Web Crawling

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Summary

Introduction

Crawler Architecture

Crawl Ordering Problem

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- A *web crawler* (also known as a *robot* or a *spider*) is a system for the downloading of web pages.
- They are used for a variety of purposes:
  - Web Search Engines
  - Web Archiving
  - Web Data Mining
  - Web Monitoring

Introduction

- The basic algorithm is simple. Given a set of seed URLs:
    1. downloads all the web pages addressed by the URLs;
    2. extracts the hyperlinks contained in the pages;
    3. iteratively downloads the web pages addressed by these hyperlinks.
- Despite the apparent simplicity of this basic algorithm, web crawling has many inherent challenges.

Challenges

- **Scale**
  - The web is very large and continually evolving.
  - Crawlers that seek coverage and freshness must achieve extremely high throughput, which poses difficult engineering problems.
- **Content selection tradeoffs**
  - Crawlers do not purport to crawl the whole web, or keep up with all the changes.
  - Goals: acquire high-value content quickly, ensure coverage of all reasonable content, and bypass low-quality, irrelevant, redundant, and malicious content.
  - The crawler must balance coverage and freshness, while obeying constraints such as per-site rate limitations.

Challenges

- **Social obligations**
  - Crawlers should not impose too much of a burden on the web sites they crawl.
  - Without safety mechanisms a high-throughput crawler can inadvertently carry out a *denial-of-service attack*.
- **Adversaries**
  - Some content providers inject useless or misleading content into the corpus assembled by the crawler.
  - Motivation: financial incentives, for example (mis)directing traffic to commercial web sites.

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Architecture Overview

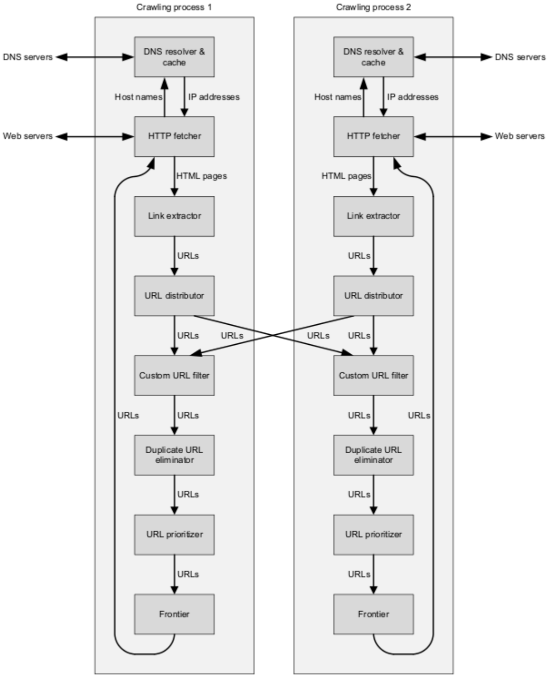
- Consists of multiple processes running on different machines connected by a high-speed network.
- Each process consists of multiple worker threads.
- Each worker thread performs repeated work cycles.
- At each work cycle, a worker obtains a URL from the **Scheduler** or *Frontier*, which organizes URLs according to priority and politeness policies.
- The worker thread invokes the **HTTP fetcher**:
  - It calls a DNS module to resolve the host component of the URL into the IP address of the corresponding web server
  - Connects to the web server and checks for robots exclusion files and attempts to download the web page.

Architecture Overview

- If the download succeeds the web page is stored in a repository.
- The **Link extractor** parses the HTML content of the page and extracts hyperlinks.
- The extracted URLs are passed to a **URL distributor**, which assigns each URL to a crawling process.
- This assignment is typically made by hashing the URLs host component, its domain, or its IP address (requires additional DNS resolutions).
- Most hyperlinks refer to pages on the same web site, thus assignment to the local crawling process is the common case.

Architecture Overview

- The URL passes through:
  - **Custom URL filter**: to exclude URLs belonging to "black-listed" sites and URLs with particular file extensions that are not of interest
  - **Duplicate URL eliminator**: maintains the set of all URLs discovered so far and passes on only never-before-seen URLs.
- The **URL prioritizer** selects a position for the URL in the Frontier or Scheduler, based on estimated page importance or rate of change.


Crawling process 1
Crawling process 2
DNS servers
DNS resolver & cache
Host names
IP addresses
Web servers
HTTP fetcher
HTML pages
Link extractor
URLs
URL distributor
Custom URL filter
Duplicate URL eliminator
URL prioritizer
Frontier
DNS servers
DNS resolver & cache
Host names
IP addresses
Web servers
HTTP fetcher
HTML pages
Link extractor
URLs
URL distributor
Custom URL filter
Duplicate URL eliminator
URL prioritizer
Frontier

Key Design Points

- Any web crawler needs to keep track the URLs.
- Operations that must be supported:
  - Adding a new URL
  - Retrieving a URL
  - Marking a URL as downloaded
  - Testing whether the set contains a URL
- In-memory data structures (e.g., trees or sorted lists) exceed the amount of memory available on a single machine.

