# Web Information Retrieval

Lecture 10

Crawling and Near-Duplicate Document Detection

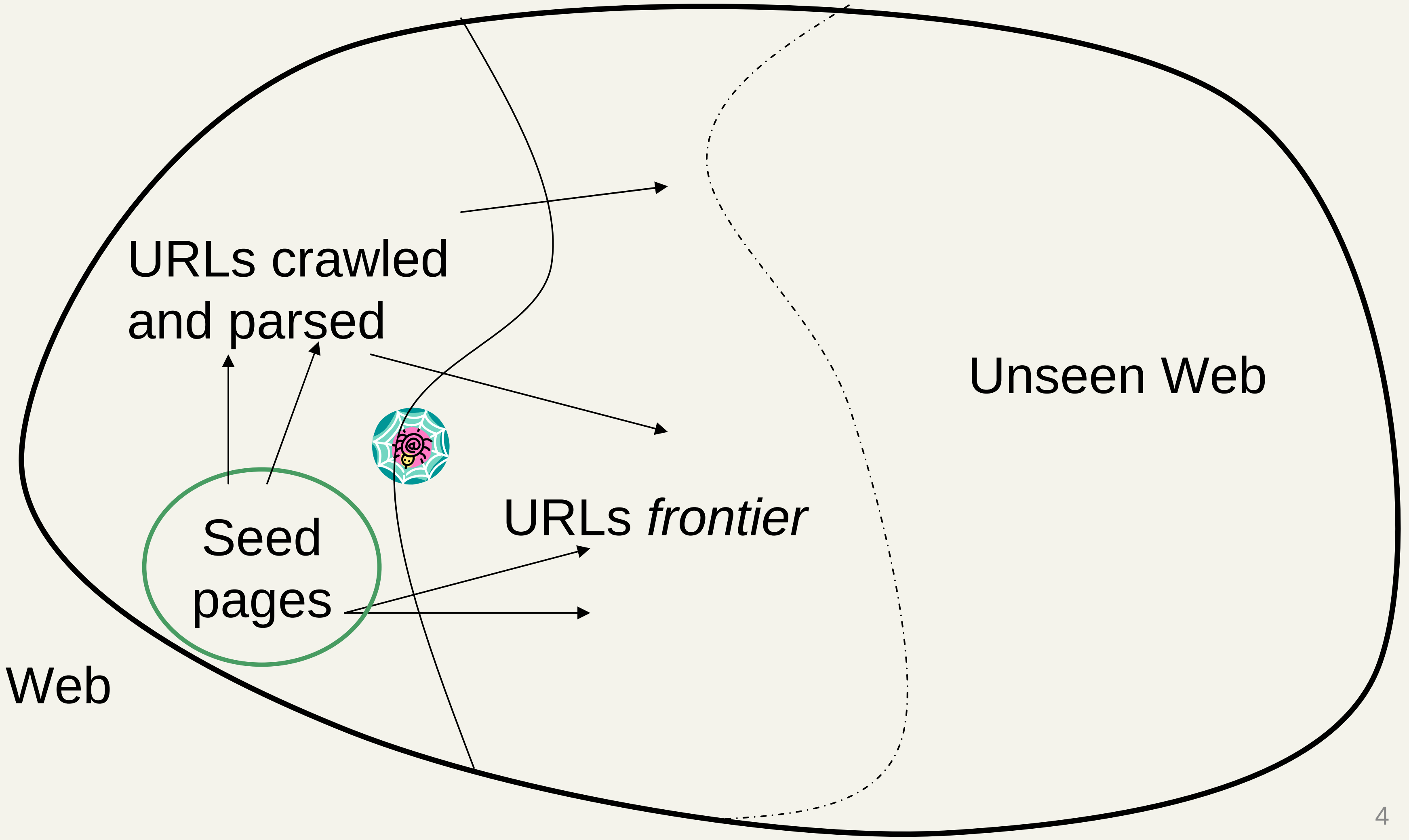
# Today’s lecture

- Crawling
- Duplicate and near-duplicate document detection

# Basic crawler operation

- Begin with known “seed” pages
- Fetch and parse them
  - Extract URLs they point to
  - Place the extracted URLs on a queue
- Fetch each URL on the queue and repeat

# Crawling picture



# Simple picture – complications

- Web crawling isn't feasible with one machine
  - All of the above steps distributed
- Malicious pages
  - Spam pages
  - Spider traps – incl dynamically generated
- Even non-malicious pages pose challenges
  - Latency/bandwidth to remote servers vary
  - Webmasters' stipulations
    - How "deep" should you crawl a site's URL hierarchy?
  - Site mirrors and duplicate pages
- Politeness – don't hit a server too often

