An application of Machine Learning to Intrusion Detection and Prevention in Web Applications

Event:Ruhrgebiet AI & Data Science Meetup
Author: Djibrilla Amadou Kountche
Email: djibrilla.amadoukountche@gmail.com

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Agenda

Data, Data, Data

Intrusion detection in Web applications

IDPS Detection Method: Behavioral Intrusion detection

RoCaWeb

Conclusion

Reading list

DATA (as in a Datalake)

Data, Data, Data

Suppose, as a Data scientist you have been given:

- Logs from web servers
- Logs from developpers (functional tests logs)
- Logs from applications
- Packet captures from your Network admin (or maybe NSA and BND)

And you are asked to get usefull information from these data for intrusion detection and prevention in web applications.

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Author: Djibrilla Amadou Kountche
Email: djib-rilla.amadoukountch

Web application

Our first problem will be a definition problem. What is a Web application ?

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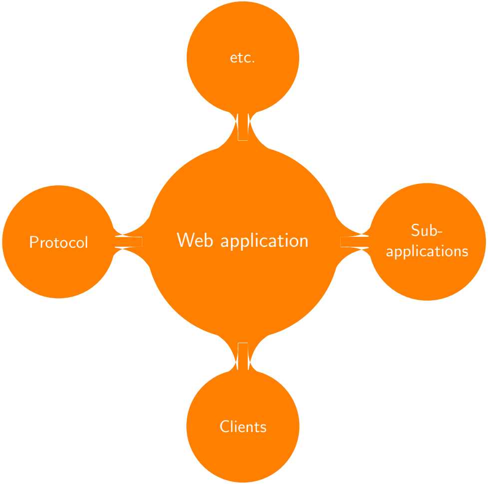

Figure: An attempt to represent a web application

Clients

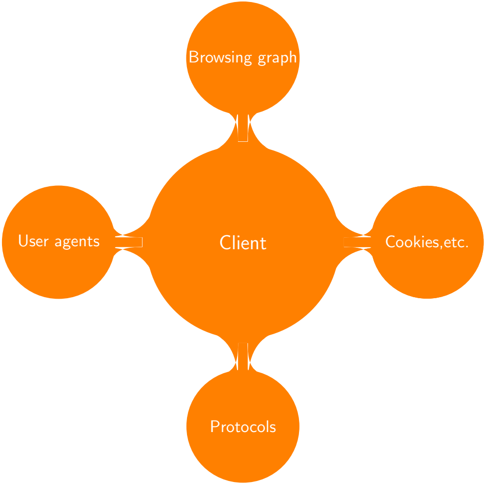

Figure: An example of client model

HTTP protocol

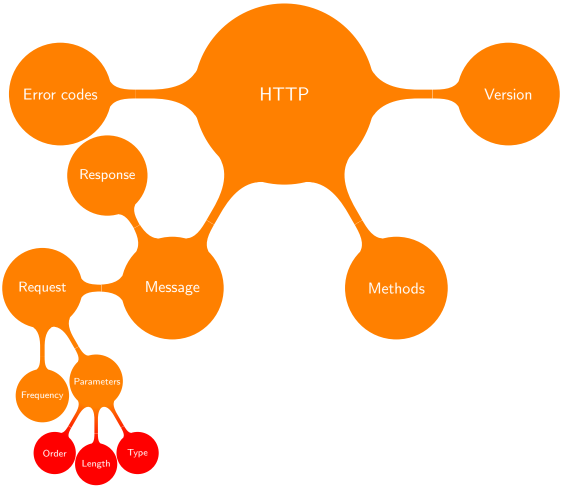

Figure: Data obtained from the HTTP protocol

Message

```
generic-message = start-line
                  *message-header
                  CRLF
                  [ message-body ]

start-line      = Request-Line | Status-Line
```


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Request

```
POST / HTTP/1.1
Host: meinesite.de

/path/code?param1=value1&param2=value2
```

Response

```
HTTP/1.1 200 OK

...
(trocated)
```


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Parameters

Consider captured values from a POST Request

$/\text{path}/\text{code}?param_1 = value_{11} \& param2 = value_{21}$
$/\text{path}/\text{code}?param_1 = value_{12}$

$$\ldots$$

$/\text{path}/\text{code}?param_1 = value_{1n} \& param_2 = value_{2n}$
Example

The problem

Web intrusion: Origin of the problem

How many of you follows Secure Development Life cycles ?

