



# CSCE 670 - Information Storage and Retrieval

## Week 1: Course Overview; Boolean Retrieval

Yu Zhang

[yuzhang@tamu.edu](mailto:yuzhang@tamu.edu)

Course Website: <https://yuzhang-teaching.github.io/CSCE670-S26.html>

# Course Logistics

# Course Website

<https://yuzhang-teaching.github.io/CSCE670-S26.html>

## Schedule (Subject to changes)

| Week | Date | Topic  | Slides | Optional Readings                   |
|------|------|--|--------|-------------------------------------|
| W1   | 1/12 | Course Logistics                                     |        | -                                   |
|      | 1/14 | Overview of Information Retrieval, Boolean Retrieval |        | [MRS Chapter 1]                     |
|      | 1/16 | Boolean Retrieval (Cont'd)                           |        | [MRS Chapter 2]                     |
| W2   | 1/19 | No Class (Martin Luther King, Jr. Day)               |        |                                     |
|      | 1/21 | TF-IDF, Vector Space Model                           |        | [MRS Chapter 6], [MRS Chapter 7]    |
|      | 1/23 | BM25   |        | [MRS Chapter 11]                    |
| W3   | 1/26 | Link Analysis: PageRank                              |        | [MRS Chapter 21], [LRU Chapter 5.1] |
|      | 1/26 | Homework 0 Due (Monday)                              |        |                                     |
|      | 1/28 | Link Analysis: PageRank (Cont'd), HITS               |        | [LRU Chapter 5.2/5.5]               |
|      | 1/30 | Link Analysis: Topic-Sensitive PageRank              |        | [LRU Chapter 5.3/5.4]               |

# Canvas

<https://canvas.tamu.edu/courses/426688>

The screenshot shows the Canvas LMS interface for the course CSCE 670 600: INFO STORAGE & RETRIEVAL. The interface is divided into a left sidebar, a top navigation bar, and a main content area.

**Left Sidebar (Navigation Menu):**

- ATM Logo
- Account (User icon)
- Dashboard (Clock icon)
- Courses (Book icon)
- Calendar (Calendar icon)
- Inbox (Envelope icon)
- History (Clock icon)
- Help (Question mark icon)
- Speaker icon and heart icon at the bottom.

**Top Navigation Bar:**

- Menu icon (three horizontal lines)
- Course ID: CSCE 670 600:

**Main Content Area:**

- Course ID: CSCE 670 600:
- Term: CS.Spring.2026
- Course Title: 26 SPRING CSCE 670 600: INFO STORAGE & RETRIEVAL <sup>▲</sup><sub>▼</sub>
- ATM Logo (Large)
- Welcome!
- Welcome to the course! I encourage you to read the syllabus and explore the resources in this Canvas course. Please contact me if you have any questions.
- Student Resources (Button)

# Course Logistics

- **Course Website:** Syllabus, Schedule, Slides, Optional Readings
- **Canvas:** Grades, Announcements, Assignments, Discussions
- Two ways to reach me/TA
  - Email us directly (please put [CSCE670] in the subject)
  - Message us through Canvas

# Grading (See Syllabus and Course Website for Details)

- Homework: 30%

- Homework 0: 2% [due Jan 26 (Mon)]
- Homework 1: 7% [due Feb 9 (Mon)]
- Homework 2: 7% [due Mar 2 (Mon)]
- Homework 3: 7% [due Mar 30 (Mon)]
- Homework 4: 7% [due Apr 20 (Mon)]

- Quizzes: 20%

- Quiz 1: 5% [in the Feb 6 class (Fri)]
- Quiz 2: 5% [in the Feb 27 class (Fri)]
- Quiz 3: 5% [in the Mar 25 class (Wed)]
- Quiz 4: 5% [in the Apr 15 class (Wed)]

- Group Project: 20%

- Proposal: 2% [due Mar 7 (Sat)]
- Presentation: 9% [in the Apr 20, Apr 22, Apr 24, and Apr 27 classes]
- Report: 9% [due May 2 (Sat)]

- Final: 30% [3:30pm – 5:30pm, May 4, HRBB 113]

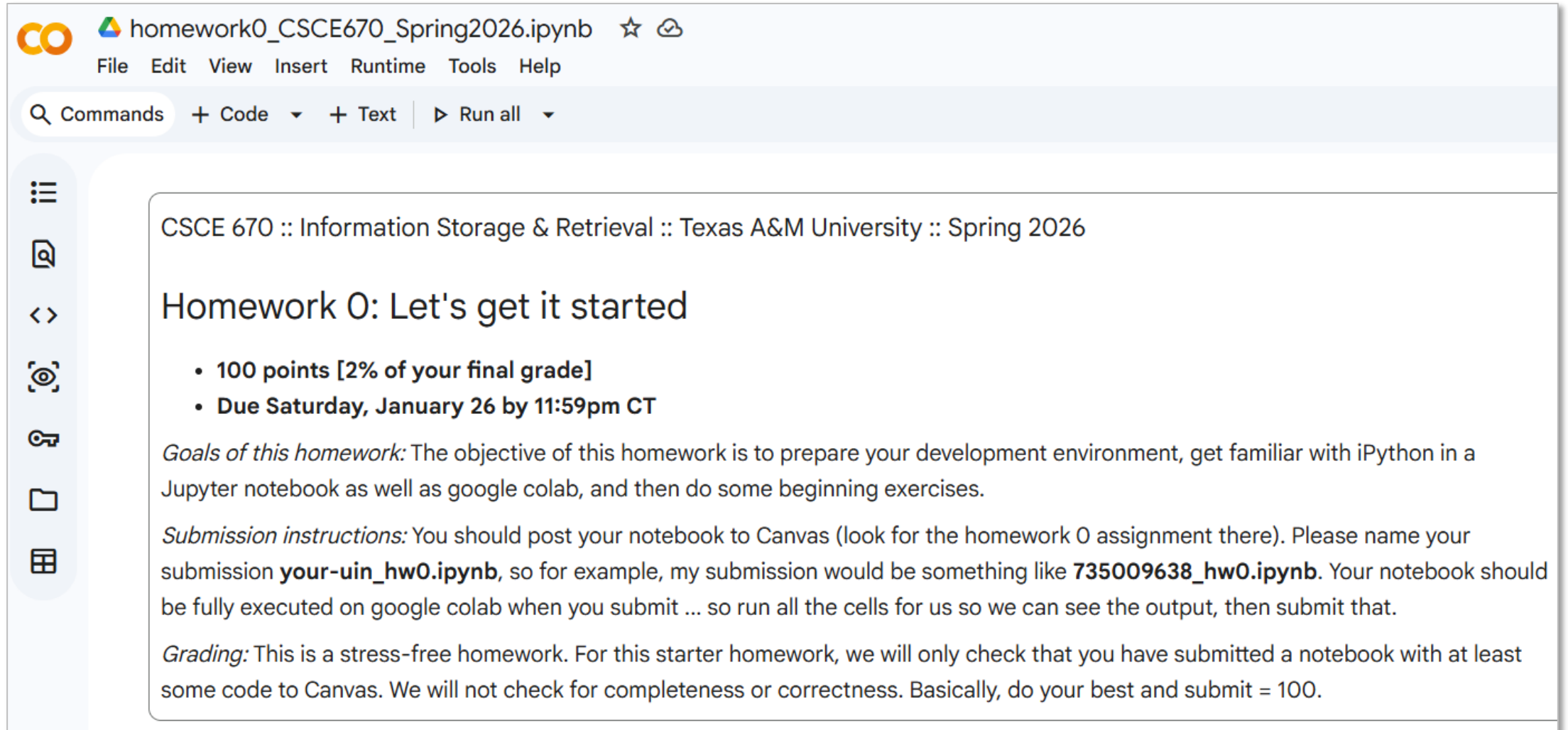
# Homework (30%)

- We will have 1 “getting-started” homework and then 4 real homework assignments
- Fun opportunity to put concepts into action
- All in Python!
- Individual work, but you may discuss generally with others
  - You should write your own code, by yourself
  - BUT you may talk amongst yourselves about approaches/methods
    - E.g., sit in a group with no laptops, just talking = totally fine
    - E.g., sit next to each other while you code = BAD NEWS
  - You must acknowledge ALL help in your homework
    - Using code comments
    - I will show you an example in 5 minutes

# AI Policy

- “In principle *you may submit AI-generated code*, or code that is based on or derived from AI-generated code, as long as this use is properly documented in the comments: you need to include the prompt and the significant parts of the response. AI tools may help you avoid syntax errors, but there is no guarantee that the generated code is correct. *It is your responsibility to identify errors* in program logic through comprehensive, documented testing. Moreover, generated code, even if syntactically correct, may have significant scope for improvement, in particular regarding separation of concerns and avoiding repetitions. The submission itself must meet our standards of attribution and validation.”
- (from Boris Steipe (2023) “Syllabus Resources”. The Sentient Syllabus Project: <http://sentientsyllabus.org>)

# Homework 0 (due Jan 26)



The screenshot shows a Jupyter Notebook interface. At the top, the title bar reads "homework0\_CSCE670\_Spring2026.ipynb" with a star icon and a cloud icon. Below the title bar is a menu bar with "File", "Edit", "View", "Insert", "Runtime", "Tools", and "Help". A toolbar below the menu bar contains a search icon, "Commands", "+ Code", "+ Text", and "Run all". On the left side, there is a vertical sidebar with icons for a list, a document, a code editor, a camera, a key, a folder, and a table. The main content area of the notebook contains the following text:

CSCE 670 :: Information Storage & Retrieval :: Texas A&M University :: Spring 2026

## Homework 0: Let's get it started

- 100 points [2% of your final grade]
- Due Saturday, January 26 by 11:59pm CT

*Goals of this homework:* The objective of this homework is to prepare your development environment, get familiar with iPython in a Jupyter notebook as well as google colab, and then do some beginning exercises.

