Introduction to

Information Retrieval

CS276

Information Retrieval and Web Search

Chris Manning and Pandu Nayak

Crawling and Duplicates

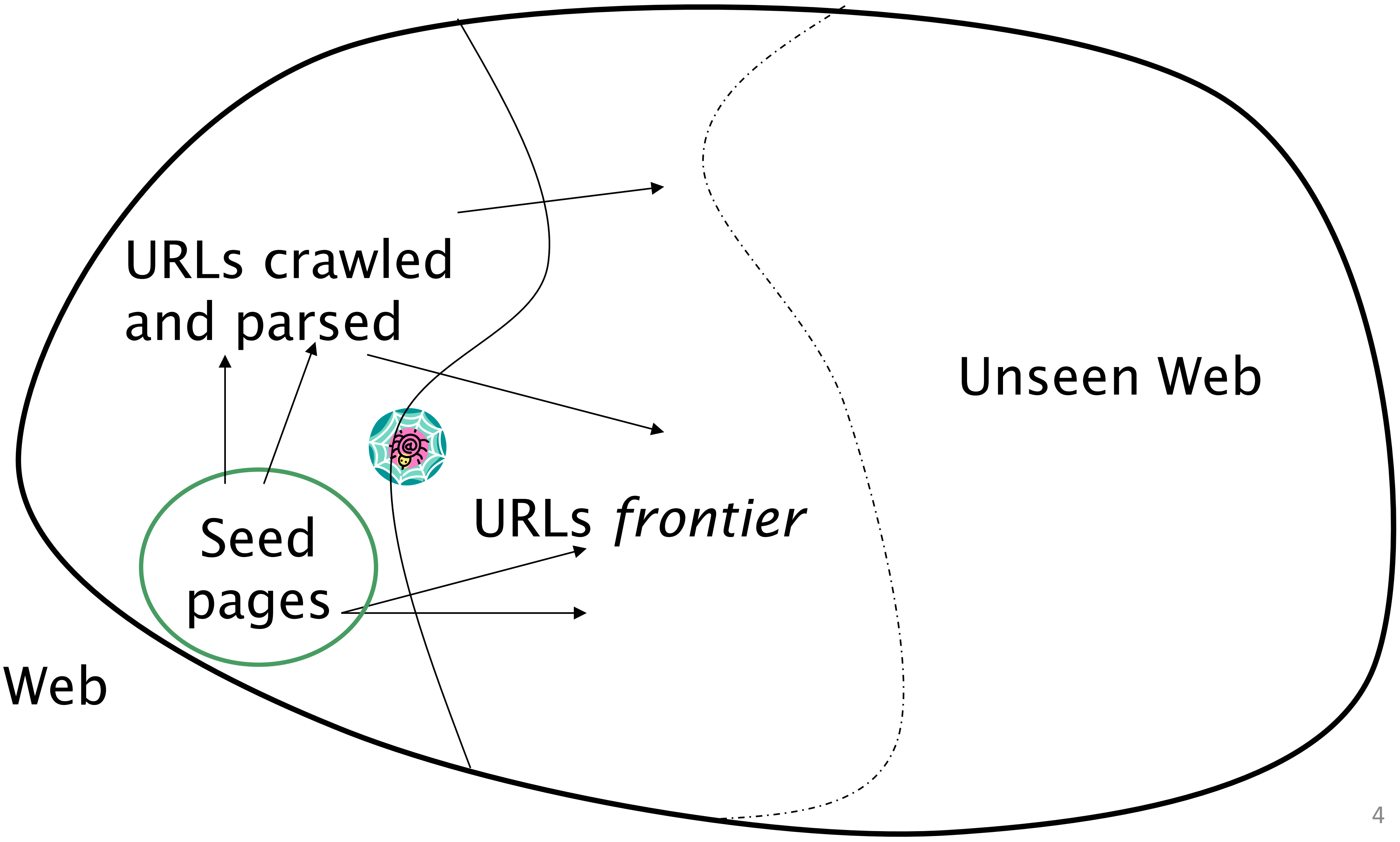
Today’s lecture

- Web Crawling
- (Near) duplicate detection

Basic crawler operation

- Begin with known “seed” URLs
- 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 Robust: Be immune to spider traps and other malicious behavior from web servers
- Be Polite: Respect implicit and explicit politeness considerations

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/robotstxt.html
- Website announces its request on what can(not) be crawled
  - For a server, create a file `/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:
```

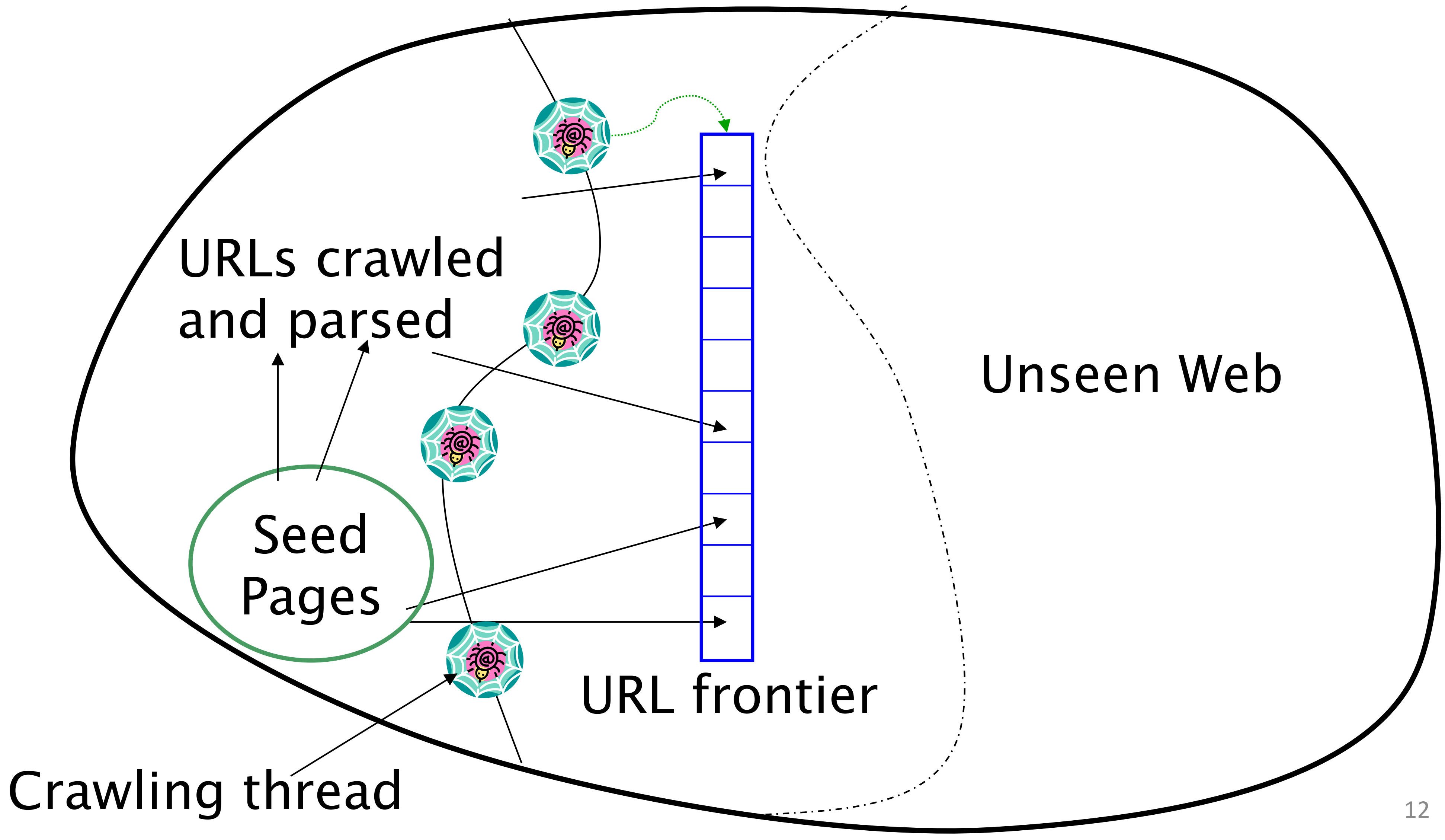
What any crawler *should* do

- Be capable of <u>distributed</u> operation: designed to run on multiple distributed machines
- Be <u>scalable</u>: designed to increase the crawl rate by adding more machines
- <u>Performance/efficiency</u>: permit full use of available processing and network resources

What any crawler *should* do

- 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

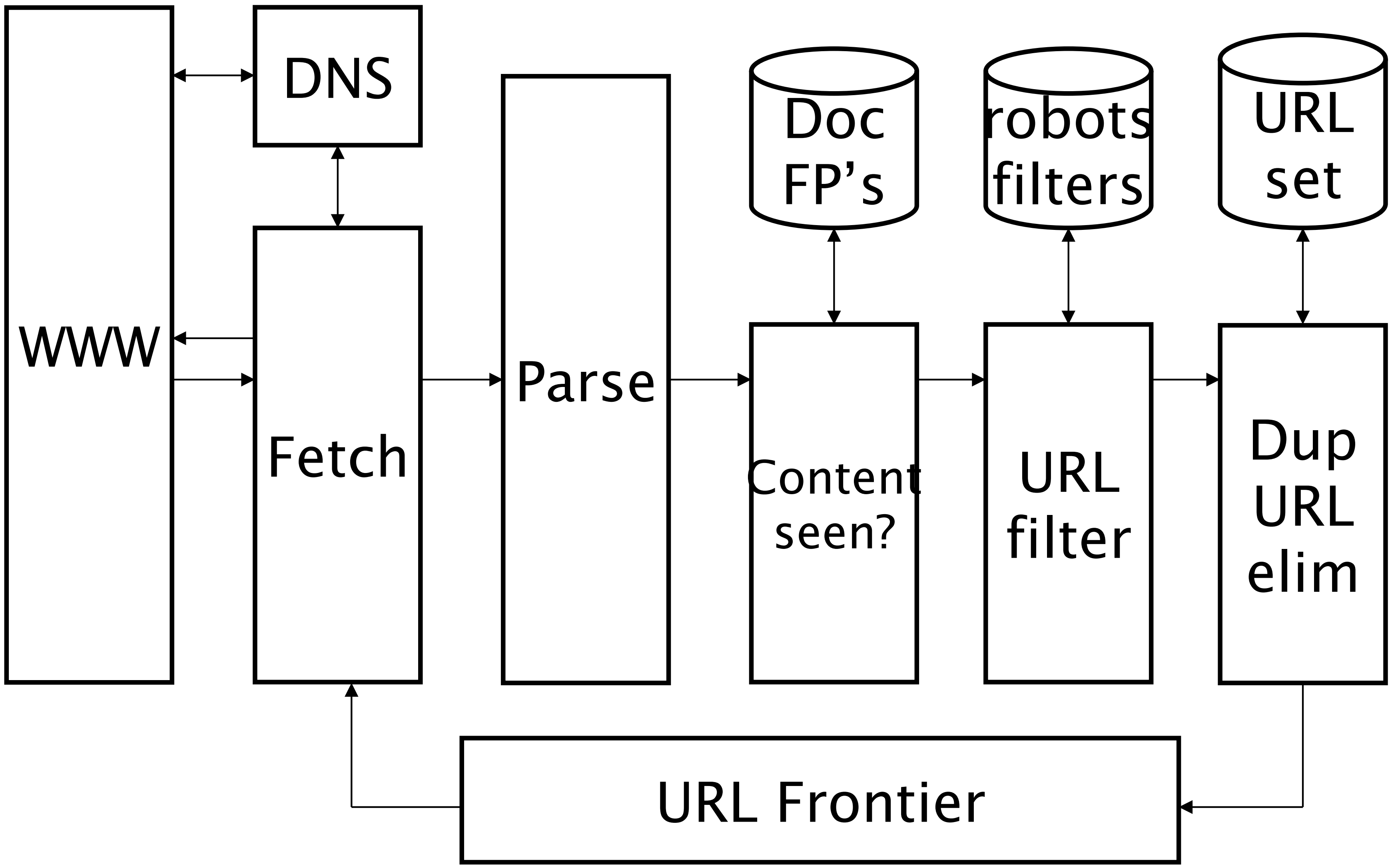
- Can include multiple pages from the same host
- Must avoid trying to fetch them all at the same time
- Must try to keep all crawling threads busy

Processing steps in crawling

