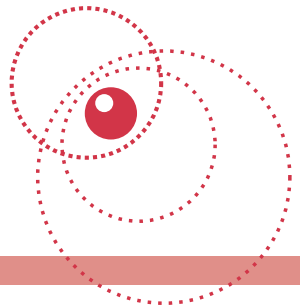


CES Data Scientist

Web Crawling

13 June 2016

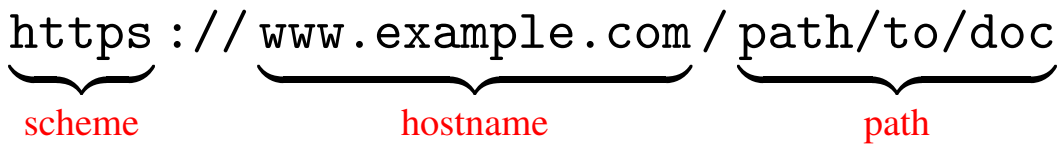
TELECOM ParisTech

Plan

Crawling the Web

- The World Wide Web: largest information repository
- By nature (mostly) public and freely accessible information
- Numerous applications require navigating the Web and retrieving Web content in bulk:
  - Web search engines (e.g., Google, Bing), to create an index of Web content
  - Web archiving (e.g., Internet Archive), to preserve parts of the Web for future generations
  - Shopping aggregators (e.g., Google Shopping, Kelkoo), to build a database of products and their prices on different sites
  - etc.

URL: Uniform Resource Locator



scheme: way the resource can be accessed; generally http or https

hostname: domain name of a host; hostname of a website may start with `www.`, but not a rule

path: logical path of the document

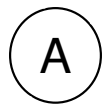
- Unique identification of a resource (page, document, etc.) on the Web
- Empty path: root of the Web server
- Relative URLs with respect to a context (e.g., the URL above):

```
/titi   https://www.example.com/titi
tata    https://www.example.com/path/to/tata
```

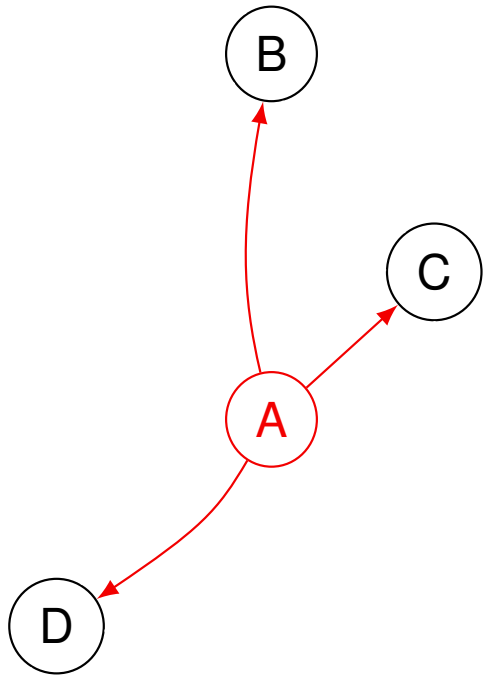
Web Crawlers

- crawlers, (Web) spiders, (Web) robots: autonomous user agents that retrieve pages from the Web
- Basics of crawling:
  1. Start from a given URL or set of URLs
  2. Retrieve and process the corresponding page
  3. Discover new URLs (see further)
  4. Repeat on each found URL
- No real termination condition (the Web is virtually infinite!)
- Graph-traversing problem

