Master Degree in Artificial Intelligence for Science and Technology

Introduction to Anomaly Detection

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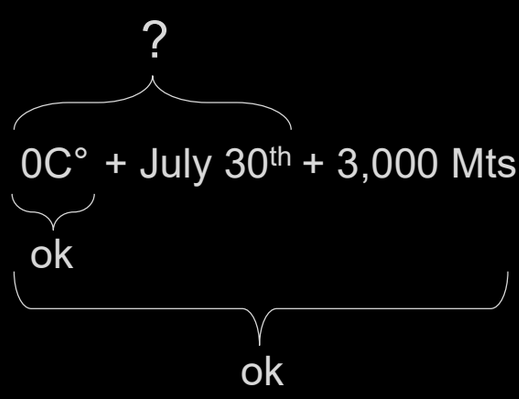
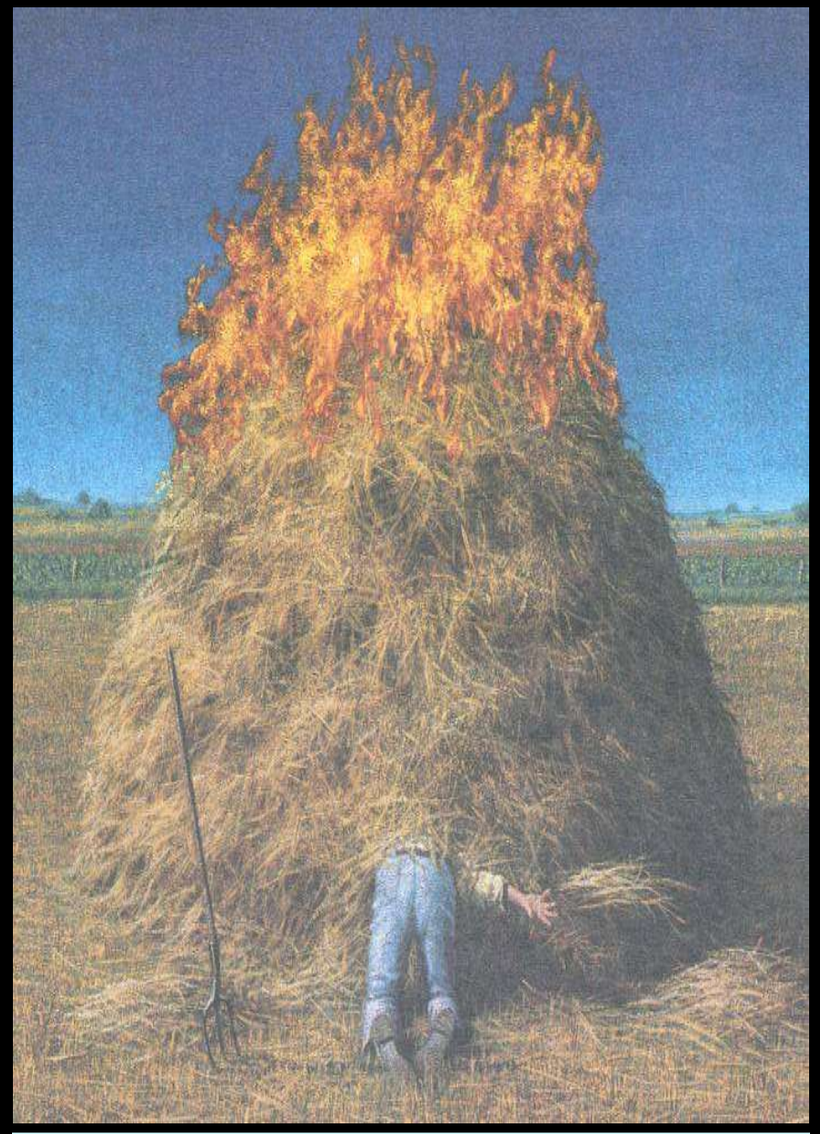
OUTLOOK

- Introduction
- Type of Attributes and Complex Data
- Types of Data
- Types of Anomalies
- Output of Anomaly Detection
- Applications of Anomaly Detection

- What are anomalies/outliers?
  - The set of data points that are considerably different than the remainder of the data
- Natural implication is that anomalies are relatively rare
  - One in a thousand occurs often if you have lots of data
  - Context is important, e.g., freezing temps in July
- Can be important or a nuisance
  - Unusually high blood pressure
  - 200 pound, 2 year old
  - 80 years old and pregnant

