Data wrangling, data quality

Web content acquisition and extraction

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ÉCOLE NORMALE SUPÉRIEURE | PSL

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Outline

Crawling the Web
- Discovering new URLs
- Identifying duplicates
- Crawling architecture

Crawling complex content

Structured Web content extraction

Conclusion

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 (cf. next slide)
  4. Repeat on each found URL
- No real termination condition (virtual unlimited number of Web pages!)
- Graph-browsing problem

  deep-first: not very adapted, possibility of being lost in robot traps

  breadth-first

  combination of both: breadth-first with limited-depth deep-first on each discovered website

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
- Referrer URLs
- 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, Gouriten et al., 2014] 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]

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 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 $S_k = \{s_{k1} \ldots s_{kn}\}$, 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)

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

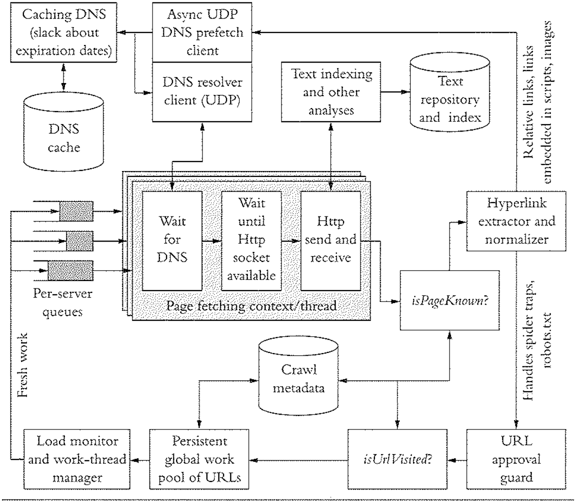
- robots.txt files are a de facto standard, and instructions in robots.txt files a receivable way to specify what can be crawled (Cour d'appel de Paris, 26 January 2011, Google vs SAIF)
- Frequent requests to a Web site can be considered as a way to disrupt the functioning of a "system for automated 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 (GDPR): personal data should be collected for a specific purpose, kept updated, and protected

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
- Use of keep-alive to reduce connexion overheads

General Architecture [Chakrabarti, 2003]



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

Importance of Timely Crawling

- The Web is very volatile, with a typical half-life of URLs of a few years [Koehler, 2003]
- For many purposes (archiving, analytics), a crawl quality can be measured by its temporal coherence [Spaniol et al., 2009]
- Ideally, Web pages pointed to by a Web page should be crawled at the same time. Unrealistic in practice.
- Crawling takes time and consumes resources:
  - Limited bandwidth, limiting computing power on the crawling side
  - Because of crawling ethics, crawling a 5 million page site takes around 2 months!
  - Limitations of social networking APIs drastic: on Twitter, using the Search API, at most 3 000 tweets per minute; other APIs exists, but they also have severe limitations;

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Outline

Crawling the Web

Crawling complex content
- Modern Web Sites
- CMS-based Web Content
- Social Networking Sites
- The Deep Web

Structured Web content extraction

Conclusion

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)

Proxys such as mitmproxy capable of recording and replaying a complex set of HTTP requests

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

Templated Web Site

- Many Web sites (especially, Web forums, blogs) use one of a few content management systems (CMS)
- Web sites that use the same CMS will be similarly structured, present a similar layout, etc.
- Information is somewhat structured in CMSs: publication date, author, tags, forums, threads, etc.
- Some structure differences may exist when Web sites use different versions, or different themes, of a CMS

Crawling CMS-Based Web Sites

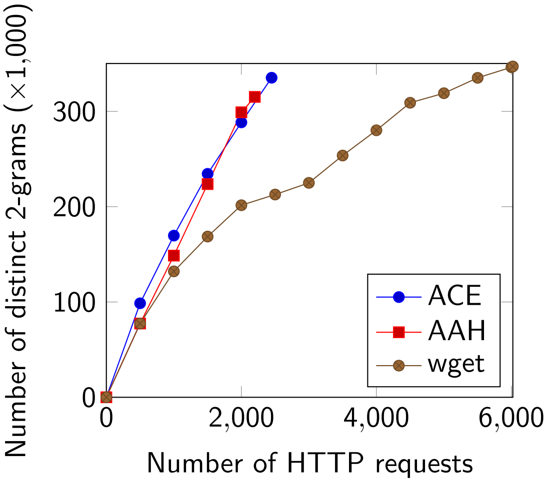
- Traditional crawling approaches crawl Web sites independently of the nature of the sites and of their CMS
- When the CMS is known:
  - Potential for much more efficient crawling strategies (avoid pages with redundant information, uninformative pages, etc.)
  - Potential for automatic extraction of structured content
- Two ways of approaching the problem:
  - Have a handcrafted knowledge base of known CMSs, their characteristics, how to crawl and extract information [Faheem and Senellart, 2013b,a] (AAH)
  - Automatically infer the best way to crawl a given CMS [Faheem and Senellart, 2014] (ACE)
- Need to be robust w.r.t. template change