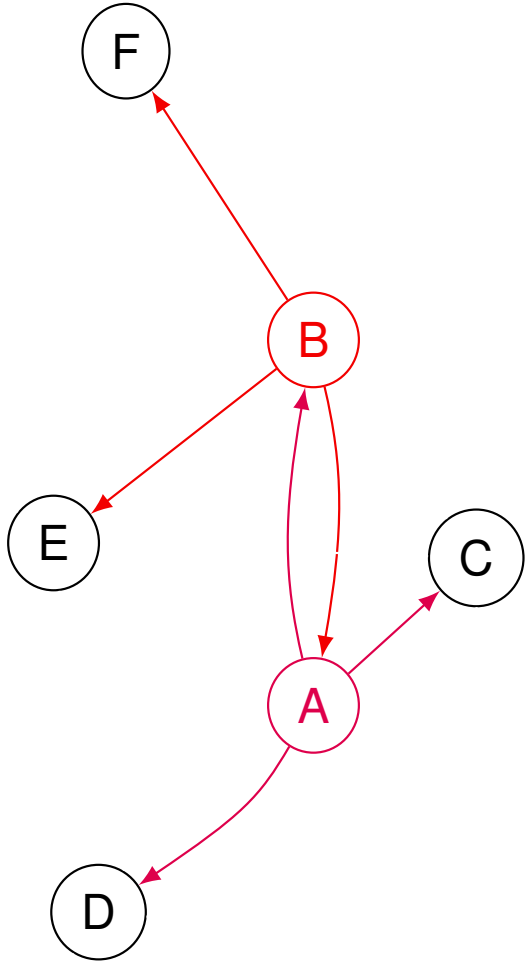
Depth-first crawl



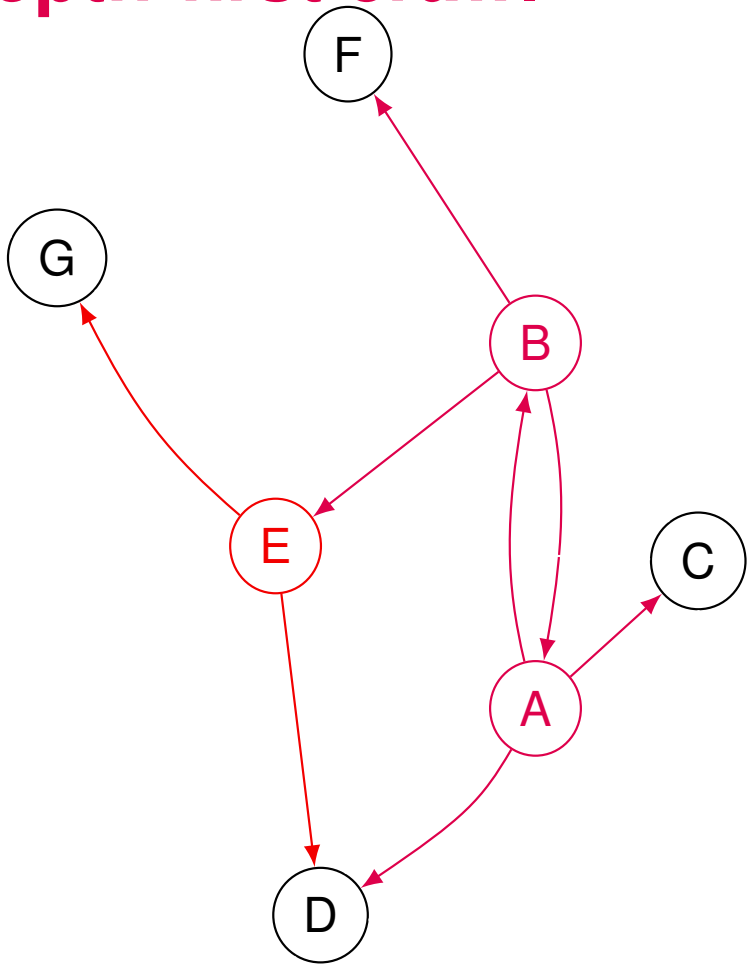
Depth-first crawl



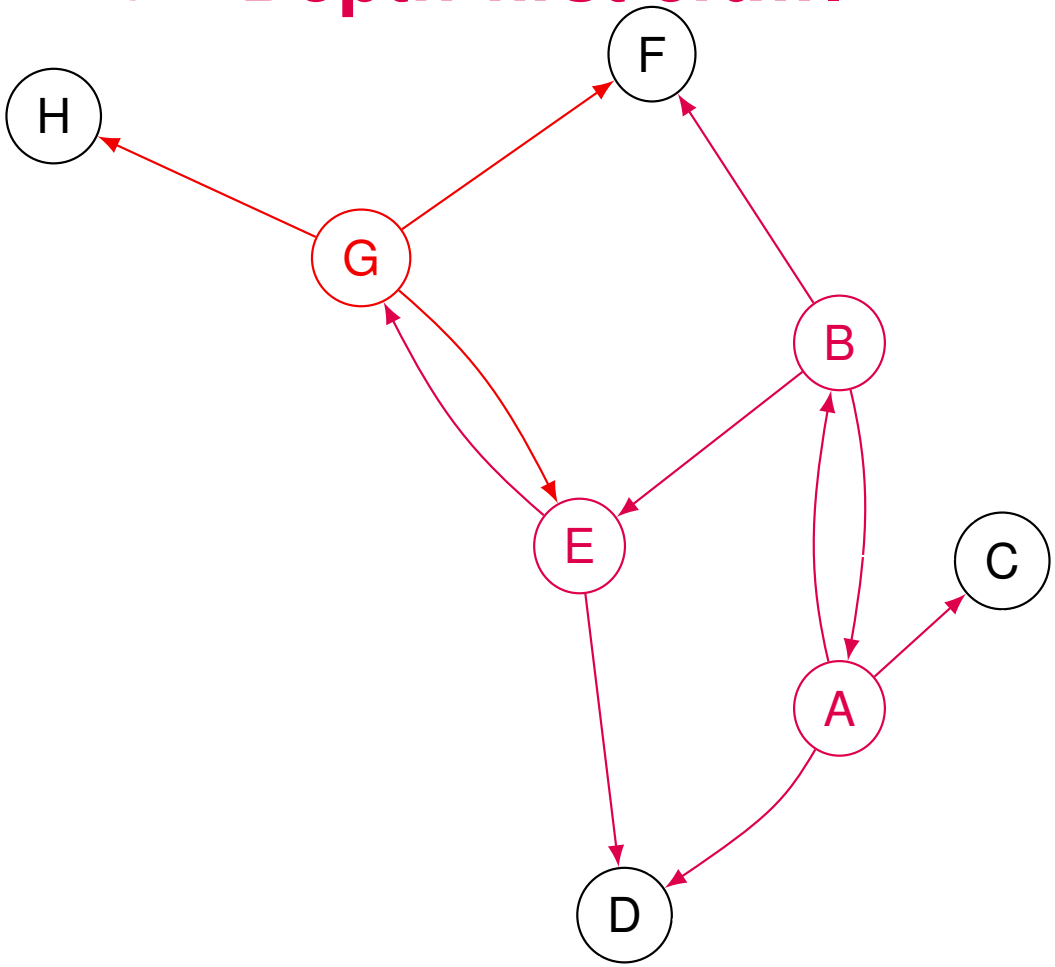
Depth-first crawl



