CMPT 733
Anomaly Detection

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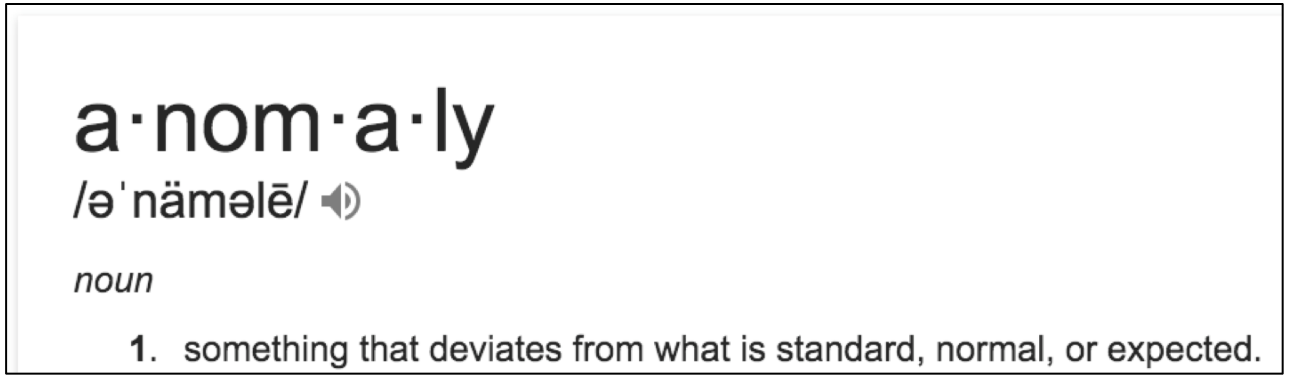
Outline

A Brief Introduction of Anomaly Detection

Application: Network Intrusion Detection

What is Anomaly Detection?

Definition from dictionary



a·nom·a·ly

/əˈnäməlē/ 🔊

noun

1. something that deviates from what is standard, normal, or expected.

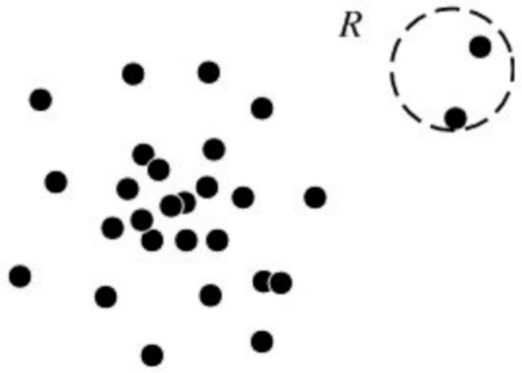
Anomaly!!

Also known as Outlier Detection

Anomaly Categories (I)

Global Anomaly

- A data point is considered anomalous with respect to the rest of data
- Example: There is a person whose age is 110

