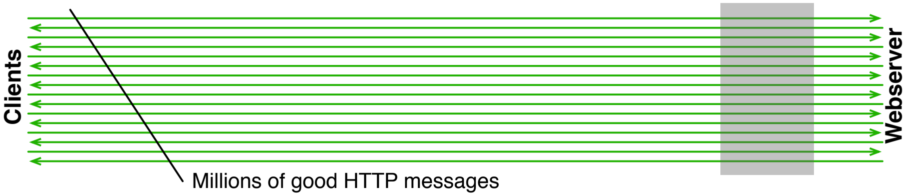

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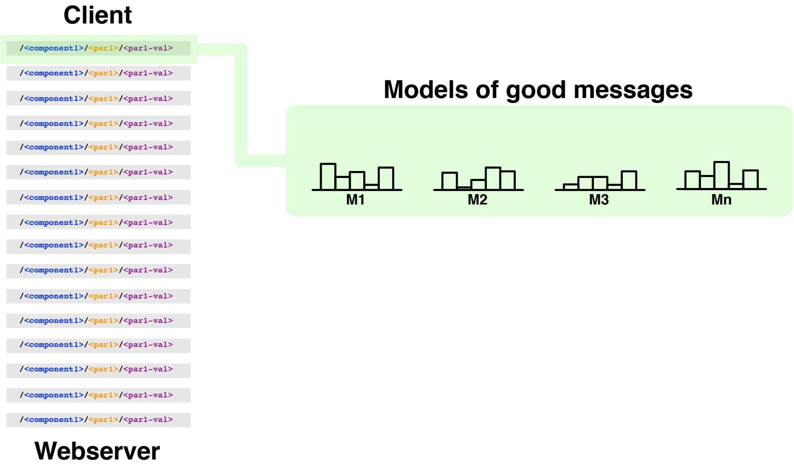

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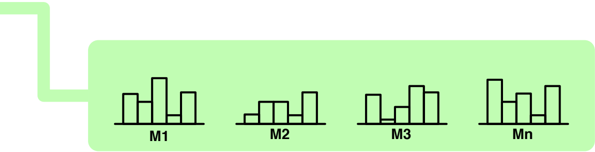

Example of models

— parameter string length
— numeric range
— probabilistic grammar of strings
— string character distribution

Simple example

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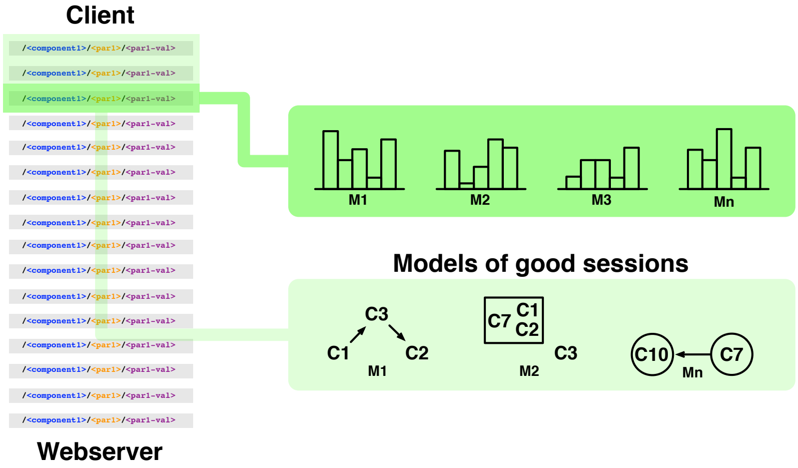

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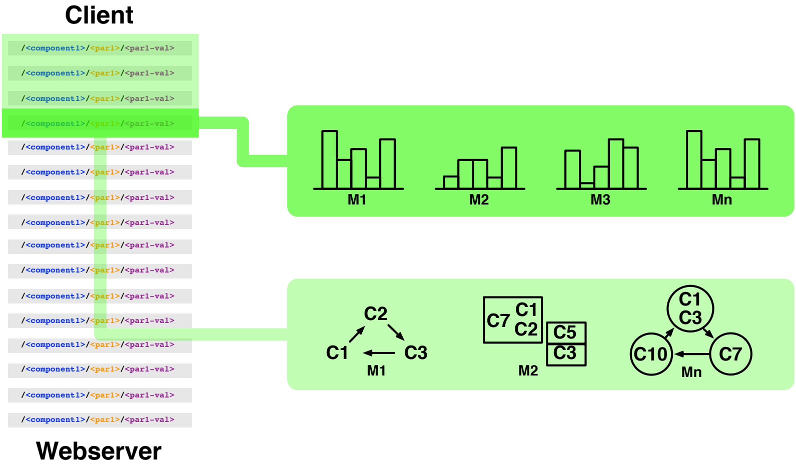

