INFORMATION RETRIEVAL

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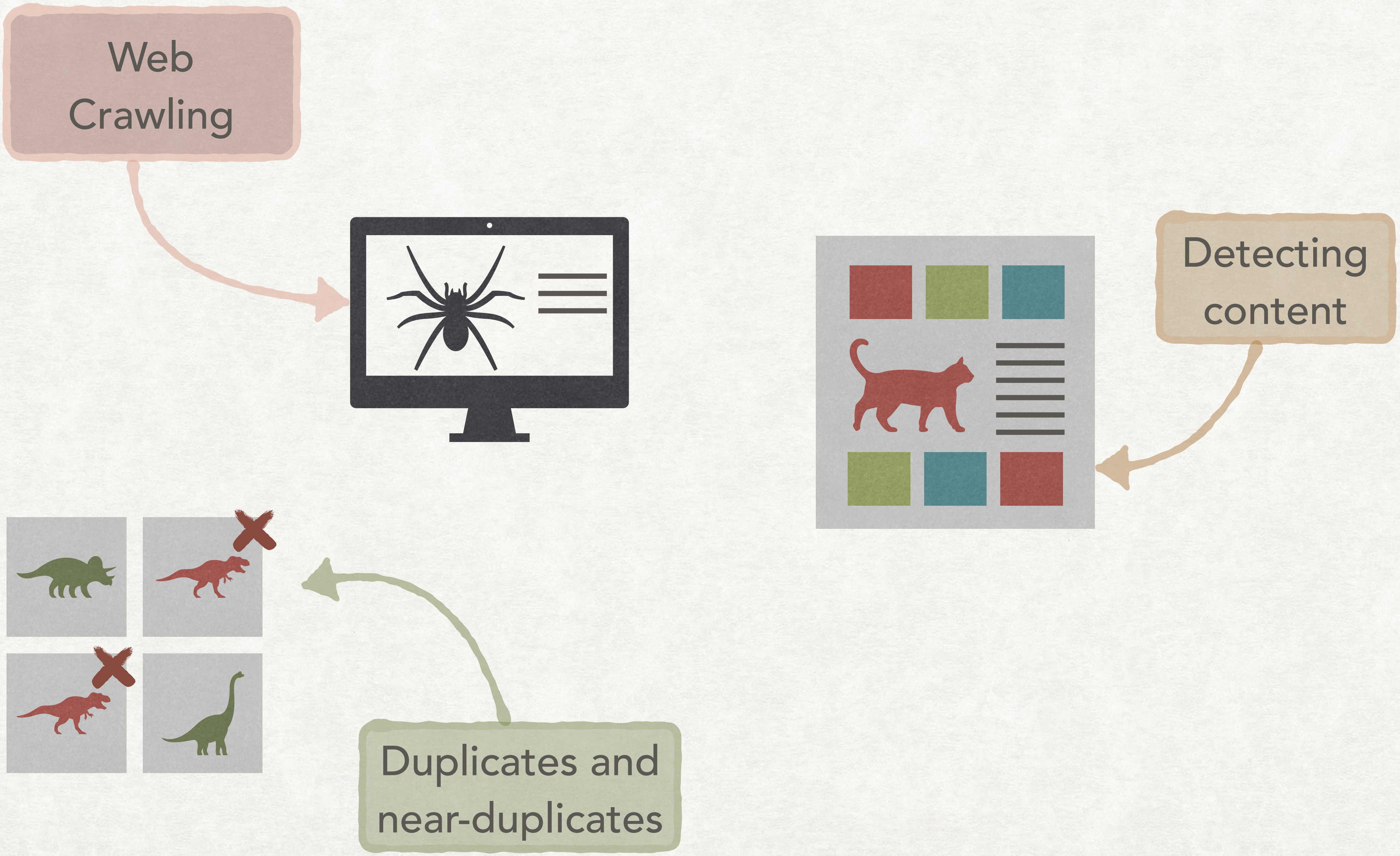
Lecture 9

LECTURE OUTLINE

*NOW AVAILABLE VIA THE INFORMATION SUPERHIGHWAY



But first of all…

BASICS OF WEB SEARCH

TERMINOLOGY

BASICS

- **HTTP** and **HTTPS**. Protocols used to transmit web pages.
- **HTML**. The markup language used to encode web pages
- **URL**. Universal Resource Locator, (protocol + hostname + resource). E.g, *https://www.example.com/a/resource.html* has
  - *https*: protocol
  - *www.example.com*: hostname
  - */a/resource.html*: resource

TERMINOLOGY

LINKS

- **Static web pages.** The content does not change between multiple requests.
- **Dynamic web pages.** Automatically generated pages, e.g., in response to a query to a database.
- **Anchor text.** The text visualised for a link:
  `<a href=URL>Anchor text</a>`
  - `<a href=URL>` is the opening tag
  - `</a>` is the closing tag

TERMINOLOGY

LINKS

- **Web graph**: we can view the (static) web consisting of HTML pages together with the hyperlinks between them as a directed graph in which each web page is a node and each hyperlink a directed edge

- **In-links**: set of links that refer to a web page (notice that they are not contained in the web page).

- **Out-links**: set of links from a web page (this can be obtained by looking at the web page)

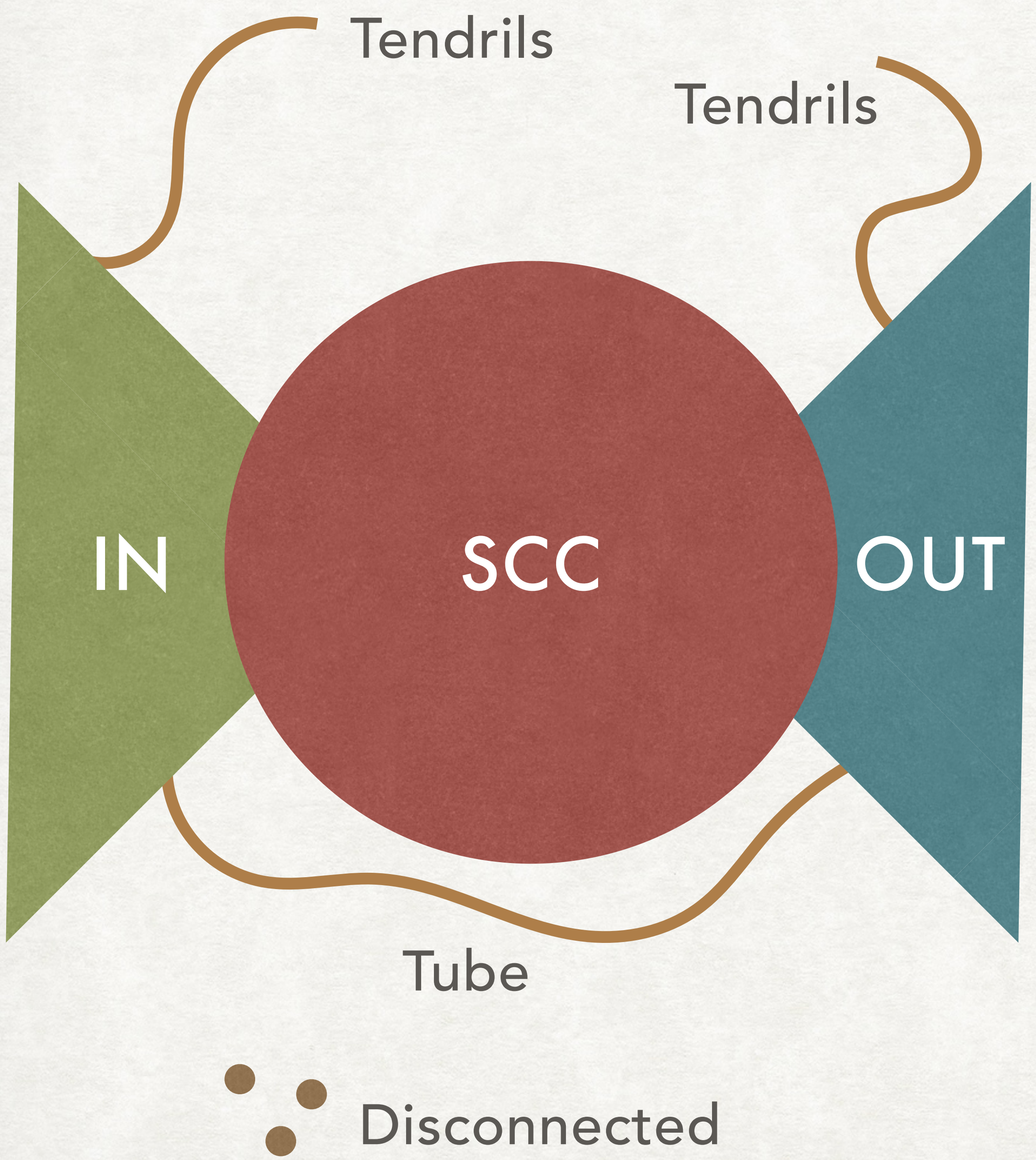
THE WEB AS A GRAPH

AT DIFFERENT LEVELS

- The web can be seen as a graph on different levels:
  - A page is a node of the graph, with outgoing edges given by the links that it contains.
  - A **PLD** (pay-level-domain, like example.com, amazon.com, etc.) is a node with outgoing edges given by all the out-links contained in the pages on the PLD.
- In both cases, the distribution of in-degrees and out-degrees of the nodes is far from the classical random graph model (the Erdős–Rényi model), it is more closely modelled by a **power law distribution** $f(x) = ax^{-k}$.

BOWTIE SHAPE

STRUCTURE OF WEB LINKS



- **SCC**. By following hyperlinks it is possible to reach each other page in SCC
- **IN**. Pages that can reach SCC, but cannot be reached by pages in SCC.
- **OUT**. Pages that can be reached from SCC, but cannot reach SCC.
- **Tubes**. Direct links from IN to OUT
- **Tendrils**. Pages reachable from IN that lead nowhere or that reach only pages in OUT.

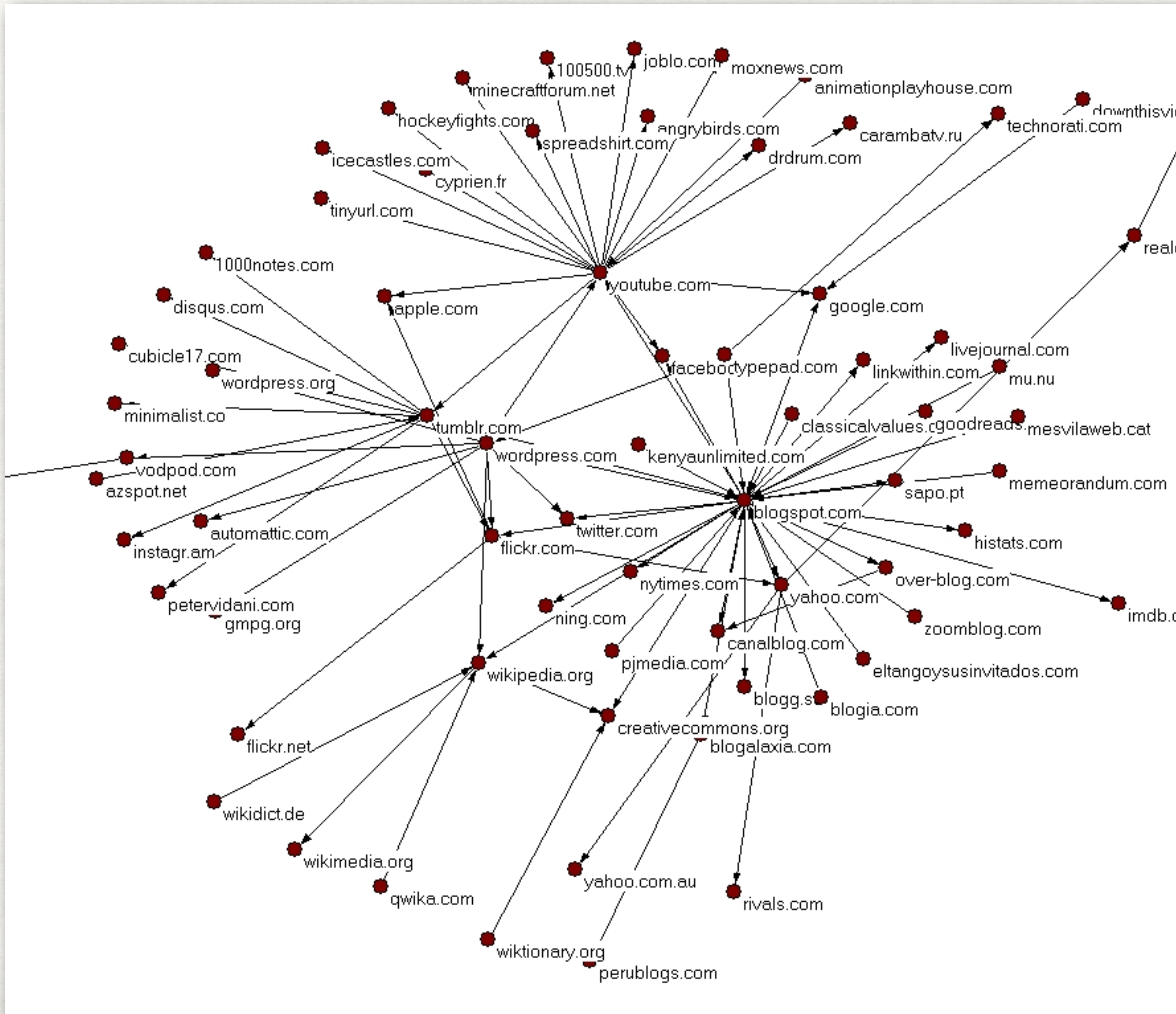
SOME REAL-WORLD DATA

2012 WDC HYPERLINK GRAPH

- The 2012 Web Data Commons (WDC) hyperlink graph includes about 3.5 billions of web pages and 128 billions of links.
- We will see the results on
  - The in- and out-degree distribution of the nodes.
  - The presence of a bow-tie shape.
  - All of this at the pay-level-domain (PLD) level.

