INFORMATION RETRIEVAL

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Many Slides made by Luca Manzoni

Lecture 1

WHO AM I

AND SOME INFORMATION ABOUT THE COURSE

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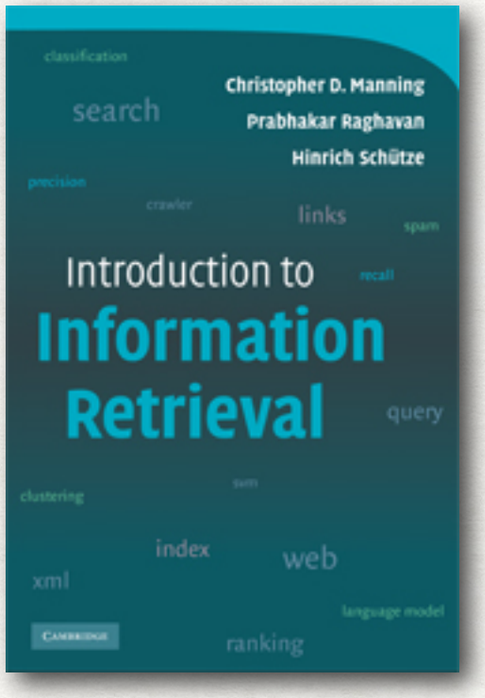
Information retrieval & data visualisation

Laura Nenzi
November and December

Tea Tušar
(you already did it)

All the material of the course will be available online on Moodle and Teams

BOOK



Christopher D. Manning
Prabhakar Raghavan
Hinrich Schütze

Introduction to Information Retrieval

Cambridge University Press. 2008.

Freely available at: https://nlp.stanford.edu/IR-book/

THE EXAM (1)

How

Project + presentation of the project (with questions)

When

From mid January (we can discuss to fix a day).
The projects will be assigned in December

Is the project the same for everybody?

No, each student will have a different project

How can we select a project?

There will be a selection of project to choose from
or you can propose your own

THE EXAM (2)

What kind of project?

Code or report (approx. 10 pages)

Can I use language X?

Generally yes, but please ask if it is not in the following list:
Python, C, C++, Java, R

I want to do a project on X

We can discuss and prepare a personalised project on X

How is the final mark computed?

It is the average of the marks in the two parts

OUTLINE OF THE COURSE

INFORMATION RETRIEVAL PART

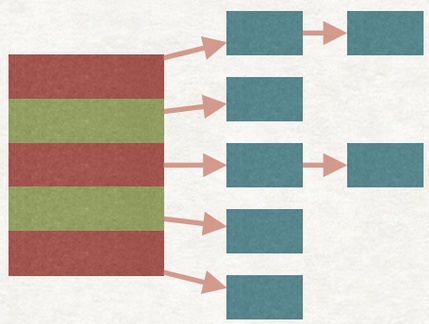
- Introduction to information retrieval (IR)
- Data structures for IR
- Models for IR:
  - Boolean
  - Vector space
  - Probabilistic
- Evaluation of IR
- IR on the Web
- Recommender Systems

LECTURE OUTLINE

Introduction to information retrieval

Boolean Retrieval

Postings list



Basic Operation on inverted indices

Information Retrieval (IR) is
finding material (usually documents)
of an unstructured nature (usually text)
that satisfies an information need
from within large collections
(usually stored on computers)

Manning, Raghavan, Schütze
Introduction to Information Retrieval

(IR) part of computer science which studies
the retrieval of information (not data)
from a collection of written documents.
The retrieved documents aim at satisfying
a user information need
usually expressed in natural language.

Baeza-Yates, Ribeiro-Neto
Modern Information Retrieval

EXAMPLES OF INFORMATION RETRIEVAL

- Web search
- Searching emails in your email client
- Searching documents using Spotlight/Windows Desktop Search/Tracker/Nepomuk/Baloo
- Search inside a knowledge base

THREE PROMINENT SCALES

- **web search**: over billions of documents stored on millions of computer
- **personal information retrieval:** searching emails in your email client, spotlight/Windows Desktop Search/Tracker/Nepomuk/ Baloo
- **enterprise, institutional, and domain-specific search**: collections such as a corporation's internal documents, a database of patents, or research articles on biochemistr

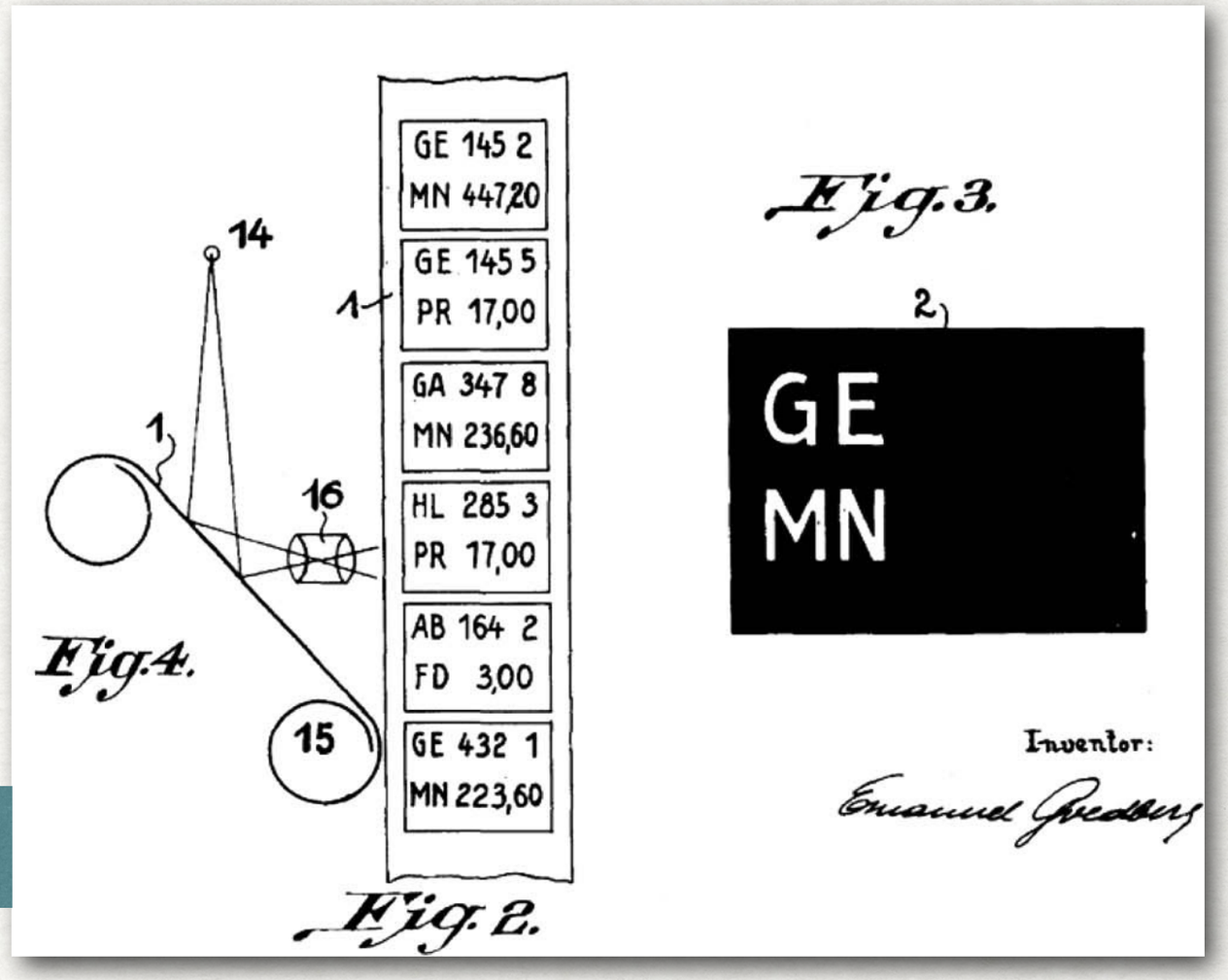
A BRIEF HISTORY OF IR

BEFORE COMPUTERS

The origin of IR is in the cataloguing of books in libraries

Each books has one or more topics associated to it

Multiple machines were invented to help librarians in retrieving books



MACHINE FOR RETRIEVAL BASED ON MICROFILM AND A PHOTOCELL. GOLDBERG, 1931

Sanderson, Mark, and W. Bruce Croft.
"The history of information retrieval research."
Proceedings of the IEEE 100.Special Centennial Issue (2012): 1444-1451.

