

# Assignment 2 + Information Theory

## (SNLP Tutorial 3)

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# Assignment 2

- Exercise 1: Perplexity Calculation
- Exercise 2: Formulating n-gram models
- Exercise 3: Perplexity Calculation for n-grams
- Bonus: Alternative metric to perplexity

# Overview of Formulas

Concepts and formulations.

- Information Content
- Entropy
- Joint entropy
- Conditional entropy
- Mutual Information
- Cross-entropy
- KL-Divergence

- $I(x) = -\log p(x)$
- $H(X) = -\sum_{x \in X} p(x) \cdot \log p(x)$
- $H(X, Y) = -\sum_{x \in X} \sum_{y \in Y} p(x, y) \cdot \log p(x, y)$
- $H(X | Y) = -\sum_{x \in X} \sum_{y \in Y} p(x, y) \cdot \log p(y | x)$
- $I(X; Y) = -\sum_{x, y} p(x, y) \cdot \log \frac{p(x, y)}{p(x) \cdot p(y)}$
- $H(p, q) = -\sum_{x, y} p(x) \cdot \log q(y)$
- $D(p || q) = -\sum_{x \in X} p(x) \cdot \log \frac{p(x)}{q(x)}$

## How do they relate to each other?

- Chain Rule:

$$H(X, Y) = H(X) + H(Y|X)$$

$$H(X_1 \dots X_n) = H(X_1) + H(X_2 | X_1) + \dots + H(X_n | X_1, \dots, X_{n-1})$$

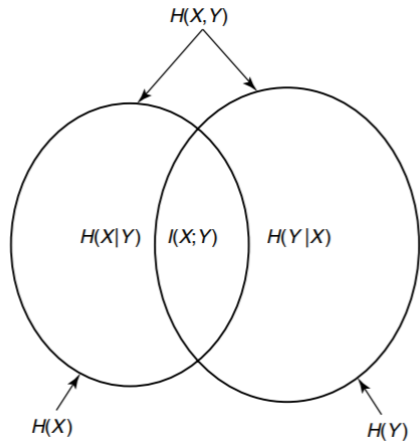
- Mutual Information and Entropy

$$I(X; Y) = H(X) - H(X | Y) = H(X) + H(Y) - H(X, Y)$$

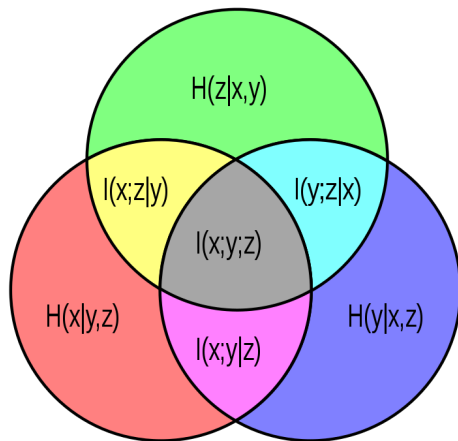
- Apply to 3 variables

$$I(X; Y | Z) = I((X; Y)|Z) = H(X | Z) - H(X | Y, Z)$$

## How do they relate to each other?



Source: <https://syncedreview.com/2020/11/30/synced-tradition-and-machine-learning-series-part-1-entropy/>



Source: [https://en.wikipedia.org/wiki/Information\\_diagram](https://en.wikipedia.org/wiki/Information_diagram)

## Examples - Entropy calculation

$X \setminus Y$	0	1
0	$1/2$	$1/6$
1	$1/3$	0

Find

- $H(X), H(Y)$
- $H(X, Y)$
- $H(X|Y), H(Y|X)$
- $I(X; Y)$
- $H(Y) - H(Y|X)$

## Examples - Entropy of functions

What is the (in)equality relationship between  $H(X)$  and  $H(Y)$  when

- $y = f(x)$  # general case
- $y = 2^x$
- $y = \sin(x)$

# KL-divergence

Question: Can we use the chain rule on KL-Divergence?

$$D(p(x, y) \parallel q(x, y)) = D(p(x) \parallel q(x)) + D(p(y \mid x) \parallel q(y \mid x))$$

Applications of KL Divergence:

- Bayesian inference
- Compression techniques
- Variational autoencoders



# Assignment 3

- Exercise 1: Understanding entropy in languages
- Exercise 2: Entropy as a measure of uncertainty
- Exercise 3: KL Divergence properties
- Bonus: Computation of KL Divergence

# Resources

- 1 <http://csustan.csustan.edu/~tom/sfi-csss/info-theory/info-lec.pdf>
- 2 <https://www.cs.cmu.edu/~odonnell/toolkit13/lecture20.pdf>
- 3 <https://syncedreview.com/2020/11/30/synced-tradition-and-machine-learning-series-part-1-entropy/>