Available at http://webdatacommons.org/hyperlinkgraph/2012-08/topology.html

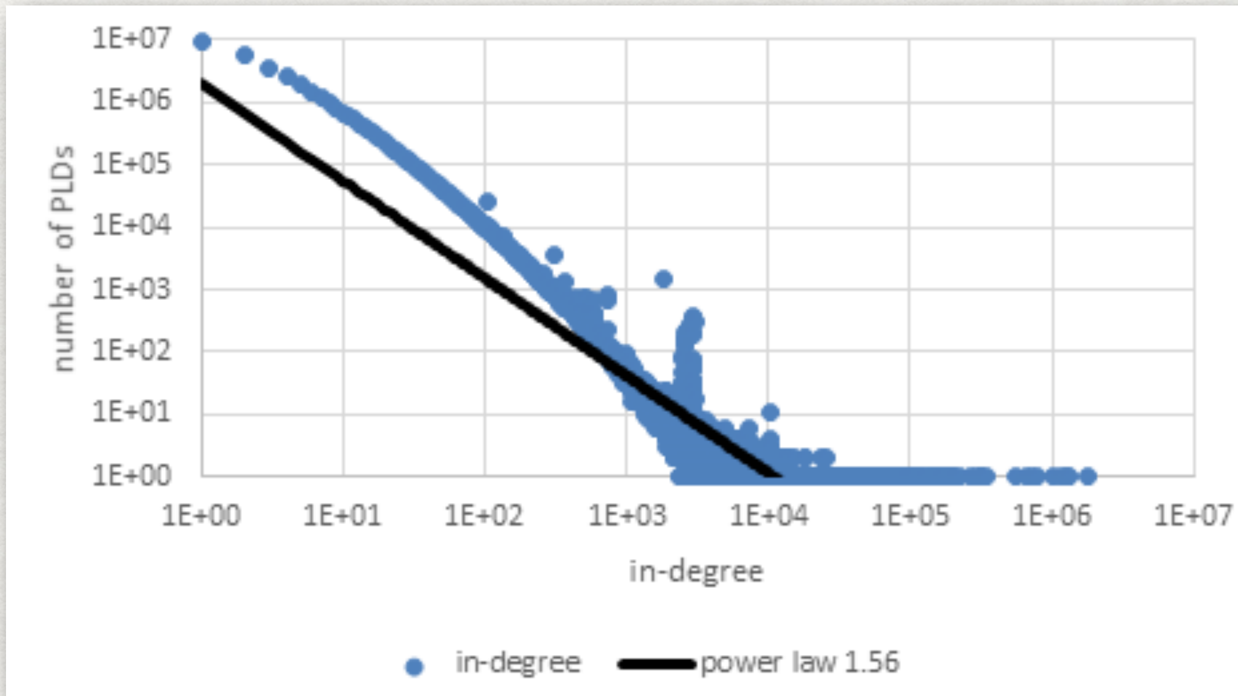
A GRAPH OF PLD



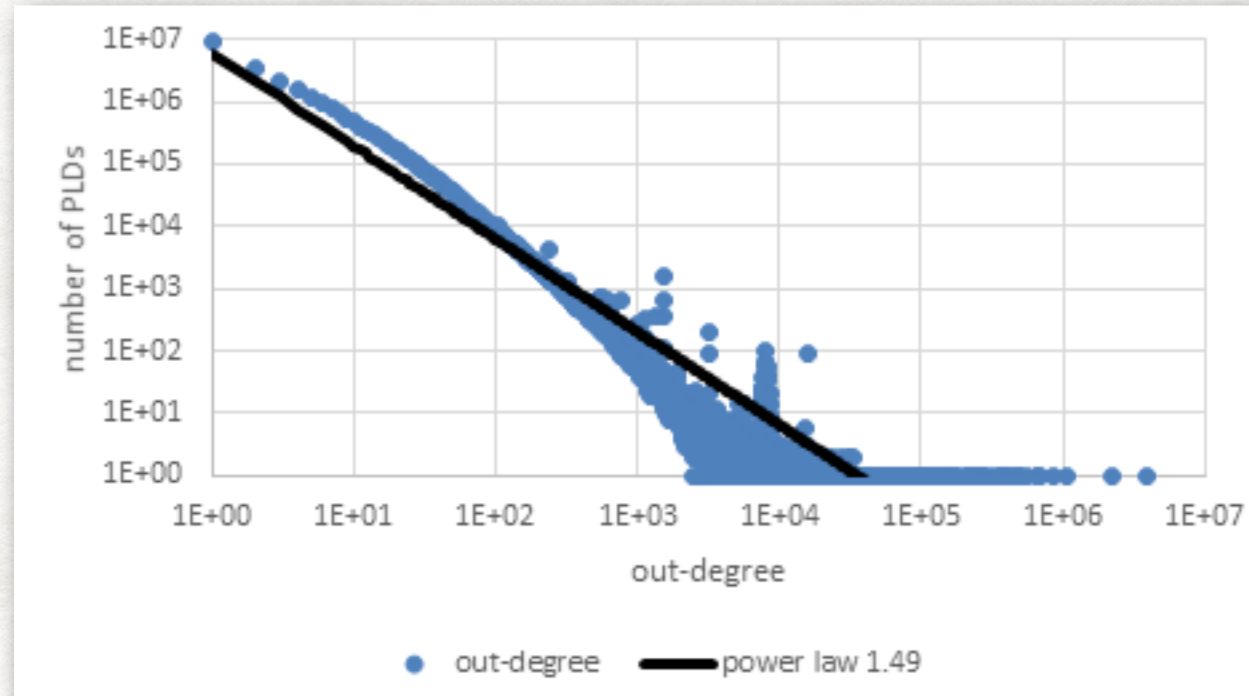
DISTRIBUTION OF DEGREES

AT THE PLD LEVEL

Both axes have a logarithmic scale



In-degree distribution
(PLD level)

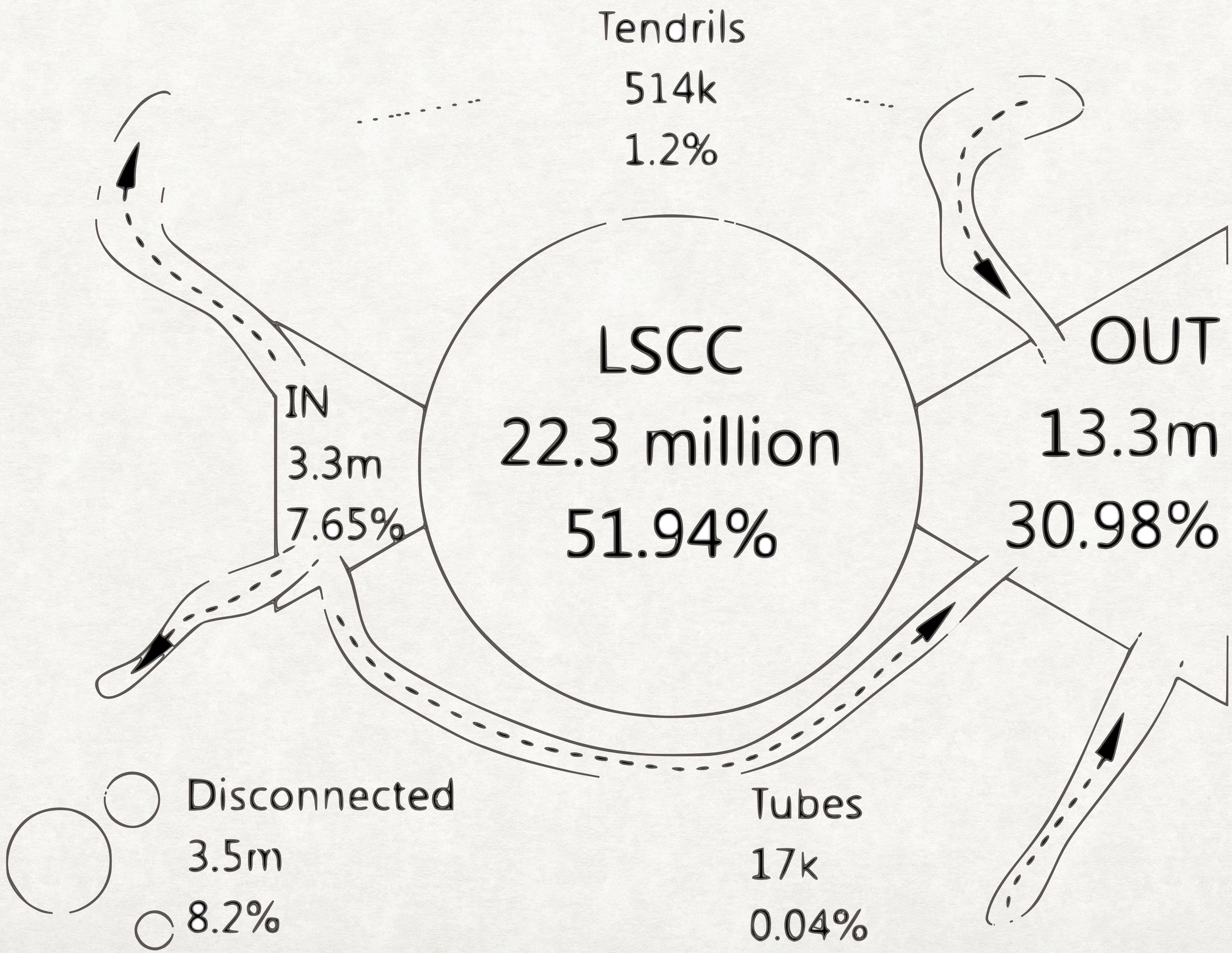


Out-degree distribution
(PLD level)

While the exact distribution of incoming and outgoing links is not completely understood, a power law (i.e., $f(x) = ax^{-k}$) seems a good approximation.

THE BOWTIES STRUCTURE

AT THE PLD LEVEL



THE DEEP WEB

THE PART OF THE WEB THAT IS DIFFICULT TO INDEX

- Web pages that are difficult or impossible to index are part of the **deep** or **hidden** web.
- Not to be confused with the dark web/darknet, a small portion of the deep web that has been purposefully made inaccessible.
- It is estimated to be larger than the conventional web.
- Usually contains private sites (where login might be needed or there are no incoming links), form results, and scripted pages (e.g., were the links are generated by scripts).

WEB CRAWLERS

WEB CRAWLERS

AKA SPIDERS

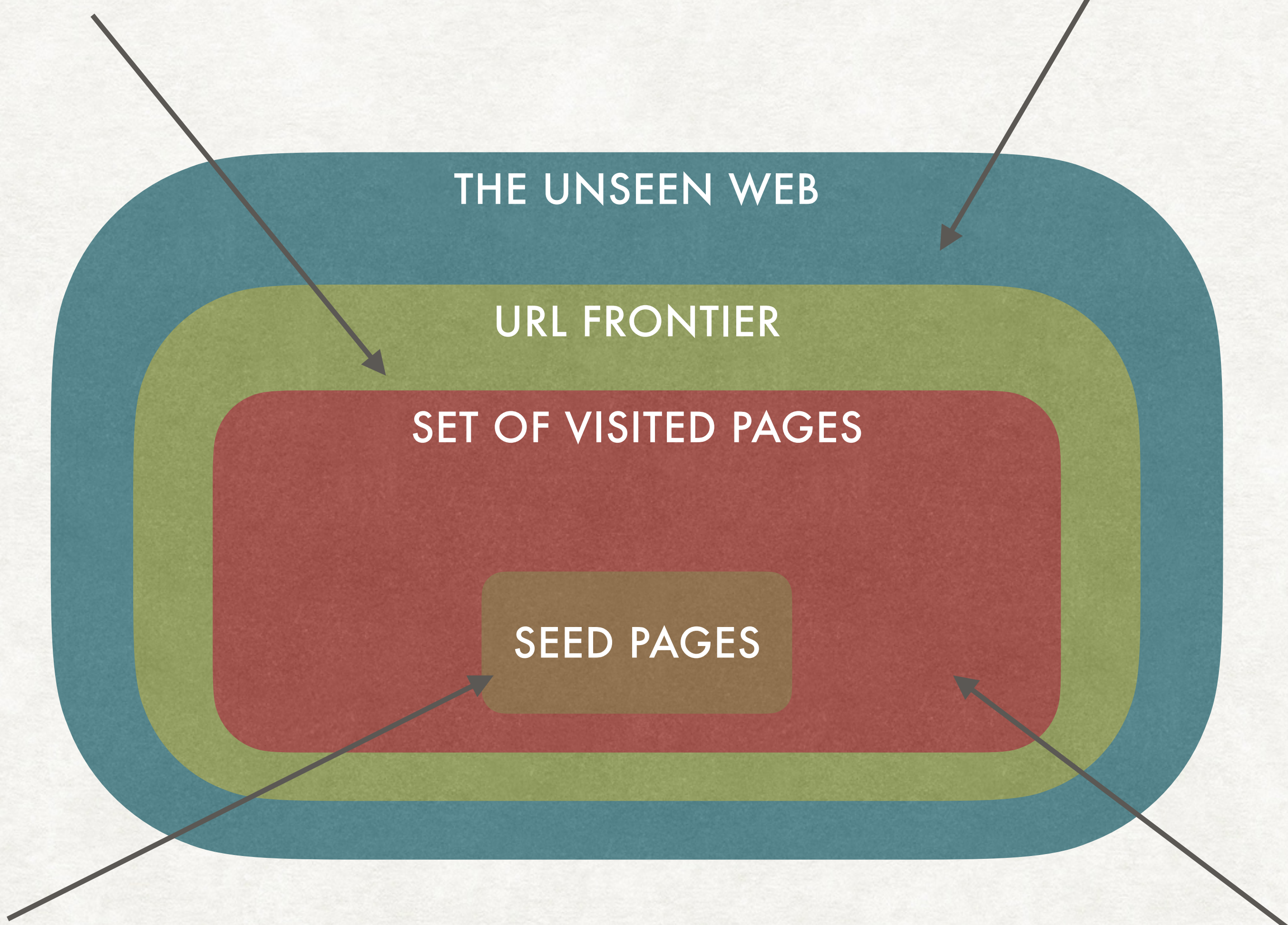
- Web crawling is the process of gathering pages from the Web to index them.
- The process is carried on by *web crawlers*, also called *spiders*.
- While retrieving a single web page is simple…
- …web crawling must take into account the scale of the web…
- …and the fact that the content to index is not under the control of the people building the index.