*Submission instructions:* You should post your notebook to Canvas (look for the homework 0 assignment there). Please name your submission **your-uid\_hw0.ipynb**, so for example, my submission would be something like **735009638\_hw0.ipynb**. Your notebook should be fully executed on google colab when you submit ... so run all the cells for us so we can see the output, then submit that.

*Grading:* This is a stress-free homework. For this starter homework, we will only check that you have submitted a notebook with at least some code to Canvas. We will not check for completeness or correctness. Basically, do your best and submit = 100.

# Homework Late Days

- Due by 11:59pm on the due date
- You get 5 late days total
- Late day = indivisible 24-hour unit
  - E.g., if due date is 11:59pm on Saturday, and you submit at 12:01am on Sunday = one late day
  - No penalty for using a late day; no need to alert me/TA that you are using a late day
- Once you are out of late days, you get 0

# Regrade Policy

- Once you receive your graded assignment (e.g., homework and quizzes), you have **7** days to **request a regrade in writing** (give to me)
- After 7 days = no regrades
- You must give us a written explanation of what the issue is
- **We will re-grade the entire assignment**

Questions?

## 4 Quizzes ( $5\% \times 4 = 20\%$ )

- In-class
- 45 minutes, but designed to only take 30-35 minutes
- 7 multiple-choice questions
- Answering 5 questions correctly will earn you full credit (5%)

| # correct answers | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
|-------------------|----|----|----|----|----|----|----|----|
| credit            | 0% | 1% | 2% | 3% | 4% | 5% | 5% | 5% |

- Closed book
  - Laptops, books, and notes are NOT allowed.
- Calculators are NOT required, and the questions will NOT involve calculations (such as square roots or logarithms) that cannot be done easily by hand.

# Absence Policy

- Please refer to Student Rule 7 (<https://student-rules.tamu.edu/rule07/>) about **excused absences**, including definitions, and related documentation and timelines.
  - For students who miss a quiz due to an excused absence, your quiz score will be counted as part of the final exam.
  - Specifically, your final exam weight will increase by 5% for each quiz missed with an excused absence (i.e.,  $30\% + 5\% \times \text{number of excused quiz absences}$ ).

## Final (30%)

- In our regular classroom
- 3:30pm – 5:30pm on May 4 (Monday)
- 120 minutes; Comprehensive
- You can bring **one cheatsheet**
  - Cheatsheet = 8.5” x 11” standard sheet of paper with anything on it, front and back

# Group Project (20%)

- Teams of **3 or 4** (any deviation from this size requires prior approval from the instructor)
  - **Option 1**: A prototype (search engine or recommender system)
  - **Option 2**: A research project (e.g., reasoning-search interleaved LLMs)
  - **Option 3**: A survey (e.g., recent studies on search-enhanced LLMs)
- **Topic-wise**: your choice, as long as it is related to information retrieval!
- Project presentations during our last four classes
- Super-fun opportunity for you to explore some compelling aspect of IR

# Group Project (20%)

- More details to be discussed in the Feb 13 class

|    |      |                                    |  |  |
|----|------|------------------------------------|--|--|
| W5 | 2/9  | Learning to Rank                   |  | [MRS Chapter 14], [Nallapati, SIGIR'04]                                |
|    | 2/9  | Homework 1 Due (Monday)            |  |  |
|    | 2/11 | Learning to Rank (Cont'd)          |  | [Joachims, KDD'02], [Burges et al., ICML'05], [Burges et al., NIPS'06] |
|    | 2/13 | Course Project Information Session |  | -  |



- Project proposal due on Mar 7 (so you still have plenty of time)

|    |     |                                   |  |  |
|----|-----|-----------------------------------|--|--|
| W8 | 3/2 | word2vec                          |  | [Mikolov et al., NIPS'13], [Levy and Goldberg, NIPS'14]                          |
|    | 3/2 | Homework 2 Due (Monday)           |  |  |
|    | 3/4 | word2vec (Cont'd), Neural Ranking |  | [Pennington et al., EMNLP'14], [Tang et al., KDD'15], [Nalisnick et al., WWW'16] |
|    | 3/6 | Neural Ranking (Cont'd)           |  | [Karpukhin et al., EMNLP'20], [Mitra et al., WWW'17]                             |
|    | 3/7 | Project Proposal Due (Saturday)   |  |  |

# Group Project (20%)

- Project presentations during our last four classes

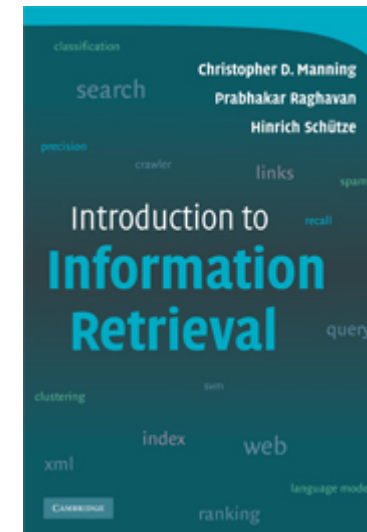
|     |      |                              |
|-----|------|------------------------------|
| W15 | 4/20 | Project Presentations (Zoom) |
|     | 4/20 | Homework 4 Due (Monday)      |
|     | 4/22 | Project Presentations (Zoom) |
|     | 4/24 | Project Presentations (Zoom) |
| W16 | 4/27 | Project Presentations (Zoom) |

- Held on Zoom
  -  To start our summer break early
  -  There will be 16-18 groups presenting in these lectures. Zoom allows us to quickly switch between shared screens, reducing transition time between groups and giving each group more time to present.

# Overview of Information Retrieval (IR)

# Information Retrieval is ...

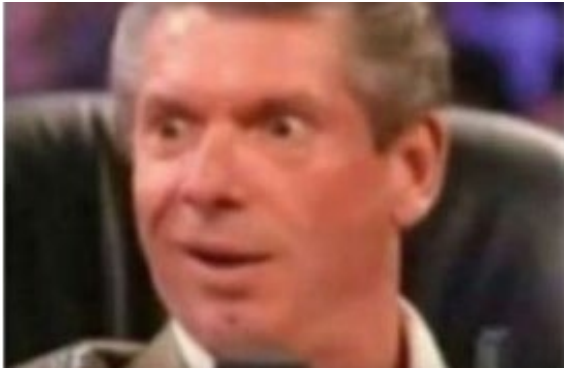
- “... *finding material (usually documents) of an unstructured nature (usually text) that satisfies an information need from within large collections (usually stored on computers).*”



(according to Manning, Raghavan, Schutze 2008)

# Information Retrieval is ...

- “... the process of obtaining information system resources that are relevant to an information need from a collection of those resources.”

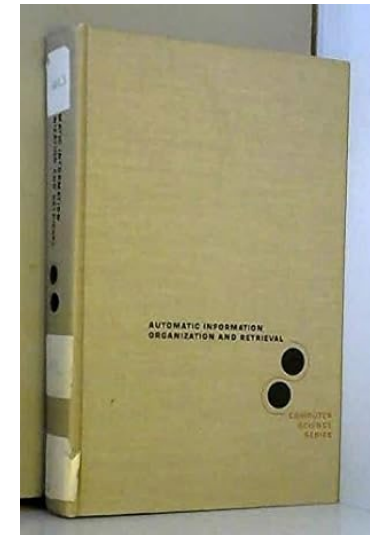


WIKIPEDIA  
The Free Encyclopedia

(according to Wikipedia)

# Information Retrieval is ...

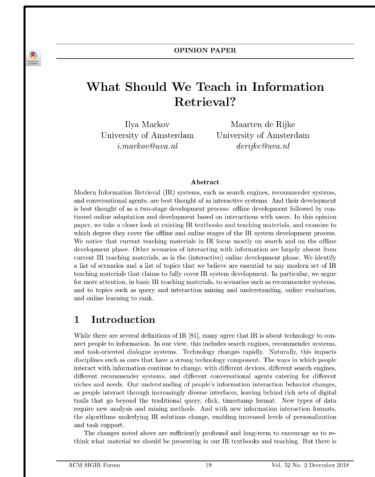
- “... a field concerned with the structure, analysis, organization, storage, searching, and retrieval of information.”