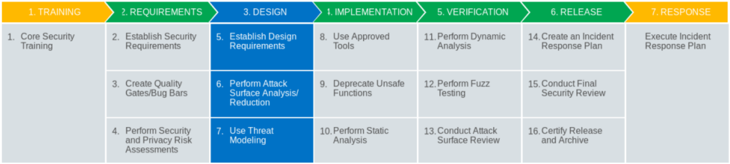

Figure: Microsoft SDL. Source

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Web intrusion: Origin of the problem

Complex Web applications ?

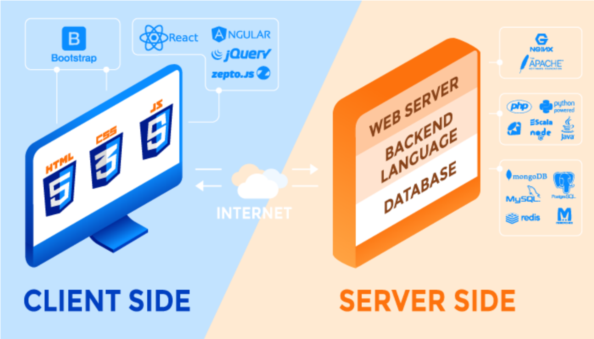

Figure: Example of the diversity of web technologies. Source

Web intrusion: Origin of the problem

An attacker has many opportunities...

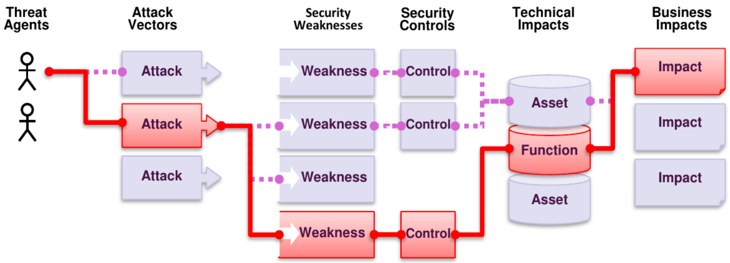

Figure: An attacker only needs the weakest link. Source

Web intrusion: Origin of the problem

An attacker only needs the weakest point.

Figure: An attacker only needs the weakest link.

How to solve the problem

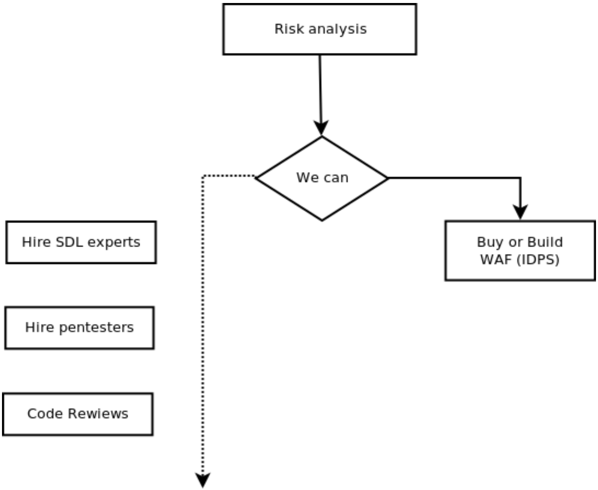

Figure: An approach to solve the problem

A solution ?

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What is an IDPS ?

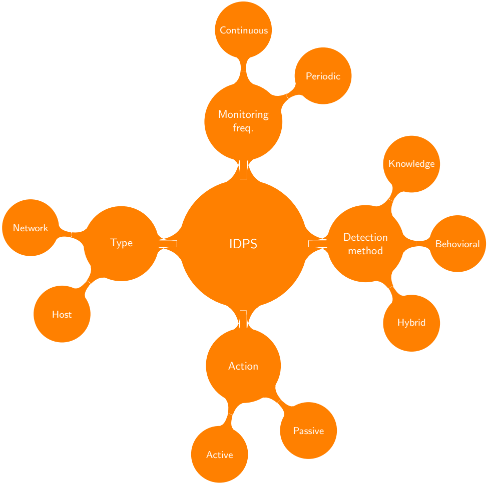

Figure: Components and different types of IDPS

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Email: djib-rilla.amadoukountch

IDPS Detection Method: Knowledge-based

Figure: Knownledge-based intrusion detection. Source

IDPS Detection Method: Knowledge-based

Issues with the oracle:

- Frequency of updates of the databases
- Polymorphic malicious programs
- *Zeroday* attacks

Behavioral Intrusion detection

Figure: Is something abnormal with Mr. Zuckerberg ? Source

Behavioral Intrusion detection

Issues with the normal behavior:

- Is it really possible to model (cover) the behavior ?
- What about new behaviors (new trends) ?
- False positive rate

Algorithmic approaches used for Behavioral Intrusion detection

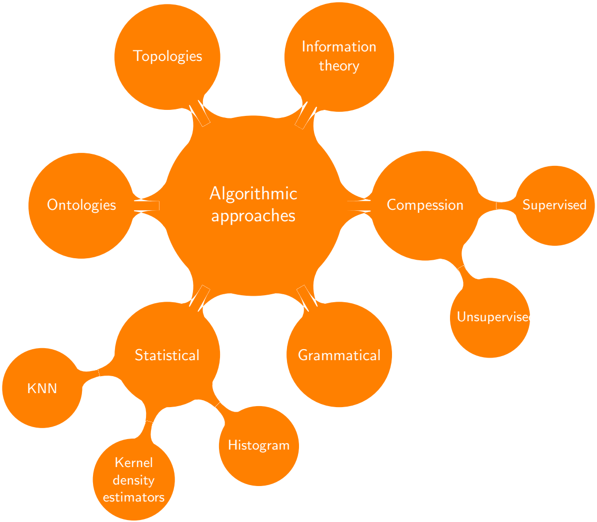

Figure: Algorithmic approaches

What we consider as Learning

Imporant remark

Learning is the process where we build a model representing the normal behavior of the application.

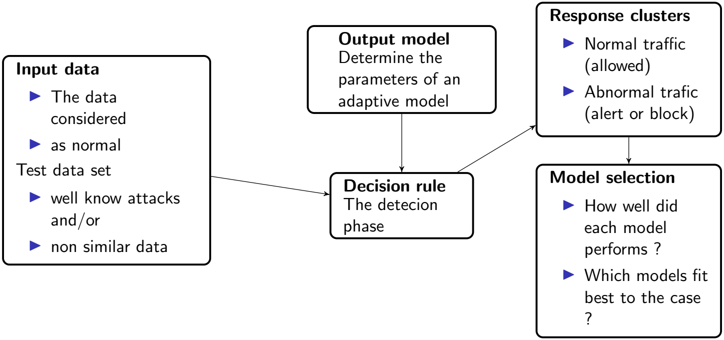

Figure: The overall view of the learning phase

How well are we learning

Performance measures

- Classification error rate
- False positive rate
- False negative rate
- Execution time

	True class	
	Normal	Abnormal
Normal	TP	FP
Abnormal	FN	TN

Librairies

Environment for DeveLoping KDD-Applications Supported by Index-Structures

ELKI

The most interesting libraries for anomaly detection

- Implemented in Java
- License GPLv3
- Anomaly detection algorithms:
  - Distance-based
  - Local factor family
  - Angle-based
  - clustering based
  - etc.

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Librairies

Lingpipe

- Implemented in Java
- Free and Paid License
- Anomaly detection algorithms:
  - General machine learning algorithms
  - Sentiment analysis algorithms (LDA)

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Librairies

Torch

- Implemented in LuaJIT C, C++
- BSD license
- GPU support
- Anomaly detection algorithms:
  - Statistical libraries such as cephes
  - General purpose machine learning algorithms
- Integration in Modsecurity

Author: Djibrilla Amadou Kountche
Email: djib-rilla.amadoukountch

RoCaWeb

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Author: Djibrilla Amadou Kountche
Email: djib-rilla.amadoukountche

RoCaWeb

About

- A research project funded by a RAPID grant
- Aimed building a WAF using Behavioral mehtods
- Implemented in Java, Lua, Scala
- Open source GPLv3 licence
- https://github.com/dakountche/RoCaWeb