Depth-first crawl



Depth-first crawl



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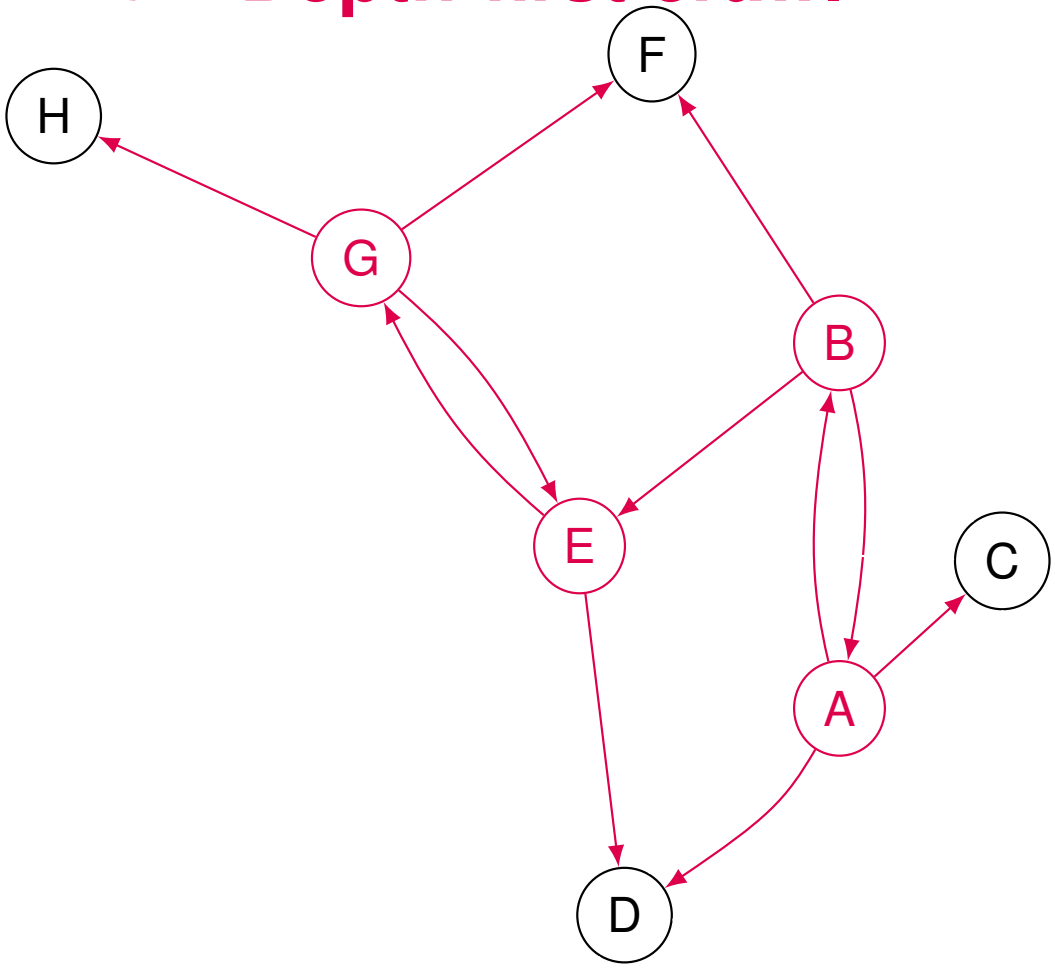
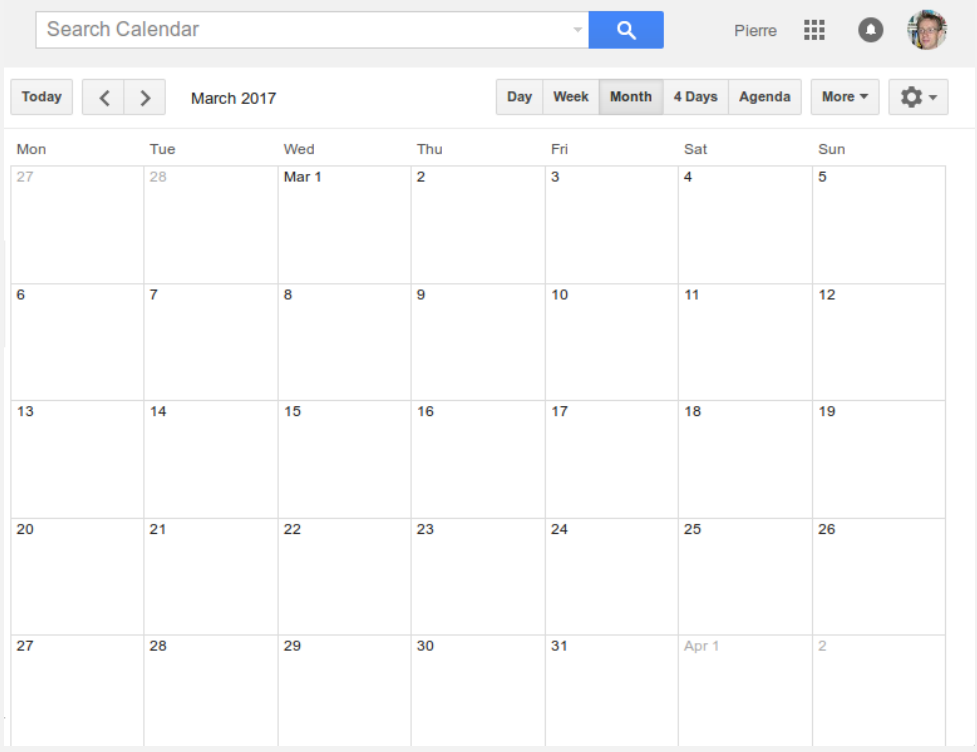