A BRIEF HISTORY OF IR

EARLY USE OF COMPUTERS

The use of computer allowed to speed up
the traditional search methods,
like searching across 10^6 records
in 15 hours using a UNIVAC computer

But new techniques were also
being developed:

First move to indexing based on words
instead of assigning topics to document
(*Uniterm system, 1952*)

How to rank the results:
position based on the frequency
of the words in the documents
(*term frequency weighting, 1958*)

A BRIEF HISTORY OF IR

PRE-INTERNET ('60–EARLY '90)

Clustering of documents
with similar contents

Representing documents as vectors:
the **vector space mode**

Relevance feedback:
the user feedback can be used
to improve the query results

First private companies focused
on information retrieval

tf-idf: less common words tend
to refer to more specific concepts,
which were more important in retrieval

Text REtrieval Conference (**TREC**)

A BRIEF HISTORY OF IR

WEB SEARCH

1993: ~100 websites
2019: ~2 billions websites

Instead of using an authoritative source
now the web must be scraped to get information

The links between the pages
are a source of additional information

Altavista:
first fully-searchable
index of the web (1995)

Google:
currently the most used
web search engine (1997)

SOME TERMINOLOGY

DOCUMENTS AND COLLECTIONS

- **Document**: individual unit on which we build an IR system
  - Books, chapters, webpages, scientific papers, etc.
  - Images, videos, Music, etc.
- **Collection** (also called **Corpus**): the group of documents on which we perform the search
  - All Shakespeare plays, the emails in your mailbox, all the products on an online shop, the web
  - Some collections are static, while others are dynamic

IR VS. DATABASES:

STRUCTURED VS UNSTRUCTURED DATA

- Structured data tends to refer to information in "tables"

Employee	Manager	Salary
Smith	Jones	50000
Chang	Smith	60000
Ivy	Smith	50000

- Typically allows numerical range and exact match (for text) queries , e.g.,

Salary < 60000 AND Manager = Smith

UNSTRUCTURED DATA

- Typically refers to free text
- Allows:
  - Keyword queries including operators
    - More sophisticated “concept” queries e.g.,
      - find all web pages dealing with drug abuse
- Classic model for searching text documents

SEMI-STRUCTURED DATA

- In fact almost no data is “unstructured”
- E.g., this slide has distinctly identified zones such as the Title and Bullets
- Facilitates “semi-structured” search such as:
  - Title contains data AND Bullets contain search

PROPERTIES OF UNSTRUCTURED DOCUMENTS

DOCUMENT

- Significant text contents
- Some structure might be present (e.g., title, author)
- The semantics of the document is not well-defined
- Example query:
  "find all stories about holidays in Ireland"

DATABASE RECORD

- Predefined structure
- Usually the semantics of the fields is well defined
- Finding matches is (usually) done by comparing specific fields
- Example Query: *"select all products that cost at most 50€"*

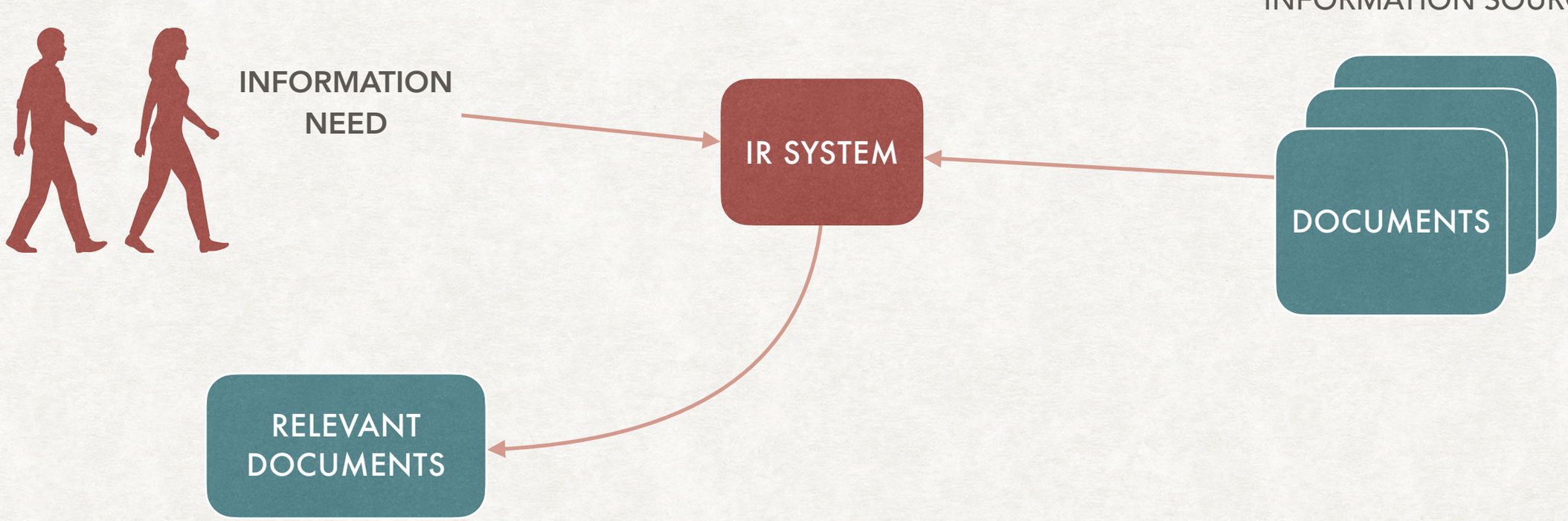
SOME TERMINOLOGY (2)

FROM INFORMATION NEED TO QUERIES

- **Information need**: a topic about which the user what to know more
- **Query**: the way the user formulate his/her information need to the IR system
  - For the same information need the users might formulate different queries
  - E.g., what query would you use to know which is the current record holder in Tetris?

GOAL OF AN IR SYSTEM

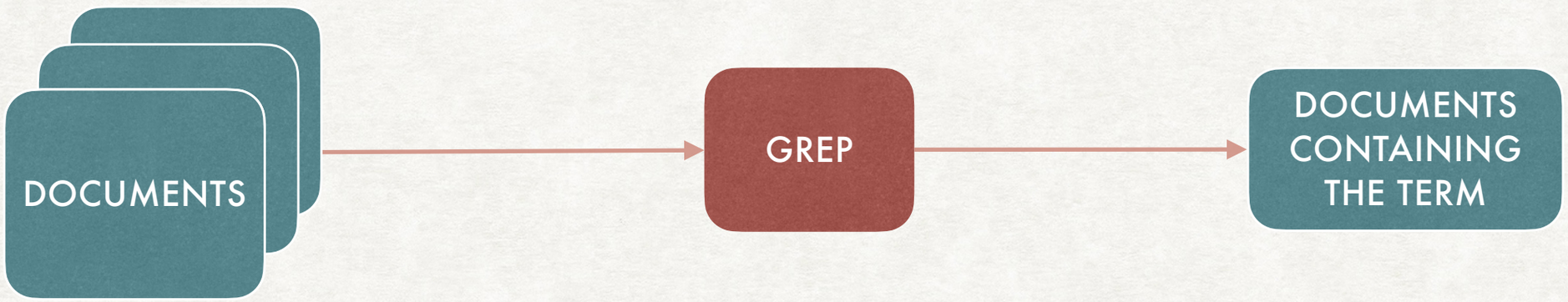
An IR System must interpret the information needs of the user and estimate the relevance of the documents with respect to it.



IS AN IR SYSTEM JUST "GREP"?

HINT: NO

```
> grep term_to_search corpus
```



- Searching across all the text does not scale to large collections
- We might want a more flexible query language
- We might want *ranked* retrieval (i.e., more relevant documents first)

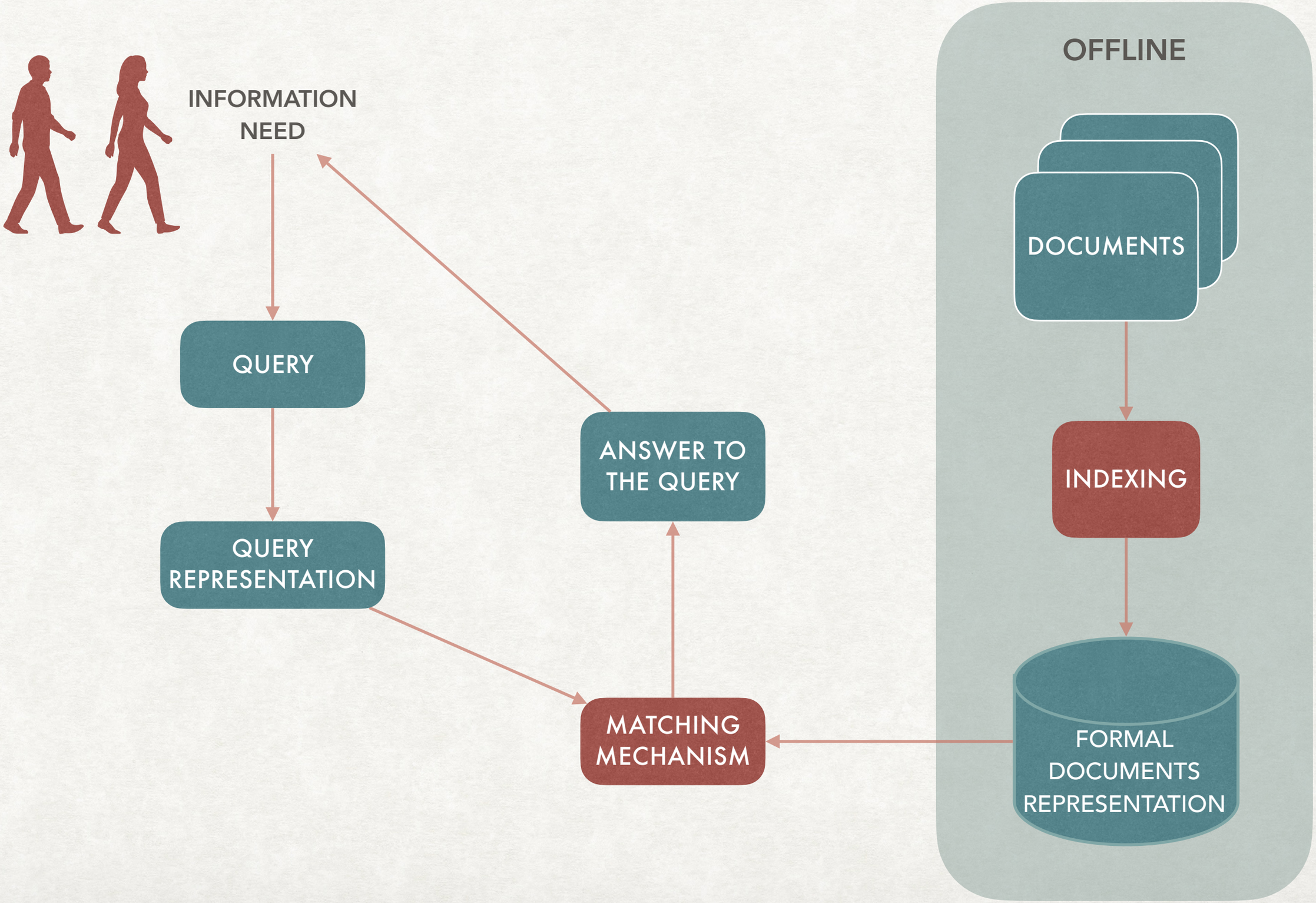
INDEXING

HOW TO AVOID GREPPING

- It is unfeasible to scan the entire corpus for each query…
- …therefore, the corpus is scanned once* and an **index** is built
- An index will have for each **term** (e.g., a word) all documents containing that term
- In this way we can avoid a linear scan of all documents