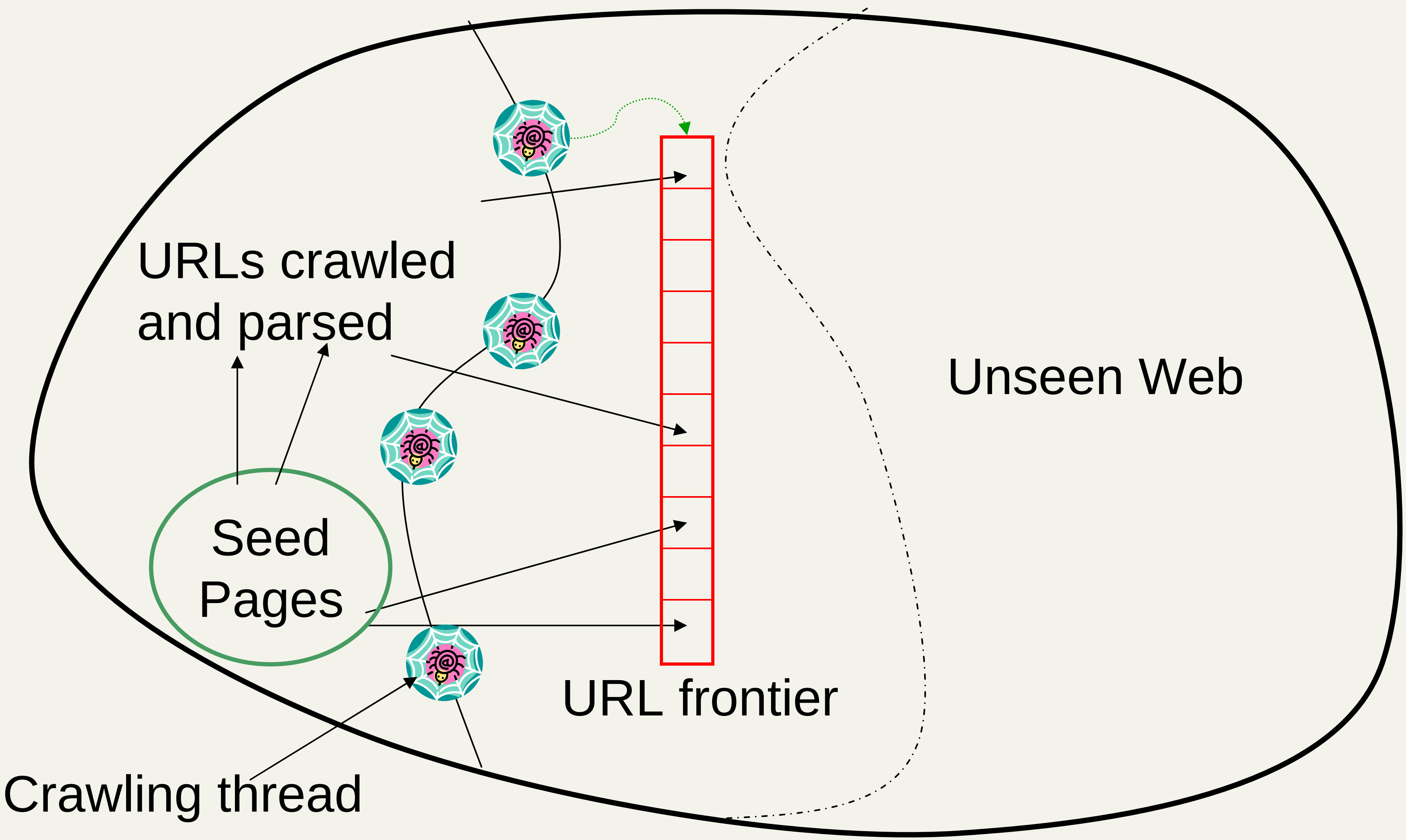
# What any crawler *must* do

- Be **Polite**: Respect implicit and explicit politeness considerations
  - Only crawl allowed pages
  - Respect *robots.txt* (more on this shortly)
- Be **Robust**: Be immune to spider traps and other malicious behavior from web servers

# What any crawler *should* do

- Be capable of **distributed** operation: designed to run on multiple distributed machines
- Be **scalable**: designed to increase the crawl rate by adding more machines
- **Performance/efficiency**: permit full use of available processing and network resources
- Fetch pages of "higher **quality**" first
- **Continuous** operation: Continue fetching fresh copies of a previously fetched page
- **Extensible**: Adapt to new data formats, protocols

# Updated crawling picture



# URL frontier

- Can include multiple pages from the same host
- Must avoid trying to fetch them all at the same time
- Must try to keep all crawling threads busy

# Explicit and implicit politeness

- **Explicit politeness:** specifications from webmasters on what portions of site can be crawled
  - robots.txt
- **Implicit politeness:** even with no specification, avoid hitting any site too often

# Robots.txt

- Protocol for giving spiders ("robots") limited access to a website, originally from 1994
  - www.robotstxt.org/wc/norobots.html
- Website announces its request on what can(not) be crawled
  - For a URL, create a file `URL/robots.txt`
  - This file specifies access restrictions

# Robots.txt example

- No robot should visit any URL starting with "/yoursite/temp/", except the robot called “searchengine":

```
User-agent: *
Disallow: /yoursite/temp/

User-agent: searchengine
Disallow:
```