- Pick a URL from the frontier ← Which one?
- 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)

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., http://en.wikipedia.org/wiki/Main_Page has 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
  - Second part of this lecture

Filters and robots.txt

- Filters – regular expressions for URLs 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

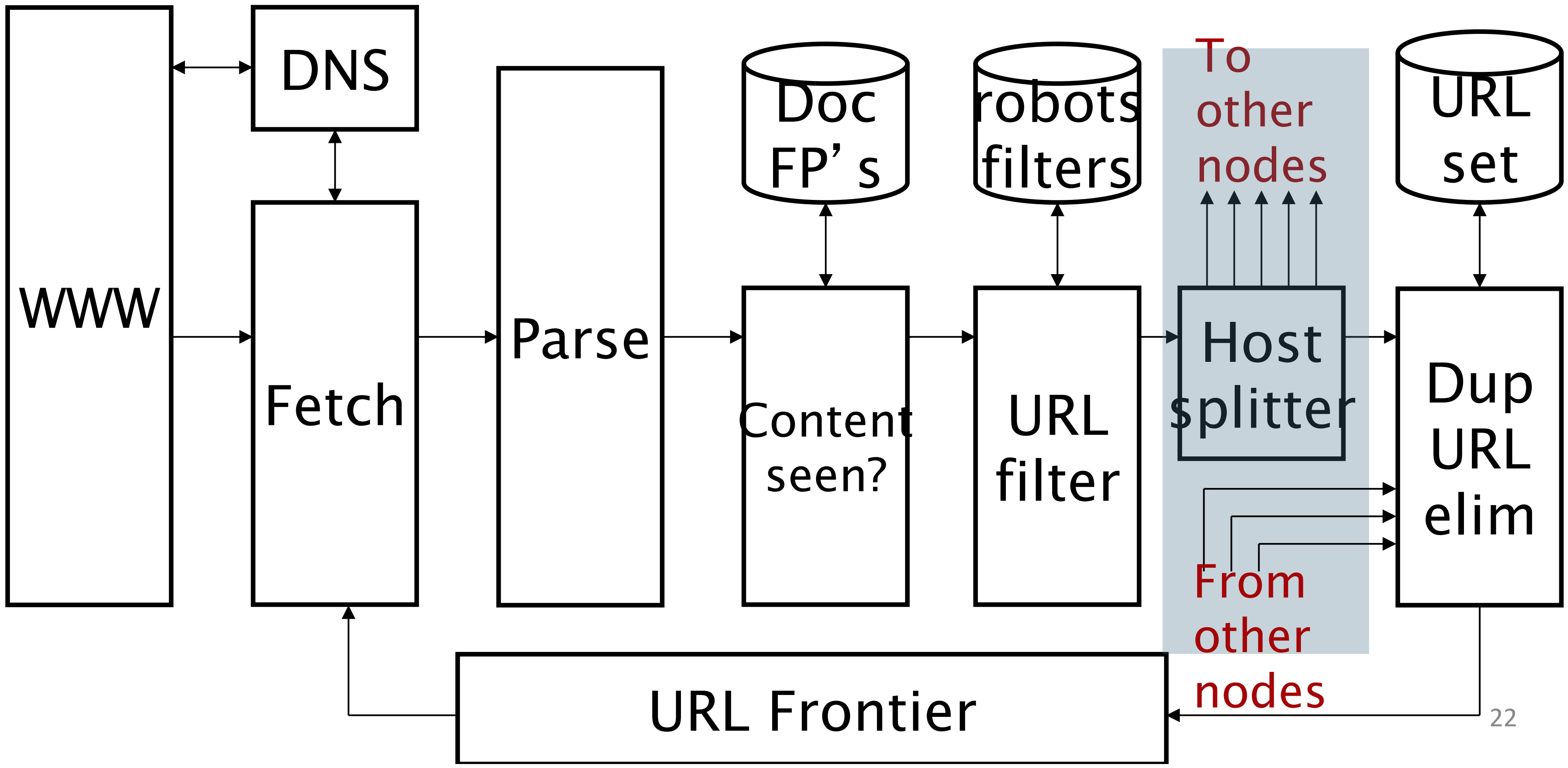
- For a non-continuous (one-shot) crawl, test to see if an extracted+filtered URL has already been passed to the frontier
- For a continuous crawl – see details of frontier implementation

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 and share URLs?