*assuming it never changes

STRUCTURE OF AN IR SYSTEM



MAIN COMPONENTS

A FORMAL REPRESENTATION
OF THE QUERIES

Exact matching
The document is either
relevant or not relevant

A WAY OF MATCHING
THE QUERY AND DOCUMENTS REPRESENTATIONS
AND A WAY TO MEASURE RELEVANCE

Partial matching
The document that are
“sufficiently similar”
to the query are recovered

A FORMAL REPRESENTATION
OF THE DOCUMENTS

DIFFERENT KINDS OF REPRESENTATIONS

QUERIES AND DOCUMENTS

Query

BOOLEAN FORMULAE

+ EXTENSIONS

cat AND dogs

FREE FORM QUERIES

common house pets

IMAGES

From https://flickr.com/photos/12836528@N00/3350737685

Document

SET OF TERMS

BINARY VECTOR

POINT IN A VECTOR SPACE

THE TWO ASPECTS OF IR

We need to manage technical and a semantic aspects

Technical aspects

- How to represent information in a computer?
- How to retrieve the information fast enough?

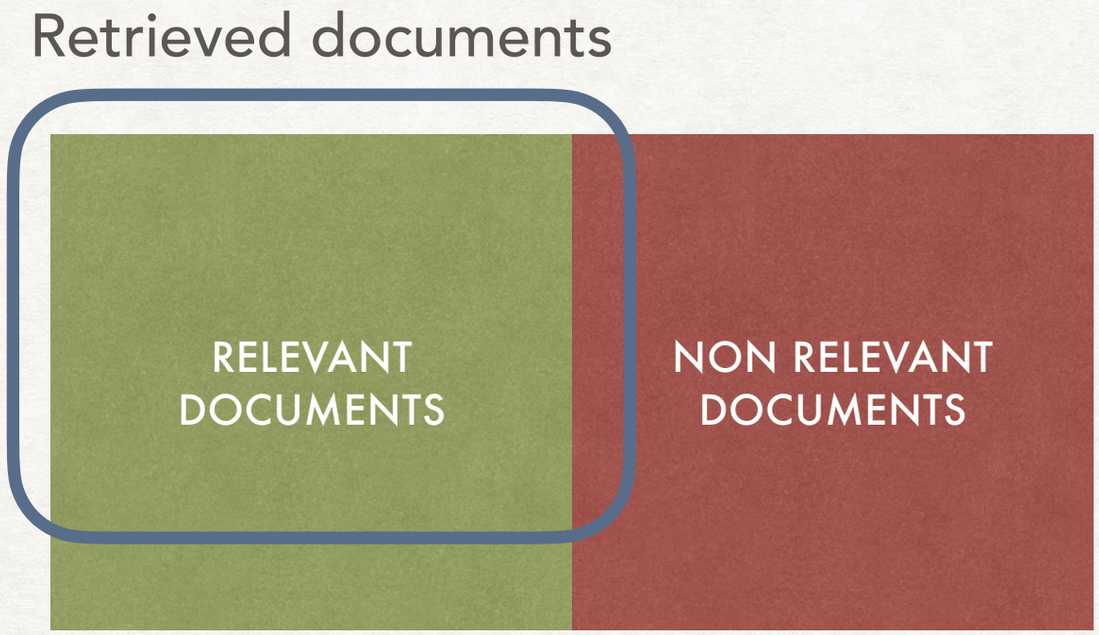
EFFICIENCY

Semantic aspects

- How can we store information in a way that preserves its meaning?
- How can we retrieve the relevant documents?

EFFECTIVENESS

MEASURING EFFECTIVENESS



$$\text{precision} = \frac{\text{relevant} \cap \text{retrieved}}{\text{retrieved}}$$

Which fraction
of the retrieved documents
is relevant

$$\text{recall} = \frac{\text{relevant} \cap \text{retrieved}}{\text{relevant}}$$

Which fraction
of the relevant documents
has been retrieved

BOOLEAN

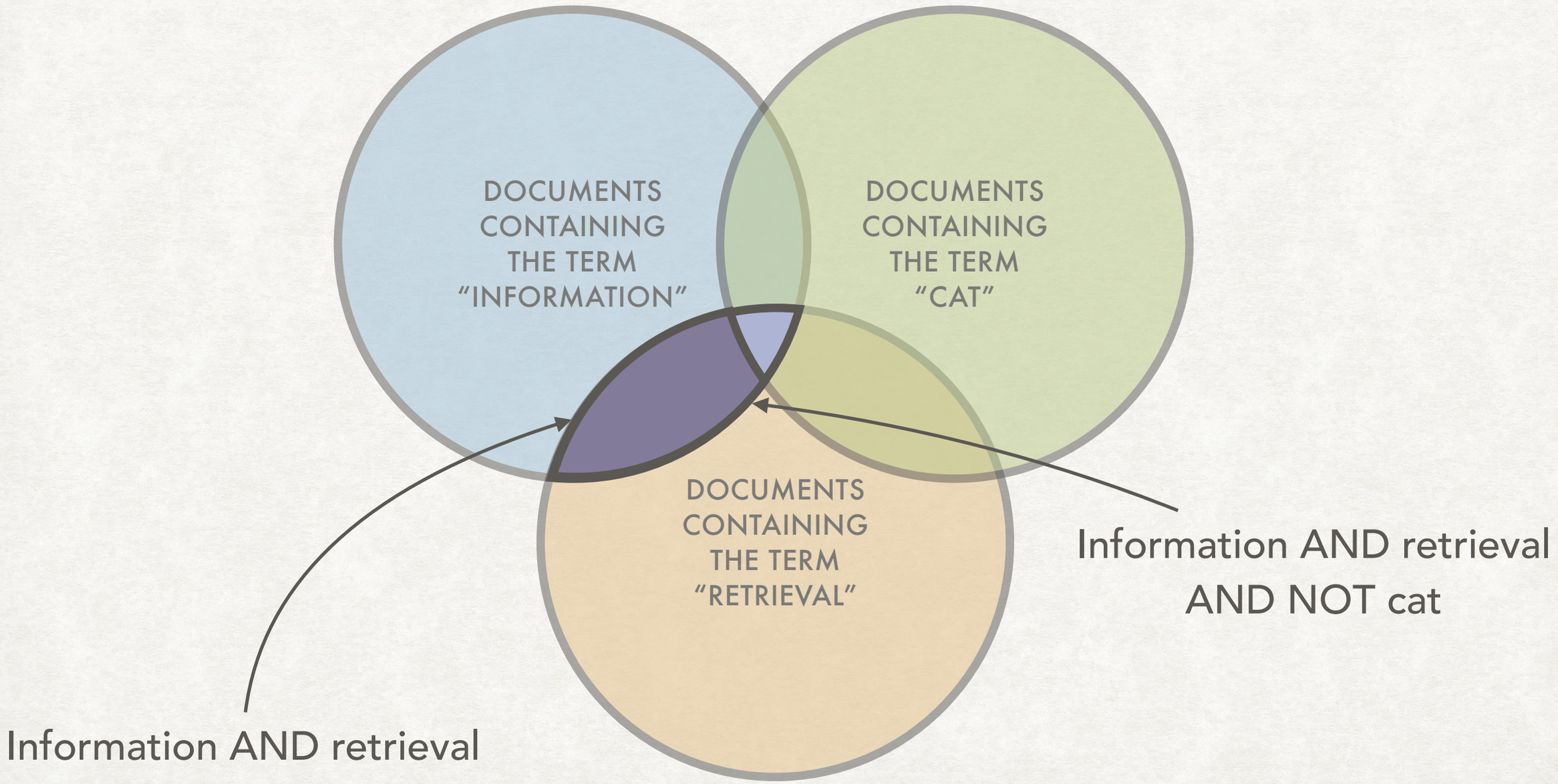
RETRIEVAL

WHAT IS BOOLEAN RETRIEVAL?

- Only exact matching: either a document is relevant or not
- The query is expressed like a Boolean formula:
  - E.g., (dog OR cat) AND box
- We can ask for the inclusion (or exclusion) of certain terms
- Going forward, we can decide to extend this model to allow more powerful queries
- For now we ignore the issue of ranking the results according to relevance.