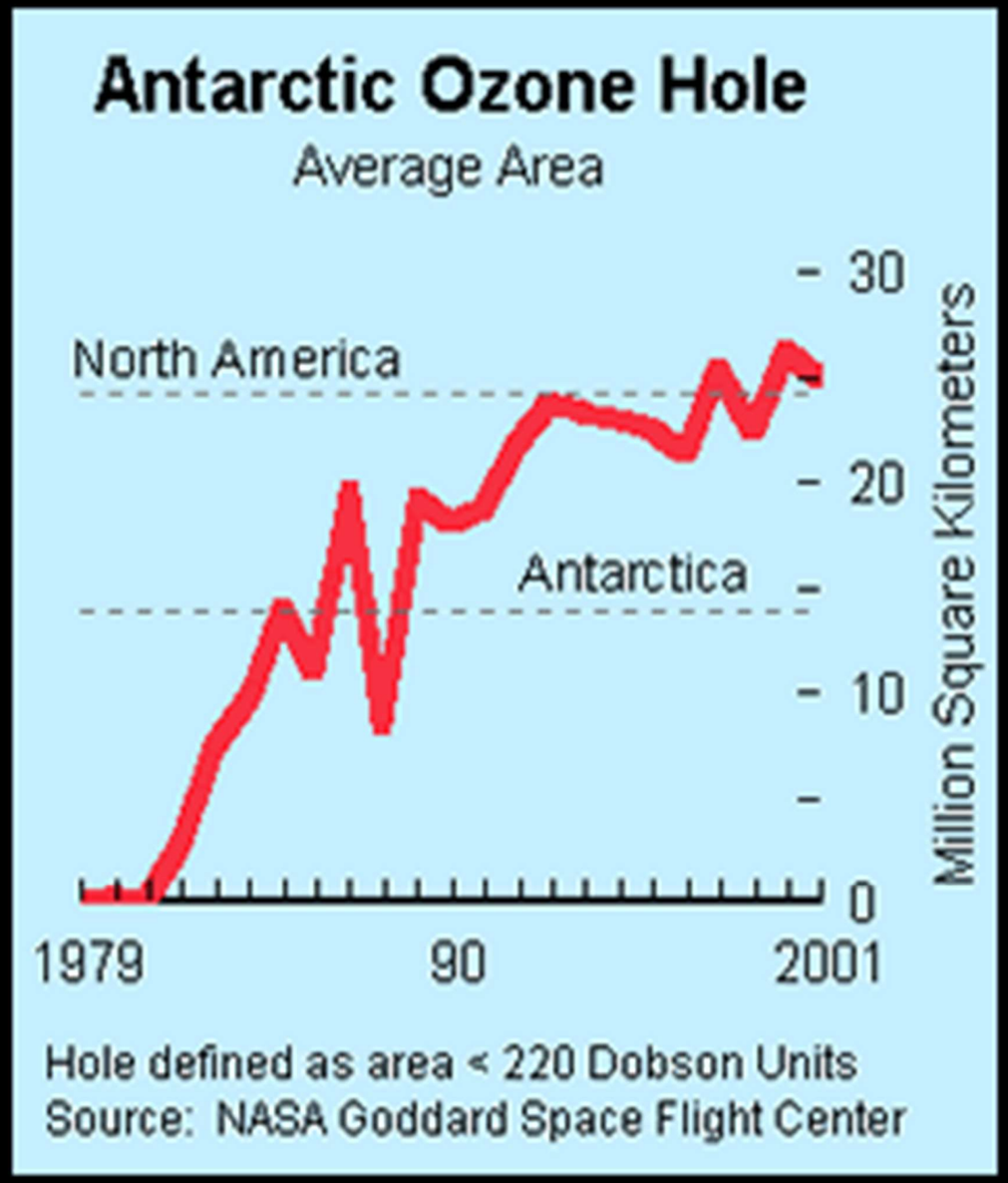




“Mining needle in a haystack. So much hay and so little time”

Ozone Depletion History

- In 1985 three researchers (Farman, Gardinar and Shanklin) were puzzled by data gathered by the British Antarctic Survey showing that ozone levels for Antarctica had dropped 10% below normal levels
- Why did the Nimbus 7 satellite, which had instruments aboard for recording ozone levels, not record similarly low ozone concentrations?
- The ozone concentrations recorded by the satellite were so low they were being treated as outliers by a computer program and discarded!

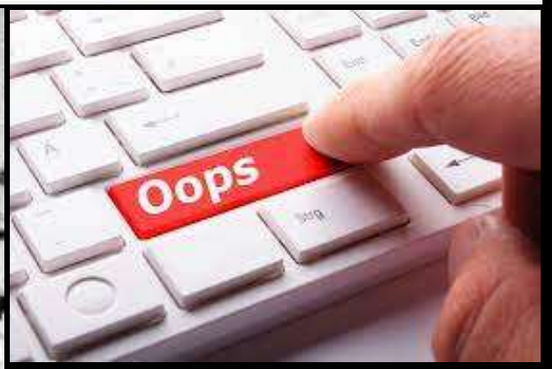


Source: http://www.epa.gov/ozone/science/hole/size.html

- Anomaly is a pattern in the data that does not conform to the expected behavior
- Also referred to as outliers, exceptions, peculiarities, surprises, etc.