RoCaWeb: Architecture

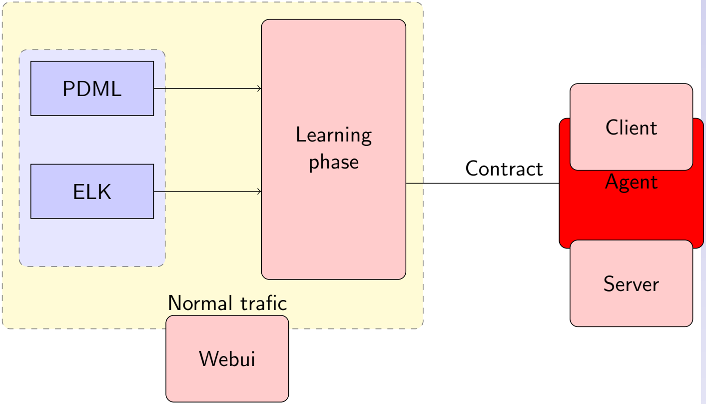

Figure: The RoCaWeb Architecture

RoCaWeb: Learning algorithms

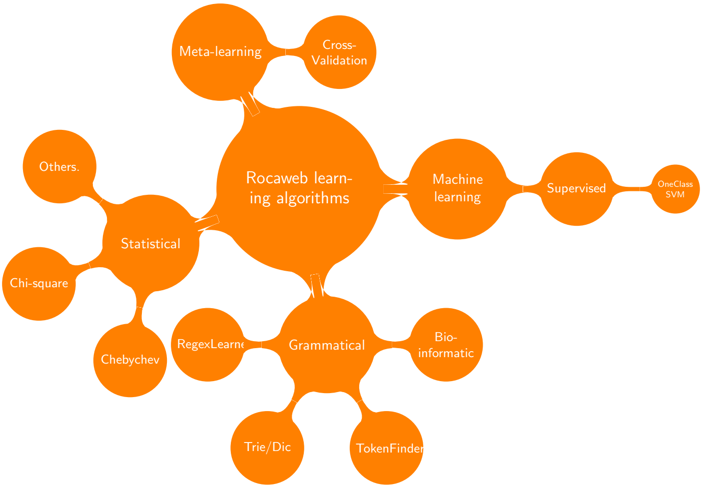

Figure: Learning algorithms considered for RoCaWeb

Grammatical inference

Definition

Let:

- Σ be a finite alphabet of symbols
- Σ^* be the set of all finite strings of symbols from Σ
- *langage* be any sub-set of Σ^*

The learning problem

Given:

- a *langage* L define over Σ
- a sequential or structured data (strings, words) drown form L

Determine the automata or a grammar of L.

Output model

A grammar explaning the data (See the Chomsky Hierarchy)

Grammatical inference: Example

Example

- $A = [a - zA - Z0 - 9]$
- L is a langage define over A
- Observed set: Ich, esse, gern, in, Essen

Infer the grammar of this langage
Is “J’aime manger à Essen” normal given this langage ?

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Grammatical inference: RegexLearner

Learning phase

Given:

- S: a set of strings
- R set of Regular expressions
- Find r, the most appropriate regex describing S

Detection phase

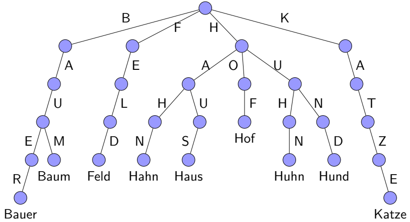
Given a string s:

- s is normal if it validates r
- abnormal otherwire

Grammatical inference: Trie structure

Learning phase

- Given S a set of strings
- Build a trie



Detection phase

Given a string s:

- s is normal if it is in the Trie
- abnormal otherwire

Grammatical inference: Sequence alignment

Origin

- Bio-informatics: computational approach to molecular biology.

Usage

Where given:

- An alphabet: $\alpha = \{A, G, T, C\}$
- And a langage S define on α
- The goal is to compare the sequences from S:
- Aligning these sequences can allow to:
  - Compare species

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Grammatical inference: Sequence alignment

Origin

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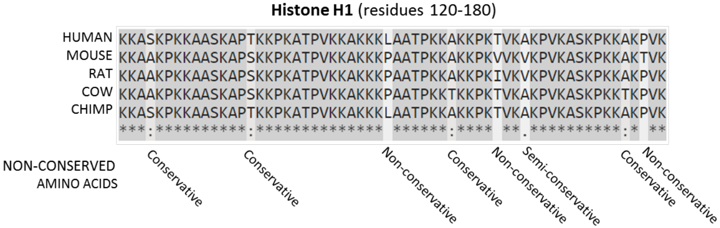

Figure: Example of sequece alginment (From Wikipedia)

Grammatical inference: Sequence Alignment

Definition : Pair alignment

Given:

- $s = s_1 \ldots s_n$ and $t = t_1 \ldots t_m$ two strings defined on an alphabet Σ
- β the gap character, $\beta \ni \Sigma$
- $\Sigma' = \Sigma \cup \beta$

