Anomaly Detection

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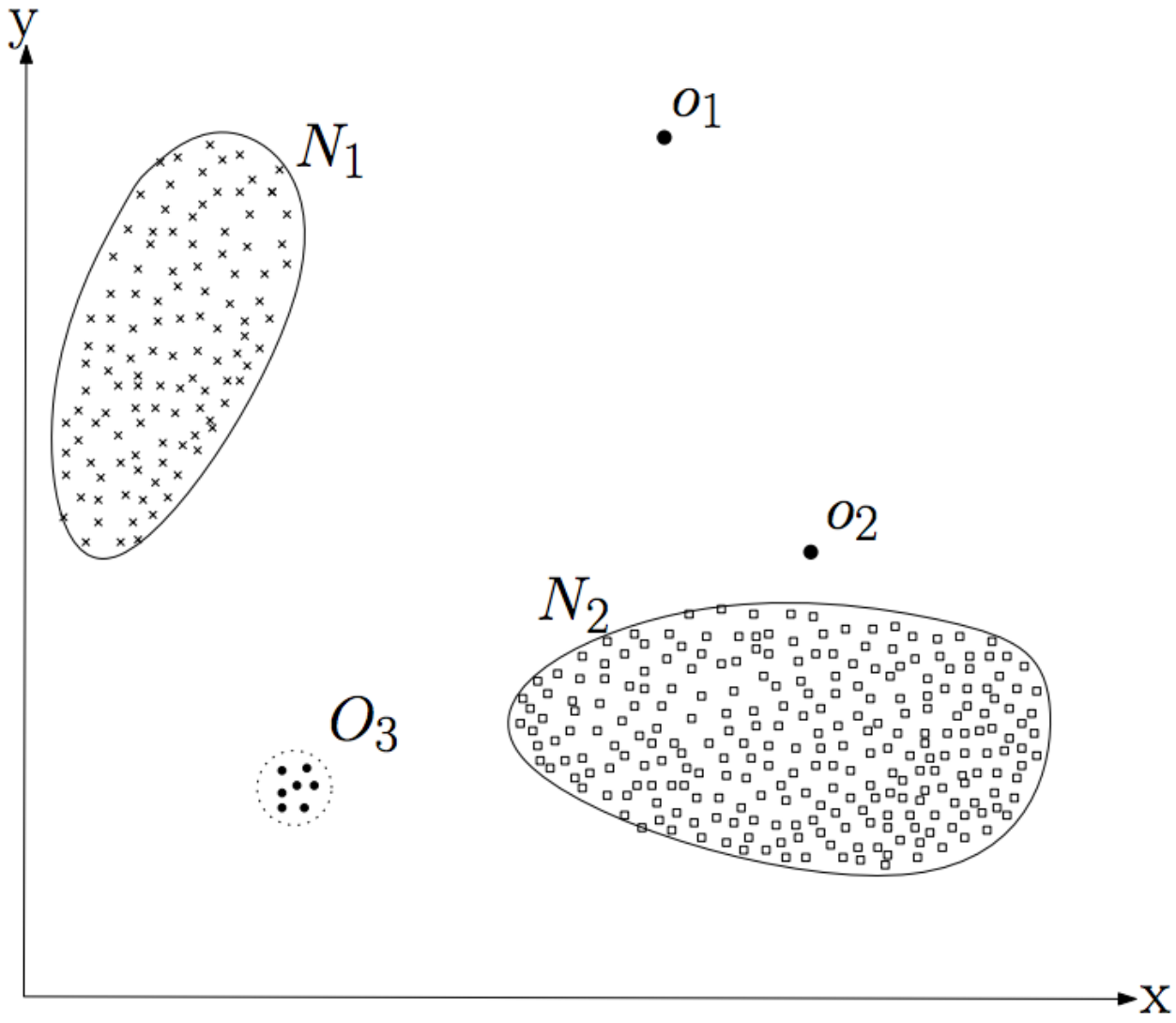
Anomaly detection

What is an anomaly?

Anomalies are patterns in data that are not “normal”.

Anomaly detection

What is an anomaly?



Anomaly detection

The task of anomaly detection is to determine if an instance is *typical* or *anomalous*.

normal vs *abnormal*

expected vs *unexpected*

An anomaly is *interesting* to the analyst.

Anomaly detection

Example

Credit card fraud

Banks lose 11 billion USD per year.

Customers lose 5 billion USD per year.

How can credit card companies deny fraudulent transactions?

. . . Without denying valid transactions?

Anomaly detection

Example

Medical diagnosis

Given a brain scan...

Is the patient likely healthy or not?

Challenge: patient can be unhealthy in novel ways.