(according to Gerard Salton “Father of IR” 1968)

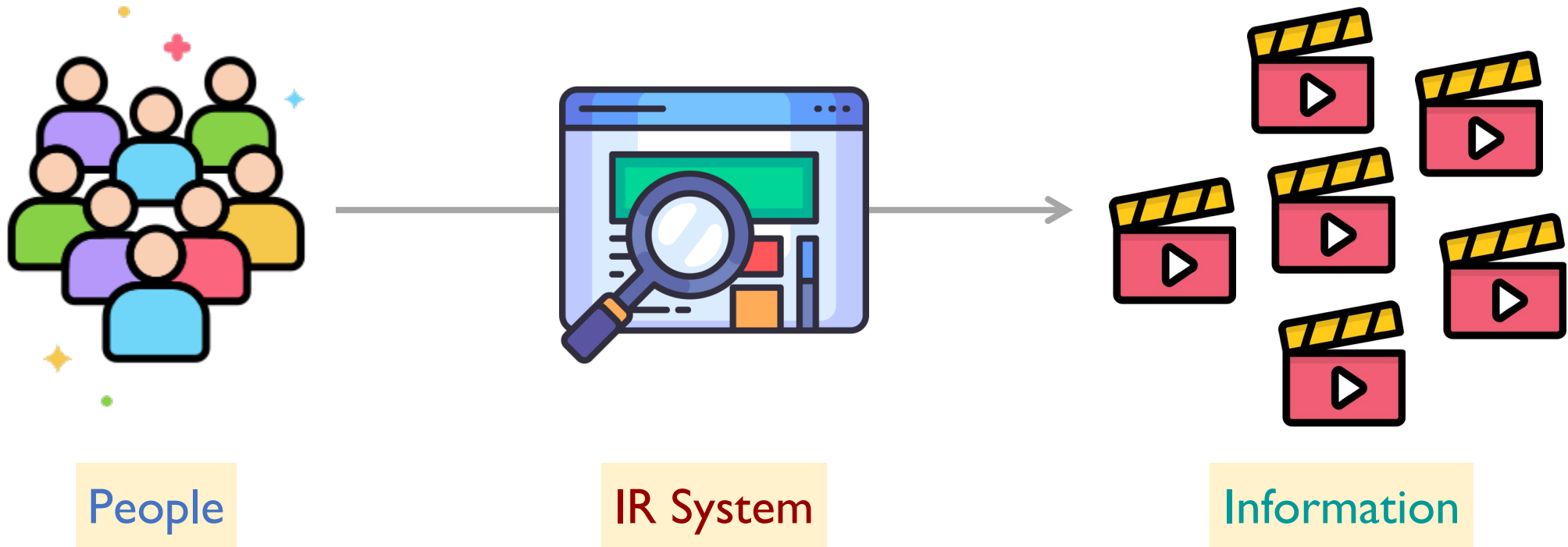
# Information Retrieval is ...

- “... *about technology to connect people to information.*”



(according to Markov and de Rijke 2018)

# IR connects people to information



- Examples?

# Example: Course Explorer



Students



Boolean  
Retrieval  
(Week 1)



Courses  
about  
“learning”

| Title ▾  | CRN<br>Syllab... ▾                | S. ▾                 | Crse ▾               | Sect ▾               | Hrs ▾                | Instructor(s) ▾          |
|--|-----------------------------------|----------------------|----------------------|----------------------|----------------------|--------------------------|
| <input type="text" value="learning"/>            | <input type="text"/>              | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/>     |
| <a href="#">MACHINE LEARNING</a>                 | 57951<br><a href="#">Syllabus</a> | CSCE                 | 633                  | 700                  | 3                    | Bobak Mortazavi (P)      |
| <a href="#">DEEP LEARNING</a>                    | 36429<br><a href="#">Syllabus</a> | CSCE                 | 636                  | 600                  | 3                    | Anxiao Jiang (P)         |
| <a href="#">DEEP LEARNING</a>                    | 62232<br><a href="#">Syllabus</a> | CSCE                 | 636                  | 700                  | 3                    | Anxiao Jiang (P)         |
| <a href="#">DEEP REINFORCEMENT<br/>LEARNING</a>  | 55177<br><a href="#">Syllabus</a> | CSCE                 | 642                  | 600                  | 3                    | Guni Sharon (P)          |
| <a href="#">DEEP REINFORCEMENT<br/>LEARNING</a>  | 60328<br><a href="#">Syllabus</a> | CSCE                 | 642                  | 700                  | 3                    | Guni Sharon (P)          |
| <a href="#">SPTP: DEEP LEARNING<br/>AND LLMS</a> | 62415<br><a href="#">Syllabus</a> | CSCE                 | 689                  | 600                  | 3                    | Tomer Joseph Galanti (P) |

# Example: PubMed, Semantic Scholar, Google Scholar



Researchers



TF-IDF,  
BM25  
(Week 2)



Papers about  
“respiratory  
disease”

NIH National Library of Medicine  
National Center for Biotechnology Information

Log in

PubMed®

respiratory disease

Search

Advanced Create alert Create RSS User Guide

Save Email Send to Sort by: Best match Display options

MY CUSTOM FILTERS

2,024,858 results

RESULTS BY YEAR

1846 2026

Global Impact of **Respiratory Disease**: What Can We Do, Together, to Make a Difference?

1

Cite Levine SM, Marciniuk DD.  
Chest. 2022 May;161(5):1153-1154. doi: 10.1016/j.chest.2022.01.014. Epub 2022 Jan 17.  
PMID: 35051424 **Free PMC article.** No abstract available.

Lessons from Dairy Farmers for Occupational Allergy and **Respiratory Disease**.

# Example: PubMed, Semantic Scholar, Google Scholar




Researchers



word2vec,  
BERT  
(Weeks 8  
and 10)



Papers about  
“Byzantine  
privacy”

 SEMANTIC SCHOLAR





About 405,000 results for “Byzantine privacy”

**Privacy-Preserving and Byzantine-Robust Federated Learning**

Caiqin Dong Jian Weng +4 authors Shui Yu Computer Science ·

IEEE Transactions on Dependable and Secure... · 1 March 2024

**TLDR** An efficient maliciously secure shuffling protocol that maintains robustness in the presence of poisoning attacks and preserves the **privacy** of local models simultaneously and leverages three-party computation (3 PC) to securely achieve a **Byzantine-robust** aggregation method.[Expand](#)

 39  IEEE  Save  Cite

**Efficient Byzantine-Robust and Privacy-Preserving Federated Learning on Compressive Domain**

# Example: Google




Aggies




PageRank  
(Week 3)



Webpages  
about “tamu  
spring break  
time 2026”



tamu spring break time 2026




Texas A&M University

<https://registrar.tamu.edu> › [academic-calendar](#) › [spring-2...](#)

[Spring 2026 - Registrar - Texas A&M University](#)

Academic Calendar - **Spring 2026** · Monday, December 22nd, 2025 · Friday, January 9th, 2026 · Monday, January 12th, 2026 · Friday, January 16th, 2026 · Monday, January ... [Read more](#)



Texas A&M University

<https://catalog.tamu.edu> › [graduate](#) › [academic-calendar](#)

[Academic Calendars < Texas A&M ...](#)

Faculty and Staff **Holiday**. March 25, Wednesday. Last day to apply for **spring 2026** graduation online. March 26 - April 10, Thursday -Friday. Preregistration ... [Read more](#)

# Example: ChatGPT



IR Beginners



LLMs with  
Search  
Engines  
(Week 12)



Most cited  
paper in IR

What is the most-cited paper in IR? Please provide sources.

You're asking: "What is the most-cited paper in Information Retrieval (IR)? Please provide sources."

## Most-Cited IR Paper

The classic and arguably most-cited foundational paper in Information Retrieval is:

### "A Vector Space Model for Automatic Indexing"

- Authors: Gerard Salton, A. Wong, and C. S. Yang
- Published in *Communications of the ACM*, November 1975.
- This landmark paper introduced the **vector space model (VSM)** and the use of **TF-IDF weighting**, both of which are cornerstones of modern IR systems [Wikipedia +1](#).

Gerard Salton, often called the "**father of Information Retrieval**," developed this model at Cornell and significantly shaped IR theory and practice [Wikipedia](#).

