Basics of the Web and Web Crawling

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Outline

Internet and the Web

Internet: physical network of computers (or hosts)

World Wide Web, Web, WWW: logical collection of hyperlinked documents

- static and dynamic
- public Web and private Webs
- each document (or Web page, or resource) identified by a URL
- the largest collection of information every built, most readily accessible!

The Internet protocol stack

A stack of communication protocols, on top of each other.

Application	HTTP, FTP, SMTP, DNS	
Security	SSL/TLS	(encryption, authentication)
Transport	TCP, UDP, ICMP	(sessions, reliability...)
Network	IP (v4, v6)	(routing, addressing)
Link	Ethernet, 802.11 (ARP)	(addressing local machines)
Physical	Ethernet, 802.11 (physical)	

IP (Internet Protocol) [IETF, 1981a]

- Addressing machines and routing over the Internet
- Two versions of the IP protocol on the Internet: IPv4 (very well spread) and IPv6 (not that well-spread yet)
- IPv4: 4-byte addresses assigned to each computer, e.g., 137.194.2.24. Institutions are given ranges of such addresses, to assign as they will.
- Problem: only 2^{32} possible addresses (actually, a large number of them cannot be assigned to new hosts, for multiple reasons). This means many hosts connected to the Internet do not have an IPv4 address and some network address translation (NAT) occurs.
- IPv6: 16-byte addresses; much larger address space! Addresses look like 2001:660:330f:2::18 (meaning 2001:0660:0330f:0002:0000:0000:0000:0018). Other nice features (multicast, autoconfiguration, etc.).

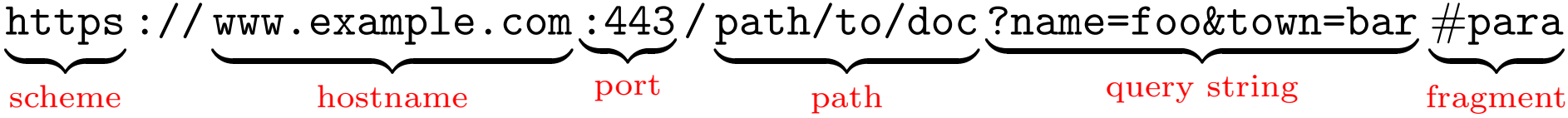
TCP (Transmission Control Protocol) [IETF, 1981b]

- One of the two main transport protocols used on IP, with UDP (User Datagram Protocol)
- Contrarily to UDP, provides reliable transmission of data (acknowledgments)
- Data is divided into small datagrams that are sent over the network, and possibly reordered at the end point
- Like UDP, each TCP transmission indicates a source and a destination port number (between 0 and 65535) to distinguish it from other traffic
- A client usually select a random port number for establishing a connection to a fixed port number on a server
- The port number on a server conventionally identifies an application protocol on top of TCP/IP: 22 for SSH, 25 for SMTP, 110 for POP3...

DNS (Domain Name System) [IETF, 1999a]

- IPv4 addresses are hard to memorize, and a given service (e.g., a Web site) may change IP addresses (e.g., new Internet service provider)
- Even more so for IPv6 addresses!
- DNS: a UDP/IP-based protocol for associating human-friendly names (e.g., `www.google.com`, `weather.yahoo.com`) to IP addresses
- Hierarchical domain names: `com` is a top-level domain (TLD), `yahoo.com` is a subdomain thereof, etc.
- Hierarchical domain name resolution: root servers with fixed IPs know who is in charge of TLDs, servers in charge of a domain know who is in charge of a subdomain, etc.
- Nothing magic with `www.google.com`: just a subdomain of `google.com`.

URL (Uniform Resource Locator) [IETF, 1994]



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

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

port: TCP port; defaults: 80 for `http` and 443 for `https`

path: logical path of the document

query string: optional additional parameters (dynamic documents)

fragment: optional subpart of the document

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`

The Web: a mixture of technologies

- For content: HTML, but also PDF, Word documents, text files, JSON documents, XML (RSS, SVG, MathML, etc.)...
- For presenting this content: CSS, XSLT
- For animating this content: JavaScript, AJAX, JavaScript libraries (React, Vue.js, etc.)...
- For interaction-rich content: <canvas>, WebGL...
- And on the server side: a Web server program (Apache, nginx, Tomcat, IIS, Node.js, etc.), any programming language and database technology to serve this content, e.g., PHP, Java servlets, Scala, Python, JavaScript, etc. with associated Web programming frameworks

Quite complex to manage! Being a Web developer nowadays requires mastering many different technologies. Exploiting Web content may require being able to handle many different technologies!

