Anomaly Detection with Extreme Value Theory

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April 26, 2017

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Context

General motivations

- Massive usage of the Internet

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  - More and more vulnerabilities

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How the Carbanak cybergang stole $1bn

A targeted attack on a bank

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- —○ Massive usage of the Internet
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1 Tbps DDoS Attack

Powered By 150,000 Hacked IoT Devices

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⇒ Network security :
a major concern

A Solution

- IDS (Intrusion Detection System)
    - Monitor traffic
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SNORT®

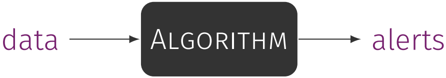
- Emerging methods : anomaly-based
  - Use the network data to estimate a normal behavior
  - Apply algorithms to detect abnormal events (→ attacks)

DARKTRACE

Reveelium
Smart predictive analytics

Overview

- Basic scheme



Overview

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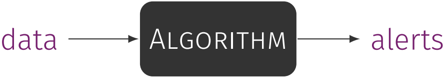

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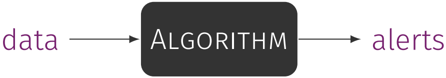
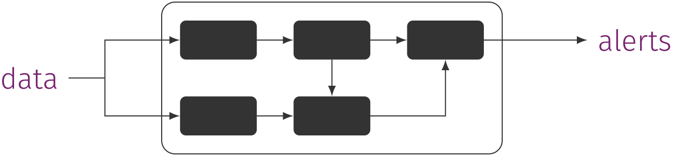


- Many ”standard” algorithms have been tested
- Complex pipelines are emerging (ensemble/hybrid techniques)



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- The thresholds are often hard-set
    - Expertise
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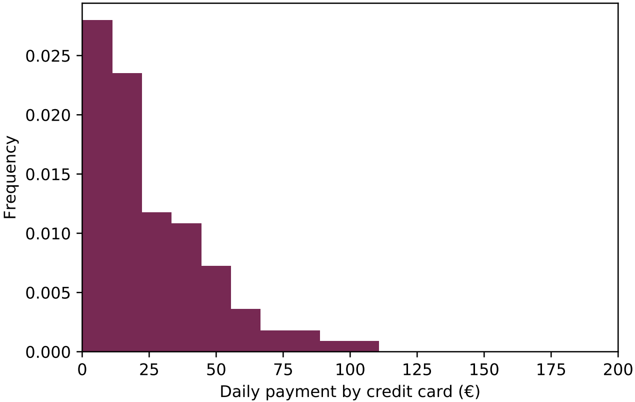
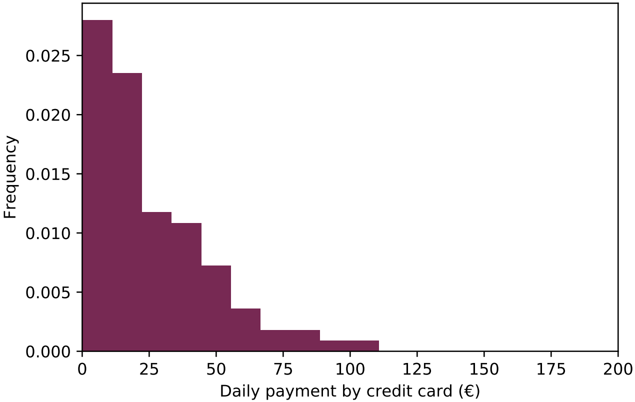
- **Our idea**: provide dynamic threshold with a probabilistic meaning

Providing better thresholds

My problem

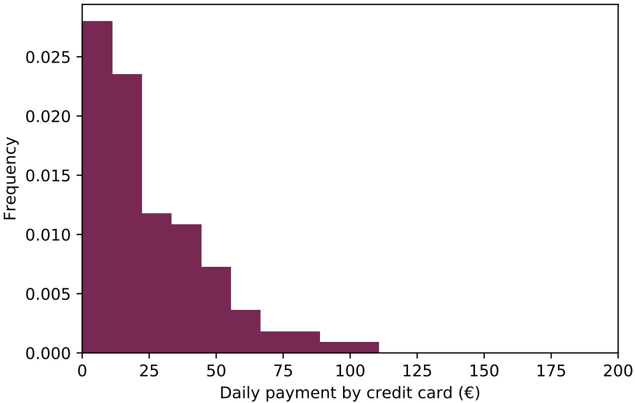

Frequency
0.000
0.005
0.010
0.015
0.020
0.025
0
25
50
75
100
125
150
175
200
Daily payment by credit card (€)

My problem



- How to set z_q such that $\mathbb{P}(X€ > z_q) < q$?