Summarizing alignment

- Insertion : the gap characters in the first string;
- Deletion : the gap character in the second string;
- Match or correspondence: the 2 characters are identical
- Mismatch : the two characters are different from each other and gap

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Grammatical inference:Example of Pair Alignment

`Andreas Wulfes`	`andreas wulfes`
`An--ja--------`	`an--ja--------`
`Andreas Wulfes`	`andreas wulfes`
`Annika- ----S.`	`annika- ----s.`
`Andreas Wulfes`	`andreas wulfes`
`-----a----rne-`	`a--r-------ne-`
`Andreas Wulfes`	`andreas wulfes`
`-Bernd Bäumler`	`-bernd bäumler`
`Andreas Wulfes`	`andreas wulfes`
`-Chr--------is`	`-chr--------is`
`-Andreas Wulfes`	`-andreas wulfes`
`Christine Gangl`	`christine gangl`
`Andreas Wulfes`	`andreas wulfes`
`----Con ---Con`	`----con ---con`

Pair alignment: Approaches

Dynamic programming

- Exact solution: Dynamic programming approach
- BLAST

Dynamic programming: Score matrix

- The first column and the first row are filled with $(j \times penalty)$ and $(i \times penalty)$
- Any other cell is filled with :

$$M(i,j) \quad = \quad \max \begin{cases} M(i-1,j) + penalty & \text{(i)} \\ M(i,j-1) + penalty & \text{(d)} \\ M(i-1,j-1) + d(s_i, t_j) & \text{(m)} \end{cases} \tag{1}$$

Grammatical inference: Sequence alignment

Definition : Score

$$\delta(s', t') = \sum_{i=1}^{l} d(s'_i, t'_i) \quad (2)$$

$$d(s'_i, t'_i) = \begin{cases} \text{match} & \text{if } s'_i, t'_i \in \Sigma \text{ and } s'_i = t'_j \\ \text{mismatch} & \text{if } s'_i, t'_j \in \Sigma \text{ and } s'_i \neq t'_j \\ \text{penalty} & \text{if } s'_i \text{ or } t'_j \text{ equals } \beta \end{cases} \quad (3)$$

Grammatical inference: Multiple sequence alignment

Multiple sequence alignment

Given:

- n sequences $s_1, \ldots, s_n$ defined on an alphabet Σ having different lengths
- β is the gap character

A multiple alignment of $s_1, \ldots, s_n$ is an $n - uplet(s'_1, \ldots, s'_n)$ of length $l \geq |s_i|, i \in [1 \ldots n]$ on the alphabet Σ' where the following conditions hold :

1. $|s_i| = |s_j|, \bigvee i, j \in [1 \ldots n]$
2. $h(s'_i) = s_i, \bigvee, i \in [1 \ldots n]$
3. there is no row in the $(n \times l)$-matrix where there is only gap characters.

Grammatical inference: Multiple sequence alignment

Solution

- Exact computation (Difficult)
- Combining with pair alignment (Heuristic)

Algorithms

- UPGMA
- T-Coffee
- etc.

Grammatical inference: Example Multiple sequence alignment

Parameters

- Pair alignment algorithm : Needleman Wunsch
- Gap character : $+$, $match = 1.0$, $mismatch = 0.0$, $penalty = -1.0$

Learning Data Set

```
GARFIELD THE LAST FAT CAT
GARFIELD THE FAST CAT
GARFIELD THE VERY FAST CAT
THE FAST CAT
```

Table: The GARFIELD dataset.

Grammatical inference: Multiple sequence alignment

```
GARFIELD THE VERY FAST CAT
+++++++++THE+++++ FAST CAT
GARFIELD THE+++++ FAST CAT
GARFIELD THE LAST FA+T CAT
```

Learning the regular expression

Learning the regular expression

- Alignment does not generate regular expression;
- Sequences of same size;
- Learn the corresponding regular expression.

Result of AMAA																									
G	A	R	F	I	E	L	D		T	H	E		V	E	R	Y		F	A	S	T		C	A	T
+	+	+	+	+	+	+	+	+	T	H	E	+	+	+	+	+		F	A	S	T		C	A	T
G	A	R	F	I	E	L	D		T	H	E	+	+	+	+	+		F	A	S	T		C	A	T
G	A	R	F	I	E	L	D		T	H	E		L	A	S	T		F	A	+	T		C	A	T
[GARFIELD]{0,1}THE[LAST]{0,1} FA[S]{0,1}T CAT																									

Table: Generation of the regular expression for the GARFIELD dataset.