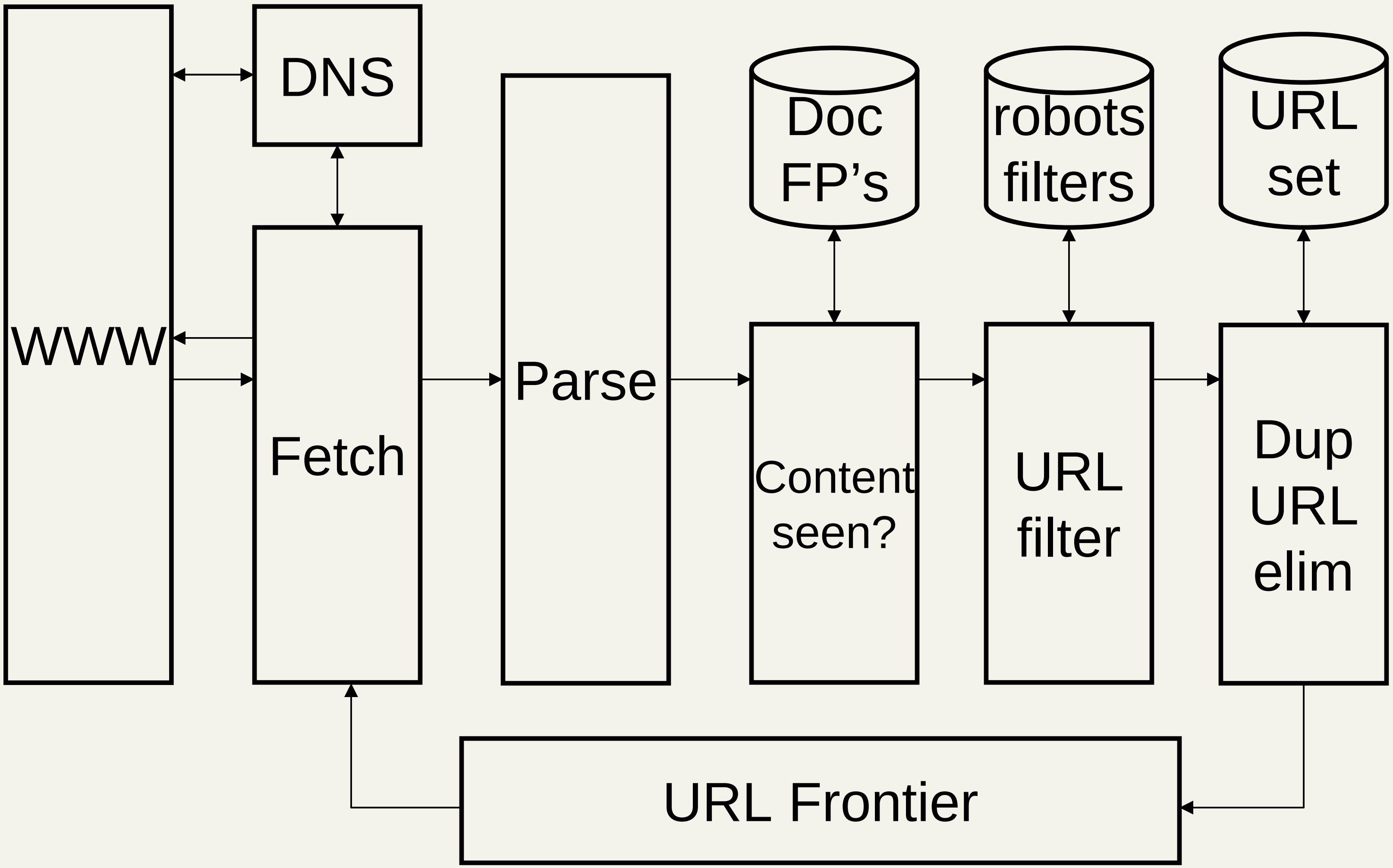
# Processing steps in crawling

- Pick a URL from the frontier
- Fetch the document at the URL
- Parse the URL
  - Extract links from it to other docs (URLs)
- Check if URL has content already seen
  - If not, add to indexes
- For each extracted URL
  - Ensure it passes certain URL filter tests
  - Check if it is already in the frontier (duplicate URL elimination)

Which one?

E.g., only crawl .edu, obey robots.txt, etc.

# Basic crawl architecture



# DNS (Domain Name Server)

- A lookup service on the internet
  - Given a URL, retrieve its IP address
  - Service provided by a distributed set of servers – thus, lookup latencies can be high (even seconds)
- Common OS implementations of DNS lookup are *blocking*: only one outstanding request at a time
- Solutions
  - DNS caching
  - Batch DNS resolver – collects requests and sends them out together

# Parsing: URL normalization

- When a fetched document is parsed, some of the extracted links are *relative* URLs
- E.g., at http://en.wikipedia.org/wiki/Main_Page

we have a relative link to /wiki/Wikipedia:General_disclaimer which is the same as the absolute URL http://en.wikipedia.org/wiki/Wikipedia:General_disclaimer

- During parsing, must normalize (expand) such relative URLs

# Content seen?

- Duplication is widespread on the web
- If the page just fetched is already in the index, do not further process it
- This is verified using document fingerprints or shingles

# Filters and robots.txt

- **Filters** – regular expressions for URL's to be crawled/not
- Once a robots.txt file is fetched from a site, need not fetch it repeatedly
  - Doing so burns bandwidth, hits web server
- Cache robots.txt files

# Duplicate URL elimination

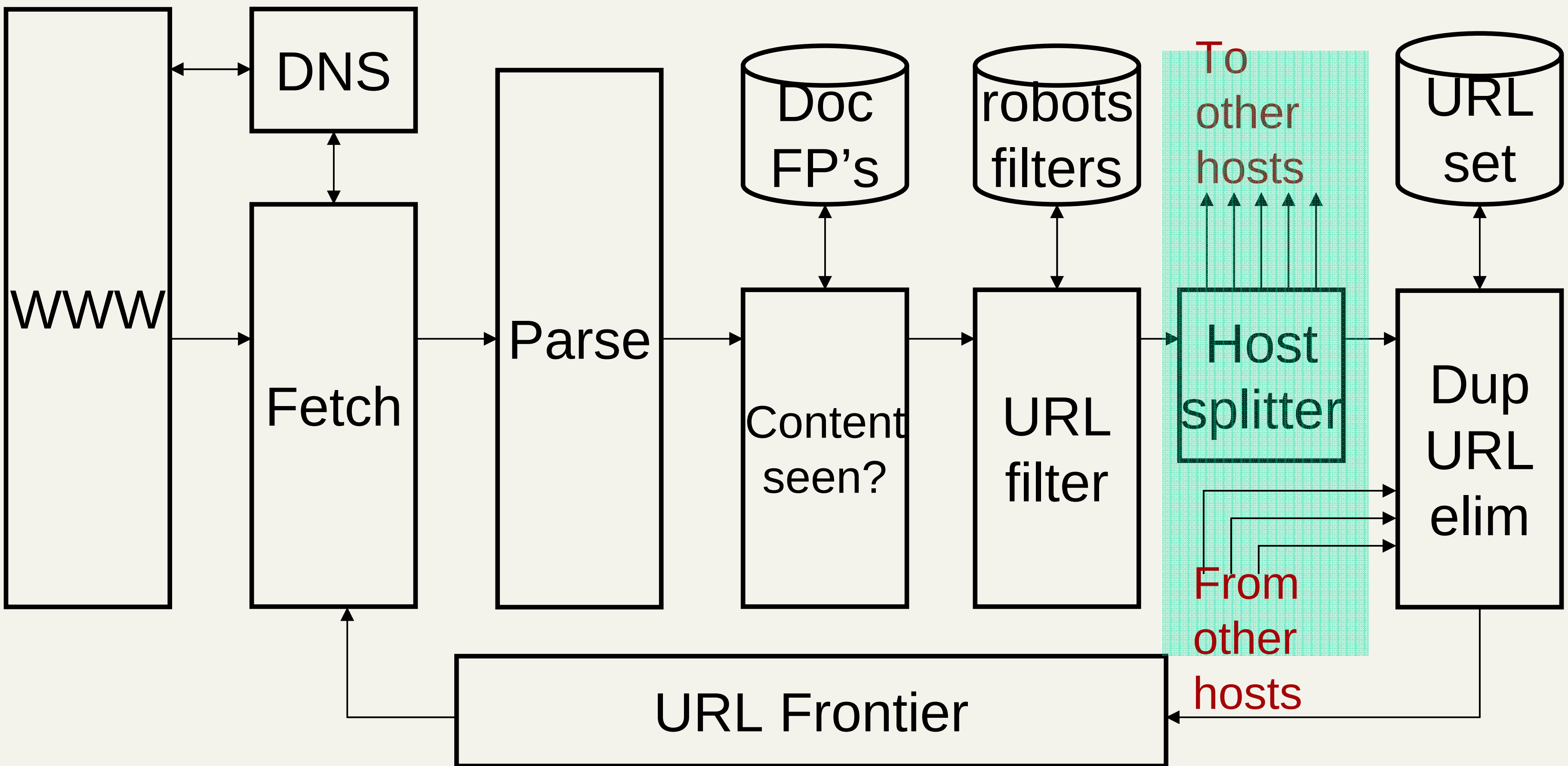
- For a non-continuous (one-shot) crawl, test to see if an extracted+filtered URL has already been passed to the frontier
- For a continuous crawl – see details of frontier implementation

# Distributing the crawler

- Run multiple crawl threads, under different processes – potentially at different nodes
  - Geographically distributed nodes
- Partition hosts being crawled into nodes
  - Hash used for partition
- How do these nodes communicate?

