

# MSc Data Mining

## Topic 12 : Text Mining

Foundation

Exploratory Data  
Analysis

Part 01 : Overview

Data Modelling  
Fundamentals

Data Modelling  
Advanced

Rule Based

Association Rules

Recommender Systems

Unsupervised

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Supervised

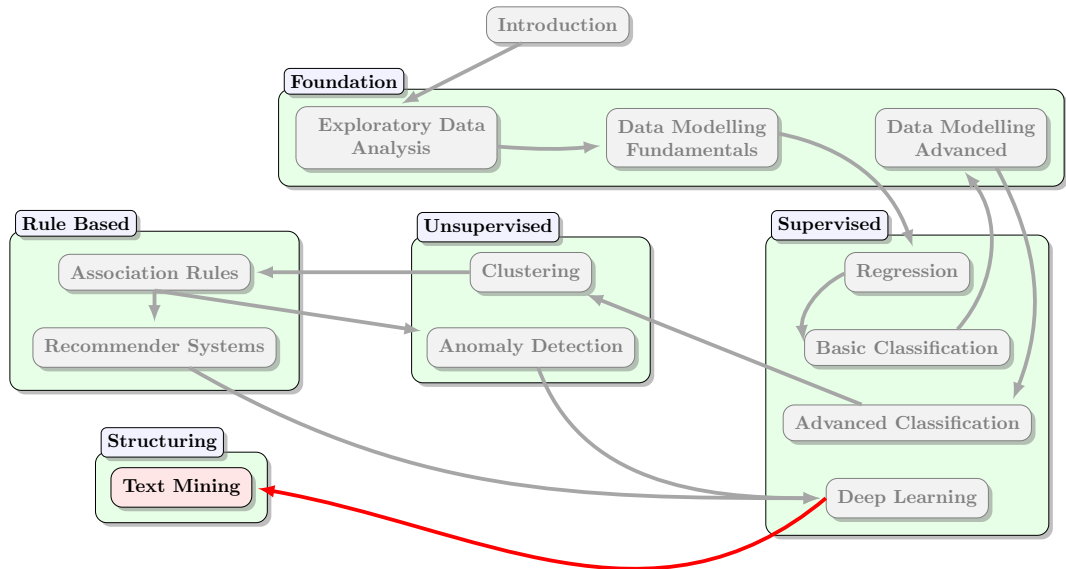
Regression

Basic Classification

### Outline

- What is text?
- Preparing text
- Analysing text
- Adding deep learning

# Data Mining (Week 12)



# Outline

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1. Introduction	3
2. Natural Language	5
3. NLP Tools and Techniques	17
4. Adding understanding and generation	31

# This Week's Aim

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This week's aim is to introduce the main concepts and representative algorithms of text mining, also known as text analytics, applied to *Natural Language Processing*.

- What is natural language?
- Pipeline models of text mining
- Insights from text
- Adding deep learning

Unstructured natural language requires a lot of processing before it can be used to make inferences about a topic, author or subject area.

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# Different types of languages

## Formal languages

Expression-oriented languages, like those used in **mathematics** (for algebra and logic), **regular expressions** (for matching strings) and **chemistry** (for formulae like  $\text{CH}_3\text{COOH}$ ) are examples of formal languages. Others formal language include general *programming languages* like python and Java, as well as *domain-specific languages* that range from application-specific configuration scripts, to SQL and HTML. Generally, humans *designed* formal languages to work with computers.

## Natural Languages

These are languages used between humans, like English, Spanish and Mandarin Chinese, that *evolved* over time.