Communication between nodes

- Output of the URL filter at each node is sent to the Dup URL Eliminator of the appropriate node



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

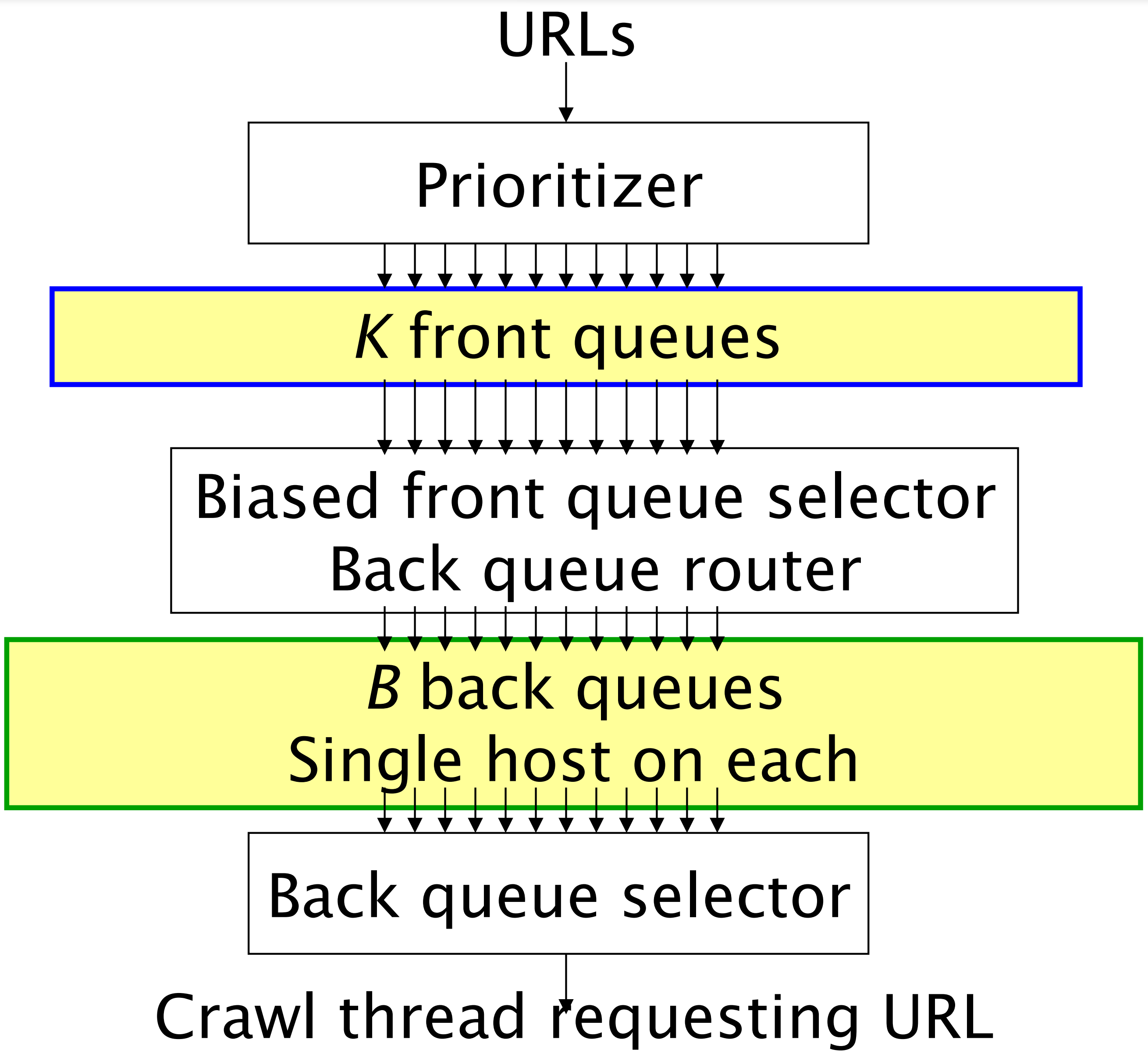
These goals may conflict with each other.