A VISUAL EXAMPLE

BOOLEAN QUERIES AND SETS



LINKING BOOLEAN QUERIES AND SETS

$d_1 = \{t_1, t_3, t_4\}$

$d_2 = \{t_1, t_2, t_5\}$

$d_2 = \{t_2, t_3, t_5\}$

Documents
as sets of terms

$t_1 = \{d_1, d_2\}$
$t_2 = \{d_2, d_3\}$
$t_3 = \{d_1, d_3\}$
$t_4 = \{d_1\}$
$t_5 = \{d_2, d_3\}$

Terms as sets
of documents

Queries		Answers
$q_1 = t_2$	→	$\{d_2, d_3\}$
$q_2 = t_2 \wedge t_3$	→	$\{d_2, d_3\} \cap \{d_1, d_3\} = \{d_3\}$
$q_3 = t_2 \vee t_3$	→	$\{d_2, d_3\} \cup \{d_1, d_3\} = \{d_1, d_2, d_3\}$

HOW TO ASSOCIATE DOCUMENTS AND TERMS

Let us consider as a corpus a set of ~400 articles from "Time"[1] in the '60s:

0. THE ALLIES AFTER NASSAU IN DECEMBER 1960, THE U.S . FIRST […]
1. RUSSIA WHO'S IN CHARGE HERE ? IT WAS IN 1954 THAT NIKITA […]
2. BERLIN ONE LAST RUN HANS WEIDNER HAD BEEN HOPING FOR MONTHS TO […]
3. THE ROAD TO JAIL IS PAVED WITH NONOBJECTIVE ART SINCE THE […]

… …

We can build an incidence matrix of documents and terms

[1] Available at http://ir.dcs.gla.ac.uk/resources/test_collections/time/

THE INCIDENCE MATRIX

	Article 0	Article 1	Article 2	Article 3	Article 4	Article 5
A	1	1	1	1	1	1
AACHEN	0	0	0	0	0	0
ABABA	0	0	0	0	0	0
ABABAS	0	0	0	0	0	0
ABACK	0	0	0	0	0	0
ABADAN	0	0	0	0	0	0
ABANDON	0	0	0	0	0	0
ABANDONED	0	0	0	0	0	0
ABANDONING	0	0	0	0	0	0
ABANDONMENT	0	0	0	0	0	0

…and another 22484 rows

QUERIES

Query 1 = FRANCE **AND** BRITAIN

FRANCE	1	0	0	0	0	0	0	0	1
BRITAIN	1	0	0	0	0	0	1	0	1

Document matching Query 1

Query 1	1	0	0	0	0	0	0	0	1

Query 2 = FRANCE **OR** BRITAIN

FRANCE	1	0	0	0	0	0	0	0	1
BRITAIN	1	0	0	0	0	0	1	0	1

Documents matching Query 2

Query 1	1	0	0	0	0	0	1	0	1

INCIDENCE MATRIX

STORAGE REQUIREMENTS

The size needed to store an incidence matrix is #terms $\times$ #documents

Hence the size requirements make this data structure impractical

A simple example

The Oxford English Dictionary has over 171000 words in common use

In 2019 the English Wikipedia contains over 5.9×10^6 articles

The resulting incidence matrix would have more than 10^{12} entries

THE INCIDENCE MATRIX

	Article 0	Article 1	Article 2	Article 3	Article 4	Article 5
A	1	1	1	1	1	1
AACHEN	0	0	0	0	0	0
ABABA	0	0	0	0	0	0
ABABAS	0	0	0	0	0	0
ABACK	0	0	0	0	0	0
ABADAN	0	0	0	0	0	0
ABANDON	0	0	0	0	0	0
ABANDONED	0	0	0	0	0	0
ABANDONING	0	0	0	0	0	0
ABANDONMENT	0	0	0	0	0	0

…and another 22484 rows

THE INVERTED INDEX

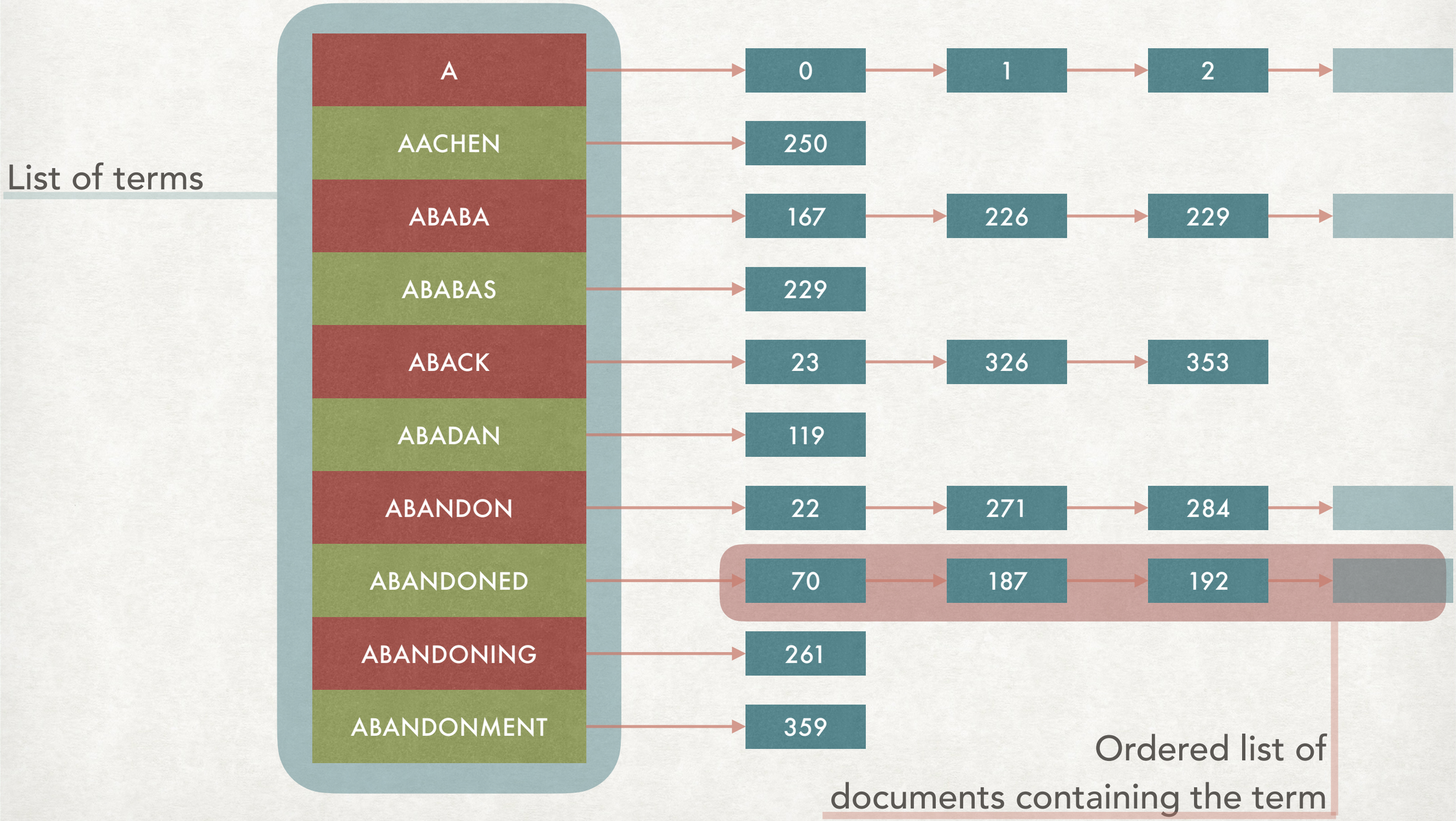
A MORE COMPACT DATA STRUCTURE

- We want to avoid storing rows that will be mostly empty
- We store, for each term, the list of documents containing it
- This is similar to the difference between adjacency *matrices* and and adjacency *lists* for graphs.
- We keep the list ordered to improve performances for union and intersection
- Why **inverted** index? Because it is not from documents to terms but from terms to documents. Apart from that, it is a “normal” index

INVERTED INDEX: UNION AND INTERSECTION

THE INVERTED INDEX

A VISUAL REPRESENTATION



SOME TERMINOLOGY (3)

THIS TIME FOR INVERTED INDICES

- **DocID** (Document Identifier): a unique number associated to a document. E.g., consecutive integers.
- **Dictionary**: the collection of all terms that we have in the inverted index
- **Posting list**: list of DocIDs associated to a term
- **Posting**: element of the list (different from a simple DocID because it is associated to a term)

BUILDING AN INVERTED INDEX

SORTING AND GROUPING

- For each document we extract the sequence of terms
- We tag each term with the corresponding DocID
- We sort the list of terms extracted from all the documents
- We group together equal terms and we “merge” the posting lists of the two terms

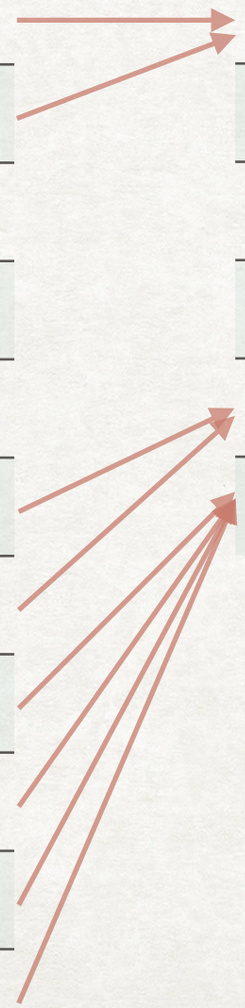
EXAMPLE OF SORTING AND GROUPING

Document 1: the cat is inside the box

Document 2: the dog is barking at the box

the	1
cat	1
is	1
inside	1
the	1
box	1
the	2
dog	2
is	2
barking	2
at	2
the	2
box	2

at	2
barking	2
box	1
box	2
cat	1
dog	2
inside	1
is	1
is	2
the	1
the	1
the	2
the	2



at	2
barking	2
box	1,2
cat	1
dog	2
inside	1
is	1,2
the	1,2

WHAT ABOUT THE SPACE REQUIREMENTS?