Outline

HTML (HyperText Markup Language) [W3C, 2014]

- normalized by the W3C (World Wide Web Consortium) formed of industrials (Microsoft, Google, Apple...) and academic institutions (ERCIM, MIT, etc.) in concert with another group of industrials, the WHATWG group (Apple, Mozilla, Google, Microsoft) representing Web browsers
- open format: possible processing by a wide variety of software and hardware
- text files with tags
- describes the structure and content of a document, focus on accessibility
- (theoretically) no presentation information (this is the role of CSS)
- no description of dynamic behaviors (this is the role of server-side languages, JavaScript, etc.)

The HTML language

- HTML is a language alternating text and tags (<blabla> or </blabla>)
  - Tags allow structuring each part of a document, and are used for instance by a browser to lay out the document.
- HTML files
  - are structured in two main parts: the header <head> ... </head>) and the body <body> ... </body>)
- In HTML, blanks (spaces, tabs, carriage returns) are generally equivalent and only serve to delimit words, tags, etc. The number of blanks does not matter.

Tags

- Syntax: (opening and closing tag)

  `<tag attributes>`*content*`</tag>`

  or (element with no content)

  `<tag attributes>`

tag	keyword referring to some particular HTML element
content	may contain text and other tags
attributes	represent the various parameters associated with the element, as a list of `name="value"` or `name='value'`, separated by spaces (quotes are not always mandatory, but they become mandatory if `value` has "exotic" characters)

Tags

- Names of elements and attributes are usually written in lowercase, but <head> and <HeAd> are equivalent.
- Tags are opened and closed in the right order (and not).
- Strict rules specify which tags can be used inside which.
- Under some conditions, a tag can be implicitly closed, but these conditions are complex to describe.
- <!--foobar--> denotes a comment, which is not to be interpreted by a Web client.

Structure of a document

```
<!DOCTYPE html>
<html lang="en">
<head>
<!-- Header of the document -->
</head>
<body>
<!-- Body of the document -->
</body>
</html>
```

- The doctype declaration `<!DOCTYPE ...>` specify which HTML version is used, here HTML5.
- The language of the document is specified with the lang attribute of the main `<html>` tag.

Header

- The header of a document is delimited by the tags `<head> ... </head>`.
- The header contains meta-informations about the document, such as its title, encoding, associated CSS and JavaScript files, etc. The two most important items are:
  - The character set of the page, usually at the very beginning of the header

    ```
    <meta charset="utf-8">
    ```
  - The title of the page (the only required item inside the header). This is the information displayed in the title bar of Web browsers.

    ```
    <title>My great website</title>
    ```

Character sets

Unicode: character repertoire, assigning to each character, whatever its script or language, an integer number.

Examples

A	$\rightarrow$	65	ε	$\rightarrow$	949
é	$\rightarrow$	233	$\aleph$	$\rightarrow$	1488

Character set: concrete method for representing a Unicode character.

Examples (é)

iso-8859-1	11101001	only for some characters
utf-8	11000011 10101001	
utf-16	11101001 00000000	

utf-8 has the advantage of being able to represent all Unicode characters, in a way compatible with the legacy ASCII encoding.

The body of a HTML document

- <body> ... </body> tags delimit the body of a document.
- The body is structured into sections, paragraphs, lists, etc.
- 6 tags describe sections, by decreasing order of importance:
  - <h1>Title of the page</h1>
  - <h2>Title of a main section</h2>
  - <h3>Title of a subsection</h3>
  - <h3>Title of a subsubsection</h3>
  - ...
- ... tags delimit paragraphs of text. All text paragraphs should be delimited thusly.
- Directly inside <body> ... </body> can only appear block elements: , <h1>, <form>, <hr>, <ul>, <table>... in addition to the tag which denotes a block without precise semantics.