CAUSES OF ANOMALIES

- Data from different classes: measuring the weights of oranges, but a few grapefruit are mixed in
- Natural variation: unusually tall people
- Data errors: 200 pound 2 year old
- Cyber intrusions
- Credit card fraud
- Faults in mechanical systems



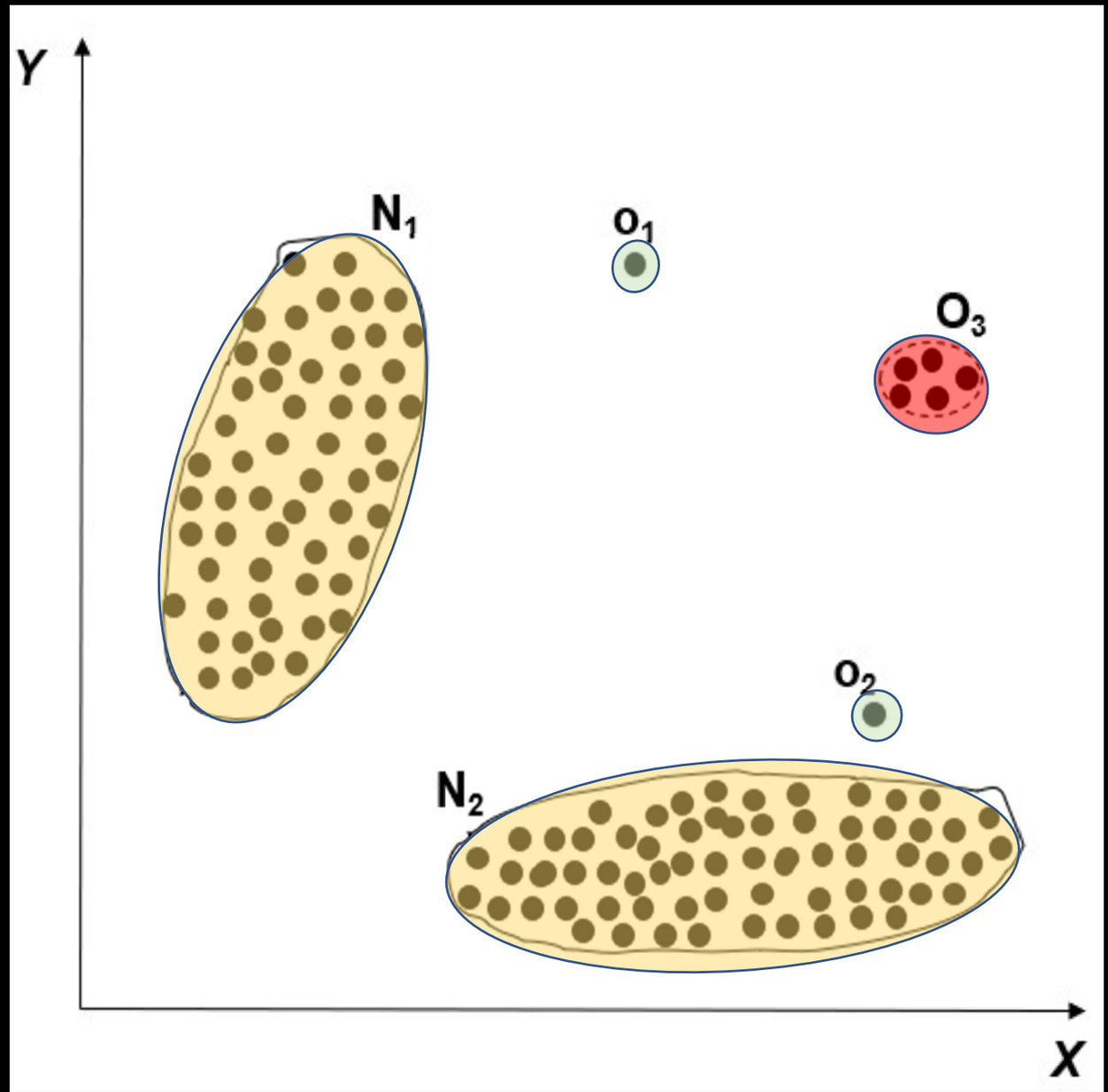
REAL WORLD ANOMALIES

- Credit Card Fraud
  - An abnormally high purchase made on a credit card

- Cyber Intrusions
  - A web server involved in ftp traffic

A Simple Example of Anomaly

- N_1 and N_2 are regions of normal behavior
- Points o_1 and o_2 are anomalies
- Points in region O_3 are also anomalies



INPUT DATA

- Most common form of data handled by anomaly detection techniques is Record Data