Depth-first crawl

H

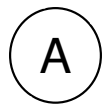
Characteristics

- Very susceptible to robot traps

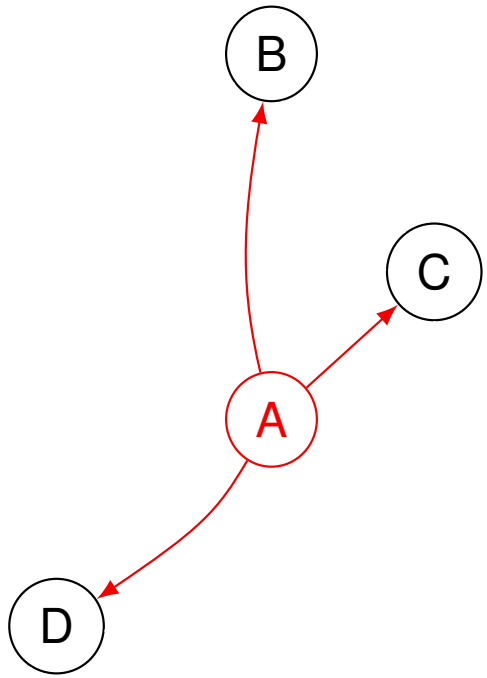


- Ensures better temporal consistency [Spaniol et al., 2009]

Breadth-first crawl



Breadth-first crawl



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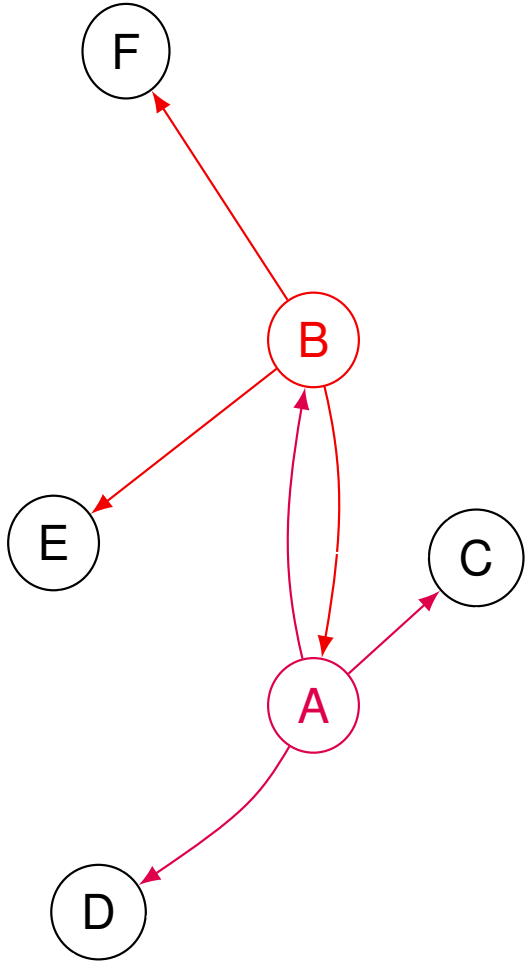

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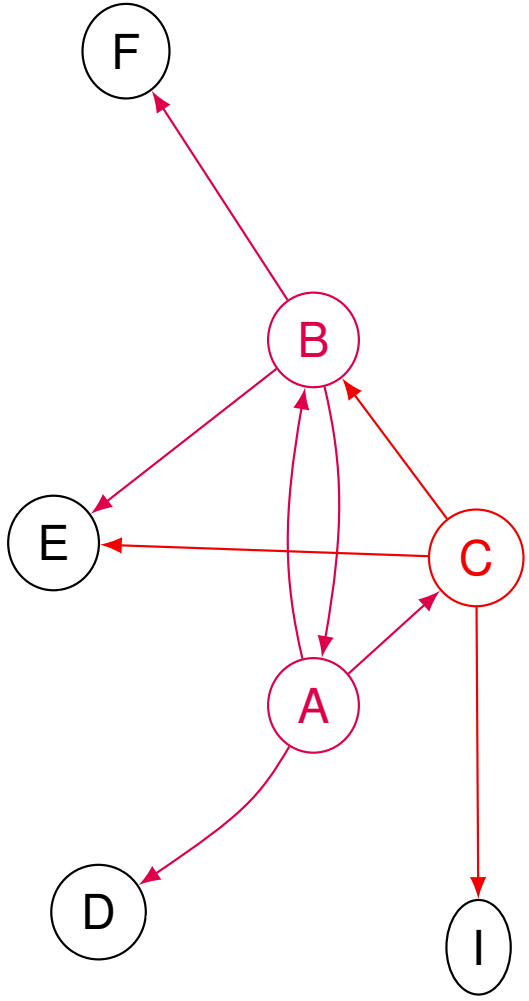