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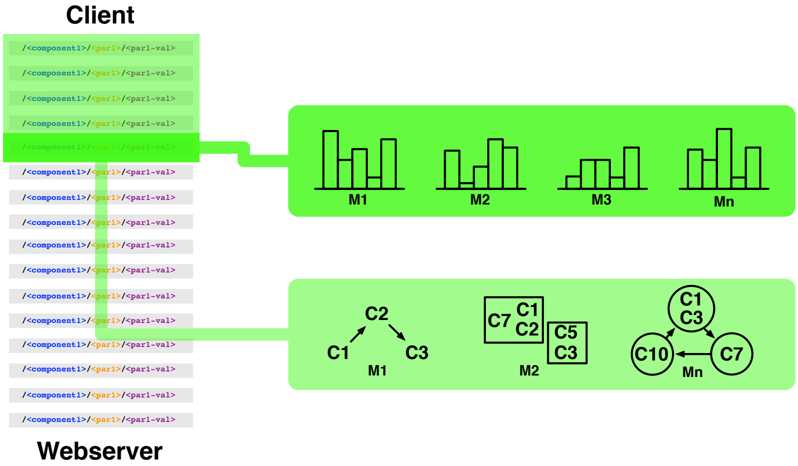

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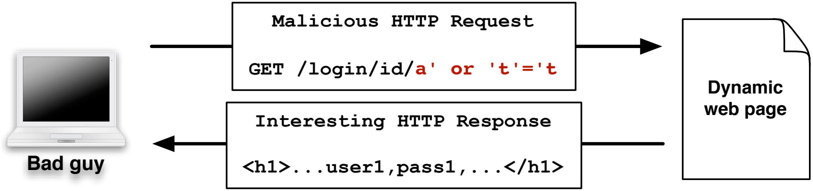

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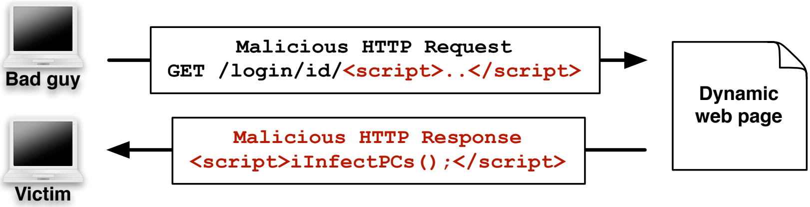

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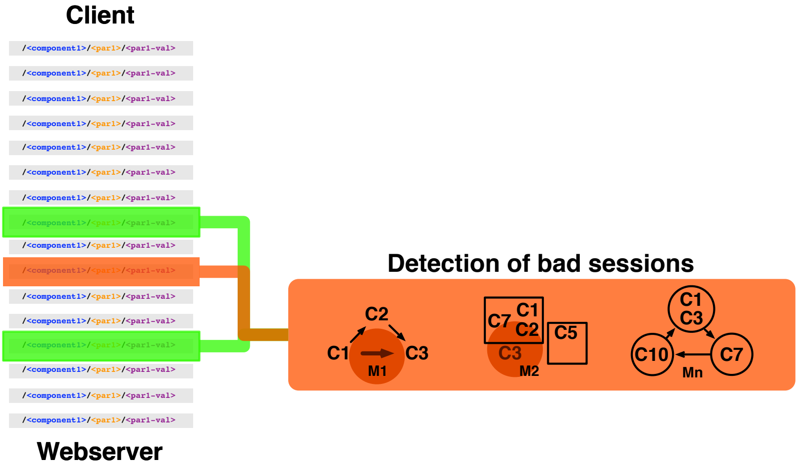

The same applies to any type of activity.
The **crucial** point is how to design **models**.

Our research

Three subjects

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3. combination of the two,
   - malicious network activity $\rightarrow$ malicious activity on the operating system.