# Example formal language

## Example formal language

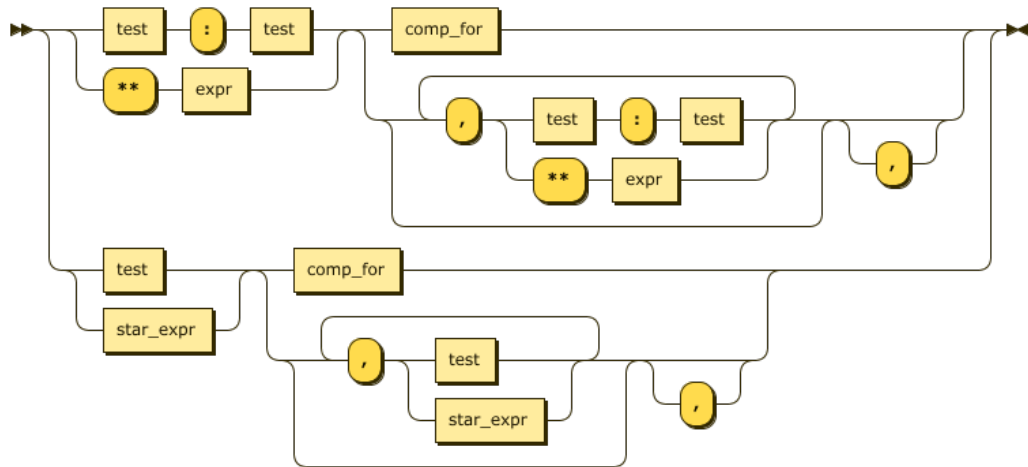
- Programming languages generally have very detailed grammar specifications.
- This makes them easy to parse and reduces the scope for ambiguity.
- Extended Backus-Naur Format is often used to express the grammar (syntax rules) of formal languages.
- Tools exist to generate a parser for a given grammar.
- The grammar (syntax rules) used to define a `dict` or `set` in python can be expressed as follows:

```
dictorsetmaker ::= ( ((test ':' test | '**' expr)
    (comp_for | (',' (test ':' test | '**' expr)) * ('(',')?)) |
    ((test | star_expr)
    (comp_for | (',' (test | star_expr)) * ('(',')?)) )
```

*Source:*

<https://discuss.python.org/t/railroad-diagrams-for-python-grammar/1017>

# Visualising a grammar using a railroad diagram



Source: <https://www.bottlecaps.de/rr/ui>

What would a grammar for a natural language like French look like?



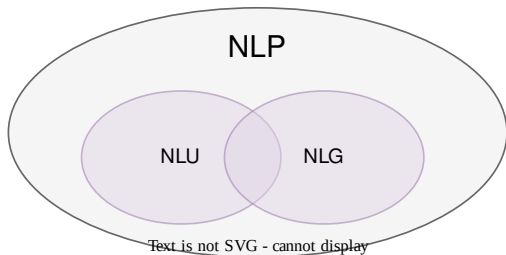
# Comparing formal and natural languages

Criterion	Natural	Formal
Origination	Evolved	Designed
Objectives	Flexible, Expressive	Predictable, Unambiguous
Syntax	Loose, forgiving	Defined, rigid
Parsing	Difficult	Easier
Semantics	Context-sensitive	Explicit

- Formal languages need to do one job well: to capture knowledge in a way that is more easily interpreted by a computer
- Natural languages need much greater flexibility, from poetry, to textspeak, to political speeches, to academic writing

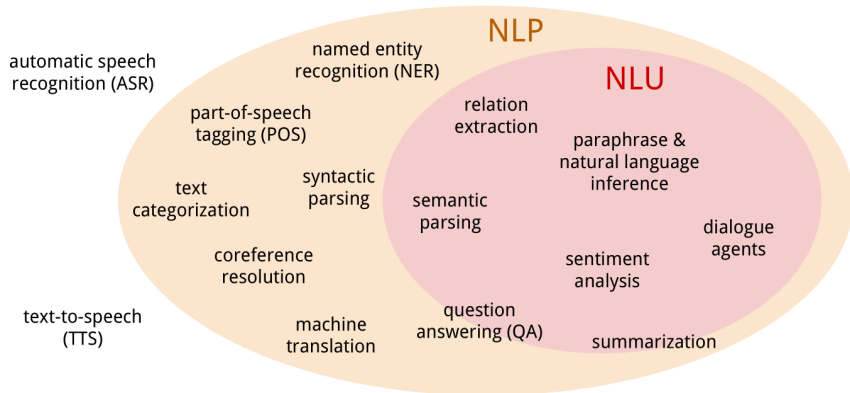
➤ Natural language (unstructured text) is much more difficult for computers to handle!