Solution 1: empirical approach



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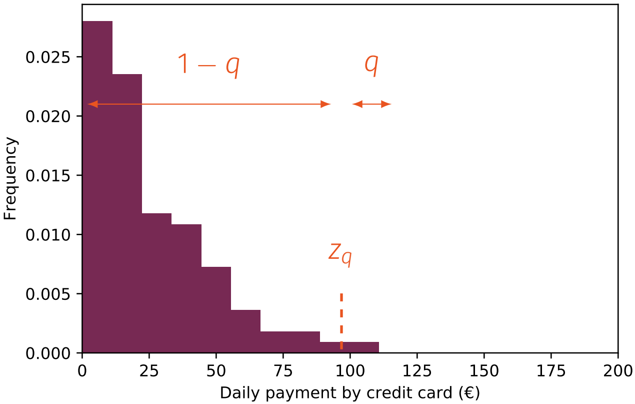

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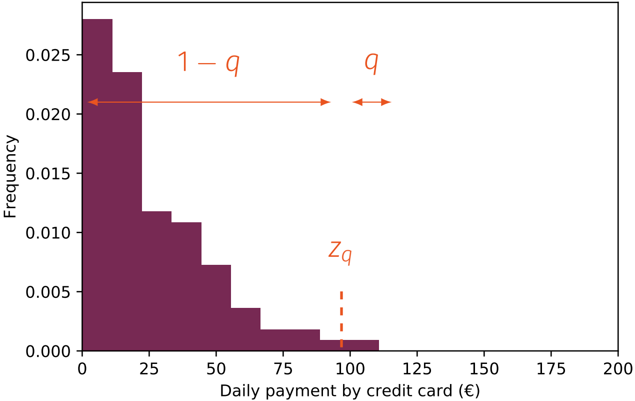
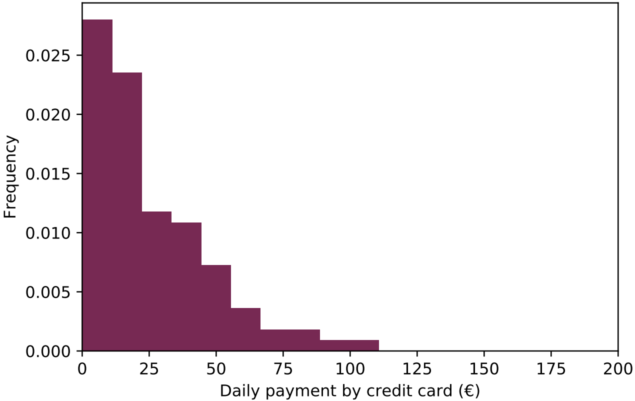


- Drawbacks: stuck in the interval, poor resolution

Solution 2: Standard Model



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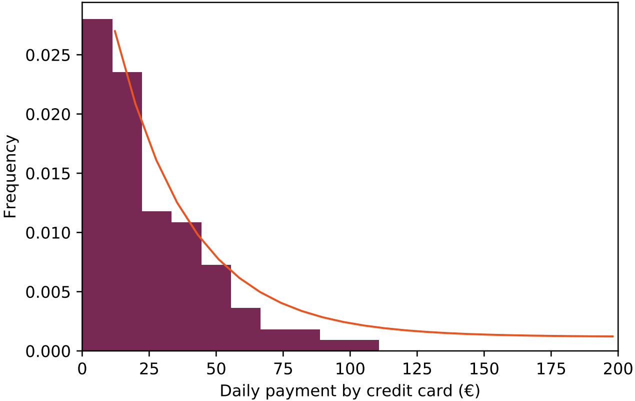