We cannot just build a classifier for healthy/not-healthy.

Anomaly detection

Example

Intrusion detection in computer security

What is typical user behavior?

Ports open to the internet on a college campus.

Is a hosted service intentional, or the result of a computer virus?

Anomaly detection

Example

Distributed denial of service attack

Did we just have a piece of content go viral?

Or, are we victims of a botnet flooding our servers with traffic?

(Is it possible to tell the difference?)

Anomaly detection

Example

Science experiments

LIGO: Laser Interferometer Gravitational-Wave Observatory

Identifying rare events: measurable gravity waves.

Finding needles in the cosmic haystack.

Anomaly detection

Example

Mechanical systems monitoring.

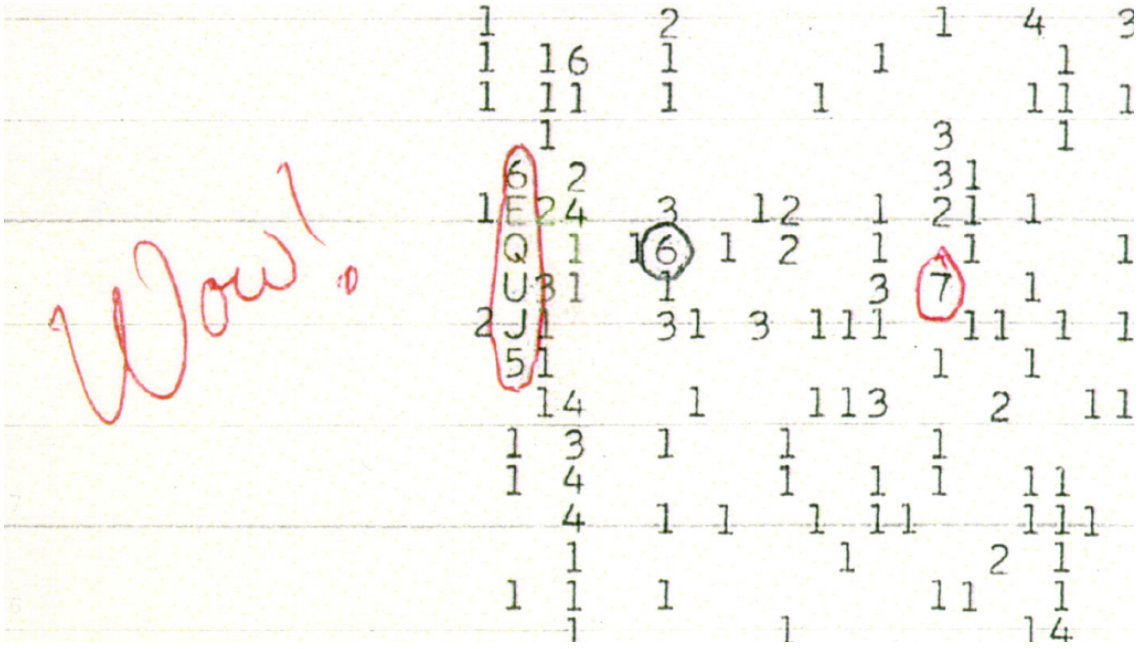
LHC cryo page

Anomaly detection

Example

Detecting abnormal radio signals from space.

Wow! signal.



ET?

Anomaly detection

Why is anomaly detection hard?

Anomaly detection would be easy if we had a training set of all anomalies.

Anomaly detection

Challenge

Defining the “normal” region that encompasses every possible “normal” behavior is very difficult.

Anomaly detection

Challenge

The border between “normal” and “abnormal” is often imprecise.

Anomaly detection

Challenge

If anomalies are the result of malicious actors, they can (and will) adapt to your actions.

Anomaly detection

Challenge

Modeling error / too little information

Example: If two customers have the same recent purchase history (both buy a BART card this morning), and one of them is a fraudulent purchase and the other is not, how could we tell the difference?

Anomaly detection

Challenge

The definition of “typical” or “normal” keeps changing.

Did a parameter in the underlying generative process change?

(Was today hot because of increasing global temperatures, or just the typical daily variation?)

Anomaly detection

Challenge

Domain-dependence

Techniques are often heavily reliant on features of a particular problem domain.

Medical diagnosis: very sensitive, we look for any abnormalities.

Stock prediction: naturally high variance, so we use low sensitivity.

Anomaly detection

Challenge

We can almost never train a classifier for “normal” vs “abnormal”: lack of training data.

Anomaly detection

Challenge

Data often contains noise.

Is the data point an anomaly?

Or just some Gaussian-distributed ϵ?