1. HTTP interactions

Protecting web applications and clients

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Models of:

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Models of:

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to protect

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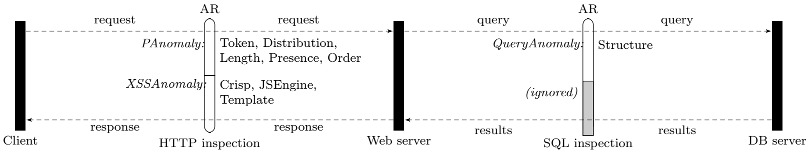
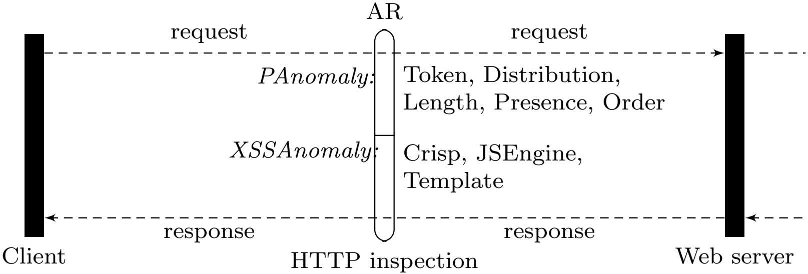


AR
request
request
PAnomaly:
Token, Distribution,
Length, Presence, Order
XSSAnomaly:
Crisp, JSEngine,
Template
response
response
Client
HTTP inspection
Web server
AR
query
query
QueryAnomaly:
Structure
(ignored)
results
results
SQL inspection
DB server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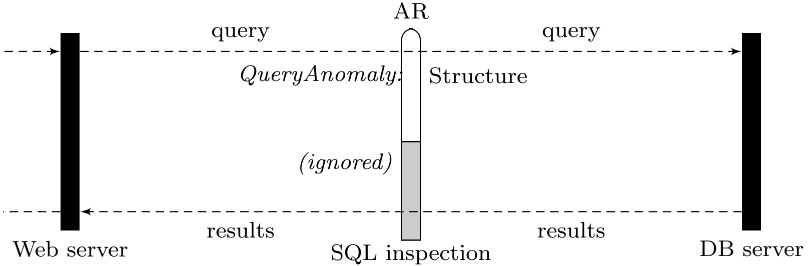
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Example of very simple models

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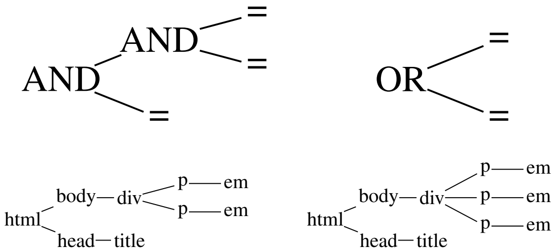
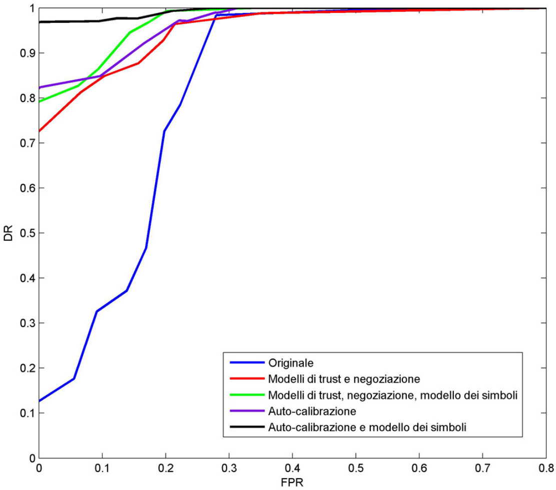


Overall detection capabilities



Tested on about HTTP 8,000 requests, 3000 attacks. EC2ND 2009 [2].

Updating obsolete models dynamically

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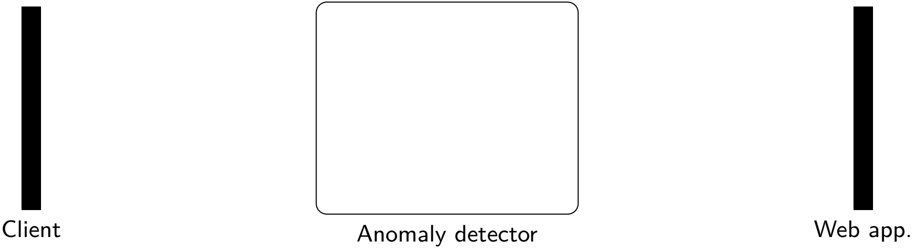