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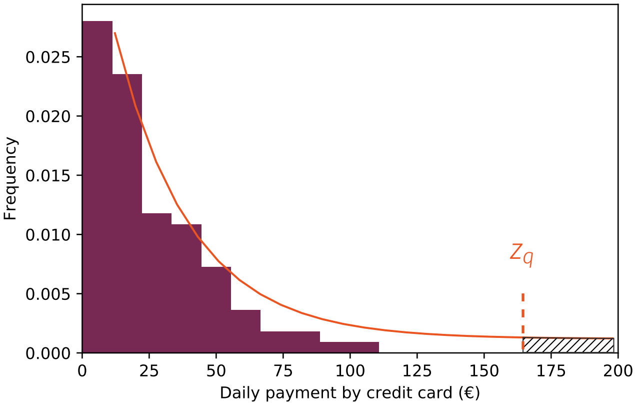

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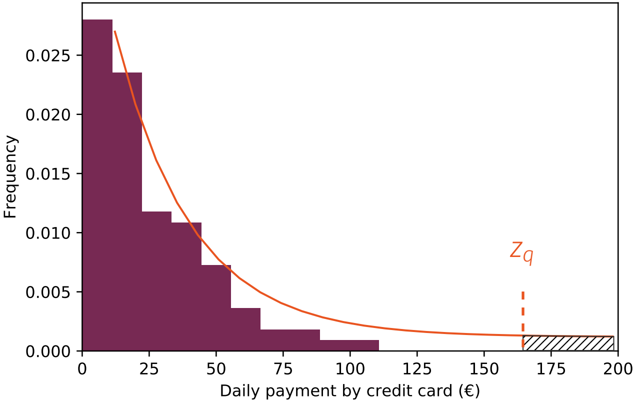
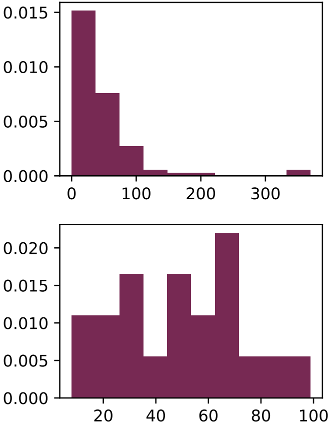


- Drawbacks: manual step, distribution assumption

Realities

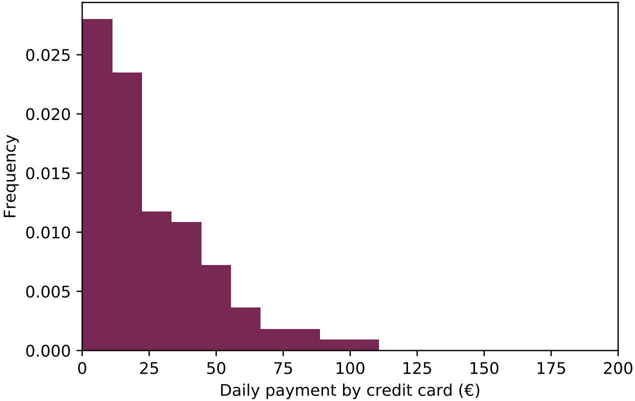


- Different clients and/or temporal drift

Results

Properties	**Empirical quantile**	**Standard model**
statistical guarantees	Yes	Yes
easy to adapt	Yes	No
high resolution	No	Yes

Inspection of extreme events



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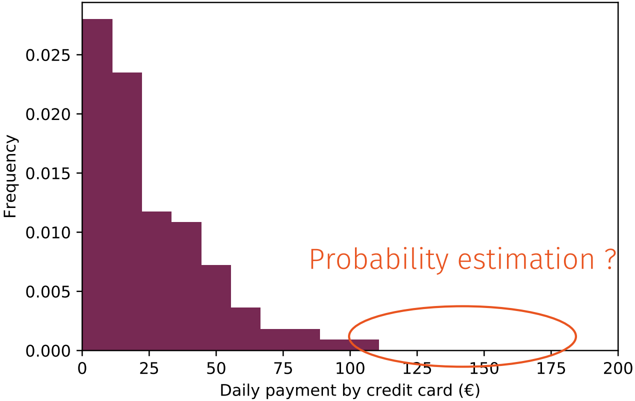

Probability estimation ?

