Applied Data Analysis (CS401)

ada

Lectures 10+11
Handling text
18 Nov 2020
+ 25 Nov 2020

EPFL

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dlab

Announcements

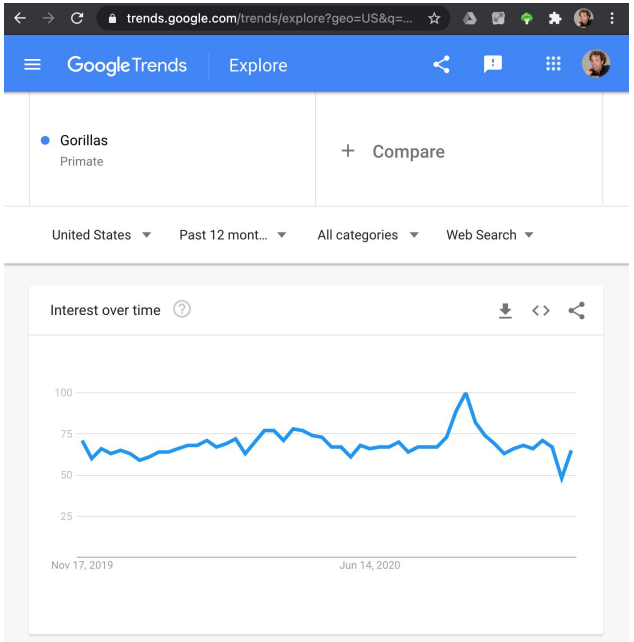
- Homework 2 due on Fri 20 Nov 23:59
  - Reminder: no questions answered on Zulip in last 24 hours
- Project milestone P3 (freestyle proposal) due next week: Fri 27 Nov 2020
  - Start thinking about ideas early on (i.e., immediately)!
  - Discuss frequently in your team
  - Feel free to bounce ideas of ADAssistants (e.g., in office hours)
- Course evaluation
  - Thanks if you've done it!
  - If you haven't done it yet: open until Sun 22 Nov
  - https://isa.epfl.ch
- Friday's lab session:
  - Hands-on tutorial on handling text
  - Homework 2 office hours (last chance to ask questions about H2)

Give us feedback on this lecture here:
https://go.epfl.ch/ada2020-lec10-feedback

- What did you (not) like about this lecture?
- What was (not) well explained?
- On what would you like more (fewer) details?
- …

Textual data

- Much of modern data is unstructured text
  - Web
  - Social media
  - News
  - …
- Frequently, “clean” datasets can be derived from “dirty” textual data
  - e.g., search queries are short texts; Google Trends time series for concepts (e.g., *Gorillas*) are obtained by aggregating all search queries referring to the concept (e.g., “gorilla”, “big black Rwandan apes”, “are gorillas humans?”)



Outline

- 4 typical tasks on text data:
  - Document retrieval
  - Document classification
  - Sentiment analysis
  - Topic detection
- How to phrase these tasks as machine learning problems
- How to preprocess text so it can be fed to ML algorithms
- Next lecture: pointers to miscellaneous advanced topics
- ADA spirit: show you what’s there; give you basic feel
  - For more, take classes on NLP and information retrieval

Typical task 1: document retrieval

- Given:
  - Document collection (a.k.a. corpus)
  - Query document (can be short query string)
- Task:
  - Rank all docs in collection by similarity to query
- An old problem (e.g., libraries)
- Document retrieval is the core task solved by Web search engines (“10 blue links”)

Document retrieval

- Straightforward approach: neighbor search (as in kNN)
- Define a distance function between documents
- Given query q, find the k docs with smallest distance to q
- k=10, docs sorted by distance, blue links, ads → G
- The hard part: craft/learn a distance function (and scale it to the Web…)

Typical task 2: document classification

- Given:
  - Document d
  - Set of classes (e.g., topics: news, sports, tech, music, romance)
- Task:
  - Decide to which one of the classes document d belongs
- Example scenario:
  - Find news articles about sports events in a large Web corpus

Document classification

- Supervised learning
- Obtain a large collection of documents
- Label each doc with the class it belongs to
- Represent docs as feature vectors
- Train a supervised classifier based on the labeled docs:
  - kNN, logistic regression, decision tree, random forest, support vector machine, neural network, …

Typical task 3: sentiment analysis

- Given:
  - Document d (e.g., product review)
- Task:
  - “Sentiment” score capturing how positive/negative d is
- Example scenario:
  - Infer what people think about a product from text only (i.e., without explicitly given ratings)
  - Historical opinion analysis; e.g., how has people’s attitude toward certain politicians changed over time?

Sentiment analysis

- Supervised learning
  - Regression
  - Classification
- Same setup as for document classification:
  - Label a training set with ground-truth sentiment scores
  - Represent documents as feature vectors
  - Train supervised model: linear/logistic regression, kNN, …

Typical task 4: topic detection

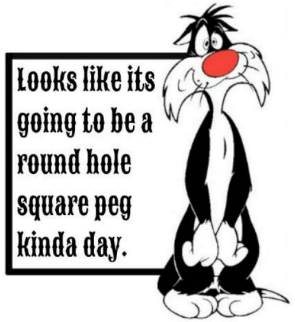
- Given:
  - Unlabeled document collection
- Task:
  - Determine a set of prevalent topics in the docs
  - Determine for each document to which topics it belongs
- Example scenario:
  - Detection of trending topics in social media (e.g., Twitter)
  - Detection of polarized viewpoints on a political subject
  - Exploratory analysis of a large doc collection

Topic detection

- Clustering
- Represent documents as feature vectors
- Run hierarchical or point-assignment clustering algorithm
  - Hierarchical: agglomerative or divisive
  - Point-assignment: e.g., k-means, DBSCAN
- Alternative: matrix factorization (cf. next lecture)

Feature vectors

- Nearly all ML methods work with feature vectors
  - E.g., previous slides: document retrieval; document classification; sentiment analysis; topic detection
- Text is not immediately a feature vector
  - Variable length
  - Even for fixed length (e.g., tweet…): Positions don't correspond to meaningful features



Feature vectors

- Need to transform arbitrarily long string to fixed-length vector
  - Traditional and vetted: bag of words
  - More recent: *learn* a mapping from strings to vectors (buzzword: “text embedding”)