VISITING WEB PAGES

SEEN, UNSEEN, AND UNKNOWN PAGES

Set of pages with URL found by the crawler but not visited

Set of unvisited web pages for which the URL is not known



A set of known web pages from which the crawling starts

Set of pages that the crawler has visited

ESSENTIAL PROPERTIES OF A WEB CRAWLER

EVERY WEB CRAWLER MUST HAVE THEM

- **Robustness**. A web crawler must not be blocked by *spider traps*, web pages built to force a crawler to fetch an infinite amount of pages from a specific domain.
  - Sometimes spider traps are not malicious. Just imagine a "calendar" page that every time allows to go to the "next month" and generates the new pages dynamically.
- **Politeness**. A web crawler cannot overload a web server with requests. All requests to a domain must be adequately spaced in time and policies like the one in "robot.txt" (robot exclusion protocol) must be adhered to.

ROBOT.TXT

WHAT WE CAN INDEX

A robot.txt file in a web server provides some information on what a crawler is allowed to index

Which crawlers should apply the following directives

Directories that should not be indexed

Directives for a specific bot: disallow everything

Directives for a specific bot: allow everything

File containing the set of URL available for crawling

```
User-agent: *
Disallow: /cgi-bin/
Disallow: /tmp/
Disallow: /private/

User-agent: BadBot
Disallow: /

User-agent: GoogleBot
Disallow:

Sitemap: http://www.example.com/sitemap.xml
```

GOOD PROPERTIES OF A WEB CRAWLER

A WEB CRAWLER SHOULD, IF POSSIBLE, HAVE THEM

- **Distributed**. Indexing the entire web from a single machine is infeasible, the web crawler should be able to execute from multiple machines
- **Scalable**. It should be possible to increase the crawl rate by simply adding more machine and bandwidth.
- **Performance and efficiency**. The crawler should try to make efficient use of system resources (e.g., by not blocking when waiting for the response from a server).

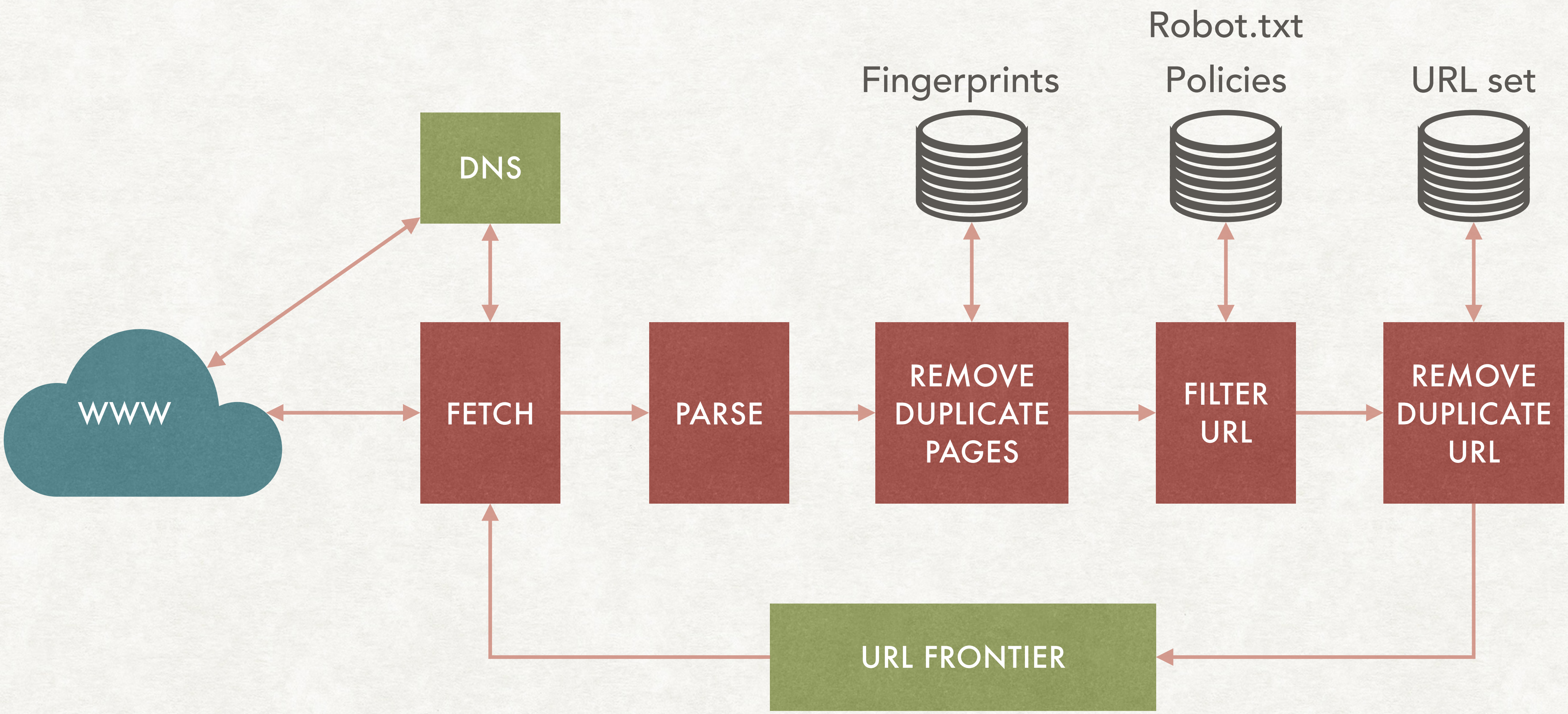
GOOD PROPERTIES OF A WEB CRAWLER

A WEB CRAWLER SHOULD, IF POSSIBLE, HAVE THEM

- **Quality**. The crawler should have a bias toward "useful" pages.
- **Freshness**. The content on the web is always changing, thus the crawler should revisit already visited pages to obtain a fresh copy.
  - A crawler should visit a page with a frequency that approximate the rate of change of the page.
- **Extensible**. There might be new data format, new protocols, etc. and the crawler should be able to be extended to handle them.