Extreme Value Theory

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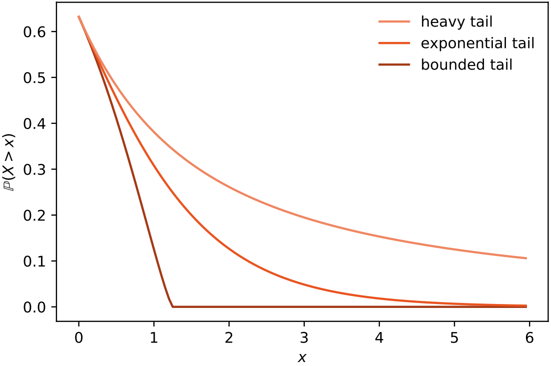

An impressive analogy

- Let $X_1, X_2, \ldots X_n$ a sequence of i.i.d. random variables with

$$S_n = \sum_{i=1}^{n} X_i \qquad M_n = \max_{1 \leq i \leq n}(X_i)$$

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- FTG Theorem

$$\frac{M_n - a_n}{b_n} \xrightarrow{d} \mathrm{EVD}(\gamma)$$

A more practical result

- Second theorem of EVT (Pickands-Balkema-de Haan, 1974)

  The excesses over a high threshold follow a Generalized Pareto Distribution (with parameters γ, σ)

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- What does it imply ?
  - we have a model for extreme events
  - we can compute z_q for q as small as desired

How to use EVT

- Get some data $X_1, X_2 \dots X_n$
- Set a high threshold t and retrieve the excesses $Y_j = X_{k_j} - t$ when $X_{k_j} > t$

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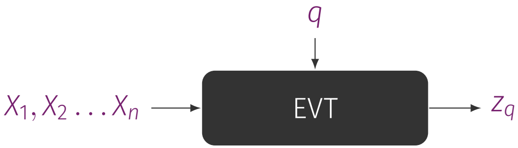

Finding anomalies in streams

Streaming Peaks-Over-Threshold (SPOT) algorithm

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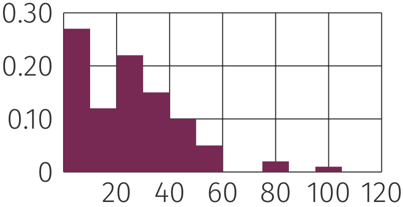
(initial batch)

$X_1, X_2 \ldots X_n$



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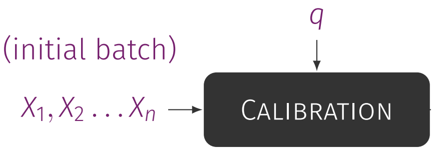

q

(initial batch)

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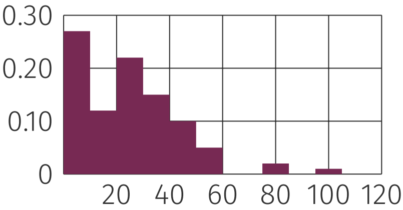
Calibration



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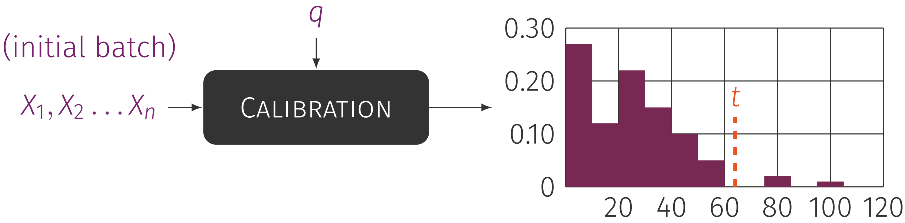

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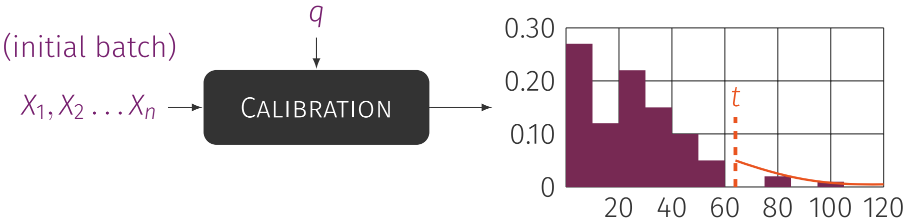