Key Design Points

- Solution: maintain the data structure on disk.
- However, cost of accessing items in the set (e.g., set membership test) involves an expensive disk seek.
- Every modern web crawler splits the crawl state into:
  - **URL-seen test** or **Duplicate URL eliminator**: maintains the set of URLs that have been discovered (whether downloaded or not)
  - **Scheduler**: maintains the set of URLs that have yet to be downloaded.

Scheduler Data Structure and Politeness

- A straightforward implementation is a First-in-First-out (FIFO) queue, which results in a breadth-first traversal of the web graph.
- However, this simple approach has drawbacks:
  - Most hyperlinks refer to another page on the same web server, resulting in many consecutive HTTP requests to that server.
  - A barrage of requests is considered “impolite”, and may end in a denial-of-service attack.

Scheduler Data Structure and Politeness

- One solution: multithreaded or distributed crawler that issues many HTTP requests in parallel.
- Avoid issuing multiple overlapping requests to the same server.
  - Maintain a mapping from web servers to crawling threads, e.g., by hashing the host component of each URL.
  - Each crawling thread has a separate FIFO queue, and downloads only URLs obtained from that queue.

Scheduler Data Structure and Politeness

- Politeness policy: space out requests to each web server according to that server's capabilities.
  - E.g., delay subsequent requests by a multiple (say $10\times$) of the time it took to download the last page from that server.
- This policy ensures that:
  - The crawler consumes a bounded fraction of the web server's resources.
  - Fewer pages will be downloaded from slow or poorly connected web servers than from fast, responsive web servers.

Scheduler Data Structure and Politeness

- It may be desirable to prioritize pages according to their estimated usefulness, based on:
  - PageRank
  - Traffic they receive
  - Reputation of the web site
  - Rate at which the page has been updated in the past
  - Etc.

URL Seen Test

- The second major data structure: **URL-seen test** (UST) or the **duplicate URL eliminator** (DUE)
- It keeps track of the set of URLs that have been previously discovered and added to frontier.
- UST needs to support:
  - Insertion
  - Set membership testing
- In a continuous crawling setting, it must also support deletion to cope with URLs that no longer point to a valid page.

URL Seen Test

- In a disk-based hash table, each lookup requires a disk seek, severely limiting the throughput.
- Caching popular URLs can increase the throughput.
- However, the average web page contains close to hundred links and each link needs to be tested for novelty.
- Implementations performing random file accesses perform poorly, but those that perform streaming sequential reads or writes achieves good throughput.

URL Seen Test

- The IRLbot crawler [84] uses:
- Batch of URLs arriving at the DUE is written to disk, distributed over multiple files keyed by the prefix of each hash.
- Once the size of the largest file exceeds a certain threshold, the files that together hold the batch are read back into memory one by one and merge-sorted into the main URL hash file on disk.

Auxiliary Data Structures: Robots File

- *Robots Exclusion Protocol*: allows an administrator to bar crawlers from crawling the site, or pages within the site.
- Provides a file at URL `/robots.txt` containing rules that specify which pages the crawler is allowed to download.
- A crawler should check whether the site supplies a `/robots.txt` file, and if so, adhere to its rules.
- To avoid repeatedly requesting `/robots.txt`, crawlers cache the results of previous requests of that file.

Auxiliary Data Structures: DNS

- URLs contain a host component (e.g., www.yahoo.com), which is “resolved” using the Domain Name Service (DNS) protocol.
- DNS requests can take quite a long time due to the request-forwarding nature of the protocol.
- Therefore, crawlers often maintain their own DNS caches.

Incremental Web Crawling

- Web crawlers can be used to:
  - Assemble one or more static snapshots of a web corpus (batch crawling)
  - Perform *incremental* or *continuous crawling*: download newly discovered pages and re-download previously crawled pages.
- Efficient incremental crawling requires a few changes to the major data structures of the crawler.
  - The DUE should support the deletion of URLs that are no longer valid (e.g., that result in a 404 HTTP return code).
  - URLs are retrieved from the scheduler and downloaded as in batch crawling, but they are subsequently reentered into the scheduler.