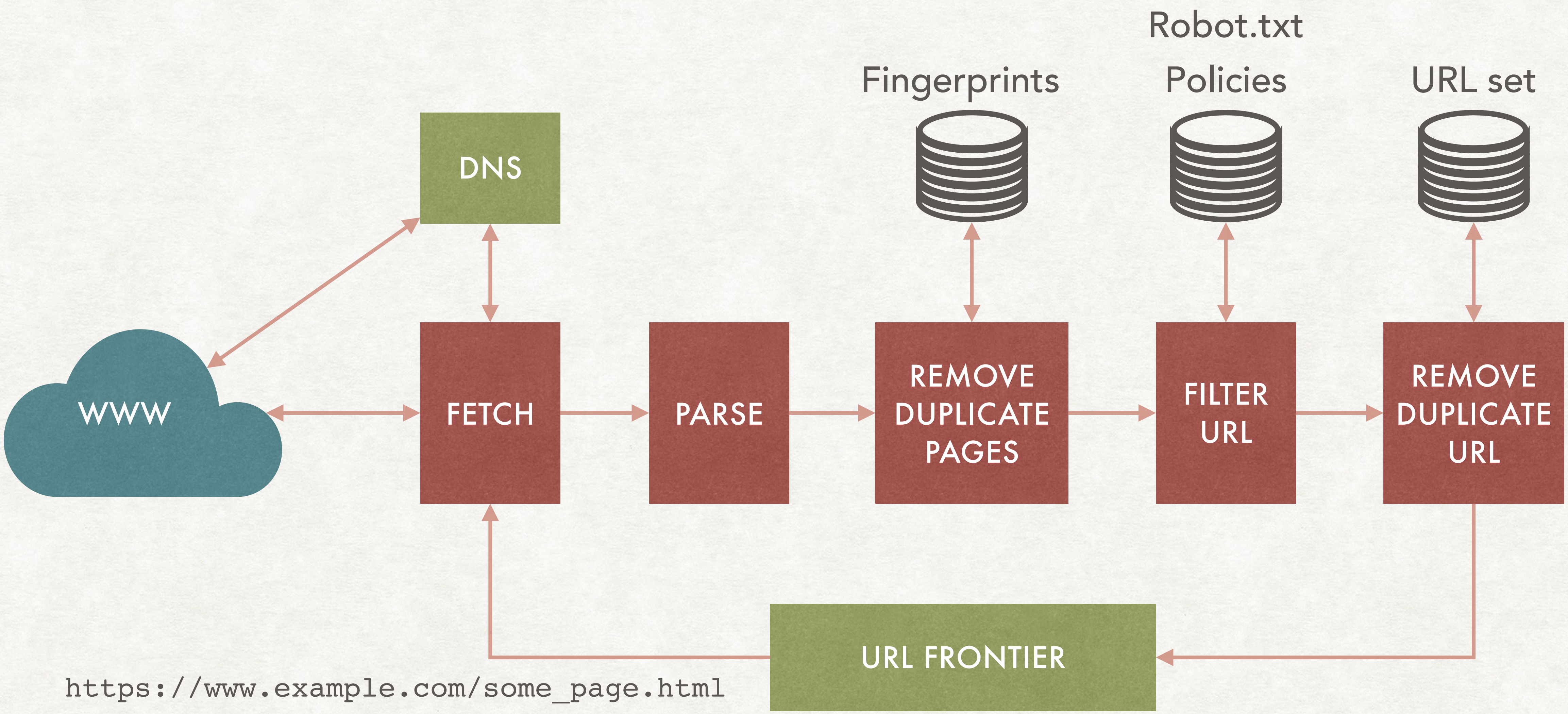
ARCHITECTURE OF A WEB CRAWLER

BASIC STRUCTURE



ARCHITECTURE OF A WEB CRAWLER

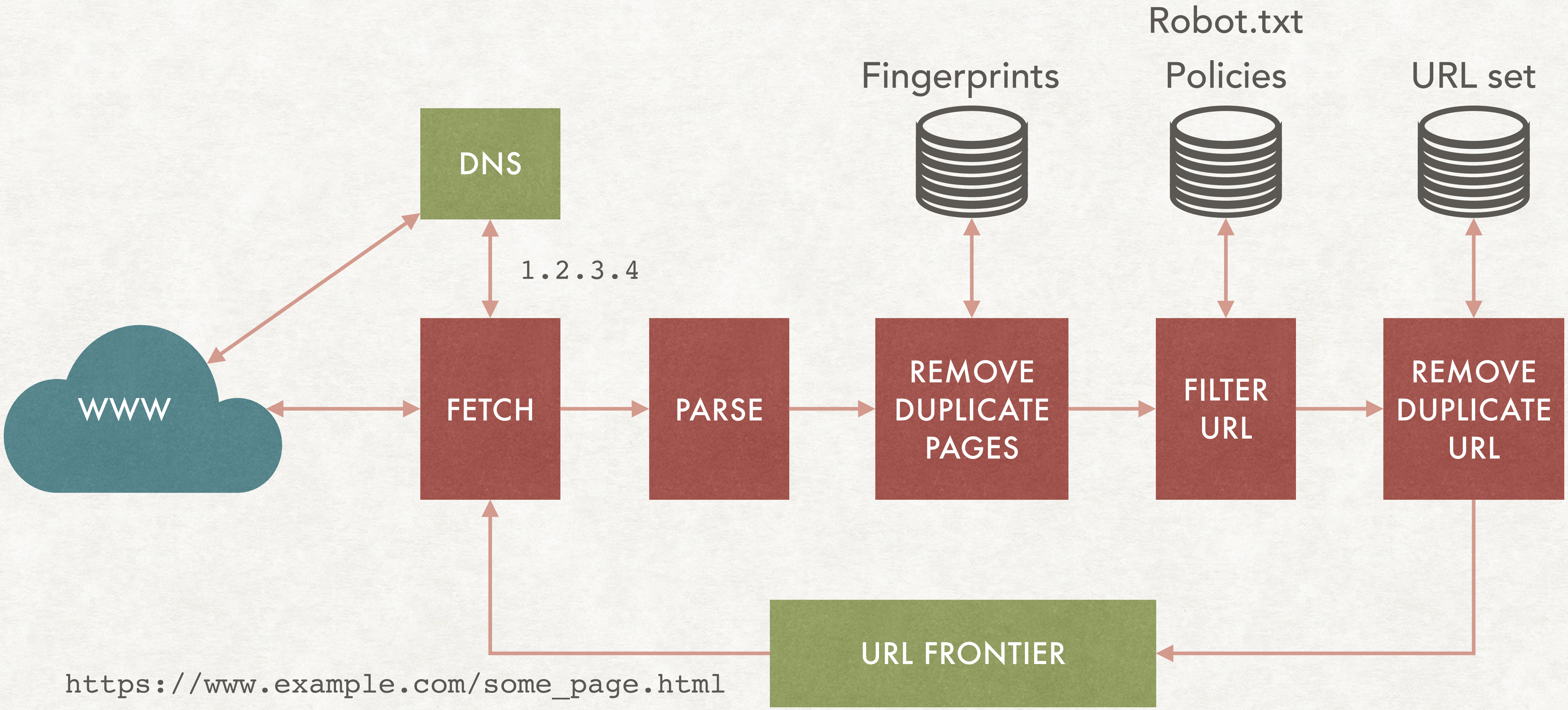
BASIC STRUCTURE



The fetch module retrive an URL to crawl from the URL frontier

ARCHITECTURE OF A WEB CRAWLER

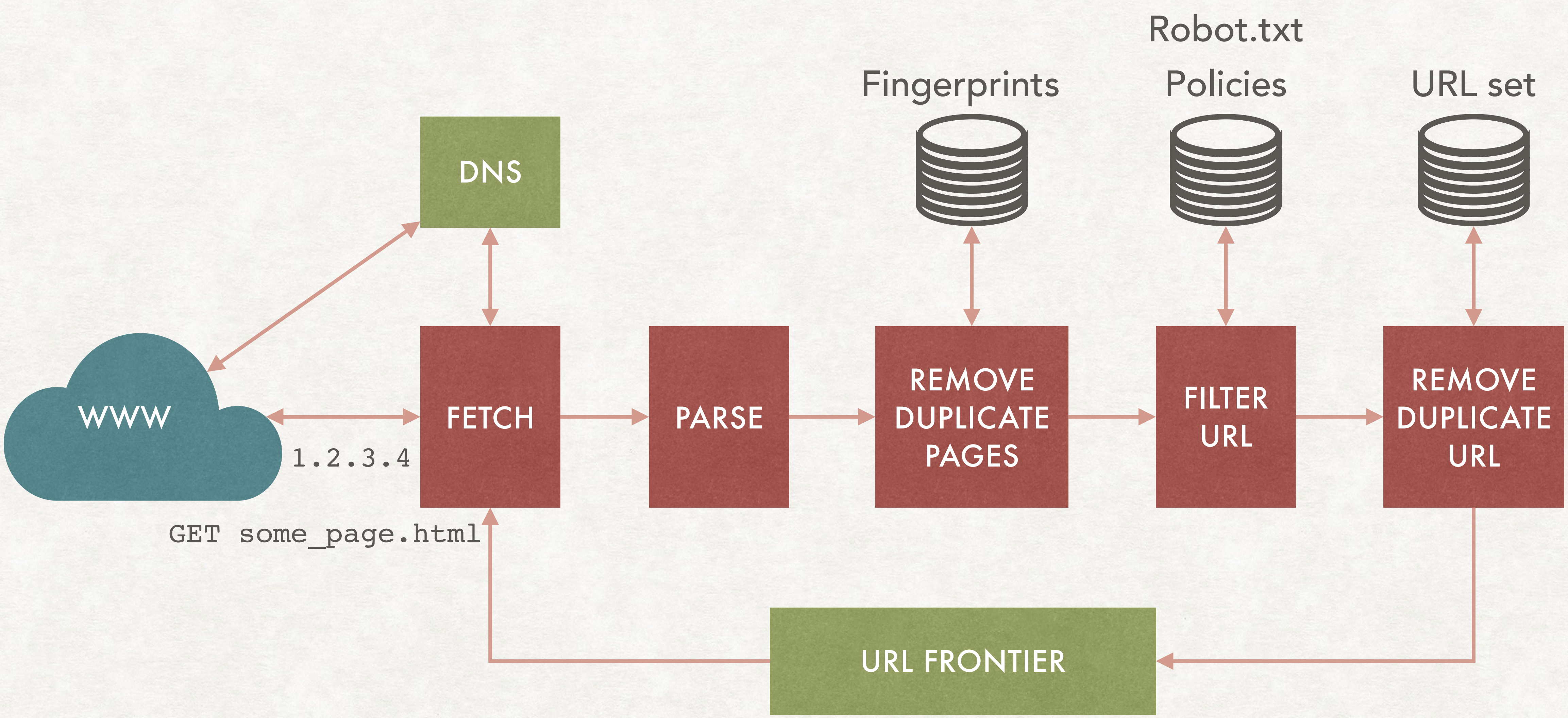
BASIC STRUCTURE



The DNS (Domain Name System) resolver find which IP address corresponds to www.example.com