Univariate

Engine Temperature
192
195
180
199
19
177
172
285
195
163

Multi-variate

Tid	SrcIP	Start time	Dest IP	Dest Port	Number of bytes	Attack
1	206.135.38.95	11:07:20	160.94.179.223	139	192	No
2	206.163.37.95	11:13:56	160.94.179.219	139	195	No
3	206.163.37.95	11:14:29	160.94.179.217	139	180	No
4	206.163.37.95	11:14:30	160.94.179.255	139	199	No
5	206.163.37.95	11:14:32	160.94.179.254	139	19	Yes
6	206.163.37.95	11:14:35	160.94.179.253	139	177	No
7	206.163.37.95	11:14:36	160.94.179.252	139	172	No
8	206.163.37.95	11:14:38	160.94.179.251	139	285	Yes
9	206.163.37.95	11:14:41	160.94.179.250	139	195	No
10	206.163.37.95	11:14:44	160.94.179.249	139	163	Yes

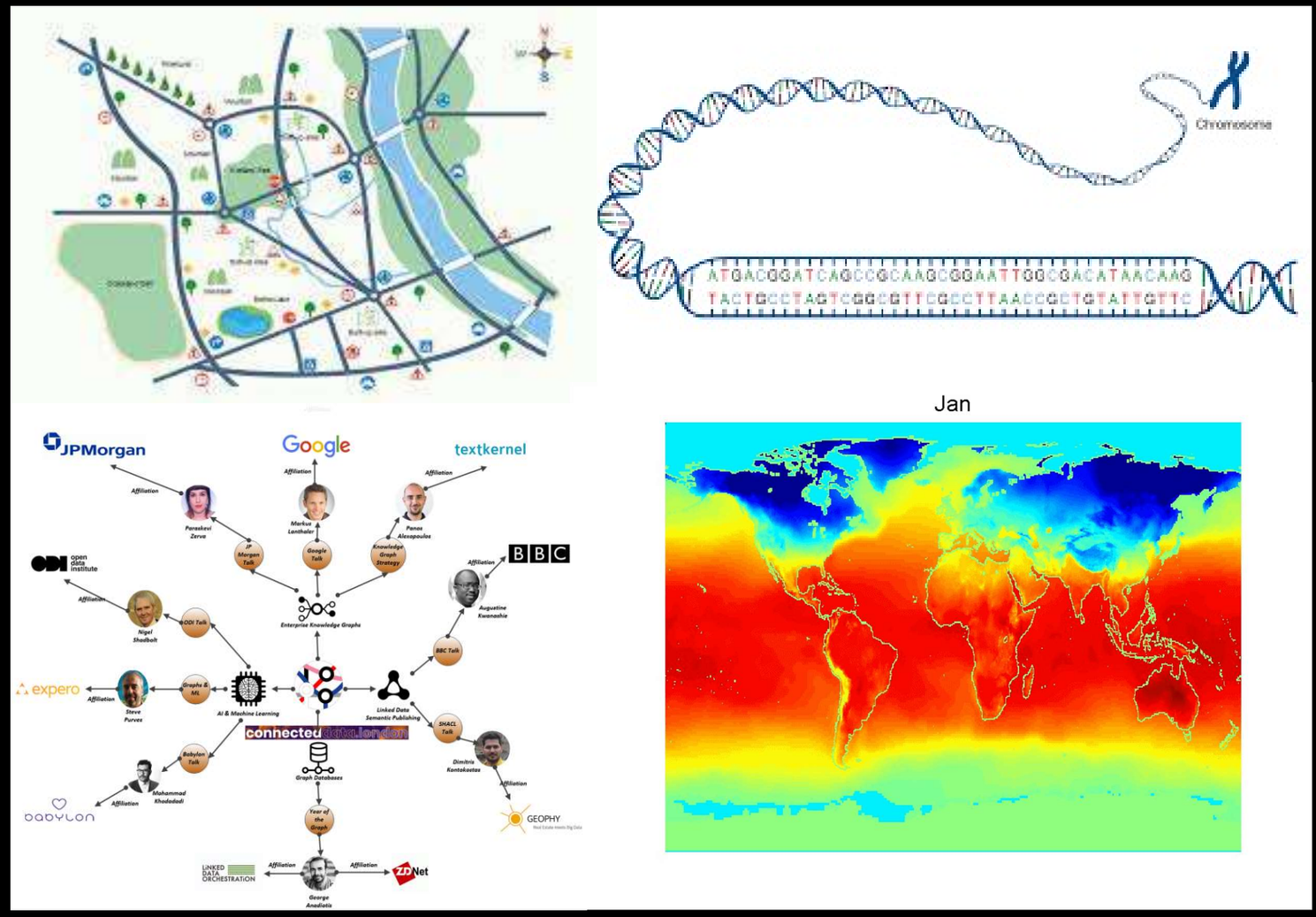
TYPE OF ATTRIBUTES

- Binary
- Categorical
- Continuous
- Hybrid

	categorical	continuous	categorical	continuous	binary
Tid	**SrcIP**	**Duration**	**Dest IP**	**Number of bytes**	**Internal**
1	206.163.37.81	0.10	160.94.179.208	150	**No**
2	206.163.37.99	0.27	160.94.179.235	208	**No**
3	160.94.123.45	1.23	160.94.179.221	195	**Yes**
4	206.163.37.37	112.03	160.94.179.253	199	**No**
5	206.163.37.41	0.32	160.94.179.244	181	**No**