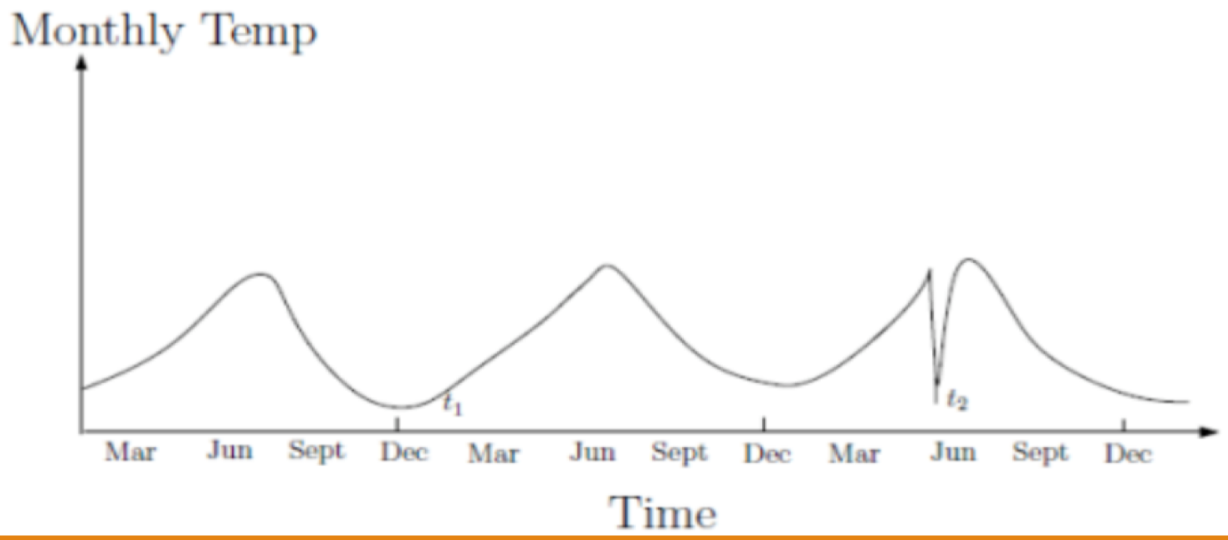


The objects in region *R* are outliers.

Anomaly Categories (II)

Context Anomaly

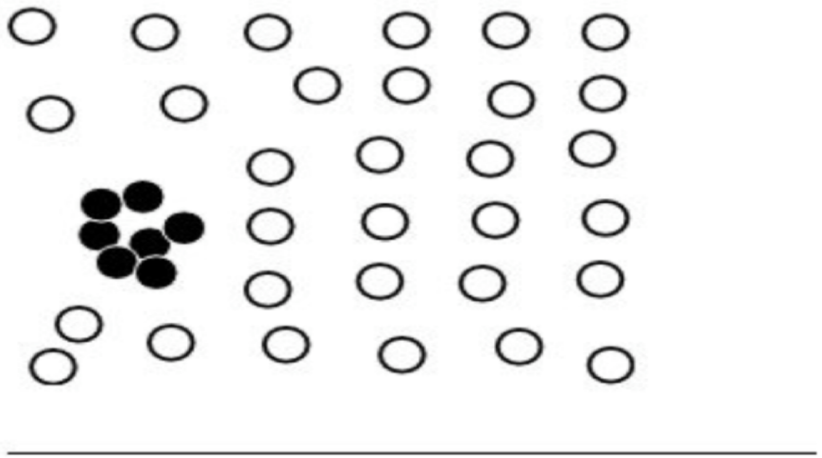
- A data point is considered anomalous with respect to a specific context
- Example: There is a person in our class whose age is 70.



Anomaly Categories (III)

Collective Anomaly

- A subset of data points as a whole deviates significantly from the entire dataset
- Example: An order may have some delay to be processed. But, what if 1000 orders are processed with delay?



The black objects form a collective outlier.

Real-world Applications

Fraud Detection

Medical Care

Public Safety and Security

Network Intrusion

Challenges

Modeling normal objects and anomalies effectively:

- Hard to enumerate all possible normal behaviors
- The border between normal objects and anomaly can be gray area

Application specific anomaly detection:

- Hard to develop general purpose anomaly detection tools

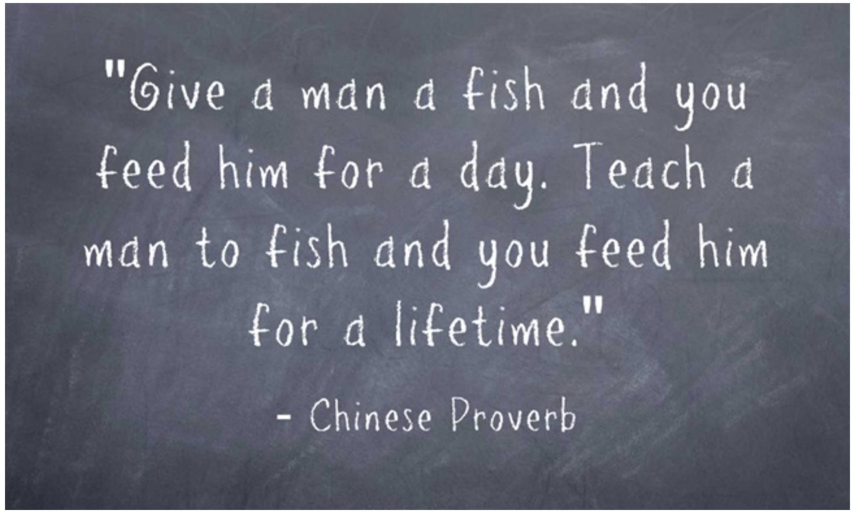
Understandability:

- Not only detect the anomalies, but also understand why they are anomalies

Outline

Recap of Anomaly Detection

Application: Network Intrusion Detection



"Give a man a fish and you feed him for a day. Teach a man to fish and you feed him for a lifetime."

- Chinese Proverb

Teach you a network-intrusion solution
vs.
Teach you how to come up with this solution

Network Intrusion

"Our web servers got attacked yesterday.
I don't want it happen again.
Please build a system to address it!"

TO DO Lists:

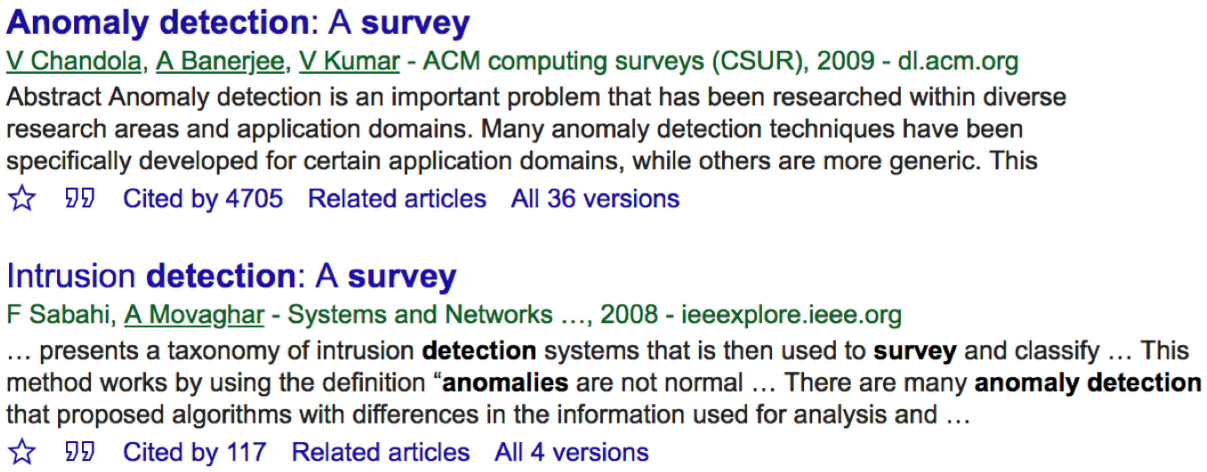
1. Finding related datasets (e.g., /var/log/apache2/access.log)
2. Figuring out how to detect attacks (anomalies) ⟵ **Key Problem**
3. Triggering an alert when an attack is detected (e.g., send an email)

How to come up with a solution?

1. Doing a survey on related work

Anomaly Detection Methods

Survey Paper



Anomaly detection: A **survey**

V Chandola, A Banerjee, V Kumar - ACM computing surveys (CSUR), 2009 - dl.acm.org

Abstract Anomaly detection is an important problem that has been researched within diverse research areas and application domains. Many anomaly detection techniques have been specifically developed for certain application domains, while others are more generic. This

☆ ” Cited by 4705 Related articles All 36 versions

Intrusion **detection**: A **survey**

F Sabahi, A Movaghar - Systems and Networks …, 2008 - ieeexplore.ieee.org

… presents a taxonomy of intrusion **detection** systems that is then used to **survey** and classify … This method works by using the definition “**anomalies** are not normal … There are many **anomaly detection** that proposed algorithms with differences in the information used for analysis and …

☆ ” Cited by 117 Related articles All 4 versions

1. Supervised Learning (e.g., Sentiment Analysis)
2. Unsupervised Learning (e.g., Find the top-10 hot topics in twitter)

Why is unsupervised learning more common?