ARCHITECTURE OF A WEB CRAWLER

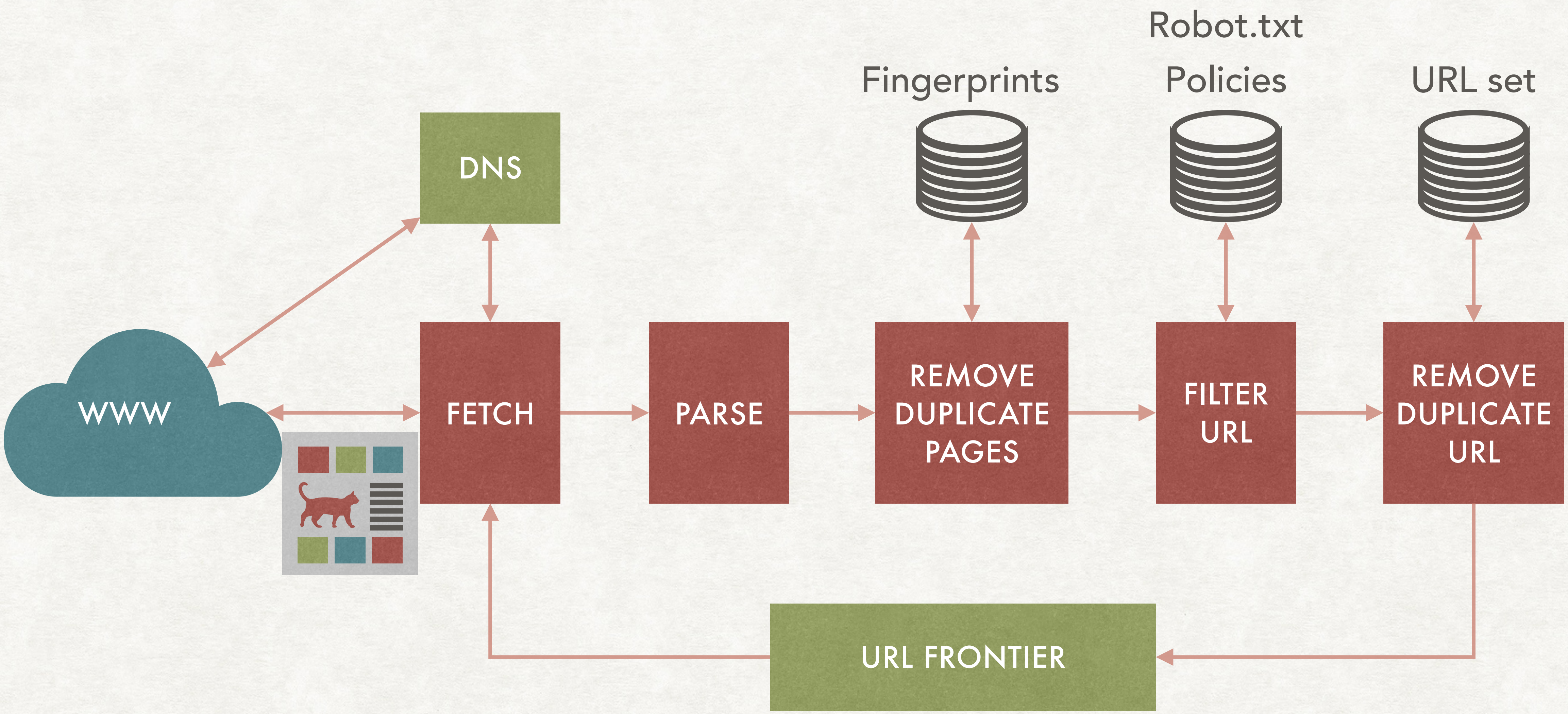
BASIC STRUCTURE



The fetch module asks for the web page to the server

ARCHITECTURE OF A WEB CRAWLER

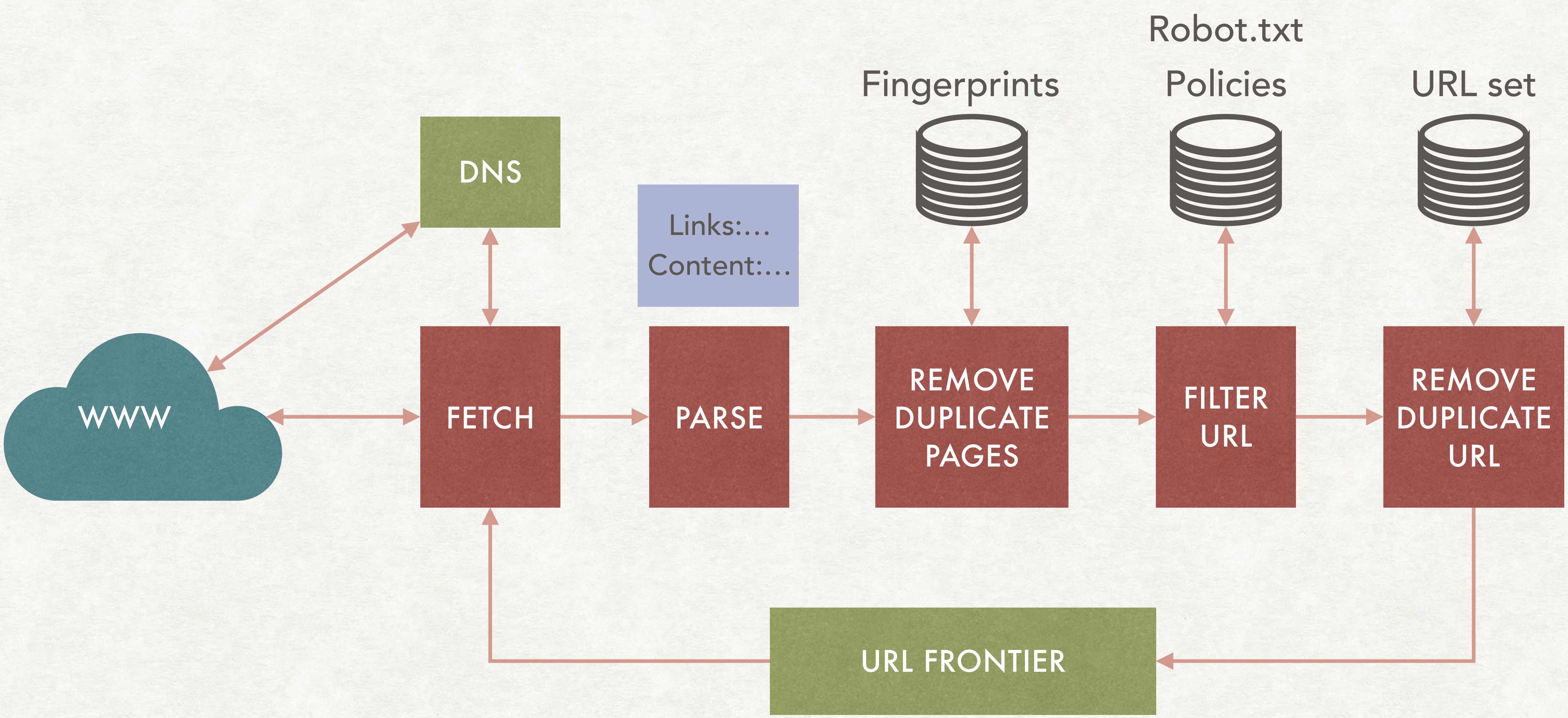
BASIC STRUCTURE



The fetch module receives the web page

ARCHITECTURE OF A WEB CRAWLER

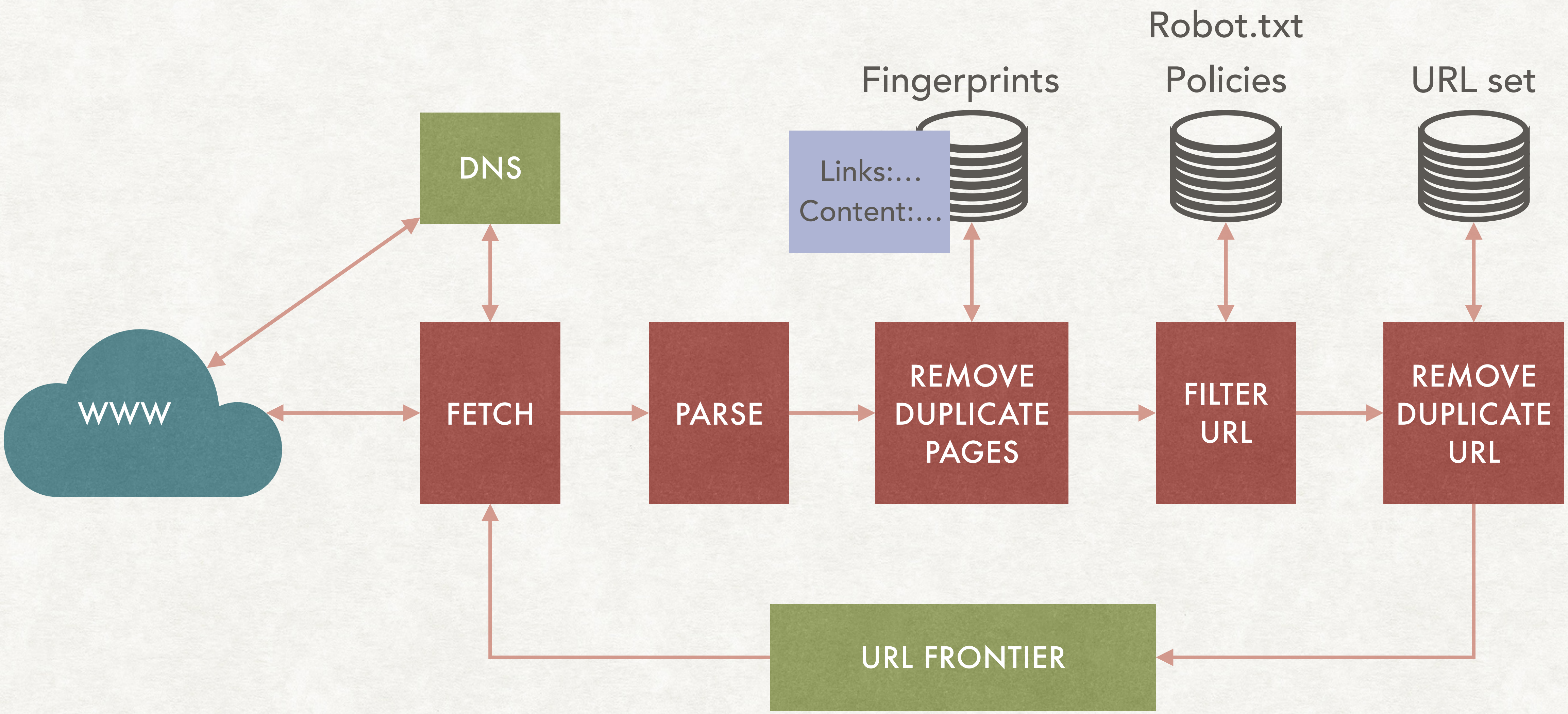
BASIC STRUCTURE



The page is parsed, the links and the main content extracted

ARCHITECTURE OF A WEB CRAWLER

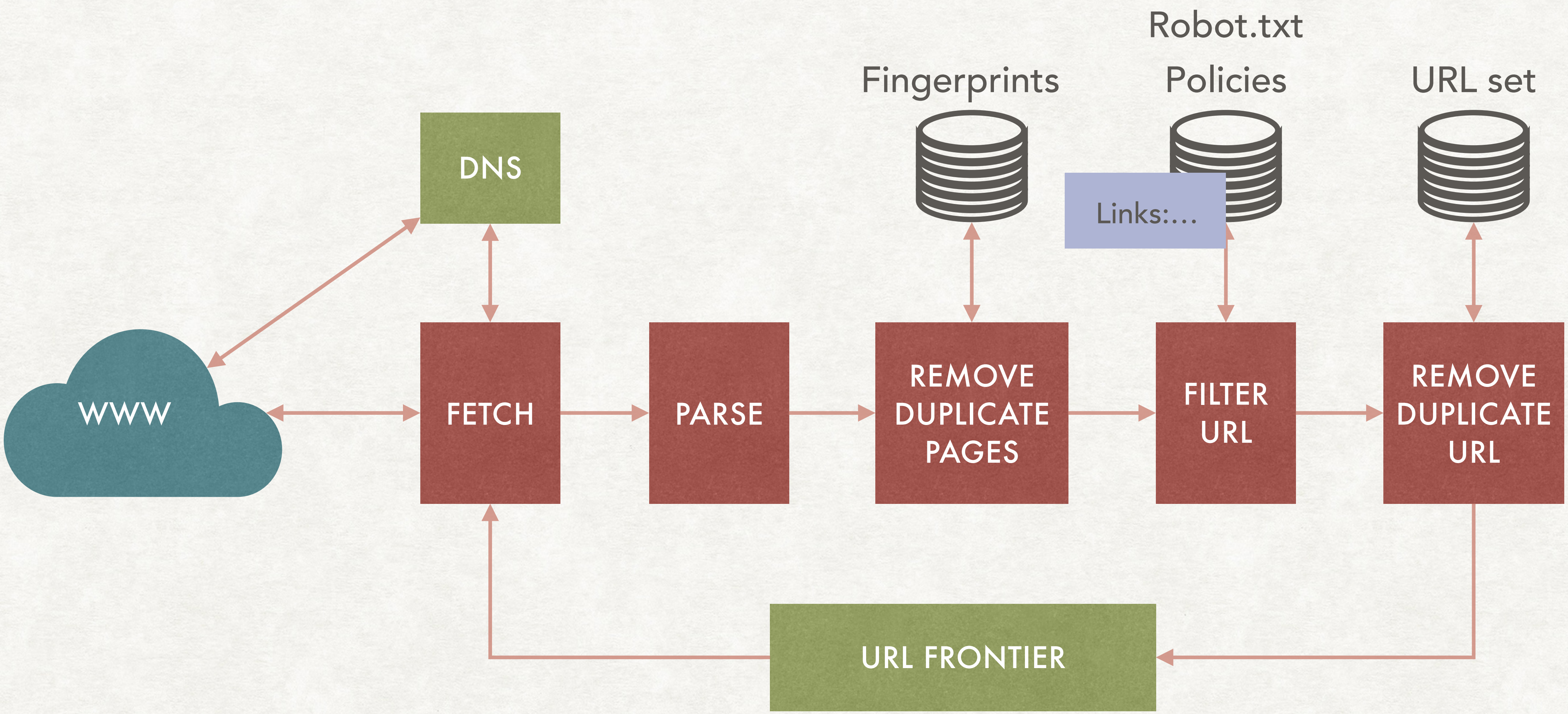
BASIC STRUCTURE



Before indexing the page is checked with a set of "fingerprints" of other pages to verify if it is a duplicate.

ARCHITECTURE OF A WEB CRAWLER

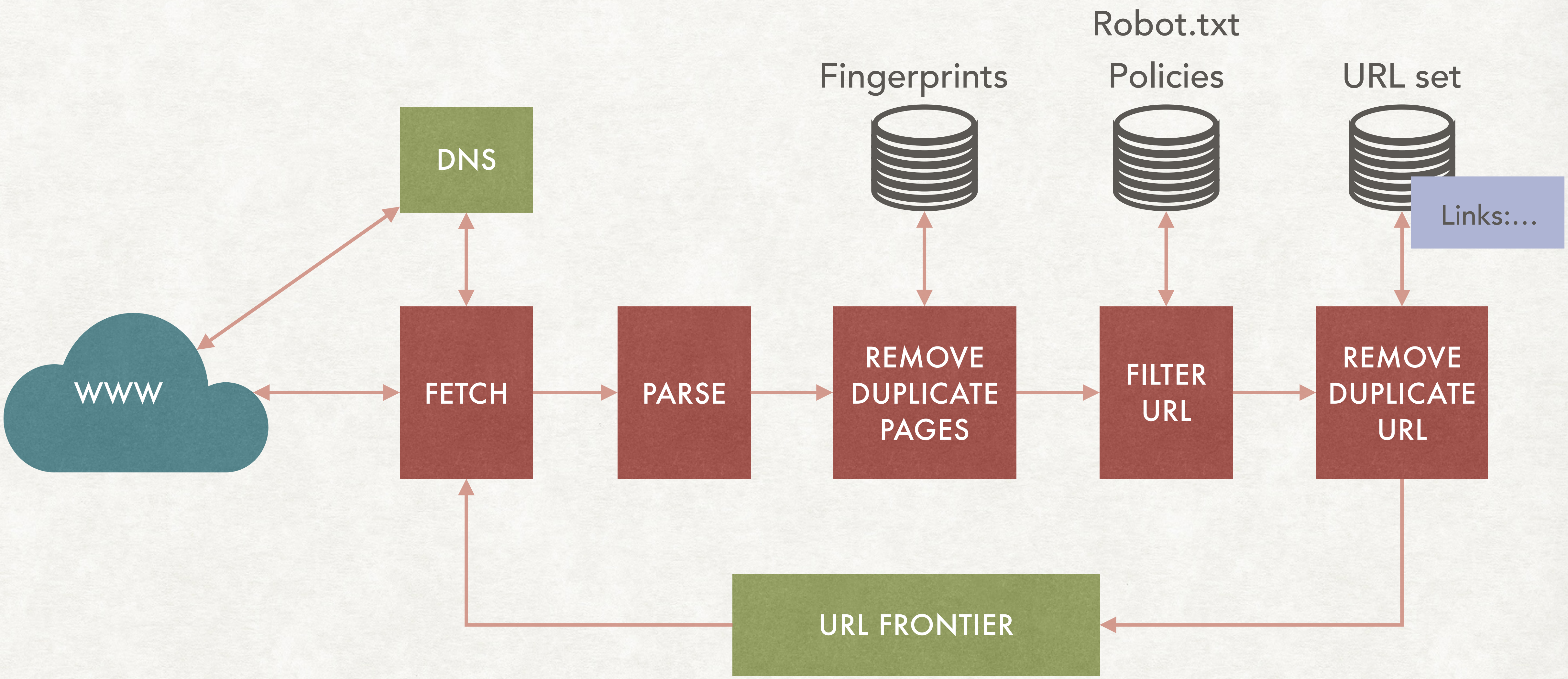
BASIC STRUCTURE



The newly extracted URL are normalised and filtered to eliminate the ones that should not be crawled.

ARCHITECTURE OF A WEB CRAWLER

BASIC STRUCTURE



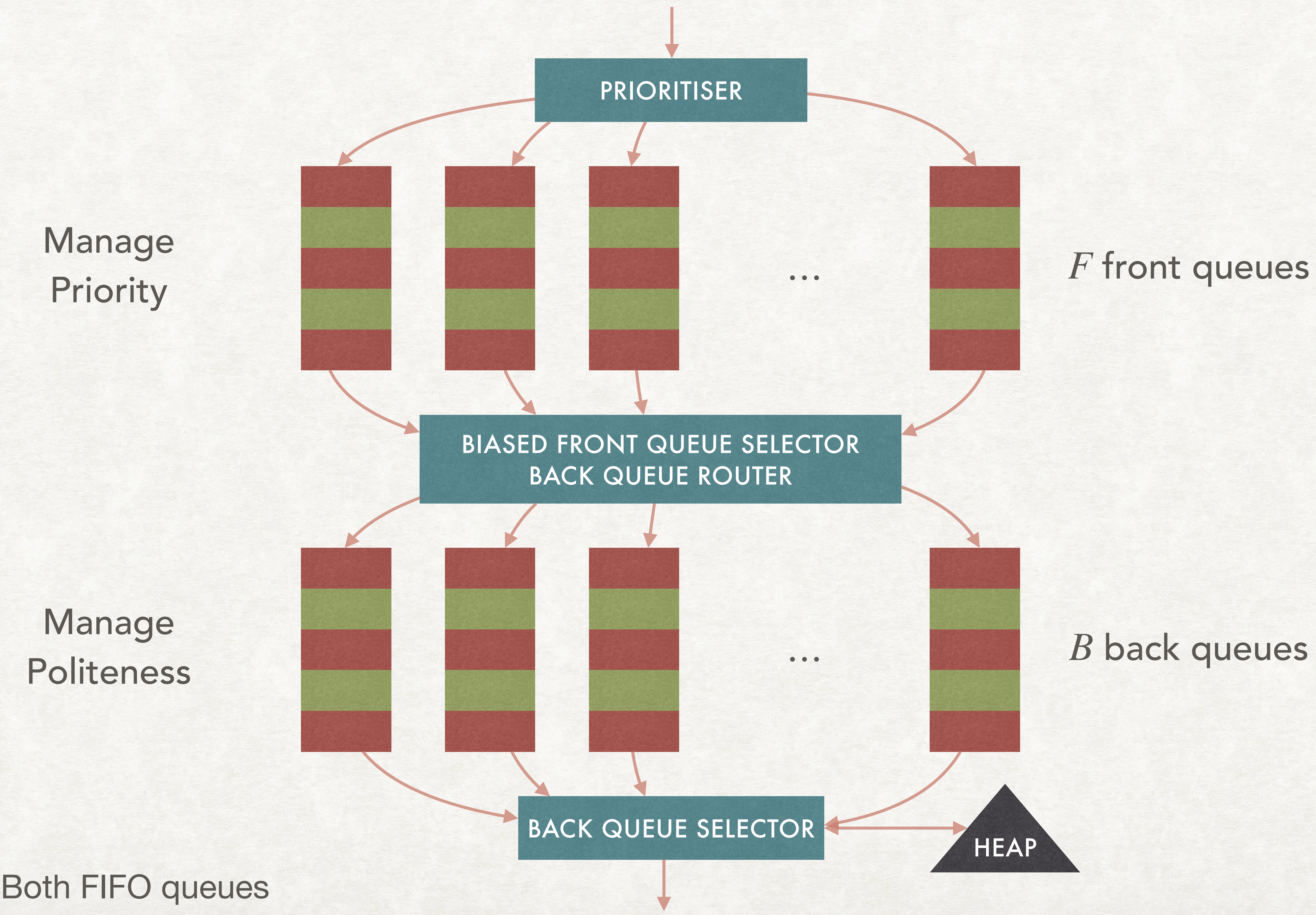
Finally, before being inserted into the URL frontier (the set of URL to visit), already visited URL are removed.

SELECTION OF THE NEXT URL

REQUIREMENTS

- We need an architecture that allows to:
  - Keep only one connection open to the host.
  - Ensure a waiting time of at least a few second between requests.
  - Have a bias for pages with higher priority.
- We present one possible architecture for achieving these goals.
- Multiple threads can extract URL from the URL frontier.