Links

- What differetiates Web pages (hypertext pages) from normal documents: links!
- Introduced with `<a> ... </a>`
- Navigating a link can bring to:
  - a resource on another server or another file of the same server
  - another part of the same document

Links

Links are made using the href attribute of the <a> tag, whose content will be the link:

```
<a href="http://www.cnrs.fr/">
<img src="images/cnrs.gif" alt="CNRS">
</a>

<a href="bio/indexbioinfo.html">Bioinformatics</a>
```

Anchors

- Anchors serve to reach a precise point in the document.
  - They are defined, either on an existing tag by using the id attribute, or with an <a id="..."> :

    ```
    <h3 id="tutorials">Tutorials</h3>
    <a id="tutorials">
    ```

  - Then, one can link to this anchor:

    ```
    <a href="#tutorials">tutorials</a>
    <a href="http://www.w3.org/#tutorials">tutorials</a>
    ```

  - Commonly, the old <a name="..."> syntax is used.

The different versions of HTML

- HTML5 (2014 and onwards): "living" standard, continuously updated
- HTML 4.01 (1999): historically the main standard before HTML5 arose
- XHTML (2000): an attempt of XML-ifying HTML, making it stricter, mostly a failure (though HTML5 also now has valid XML syntax variant)
- XHTML 1.1 and XHTML 2.0: complete failures, unusable and unused

Tag soup

- Quite a few HTML documents on the Web date back from before HTML 4.01!
- In practice: many Web pages do not respect any standards at all (with or without doctype declarations) $\Longrightarrow$ browsers do not respect these standards $\Longrightarrow$ tag soup!
- When dealing with pages from the real Web, necessary to use all sorts of heuristics to interpret a Web page.

HTML vs XHTML

- XHTML: an XML format
- Tags without content <img>, are written <img /> in XHTML.
- Some elements can be left unclosed in HTML (<ol> one <li> two), but closing is mandatory in XHTML.
- Attribute values can be written without quotes (<img src=toto.png alt=toto>) in HTML, quotes are required in XHTML.
- Element and attribute names are not case-sensitive in HTML (<HTMl laNg=fr>), but are in XHTML (everything must be in lowercase).
- Attributes xmlns and xml:lang on the <html> tag in XHTML.
- And some other small subtleties...

Outline

HTTP (HyperText Transfer Protocol) [IETF, 1999b]

- Application protocol at the basis of the World Wide Web
- Diverse versions on the Web: HTTP/1.1, HTTP/2, HTTP/3; HTTP/1.1 uses plain text, HTTP/2 and HTTP/3 (based on UDP and not TCP) use binary

- Client request:

```
GET /MarkUp/ HTTP/1.1
Host: www.w3.org
```

- Server response:

```
HTTP/1.1 200 OK
...
Content-Type: text/html; charset=utf-8

<!DOCTYPE html ...> ...
```

- Two main HTTP methods: GET and POST (HEAD is also used in place of GET, to retrieve meta-information only).
- Additional headers, in the request and the response
- Possible to send parameters in the request (key/value pairs).

GET

- Simplest type of request.
- Possible parameter are sent at the end of a URL, after a '?'
- Not applicable when there are too many parameters, or when their values are too long.
- Method used when a URL is directly accessed in a browser, when a link is followed, and for some forms.

Example (Google query)

URL: `http://www.google.com/search?q=hello`

Corresponding HTTP GET request:

```
GET /search?q=hello HTTP/1.1
Host: www.google.com
```

POST

- Method mostly used when submitting large amount of content, or when the request has a side effect, through forms or JavaScript

Example

```
POST /php/test.php HTTP/1.1
Host: www.w3.org
Content-Type: application/x-www-form-urlencoded
Content-Length: 100

type=search&title=The+Dictator&format=long&country=US
```

Parameter encoding

- By default, parameters are sent (with GET or POST) in the form: `name1=value1&name2=value2`, and special characters (accented characters, spaces...) are replaced by codes such as +, %20. This way of sending parameters is called `application/x-www-form-urlencoded`.
- For the POST method, another heavier encoding can be used (several lines per parameter), similar to the way emails are built: mostly useful for sending large quantity of information. Encoding named `multipart/form-data`.