# Example: Amazon



Customers  
who bought an  
IR book



Recommender  
Systems  
(Weeks 6-7)



Other books  
the customers  
may also like

The screenshot shows the Amazon product page for the book 'Information Retrieval: Implementing and Evaluating Search Engines'. The page features a navigation bar with the Amazon logo, delivery location (Yu Bryan 77802), and a search bar containing 'information retrieval'. Below the navigation bar, there are tabs for 'Top', 'About this item', 'Similar', 'From the Author', 'Questions', and 'Reviews'. The 'Similar books' section is highlighted, showing four recommended books:

- Information Retrieval: Implementing and Evaluating Search Engines** by Stefan Bittcher, Charles L.A. Clarke, and Gordon V. Cormack. Rating: 4.5 stars (20 reviews).
- Relevant Search: With applications for Solr and Elasticsearch** by Doug Turnbull and John Turnbull. Rating: 4.5 stars (37 reviews).
- Foundations of Statistical Natural Language Processing** by Christopher D. Manning and Hinrich Schütze. Rating: 4.5 stars (71 reviews).
- AI-Powered Search** by Terry Golubov, Doug Turnbull, and Peter Byrne. Rating: 4.5 stars (11 reviews). Paperback, \$57.12.

# Example: Amazon



Customers  
who bought an  
IR book



LLMs for  
RecSys  
(Week 13)



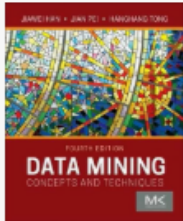
Other data  
mining books  
the customers  
may also like

Rufus ai  
beta

I just bought the book "Introduction to Information Retrieval". Could you recommend a data mining book to me?

Great choice on "Introduction to Information Retrieval"! Since you're building a strong foundation in data science, here are excellent data mining books that complement your information retrieval studies:

**Classic Data Mining Textbooks** [See more](#)




**Data Mining: Concepts and Techniques (The Morgan Kaufman...**  
by Jiawei Han, Jian Pei, et al.  
4.4 ★★★★★ (68)  
Paperback  
\$57<sup>95</sup> List: \$89.95  
[Prime members](#) get FREE delivery  
Wed, Aug 20

Rufus ai  
beta

**Prime members** get FREE delivery  
Wed, Aug 20

The definitive comprehensive textbook covering all essential data mining concepts, from basic principles to advanced techniques  
[More details](#)



**Data Mining: The Textbook**  
by Charu C. Aggarwal  
4.5 ★★★★★ (44)  
Hardcover  
\$57<sup>00</sup> List: \$89.99  
[Prime members](#) get FREE delivery  
Wed, Aug 20

In-depth textbook with strong theoretical foundation and practical algorithms for data mining applications

# Example: TikTok



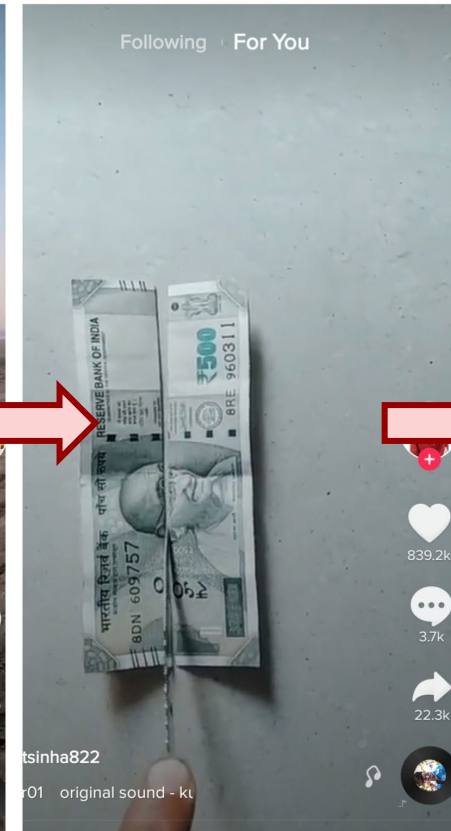
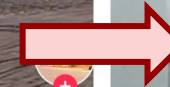
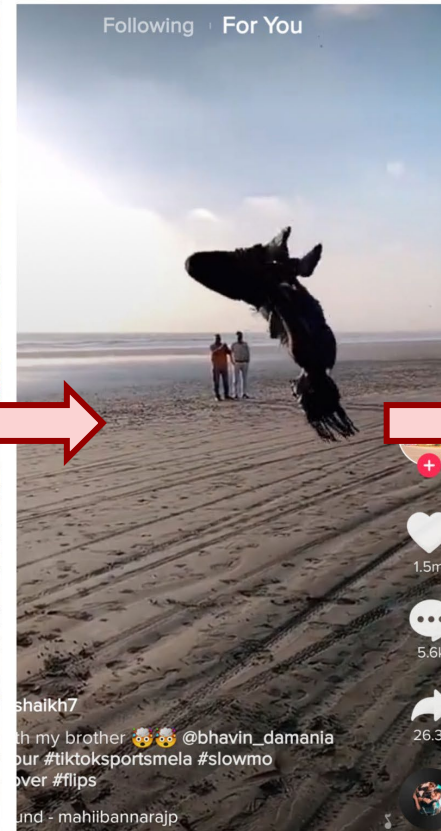
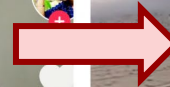
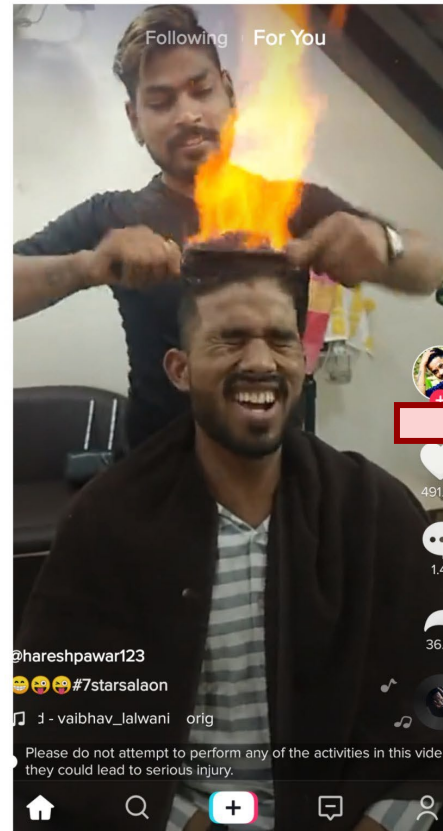
Video  
scrollers



Sequential  
RecSys  
(Week 11)



Next video  
they may be  
interested in



?

IR algorithmically mediates what items a user encounters

## *YouTube's Product Chief on Online Radicalization and Algorithmic Rabbit Holes*

Neal Mohan discusses the streaming site's recommendation engine, which has become a growing liability amid accusations that it steers users to increasingly extreme content.



# We as computer scientists need to ...

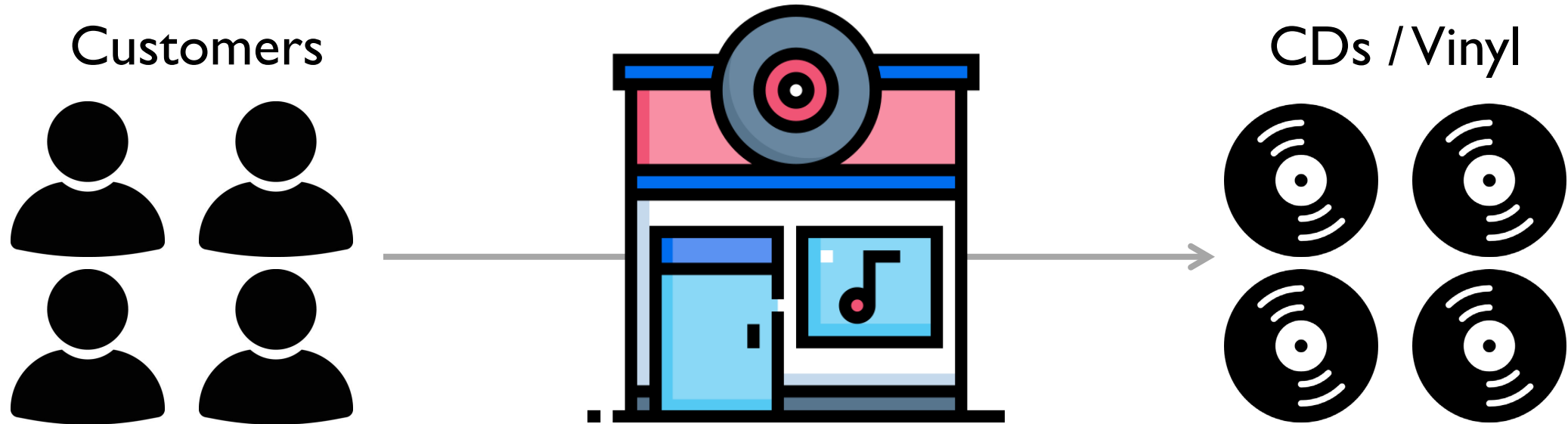
- **Understand** these algorithms
  - How can we build a search engine or a recommender system? What algorithms can we use? What “features” are important? How to evaluate if it is doing a good job?
- **Design** new approaches
  - Can we keep pace with rapid developments in industry and in academia? Adopt new ML/DL approaches? Anticipate the “next” big thing?
- **Be mindful** of the power we wield! Important issues around fairness, bias, misinformation, and other negative outcomes.