# Natural Language Processing, Understanding and Generation



- Natural Language Processing (NLP) includes all operations (including preprocessing) relating to text.
- Natural Language Understanding (NLU) derives *meaning* from unstructured text, for *computer* consumption.
- Natural Language Generation (NLG) generates text from internal computer models, for *human* consumption.
- The tools and techniques used by NLP are often categorised as *text mining*.

# NLP, NLU and Speech



Source: <https://nlp.stanford.edu/~wcmac/papers/20140716-UNLU.pdf>

- This diagram classifies selected tasks as NLP and/or NLU.
- By convention, speech tasks (recognition and generation) are not classed as NLP tasks.
- In today's talk, we do not cover speech tasks, just written text.

- The following is a **word cloud** of “text mining” terms used by presenters of the top 25 NLP lectures on the [videolectures.net](http://videolectures.net) site.
- A word cloud is itself a popular NLP way to summarise text data...



Source: <https://bit.ly/3vkP06n>

# Uses of NLP

- Natural Language interfaces to search engines, shopping sites, social media sites
- Language translation applications such as Google Translate
- Writing tools such as Microsoft Word and Grammarly that employ NLP to autocorrect spellings and/or to check grammatical accuracy of texts.
- Interactive Voice Response (IVR) applications used in call centers, or chatbots on support web pages, to respond to user requests.
- Personal assistant applications such as “OK Google”, Siri, Cortana, and Alexa that “converse with” humans
- Monitoring sentiment, trends and virality of posts on social media sites
- Information retrieval from document databases, CVs (resumés) and surveys (going beyond keyword search)
- “Voice of customer” analysis by email filtering, voice message analysis, etc.

# Challenges for NLP interpretation

Challenge	Example
Words are misspelled	“belive”, “begining”
Words are inflected	“matrix” versus “matrices”
Tone is unclear	“The waiter was as friendly as all Parisian waiters.”
Varying context	“The food was good. However I cannot recommend. . .”
Idioms	“to take a rain check”; “to blow him away”
Jargon	“the device uses fractal resonance harmonics”*
Ambiguity	Several types: see next slide

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\*<http://www.davidbarrow.com/psjg/>

# Examples of ambiguity

Type	Example	Analysis
Lexical	Don't get funny with me!	Funny: ha-ha or strange.
Syntactic	He hit the man with a bat	Who had the bat?
Referential	Mary called Jane because she knew.	Who knew?
Colloquial	It's grand.	It is big (or, in Ireland, barely adequate).

- Other **homographs** include “park”, “tear”, “wave”, “fine”, “lead”, ...
- Some homographs (spelled the same) are also **homonyms** (sound the same), e.g., “bark”
- Syntactic and referential ambiguity are both examples of **structural** ambiguity

# Translation failures

- A 1950s machine translation program translated “The spirit is willing but the flesh is weak” to Russian and back, resulting in “The vodka is good, but the meat is rotten” - Ooops!!
- On US TV, The Jimmy Fallon Show had a “Google Translates songs” segment with similar wacky translations for comic effect.
- US Immigration Service has used Google Translate to vet social media posts of incoming passengers, with embarrassing results
- Facebook Thailand sent a message on the King’s birthday that nearly saw it prosecuted according to *lèse majesté* laws there.
- A Tory MP used Google Translate for her Welsh language page, offering constituents (medical) surgeries and (botanical) plants to increase employment in her region

Of course, that is just a small sample!



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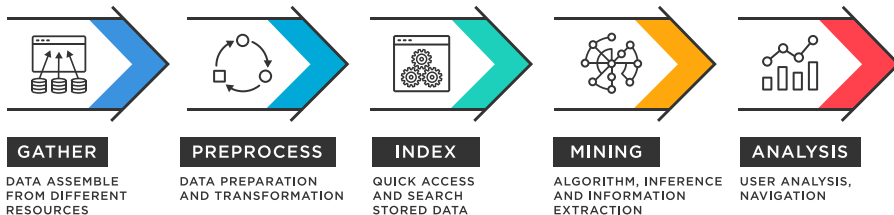
# NLP processes

## Text Analytics

This focuses on producing *quantitative* results, e.g., how often a term appears in a corpus of documents, or the (statistical) distribution of **bi-grams** (two-word phrases) in a set of tweets.