The Chebychev inequality applied to the length

Learning phase

Given:

- a parameter A of a request ;
- $A = \{a_i, i = 1...n\}$ values of this parameters are collected

Determine:

- μ : the sample mean of the lengths of a_i;
- σ : the variance ;

The Chebychev inequality applied to the length

The detection phase

Soient :

- a_k: the current value to test
- μ, σ : the mean and variance.

Variante :

$$p(|X-\mu| > |l-\mu|) < p(l) = \begin{cases} \frac{\sigma^2}{(l-\mu)^2} & \text{if l} \geq \mu \\ 1 & \text{otherwise} \end{cases} \tag{4}$$

l the current length. Return $p(l)$

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Character distribution

Learning phase

- Determine the reference character distribution

Given:

- $A = \{a_1, a_2, ..., a_n\}$;
- Σ an alphabet;
- a_i defined on Σ^*.

A character distribution is défined by :

$$CD = \{n_i, i = 1..k\} \tag{5}$$

Character distribution

Reference character distribution

- For each value of the parameter determine its CD
- $RCD = \{f_i = n_i/k, i = 1...k\}$ is the mean CD
- Where k is the size of the alphabet

Detection phase

Given:

- the CD a value and its length
- the RCD computed earlier

Determine the value of the χ^2 probability

RoCaWeb: Agent

Reserve proxy

- Apache configure as Reverse proxy for each website

Modsecurity

- Contract are formated in the Modsecurity format
- Validation for each method is implemented in Lua
- Modsecurity phases:
  1. Request header
  2. Request body
  3. Response Header
  4. Response body
  5. Logging

RoCaWeb: User interface

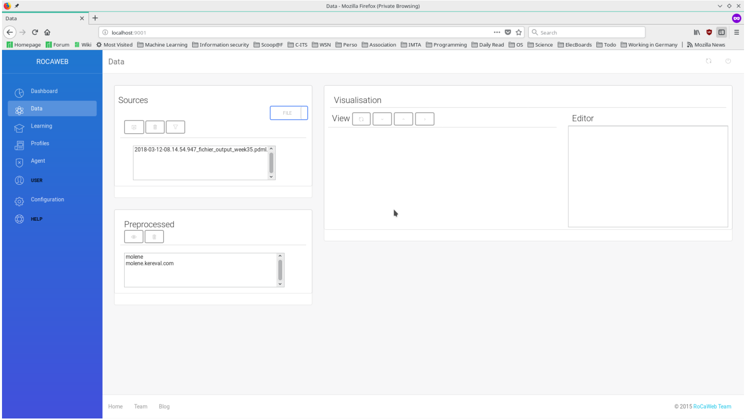

Figure: RoCaWeb User Interface

RoCaWeb: The docker platform

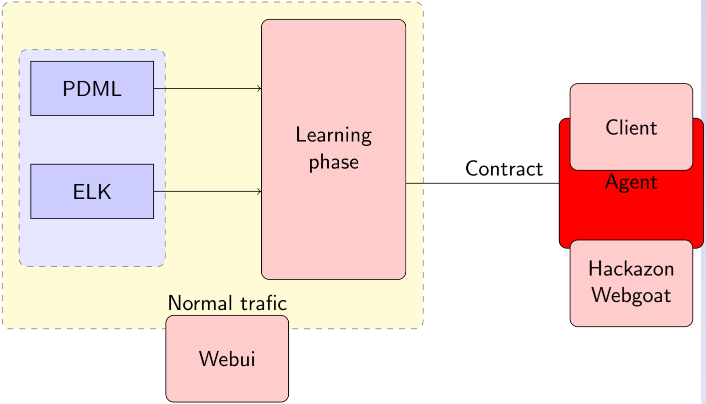

Figure: The RoCaWeb docker platform

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Email: djibrilla.amadoukountch

Similar projects

- Apache metron
- Vulture

Conclusion and perspectives

- Fondamental limitation of Behavioral based

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Email: djib-rilla.amadoukountche

Reading list I

Anamaly detection

- Anomaly detection: A survey, Varun Chandola

Grammatical inference

- A bibliographical study of grammatical inference, Colin de la Higuera

Fondament Limitation of Anomaly detection:

- http://all.net