Detecting CMSs

- One main challenge in intelligent crawling and content extraction is to identify the CMS and then perform the best crawling strategy accordingly
- Detecting CMS using:
  1. URL patterns,
  2. HTTP metadata,
  3. textual content,
  4. XPath patterns, etc.
- These can be manually described (AAH), or automatically inferred (ACE)
- For instance the vBulletin Web forum content management system, that can be identified by searching for a reference to a `vbulletin_global.js` JavaScript script by using a simple `//script/@src` XPath expression.

Crawling http://www.rockamring-blog.de/

[Faheem and Senellart, 2014]



Social data on the Web

Huge numbers of active users of social networking sites (2020):

Facebook	2.7 billion
YouTube	2.0 billion
TikTok+DouYin	1.3 billion
WeChat	1.2 billion
Instagram	1.2 billion
Weibo	520 million
QZone	520 million
Reddit	430 million
Kuaishou	430 million
Pinterest	416 million
Twitter	350 million

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Huge volume of shared data:

500 million tweets per day on Twitter (6,000 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
- May be impossible: https://www.facebook.com/robots.txt
- Often very inefficient, considering politeness constraints
- Better solution: Use provided social networking APIs
  https://developer.twitter.com/en/docs/api-reference-index
  https://developers.facebook.com/docs/graph-api/reference/
  https://docs.microsoft.com/en-us/linkedin/
  https://developers.google.com/youtube/
- Also possible to buy access to the data, directly from the social network or from brokers. See, e.g., https://developer.twitter.com/en/products/twitter-api/enterprise

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://developer.twitter.com/en/docs/twitter-api/rate-limits`

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

- Different features accessible through a REST API:
  - searching tweets, getting information about a user, a list, followers, etc.
  - access to a filtered stream of results in real-time `https://developer.twitter.com/en/docs/twitter-api/tweets/filtered-stream/api-reference`
- Very limited history available using regular search features (one week) unless one pays for enterprise access or qualify for academic research access
- Search can be on keywords, language, geolocation, etc.

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.

The Deep Web

Definition (Deep Web, Hidden Web, Invisible Web)

All the content on the Web that is not directly accessible through hyperlinks. In particular: HTML forms, Web services.

Size estimate: 500 times more content than on the surface Web! [BrightPlanet, 2000]. Hundreds of thousands of deep Web databases [Chang et al., 2004]

Sources of the Deep Web

Example

- *Yellow Pages* and other directories;
- Library catalogs;
- Weather services;
- US Census Bureau data;
- etc.

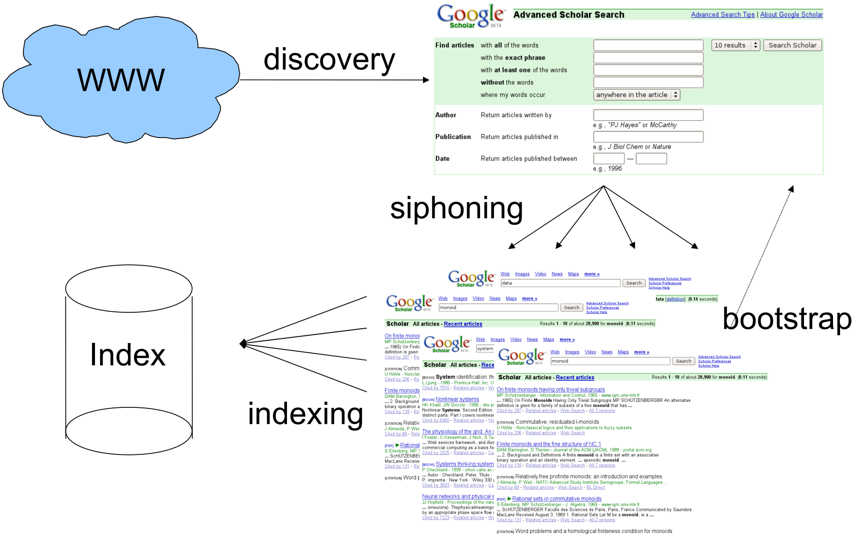
Discovering knowledge from the deep Web

[Nayak et al., 2012]

- Content of the deep Web hidden to classical Web search engines (they just follow links)
- But very valuable and high quality!
- Even services allowing access through the surface Web (e.g., e-commerce) have more semantics when accessed from the deep Web
- How to benefit from this information?
- How to analyze, extract and model this information?