WORST-CASE BOUNDS AND THE REAL WORLD

- But… the space occupied by an inverted index is not necessarily lower than the one of the incidence matrix.
- In the worst case (each document contains all the terms) they both occupy $O\left(\#\text{terms} \times \#\text{documents}\right)$ space.
- In practice most document contains only a small subset of the terms.
- The same reasoning applies to the time complexity of the operations (intersection and union) performed on the set of documents.

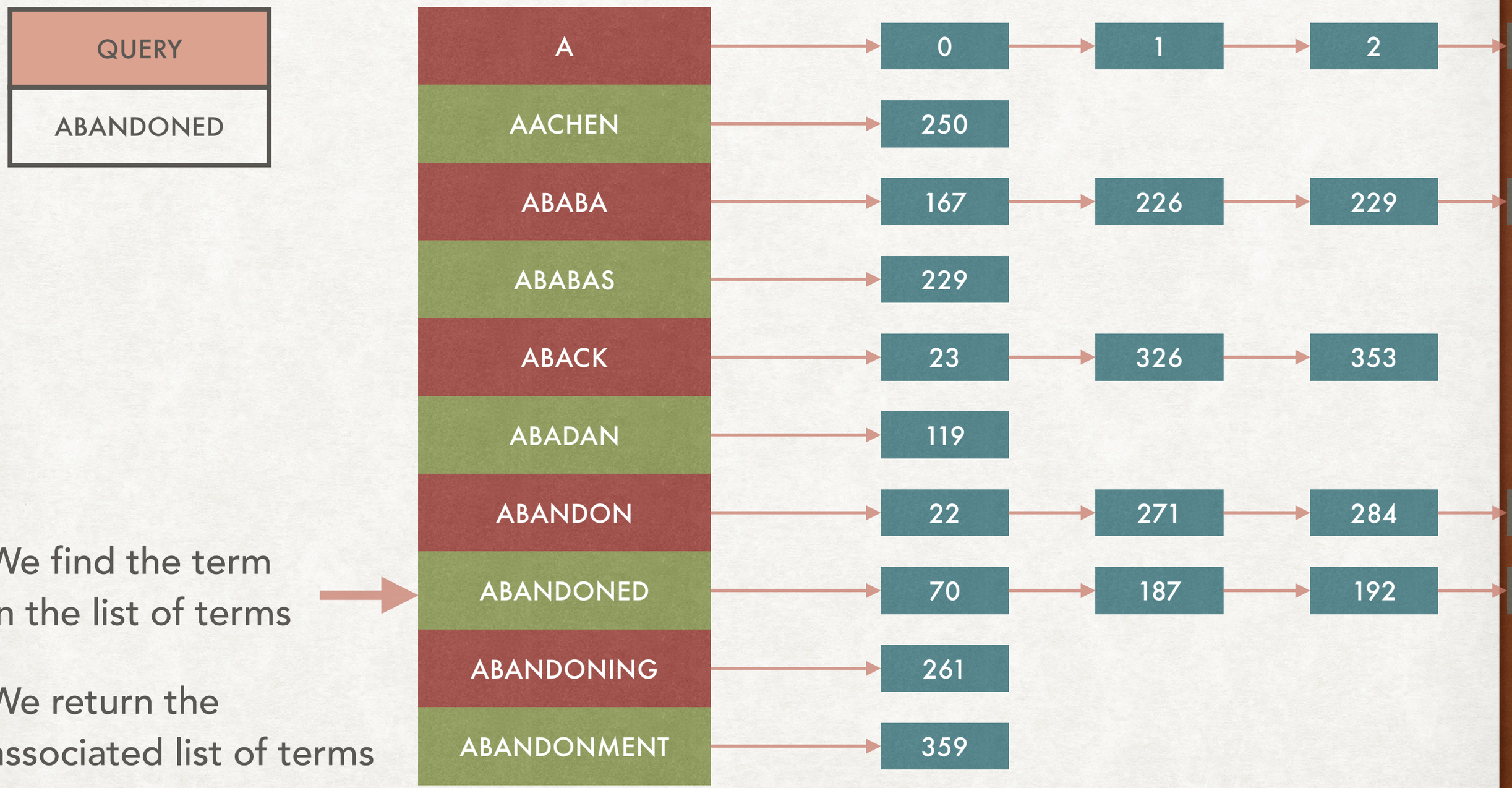
HOW TO IMPLEMENT AN INVERTED INDEX

BASIC IMPLEMENTATION AND OTHER IMPROVEMENTS

- We will spend some time in discussing how to implement and improve the inverted index
- Basic functionality: answer queries of the form
  - term1 AND term2
  - term1 OR term2

ANSWERING A SIMPLE QUERY

A SINGLE WORD QUERY

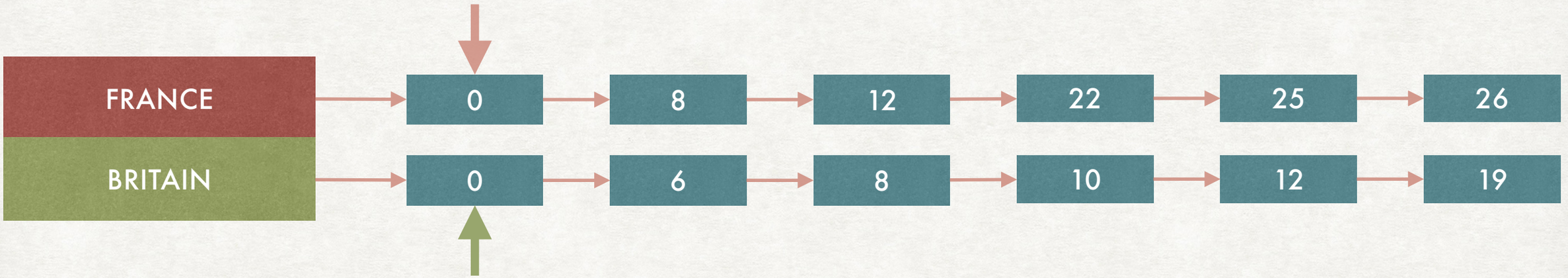


ANSWERING AN "AND" QUERY

NOW WITH TWO WORDS

QUERY	FRANCE	**AND**	BRITAIN

Now we need to compare the two lists of documents



ANSWER

ANSWERING AN "AND" QUERY

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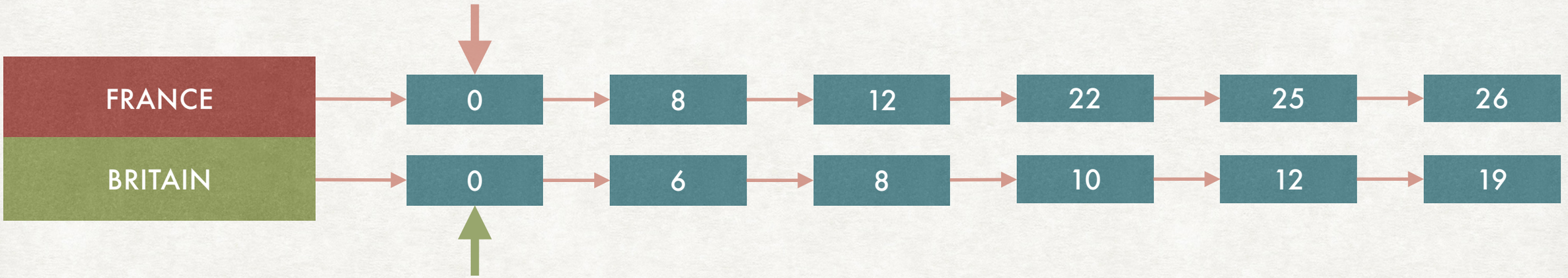

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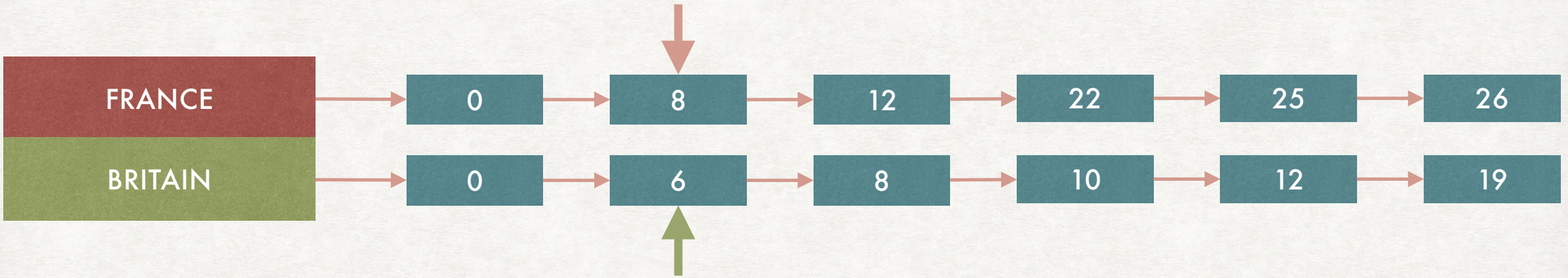