# This Course

- **Phase 1:** Search Engines
  - Boolean and ranked retrieval, link analysis, evaluation, learning to rank (ML + ranking), ...
- **Phase 2:** Recommender Systems
  - content-based recommendation, collaborative filtering, matrix factorization, recommendation with implicit feedback, ...
- **Phase 3:** From Foundations to Modern Methods
  - word embedding learning, Transformer, “small” language models, ... (for search and recommendation)
- **Phase 4:** Large Language Models (!!)

# Boolean Retrieval

# We are opening a record store!



- Over the course of the semester, we will progressively build up the **search** and **recommendation** capabilities of our store.
  - This + next few weeks: Focus on **search** basics
  - Then: Focus on **recommendation** basics
  - Later: Revisit both search and recommendation via advanced topics (e.g., **LLMs**)

## This + Next Few Weeks: Help Users Search our Store



# Basic Concepts

- Information need
  - *“I want Taylor Swift's latest album.”*
- Query
  - *“Taylor Swift's latest album”*
  - *“Taylor Swift album 2025”*
  - ...
- Documents
  - A pool of candidates (e.g., CDs)
  - Some candidates may satisfy the information need.
  - Each candidate is associated with some text information.
    - *“Artist: Taylor Swift; Lyrics: Meet me at midnight, Staring at the ceiling with you ...”*

# Basic Concepts

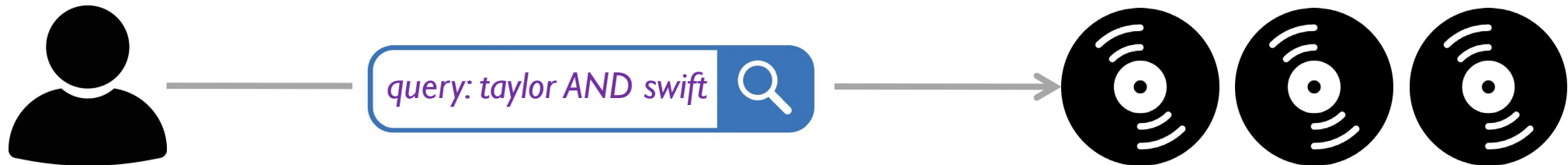
- Query Representation
  - If we want to design an automated algorithm for search, we need a way to represent the query that a computer can understand.
  - $[0, 1, 1, 0, \dots]$
  - $[0.255, -1.342, \dots]$
- Document Representation
  - We need to use a similar way to represent each “document” (i.e., candidate).
- Relevance Function
  - How can we decide which “document” can satisfy the information need?
  - $\text{Relevance}(\text{Query}, \text{Document1}) = 0.8$
  - $\text{Relevance}(\text{Query}, \text{Document2}) = 0.5$
  - ...

# Key Challenges Motivating Much of this Course

- How do we represent our queries and documents?
  - What is our “representation function”?
- What is our relevance function?
- How do we know if we are doing a good job?

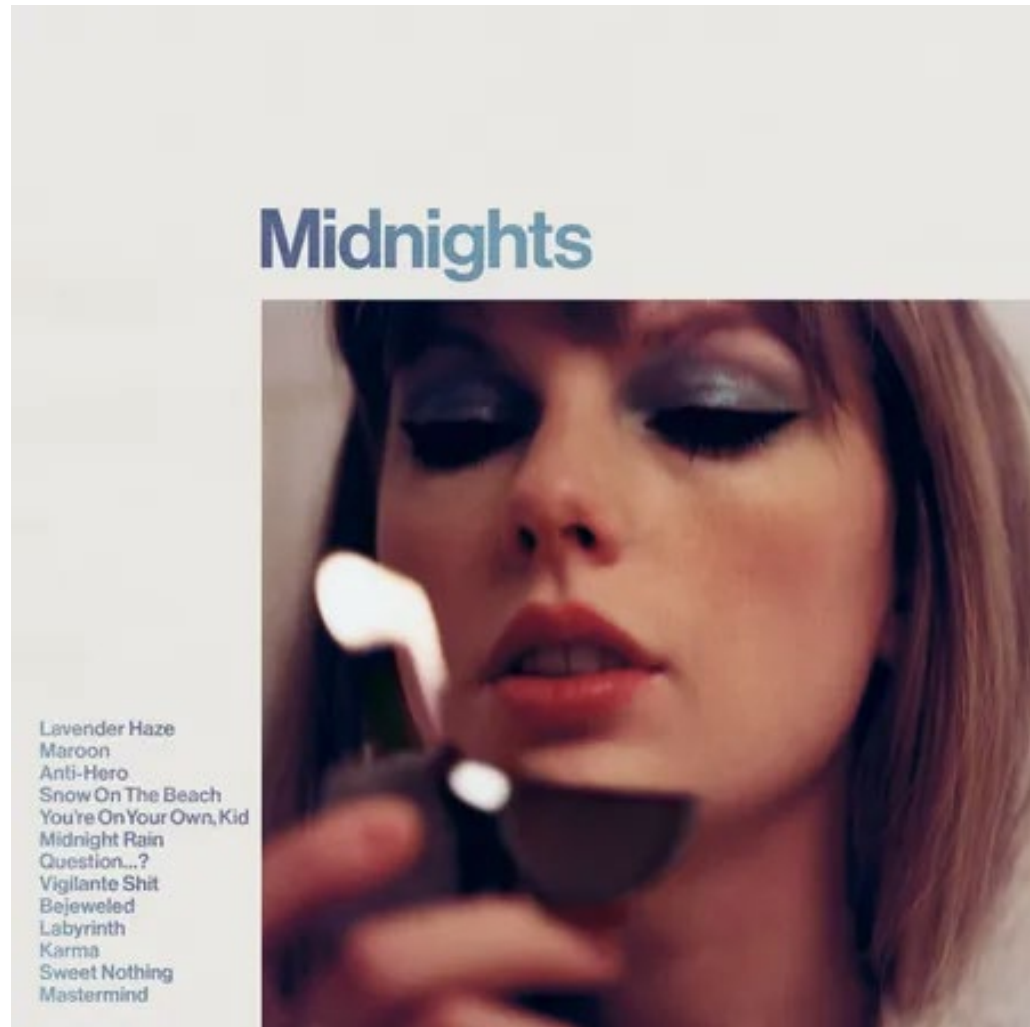
# Today: Simplifying Assumptions

- Our store front-page only supports **Boolean keyword queries**.
  - “karma”
  - “love OR song”
  - “taylor AND swift”
  - “taylor AND (NOT swift)”
  - ...
- Based on these queries, we return a list of matching albums.



We return a set of matching albums. (No rank order!)

# Example Album



- **Artist:** *Taylor Swift*
- **Album Title:** *Midnights*
- **Year:** *2022*
- **Track Listing:** *Lavender Haze, Maroon, Anti-Hero, ...*
- **Lyrics:** *Meet me at midnight, Staring at the ceiling with you, Oh, you don't ever say too ...*

# What do our users want to search for?

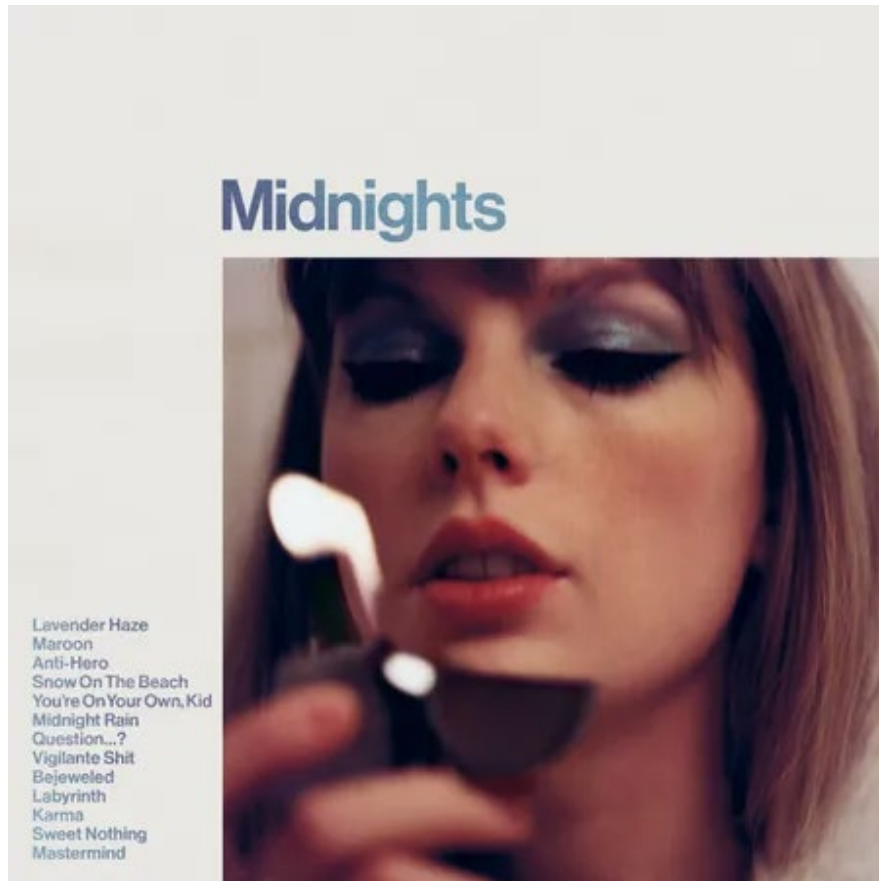
- Another example where each “document” has multiple fields: Course Explorer