## Text Analysis

This *qualitative* procedure focuses on meaning, translation and interaction between humans and systems.



# Text Analysis Techniques and Uses

- Text Classification
  - Sentiment analysis: Are customers happy with the service?
  - Topic detection: What are the latest covid treatments?
  - Intent detection: Are people supporting us or complaining?
- Text Extraction
  - Keyword extraction: What terms summarise recent news reports?
  - Entity recognition: Which persons or companies are trending?
- Word Frequency: Which words are most common for this author/genre?
- Collocation: Which phrases are significant for this domain?
- Concordance: How are keywords/phrases being used in context?
- Word Sense Disambiguation: How can we parse reliably?
- Clustering: What documents can be grouped by topic/author/genre?

# The basics: NLTK vs spaCy

## Advantages of NLTK

- NLTK is more mature (available since 2001), from academia (especially Stanford)
- Has more algorithms and tutorials/documentation
- Offers a toolbox approach so easily extended
- Generally uses less memory than spaCy for the same task

## Advantages of spaCy

- spaCy is newer and returns objects rather than strings and arrays
- arguably has a more consistent API
- has fewer options but generally they are well-chosen, especially syntax analysis
- often runs faster than NLTK for the same task

➤ We use NLTK in this module

# Preprocessing text

- ➊ **Load data:** use standard python/pandas utilities or load document corpus prepared for NLTK
- ➋ **Remove punctuation:** use python's *regular expression* matcher
- ➌ **Tokenise to sentences or words:** use NLTK's `sent_tokenize(...)` or `word_tokenize(...)`
- ➍ **Standardise case:** use Python's `.lower()` method on each word that was tokenized
- ➎ **Removal of stop words:** use list provided by NLTK and remove them with a python list comprehension
- ➏ **Stemming:** use NLTK's `PorterStemmer().stem(...)` applied using a python list comprehensions
- ➐ **Lemmatisation:** use NLTK's `WordNetLemmatizer().lemmatize(...)` applied using a python list comprehension

➤ Stemming (faster) and lemmatisation (more reliable) are alternatives to each other

# Terms in context - Concordance

## Definition 1 (Concordance)

NLTK's `.concordance(keyword)` outputs a line for each instance of keyword in the document(s), surrounded by words before and after it. This shows how the author(s) use the given keyword(s) in context. If a keyword is potentially ambiguous, this provides a convenient way to check how it is being used in this case.

Concordance can be computed quickly and acts a quick check on the topics being considered. By providing the context, it is easier to test assumptions.

# Term frequencies over time - Dispersion

## Definition 2 (Dispersion)

If the text was collected over an extended period, the frequency of words might vary with time. In such cases, the placement of a word relative to the rest of the document is significant. A rugplot of a term's dispersion through the document can help to indicate whether a term is gaining or losing popularity. NLTK offers `.dispersion_plot(topicList)` for this purpose.

Dispersion is most often used to identify trending topics among social media posts.

# Word frequencies relative to their peers

## Definition 3 (Word Frequency)

If we ignore any temporal aspect, we can ask whether certain words appear more frequently than others. Indeed, a common “report” on text is to provide a list of words and their frequency of occurrence, sorted in decreasing order. The NLTK `.FreqDist(text).most_common(n)` function provides such a report, with only the top  $n$  words.

- Word frequency is the characteristic metric for a *bag of words model*.
- Word frequencies are helpful, but limiting to single words can make interpretation more difficult.



# Adjacent Word frequencies

## Definition 4 (Bi-gram (tri-gram) Frequency)

A bi-gram (tri-gram) is a pair (triple) of adjacent words occurring in the text. Often such adjacent word phrases (which are often *nouns* or *noun phrases*) carry more meaning than the individual words. The frequency distribution of such bi-grams (tri-grams) is often interesting and the top  $n$  bi-gram frequencies can be calculated by NLTK using `Counter(list(bigrams(text))).most_common(n)`.