(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

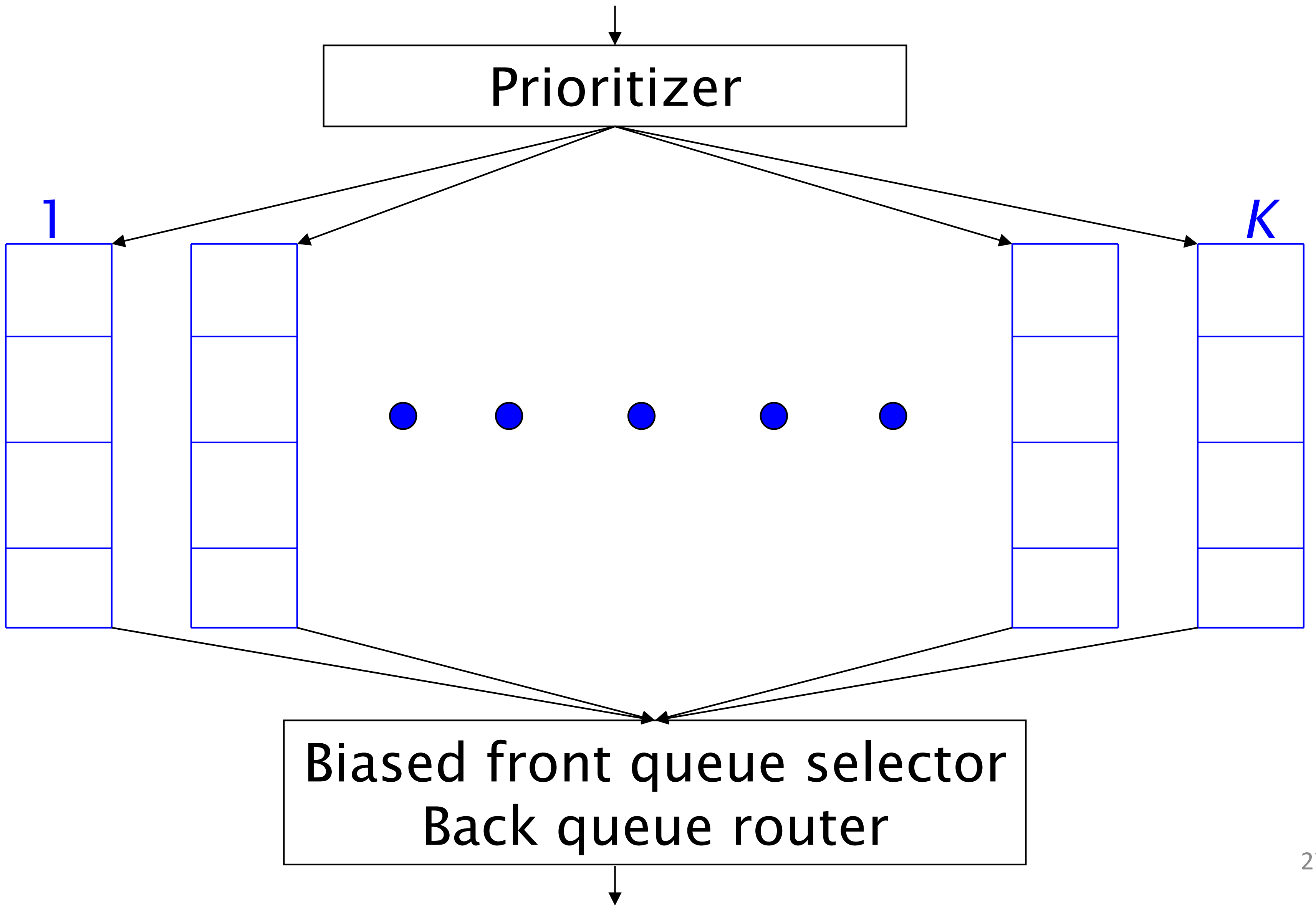
URL frontier: Mercator scheme



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



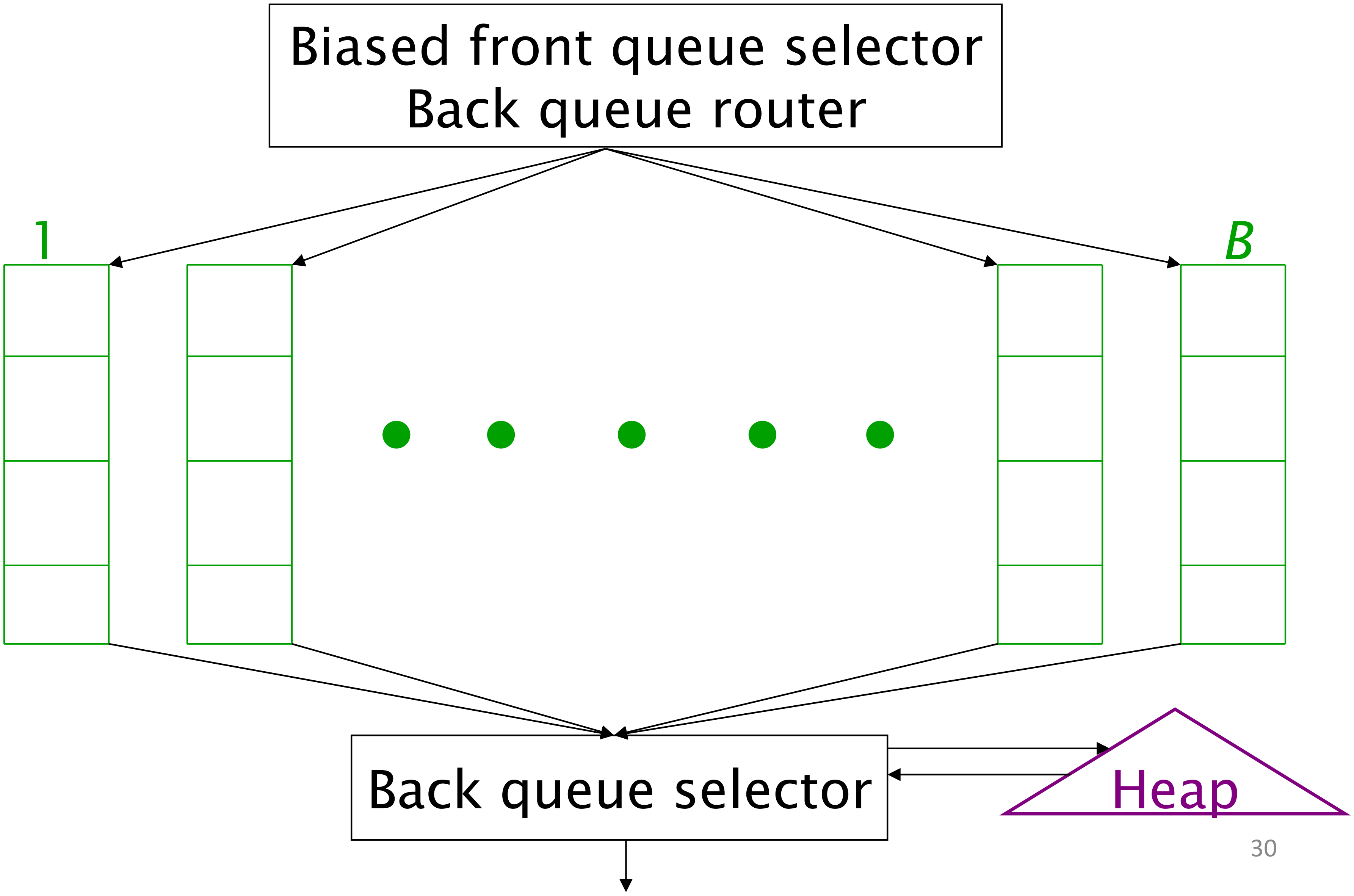
Front queues

- 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
…	3
	1
	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 it 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

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Information Retrieval

Near duplicate document detection

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

Duplicate/Near-Duplicate Detection

- *Duplication*: Exact match can be detected 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

Computing Similarity

- Features:
  - Segments of a document (natural or artificial breakpoints)
  - Shingles (Word N-Grams)
  - ***a rose is a rose is a rose*** → 4-grams are

    a_rose_is_a

    rose_is_a_rose

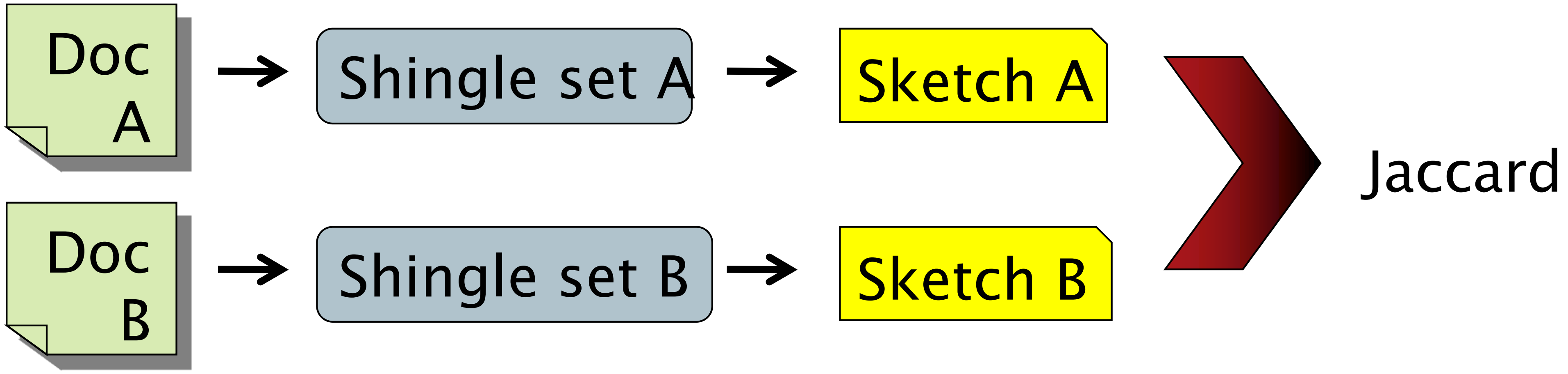