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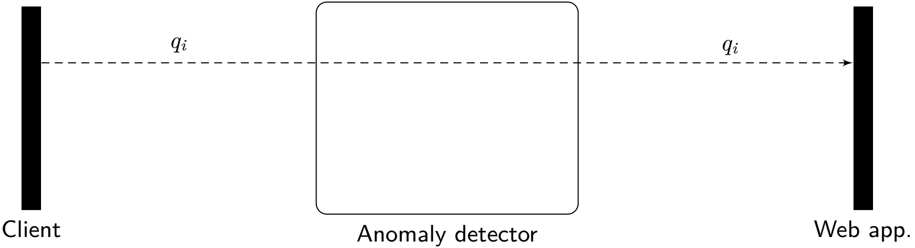

for each request q_i

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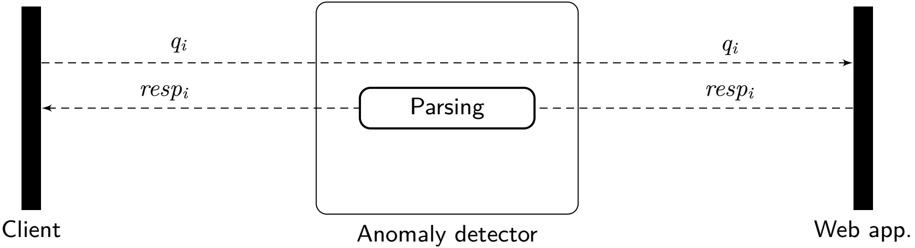

for each request q_i

intercept the corresponding response $resp_i$

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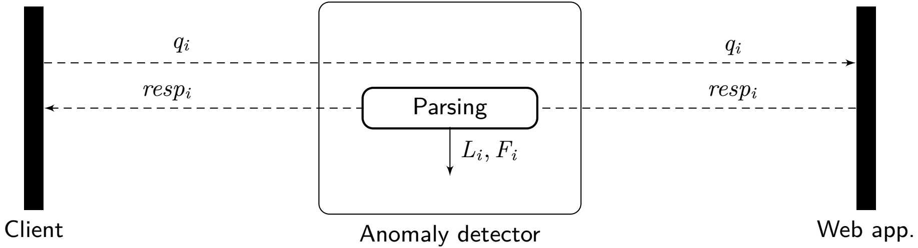
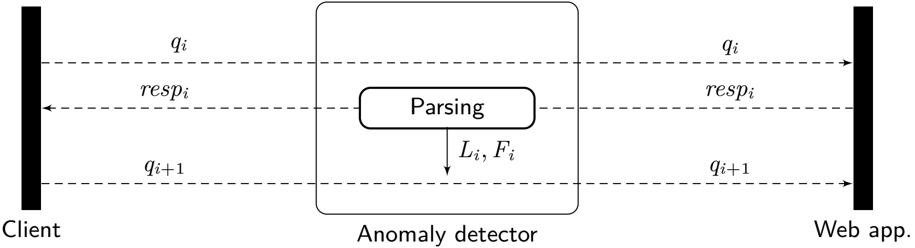


for each request q_i

intercept the corresponding response $resp_i$

extract parmeters and values from links, forms, fields

Parsing HTTP responses to update models



for each request q_i

- intercept the corresponding response $resp_i$
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at next request q_{i+1}

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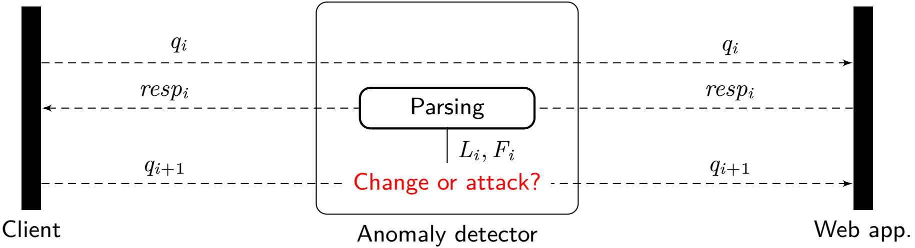
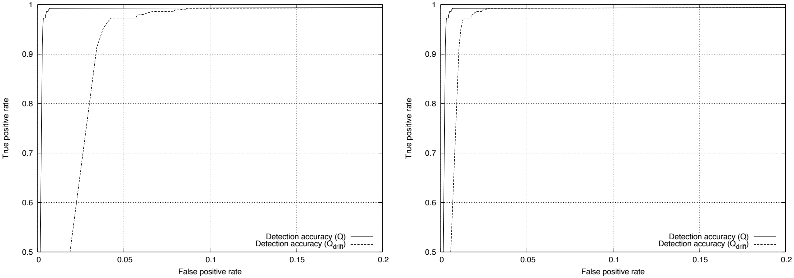


for each request q_i

- intercept the corresponding response $resp_i$
- extract parmeters and values from links, forms, fields

at next request q_{i+1}

- compare parameter and values to spot legit changes



(a) Response modeling disabled. (b) Response modeling enabled.