Focus here: Automatic, unsupervised, methods, for a given domain of interest

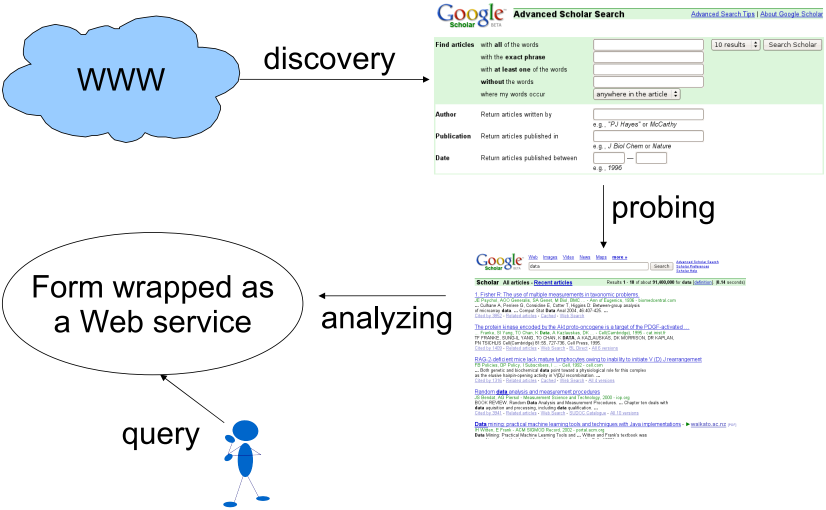
Extensional Approach



Notes on the Extensional Approach

- Main issues:
  - Discovering services
  - Choosing appropriate data to submit forms
  - Use of data found in result pages to bootstrap the siphoning process
  - Ensure good coverage of the database
- Approach favored by Google, used in production [Madhavan et al., 2006]
- Not always feasible (huge load on Web servers)

Intensional Approach



Notes on the Intensional Approach

- More ambitious [Chang et al., 2005, Senellart et al., 2008]
- Main issues:
  - Discovering services
  - Understanding the structure and semantics of a form
  - Understanding the structure and semantics of result pages
  - Semantic analysis of the service as a whole
  - Query rewriting using the services
- No significant load imposed on Web servers

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Languages for extraction

- Based on serialization: regular expressions
- Based on DOM:

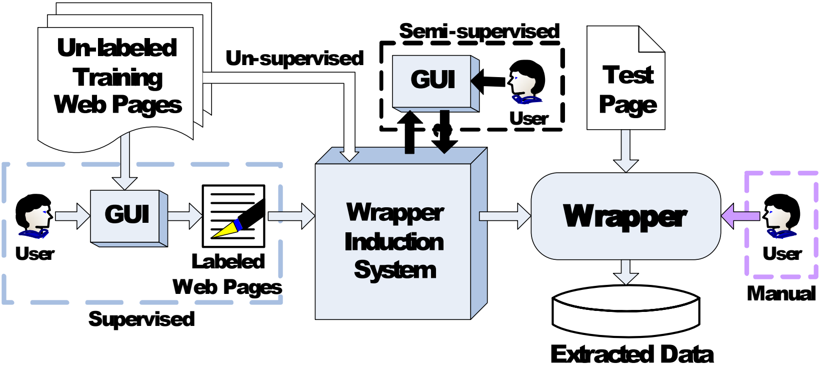
DOM navigation
: expresses local navigation in the DOM, from a node to its parent, its children, its attribute, etc. Standard API [WHATWG, 2021] but variations.

searching elements
: by tag names, identifiers, names, class names

CSS selectors

XPath

Wrapper induction [Chang et al., 2006]



Supervised, semi-supervised, and domain-based techniques

- Many academic approaches and systems
- No ready-to-use free software for supervised and semi-supervised extraction (as far as I know)

Unsupervised techniques

- Exploiting data redundance within a page [Liu et al., 2004] or across pages [Crescenzi et al., 2001, Arasu and Garcia-Molina, 2003]
- RoadRunner: freely downloadable and existing demos at `http://www.dia.uniroma3.it/db/roadRunner/`

Outline

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

Free software

wget simple yet effective Web spider

Heritrix Web-scale highly configurable Web crawler, used by the Internet Archive

Beautiful Soup Python module for parsing real-world Web pages

Scrapy rich Python module for Web crawling and content extraction

Selenium browser instrumentor, with API in several languages

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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