THE URL FRONTIER



Both FIFO queues

FRONT AND BACK QUEUES

FOR PRIORITY AND POLITENESS

- The prioritiser assign an integer priority between 1 and F to each new URL
- There are F front FIFO queues (one for each priority).
- Each of the B back queues has the properties that:
  - The queue is non-empty while crawling is in progress.
  - Each queue contains URL from a single host.
  - To do so we need to keep a mapping from hosts to queues.

FRONT AND BACK QUEUES

FOR PRIORITY AND POLITENESS

- We keep an heap that returns the minimum time to wait to contact again an host.
- We extract the top of the heap, wait the required time, and extract a new URL from the corresponding queue.
- If the queue is now empty, then a new URL is taken from the front queues in a biased manner (i.e., higher probability of being selected to higher priority queues).
    - If the URL is from an host with an already assigned queue then it is inserted in that queue, and the extraction is repeated.

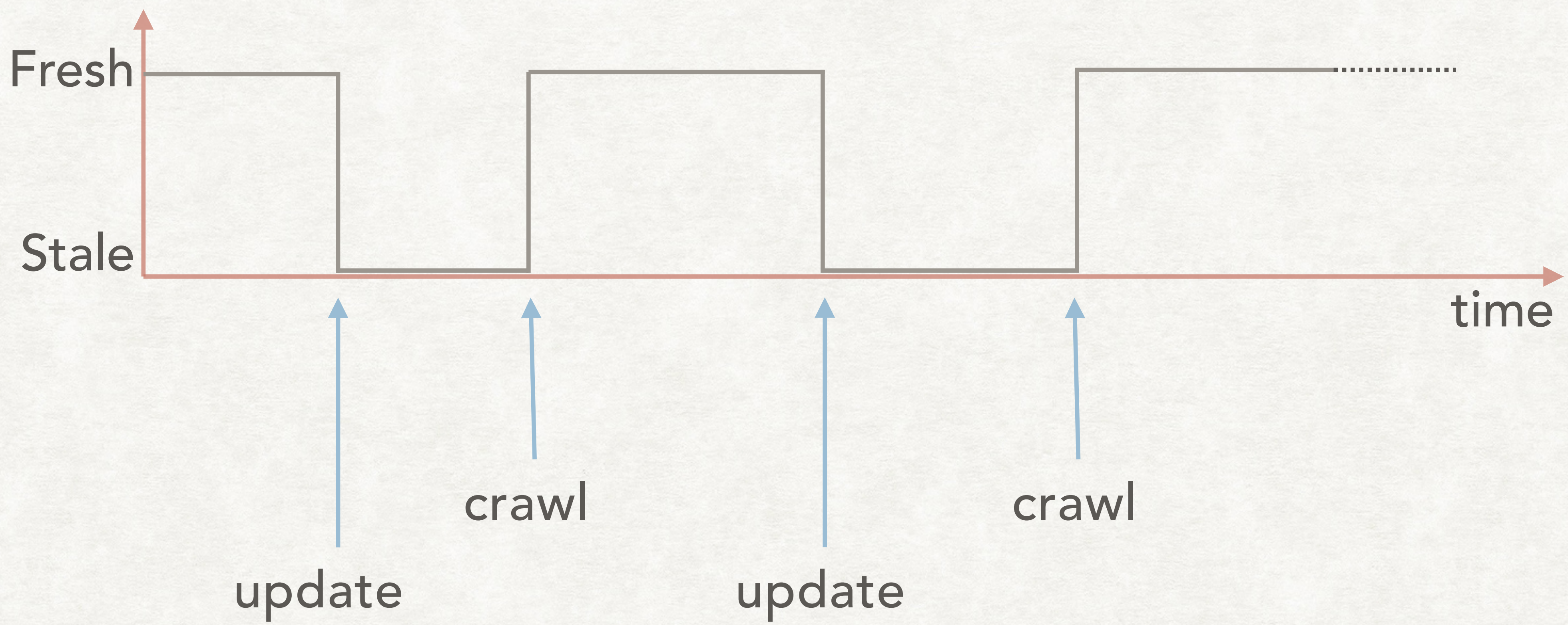
FRESHNESS

AND HOW TO SELECT WHAT TO RE-CRAWL

- A HEAD request is a kind of request where the server send some information about a page, but not the page itself. Among the information there is the "*Last-modified*" time.
- We can use HEAD requests to check pages for freshness.
- However, it is impossible to constantly check all pages.
- We must decide a policy on what pages to check.
- We have two metrics: **freshness** and **age**.

FRESHNESS

A BINARY WAY OF MEASURING "OLD" PAGES



A page is fresh if the crawler has the most recent copy of the page, otherwise the page is stale.

Freshness = fraction of web pages that are currently fresh.

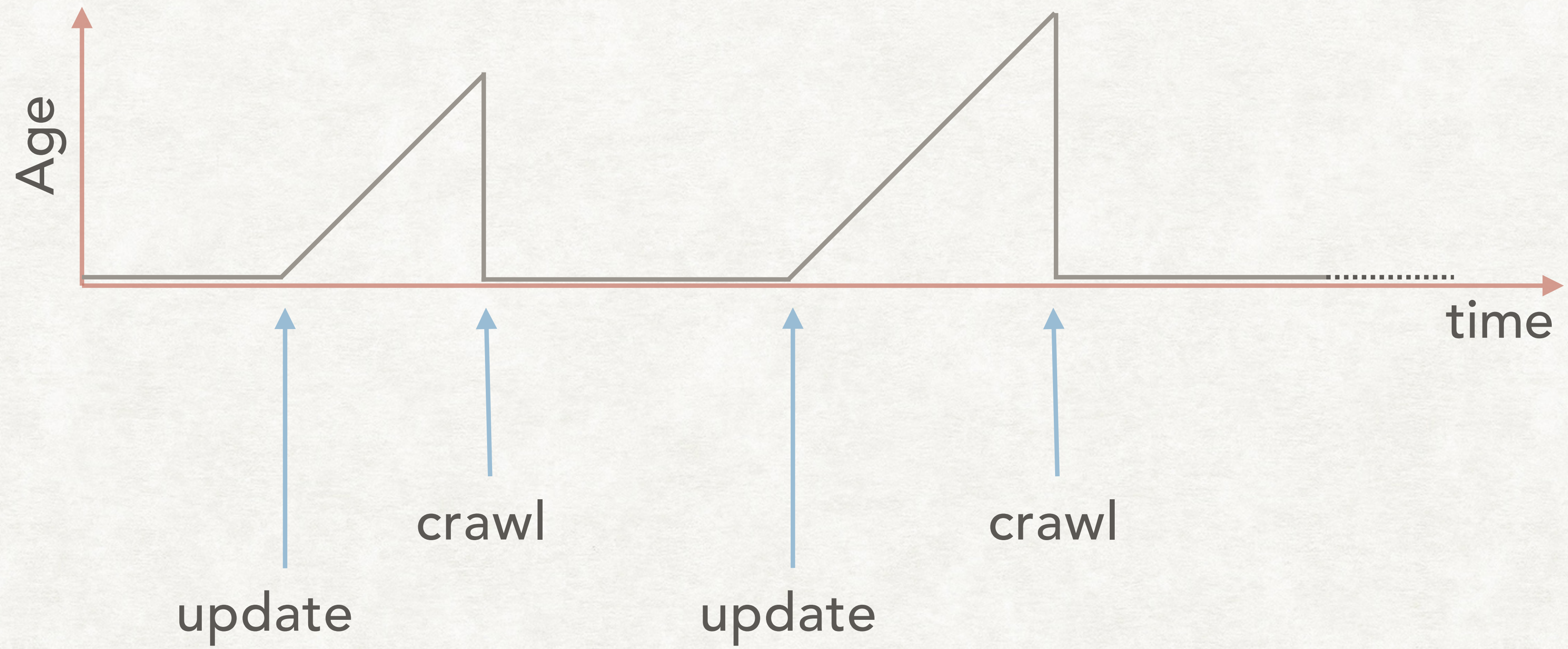
FRESHNESS

A BINARY WAY OF MEASURING "OLD" PAGES

- Should we optimise for freshness?
- Actually there can be unintended consequences.
- Suppose that a page updates very frequently (e.g., every minute).
- You will almost always have a stale copy of the page.
- If you have limited resources for crawling then a good strategy would be to never crawl that page again: it will always be stale after a very short time.
- Which is not what the user want. Hence we can optimise for **age**.

AGE

A MORE REFINED WAY OF FINDING OUTDATED PAGES



A page start ageing when it is modified. Its age returns to 0 when it is crawled again.

Age = time passed since the first update after a crawl event.

AGE

A MORE REFINED WAY OF FINDING OUTDATED PAGES

Suppose that a page is updated λ times a day.

Then its expected age at time t after it was visited last time is:

$$\text{Age}(\lambda, t) = \int_0^t P(\text{Change at time } x)(t - x)\, dx$$

The probability of a page changing at a certain time x can be estimated: according to studies, the updates to a web page follows a Poisson distribution, hence we obtain:

$$\text{Age}(\lambda, t) = \int_0^t \lambda e^{-\lambda x}(t - x)\, dx$$

AGE

A MORE REFINED WAY OF FINDING OUTDATED PAGES

By trying to minimise the expected age of a set of pages we will visit them all.

$$\text{Age}(\lambda, t) = \frac{t + \lambda e^{-\lambda t} - 1}{\lambda} \qquad\qquad \frac{\partial^2 \text{Age}(\lambda, t)}{\partial t^2} = \lambda e^{-\lambda t}$$

Notice that the rate of increase of the age function (its second derivative) is always positive for $\lambda > 0$ (which is always the case).

This means that *not* visiting a web page has an increasing cost the older the page gets. We will never conclude that we do not have to visit a web page.

DUPLICATES AND NEAR-DUPLICATES

THE PROBLEM

DUPLICATED WEB PAGES

- Studies show that about 30% of the crawled pages are duplicates or near-duplicates of the other 70%[1].
- Duplicates can be created by spam or plagiarism…
- …but also via mirror sites, to provide redundancy and access reliability.
- Duplicates or near-duplicates provide very little information to the user while consuming resources for crawling and indexing.
- There exist algorithms to mitigate this problem, without comparing each document across all already-indexed documents.

[1] Fetterly, Dennis, Mark Manasse, and Marc Najork. "On the evolution of clusters of near-duplicate web pages.”

DETECTING EXACT DUPLICATES

CHECKSUMMING

The detection of exact duplicate is relatively easy;
it can be performed by comparing the *checksums* of the documents

One of the simplest kinds of checksums is to simply sum all the bytes in the document

"The quick brown fox jumps over the lazy dog"

84 104 101 32 113 117 105 99 107 32 … 32 100 111 103 —Sum→ 4057

There are more complex checksum algorithms where the position of the bytes is considered (like CRC - cyclic redundancy check),

NEAR-DUPLICATES

WHAT THEY ARE AND HOW TO DETECT THEM

- Detecting near-duplicates is more complex…
- …but even *defining* them is more problematic:
- E.g., same text but different advertising/formatting
- Slight difference in text due to small edits
- In general a similarity measure is defined…
- …and two documents are considered near-duplicates above a certain threshold.

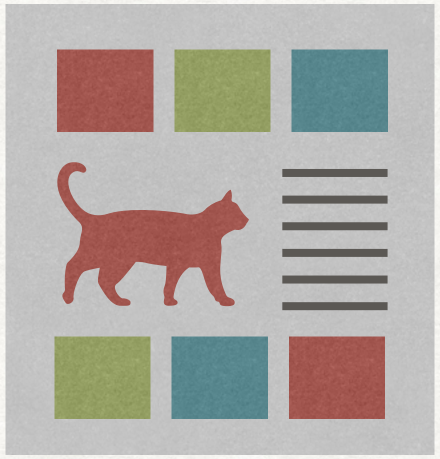
NEAR-DUPLICATES

TWO SCENARIOS

- Detecting near-duplicates can happen in two scenarios:
- **Search**. When the goal is to find the duplicates of a given document.
- **Discovery**. When, given a collection, the goal is to find all pairs of duplicates or near duplicates.
- Similarity-based IR techniques can be used in the *search* scenario.
- For the *discovery* scenario more efficient techniques are usually employed, e.g., **fingerprints**.

FINGERPRINTS

A POSSIBLE ALGORITHM



Web page

1. All non-word content is removed
The document is parsed into words

The quick brown fox jumps over the lazy dog

2. Words grouped in n-grams for some n

The quick brown

quick brown fox

brown fox jumps

fox jumps over

jumps over the

over the lazy

the lazy dog

Continues in the next slide

FINGERPRINTS

A POSSIBLE ALGORITHM

2.Words grouped in n-grams for some n

The quick brown

quick brown fox

brown fox jumps

fox jumps over

jumps over the

over the lazy

the lazy dog

3.A subset of n-grams is selected

quick brown fox

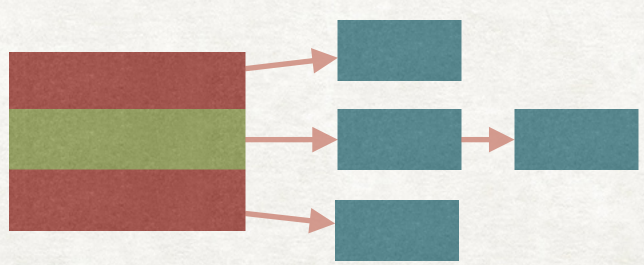
fox jumps over

4.The n-grams are hashed

1490

1400

5.The hashes are stored in an inverted index



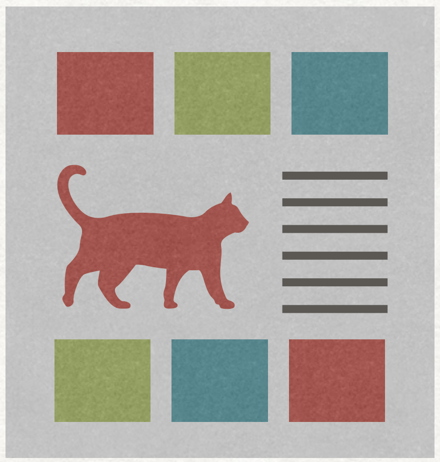
FINGERPRINTS

HOW TO SELECT A SUBSET

- Two documents are considered near-duplicates if they share enough n-grams (by measuring, for example, the Jaccard coefficient).
- It is essential to have a "good" way of selecting which subset of n-grams to keep:
  - Random selection is a bad choice: the overlap between randomly selected n-grams of identical documents can be low!
  - A better choice is to select all n-grams starting with the same letter.
  - Another choice is to select all n-grams with hash value equal to $0 \bmod p$ for some choice of p.