Anomaly detection

Types of anomalies

Point anomalies

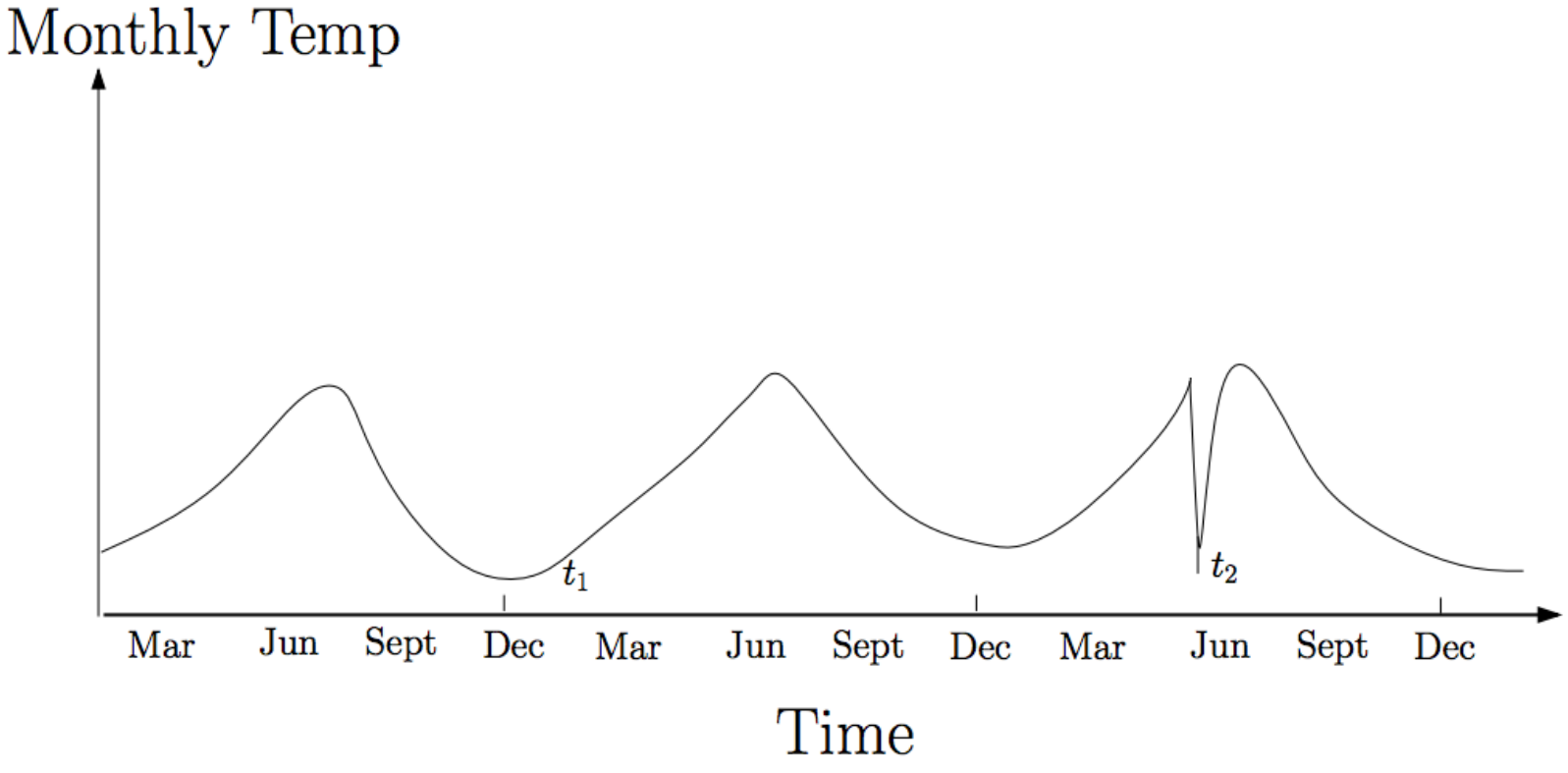
If a single data point can be judged based on its similarity to the rest of the dataset.

Anomaly detection

Types of anomalies

Contextual anomalies

If a single data point is atypical within its particular context.