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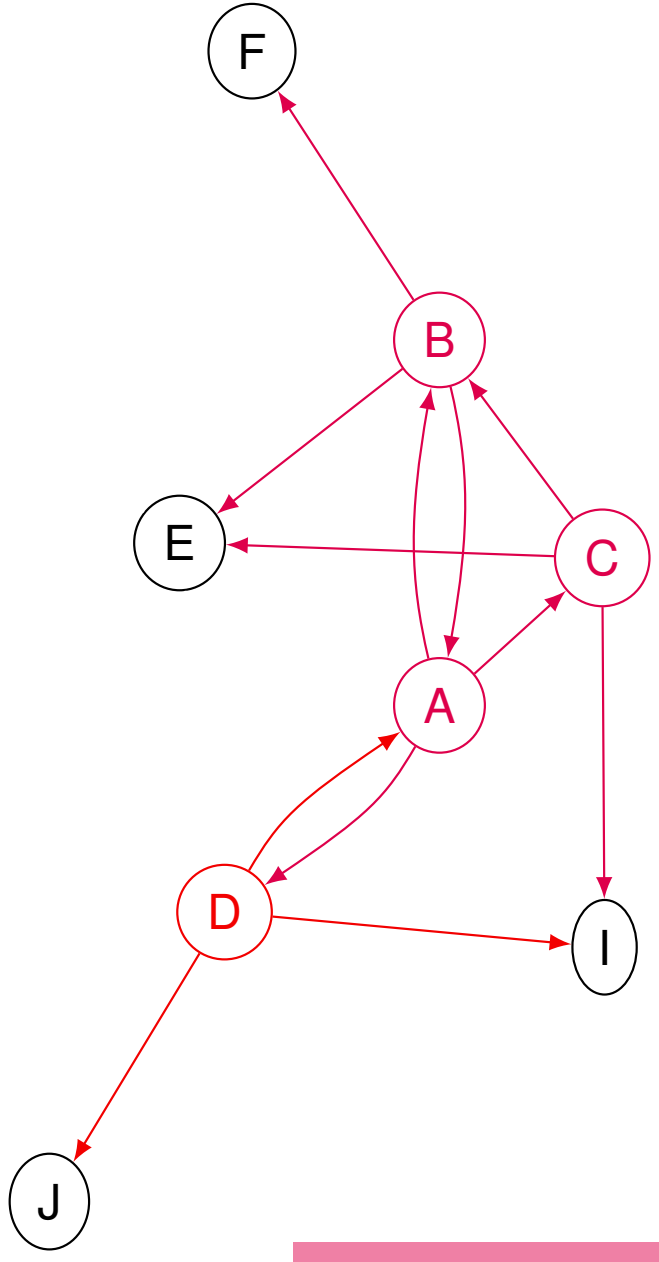
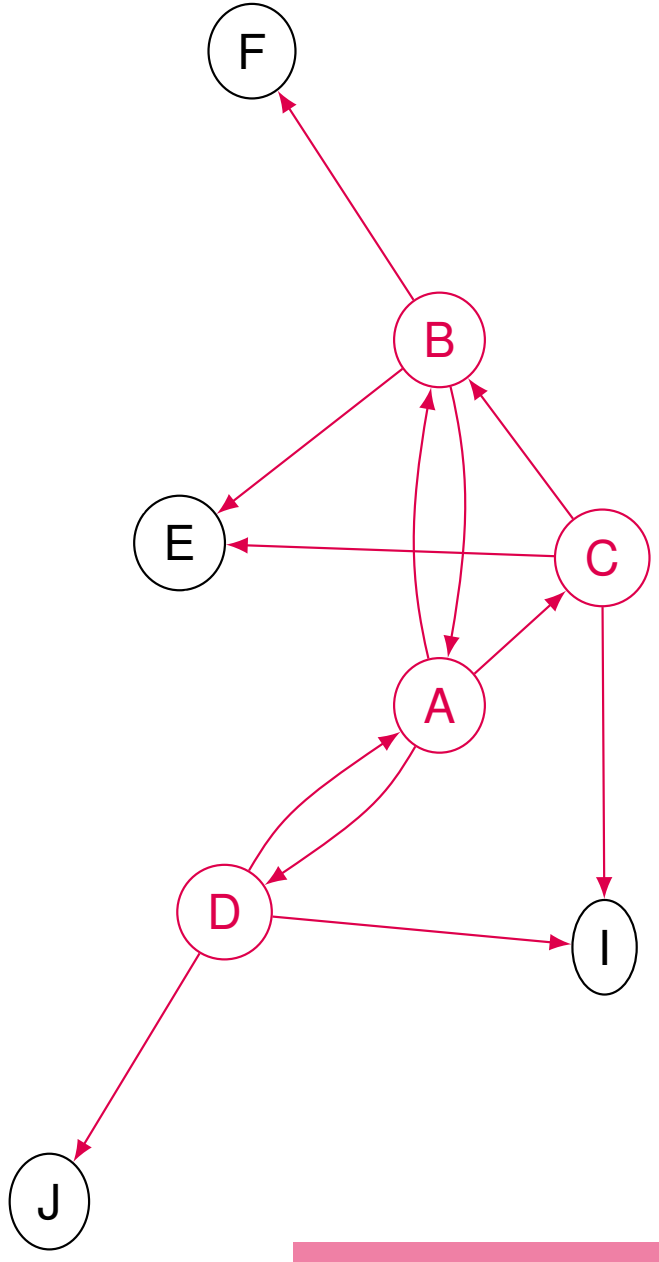


Breadth-first crawl



Breadth-first crawl

Characteristics

- Better overall for exploring a large part of the Web
- Risk of crawling too superficially given Web sites
- In practice, pragmatic strategy:
  - breadth-first crawl at the level of the whole Web
  - limited-depth depth-first crawl within a given Web site

Sources of new URLs

- From HTML pages:
  - hyperlinks `<a href="...">...</a>`
  - media `<img src="...">` `<embed src="...">` `<object data="...">`
  - frames `<frame src="...">` `<iframe src="...">`
  - JavaScript links `window.open("...")`
  - etc.
- Other hyperlinked content (e.g., PDF files)
- Non-hyperlinked URLs that appear anywhere on the Web (in HTML text, text files, etc.): use regular expressions to extract them
- Sitemaps [sitemaps.org, 2008]