SIMHASH

A MORE RECENT FINGERPRINTING TECHNIQUE



Web page

The	2
Quick	1
Brown	1
Fox	1

Extract a set of features (e.g., words) each with a weight (e.g., frequency)

For each word compute a unique hash of b bits (the desired size of the fingerprint)

The	Quick	Brown	Fox
0101	1100	1001	0001

Continues in the next slide

SIMHASH

A MORE RECENT FINGERPRINTING TECHNIQUE

The	2
Quick	1
Brown	1
Fox	1

The	Quick	Brown	Fox
0101	1100	1001	0001

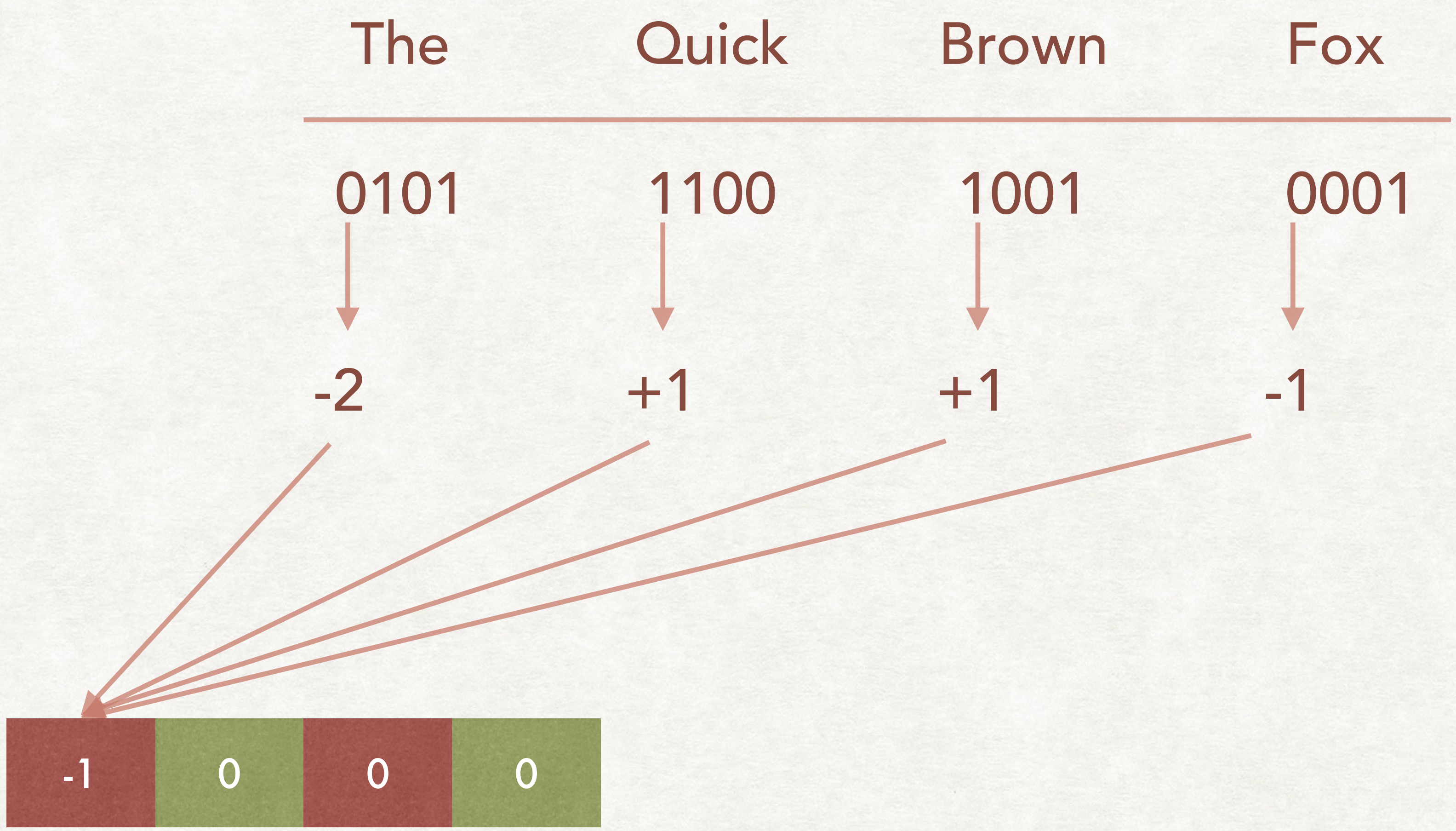
Start with a vector of size b with all positions initially set to 0

0	0	0	0

SIMHASH

A MORE RECENT FINGERPRINTING TECHNIQUE

The	2
Quick	1
Brown	1
Fox	1

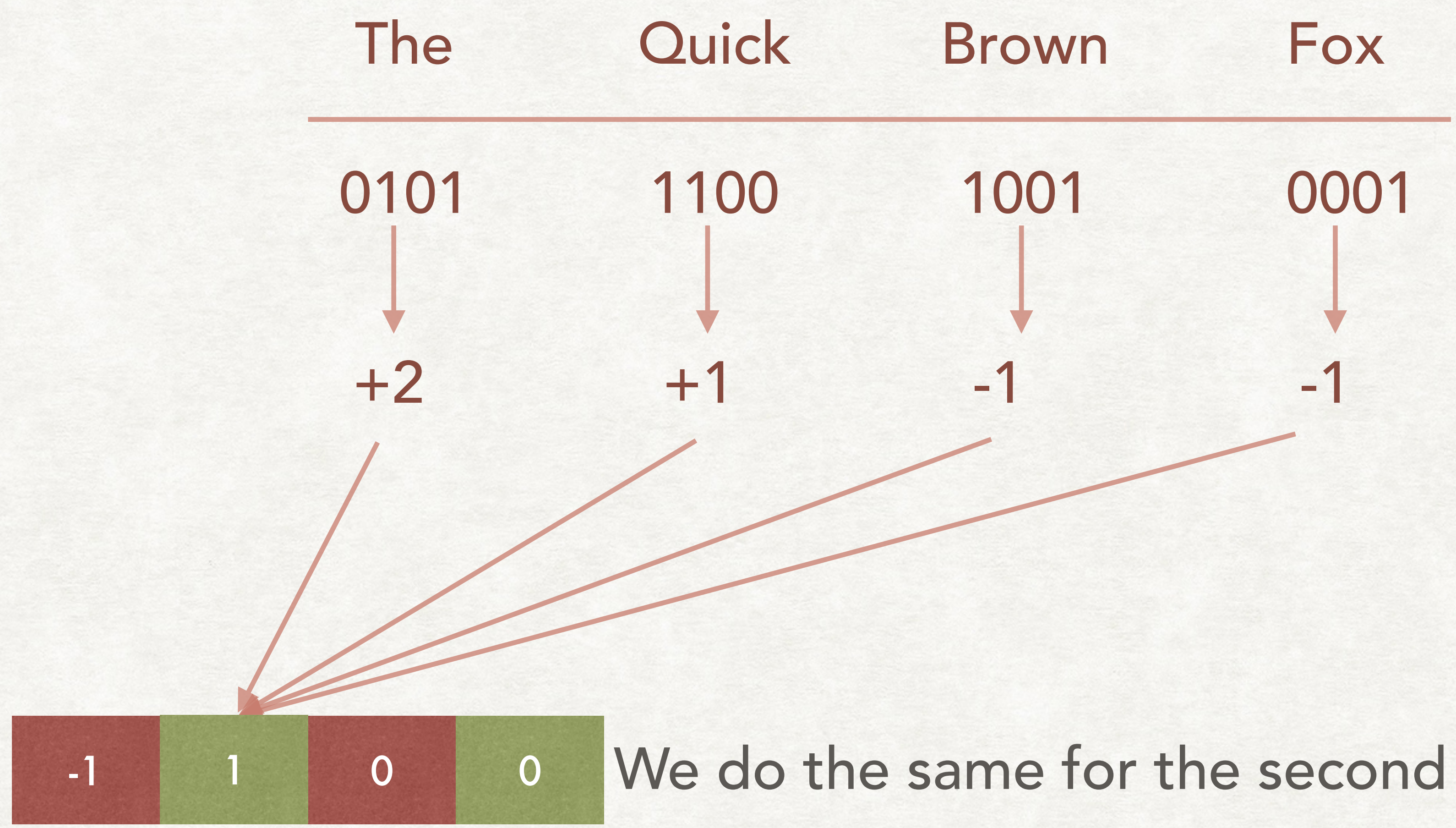


Look at the first bit of the hash of every word.
Add the weight to the word if the bit is 1.
Subtract the weight of the word if the bit is 0

SIMHASH

A MORE RECENT FINGERPRINTING TECHNIQUE

The	2
Quick	1
Brown	1
Fox	1



We do the same for the second bit

SIMHASH

A MORE RECENT FINGERPRINTING TECHNIQUE

The	2
Quick	1
Brown	1
Fox	1

The	Quick	Brown	Fox
0101	1100	1001	0001
-2	-1	-1	-1

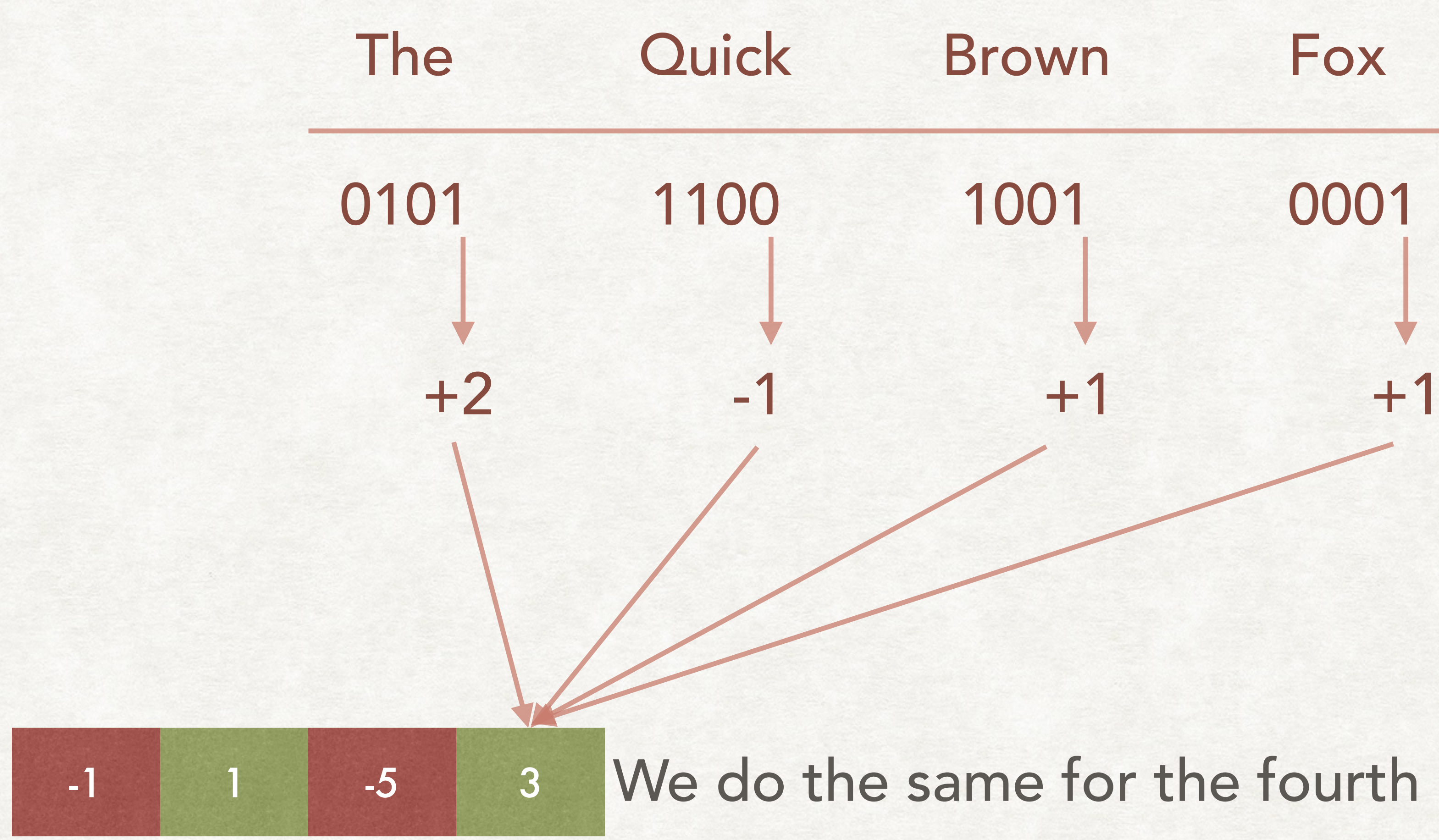
-1	1	-5	0

We do the same for the third bit

SIMHASH

A MORE RECENT FINGERPRINTING TECHNIQUE

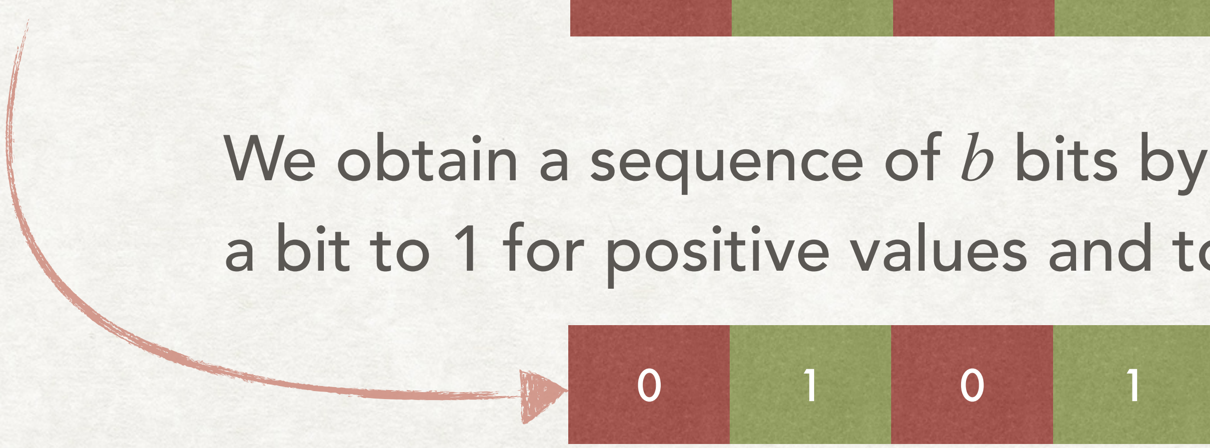
The	2
Quick	1
Brown	1
Fox	1



We do the same for the fourth bit

The hash value of the document

We obtain a sequence of b bits by setting a bit to 1 for positive values and to 0 otherwise