Status codes

- The HTTP response always starts with a status code with three digits, followed by a human-readable message (e.g., 200 OK).
- The first digit indicates the class of the response:
  1. Information
  2. Success
  3. Redirection
  4. Client-side error
  5. Server-side error

Most common status codes

200	OK
301	Permanent redirection
302	Temporary redirection
304	No modification
400	Invalid request
401	Unauthorized
403	Forbidden
404	Not found
500	Server error

Virtual hosts

- Different domain names can refer to the same IP address, i.e., the same physical machine (e.g., `www.google.fr` and `www.google.com`)
- When a machine is contacted by TCP/IP, it is through its IP address
- No *a priori* way to know which precise domain name to contact
- In order to serve different content according to the domain name (virtual host): header `Host:` in the request (only header really required)

Example

```
GET /search?hl=fr&q=hello HTTP/1.1
Host: www.google.fr
```

Content type

- The browser behaves differently depending on the content type returned: display a Web page with the layout engine, display an image, load an external application, etc.
- MIME classification of content types (e.g., `image/jpeg`, `text/plain`, `text/html`, `application/xhtml+xml`, `application/pdf` etc.)
- For a HTML page, or for text, the browser must also know what character set is used (this has precedence over the information contained in the document itself)
- Also returned: the content length (can be used to display a progress bar)

Example

```
HTTP/1.1 200 OK
Content-Type: text/html; charset=UTF-8
Content-Length: 3046
```

Client and server identification

- Web clients and servers can identify themselves with a character string
- Useful to serve different content to different browsers, detect robots...
- ... but any client can say it's any other client!
- Historical confusion on naming: all common browsers identify themselves as Mozilla!

Example

```
User-Agent: Mozilla/5.0 (X11; U; Linux x86_64; fr;
rv:1.9.0.3) Gecko/2008092510 Ubuntu/8.04 (hardy)
Firefox/3.0.3

Server: Apache/2.0.59 (Unix) mod_ssl/2.0.59 OpenSSL/0.9.8e
PHP/5.2.3
```

Content negotiation

- A Web client can specify to the Web server:
  - the content type it can process (text, images, multimedia content), with preferrence indicators
  - the languages preferred by the user
- The Web server can thus propose different file formats, in different languages.
- In practice, content negociation on the language works, and is used, but content negociation on file types does not work because of bad default configuration of some browsers.

Example

```
Accept: text/html,application/xhtml+xml,application/xml;
q=0.9,*/*;q=0.8
Accept-Language: fr,fr-fr;q=0.8,en-us;q=0.5,en;q=0.3
```

Cookies [IETF, 2000]

- Information, as key/value pairs, that a Web server asks a Web client to keep and retransmit with each HTTP request (for a given domain name).
- Can be used to keep information on a user as she is visiting a Web site, between visits, etc.: electronic cart, identifier, and so on.
- Practically speaking, most often only stores a session identifier, connected, on the server side, to all session information (connected or not, user name, data...)
- Simulates the notion of session, absent from HTTP itself

Example

```
Set-Cookie: session-token=RJYBsG//azkfZrRazQ3SPQhlo1FpkQka2;
path=/; domain=.amazon.de;
expires=Fri Oct 17 09:35:04 2008 GMT

Cookie: session-token=RJYBsG//azkfZrRazQ3SPQhlo1FpkQka2
```

Originating URL

- When a Web browser follows a link or submits a form, it transmits the originating URL to the destination Web server.
- Even if it is not on the same server!

Example

```
Referer: http://www.google.fr/
```

Outline

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]

Outline

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) – Principles

- 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

Legal aspects (France) – Case law

- 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")
- 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

Legal aspects (France) – Other aspects

- Web content is subject to intellectual property ("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
- EU AI Act (in force since August 2024) bans some data collection which causes *unacceptable risk* (e.g., social scoring) and adds some transparency requirements on AI applications built from collected data