    is_a_rose_is

    a_rose_is_a
- Similarity Measure between two docs (= sets of shingles)
  - Jaccard cooefficient: (Size_of_Intersection / Size_of_Union)

Shingles + Set Intersection

- Computing exact set intersection of shingles between all pairs of documents is expensive

- Approximate using a cleverly chosen subset of shingles from each (a *sketch*)
- Estimate (size_of_intersection / size_of_union) based on a short sketch

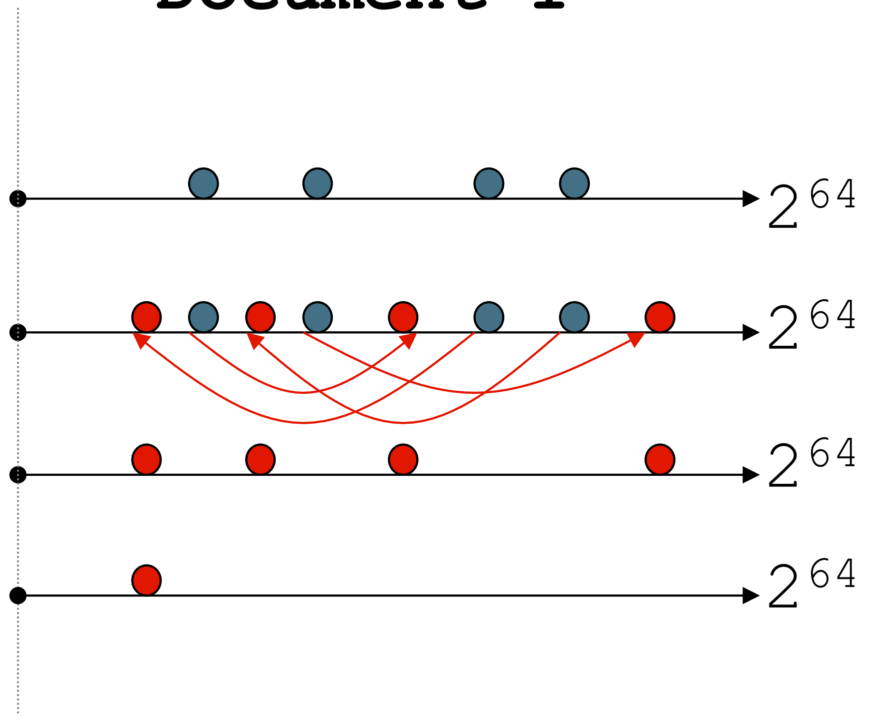


Sketch of a document

- Create a "sketch vector" (of size ~200) for each document
  - Documents that share ≥ *t* (say 80%) corresponding vector elements are deemed near duplicates
  - For doc *D*, sketch$_D$[*i*] is as follows:
    - Let f map all shingles in the universe to 1..2^m (e.g., f = fingerprinting)
    - Let π_i be a *random permutation* on 1..2^m
    - Pick MIN $\{\pi_i(f(s))\}$ over all shingles *s* in *D*

Computing Sketch[i] for Doc1

Document 1