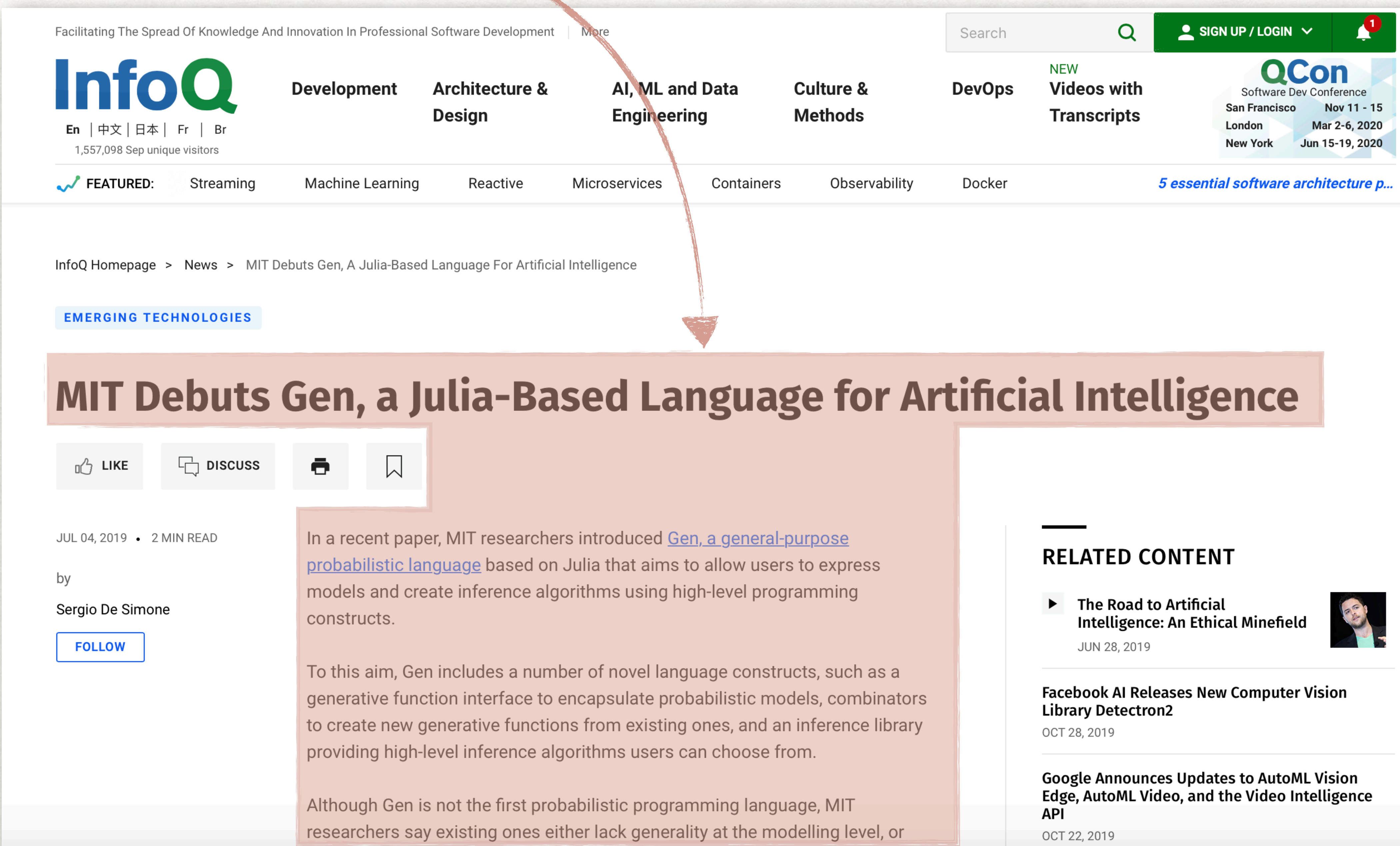


FINDING THE CONTENT

FINDING THE CONTENT

UNDERSTANDING THE PROBLEM

Main Content Block



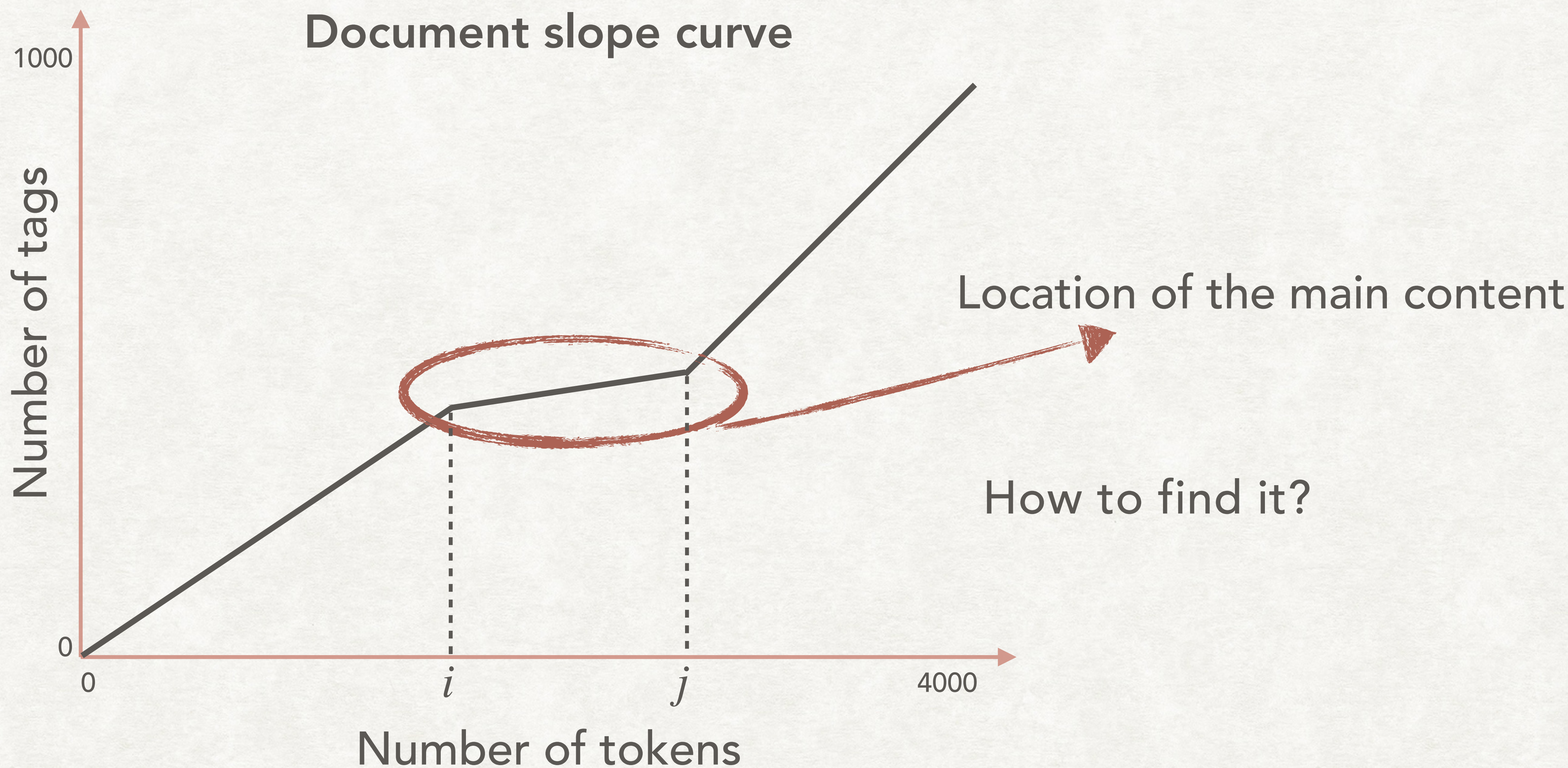
HOW TO FIND WHERE THE CONTENT IS

TAGS AND TOKENS

- The main content of the page might be only a fraction of the total area. The rest is advertisement, navigation links, etc.
- From the point of view of the user the rest is *noise* that can have a negative effect on the ranking.
- We need a way to identify the non-main content of the page and either ignore it or reduce its weight.
- An observation is that, usually, the main content of the page contains less tags than the rest of the page.

HOW TO FIND WHERE THE CONTENT IS

TAGS AND TOKENS



How to find it?

HOW TO FIND WHERE THE CONTENT IS

TAGS AND TOKENS

Document as a binary vector of length N (the number of tokens) with:

$$b_k = \begin{cases} 1 & \text{if the } k\text{-th term is a tag} \\ 0 & \text{otherwise} \end{cases}$$

Find two “cutting points” i and j with $1 \leq i < j \leq N$ maximising:

$$\sum_{k=1}^{i-1} b_k + \sum_{k=i}^{j} (1 - b_k) + \sum_{k=j+1}^{N} b_k$$

Tags before content

non-tags in the content

Tags after content

ANOTHER POSSIBILITY

LOOKING AT THE DOM

- To parse a webpage a browser construct a representation using the HTML tags.
- This representation is the DOM (Document Object Model)
- It is a tree-like structure that can be navigated to find the major components of a web page.
- A set of heuristics and filtering techniques can be used to remove images, advertising, and leave only the content.
- It is also possible to analyse the visual feature of a page to identify the location of the main content.

ANOTHER POSSIBILITY

LOOKING AT THE DOM

```
▶ <script type="text/javascript">…</script>
▼ <div class="infoq" id="infoq">
    <!-- ####### SITE START ######### -->
  ▶ <header class="header nocontent">…</header>
    <!-- ####### CONTENT START ######### -->
  ▼ <main>
    ▼ <article data-type="news" class="article">
      ▼ <section class="section container white">
          ::before
        ▼ <div class="container__inner">
          ▶ <p class="crumbs">…</p>
          ▶ <div class="actions">…</div>
          ▶ <div class="actions heading__container article__heading">…</div>
          ▶ <p id="translated_jp" class="article__translated">…</p>
          ▶ <script type="text/javascript">…</script>
          ▶ <div class="article__actions actions">…</div>
          ▼ <div class="columns article__explore">
              ::before
            ▼ <div class="column article__main" data-col="4/6">
              ▶ <div class="column article__metadata metadata">…</div>
              ▼ <div class="article__content">
                  <!-- Start PSA Section -->
                  <!-- End PSA Section -->
                ▶ <div class="article__data">…</div>
                ▶ <input type="hidden" name value="Thank you for your review!" id="cr_messages_submitSuccess">
                ▶ <input type="hidden" name value="Rating is required" id="cr_messages_ratingRequired">
                ▶ <input type="hidden" name value="MIT Debuts Gen, a Julia-Based Language for Artificial Intelligence" id="cr_item_title">
                ▶ <input type="hidden" name value="Sergio De Simone" id="cr_item_author">
                ▶ <input type="hidden" name value="http://www.infoq.com/news/2019/07/mit-gen-probabilistic-programs/" id="cr_item_url">
                ▶ <input type="hidden" name value="news" id="cr_item_ctype">
                ▶ <input type="hidden" name value="en" id="cr_item_lang">
                ▶ <input type="hidden" name value="1562223600000" id="cr_item_published_time">
                ▶ <input type="hidden" name value="6230" id="cr_item_primary_topic">
                  <script type="text/javascript">ContentRating.readMessages(); ContentRating.readContentItem();</script>
                ▶ <script type="text/javascript">…</script>
                ▶ <div class="widget article__fromTopic topics">…</div>
                </div>
              ▶ <script type="text/javascript">…</script>
              ▶ <input type="hidden" name value="6230" id="cont_item_primary_topic">
```

This is the location of the main content of the example page, helpfully labeled with the class “article__content”