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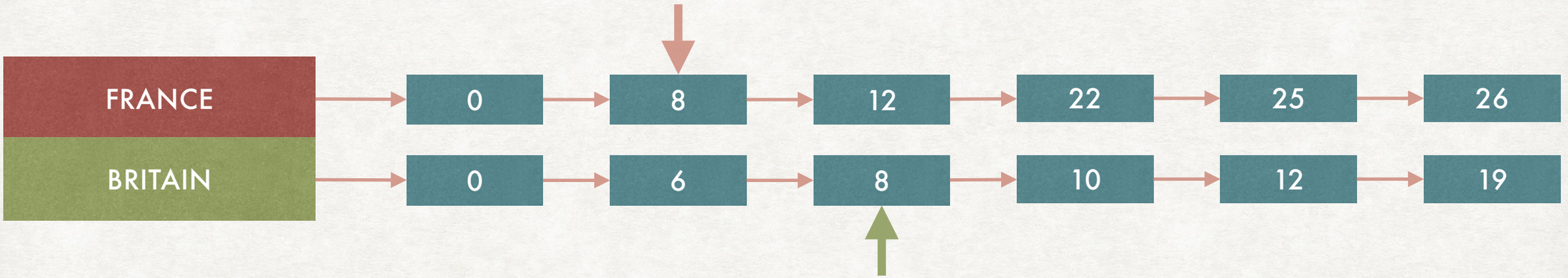

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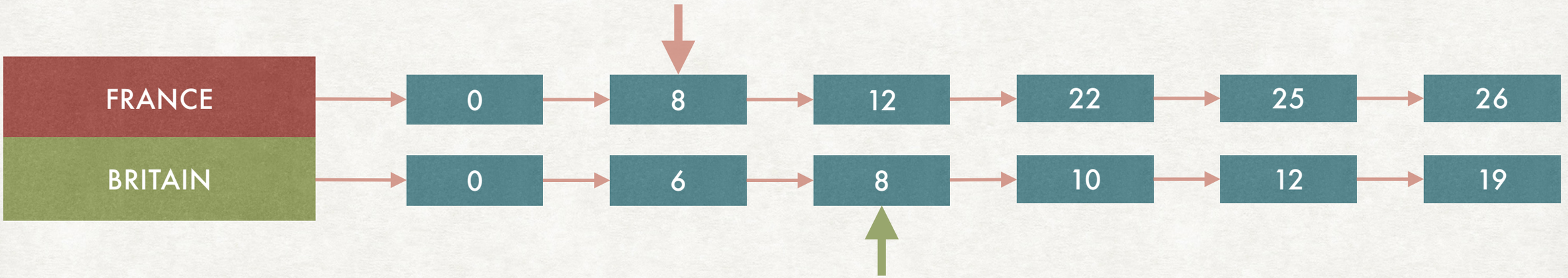

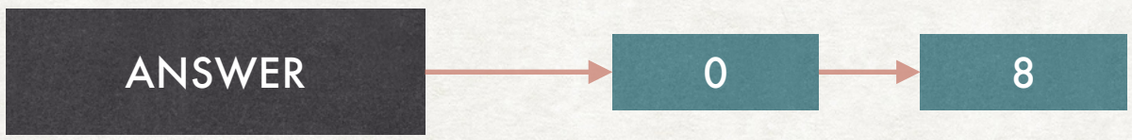

ANSWERING AN "AND" QUERY

NOW WITH TWO WORDS

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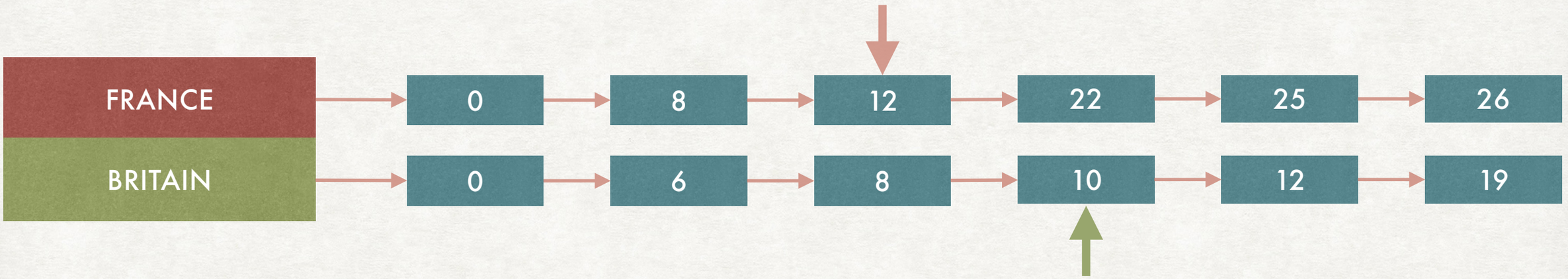

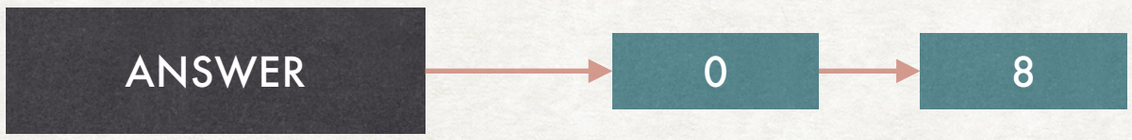

ANSWERING AN "AND" QUERY

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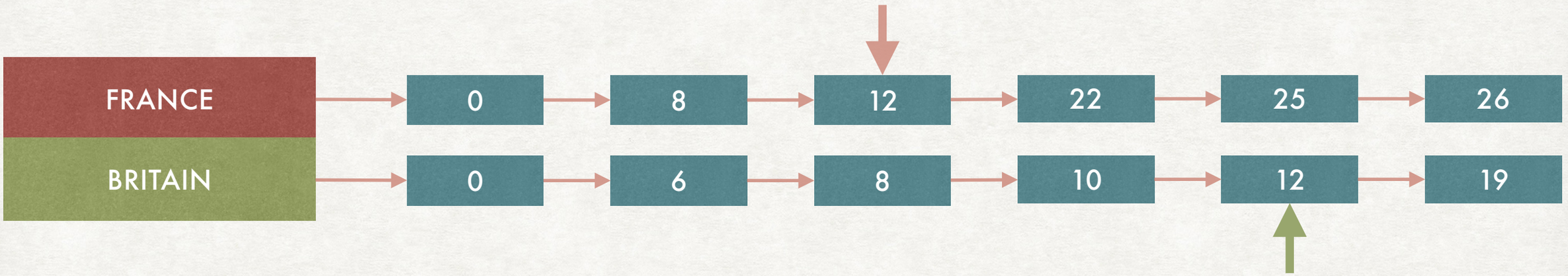

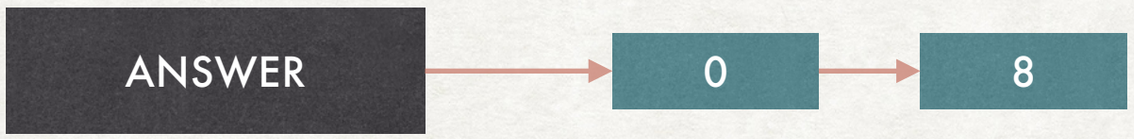

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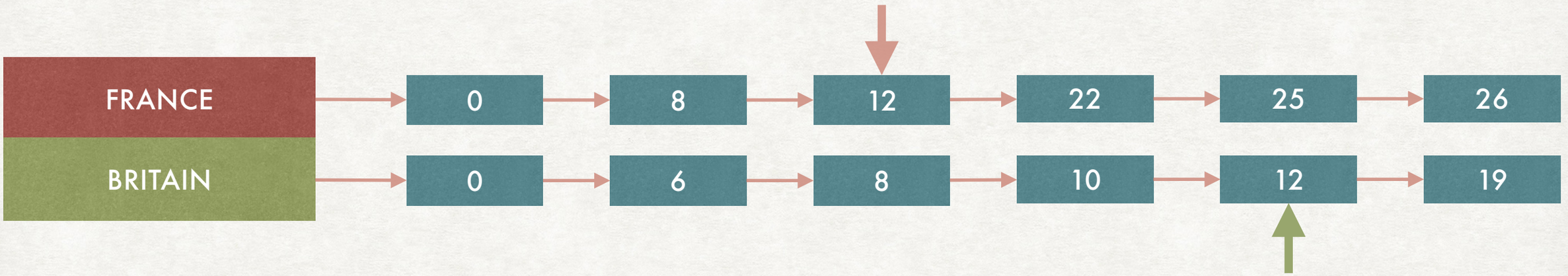

ANSWERING AN "AND" QUERY

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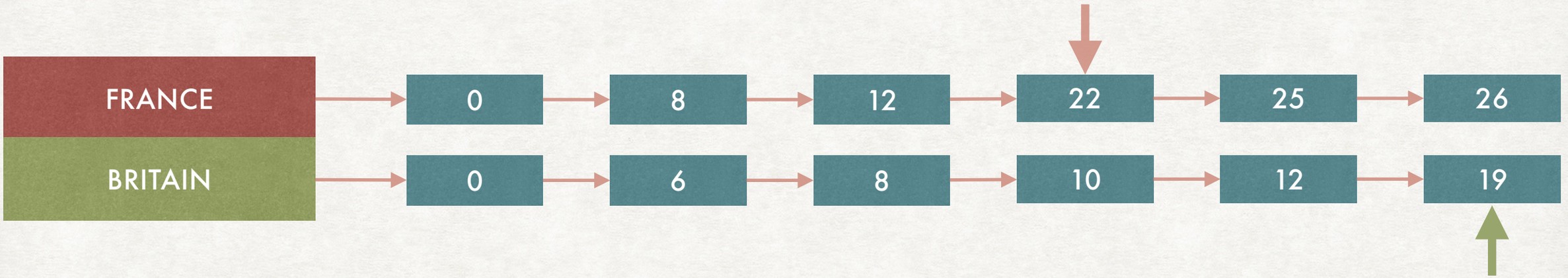