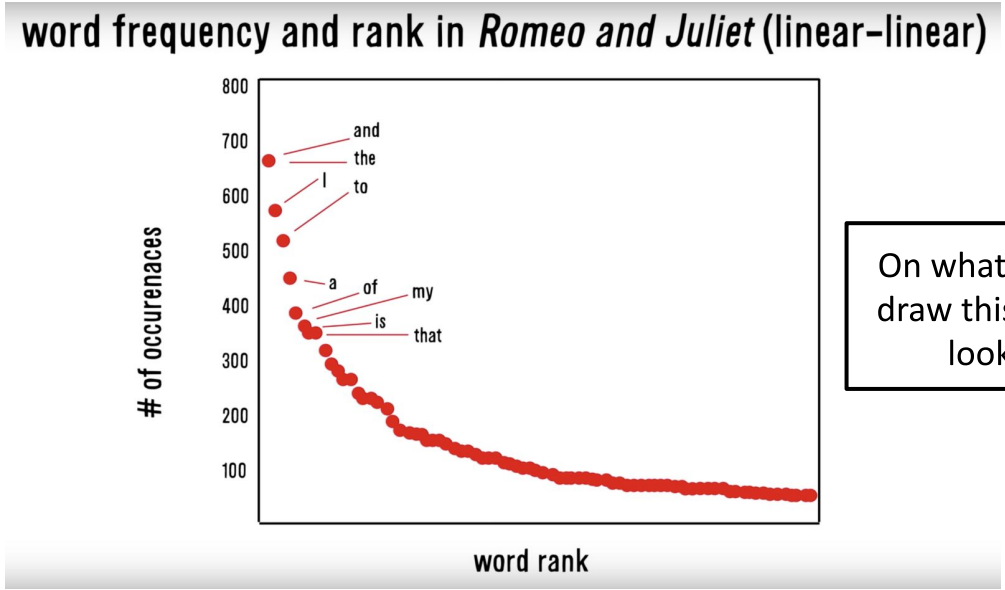
Bag of words

Tom Mitchell (CMU)

- Bag == multiset
  - “multi-”: Keep multiplicity of words
  - “-set”: Don’t keep order of words
  - E.g., document “what you see is what you get”
    → bag of words {get:1, is:1, see:1, what:2, you:2}
- To have fixed-length representation for all documents:
  - One entry for each unique word in vocabulary
  - Bag-of-word vectors are very high-dimensional (typically 1e5 or 1e6) and very sparse
  - E.g., above: [0…0 1 0…0 1 0…0 1 0…0 2 0…0 2 0…0]

Reason for sparsity: Zipf's law

A famous power law



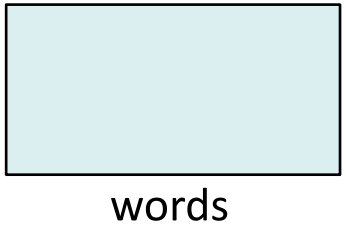
POLLING TIME!

On what axes would you need to draw this plot in order to make it look like a straight line?

The probability of observing a word scales inversely with its frequency rank:

$p(w_i) \propto 1/i$ (where w_i is the i-th most frequent word)

Bag-of-words matrix



- Combine document vectors as rows in a matrix
  - One row per doc
  - One column per word in vocabulary
- This matrix is huge!
  - E.g., Wikipedia: 5M docs, 2M words → 10 trillion entries
- Use a sparse matrix format
  - Triples: (doc_idx, word_idx, count)
  - E.g., Wikipedia, assuming 2000 words per article on avg.: 10 billion non-zero entries (fits in memory)
- With matrix representation, you're ready to use any ML model

… are you?

- In theory, yes
- In practice: “garbage in, garbage out”
- Be careful when mapping raw text to bag-of-words matrix!
  - Character encoding
  - Language identification
  - Tokenization
  - Stopword removal
  - Word normalization
- Tweaking the matrix a bit can lead to much better performance
  - Reweight/normalize rows and/or columns of matrix

Bag of tricks for bags of words

Character encoding

- Mapping from (abstract) characters to bytes
- Old school: ASCII, Latin-1
- New school: Unicode (e.g., UTF-8, UTF-16, UTF-32)
- E.g., W → 0x57
- Reading text from file:
  - Need to read with encoding that was used to write file
  - Especially important for non-English text: à, ê, ü, ß, …
- Writing to file: Always use UTF-16; hard-code the output format!

```
file = codecs.open("temp", "w", "utf-8")
file.write(codecs.BOM_UTF8)
file.close()
```

- Otherwise, your future self will be very angry at you (example)

Language identification

- Typically, you're interested in text from a single language
- Increasingly, content is multilingual (e.g., Twitter, Wikipedia)
- Ideally, language code is specified (e.g., headers in HTML; JSON field in Twitter API results)
- But not always…
- There are great libraries (e.g., this)
  - Most commonly based on letter trigrams (e.g., "eau", "ghi", "ijs", "sch", "eiß", "ção")
  - Much harder if you messed up character encoding…

Tokenization

- Maps character string into sequence of tokens (≈ words)
- E.g., “Hello! How are you?” → Hello_!_How_are_you_?
- Tempting to do this yourself by splitting at whitespaces and punctuation
- But many corner cases:
  - “Hello, Mr. President! How are you?! :-)”
    → Hello_,_Mr._President_!_How_are_you_?!_:-)
- Don’t do it yourself, use libraries instead; e.g.,
  - Python: nltk; Java: Stanford CoreNLP
  - Rule-based, deterministic, fast

Tokenization

- Optimal tokenizer different for different languages (e.g., Swedish “Saint Peter” → “S:t Peter”), but English tokenizer often good enough
- Tokenization straightforward in English
- Hard in, e.g., Chinese: no whitespace between words
- Compound words, e.g. in German:
  - Advanced models can split “Donaudampfschifffahrtskapitän” into “Donau dampf schiff fahrts kapitän”
  - But what to keep together…? “Schiff fahrt” or “Schifffahrt”?

Stopword removal

- Very frequent, “small” words carry little information for most tasks and can “drown out” information contained in real content words
- E.g., “a”, “the”, “is”, “you”, “I”, punctuation marks
- Many stopword lists online, but be careful!
  - Different tasks require removing different stopwords
  - Good heuristic: remove words appearing in at least p% of all documents (but what should p be…?)
  - Sometimes stopword removal hurts!
    - Author identification, psychological modeling; punctuation can be useful as well: e.g., “!!!”, “:-)”

Word normalization: casefolding

- E.g., “I love yams. Yams are yummy.”
- Should “yams” and “Yams” really be different features?
- Simple solution: make everything lower-case (“casefolding”)
- But then: “I’d rather have an apple than an Apple.”
- Hand-code exceptions?
- In practice (especially when dataset is large), typically best to **not** do casefolding
- But when dataset is small, might help because less sparsity

Word normalization: Stemming

- Map different forms of same word to same, normalized form, by stripping affixes
- E.g., “walking”, “walks”, “walked” → “walk”
  “business”, “busy” → “busi”
- Typically done in hacky, heuristic way (e.g., Porter stemmer)
- Pro: decreases sparsity in bag-of-words matrix
- Con: discards information
  - E.g., “business” vs. “busy”; “operating” (as in “op. system”)
- In English (esp. with big data) typically not done anymore
- Still very useful in morphologically richer languages (e.g., German, Finnish, Bantu languages)