| Title                         | CRN<br>Syllabus      | S..<br>Syllabus      | Crse                 | Sect                 | Hrs                  | Instructor(s)        | Meeting<br>Times   |
|-------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|--|
| <input type="text"/>          | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/>   |
| <a href="#">PROGRAMMING I</a> | 45405<br>Syllabus    | CSCE                 | 110                  | 500                  | 4                    | Ki Hwan K. Yum (P)   | <div>Su M T W R F S 12:40 PM-01:30 PM <b>Type:</b> Lecture</div> <div><b>Building:</b> ZACH <b>Room:</b> 350 <b>Date:</b> 08/25/2025 - 12/16/2025</div> <div>Su M T W R F S 02:35 PM-03:25 PM <b>Type:</b> Laboratory</div> <div><b>Building:</b> ZACH <b>Room:</b> 596 <b>Date:</b> 08/25/2025 - 12/16/2025</div> |

- What parts of an album do we index?
- How to index these parts?
  - Everything in one index?
  - Some parts in one index?
  - Each facet in its own separate index?

# One More Simplifying Assumption

- Record store front-page only supports **Boolean keyword queries** over **song lyrics**.



- Artist: *Taylor Swift*
- Album Title: *Midnight*
- Year: *2022*
- Track Listing: *Lavender Haze, Maroon, Anti-Hero, ...*
- Lyrics:** *Meet me at midnight, Staring at the ceiling with you, Oh, you don't ever say too ...*

# A Simple (but not Good) Boolean Retrieval Algorithm

- Query: *midnight AND staring*

- Algorithm Pseudo Code:

```
results = []
```

```
For CD in CDs:
```

```
    If “midnight” in CD.lyrics and “staring” in CD.lyrics:
```

```
        results.append(CD)
```

```
return results
```

# A Simple (but not Good) Boolean Retrieval Algorithm

- Query: *believe OR (NOT love)*

- Algorithm Pseudo Code:

```
results = []
```

```
For CD in CDs:
```

```
    If “believe” in CD.lyrics or “love” not in CD.lyrics:
```

```
        results.append(CD)
```

```
return results
```

- What if a new CD arrives in our store?

```
CDs.append(new_CD)
```

# Problems?

- For each query, we need to scan all the documents.
  - If there are  $M$  documents in total, and each document has  $N$  words on average, the time complexity will be  $O(MN)$ .



- 240,000,000+ papers on the Web by the end of 2019 [1].
- Let's assume that the title and abstract of each paper contain about 200 words.

- Scanning 48 billion words for each query!
- If you had to wait several minutes every time to get the paper you are looking for, would you still use this academic search engine?

# Inverted Index: A More Efficient Solution

- Document 1 (d1): “*any choose love*”
- Document 2 (d2): “*zebra any love*”
- ...

| <i>Vocabulary</i> |
|-------------------|
| any               |
| believe           |
| choose            |
| love              |
| midnight          |
| starring          |
| zebra             |

# Inverted Index: A More Efficient Solution

- Document 1 (d1): *“any choose love”*
- Document 2 (d2): *“zebra any love”*
- ...

| Vocabulary |   |    |
|------------|---|----|
| any        | → | d1 |
| believe    |   |    |
| choose     | → | d1 |
| love       | → | d1 |
| midnight   |   |    |
| starring   |   |    |
| zebra      |   |    |

# Inverted Index: A More Efficient Solution

- Document 1 (d1): “*any choose love*”
- Document 2 (d2): “*zebra any love*”
- ...

| Vocabulary |   |    |   |    |
|------------|---|----|---|----|
| any        | → | d1 | → | d2 |
| believe    |   |    |   |    |
| choose     | → | d1 |   |    |
| love       | → | d1 | → | d2 |
| midnight   |   |    |   |    |
| starring   |   |    |   |    |
| zebra      | → | d2 |   |    |

# Inverted Index: A More Efficient Solution

| Vocabulary |   |    |   |    |   |    |       |
|------------|---|----|---|----|---|----|-------|
| any        | → | d1 | → | d2 | → | d5 |       |
| believe    | → | d4 |   |    |   |    |       |
| choose     | → | d1 | → | d5 | → | d6 | → d10 |
| love       | → | d1 | → | d2 | → | d8 |       |
| midnight   | → | d7 | → | d9 |   |    |       |
| starring   | → | d7 | → | d9 |   |    |       |
| zebra      | → | d2 | → | d8 |   |    |       |

- Query: “any”
  - {d1, d2, d5}
- Query: “any AND zebra”
  - $\{d1, d2, d5\} \cap \{d2, d8\} = \{d2\}$

# Inverted Index: A More Efficient Solution

| Vocabulary |   |    |   |    |   |    |   |     |
|------------|---|----|---|----|---|----|---|-----|
| any        | → | d1 | → | d2 | → | d5 |   |     |
| believe    | → | d4 |   |    |   |    |   |     |
| choose     | → | d1 | → | d5 | → | d6 | → | d10 |
| love       | → | d1 | → | d2 | → | d8 |   |     |
| midnight   | → | d7 | → | d9 |   |    |   |     |
| starring   | → | d7 | → | d9 |   |    |   |     |
| zebra      | → | d2 | → | d8 |   |    |   |     |

- Query: “*believe OR midnight*”
  - $\{d4\} \cup \{d7, d9\} = \{d4, d7, d9\}$
- Query: “*any AND (NOT zebra)*”
  - $\{d1, d2, d5\} - \{d2, d8\} = \{d1, d5\}$

Questions?

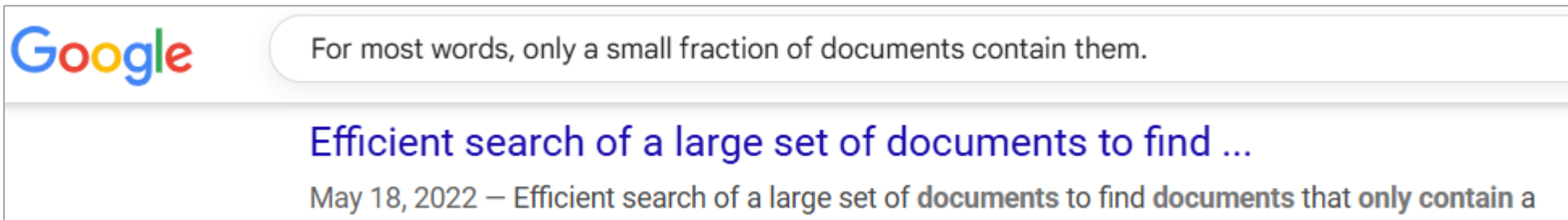
# Inverted Index: A More Efficient Solution

| Vocabulary |   |    |   |    |   |    |       |
|------------|---|----|---|----|---|----|-------|
| any        | → | d1 | → | d2 | → | d5 |       |
| believe    | → | d4 |   |    |   |    |       |
| choose     | → | d1 | → | d5 | → | d6 | → d10 |
| love       | → | d1 | → | d2 | → | d8 |       |
| ...        |   |    |   |    |   |    |       |

- What if a new CD (d1000) arrives in our store?
  - Scan its lyrics and update our inverted index
  - Move the scanning process into index construction, so it does not take up time during the on-the-fly processing of user queries.
  - Moreover, the data only needs to be scanned once, instead of being scanned for every query.

# Inverted Index: A More Efficient Solution

- What is the time complexity of the Boolean retrieval process now?
  - Number of words in the query: usually less than 20
  - × Time to access the linked list of a word:  $O(1)$
  - + Set operations based on these linked lists: proportional to the total length of these linked lists (i.e., the total number of documents containing these words)
    - For most words, only a small fraction of documents contain them.
    - The remaining words (i.e., stop words) appear in many documents and are typically considered uninformative, so they are usually ignored.



# Summary: Boolean Retrieval

- Advantages
  - Precise, if you know the right strategies (e.g., how to iteratively refine your queries, use of boolean operators, ...)
  - Typically, efficient in practice
- Disadvantages
  - Users must understand Boolean logic!
  - Boolean logic does not capture language richness.
  - Feast or famine in results: often get 0 results or 1000s
  - Result sets are unordered.
  - What about partial matches? E.g., a document does not exactly match the query but it is “close”?