Aside: Content Acquisition for LLMs

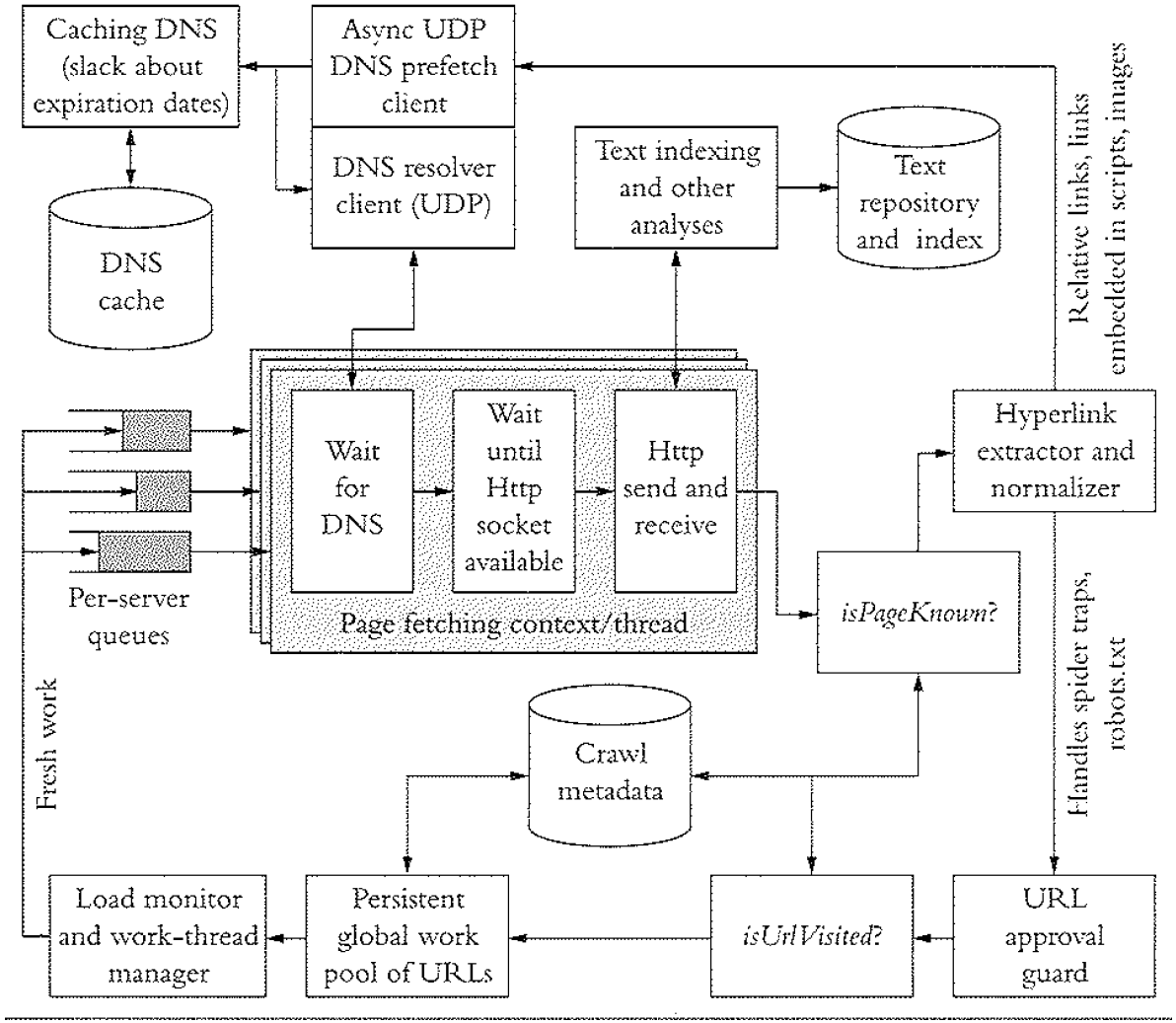
- LLMs (GPT, Llama Mistral, Gemini, etc.) are trained on a huge collection of textual documents
- Often given as # tokens read (e.g., 15 trillion for Llama 3.1)
- Exact dataset never disclosed, at best high-level description of what data sources were used and to which extent
- Usually: Web crawls (directly or using CommonCrawl), scientific publications (e.g., arXiv), Wikipedia, online community data dumps (e.g., Reddit, StackOverflow), other archives (e.g., Project Gutenberg's public domain literary works), potentially other non-public sources
- Raise the same issues w.r.t. crawling, intellectual property, and personal data protection
- These issues are mostly ignored by companies developing LLMs, but no legal guarantee
- EU AI Act imposes some (mild) requirements about describing of used data

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/X, using the *Recent search* endpoint, at most 3 000 tweets per minute; other endpoints exist, but they also have severe limitations;

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Outline

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:
  - HTML5 living standard [W3C, 2014]
  - HTTP/1.1 RFC [IETF, 1999b]

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