Scope of a crawler

- Web-scale
  - The Web is infinite! Avoid robot traps by putting depth or page number limits on each Web server
  - Focus on important pages [Abiteboul et al., 2003]
- Web servers under a list of DNS domains: easy filtering of URLs
- A given topic: focused crawling techniques [Chakrabarti et al., 1999, Diligenti et al., 2000] based on classifiers of Web page content and predictors of the interest of a link.
- The national Web (cf. public deposit, national libraries): what is this? [Abiteboul et al., 2002]
- A given Web site: what is a Web site? [Senellart, 2005]

Web search APIs

- Used to be plenty of free APIs to Web search engines. . . not the case any more
- Paid-for Web search APIs:

  Yahoo! BOSS 0.80 USD per 1,000 queries (uses Bing's index)
  `https://developer.yahoo.com/boss/search/`

  Google Custom Search Engine 100 free queries per day, 5 USD per further 1,000 queries, up to 10,000 queries per day
  `https://developers.google.com/custom-search/`

  Bing Search API free for 5,000 queries per month; $\approx$ 20 USD per further 5,000 queries
  `https://datamarket.azure.com/dataset/5BA839F1-12CE-4CCE-BF57-A49D98D29A44`

- Anything else?

Plan

A word about hashing

Definition

A hash function is a deterministic mathematical function transforming objects (numbers, character strings, binary...) into fixed-size, seemingly random, numbers. The more random the transformation is, the better.

Example

Java hash function for the `String` class:

$$\sum_{i=0}^{n-1} s_i \times 31^{n-i-1} \bmod 2^{32}$$

where s_i is the (Unicode) code of character i of a string s.

Identification of duplicate Web pages

Problem

Identifying duplicates or near-duplicates on the Web to prevent multiple indexing

trivial duplicates: same resource at the same canonized URL:

```
http://example.com:80/toto
http://example.com/titi/../toto
```

exact duplicates: identification by hashing

near-duplicates: (timestamps, tip of the day, etc.) more complex!

Near-duplicate detection

Edit distance. Count the minimum number of basic modifications (additions or deletions of characters or words, etc.) to obtain a document from another one. Good measure of similarity, and can be computed in $O(mn)$ where m and n are the size of the documents. But: does not scale to a large collection of documents (unreasonable to compute the edit distance for every pair!).

Shingles. Idea: two documents similar if they mostly share the same succession of k-grams (succession of tokens of length k).

Example

I like to watch the sun set with my friend.
My friend and I like to watch the sun set.

$S = \{$i like, like to, my friend, set with, sun set, the sun, to watch, watch the, with my$\}$
$T = \{$and i, friend and, i like, like to, my friend, sun set, the sun, to watch, watch the$\}$

Hashing shingles to detect duplicates [Broder et al., 1997]

- Similarity: Jaccard coefficient on the set of shingles:

$$J(S, T) = \frac{|S \cap T|}{|S \cup T|}$$

- Still costly to compute! But can be approximated as follows:
  1. Choose N different hash functions
  2. For each hash function h_i and each set of shingles $S_k = \{s_{k1} \dots s_{kn}\}$, store $\phi_{ik} = \min_j h_i(s_{kj})$
  3. Approximate $J(S_k, S_l)$ as the proportion of ϕ_{ik} and ϕ_{il} that are equal
- Possibly to repeat in a hierarchical way with super-shingles (we are only interested in very similar documents)

Plan

Crawling ethics

- Standard for robot exclusion: robots.txt at the root of a Web server [Koster, 1994].

```
User-agent: *
Allow: /searchhistory/
Disallow: /search
```

- Per-page exclusion.

```
<meta name="ROBOTS" content="NOINDEX,NOFOLLOW">
```

- Per-link exclusion.

```
<a href="toto.html" rel="nofollow">Toto</a>
```

- Avoid Denial Of Service (DOS), wait ≈1s between two repeated requests to the same Web server

Legal aspects (France) – 1/2

- General principles:
  - to access or keep access to a “system for automated data processing” *in a fraudulous manner* is punished of two years of prison and 60,000 euros fine (Code pénal 323-1, modified by law 2015-912 on “Renseignement”)
  - to disrupt the functioning of a “system for automated data processing” is punished of five years of prison and 150,000 euros fine, extended to seven years and 300,000 euros when the system is a public one containing personal information (Code pénal 323-2, modified by law 2015-912 on “Renseignement”)
- A Web site hosted in a different country may invoke completely different legal principles, under a different jurisdiction
- Crawling content can be considered accessing and keeping access to a “system for automated data processing” (Cour d’appel de Paris, 5 February 2014, “Bluetouff case”)