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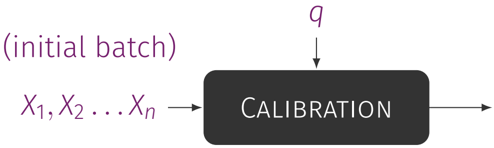

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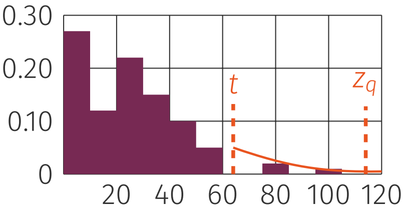

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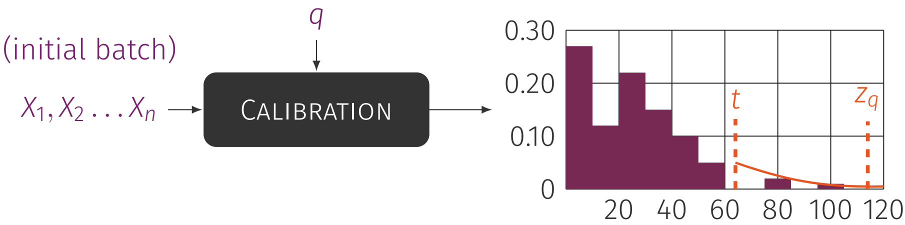

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(stream)

$X_{i>n}$

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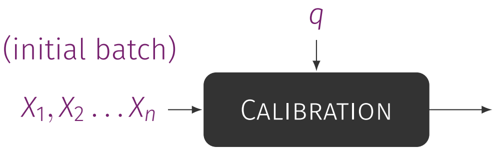

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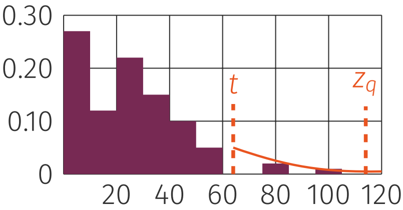

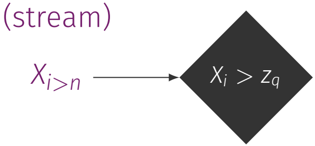

(stream)

$X_{i>n}$

$X_i > z_q$

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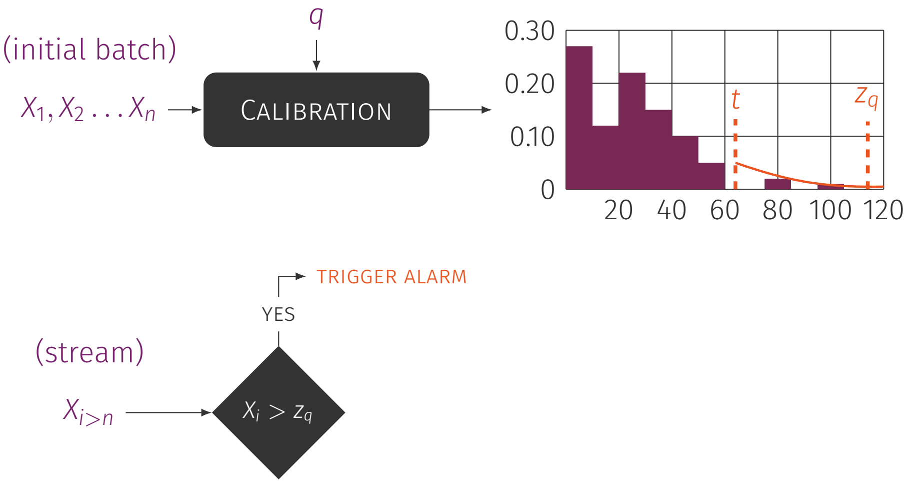

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TRIGGER ALARM

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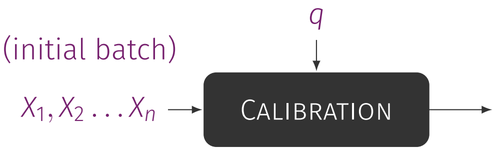