## Definition 5 (Bi-gram (tri-gram) Collocations)

Rather than considering just the frequency of bi-gram (tri-gram) occurrence, sometimes it is more informative to focus more on the word pairs (triples) that are more frequent than their individual words would suggest. Such pairs (triples) are called **collocations** and can be found by NLTK using `text.collocations()` for bi-gram collocations (with default settings) and `trigram_collocation = TrigramCollocationFinder.from_words(words); trigram_collocation.nbest(TrigramAssocMeasures.likelihood_ratio, n)` for tri-gram collocations, showing some of the optional settings.

# Word frequency analysis

- Word, bi-gram and tri-gram frequencies in a single document or across a corpus of documents can reveal a lot of information
- In particular, such frequencies are indicative of the subject matter, and help to highlight *keywords*
- Anecdotaly, the importance of a term is correlated with its frequency (other factors being equal).
- Thus it is a candidate feature of the document or corpus of such documents.
- However, this is not the whole story: stop words are very frequent (have a high *term frequency* score) but are not considered important.
- Perhaps a better feature exists. . .

# Conditional word frequency analysis

- Term frequency has limitations when considering importance at a whole document or whole corpus level.
- Another consideration is how much focus there is on that term in
  - part of a document, say a chapter of a book, or a segment of a news articles, or
  - a document within a corpus, say a book within a series, or a single social media post.
- What is the frequency of a given term in other parts of a document, or documents in the corpus?
- If the term is limited to this text segment, that might make it more interesting
- Stop words are common across all document segments, this is one of the reasons we remove them!

➤ The terms in the first article to cover a news story are more significant than articles without that story.

## Term importance in context: its TF-IDF score

### Definition 6 (Term Frequency (TF) score)

The **term frequency** (TF) measures the frequency of a term  $t$  in a document. It is often expressed as the ratio of the number of times the term occurs, divided by the number of such terms in the document.

### Definition 7 (Inverse Document Frequency (IDF) score)

The **inverse document frequency** (IDF) is the ratio of the number of documents  $n$  in the corpus, divided by the number of documents containing the term  $t$ , which is  $\text{df}(t)$ . The **log** is taken to prevent it growing too quickly with corpus size, so  $\text{IDF} = \log\left(\frac{n}{\text{df}(t)}\right)$ . If no document in the corpus contains the term, the denominator would be zero, so 1 is added by convention:  $\text{IDF} = \log\left(\frac{n}{1+\text{df}(t)}\right)$ . sklearn uses as “smoothed” version:  $\text{IDF} = \log\left(\frac{1+n}{1+\text{df}(t)}\right) + 1$ .

### Definition 8 (TF-IDF score)

The **TF-IDF score** is the product of TF and IDF:  $\text{TF} \times \text{IDF}$ .

TF and IDF measure term importance - their product is an even better feature for this purpose.

# Uses of TF-IDF scores

## Vectorisation

If every term in a corpus is assigned a TF-IDF score, the vector of such scores is unique to the document. This gives a way to compute the distance between documents, say by the cosine distance between their TF-IDF vectors.

## Information retrieval

When searching for relevant documents associated with  $t$ ,  $\text{TF-IDF}(t)$  can be used to rank the search results by relevance.

## Keywords and Text summarisation

TF-IDF is efficient at finding key words. Adding context to terms with high TF-IDF means that text can be summarised.

# Computing TF-IDF scores

- sklearn (not NLTK) offers TF-IDF calculation
- The calculation is computationally efficient, but ignores semantics, word order and context

## Example code

```
# Initialize TfidfVectorizer with desired parameters (default
# smoothing and normalization)

tfidf_vectorizer = TfidfVectorizer(input='content', stop_words='english')

# Run TfidfVectorizer on the text in df.

tfidf_vector = tfidf_vectorizer.fit_transform(df["text"])

# Make a DataFrame out of the resulting tf-idf vector, setting the
# "feature names" or words as columns and the titles as rows

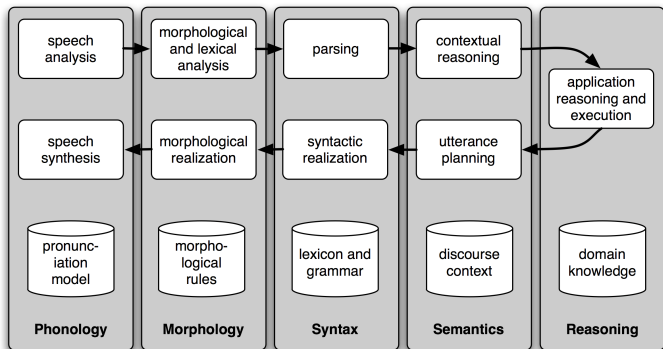
tfidf_df = pd.DataFrame(tfidf_vector.toarray(), index=Df['year_Name'],
                        columns=tfidf_vectorizer.get_feature_names_out())
```