Legal aspects (France) – 2/2

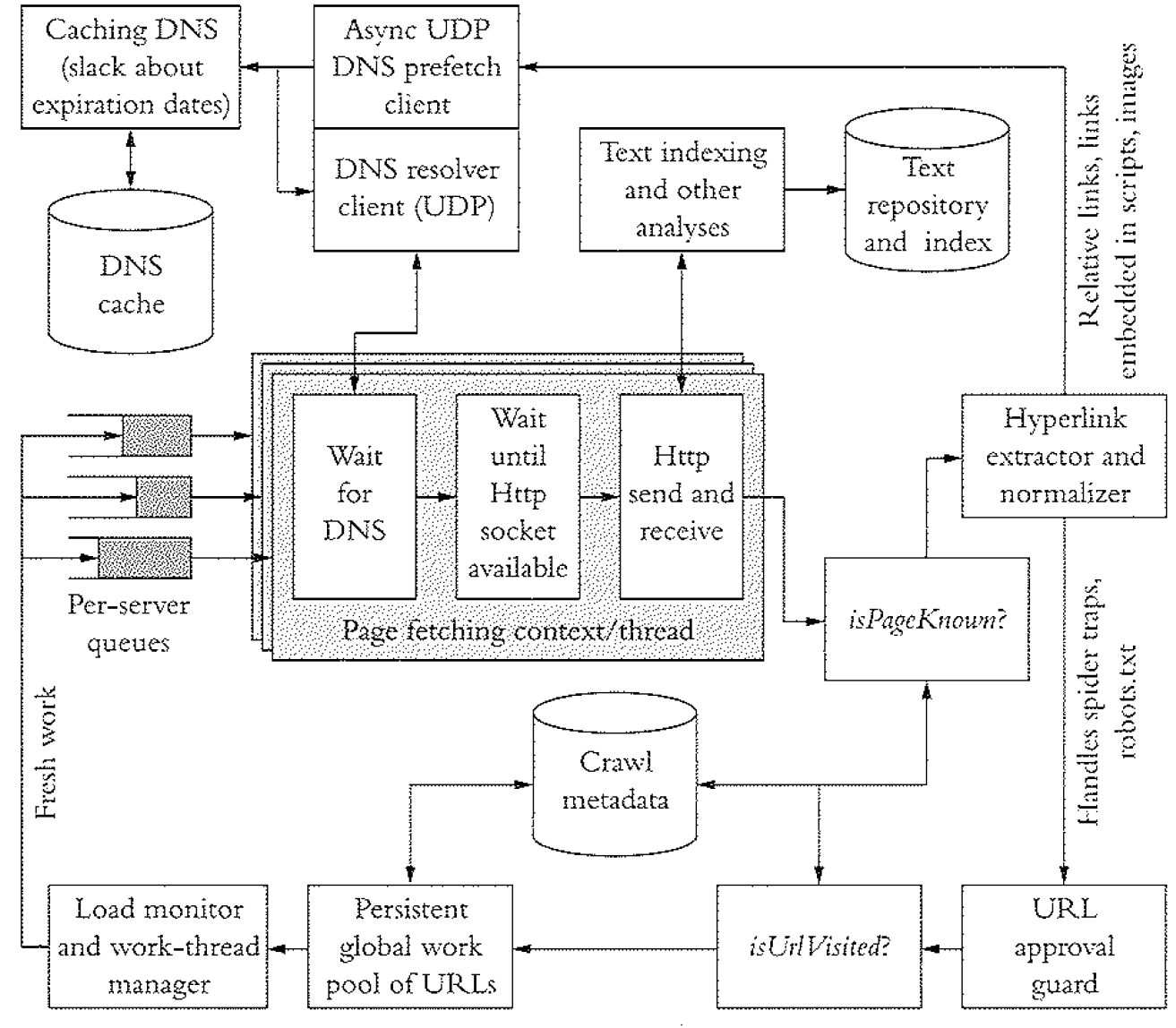
- robots.txt files are a de facto standard, and instructions in robots.txt files can be taken are a receivable way to specify what can be crawled (Cour d'appel de Paris, 26 January 2011, Google vs SAIF)
- Frequent requests to a Web site can be considered as a way to disrupt the functioning of a "system for automated data processing" (Cour d'appel de Bordeaux, 15 November 2011, Cédric M. vs C-Discount), but only if it reaches abusive levels and can be shown to have cause disruption
- Web content is subject to "droit d'auteur" (Code de la propriété intellectuelle, Première partie, Livre Ier) and cannot generally be broadcast by third-parties; only transient copies are allowed (CJEU, 5 June 2014, PRCA vs NLA)
- Web content containing personal data is even more sensitive (Loi "Informatique et Libertés"): personal data should be collected for a specific purpose, and should be kept updated

Parallel processing

Network delays, waits between requests:

- Per-server queue of URLs
- Parallel processing of requests to different hosts:
  - multi-threaded programming
  - asynchronous inputs and outputs (`select`, classes from `java.util.concurrent`): less overhead
- Many engineering tricks (HTTP keep-alive, DNS pre-caching, etc.) to optimize a crawler and reduce connection overheads

General Architecture [Chakrabarti, 2003]



Plan

Refreshing URLs

- Content on the Web changes
- Different change rates:

  online newspaper main page: every hour or so
  published article: virtually no change
- Continuous crawling, and identification of change rates for adaptive crawling: how to know the time of last modification of a Web page?

Estimating the Freshness of a Page

1. Check HTTP timestamp.
2. Check content timestamp.
3. Compare a hash of the page with a stored hash.
4. Non-significant differences (ads, fortunes, request timestamp):
   - only hash text content, or “useful” text content;
   - compare distribution of *n*-grams (shingling);
   - or even compute edit distance with previous version.

Adapting strategy to each different archived website?