Tested on 823 web applications, 58,732,624 HTTP requests, 1000 attacks. RAID 2009 [6] (w/ UC Santa Barbara).

Training with almost no data

Some pages are infrequently accessed

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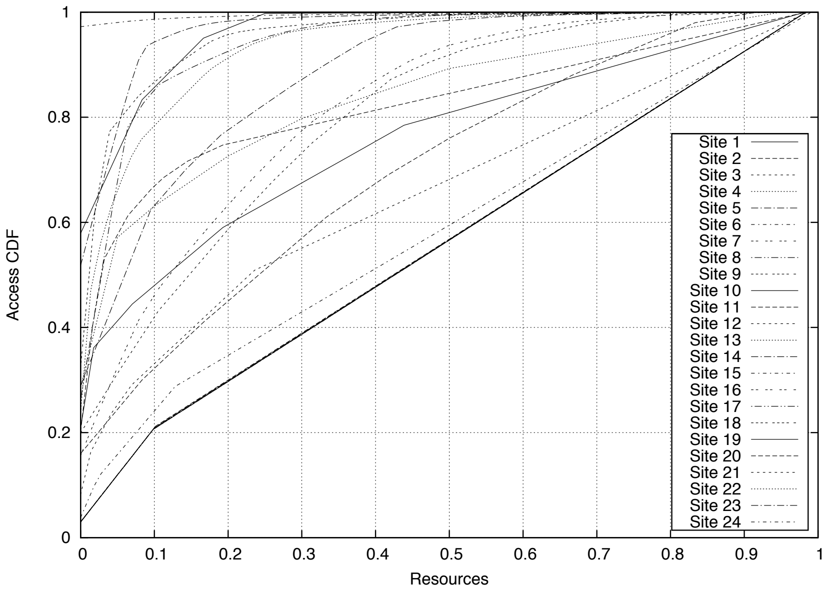
- rank models according to their completeness,
- substitute a poorly-trained model with a similar one, but well-trained.