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# NLP round trip



- The schematic above shows a conversational system enabled by NLP
- NLTK (and equivalent) help with the *Morphology* and *Syntax* phases
- These days, deep-learning based approaches show great promise for *Semantics* and *Reasoning*, and can help with all the other phases



## 2018: DL and NLP come together

- Before 2018: State of the art NLU/NLG used RNN
- RNN: recurrent neural network: parse/build sentences additively “left to right”
- That and (relatively) limited training data...
- Resulting language models (that might express any valid form of text) were limited
  - Capability was good ( $\sim$  bias was low): model fitted the training data well
  - Alignment was poor ( $\sim$  variance was high): generated text was not consistent with intention
  - Result: well-structured but unreliable text output
  - Good enough for a chatbot in a restricted domain
- Enter GPT and BERT...

# GPT: Generalised Pre Training

- Latest is GPT-4 (limited release) and GPT-3.5
- Launched by OpenAI (founded by Elon Musk and others)
- Overview at GPT-3 demo and
- Trained on ever larger data sets - now based on billions of articles, tweets, etc
- GPT-3 claimed to use 175 billion(!) parameters; GPT-4 uses more
- Autoregressive, so unidirectional (lookback window size has been challenged)
- Typical use case: Give GPT-3.5 the starting point, it generates the rest
- Does not consider meaning, so can provide plausible but nonsense answers to questions: **hallucination**
- “Write a story” vs “Write an award-winning story” - latter filters the input better
- Not open source - access via OpenAI API (SaaS / PaaS)
- API is simple: little tuning needed - “text in, text out”

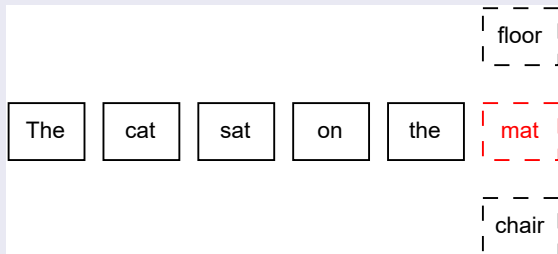
# BERT, the contender from Google

Also see [ELMO](#) and [ERNIE](#)...

- BERT: Bidirectional Encoder Representations from Transformers
- Released as open source by Google
- Requires TPUs and GPUs - training time of the order of hours
- Considers latent relationships so is more sophisticated than GPT-3.5 (GPT-4?)
- Uses fewer parameters (less than 1 billion)
- More tuning required
- Fewer built-in models, so more effort for user
- Rise of companies like HuggingFace and MonkeyLearn with pre-built models

# But first—Text Generation

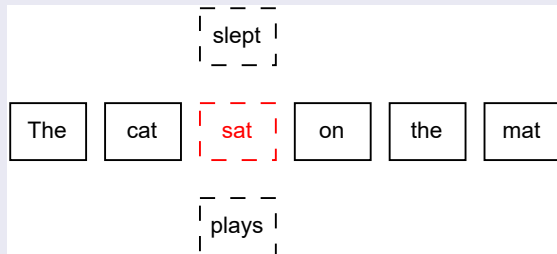
## Causal Language Modelling



- Given “The cat sat on the” what should the *next* word be?

- Generally: choose the word (token) with the highest probability from the training set.
- Use of *temperature* parameter to choose lower probability alternatives *sometimes*
- Analogous to accuracy vs diversity in recommender systems

## Masked Language Modelling



- Given “The cat **MASK** on the mat” what should the **MASK**ed word be?