INPUT DATA: COMPLEX DATA TYPES

- Relationship among data instances
  - — Sequential
    - Temporal
  - — Spatial
  - — Spatio-temporal
  - — Graph



Data Labels

- Supervised Anomaly Detection
  - Labels available for both normal data and anomalies
  - Similar to rare class mining
- Semi-supervised Anomaly Detection
  - Labels available only for normal data
- Unsupervised Anomaly Detection
  - No labels assumed
  - Based on the assumption that anomalies are very rare compared to normal data

Types of Anomalies

- Point Anomalies
- Contextual Anomalies
- Collective Anomalies

Types of Anomalies

- **Point Anomalies**
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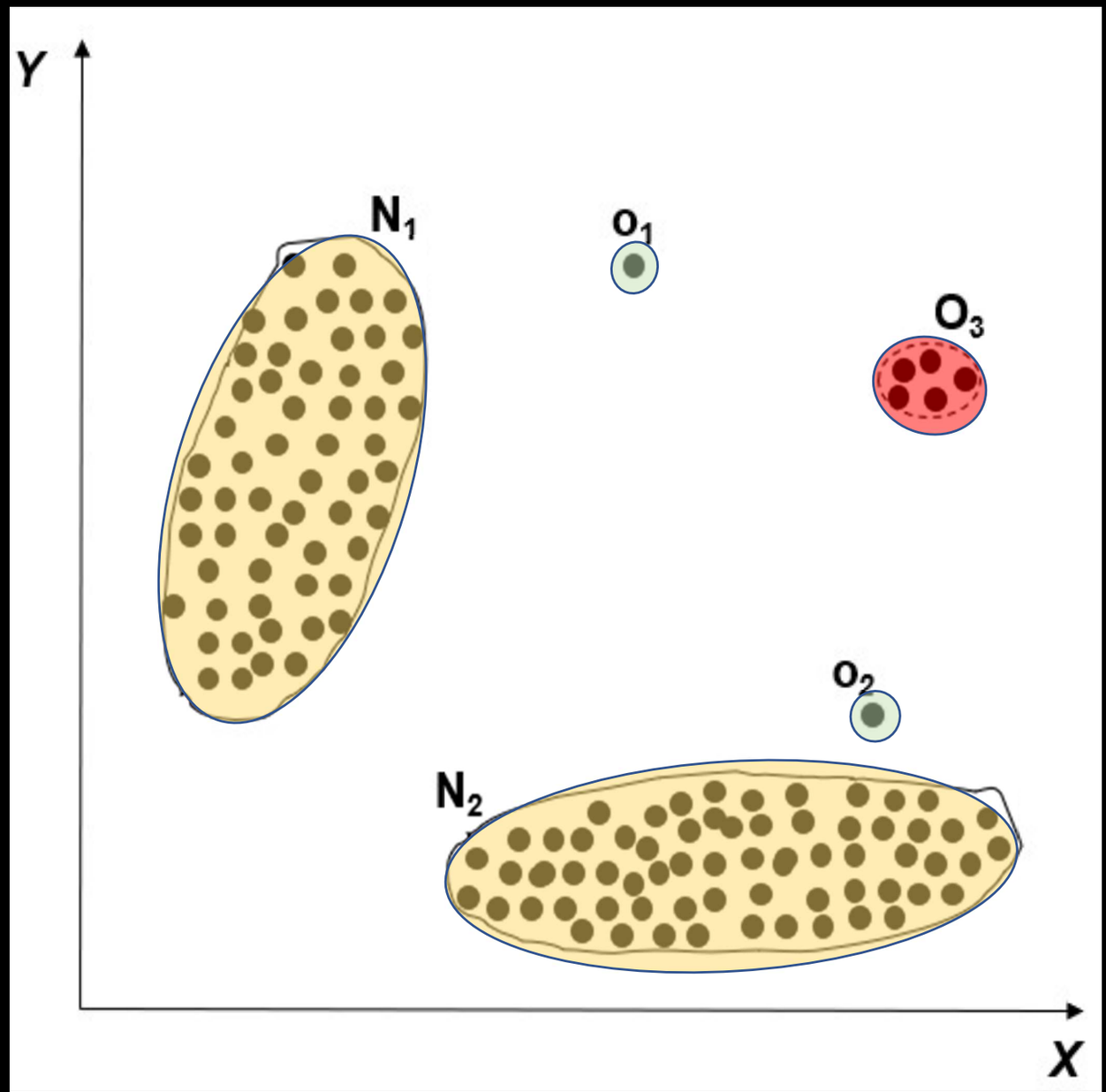
An individual data instance is anomalous w.r.t. the data