# Communication between nodes

- The output of the URL filter at each node is sent to the Duplicate URL Eliminator at all nodes



# URL frontier: two main considerations

- **Politeness**: do not hit a web server too frequently
- **Freshness**: crawl some pages more often than others
  - E.g., pages (such as News sites) whose content changes often

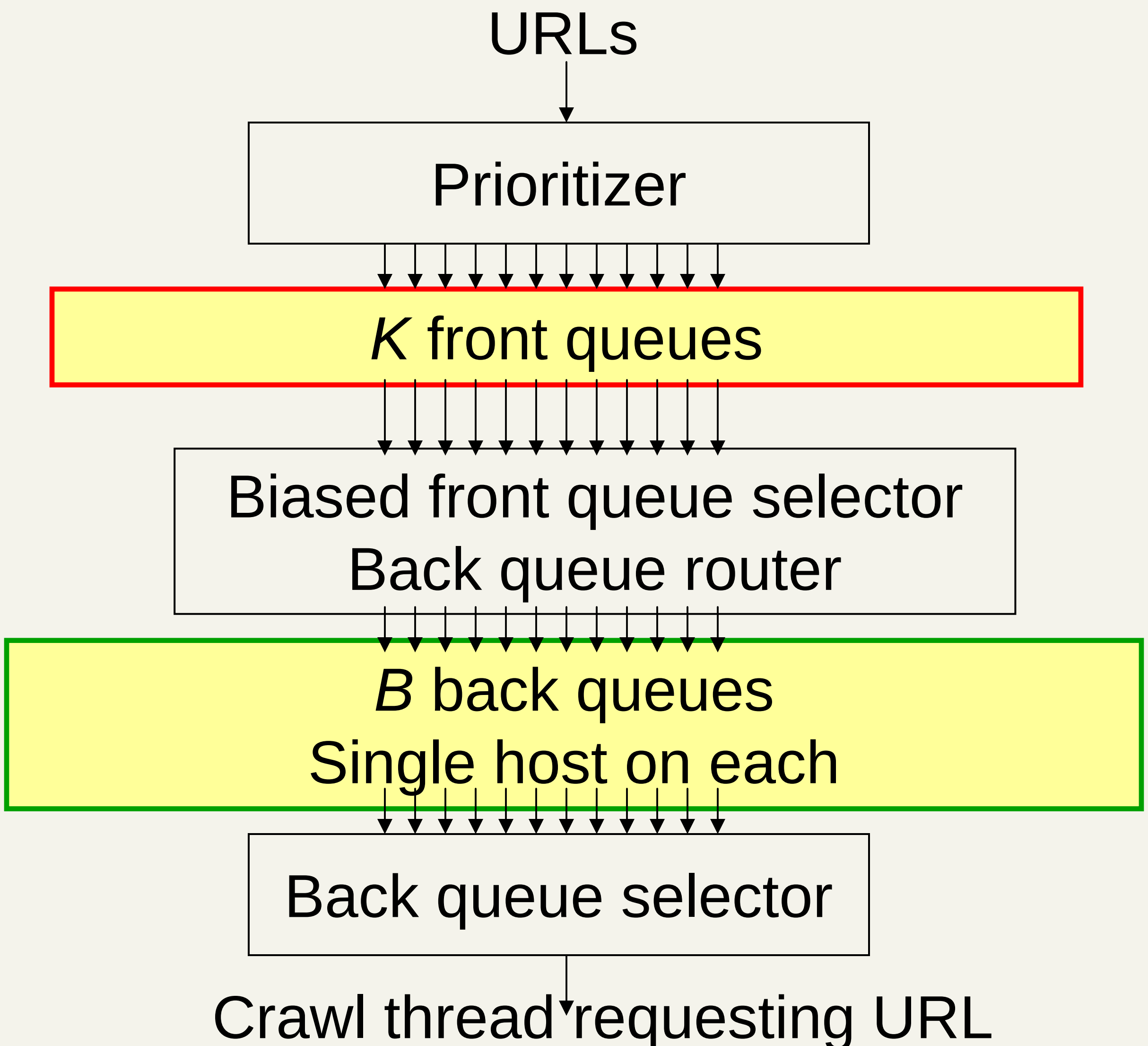
These goals may conflict each other.

(E.g., simple priority queue fails – many links out of a page go to its own site, creating a burst of accesses to that site.)

# Politeness – challenges

- Even if we restrict only one thread to fetch from a host, can hit it repeatedly
- Common heuristic: insert time gap between successive requests to a host that is >> time for most recent fetch from that host