# Can we improve the index?

- To support **phrase queries**?
  - “*taylor swift*”, “*670 homework solution*”
- To support **proximity queries**?
  - “*taylor NEAR:2 swift*”, “*670 NEAR:5 solution*”
- To support **wildcard queries**?
  - “*tayl\**”, “*\*ift*”

# Phrase Queries

- “*taylor swift*”, “*670 homework solution*”
- Why might we like to support **phrase queries**?
  - “*taylor made a swift decision to pivot the project after noticing the early results.*”
  - “*the professor teaches both 670 and 698, but only the 698 homework solution was shared on the course website.*”

# Phrase Queries: One Idea

- **Bigram index**: Index every consecutive pair of terms in the text as a phrase
  - “*taylor* made a *swift* decision ...”

| Vocabulary     |   |     |
|----------------|---|-----|
| taylor         | → | ... |
| made           | → | ... |
| ...            |   |     |
| taylor made    | → | ... |
| made a         | → | ... |
| a swift        | → | ... |
| swift decision | → | ... |
| ...            |   |     |

- What if the query has three words?
  - **Trigram index**: Index every consecutive span of three terms in the text as a phrase.
- What if the query has four words?
  - ...
- Problems with this strategy?

# Instead: Positional Index

- Store the **position** in the index!
- Document 1 (d1): “*any choose love*”
- Document 2 (d2): “*zebra any love any zebra*”

| <i>Vocabulary</i> |
|-------------------|
| any               |
| believe           |
| choose            |
| love              |
| midnight          |
| starring          |
| zebra             |

# Instead: Positional Index

- Store the **position** in the index!
- Document 1 (d1): *“any choose love”*
- Document 2 (d2): *“zebra any love any zebra”*

| Vocabulary |   |        |
|------------|---|--------|
| any        | → | d1 (0) |
| believe    |   |        |
| choose     | → | d1 (1) |
| love       | → | d1 (2) |
| midnight   |   |        |
| starring   |   |        |
| zebra      |   |        |

# Instead: Positional Index

- Store the **position** in the index!
- Document 1 (d1): “any choose love”
- Document 2 (d2): “zebra any love any zebra”

| Vocabulary |   |           |             |
|------------|---|-----------|-------------|
| any        | → | d1 (0)    | → d2 (1, 3) |
| believe    |   |           |             |
| choose     | → | d1 (1)    |             |
| love       | → | d1 (2)    | → d2 (2)    |
| midnight   |   |           |             |
| starring   |   |           |             |
| zebra      | → | d2 (0, 4) |             |

# Positional Index: Querying

- Query 1: “*any love*” (phrase)

| Vocabulary |   |        |             |
|------------|---|--------|-------------|
| any        | → | d1 (0) | → d2 (1, 3) |
| love       | → | d1 (2) | → d2 (2)    |

- Constraint 1: “*any*” and “*love*” should appear in the same document.
- Constraint 2: In this document,  $\text{position}(\text{“love”}) = \text{position}(\text{“any”}) + 1$
- Query 2: “*love any zebra*” (phrase)

| Vocabulary |   |           |             |
|------------|---|-----------|-------------|
| any        | → | d1 (0)    | → d2 (1, 3) |
| love       | → | d1 (2)    | → d2 (2)    |
| zebra      | → | d2 (0, 4) |             |

# Proximity Queries

- “*taylor NEAR:2 swift*”, “*670 NEAR:5 solution*”
- “*NEAR:k*” (or “*/k*”): within  $k$  words of (on either side)
- Why might we like to support **proximity queries**?
  - “*Taylor Alison Swift (born December 13, 1989) is an American singer-songwriter. Known for her autobiographical songwriting, artistic versatility, and cultural impact ...*”
- Positional index still works!
- Query: “*zebra NEAR:2 love*”
  - Constraint 1: “zebra” and “love” should appear in the same document.
  - Constraint 2: In this document,  $|\text{position}(\text{“zebra”}) - \text{position}(\text{“love”})| \leq 2$ .

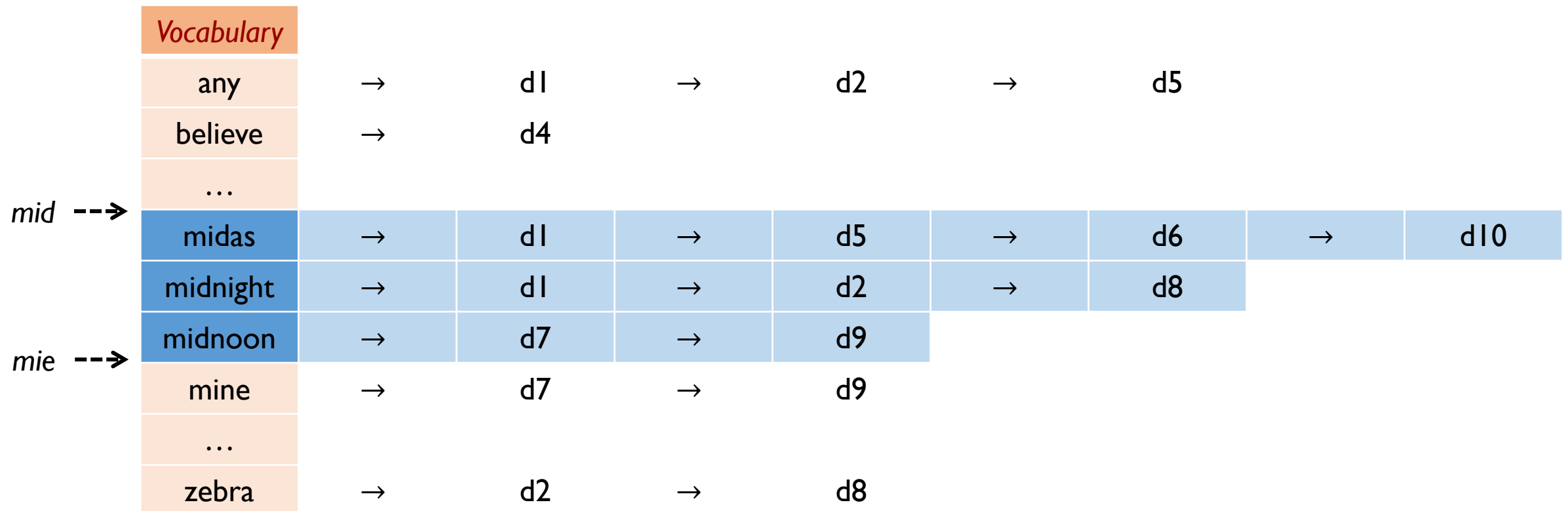
| Vocabulary |   |           |   |        |
|------------|---|-----------|---|--------|
| love       | → | d1 (2)    | → | d2 (2) |
| zebra      | → | d2 (0, 4) |   |        |

# Wildcard Queries

- “*mid\**”
- Find all documents containing any word that begins with “*mid*”
  - “*midnight*”, “*midnights*”, “*midnoon*”, “*midas*”, ...

# Wildcard Queries: One Idea

- “*mid\**”
- Suppose we have a **binary search tree** over our dictionary
  - Find all words in range: “*mid*”  $\leq$  words  $<$  “*mie*”



## But we have harder cases

- What about wildcards at the beginning of a word?
  - “*\*ift*”
  - Find all documents containing any word that ends with “*ift*”
    - “*swift*”, “*lift*”, “*rift*”, ...
- What about wildcards at any point of a word?
  - “*ta\*r*”: “*taylor*”, “*tater*”, “*tailor*”, ...
  - “*m\*ight*”: “*midnight*”, “*moonlight*”, ...
- Ideas?

# Permuterm Index

- Use a special end-of-word token, e.g., “\$”
  - “*taylor\$*”
- Rotate every term:
  - “*taylor\$*”, “*aylor\$t*”, “*ylor\$ta*”, “*lor\$tay*”, “*or\$tayl*”, “*r\$taylo*”, “*\$taylor*”
- If we have the query
  - “*ta\*r*”
- Rotate the query, so that the “\*” is at the end!
  - “*r\$ta\**”
- Look up in the rotated dictionary. “*taylor*”, “*tater*”, “*tailor*” should all be near each other:
  - “*r\$**taylor***”, “*r\$**tater***”, “*r\$**tailor***”

# Summary

- To support **phrase queries?**
  - “*taylor swift*”, “*670 homework solution*”
  - **Positional index**
- To support **proximity queries?**
  - “*taylor NEAR:2 swift*”, “*670 NEAR:5 solution*”
  - **Positional index**
- To support **wildcard queries?**
  - “*tayl\**”, “*\*ift*”
  - **Permuterm Index**

Extended Content  
(will not appear in quizzes or the exam)

# What should be in the index?

- What are the valid tokens to go in our dictionary?
- Input: a bunch of text
  - E.g., *“Welcome to class 670ers!”*
- Output: valid tokens
  - Approach 1: *“Welcome”, “to”, “class”, “670ers!”*
  - Approach 2: *“welcome”, “to”, “class”, “670ers”, “!”*
  - Approach 3: *“wel”, “elc”, “lco”, “com”, “ome”, “to”, “cla”, ...*
- Critical step in determining what our users can search for.
  - If a token is not in our index, then our user cannot search for it!