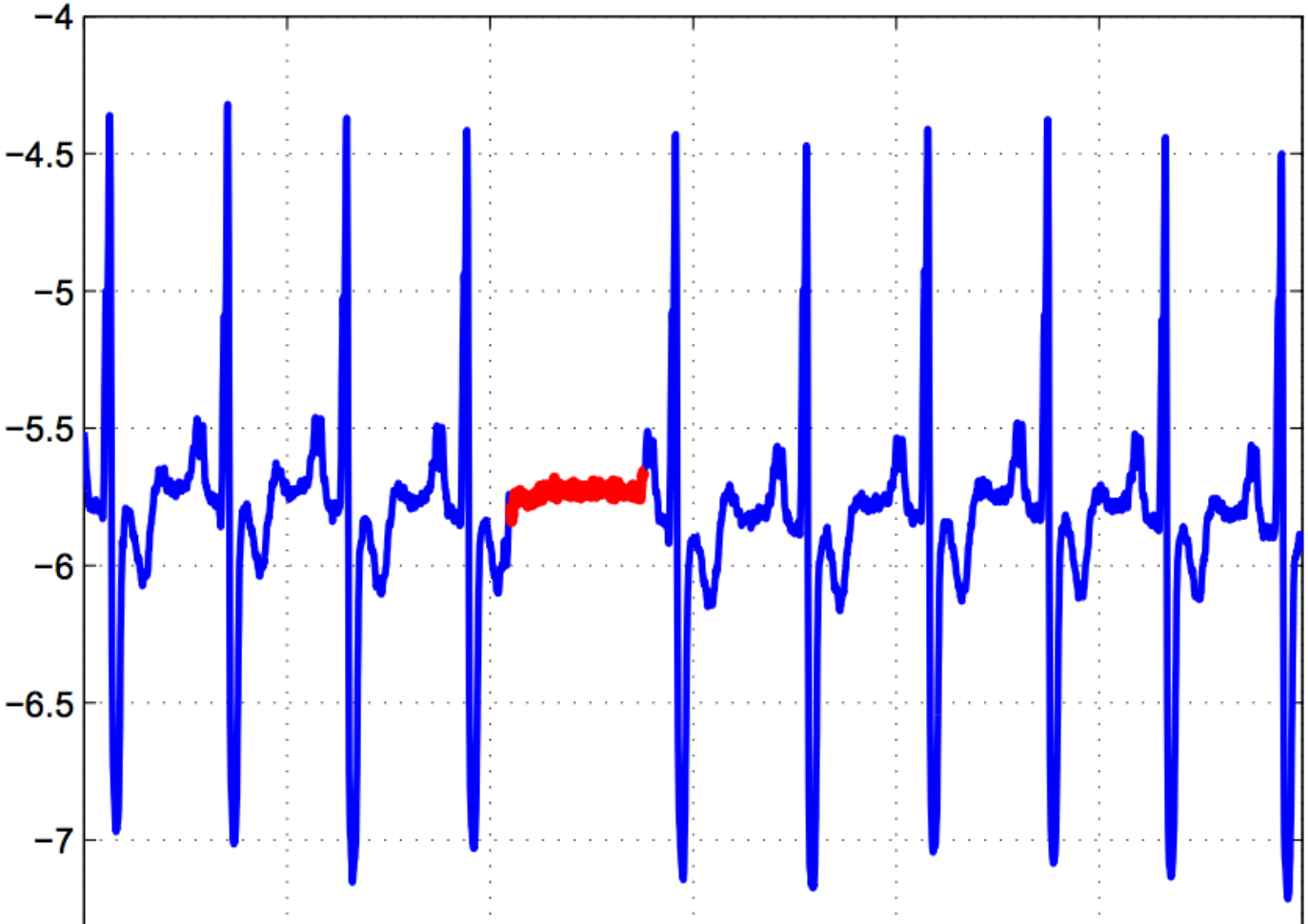


Anomaly detection

Types of anomalies

Collective anomalies

A data point is atypical given its surrounding data points.



Anomaly detection

Models

Supervised learning

Build a classifier: anomalous or not?

Challenges?

Anomaly detection

Models

Semi-Supervised learning

Only have training data for typical points, not atypical ones.

Think: if data points are in low-probability regions.

Challenges?

Anomaly detection

Models

Unsupervised learning

Think: dimensionality reduction like clustering

Challenges?

Anomaly detection

Outputs

Score: how anomalous is this instance?

A human or other system can then decide whether to take action.

Anomaly detection

Outputs

Label: is this instance typical or atypical?

Opaque, but perhaps easier to create a model for this.

Example: naive Bayes can give a probability output, but it is a bad estimate of the true probability.

But, NB can be fine if just using it for labeling.

Anomaly detection

Generative model interpretation:

Is this data point "close" to our training data?

How likely is it that this instance can be generated from our model?

Given a model f with parameters $\sigma \ldots$

$$P(y|f;\sigma)$$

Anomaly detection

Connections

"Happy families are all alike; every unhappy family is unhappy in its own way." -Tolstoy

Manifold learning

Dog or cat?

Dog or cat or *other*?