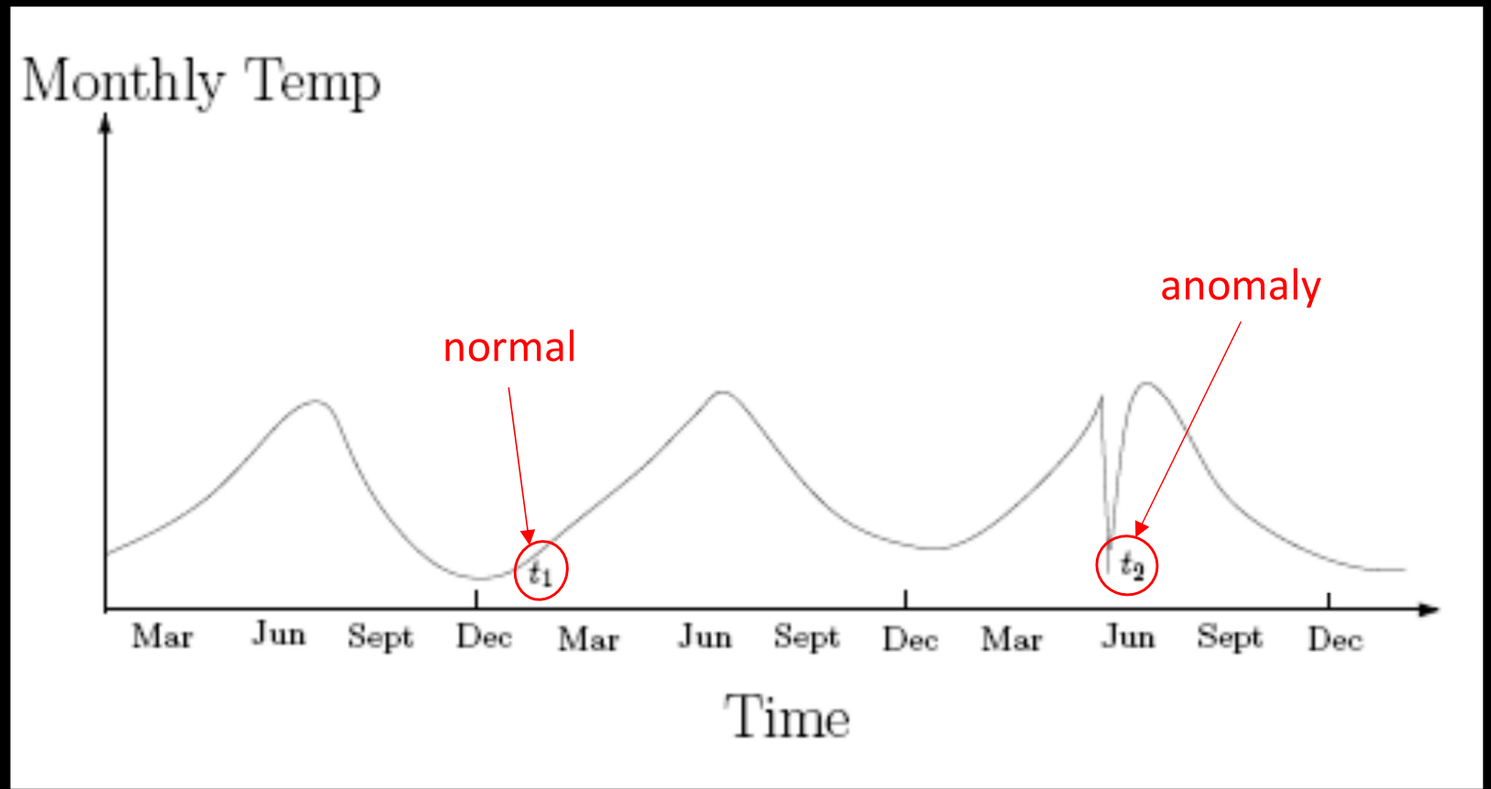
TYPES OF ANOMALIES

- Point Anomalies
- **CONTEXTUAL ANOMALIES**
- Collective Anomalies

— An individual data instance is anomalous within a context

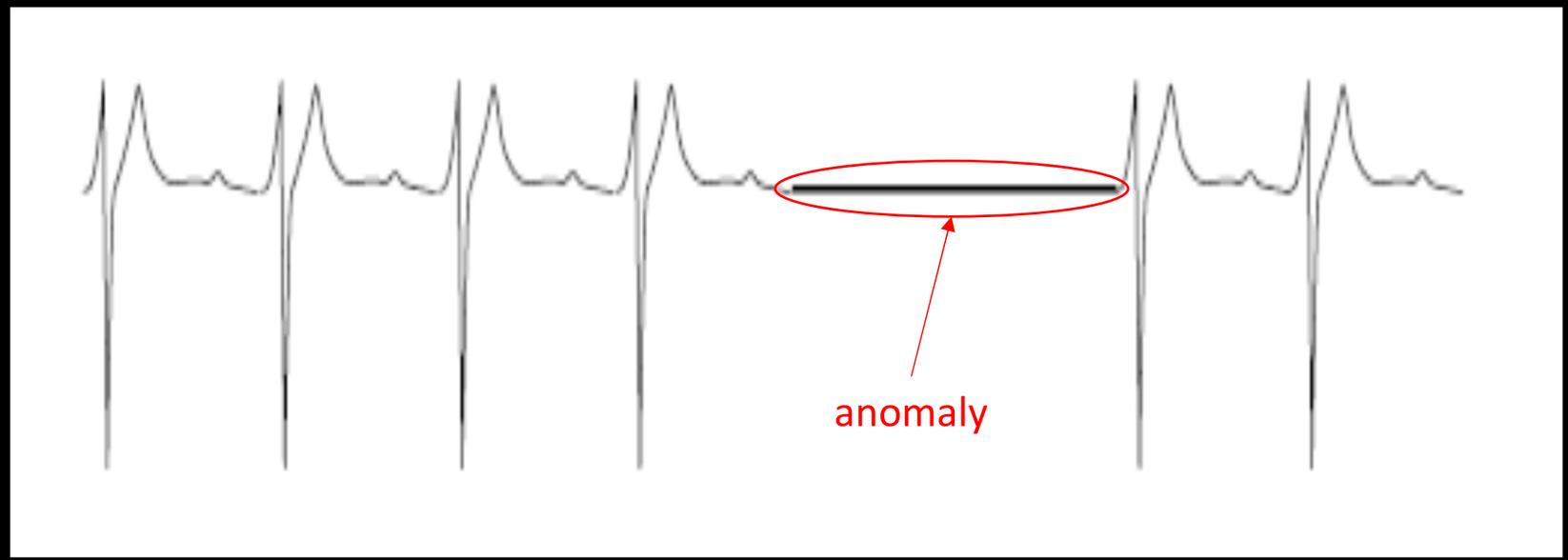
— Requires a notion of context

— Also referred to as conditional anomalies*



Types of Anomalies

- Point Anomalies
- Contextual Anomalies
- **Collective Anomalies**
  - A collection of related data instances is anomalous
  - Requires a relationship among data instances