Complexity: linear in the lengths of the lists

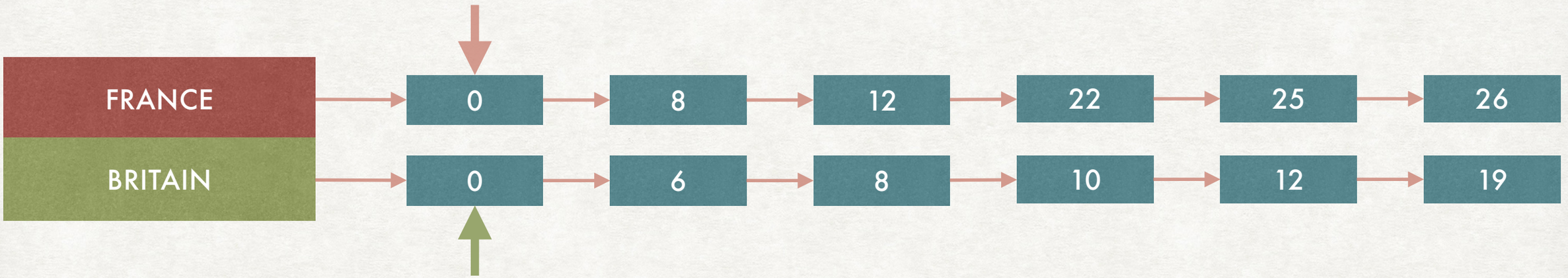
Size of the answer ≤ minimum of the lengths of the lists

ANSWERING A "OR" QUERY

WITHOUT DUPLICATES!

QUERY	FRANCE	OR	BRITAIN

We still need to compare the two lists of documents

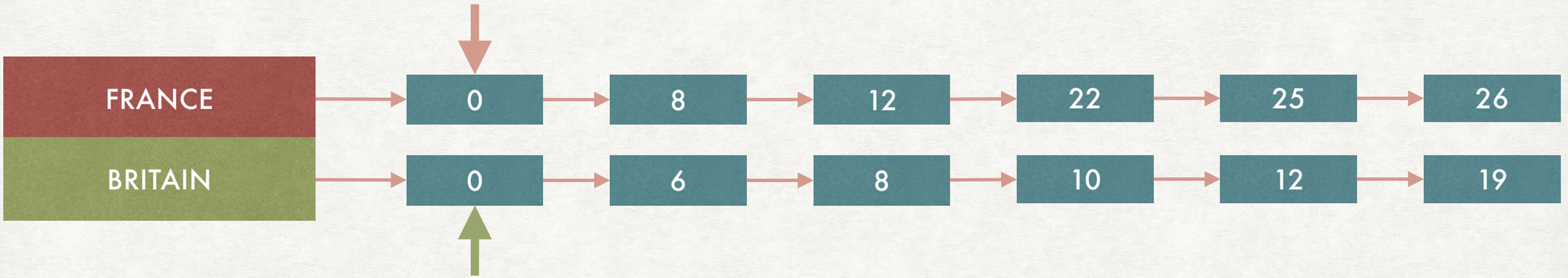


ANSWER

ANSWERING A "OR" QUERY

WITHOUT DUPLICATES!

QUERY	FRANCE	OR	BRITAIN



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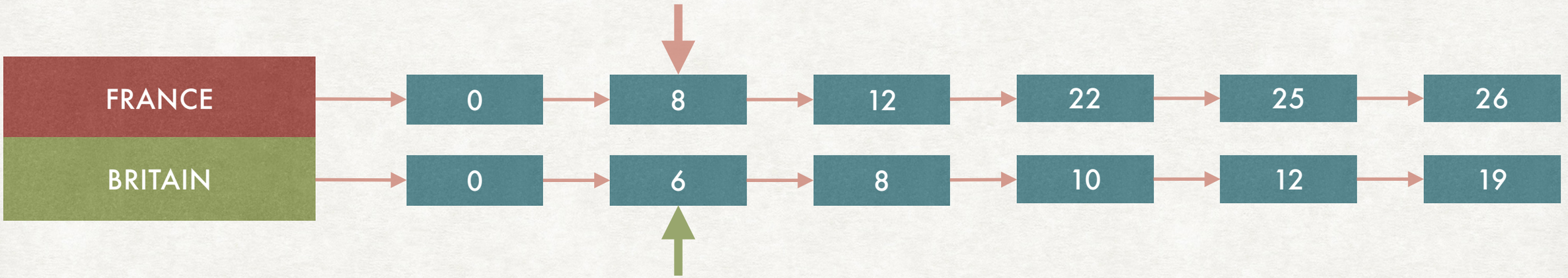

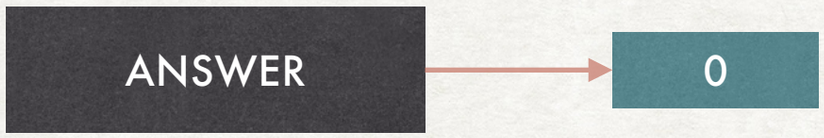

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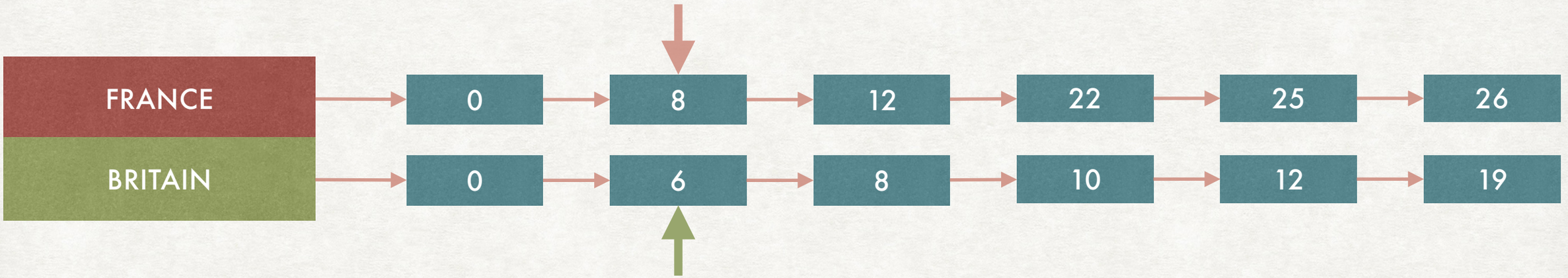

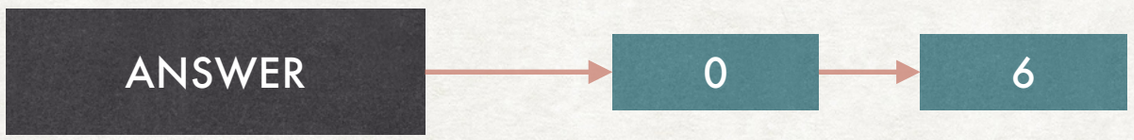

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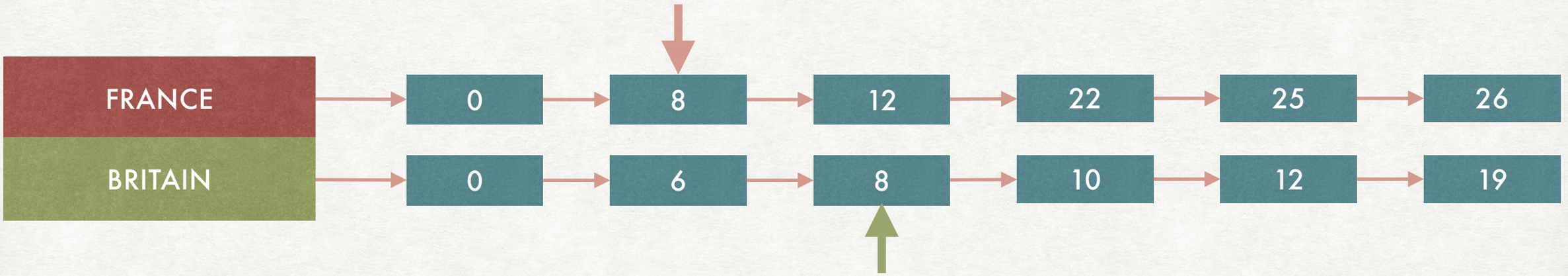