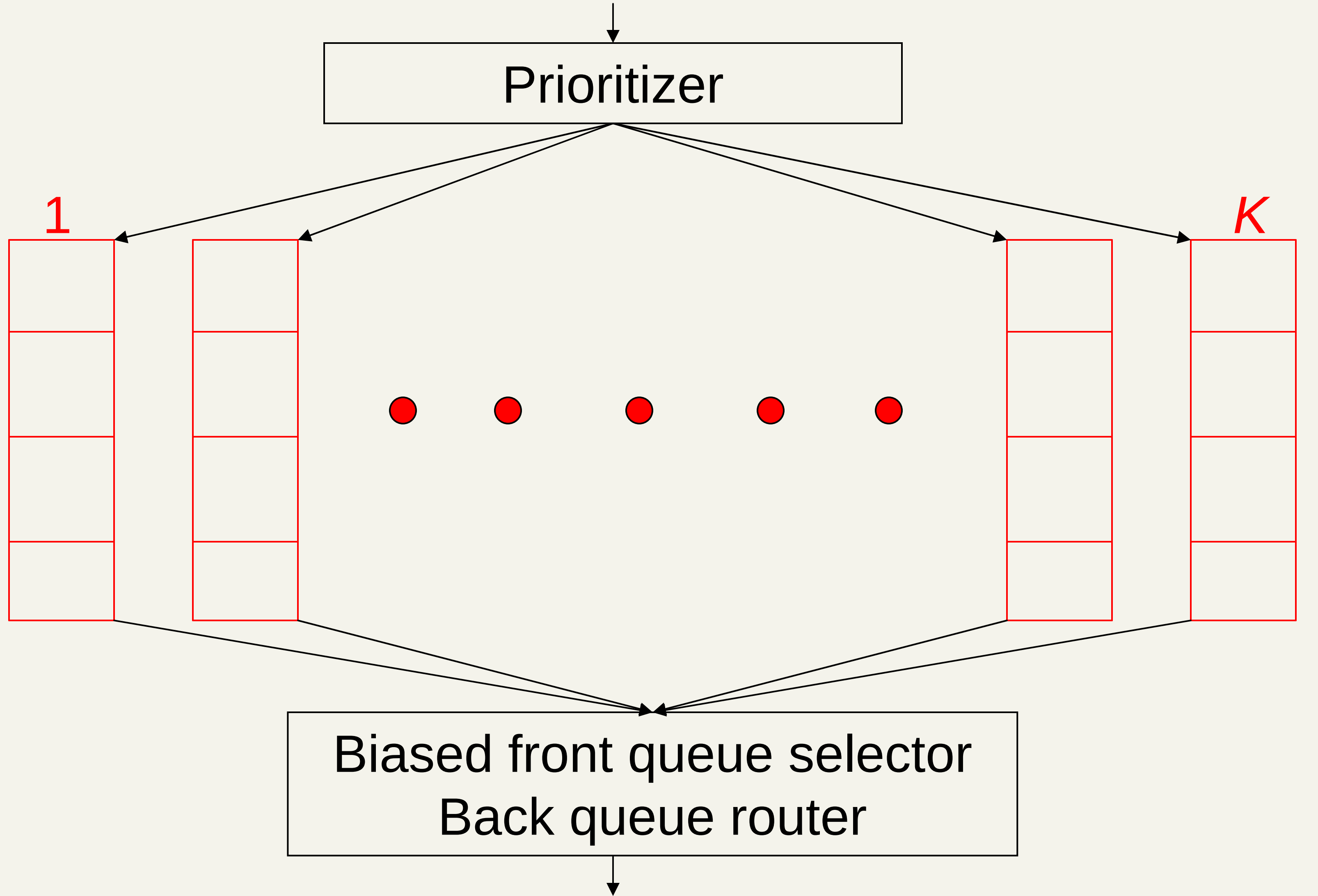
# URL frontier: Mercator scheme



# Mercator URL frontier

- URLs flow in from the top into the frontier
- Front queues manage prioritization
- Back queues enforce politeness
- Each queue is FIFO

# Front queues



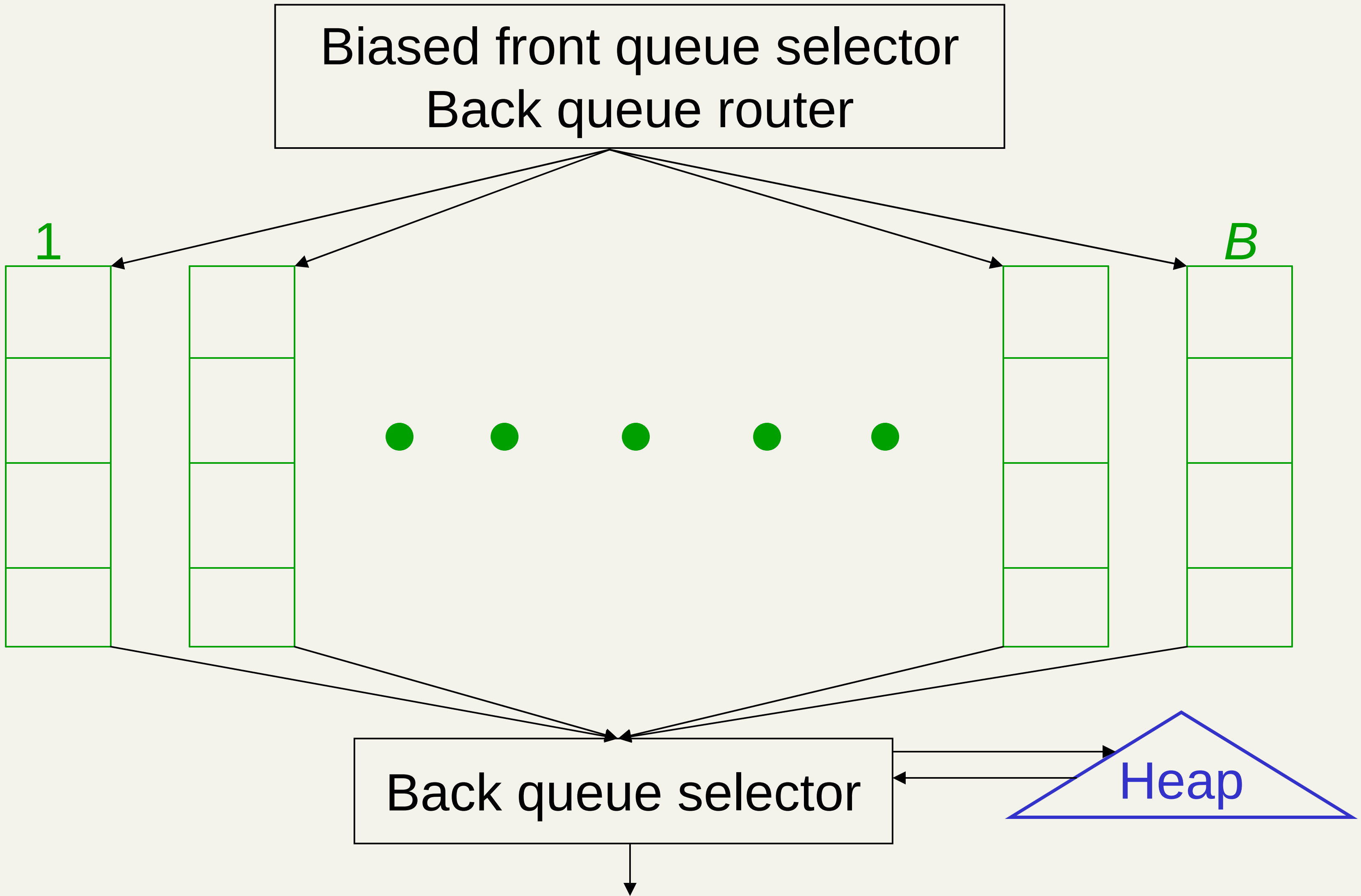
# Front queues

- Prioritizer assigns to URL an integer priority between 1 and *K*
  - Appends URL to corresponding queue
- Heuristics for assigning priority
  - Refresh rate sampled from previous crawls
  - Application-specific (e.g., “crawl news sites more often”)