No need to label data

- Labeling is a tedious and expensive process

Able to identify “unknown unknowns”

- Not only detect a known attack pattern
- but also detect an unknown attack pattern

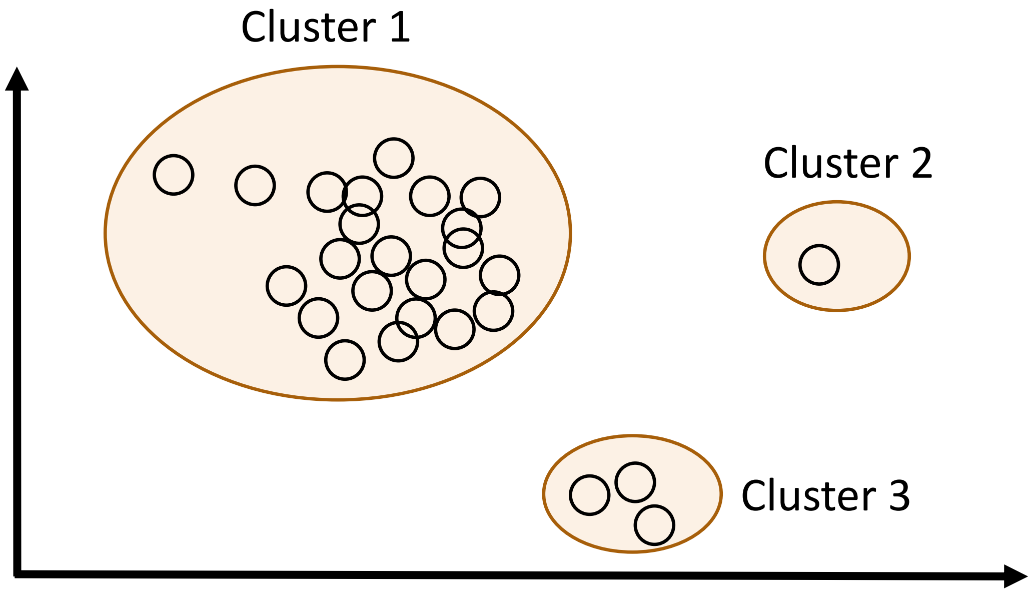
How to come up with a solution?

1. Doing a survey on related work
2. **Choosing an unsupervised learning approach**

Clustering-based

Basic Idea

- Cluster data points into groups.
- Decide which points are anomalies:
  - Points in small clusters
  - Using distance to the closest cluster



How to come up with a solution?

1. Doing a survey on related work
2. Choosing an unsupervised learning approach
3. **Picking up a clustering algorithm**

K-Means

Iterative Algorithm

- This is the initial motivation for creating Spark

Algorithm Overview

1. Picking up K random points as cluster centers
2. Assigning each point to the closest center
3. Updating cluster centers accordingly
4. Repeat Steps 2 and 3 until some termination conditions are met

How to optimize?

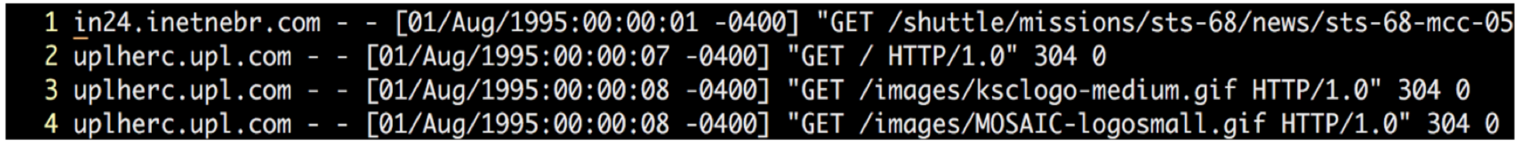
1. RDD.cache()
2. K-Means++ Initialization

How to come up with a solution?