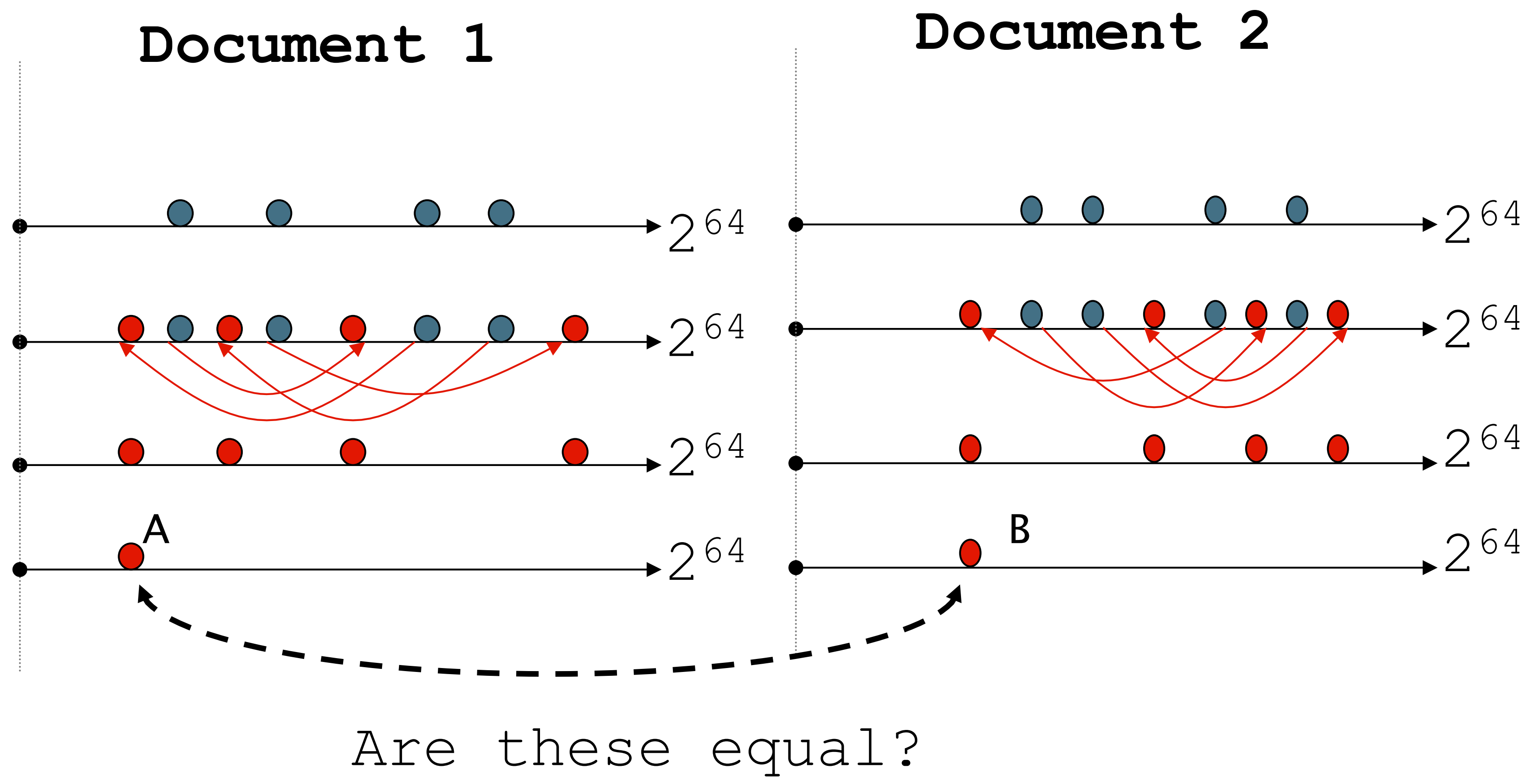


Start with 64-bit *f*(shingles)

Permute on the number line with π_i

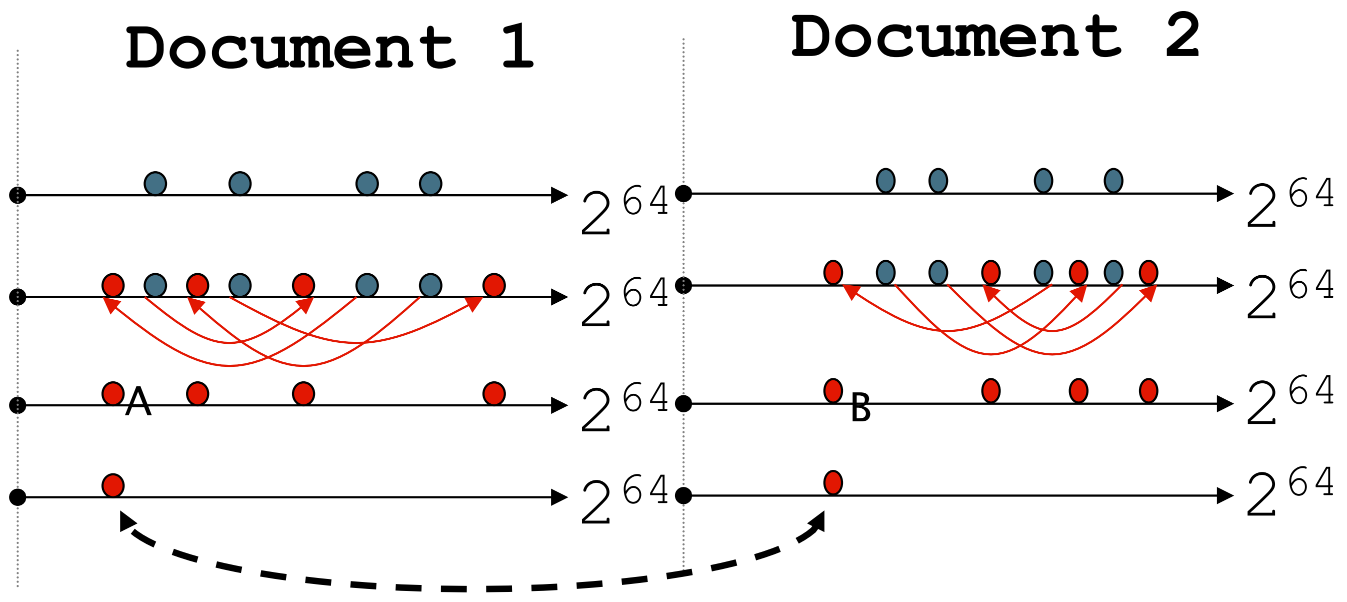
Pick the min value

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



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

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)

Claim: This happens with probability

Why?

`Size_of_intersection / Size_of_union`

Set Similarity of sets C_i , C_j

$$\mathrm{Jaccard}(C_i, C_j) = \frac{|C_i \cap C_j|}{|C_i \cup C_j|}$$

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

$$\begin{array}{cc} \mathbf{C_1} & \mathbf{C_2} \\ 0 & 1 \\ 1 & 0 \\ 1 & 1 \\ 0 & 0 \\ 1 & 1 \\ 0 & 1 \end{array}$$

Jaccard$(\mathbf{C_1},\mathbf{C_2}) = \mathbf{2/5 = 0.4}$

Key Observation

- For columns C_i, C_j, four types of rows

	C_i	C_j
A	1	1
B	1	0
C	0	1
D	0	0

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

$$\mathrm{Jaccard}(C_i, C_j) = \frac{A}{A + B + C}$$

"Min" Hashing

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

$$P\left[h(C_i) = h(C_j)\right] = \text{Jaccard}\left(C_i, C_j\right)$$

- Why?
  - Both are A/(A+B+C)
  - Look down columns C_i, C_j until first non-Type-D row
  - $h(C_i) = h(C_j) \leftarrow\rightarrow$ type A row

Random permutations

- Random permutations are expensive to compute
- Linear permutations work well in practice
  - For a large prime p, consider permutations over $\{0, \ldots, p-1\}$ drawn from the set:

$\mathcal{F}_p = \{\pi_{a,b} : 1 \leq a \leq p-1,\ 0 \leq b \leq p-1\}$ where

$$\pi_{a,b}(x) = ax + b \bmod p$$

Final notes

- Shingling is a *randomized algorithm*
  - Our analysis did not presume any probability model on the inputs
  - It will give us the right (wrong) answer with some probability on *any input*
- We've described how to detect near duplication in a pair of documents
- In "real life" we'll have to concurrently look at many pairs
  - See text book for details