# Text Generation - from the ground up

## Character-oriented

- 1 Add alphabetic characters, assuming they are uniformly distributed (e.g., Z is as common as A)
- 2 Now assume characters have a distribution based on the (target) language.
- 3 Include whitespace characters so the resulting word lengths are distributed per the language

## Word-oriented

- 4 Generate words by sampling from a dictionary based on their frequency in the language.
- 5 Aside: such nonsense text is recommended for long but memorable passwords...
- 6 Given the previous word, pick the next word based on the frequency of **word digrams** in the language
- 7 Repeat with **word trigrams**, etc

➤ Looking back gives better *context*, but how much is needed? And what about sentences, paragraphs...?

# Enter... Large Language models

## Step 1: Pre-training - Once-off

- Use **unsupervised learning** on unlabeled data to derive latent relationships between words

## Step 2: Fine Tuning - Ongoing

- Use *self-supervised learning* using inferences from the pre-trained *relationship model* to improve the predictive ability of the *generative model*.
- Can distinguish between *zero-shot models* (general purpose, like ChatGPT) and domain-specific, like OpenAI Codex.

## Step 3: Generation

- Given a prompt, or text to complete, or text to translate, use the *generative model* to generate new text

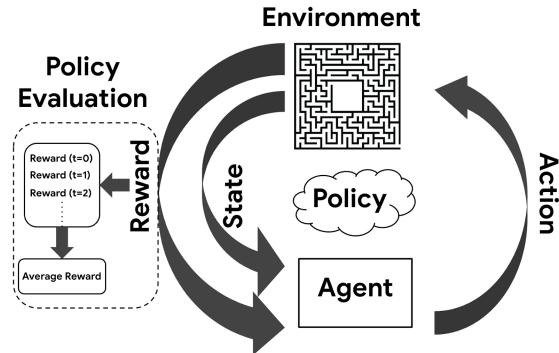
➤ The generated text is not simply extracted from the training corpus, but is motivated by it!

# Transformers - the new architecture for LLM and NLP

- State of the art for NLU and NLG
- Innovations include
- **Positional encoding**: ["hello", "world"] becomes [("hello", 1), ("world", 2)]
- **Attention**: Word combinations map to other Word combinations - easiest seen with translation
- **Self-attention**: Use attention mechanism in a “round trip” to resolve ambiguities
- Transformer concept was introduced by Google researchers in a *heavily cited* 2017 paper Attention Is All You Need.

Deep learning is used throughout, for both the relationship and generative models

# Sidebar: Reinforcement Learning - learning from rewards



Source: <https://bit.ly/3Ld8CzT>

## Overview - Mazes

- Agent (mouse) wishes to find cheese hidden in a maze (*goal*).
- Has knowledge of state (local *environment*).
- Makes navigation decisions based on heuristics encoded as *policies*.
- Each decision (*action*) has an associated *reward*.
- Aim is to maximise rewards and achieve the goal.

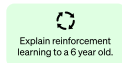


# ChatGPT - Overview of its LLM and training

## Step 1

**Collect demonstration data and train a supervised policy.**

A prompt is sampled from our prompt dataset.



A labeler demonstrates the desired output behavior.



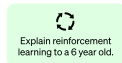
This data is used to fine-tune GPT-3.5 with supervised learning.



## Step 2

**Collect comparison data and train a reward model.**

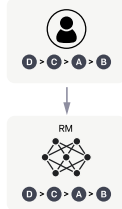
A prompt and several model outputs are sampled.



A labeler ranks the outputs from best to worst.



This data is used to train our reward model.



## Step 3

**Optimize a policy against the reward model using the PPO reinforcement learning algorithm.**

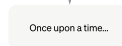
A new prompt is sampled from the dataset.



The PPO model is initialized from the supervised policy.



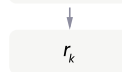
The policy generates an output.



The reward model calculates a reward for the output.



The reward is used to update the policy using PPO.



Source: <https://bit.ly/3NlAche>

# Summary

- Text mining is closely linked to AI - think Turing's test for AI
- Computers have been working on languages and text for decades
- With Big Data and tools like NLTK, *discriminative* tasks like text and sentiment analysis have become mainstream
- Recent developments in LLMs mean that the next wave of AI will focus on *generative* tasks like conversational AI
- Many challenges to overcome: bias, data ownership, alignment issues, concentration of power, deep fakes, ...
- In the lab: text processing with NLTK