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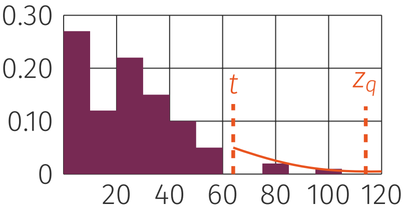

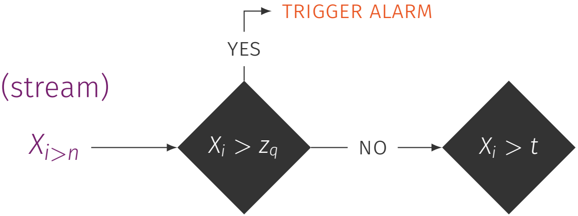

Trigger alarm

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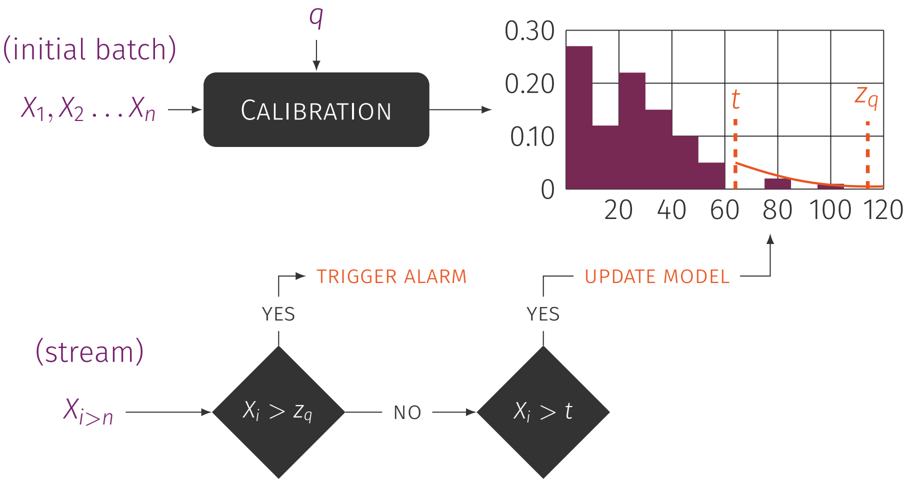

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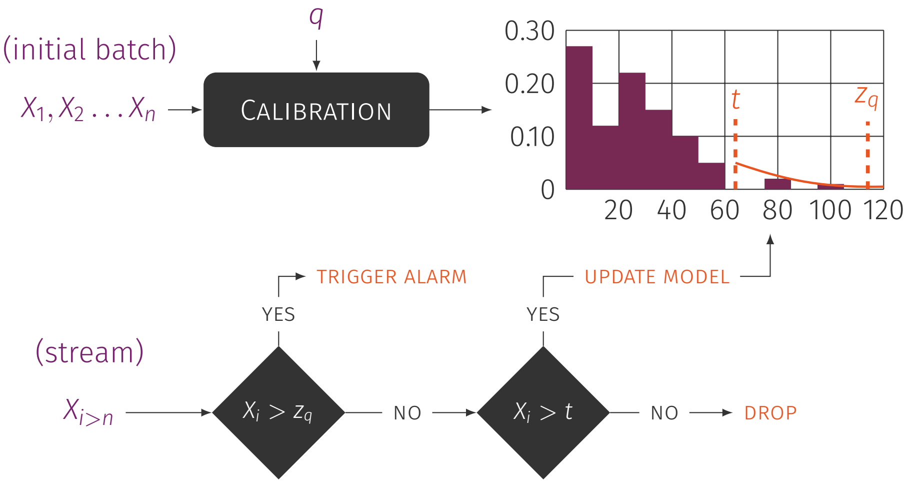

Can we trust that threshold z_q ?