Plan

Plan

Crawling Modern Web Sites

- Some modern Web sites only work when cookies are activated (session cookies), or when JavaScript code is interpreted
- Regular Web crawlers (wget, Heritrix, Apache Nutch) do not usually perform any cookie management and do not interpret JavaScript code
- Crawling of some Websites therefore require more advanced tools

Advanced crawling tools

Web scraping frameworks such as scrapy (Python) or WWW::Mechanize (Perl) simulate a Web browser interaction and cookie management (but no JS interpretation)

Headless browsers such as htmlunit simulate a Web browser, including simple JavaScript processing

Browser instrumentors such as Selenium allow full instrumentation of a regular Web browser (Chrome, Firefox, Internet Explorer)

OXPath: a full-fledged navigation and extraction language for complex Web sites [Sellers et al., 2011]

Plan

Most popular Web sites

1	google.com
2	facebook.com
3	youtube.com
4	yahoo.com
5	baidu.com
6	wikipedia.org
7	live.com
8	twitter.com
9	qq.com
10	amazon.com
11	blogspot.com
12	linkedin.com
13	google.co.in
14	taobao.com
15	sina.com.cn
16	yahoo.co.jp
17	msn.com
18	wordpress.com
19	google.com.hk
20	t.co
21	google.de
22	ebay.com
23	google.co.jp
24	googleusercontent.com
25	google.co.uk
26	yandex.ru
27	163.com
28	weibo.com

(Alexa)

Most popular Web sites

1	google.com
2	facebook.com
3	youtube.com
4	yahoo.com
5	baidu.com
6	wikipedia.org
7	live.com
8	twitter.com
9	qq.com
10	amazon.com
11	blogspot.com
12	linkedin.com
13	google.co.in
14	taobao.com
15	sina.com.cn
16	yahoo.co.jp
17	msn.com
18	wordpress.com
19	google.com.hk
20	t.co
21	google.de
22	ebay.com
23	google.co.jp
24	googleusercontent.com
25	google.co.uk
26	yandex.ru
27	163.com
28	weibo.com

(Alexa)

Social networking sites

Most popular Web sites

1	google.com
2	facebook.com
3	youtube.com
4	yahoo.com
5	baidu.com
6	wikipedia.org
7	live.com
8	twitter.com
9	qq.com
10	amazon.com
11	blogspot.com
12	linkedin.com
13	google.co.in
14	taobao.com
15	sina.com.cn
16	yahoo.co.jp
17	msn.com
18	wordpress.com
19	google.com.hk
20	t.co
21	google.de
22	ebay.com
23	google.co.jp
24	googleusercontent.com
25	google.co.uk
26	yandex.ru
27	163.com
28	weibo.com

(Alexa)

Social networking sites

Sites with social networking features (friends, user-shared content, user profiles, etc.)

Social data on the Web

Huge numbers of users (2012):

Facebook	900 million
QQ	540 million
W. Live	330 million
Weibo	310 million
Google+	170 million
Twitter	140 million
LinkedIn	100 million

Social data on the Web

Huge numbers of users (2012):

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Twitter	140 million
LinkedIn	100 million

Huge volume of shared data:

250 million tweets per day on Twitter (3,000 per second on average!)...

... including statements by heads of states, revelations of political activists, etc.

Crawling Social Networks

- Theoretically possible to crawl social networking sites using a regular Web crawler
- Sometimes not possible:
  `https://www.facebook.com/robots.txt`
- Often very inefficient, considering politeness constraints
- Better solution: Use provided social networking APIs
  `https://dev.twitter.com/docs/api/1.1`
  `https://developers.facebook.com/docs/graph-api/reference/v2.1/`
  `https://developer.linkedin.com/apis`
  `https://developers.google.com/youtube/v3/`
- Also possible to buy access to the data, directly from the social network or from brokers such as `http://gnip.com/`

Social Networking APIs

- Most social networking Web sites (and some other kinds of Web sites) provide APIs to effectively access their content
- Usually a RESTful API, occasionally SOAP-baed
- Usually require a token identifying the application using the API, sometimes a cryptographic signature as well
- May access the API as an authenticated user of the social network, or as an external party
- APIs seriously limit the rate of requests:
  `https://dev.twitter.com/docs/api/1.1/get/search/tweets`

REST

- Mode of interaction with a Web service
- Follow the KISS (Keep it Simple, Stupid) principle
- Each request to the service is a simple HTTP GET method
- Base URL is the URL of the service
- Parameters of the service are sent as HTTP parameters (in the URL)
- HTTP response code indicates success or failure
- Response contains structured output, usually as JSON or XML
- No side effect, each request independent of previous ones

The Case of Twitter

- Two main APIs:
  - REST APIs, including search, getting information about a user, a list, followers, etc. `https://dev.twitter.com/docs/api/1.1`
  - Streaming API, providing real-time result
- Very limited history available
- Search can be on keywords, language, geolocation (for a small portion of tweets)

Cross-Network Crawling

- Often useful to combine results from different social networks
- Numerous libraries facilitating SN API accesses (twipy, Facebook4J, FourSquare VP C++ API...) incompatible with each other... Some efforts at generic APIs (OneAll, APIBlender [Gouriten and Senellart, 2012])
- Example use case: No API to get all check-ins from FourSquare, but a number of check-ins are available on Twitter; given results of Twitter Search/Streaming, use FourSquare API to get information about check-in locations.

Plan

Conclusion

What you should remember

- Crawling as a graph-browsing problem.
- Shingling for identifying duplicates.
- Numerous engineering issues in building a Web-scale crawler.
- Crawling modern Web content is not as easy as launching a traditional Web crawler
- Often critical to focus the crawl towards content of interest
- Ideally: a traditional large-scale crawler that knows when to delegate to more specialized crawling mechanisms (tools querying social networking APIs, deep Web crawlers, JS-aware crawlers, etc.)
- Huge variety of tools, techniques, suitable for different needs

References

Software

- Wget, a simple yet effective Web spider (free software)
- Heritrix, a Web-scale highly configurable Web crawler, used by the Internet Archive (free software)
- HTML Parser, TagSoup: Java libraries for parsing real-world Web pages

To go further

- A good textbook [Chakrabarti, 2003]
- Main references:
  - HTML 4.01 recommendation [W3C, 1999]
  - HTTP/1.1 RFC [IETF, 1999]

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