

Lecture 3: Anomaly Detection

CMPT 733, SPRING 2017

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Outline

Recap 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.

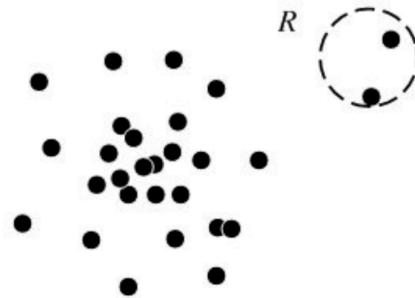


Also known as Outlier Detection

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

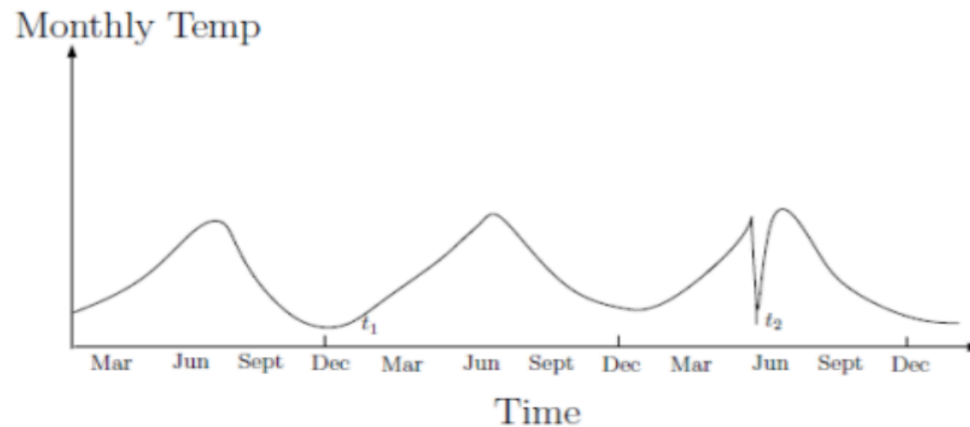


The objects in region R are outliers.

Anomaly Categories (II)

Context Anomaly

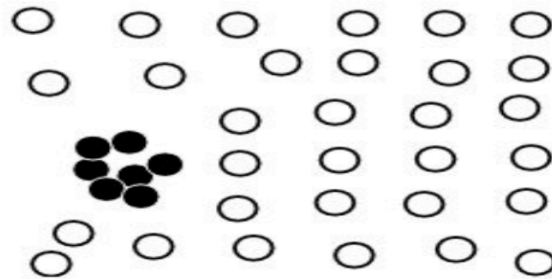
- A data point is considered anomalous with respect to a **specific context**
- Example: There is a person in our class whose age is 70.



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

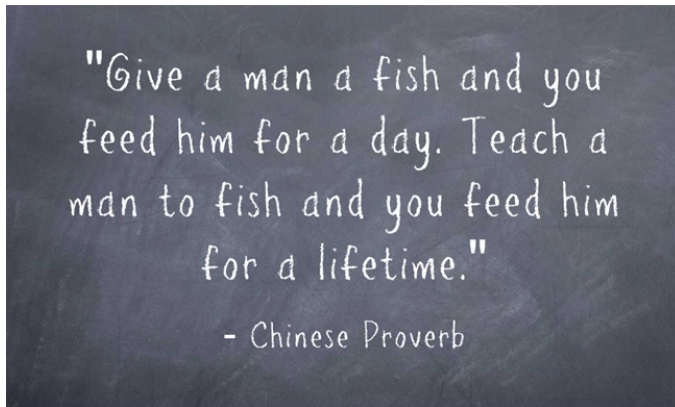
Understandability:

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

Outline

Recap of Anomaly Detection

Application: Network Intrusion Detection



**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

- V. Chandola, A. Banerjee, V. Kumar: [Anomaly detection: A survey](#). ACM Computing Surveys (2009)

Supervised Learning (e.g., Assignment 2 – Sentiment Analysis)

- Both normal and anomalous instances are given
- Classification models can be used

Unsupervised Learning (e.g., Find the top-10 hot topics in twitter)

- No labeled instances are given
- Clustering models can be used

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

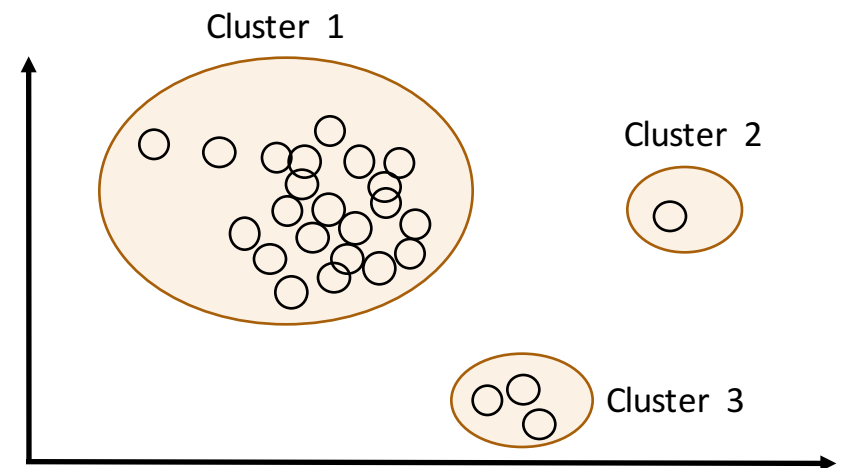
How to come up with a solution?

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

```
1 in24.inetnebr.com - - [01/Aug/1995:00:00:01 -0400] "GET /shuttle/missions/sts-68/news/sts-68-mcc-05
2 uplherc.upl.com - - [01/Aug/1995:00:00:07 -0400] "GET / HTTP/1.0" 304 0
3 uplherc.upl.com - - [01/Aug/1995:00:00:08 -0400] "GET /images/kscllogo-medium.gif HTTP/1.0" 304 0
4 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 Transformation


Feature Vector

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

Categorical
feature



Numerical
feature



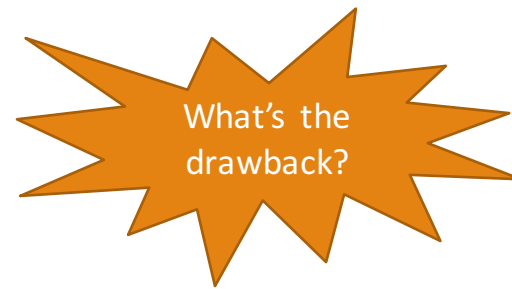
Will this feature vector work for KMeans?

- What's 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



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

- You have done it in Assignment 2

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



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**

Parameter Tuning

You need to describe your solution in Assignment 3

Key Questions

- How different is it from supervised learning?
- Which parameters do you need to tune?
- What are possible values for them?
- How can you tell which values are better?

How did we 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
6. **If not satisfied, go back to previous steps**

How did we 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
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 did we 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
 6. If not satisfied, go back to previous steps
 7. Deploying your model in production
-
- The diagram uses curly braces to group the steps into four categories:
- Theory** (orange brace): Steps 1, 2, and 3.
 - Practice** (orange brace): Steps 4, 5, and 6.
 - Model Development** (blue brace): Steps 1 through 6.
 - Model Serving** (blue brace): Step 7.

Assignment 3: Anomaly Detection

Part 1. Model Development (required)

Part 2. Model Serving (optional)

Deadline: 11:59pm, Jan 29th

<http://tiny.cc/cmpt733-a3>