Word normalization: Lemmatization

- Lemmatization == stemming++
- Map tokens to lexicon entries
- E.g., “U.S.A.”, “US” → “United States”
  “Grüße”, “Gruesse” → “Grüße”
  “You **lie** in the grass” vs. “You **lie** to me”
- Frequently omitted, as it requires complete lexicon and complex mapping rules
- Especially hard for non-English

Social media

A real tweet:
“ikr smh he asked fir yo last name so he can add u on fb lololol”

- Translation:
  - *"ikr"* means "I know, right?"
  - *"smh"* means "shake my head"
  - *"fb"* means "Facebook", a very common proper noun.
  - *"yo"* is being used as equivalent to *"your".*
  - *"fir"* is a misspelling or spelling variant of the preposition *for*. (But who knows?!)
- Also common: repeating letters/syllables (“yeahhh”, “hahahaha”, “haha”)
- Good luck with traditional NLP tools…
- Need dedicated toolkits such as [TweetNLP]

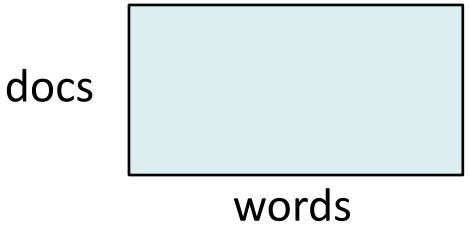
Tokens vs. n-grams

- So far: bag-of-words matrix
  - Rows: documents
  - Columns: tokens (a.k.a. unigrams, or 1-grams)
- Frequently, longer sequences belong together
  - E.g., “United States”, “operating system”
- Brute-force approach: use n > 1
  - E.g., all bigrams (n=2), all trigrams (n=3)
  - Using all 5-grams can beat neural networks (Table 1 here)
  - Problem: combinatorial explosion

Tokens vs. n-grams

- Smarter:
  - Feature selection (“multi-word expressions”, “phrase extraction”)
  - Simple approach for bigrams: keep bigram if *mutual information* between constituent tokens is large
  - How to generalize to n > 2?
    - Frequent itemset/sequence mining
    - Wikipedia anchor texts
    - Compressive feature learning (link)

Postprocessing the BOW matrix



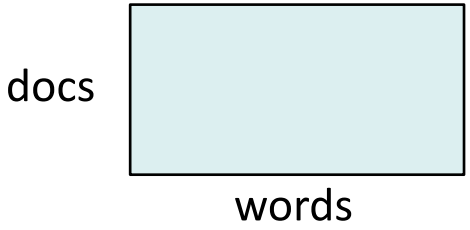
Inverse document frequency

- Not all words equally informative
- This is the reason for removing stopwords (“a”, “the”, “is”, …)
- Beyond discarding stopwords, want to give less weight to more common words
  - E.g., “permanent” vs. “perceptron”
- Standard way: **IDF = inverse document frequency**
  - docfreq(w): number of documents that contain word w
  - N: overall number of documents
  - idf(w) = -log(docfreq(w) / N) = log(N) - log(docfreq(w))

Inverse document frequency

- idf(w) = -log(docfreq(w) / N)
- Interpretation: information content (in terms of #bits) of event "randomly drawing a document that contains w"
- Beyond this theoretical justification, IDF weighting has been shown to work well in practice

TF-IDF matrix



- tf(w, d): term frequency of word w in doc d
  - This is what the bag of words captures
  - E.g., document “what you see is what you get”
    → bag of words {get:1, is:1, see:1, what:2, you:2}
- idf(w): inverse doc freq of w (computed on entire corpus)
- TF-IDF matrix:
  - Entry in row d and column w has value
    tf(w, d) * idf(w)
  - Amounts to multiplying column w with constant idf(w)

Row normalization of TF-IDF matrix

- Longer docs have more non-zero entries
- Interpreted as vectors, longer docs have longer vectors
- This may throw off ML algorithms
  - Long vectors far away from short vectors
  - Dot product: random vector has higher dot product with longer vector
- Fix: normalize doc vectors, i.e., rows of TF-IDF matrix
  - L2-normalization: all rows have Euclidean distance 1 from origin (all data points lie on a unit sphere)
  - L1-normalization: all rows sum to 1, i.e., can be interpreted as distribution
- How to know which one is better?

Column normalization

- IDF-scaling may be seen as column normalization
- Additionally, it may help to apply any of the normalization techniques we discussed in lecture 8 (“Applied ML”)
  - Min-max scale
  - Standardize: subtract mean; divide by standard deviation
- How to know which one (if any) to use?

Bag of tricks for bags of words

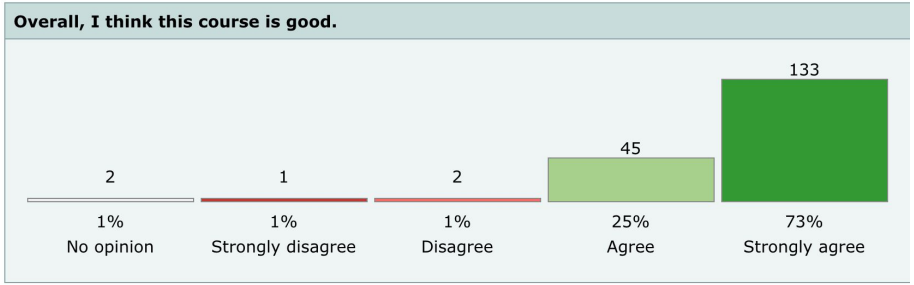
Stay tuned!

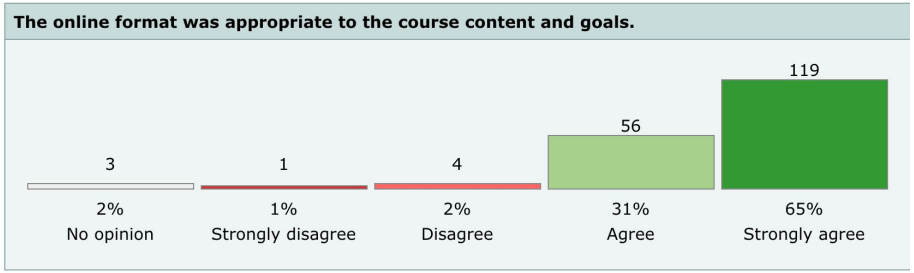
Next week: Part 2

Announcements

- Happy Thanksgiving!
- Homework 2 grades to be released early next week
- Projects:
  - Milestone P3 (freestyle proposal) due on Fri 27 Nov 23:59
  - Milestone P4 (data story and notebooks) due in 3 weeks (Fri 18 Dec)
  - Get crackin'!
  - Video deadline (previously part of P4) pushed back to 23 Dec
- Tomorrow's lab session:
  - More exercises on handling text
  - Project office hours