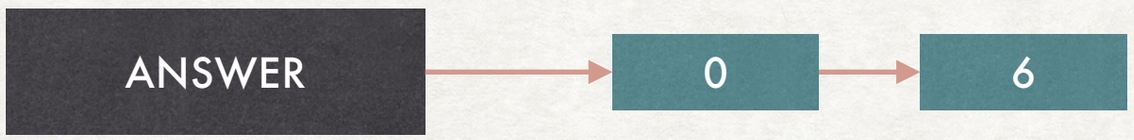

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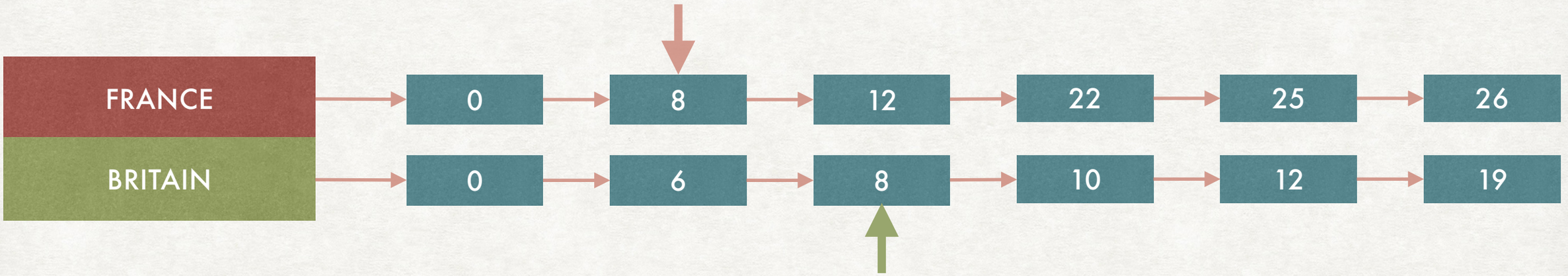

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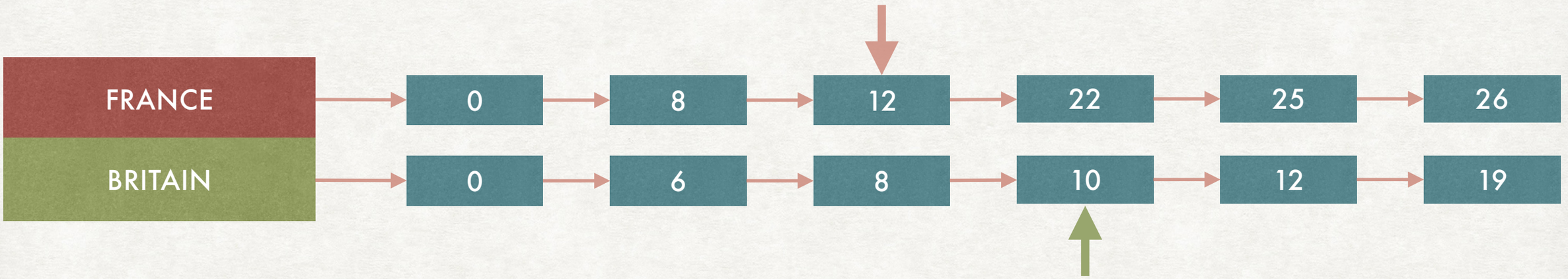

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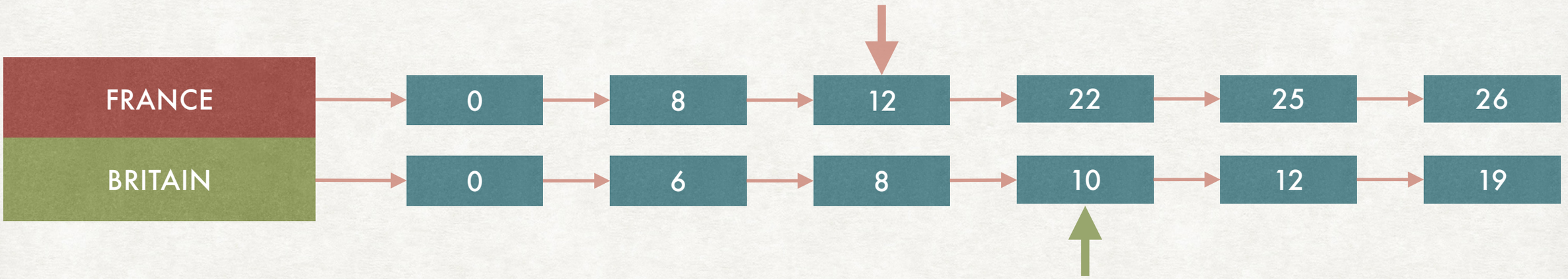

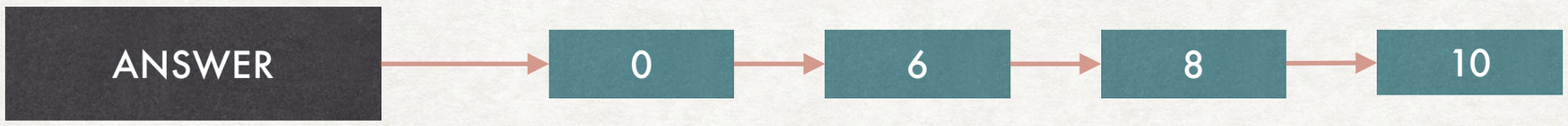

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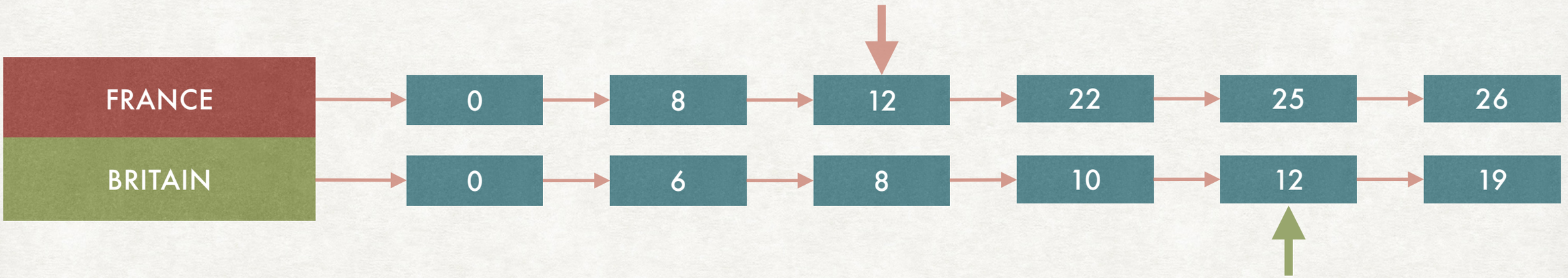

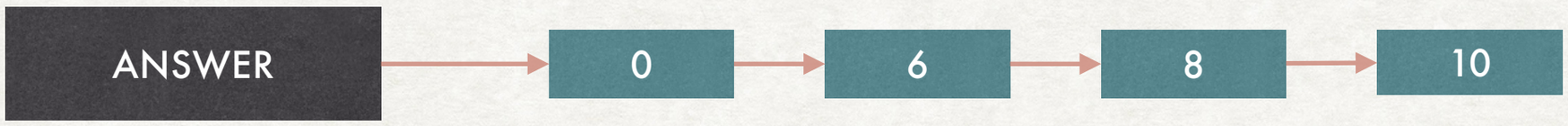

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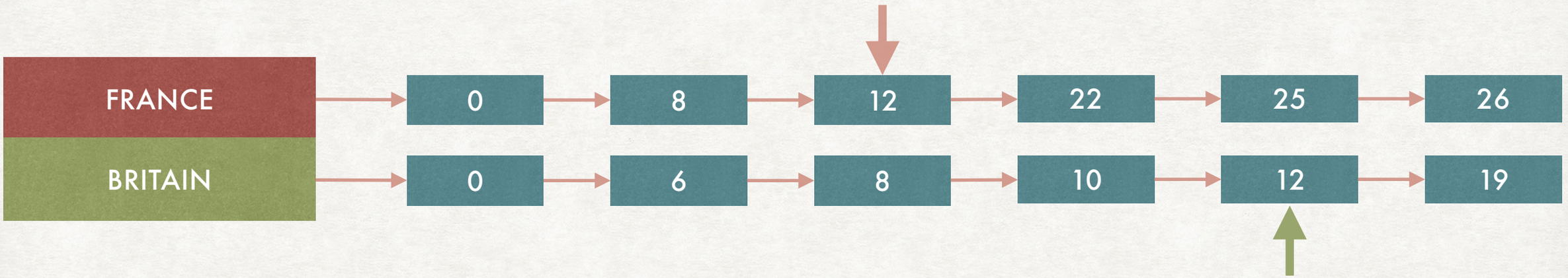
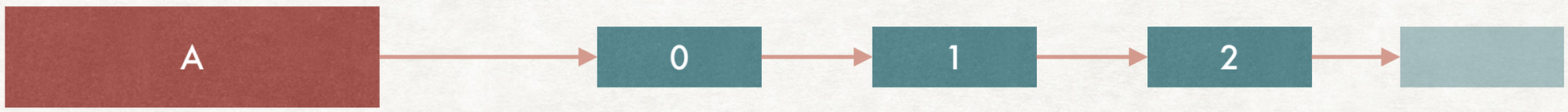


Complexity: linear in the lengths of the lists

Size of the answer ≤ sum of the lengths of the lists

IS THAT ALL?

HINT: NO



Some terms are not useful: “A” is in all the documents!

Some terms are very similar semantically.

Example

Do we really want to keep “CAR” and “CARS” separated?

We would like to better determine the set of terms in the dictionary and to provide retrieval that is tolerant to spelling mistakes and inconsistent choice of words.

BUILDING AN INVERTED INDEX

MAJOR STEPS

1. Collect the documents to be indexed

2. Tokenize the text, turning each document into a list of tokens

3. Do linguistic preprocessing, producing a list of normalized tokens, which are the indexing terms

4. Index the documents that each term occurs in by creating an inverted index, consisting of a dictionary and postings.

IS THAT ALL?

HINT: NO

- Often useful to search for compounds or phrase: biwords, term1 NEAR term2, “term1 term2”, term1* (wildcards), etc.

- Term frequency information (the number of times a term occurs in a document) in postings lists

- An effective method to order (or “rank”) the returned results

- How to compress the index, how to update it, etc.