# Biased front queue selector

- When a back queue requests a URL (in a sequence to be described): picks a front queue from which to pull a URL
- This choice can be round robin biased to queues of higher priority, or some more sophisticated variant
  - Can be randomized

# Back queues


Biased front queue selector
Back queue router
1
B
Back queue selector
Heap

# Back queue invariants

- Each back queue is kept non-empty while the crawl is in progress
- Each back queue only contains URLs from a single host
  - Maintain a table from hosts to back queues

| **Host name** | **Back queue** |
|---|---|
| www.uniroma1.it | 3 |
| www.cnn.com | 27 |
| | *B* |

# Back queue heap

- One entry for each back queue
- The entry is the earliest time $t_e$ at which the host corresponding to the back queue can be hit again
- This earliest time is determined from
  - Last access to that host
  - Any time buffer heuristic we choose

# Back queue processing

- A crawler thread seeking a URL to crawl:
- Extracts the root of the heap
- Fetches URL at head of corresponding back queue *q* (look up from table)
- Checks if queue *q* is now empty – if so, pulls a URL *v* from front queues
  - If there's already a back queue for *v*'s host, append *v* to *q* and pull another URL from front queues, repeat
  - Else add *v* to *q*
- When *q* is non-empty, create heap entry for it

# Number of back queues *B*

- Keep all threads busy while respecting politeness
- Mercator recommendation: three times as many back queues as crawler threads

# Duplicate/Near-duplicate detection

- *Duplication*: Exact match with fingerprints
- *Near-Duplication*: Approximate match
  - Overview
    - Compute syntactic similarity with an edit-distance measure
    - Use similarity threshold to detect near-duplicates
      - E.g., Similarity > 80% => Documents are “near duplicates”
      - Not transitive though sometimes used transitively

# Duplicate documents

- The web is full of duplicated content
- Strict duplicate detection = exact match
  - Not as common
- But many, many cases of near duplicates
  - E.g., last-modified date the only difference between two copies of a page

# Computing near similarity

- Features:
  - Segments of a document (natural or artificial breakpoints)
  - *Shingles* (Word N-Grams) [Brod98]

    "**a rose is a rose is a rose**" =>

    a_rose_is_a

    rose_is_a_rose

    is_a_rose_is

    a_rose_is_a
- Similarity Measure
  - TFIDF
  - Set intersection

    (Specifically, Size_of_Intersection / Size_of_Union )

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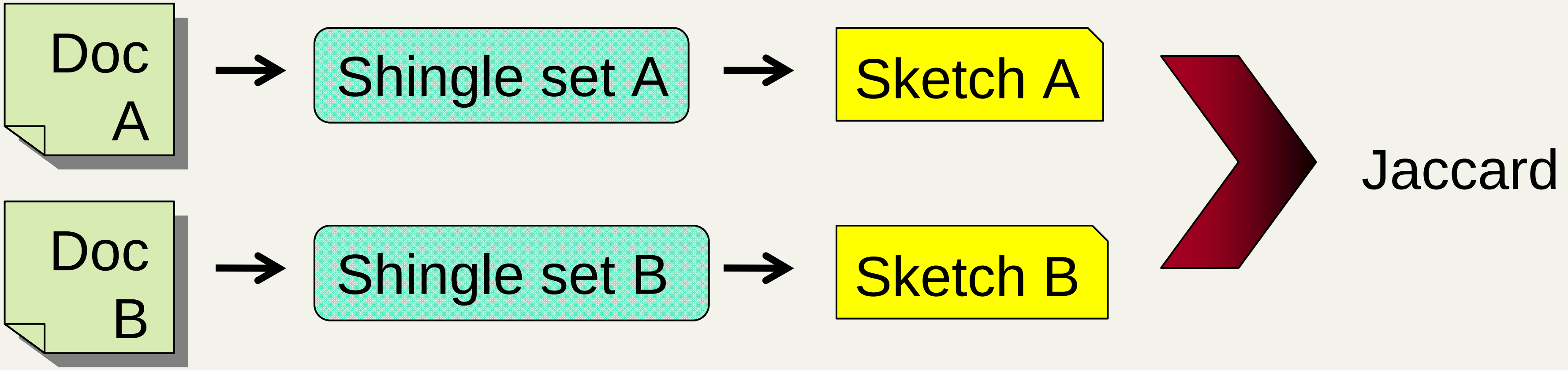
$$\text{Jaccard}(X, Y) = \frac{|X \cap Y|}{|X \cup Y|}$$

# Shingles + Set intersection

- Computing **exact** set intersection of shingles between all pairs of documents is expensive/intractable
  - Approximate using a cleverly chosen subset of shingles from each (a **sketch**)
- Estimate **Jaccard** based on a short sketch