1. Doing a survey on related work
2. Choosing an unsupervised learning approach
3. Picking up a clustering algorithm
4. **Selecting and transforming features**

Feature Selection

Raw Data



```
in24.inetnebr.com - - [01/Aug/1995:00:00:01 -0400] "GET /shuttle/missions/sts-68/news/sts-68-mcc-05
uplherc.upl.com - - [01/Aug/1995:00:00:07 -0400] "GET / HTTP/1.0" 304 0
uplherc.upl.com - - [01/Aug/1995:00:00:08 -0400] "GET /images/ksclogo-medium.gif HTTP/1.0" 304 0
uplherc.upl.com - - [01/Aug/1995:00:00:08 -0400] "GET /images/MOSAIC-logosmall.gif HTTP/1.0" 304 0
```

Turning Raw Data into Connection Data

- A connection is a sequence of HTTP requests starting and ending at some well defined times

Turning Connection Data into Feature Vectors

- Requiring a fair bit of domain knowledge
- Asking yourself how to distinguish attacks from normal connections (e.g., number of failed login attempts, duration of the connection)

Feature Scaling

Feature Vector

- e.g., [http, BC, 0, 105, 146, 0, … , 0.00, 0.00]

Categorical feature

Numerical feature

Will this feature vector work for KMeans?

- What's the distance between "http" and "ftp"?
- The distance between two feature vectors will be dominated by the features with a broad range of values (e.g., the 4th feature)

Categorical Features → Numerical Features

Naïve solution

- http→ 0
- ftp → 1
- ssh → 2

What's the drawback?

Distance("http", "ssh") > Distance("http", "ftp")

One-hot encoding

- http → [1,0,0]
- ftp → [0,1,0]
- ssh → [0,0,1]

Scaling Numerical Features

1. Rescaling

$$x' = \frac{x - min(x)}{max(x) - min(x)}$$

2. Standardization

$$x' = \frac{x - \bar{x}}{\sigma}$$

3. Scaling to unit length

$$x' = \frac{x}{||x||}$$

Which one to use?

It depends on data. Some heuristics:

- (2) is more popular than (1)
- (1) or (2) are often first applied, and then (3) is applied afterward

How to come up with a solution?

1. Doing a survey on related work
2. Choosing an unsupervised learning approach
3. Picking up a clustering algorithm
4. Selecting and transforming features
5. **Parameter tuning and evaluation**

Parameter Tuning and Evaluation

You need to describe your solution in Assignment 7

Key Questions

- Which parameters do you need to tune?
- What are possible values for them?
- How can you tell which values are better?

How to come up the solution?

1. Doing a survey on related work
2. Choosing an unsupervised learning approach
3. Picking up a clustering algorithm
4. Selecting and transforming features
5. Tuning parameters and evaluation
6. **If not satisfied, go back to previous steps**

How to come up the solution?

1. Doing a survey on related work
2. Choosing an unsupervised learning approach
3. Picking up a clustering algorithm
4. Selecting and transforming features
5. Tuning Parameters and evaluation
6. If not satisfied, go back to previous steps
7. **Deploying your model in production**

Model Serving

New Challenges

- Model has to reflect to the latest data updates.
  - Kmeans → Streaming Kmeans

- Predictions have to be made in real-time.
  - Parallelizing prediction process

Summary

How to come up the solution?

1. Doing a survey on related work
2. Choosing an unsupervised learning approach
3. Picking up a clustering algorithm

Theory

4. Selecting and transforming features
5. Tuning parameters and evaluation
6. If not satisfied, go back to previous steps

Practice

Model Development

7. Deploying your model in production

Model Serving