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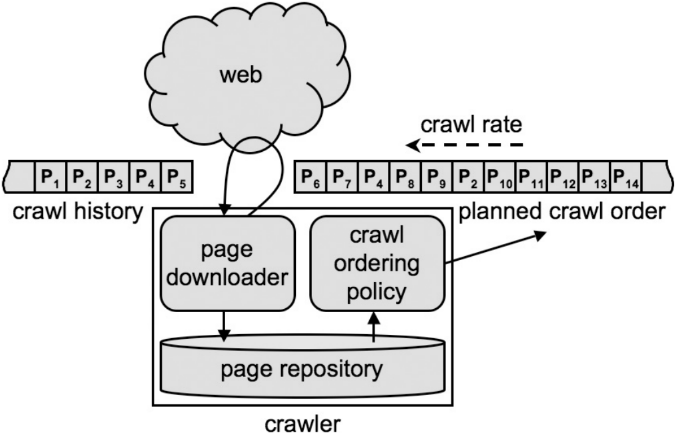
Crawl Ordering Problem

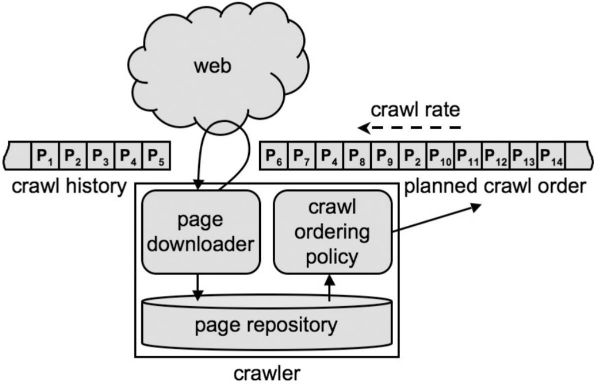
- The crawl order is extremely important:
  - due to the growth rate of new content
  - due to dynamically generated content
- A good crawler order must consider:
  - **Coverage.** The fraction of desired pages that the crawler acquires successfully.
  - **Freshness.** The degree to which the acquired page snapshots remain up-to-date, relative to the current “live” web copies.

Simplified Crawl Ordering Model



Model

- At a given point in time, some historical crawl order has already been executed (P1, P2, P3, P4, P5 in the diagram).
- Some future crawl order has been planned (P6, P7, P4, P8, ...).



Model

- Pages downloaded by the crawler are stored in a *repository*.
- The future crawl order is determined, at least in part, by analyzing the repository.
- The content of a web page is subject to change over time.
- It is sometimes desirable to re-download a page that has already been downloaded, to obtain a more recent snapshot of its content.

Model: Two Approaches

- **Batch crawling**:
  - The crawl order does not contain duplicate occurrences of any page
  - The entire crawling process is periodically halted and restarted as a way to obtain more recent snapshots of previously crawled pages.
- **Incremental crawling**:
  - Pages may appear multiple times in the crawl order.
  - Crawling is a continuous process that conceptually never terminates.
- Most modern commercial crawlers perform incremental crawling, which is more powerful because it allows re-visitation of pages at different rates.

Web Characteristics

- One notable study is by Broder et al. [26], which uncovered a “bowtie” structure consisting of:
  - a central strongly connected component (the core).
  - a component that can reach the core but cannot be reached from the core.
  - a component that can be reached from the core but cannot reach the core.
- In addition, there are a number of small, irregular structures such as disconnected components and long “tendrils”.

Web Characteristics

- In an earlier study, Broder et al. [28] showed that there is an abundance of near-duplicate content of the web.
- Using a corpus of 30 million web pages collected by the AltaVista crawler, they found that:
  - 29% of the pages were more than 50% similar to other pages in the corpus
  - 11% of the pages were exact duplicates of other pages.
- Sources of near-duplication include mirroring of sites (or portions of sites) and URL synonymy.

Taxonomy of Crawl Ordering Policies

- Next figure presents a high-level taxonomy of published crawl ordering techniques.
- The first group of techniques focuses exclusively on ordering pages for first-time downloading, which affects *coverage*.
  - Can be applied either in the batch crawling scenario, or in the incremental crawling scenario in conjunction with a separate policy of the second group.
- The second group of techniques governs re-downloading of pages to maintain *freshness*.
- Techniques in the third group consider the combined problem of interleaving first-time downloads with re-downloads, to balance coverage and freshness.

Taxonomy of Crawl Ordering Policies

Technique	Objectives		Factors considered		
	Coverage	*Freshness*	*Importance*	*Relevance*	*Dynamicity*
Breadth-first search [43, 95, 108]	√				
Prioritize by indegree [43]	√		√		
Prioritize by PageRank [43, 45]	√		√		
Prioritize by site size [9]	√		√		
Prioritize by spawning rate [48]	√				√
Prioritize by search impact [104]	√		√	√	
Scoped crawling (Section 4.2)	√			√	
Minimize obsolescence [41, 46]		√	√		√
Minimize age [41]		√	√		√
Minimize incorrect content [99]		√	√		√
Minimize embarrassment [115]		√	√	√	√
Maximize search impact [103]		√	√	√	√
Update capture (Section 5.2)		√		√	√
WebFountain [56]	√	√			√
OPIC [1]	√	√	√		

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