Access CDF
Resources
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Site 7
Site 8
Site 9
Site 10
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Site 12
Site 13
Site 14
Site 15
Site 16
Site 17
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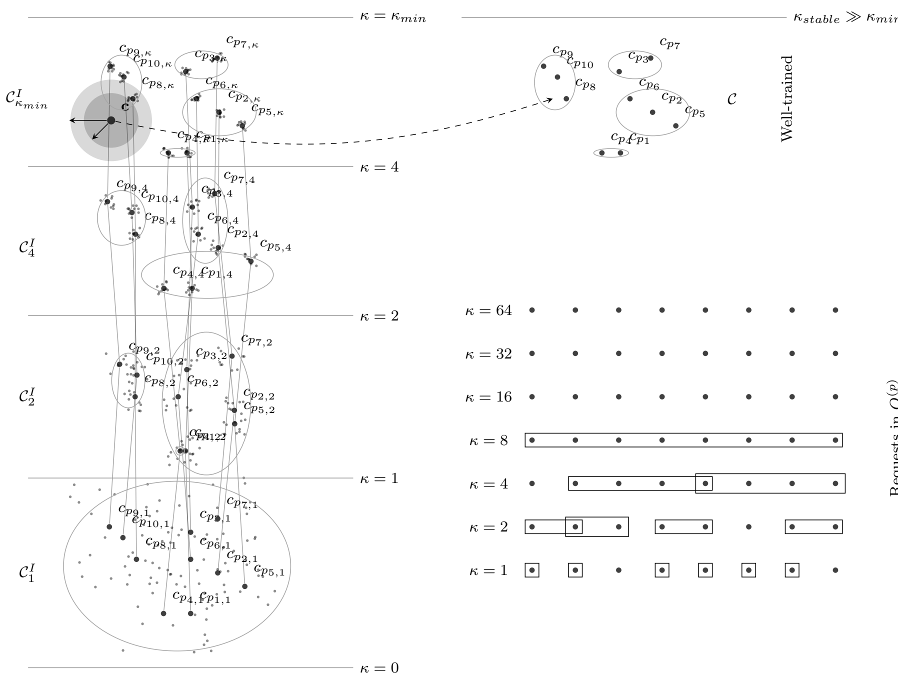
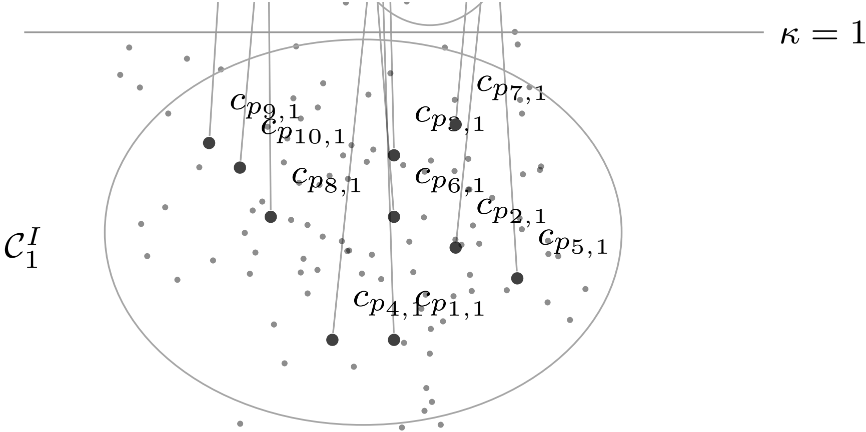
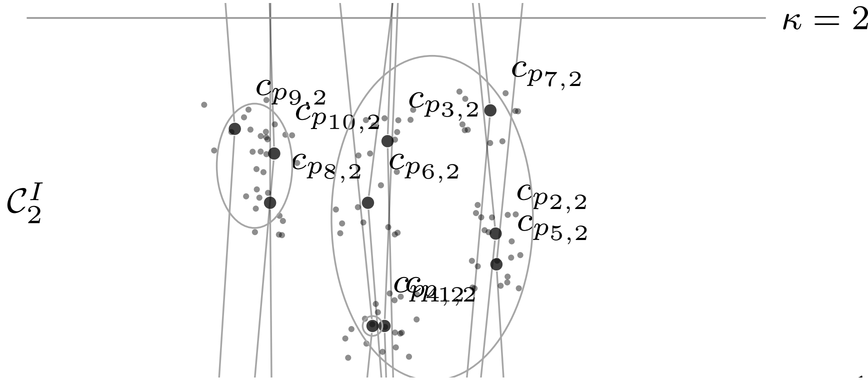
Site 19
Site 20
Site 21
Site 22
Site 23
Site 24

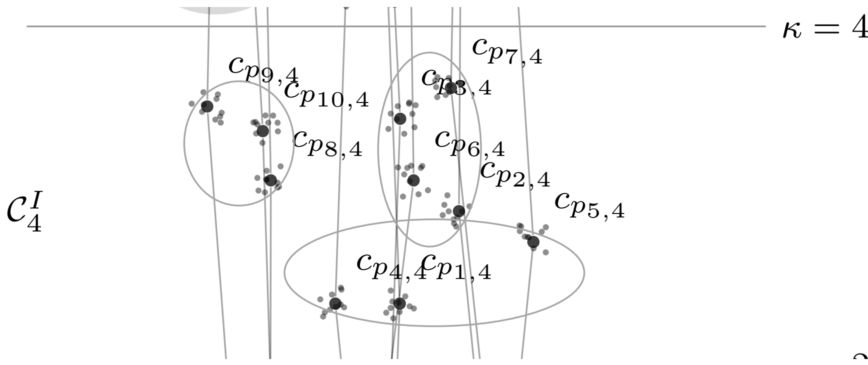


(a) (b)