    - Sequential Data
    - Spatial Data
    - Graph Data
  - The individual instances within a collective anomaly are not anomalous by themselves



Output of Anomaly Detection

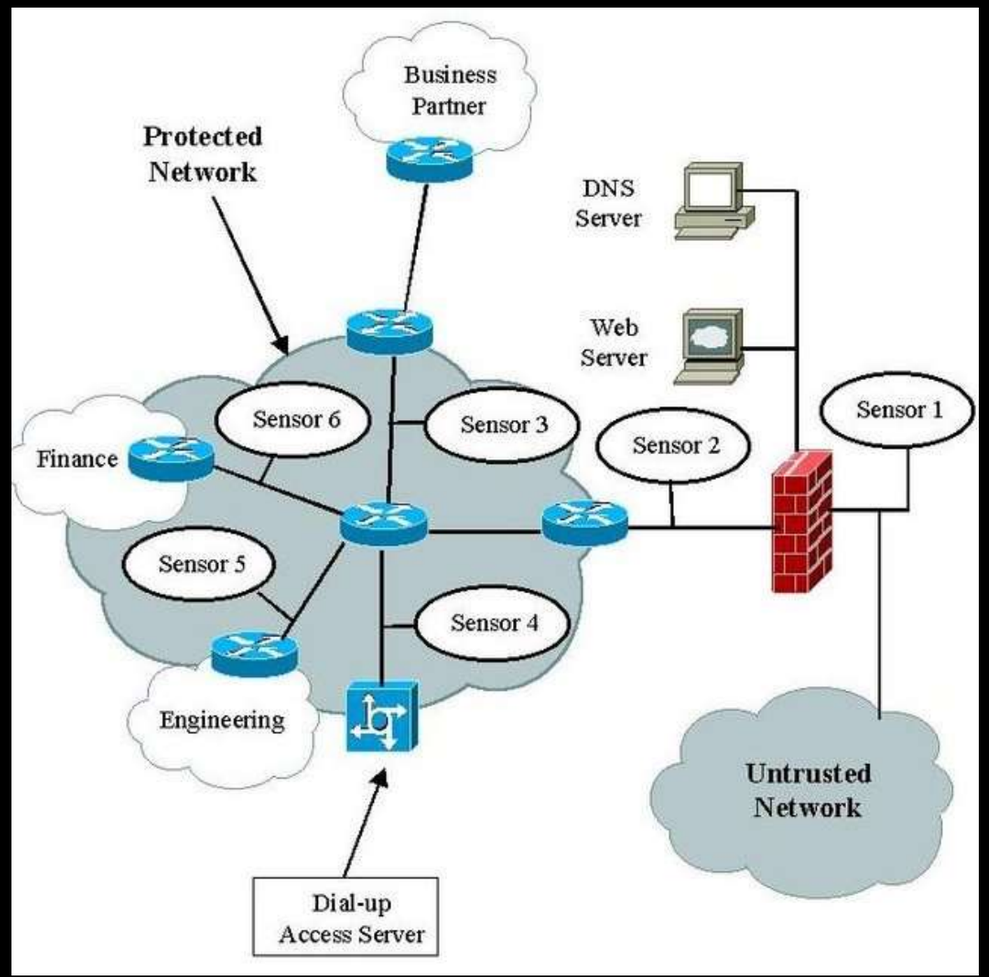
- **LABEL**
  - Each test instance is given a normal or anomaly label
  - This is especially true of classification-based approaches
- **SCORE**
  - Each test instance is assigned an anomaly score
  - Allows the output to be ranked
  - Requires an additional threshold parameter