# Typical Issues in Tokenization

- Punctuation
  - “*pre-trained*” → “*pre-trained*” or even “*pretrained*” (better than “*pre*”, “*trained*”)
  - “*U.S.A.*” → “*U.S.A.*” or even “*USA*” (better than “*U*”, “*S*”, “*A*”)
  - “*C.A.T.*” → “*C.A.T.*” (better than “*cat*”)
  - “*A&M*” → “*A&M*” (better than “*AM*” or “*A*”, “*M*”)
- Case
  - “*PageRank*”, “*Pagerank*”, “*PAGERANK*” → “*pagerank*”
  - “*Apple*”, “*Windows*” → ? (depending on the context)
- Domain/Task
  - “*F = ma*” → “*F = ma*” (better than “*F*”, “*=*”, “*ma*”)
  - “*2%-4%*” → “*2%*”, “*-*”, “*4%*”
  - “*CaO + CO2 = CaCO3*” → ? (depending on your task: retrieving the reactants vs. retrieving the equation)

# Stemming

- The same word can be used in different forms.
  - “*organize*”, “*organized*”, “*organizes*”, “*organizing*”
- There are families of derivationally related words with similar meanings.
  - “*democracy*”, “*democratic*”, “*democratization*”
- When you search one of these words, you may also want documents containing other words in the set.
- **Stemming**: Reducing inflectional forms and sometimes derivationally related forms of a word to a common base form

# Porter's Algorithm

- **Stemming**: Reducing inflectional forms and sometimes derivationally related forms of a word to a common base form
- **Porter's Algorithm**: 5 phases of word reduction applied sequentially
  - Phase I

| Rule |   |    | Example  |   |        |
|------|---|----|----------|---|--------|
| SSES | → | SS | caresses | → | caress |
| IES  | → | I  | ponies   | → | poni   |
| SS   | → | SS | caress   | → | caress |
| S    | → |    | cats     | → | cat    |

- For more information: <http://www.tartarus.org/martin/PorterStemmer/>

# Examples of Stemming

*Sample text:* Such an analysis can reveal features that are not easily visible from the variations in the individual genes and can lead to a picture of expression that is more biologically transparent and accessible to interpretation

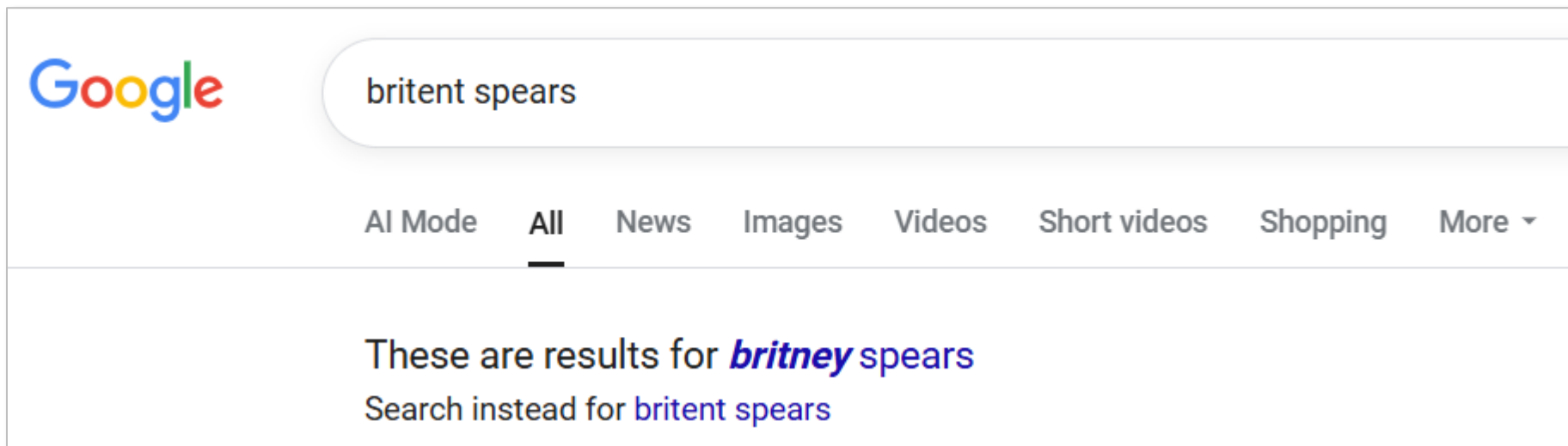
*Lovins stemmer:* such an analysis can reveal features that are not easily visible from the variations in the individual genes and can lead to a picture of expression that is more biologically transparent and accessible to interpretation

*Porter stemmer:* such an analysis can reveal features that are not easily visible from the variations in the individual genes and can lead to a picture of expression that is more biologically transparent and accessible to interpretation

*Paice stemmer:* such an analysis can reveal features that are not easily visible from the variations in the individual genes and can lead to a picture of expression that is more biologically transparent and accessible to interpretation

# Spelling Errors

- Users make spelling mistakes all the time.
- How do we know that?
  - “*britent spears*” → “*britney spears*”



# Spelling Correction

- Based on edit distance
- Based on everyone's search logs

<https://archive.google/jobs/britney.html>

|                       |                     |                    |                    |                     |                    |
|-----------------------|---------------------|--------------------|--------------------|---------------------|--------------------|
| 488941 britney spears | 29 britent spears   | 9 brinttany spears | 5 brney spears     | 3 britiy spears     | 2 brirreny spears  |
| 40134 brittany spears | 29 brittnany spears | 9 britanay spears  | 5 broitney spears  | 3 britmeny spears   | 2 brirtany spears  |
| 36315 brittney spears | 29 britttany spears | 9 britinany spears | 5 brotny spears    | 3 britneey spears   | 2 brirttany spears |
| 24342 britany spears  | 29 btiney spears    | 9 britn spears     | 5 bruteny spears   | 3 britnehy spears   | 2 brirttney spears |
| 7331 britny spears    | 26 birttney spears  | 9 britnew spears   | 5 btiyney spears   | 3 britnely spears   | 2 britain spears   |
| 6633 briteny spears   | 26 breitney spears  | 9 britneyn spears  | 5 btrittney spears | 3 britnesy spears   | 2 britane spears   |
| 2696 britteny spears  | 26 brinity spears   | 9 britrney spears  | 5 gritney spears   | 3 britnetty spears  | 2 britaneny spears |
| 1807 briney spears    | 26 britenay spears  | 9 brtiny spears    | 5 spritney spears  | 3 britnex spears    | 2 britania spears  |
| 1635 brittny spears   | 26 britneyt spears  | 9 brtittney spears | 4 bittny spears    | 3 britneyxxx spears | 2 britann spears   |
| 1479 brintey spears   | 26 brittan spears   | 9 brtny spears     | 4 bnritney spears  | 3 britnity spears   | 2 britanna spears  |
| 1479 britanny spears  | 26 brittne spears   | 9 brytny spears    | 4 brandy spears    | 3 britnteys spears  | 2 britannie spears |
| 1338 britiny spears   | 26 btittany spears  | 9 rbitney spears   | 4 brbritney spears | 3 britnyey spears   | 2 britannt spears  |
| 1211 britnet spears   | 24 beitney spears   | 8 birtiny spears   | 4 breatiny spears  | 3 britteny spears   | 2 britannu spears  |
| 1096 britiney spears  | 24 birtney spears   | 8 bithney spears   | 4 breetney spears  | 3 brittneey spears  | 2 britanyl spears  |
| 991 britaney spears   | 24 brightney spears | 8 brattany spears  | 4 bretiney spears  | 3 brittnney spears  | 2 britanyt spears  |
| 991 britnay spears    | 24 brintiny spears  | 8 breitny spears   | 4 brfitney spears  | 3 brittnyey spears  | 2 briteeny spears  |
| 811 brithney spears   | 24 britanty spears  | 8 breteny spears   | 4 briattany spears | 3 brityen spears    | 2 britenany spears |
| 811 brtiny spears     | 24 britenny spears  | 8 brightny spears  | 4 brieteny spears  | 3 briytney spears   | 2 britenet spears  |
| 664 birtney spears    | 24 britini spears   | 8 brintay spears   | 4 briety spears    | 3 brltney spears    | 2 briteniy spears  |
| 664 brintney spears   | 24 britnwy spears   | 8 brinttey spears  | 4 briitny spears   | 3 broteny spears    | 2 britenys spears  |
| 664 briteney spears   | 24 brittni spears   | 8 briotney spears  | 4 briittany spears | 3 brtaney spears    | 2 britianey spears |



Thank You!

Course Website: <https://yuzhang-teaching.github.io/CSCE670-F25.html>