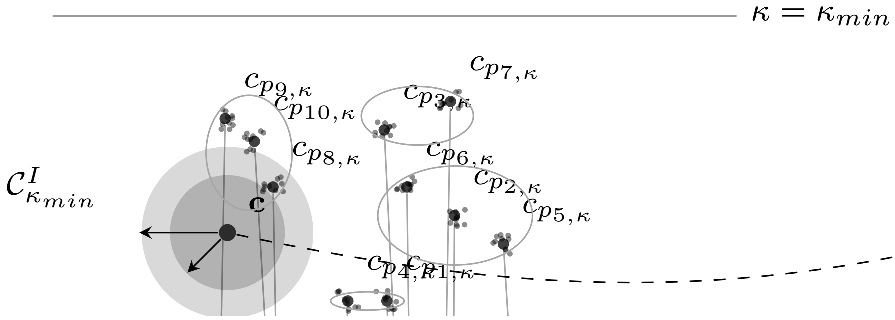


$\kappa = 1$
$c_{p_{9,1}}$
$c_{p_{10,1}}$
$c_{p_{7,1}}$
$c_{p_{3,1}}$
$c_{p_{8,1}}$
$c_{p_{6,1}}$
$c_{p_{2,1}}$
$c_{p_{5,1}}$
$\mathcal{C}_1^I$
$c_{p_{4,1}}$
$c_{p_{1,1}}$

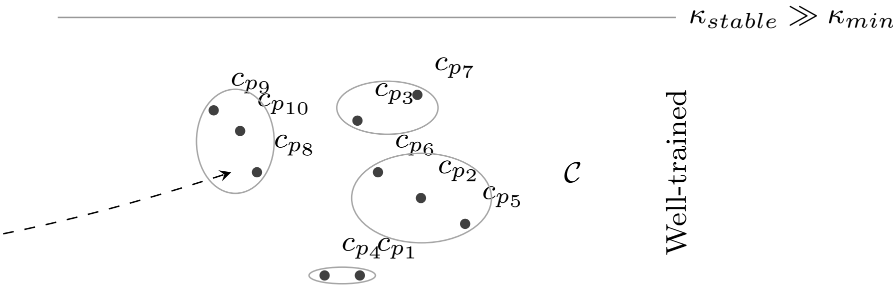

$\kappa = 2$
$\mathcal{C}_2^I$
$c_{p_{7,2}}$
$c_{p_{9,2}}$
$c_{p_{3,2}}$
$c_{p_{10,2}}$
$c_{p_{8,2}}$
$c_{p_{6,2}}$
$c_{p_{2,2}}$
$c_{p_{5,2}}$

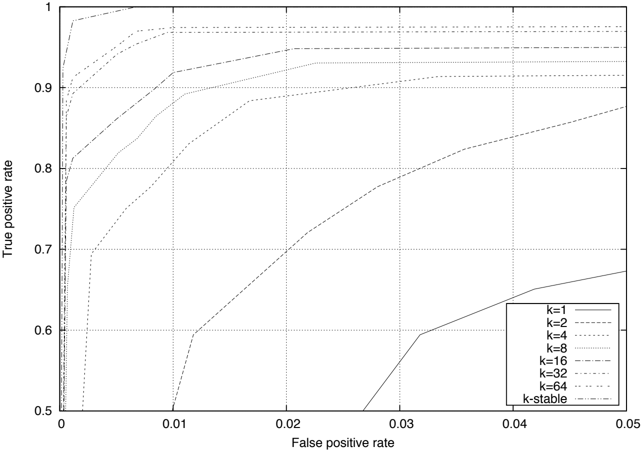


$\kappa = 4$
$c_{p_7,4}$
$c_{p_9,4}$
$c_{p_3,4}$
$c_{p_{10},4}$
$c_{p_8,4}$
$c_{p_6,4}$
$c_{p_2,4}$
$c_{p_5,4}$
$\mathcal{C}_4^I$
$c_{p_4,4}$
$c_{p_1,4}$



$\kappa = \kappa_{min}$
$c_{p_{7,\kappa}}$
$c_{p_{9,\kappa}}$
$c_{p_{10,\kappa}}$
$c_{p_{3,\kappa}}$
$c_{p_{8,\kappa}}$
$c_{p_{6,\kappa}}$
$\mathcal{C}^I_{\kappa_{min}}$
$c_{p_{2,\kappa}}$
$\mathbf{c}$
$c_{p_{5,\kappa}}$
$c_{p_{4,\kappa}}$
$c_{p_{1,\kappa}}$


$\kappa_{stable} \gg \kappa_{min}$
c_{p_7}
c_{p_9}
c_{p_3}
$c_{p_{10}}$
c_{p_8}
c_{p_6}
c_{p_2}
$\mathcal{C}$
c_{p_5}
c_{p_4}
c_{p_1}
Well-trained



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2. Operating system processes

Protecting the operating system

How to model a process' activity?