Applications of Anomaly Detection

- Network intrusion detection
- Insurance / Credit card fraud detection
- Healthcare Informatics / Medical diagnostics
- Industrial Damage Detection
- Image Processing / Video surveillance
- Novel Topic Detection in Text Mining

APPLICATIONS OF ANOMALY DETECTION: NETWORK INTRUSION DETECTION

- Intrusion Detection:
  - Process of monitoring the events occurring in a computer system or network and analyzing them for intrusions
  - Intrusions are defined as attempts to bypass the security mechanisms of a computer or network
- Challenges
  - Traditional signature-based intrusion detection systems are based on signatures of known attacks and cannot detect emerging cyber threats
  - Substantial latency in deployment of newly created signatures across the computer system
- Anomaly detection can alleviate these limitations



APPLICATIONS OF ANOMALY DETECTION: FRAUD DETECTION

- Fraud detection refers to detection of criminal activities occurring in commercial organizations:
  - Malicious users might be the actual customers of the organization or might be posing as a customer (also known as identity theft).
- Types of fraud
  - Credit card fraud
  - Insurance claim fraud
  - Mobile / cell phone fraud
  - Insider trading
- Challenges
  - Fast and accurate real-time detection
  - Misclassification cost is very high

Applications of Anomaly Detection: Health Informatics

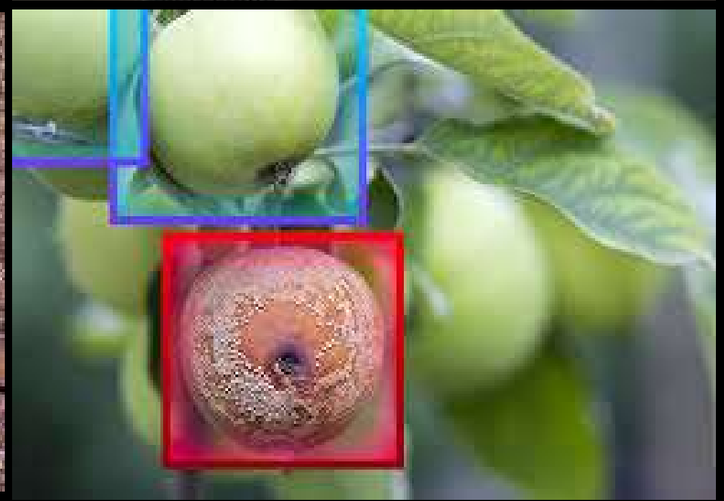
- Detect anomalous patient records:
  - Indicate disease outbreaks, instrumentation errors, etc.
- Key Challenges
  - Only normal labels available
  - Misclassification cost is very high
  - Data can be complex: spatio-temporal

APPLICATIONS OF ANOMALY DETECTION: INDUSTRIAL DAMAGE DETECTION

- Industrial damage detection refers to detection of different faults and failures in complex industrial systems, structural damages, intrusions in electronic security systems, abnormal energy consumption, etc.
  - Example: Aircraft Safety
    - Anomalous Aircraft (Engine) / Fleet Usage
    - Anomalies in engine combustion data
    - Total aircraft health and usage management
- Key Challenges
  - Data is extremely huge, noisy and unlabelled
  - Most of applications exhibit temporal behavior
  - Detecting anomalous events typically require immediate intervention

APPLICATIONS OF ANOMALY DETECTION: IMAGE PROCESSING

- Detecting outliers in an image or video monitored over time
- Detecting anomalous regions within an image
- Used in
  - mammography image analysis
  - video surveillance
  - satellite image analysis
- Key Challenges
  - Detecting collective anomalies
  - Data sets are very large



Model-based vs Model-free

- **Model-based Approaches**
  - Model can be parametric or non-parametric
  - Anomalies are those points that don't fit well
  - Anomalies are those points that distort the model

- **Model-free Approaches**
  - Anomalies are identified directly from the data without building a model

- Often the underlying assumption is that most of the points in the data are normal

Point Anomaly Detection Techniques

- **Nearest Neighbor Based**
  - Anomalies are points far away from other points
- **Clustering Based**
  - Points far away from cluster centers are outliers
  - Small clusters are outliers
- **Statistical Approaches**
- **Reconstruction Based**

RECAP

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