Course evaluation



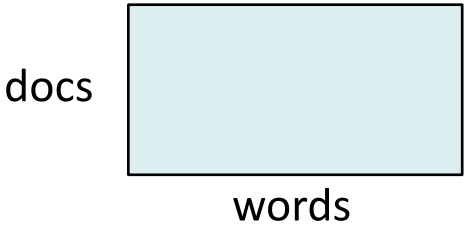


- Thanks for your feedback! -- We'll use it to improve the class further
- Most of you like the applied character of the class, and especially the extra value of the lab sessions
- Some concerns: workload; class too hands-on; class too hands-off; Zulip; "The course feels very pretentious and the lectures are mostly a bunch of hand-waving mambo jumbo" ;-)

Recap

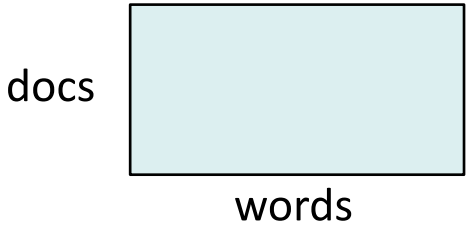
Let me open my **bag of tricks for bags of words** for you! But only if you were good children...

Reminder:
bag-of-words matrix



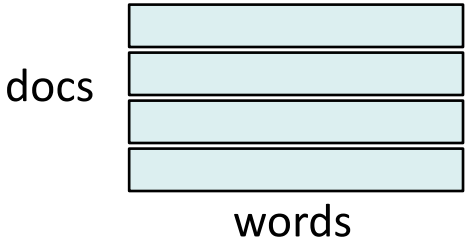
Revisiting the 4 typical tasks

- Document retrieval
- Document classification
- Sentiment analysis
- Topic detection



- TF-IDF matrix to the rescue
  - Entry for doc d, word w:
    tf(w, d) * idf(w)

Typical task 1: document retrieval



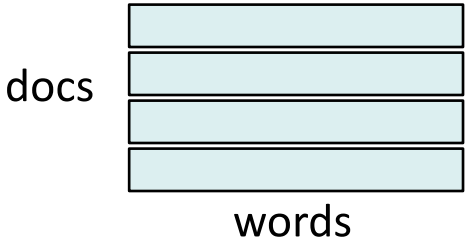
- Nearest-neighbor method in spirit of kNN
- Compare query doc q to all documents in the collection (i.e., rows of the TF-IDF matrix)
- Rank docs from collection in increasing order of distance
- Distance metrics
  - Typically cosine distance (= 1 - cosine similarity)
  - Recall: cosine similarity of q and v = <q/|q|, v/|v|>
  - If rows are L2-normalized, may simply take dot products <q,v>

Typical task 1: document retrieval

- This is just the most basic approach
- Google does much more…
  - Query-independent relevance: PageRank
  - Boost recent results
  - Personalization, contextualization
  - …
- For efficiency
  - Start by filtering documents by presence of query terms (use efficient full-text index)
  - Hugely narrows down set of documents to be ranked

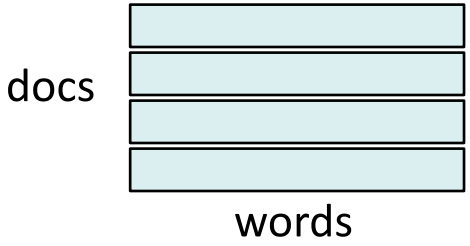
Typical task 2: document classification

- Use TF-IDF matrix as feature matrix for supervised methods (cf. lecture 7)
- Often more features (words) than documents
- What's the danger with this?
- High model capacity can lead to overfitting (high variance)
- Potential solutions:
  - Use more data (i.e., more labeled training docs)
  - Decrease model capacity:
    - Feature selection
    - Regularization (two slides from now)
    - Dimensionality reduction (a few slides from now)
  - Use ensemble methods such as random forests



Typical task 3: sentiment analysis

- Ctrl-C Ctrl-V previous slide



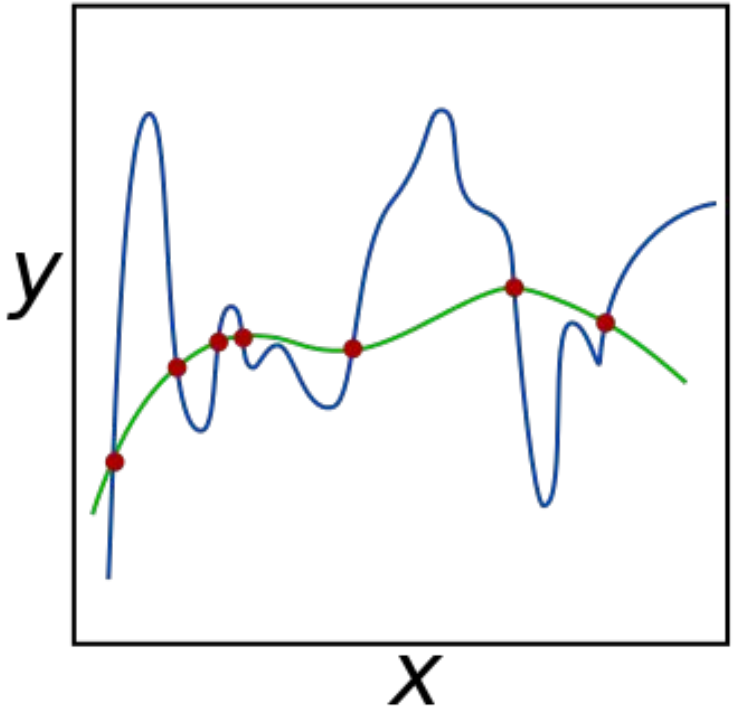
Regularization

- E.g., linear regression:
  Find weight vector β that minimizes $\sum_{i=1}^{n}(y_i - \mathbf{z}_i^\top \boldsymbol{\beta})^2$

  (z_i: feature vector of i-th data point; y_i: label of i-th data point, i.e., here: sentiment [1-5 stars] in document i)
- If one word j appears only in docs with sentiment 5, we can obtain very small training error on these docs by making β_j large enough
- But doesn't generalize to unseen test data!
- Remedy: penalize very large positive and very large negative weights:

$$\sum_{i=1}^{n}(y_i - \mathbf{z}_i^\top \boldsymbol{\beta})^2 + \boxed{\lambda \sum_{j=1}^{p} \beta_j^2}$$

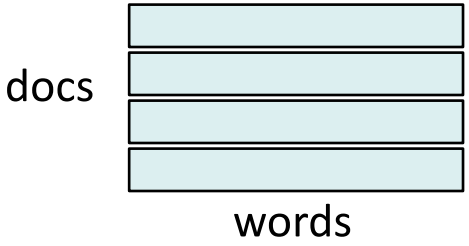
Regularization



POLLING TIME!