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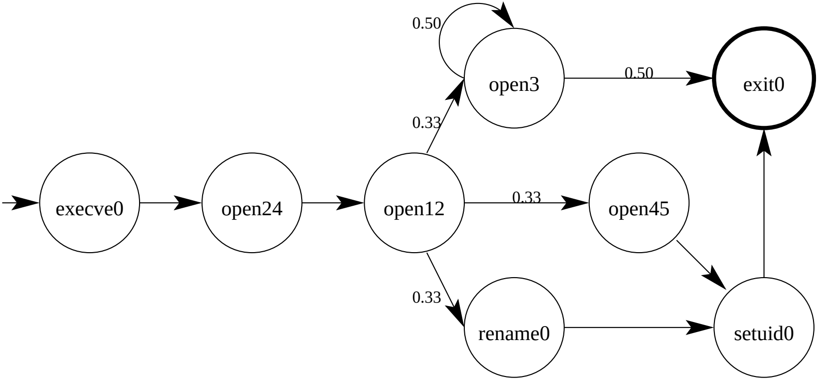
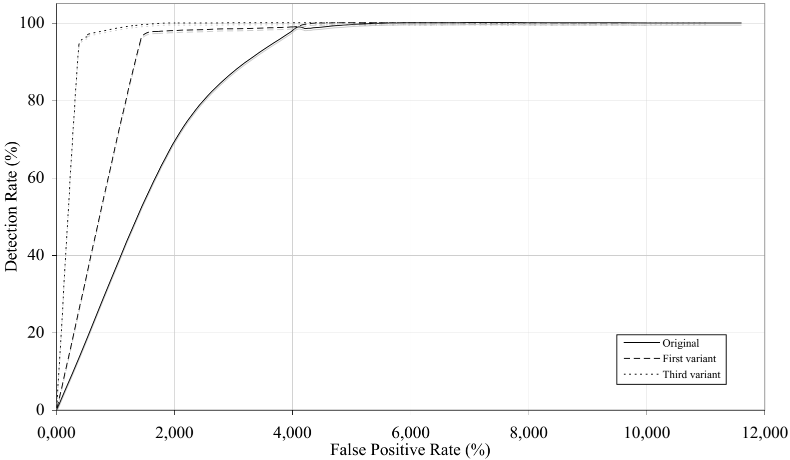
- group similar calls to make the problem feasible,
- encode the sequence of classes of calls as a Markov chain,
- deviant process $\rightarrow$ malicious process.

Example of model



Overall detection capabilities



Tested on one week of kernel activity (about 100,000 syscalls/day), 142 attacks. IEEE Transaction on Dep. and Secure Systems [4], ACM SIGOPS' O.S. Reviews [8].

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Tested on one day of kernel activity (about 145,000 syscalls), 5 attacks. DIMVA 2009 [3].

3. Combination of the two

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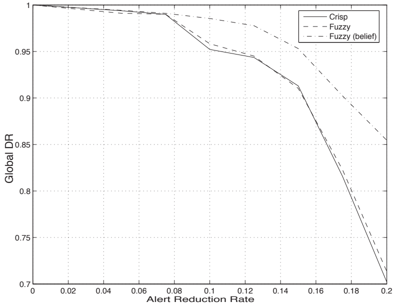
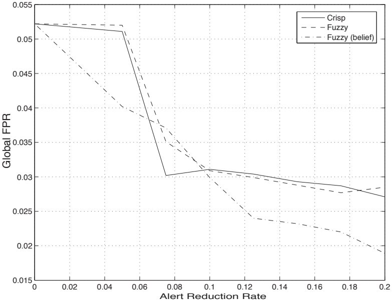
Tested on about two weeks of detection resulting in about 2,000 alerts overall. Information Fusion, Elsevier [5].

Overall detection capabilities





Detecting related alerts

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Malicious network behavior is reflected onto malicious kernel behavior.

How to detect relationships?

- model alerts as stochastic processes,
- use statistical hypothesis tests (e.g., KS' goodness of fit),
- matching series $\rightarrow$ related alerts.

Tested on about two weeks of detection resulting in about 1,000 alerts per system. RAID 2007 [7].

Conclusions and lesson learned during my PhD

- some of our systems require refactoring because performance was not our primary focus,
- the most difficult task ever, in our research area, is gathering **enough experimental data**,
- often, scientifically sound experiments are very difficult to prepare because data is also non-labeled,
- in our future research we really want to spend a considerable amount of time and efforts at designing **public data collection infrastructure**.

Obligatory Slide

Thanks!
Questions?

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