# Shingles + Set intersection

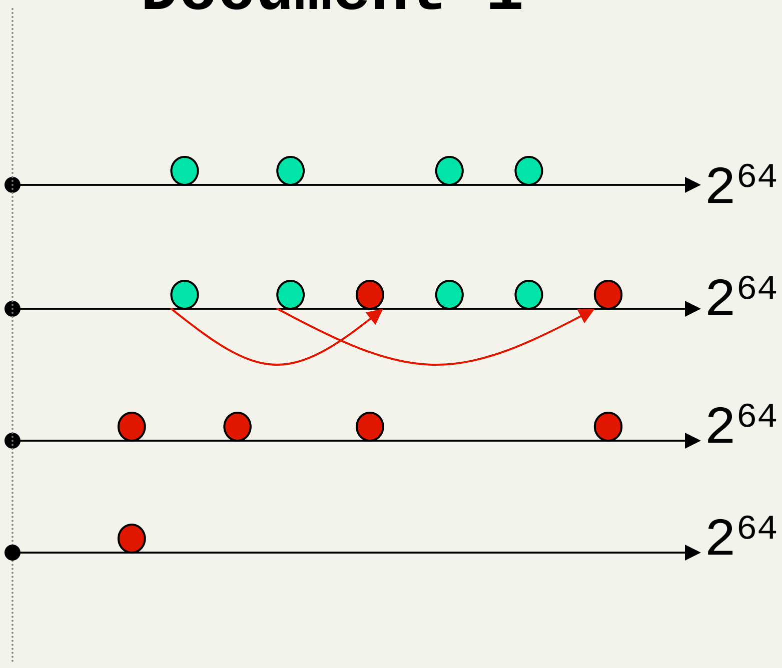
- Computing **exact** set intersection of shingles between all pairs of documents is expensive and infeasible
  - Approximate using a cleverly chosen subset of shingles from each (a **sketch**)

# Shingles + Set intersection

- Estimate **Jaccard** based on a short sketch
- Create a "sketch vector" (e.g., of size 200) for each document
  - Documents which share more than **t** (say 80%) corresponding vector elements are **similar**
  - For doc D, sketch[ i ] is computed as follows:
    - Let f map all shingles in the universe to $0..2^m$ (e.g., f = fingerprinting)
    - Let $\pi_i$ be a specific random permutation on $0..2^m$
    - Pick sketch[i] := MIN $\{\pi_i ( f(s) )\}$ over all shingles s in D