Which curve resulted from adding a regularization term to the loss function?

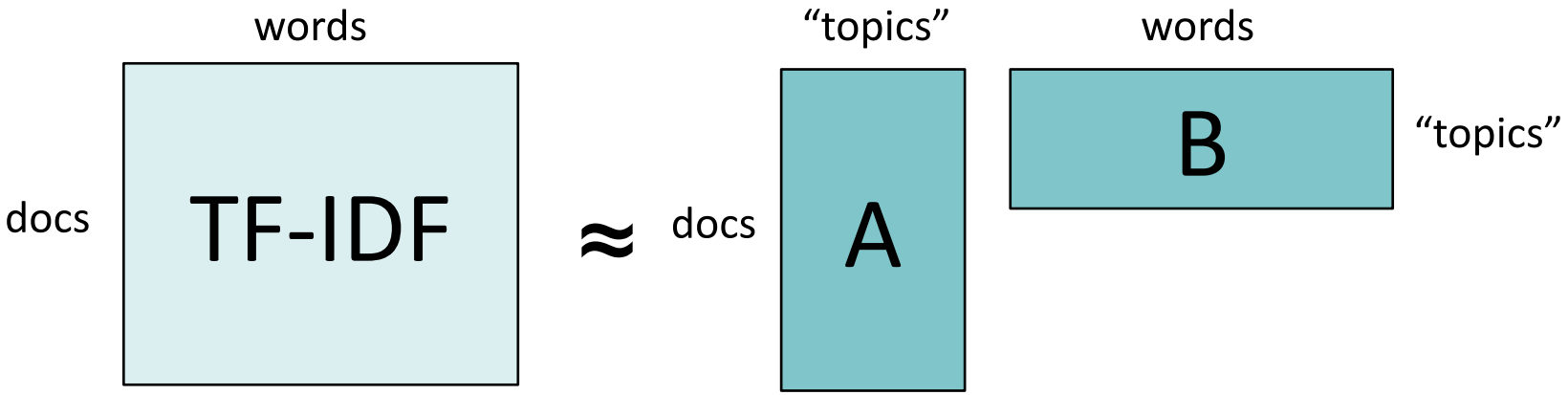
Typical task 4: topic detection



- Cluster rows of TF-IDF matrix (each row a data point)
- Manually inspect clusters and label them with descriptive names (e.g., “news”, “sports”, “romance”, “tech”, “politics”)
- Typically, use k-means or k-medoids algorithms
- Can be difficult if dimensionality is large (#words >> #docs)
  - “Curse of dimensionality”
  - Many outliers

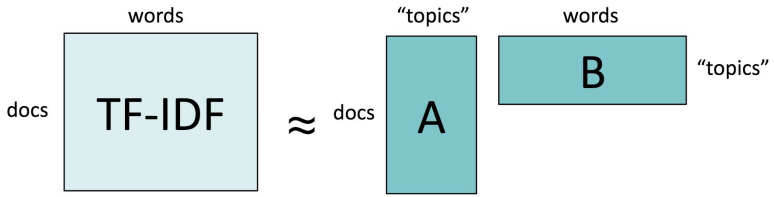
Typical task 4: topic detection

- Alternative approach: **matrix factorization**



- #topics << #words (→ "dimensionality reduction")
- Assume docs and words have representation in "topic space"
- Word frequency (IDF-weighted) modeled as dot product of doc's vectors and word's vectors in topic space
- Topics interpretable in doc space (A's cols) and word space (B's rows)

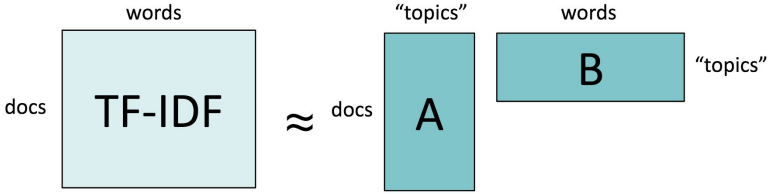
Typical task 4: topic detection



- Optimization problem:
  - Find A, B such that AB is as close to TF-IDF matrix as possible
  - Minimize $$\sum_{d=1}^{N} \sum_{w=1}^{M} (T_{dw} - A_d{}^T B_w)^2$$

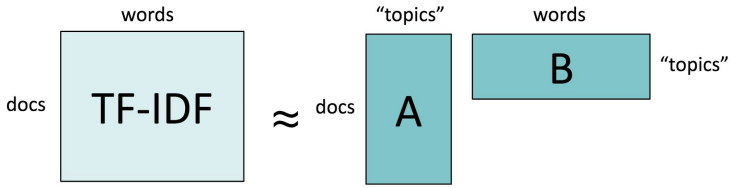
    where T is TF-IDF matrix, A_d is d-th row of A, B_w is w-th column of B
- This is called **latent semantic analysis (LSA)**

Typical task 4: topic detection



- You already know how to efficiently compute this, from your linear algebra class: singular-value decomposition (SVD)
  - $T = USV^T$
  - Freebie: columns of U and V are orthonormal bases (yay!)
  - S is diagonal and captures "importance" of topic (amount of variation in corpus w.r.t. topic)
  - If you want k topics, keep only the first k columns of U and V, and the first k rows and columns of S
    $\longrightarrow$ U', S', V'
  - E.g., A = U', B = $S'V'^T$