- An example with ground truth : a Gaussian White Noise
  - 40 streams with 200 000 iid variables drawn from $\mathcal{N}(0, 1)$
  - $q = 10^{-3} \Rightarrow$ theoretical threshold $z_{th} \simeq 3.09$

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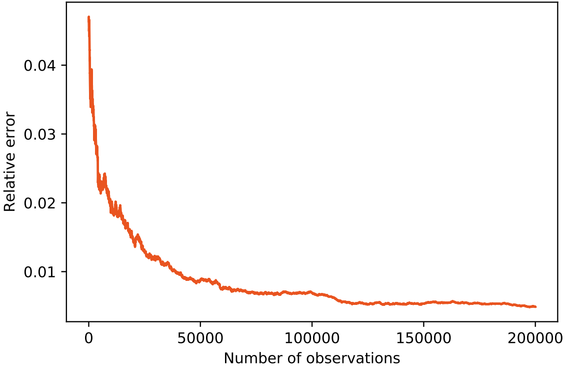
  - $q = 10^{-3} \Rightarrow$ theoretical threshold $z_{th} \simeq 3.09$
- Averaged relative error



Application to intrusion detection

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- Preprocessing step : raw .pcap → NetFlow format (only metadata)

An example to detect network syn scan

- The ratio of SYN packets : relevant feature to detect network scan [Fernandes & Owezarski 2009]

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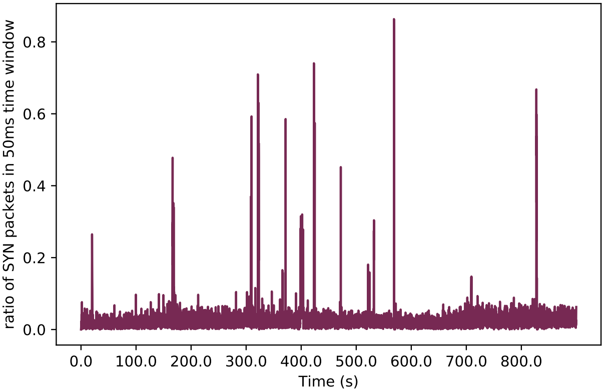

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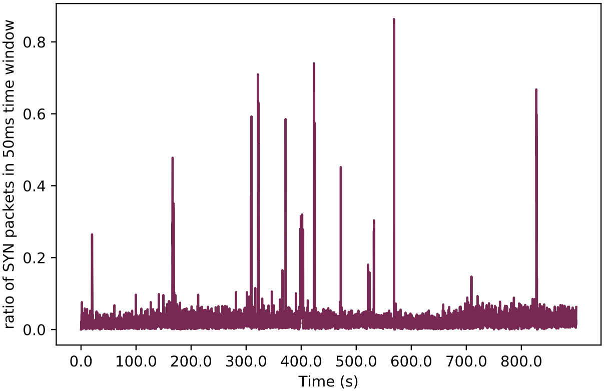

- Goal: find peaks

SPOT RESULTS

- Parameters : $q = 10^{-4}, n = 2000$ (from the previous day record)

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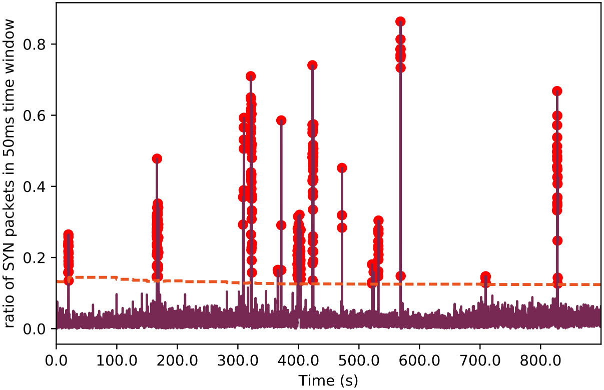

Do we really flag scan attacks ?

