

Abigail Cummings

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Information Theory

Information theory is a branch of applied mathematics that quantifies information, communication, and data transmission. While it can be applied to a variety of different fields in STEM (science, technology, engineering, and math) including physics, computer science, communication theory and more, our focus will be on its statistical applications.

Information theory is relevant in many different areas of society. Through data science and technology, we can see a variety of ways it is useful.

- Machine learning and information theory work hand in hand. Information theory guides intuition and helps individuals through the theoretical understanding of given data while machine learning operates on algorithms and navigating issues with those algorithms, while learning in the process.
- Artificial intelligence is becoming more and more relevant in our daily lives, and it is continuously learning and evolving with the help of information theory.
- Data mining is a powerful tool used to extract valuable information from datasets and provide that data to businesses who will then make informed decisions based on what they can conclude from the information at hand.

As you can see, data science and technology is very useful and even enables significant advancements in fields such as, but not limited to, healthcare, finance, and cybersecurity. In addition, information theory is also relevant to communication technology such as the internet, mobile networks, and broadcasting.

- The internet is used for nearly everything and is a significant part of our daily lives. To even learn about information theory in the first place, textbooks had to be downloaded off of the internet for our observation.
- Mobile networks aid in our communication with others through calls, email, text messages, and social media. This is a massive advancement in society and as seen through the telegraph is one of the most significant inventions created. It allowed instant communication over vast differences for the first time in human history, and through information theory we are able to discover effective ways to send these messages and have improved the process over time.
- With wars and pandemic taking place in present time, the news has been crucial in spreading information across the globe. These broadcasts including videos seen on YouTube or social media are made possible through the study of information theory.

Communication technology is the backbone of all modern technology. However, information theory can be used in practices outside the field of big data and it can be used in healthcare. We are now able to:

- Observe genetic sequencing.
- Model neural networks.
- Examine the memory and learning development in children and use that information to better understand and supplement their growth.

- Understand the flow of information through ecosystems.

Information theory is relevant in many ways and there is no limit to what is being observed and improved.

### **Fundamental Concepts**

Entropy was first noticed in thermodynamics as a way to measure the amount of disorder in the universe. Now, there is focus on entropy in other fields such as information theory. It is beneficial as a measure of the average amount of information given to us by random variables, and is interpreted as the measure of uncertainty.

The Kullback-Leibler (KL) divergence quantifies how close a given distribution is from the true distribution, or the goal we are aiming for when it comes to efficiently transporting information from one location to another.

Cross entropy is more robust than the KL divergence. This measures the average number of bits needed to represent information from a distribution when observing the data from a different distribution. In other words, it measures how well a probability distribution approximates the true distribution we are looking for.

Mutual information measures the interdependence between two random variables, and the more information we know about one variable will reduce the uncertainty about the other.

### **Applications**

Information theory applies to many concepts like parameter estimation, data analysis, variational inference, and data compression. In this essay, we will expand on data analysis and compression.

Information theory provides a collection of tools in data analysis to help assess information within datasets. These tools assist in model evaluation, understanding relationships between distributions, and optimizing data representation.

This goes back to our example in data science and technology which is data mining. These two concepts go hand in hand in the economy as they are both used to create efficiency in businesses to make sure the owners are making the best possible decisions for their company.

Data compression is represented by many subtopics which will be broken down individually.

- Entropy represents the fundamental limit of how efficiently data can be compressed.
- Redundancy refers to the extra information in a given message that is deemed non-essential.

These feed into the next topics of lossless and lossy compression.

- Lossless compression means to retain all original data from a message without any loss, ensuring perfect reconstruction of the original message.
  - o We see this through sending text messages. A message is created, and each character in that message is assigned digits, which is then encrypted into code and with the right key, can be decrypted by the receiver to get the exact message they were meant to receive.
- Lossy compression is discarding some information seen as less essential. These have much higher compression rates but is at risk for the potential loss of data.

- In audio files, there are frequencies that we cannot hear as humans. These frequencies are therefore non-essential and would make sending these files to another location less efficient. Hence, they are removed from the original message and sent, without the receiver ever knowing it was changed in the first place. This is used in linear algebra as well.

From this, it can be concluded that information theory plays a role in many aspects of life and is becoming increasingly relevant in our day to day life.