Typical task 4: topic detection

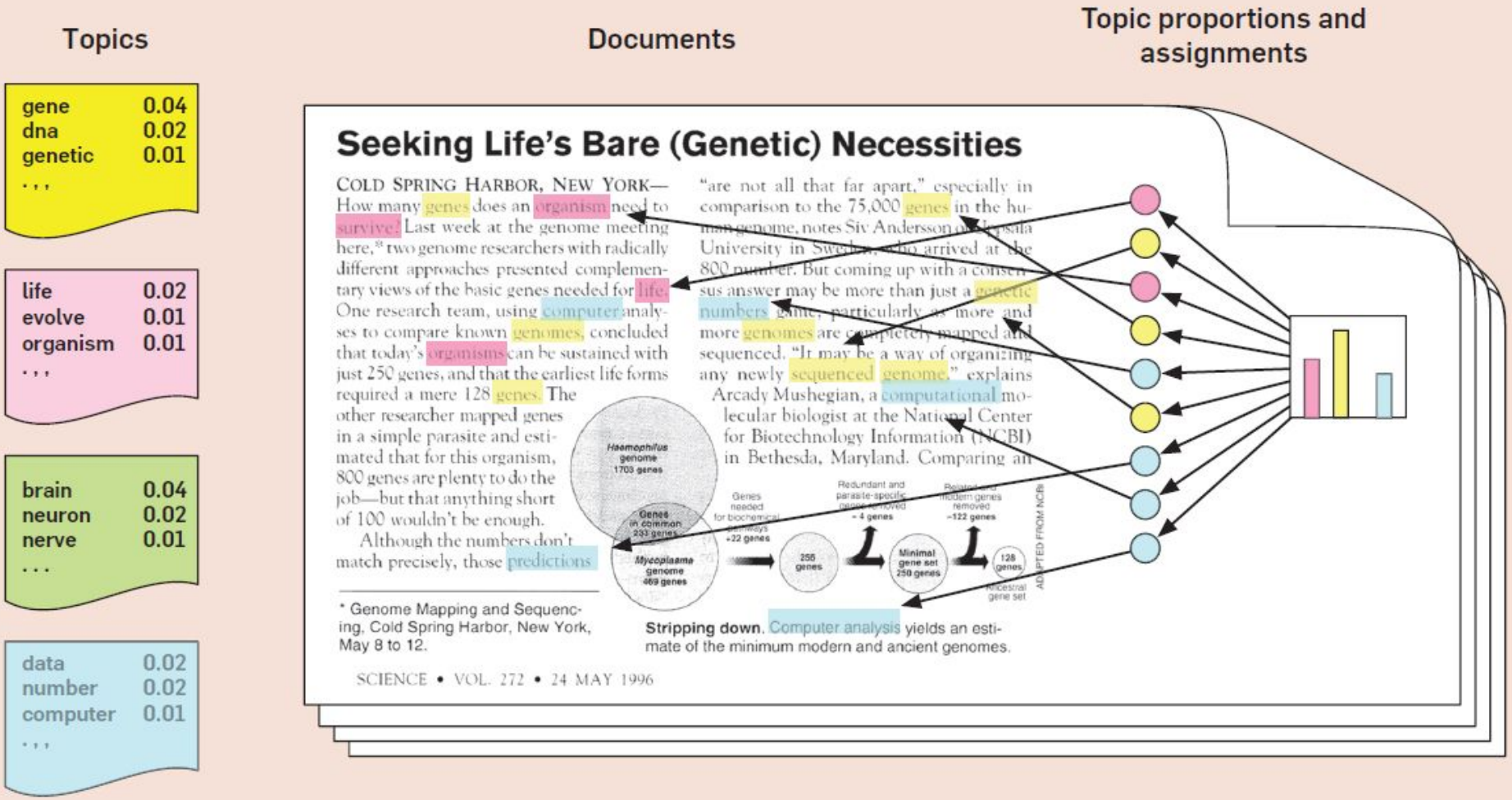


- Recall potential problem with clustering and classification and regression: "curse of dimensionality"
- Matrix factorization via LSA solves these problems for you:
  - Use A instead of original TF-IDF matrix
  - That is, cluster (or learn to classify or regress) in topic space, rather than word space

- Topic representation from LSA is simply a vector, not a probability distribution over topics
- Probabilistic: LDA = Latent Dirichlet Allocation (p.t.o.)

LDA: probabilistic topic modeling

- **L**atent **D**irichlet **A**llocation (*not* Latent Discriminant Analysis!)
- Document := bag of words
- Topic := probability distribution over words
- Each document has a (latent) distribution over topics
- "Generative story" for generating a doc of length n:
  d := sample a topic distribution for the doc (← "Dirichlet")
  for i = 1, …, n
    t := sample a topic from topic distribution d
    w := sample a word from topic t
    Add w to the bag of words of the doc to be generated

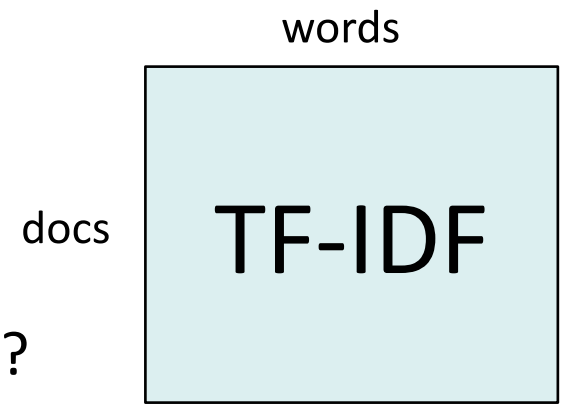

Topics
gene 0.04
dna 0.02
genetic 0.01
. . .
life 0.02
evolve 0.01
organism 0.01
. . .
brain 0.04
neuron 0.02
nerve 0.01
. . .
data 0.02
number 0.02
computer 0.01
. . .
Documents
Topic proportions and assignments
Seeking Life's Bare (Genetic) Necessities
COLD SPRING HARBOR, NEW YORK—How many genes does an organism need to survive? Last week at the genome meeting here,* two genome researchers with radically different approaches presented complementary views of the basic genes needed for life. One research team, using computer analyses to compare known genomes, concluded that today's organisms can be sustained with just 250 genes, and that the earliest life forms required a mere 128 genes. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.
Although the numbers don't match precisely, those predictions "are not all that far apart," especially in comparison to the 75,000 genes in the human genome, notes Siv Andersson of Uppsala University in Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a genetic numbers game, particularly as more and more genomes are completely mapped and sequenced. "It may be a way of organizing any newly sequenced genome," explains Arcady Mushegian, a computational molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing an
Haemophilus genome 1703 genes
Genes in common 333 genes
Mycoplasma genome 469 genes
Genes needed for biochemical pathways +22 genes
255 genes
Redundant and parasite-specific genes removed − 4 genes
Minimal gene set 250 genes
Related and modern genes removed −122 genes
128 genes
Ancestral gene set
ADAPTED FROM NCBI
Stripping down. Computer analysis yields an estimate of the minimum modern and ancient genomes.
* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.
SCIENCE • VOL. 272 • 24 MAY 1996

Topic inference in LDA

- LDA is unsupervised (topics come out “magically”)
- Input:
  - Docs represented as bags of words
  - Number K of topics
- Output:
  - K topics (distributions over words)
  - For each doc: distribution over K topics
- How is this done?
  - Find distributions (i.e., topics, docs) that maximize the likelihood of the observed documents (maximum likelihood)

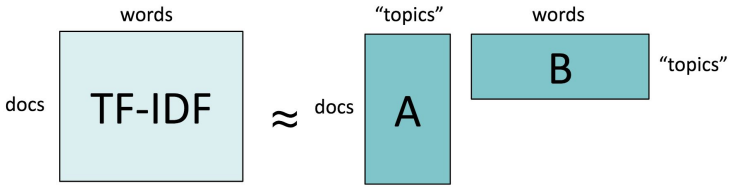
Question:

- "Which of these word pairs is more closely related?"
  - car, bus
  - car, astronaut
- How to quantify this?
- Detour:
  - How to quantify closeness of two docs?
  - E.g., cosine of **rows** of TF-IDF matrix
- Retour:
  - How to quantify closeness of two words?
  - E.g., cosine of **cols** of TF-IDF matrix



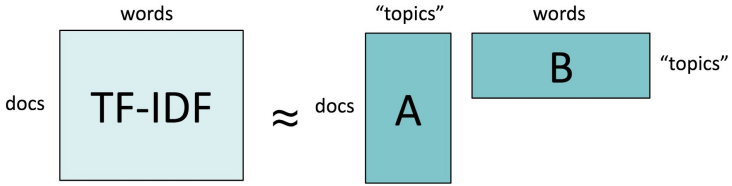
Sparsity in TF-IDF matrix

- Two docs (i.e., rows of TF-IDF matrix)
  - “Do you love men?”
  - “Adorest thou the likes of Adam?”
  - Cosine of row vectors == 0
- Solution:
  - Move from sparse to dense vectors
  - But how?
  - Latent semantic analysis (LSA)!

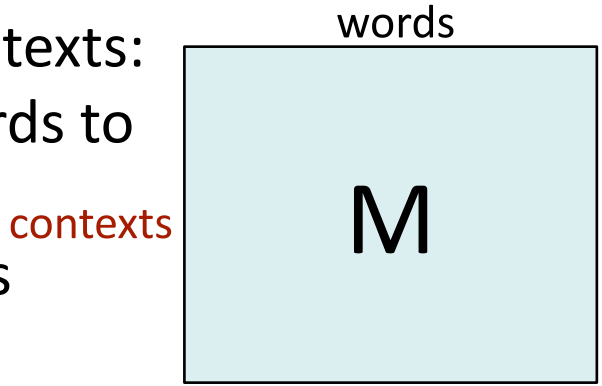


“Word vectors”

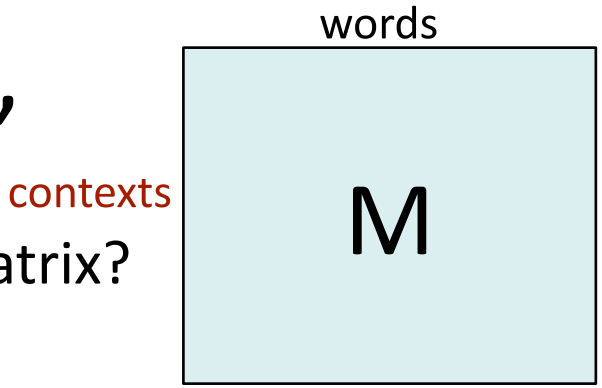
- Columns of TF-IDF matrix (sparse) or of word-by-topic matrix B (dense)



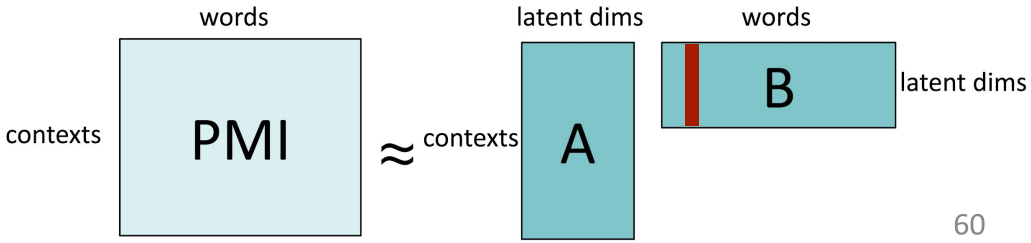
- Problem:
  - Entire doc treated as one bag of words
  - All information about word proximity, syntax, etc., lost
- Solution:
  - Instead of full docs, consider local contexts: windows of L (e.g., 3) consecutive words to left and right of the target word
  - Rows of matrix: not docs, but contexts



"Word vectors"



- What to use as entries of word/context matrix?
- Straightforward: same as TF-IDF, but with contexts as "pseudo-docs": M[c,w] = TF-IDF(c,w)
- May use any other measures of statistical association
- E.g., pointwise mutual information (PMI):
  M[c,w] = PMI(c,w) = $\log \frac{\Pr(c, w)}{\Pr(c)\ \Pr(w)}$
  "How much more likely are c and w to occur together than if they were independent?"
- word2vec: factor PMI matrix and use columns of B as word vectors

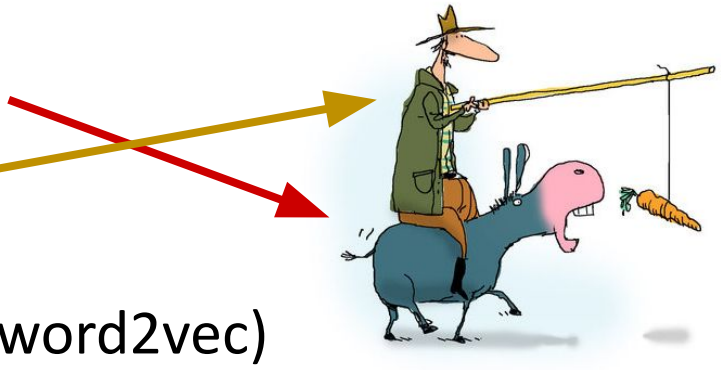


From words to texts

- Word vectors represent, well, words
- How to represent larger units, such as sentences, paragraphs, docs?
- Typical approach: take sum/average of word vectors
- Note: this is roughly also what bags of words are (when using "one-hot" encoding for words, i.e., vector with exactly one 1, rest 0)
- Current research: **learn** vectors for longer units
  - Cr5, sent2vec
  - Convolutional neural networks
  - Recurrent neural networks, e.g., LSTM, ELMo
  - Transformer-based models, e.g., BERT (next slide)

Contextualized word vectors

- Motivating example:
  - “My ass likes carrots”
  - vs. “He’s such an ass”