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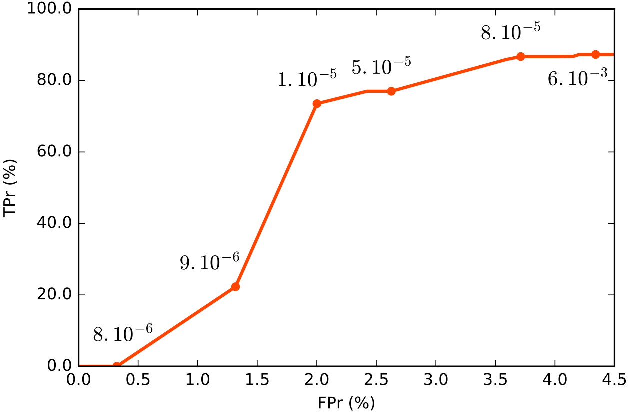
- The main parameter *q*: a False Positive regulator



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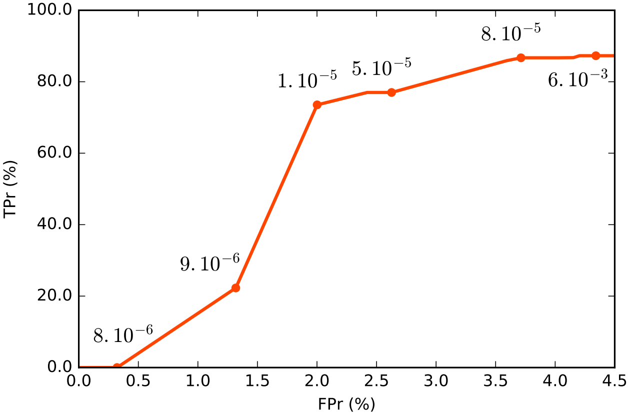

- 86% of scan flows detected with less than 4% of FP

A more general framework

SPOT Specifications

- A single main parameter q
  - With a probabilistic meaning → $\mathbb{P}(X > z_q) < q$
  - False Positive regulator

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- A single main parameter q
  - With a probabilistic meaning → $\mathbb{P}(X > z_q) < q$
  - False Positive regulator
- Stream capable
  - Incremental learning
  - Fast ($\sim$ 1000 values/s)
  - Low memory usage (only the excesses)

OTHER THINGS ?

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  - performs dynamic thresholding without distribution assumption
  - uses it to detect network anomalies

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  - other fields
  - drifting contexts (with an additional parameter) → DSPOT

A recent example

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- Thursday the 9th of February 2017

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  - **9h** : explosion at Flamanville nuclear plant
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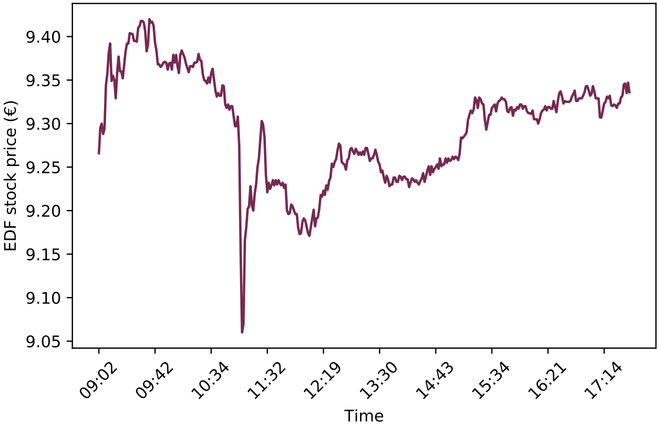
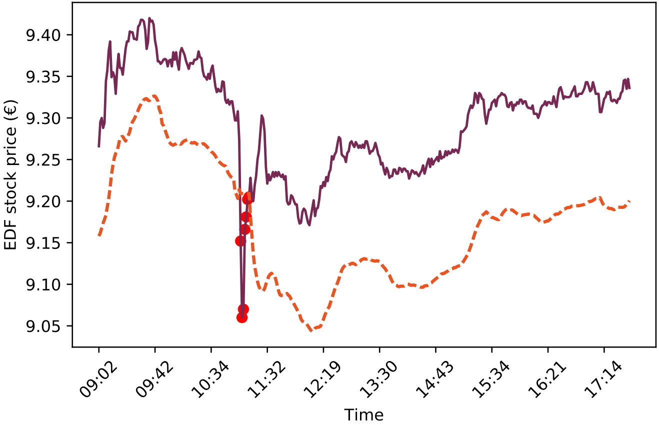
- What about the EDF stock prices ?

EDF stock prices



EDF STOCK PRICES



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- Future: Adapt the method to higher dimensions