# Computing Sketch[i] for Doc1

**Document 1**



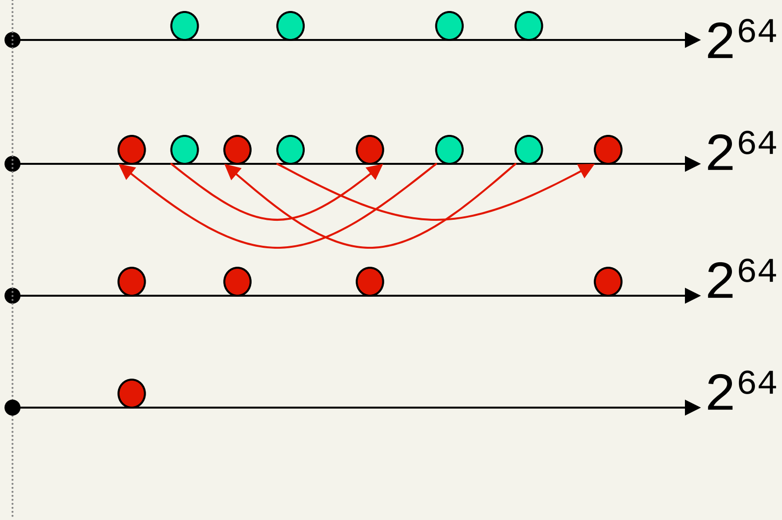

**Start with 64 bit shingles**

**Permute on the number line with $\pi_i$**

**Pick the min value**

# Computing Sketch[i] for Doc1

**Document 1**

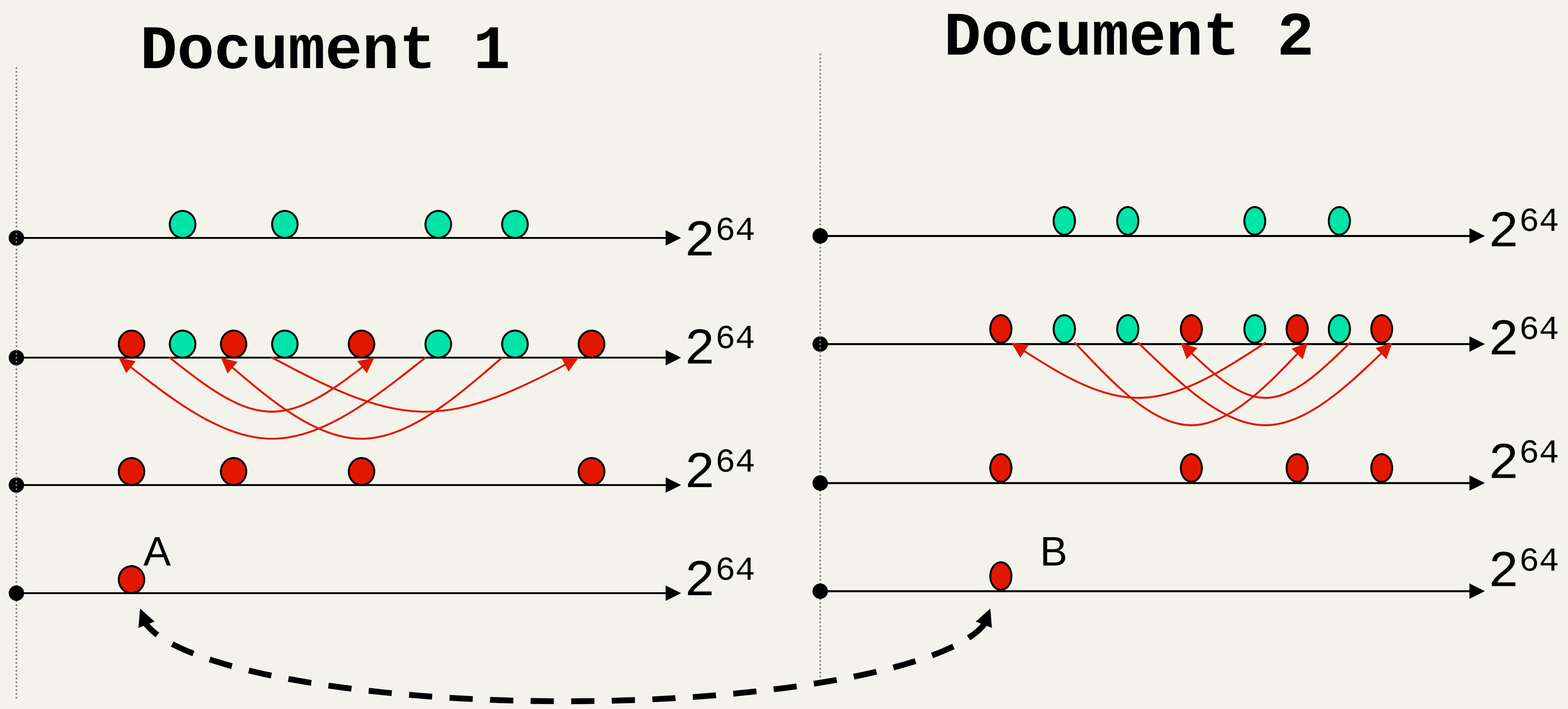



**Start with 64 bit shingles**

**Permute on the number line with $\pi_i$**

**Pick the min value**

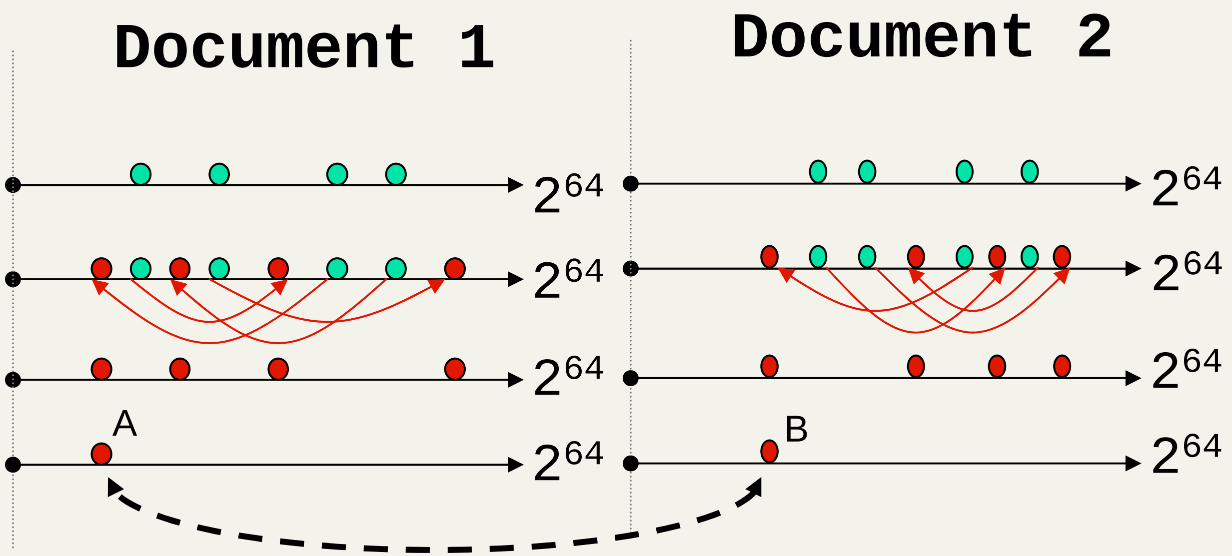
# Test if Doc1.Sketch[i] = Doc2.Sketch[i]




Are these equal?

Test for 200 random permutations: $\pi_1, \pi_2, \dots \pi_{200}$

# However…




A = B iff the shingle with the MIN value in the union of Doc1 and Doc2 is common to both (I.e., lies in the intersection)

Why?

This happens with probability:

**`Size_of_intersection / Size_of_union`**

# Set Similarity of sets X, Y

$$\text{Jaccard}(X,Y) = \frac{|X \cap Y|}{|X \cup Y|}$$

- View sets as columns of a matrix M; one row for each element in the universe. $m_{ij}$ = 1 indicates presence of item i in set j
- Example

| X | Y |
|---|---|
| 0 | 1 |
| 1 | 0 |
| 1 | 1 |
| 0 | 0 |
| 1 | 1 |
| 0 | 1 |

Jaccard**(X,Y) = 2 / 5 = 0.4**

# Key Observation

- For columns $C_i$, $C_j$, four types of rows

| | X | Y |
|---|---|---|
| **A** | 1 | 1 |
| **B** | 1 | 0 |
| **C** | 0 | 1 |
| **D** | 0 | 0 |

- Overload notation: A = # of rows of type A
- **Claim**

$$\mathrm{Jaccard}(X, Y) = \frac{A}{A + B + C}$$

# "Min" Hashing

- Randomly permute rows
- Hash h(X) = index of first row with 1 in column X
- Surprising Property

$$P\left(h(X) = h(Y)\right) = \text{Jaccard}\left(X, Y\right)$$

- Why?
  - Both are A/(A+B+C)
  - Look down columns X, Y until first non-Type-D row
  - h(X) = h(Y) ⇔ type A row

# Min-Hash sketches

- Pick $P$ random row permutations
- MinHash sketch

$Sketch_D$ = list of $P$ indexes of first rows with 1 in column C

- Similarity of signatures
  - Let sim[sketch(X),sketch(Y)] = fraction of permutations where MinHash values agree
  - Observe E[sim(sketch(X),sketch(Y))] = Jaccard(X,Y)

# Question

- Document $D_1=D_2$ iff size_of_intersection=size_of_union ?

# Example

| | $C_1$ | $C_2$ | $C_3$ |
|---|---|---|---|
| $R_1$ | 1 | 0 | 1 |
| $R_2$ | 0 | 1 | 1 |
| $R_3$ | 1 | 0 | 0 |
| $R_4$ | 1 | 0 | 1 |
| $R_5$ | 0 | 1 | 0 |

**Signatures**

| | $S_1$ | $S_2$ | $S_3$ |
|---|---|---|---|
| Perm 1 = (12345) | 1 | 2 | 1 |
| Perm 2 = (54321) | 4 | 5 | 4 |
| Perm 3 = (34512) | 3 | 5 | 4 |

**Similarities**

| | 1-2 | 1-3 | 2-3 |
|---|---|---|---|
| **Col-Col** | 0.00 | 0.50 | 0.25 |
| **Sig-Sig** | 0.00 | 0.67 | 0.00 |

# All signature pairs

- Now we have an extremely efficient method for estimating a Jaccard coefficient for a single pair of documents.
- But we still have to estimate $N^2$ coefficients where $N$ is the number of web pages.
  - Still slow
- One solution: locality sensitive hashing (LSH)
- Another solution: sorting (Henzinger 2006)

# Resources

- IIR Chapters 20, 19.6