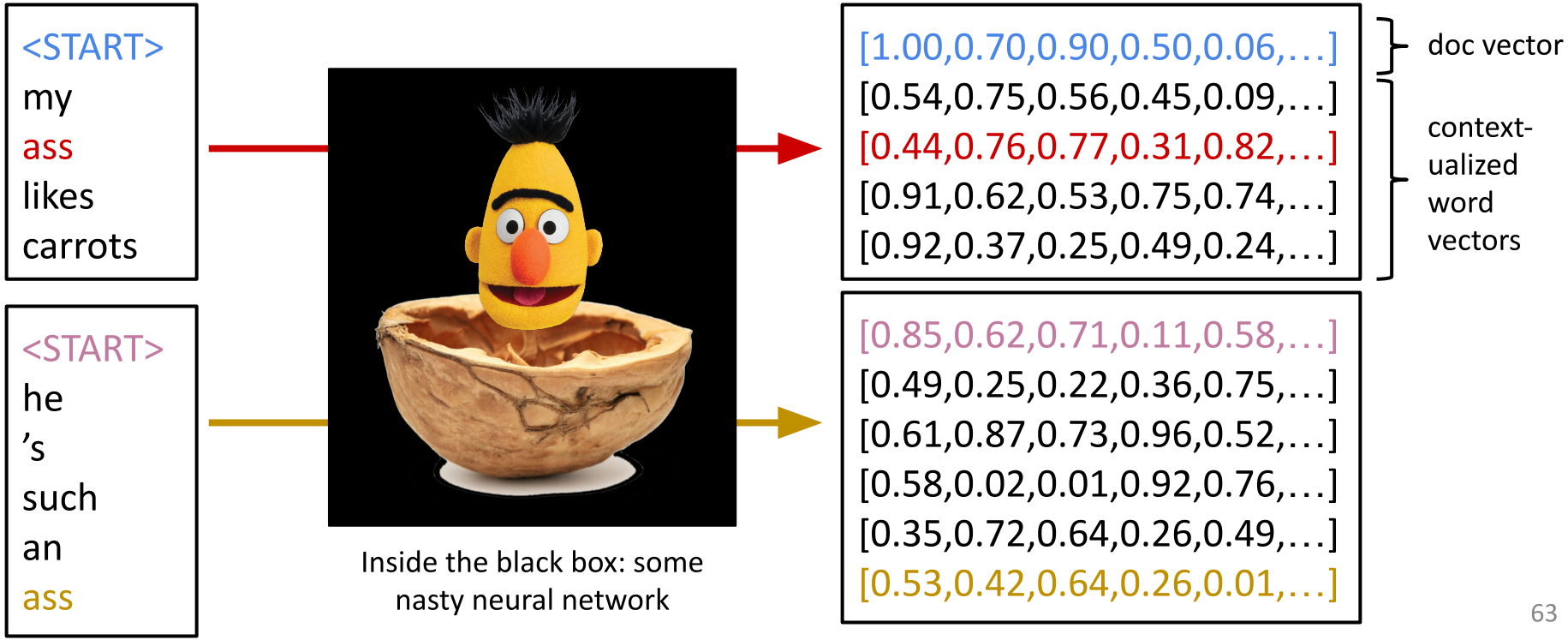


- Classic word vectors (e.g., word2vec) cannot distinguish these two cases; same vector used for both instances of “ass”

- Solution: contextualized word vectors
  - E.g., BERT

BERT in a nutshell

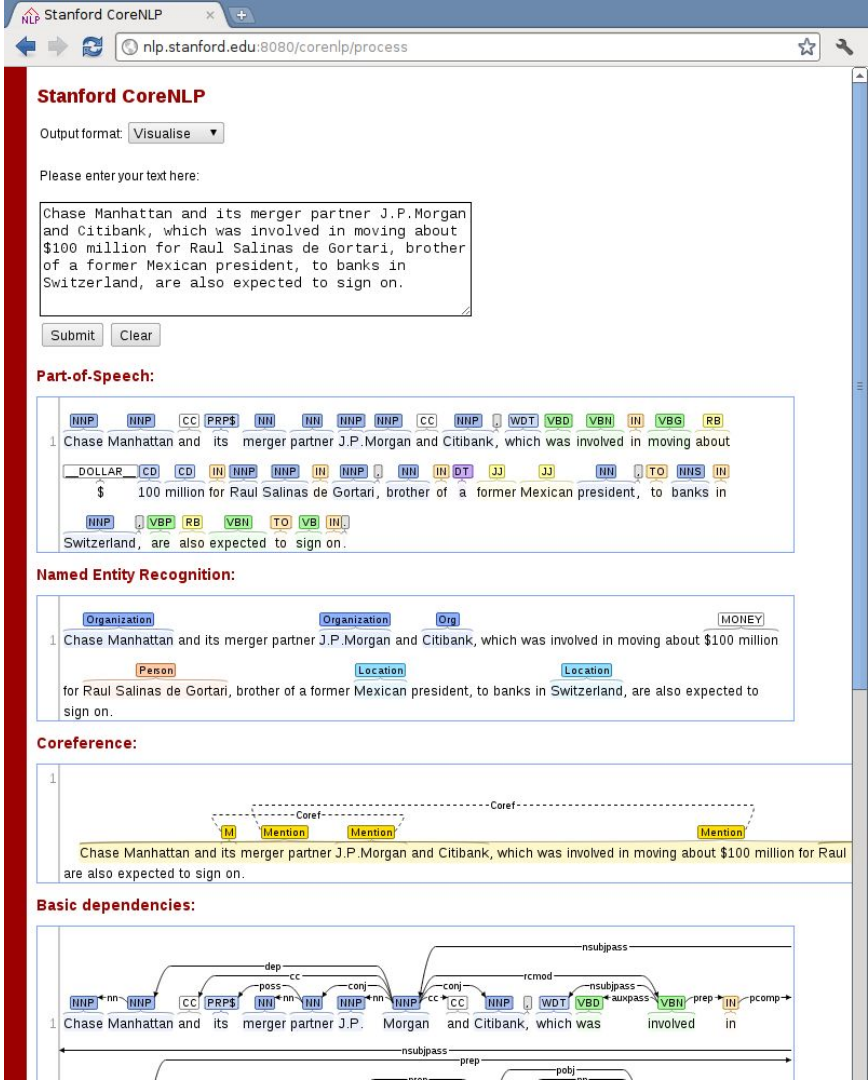
- Introduced two years ago (Oct 2018) by Google Research



Beyond bags of words

NLP pipeline

- Tokenization
- Sentence splitting
- Part-of-speech (POS) tagging
- Named-entity recognition (NER)
- Coreference resolution
- Parsing
  - Shallow parsing (a.k.a. chunking)
  - Constituency parsing
  - Dependency parsing



NLP pipeline

- Implemented by Stanford CoreNLP, nltk, spaCy, etc.
- Sequential model
  - Fixed order of steps
  - Early errors will propagate downstream
  - Fixed order not optimal for all cases (e.g., syntax usually done before semantics, but semantics might be useful for inferring syntax)
- Hence, current research: learn all tasks jointly (early example)
- To learn how all this magic is implemented
  - Take CS-431 (Intro to NLP) in the spring semester

Give us feedback on this lecture here:
https://go.epfl.ch/ada2020-lec10-feedback

- What did you (not) like about this lecture?
- What was (not) well explained?
- On what would you like more (fewer) details?
- …