# Crawling for Temporal Information Retrieval

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2014-11-03

# Introduction

- Today: Only looking at Web IR
- Web IR: First step is collecting documents from the Web
  - no ‘predefined’ collection
- Typically through crawlers
- In this lecture: How does time affect the crawling process?

# Overview

1. Introduction

2. Short Introduction to Crawling

3. Crawling & Time

4. Re-Crawling

5. Temporally Coherent Crawling

# Web Crawling

- Standard method for collection of Web documents
- Using a program called (web) crawler
  - also: harvester, spider, robot
- Uses hyperlinks between documents for discovery
- Store collected documents for further processing (indexing, analysis, . . . )
- Further reading: Christopher Olston and Marc Najork. "Web Crawling". In: *Foundations and Trends in Information Retrieval* 4.3 (2010), pp. 175–246. DOI: 10.1561/1500000017

# Web Crawling Algorithm

## Basic Web Crawling Algorithm

```
WHILE not done
    Get URL to fetch from queue
    Fetch URL
    Parse retrieved document
    Add new URLs from document to queue
    Store document
```

# Additional considerations

**Politeness** Only download one documents every *n* seconds (typically 5-10s) to avoid overloading servers or being blocked

**robots.txt** Obey instructions from Web sites to crawlers

**Parallel crawling** Crawler typically waits for remote servers or network, run in parallel to ensure high throughput (typically 100s of parallel threads)

**Robustness**

- Against malformed input (at every layer: network, TCP/IP, HTTP, content)
- Against spider traps (Web sites that generate infinitely many pages)
- Against spam

**Quality** Resulting collection should have good documents. Criteria are e.g. Relevance, Freshness, Diversity, . . .

# Special Considerations for Time

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- Changing content of already crawled pages
- Appearance / disappearance of pages
- Appearance / disappearance of links between pages
- Users of IR system change interests

# Content changes

- Individual pages change their content often
  - More than 40% change at least daily [CG00]
- But: No overall pattern, change occurs at different frequencies & time scales (seconds to years)

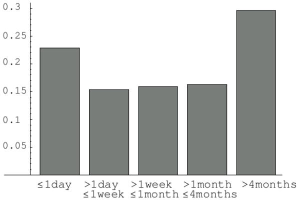


**Figure:** Change rate of Web pages

- Frequency can be modelled as a Poisson process: With

$X(t))$ number of occurrence of a change in $(0, t]$
$\lambda$ change rate

$$Pr\{X(s+t) - X(t) = k\} = \frac{(\lambda t)^k}{k!} e^{-\lambda t}$$

for $k = 0, 1, ...$

# Change types [OP08]

Temporal behavior of page (regions) can be classified as

**static** no changes

**churn** new content supplants old content, e.g., quote of the day

**scroll** new content is appended to old content, e.g., blog entries

# The Web changes [NCO04; Das+07]

- New pages are created at a rate of 8% per week
- During one year 80% of pages disappear
- New links are created at the rate of 25% per week
  - significantly faster than the rate of new page creation
- Links are retired at about the same pace as pages

# Users change

- User interests change
- Goals of IR system maintainer change
- → requires adaptation of crawl strategy

# Re-Crawling Strategies

Crawlers need to balance different considerations:

**Coverage** fetch new pages

**Freshness** find updates of existing pages

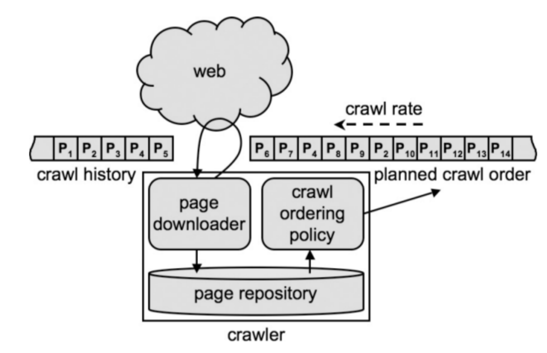


**Figure:** Crawl ordering model [ON10]

# Basic strategies

## Batch crawling

- Stop and restart crawl process periodically
- Each document is only crawled one time per crawl

## Incremental crawling

- Crawling is run continuously
- A document can be crawled multiple times during a crawl
- Crawl frequency can differ between different sites

Batch crawling is easier to implement, incremental more powerful.

# Batch Crawling Strategies

- Goal is to maximize Weighted Coverage:

$$WC(t) = \sum_{p \in C(t)} w(p),$$

with

| | |
|---|---|
| $t$ | time since start of crawl |
| $C(t)$ | pages crawled until time $t$ |
| $w(p)$ | weight of page $p$, $(0 \leq p \leq 1)$ |

- Main strategy types (ordered by complexity):
  - Breadth-first search
  - Order by in-degree
  - Order by PageRank

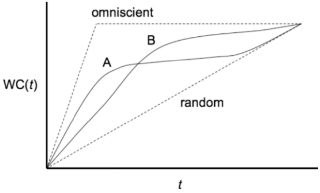


**Figure:** Weighted coverage as a function of time $t$

# Incremental Crawling Strategies

- Goal is to maximize Weighted Freshness:

$$WF(t) = \sum_{p \in C(t)} w(p) \times f(p, t),$$

  with $f(p, t)$: freshness level of page $p$ at time $t$

- Steady state average of WF:

$$\overline{WF} = \lim_{t \to \infty} \frac{1}{t} \int_{o}^{t} WF(t) dt$$

- Trade-off between coverage and freshness: Often treated as a business decision, needs to be tuned towards goals of specific application

# Maximizing Freshness [CG03]

**Model estimation** create a temporal model for each page $p$

**Resource allocation** Given a maximum crawl rate $r$, decide on a revisitation frequency $r(p)$ for each page

**Scheduling** Produce a crawl order that implements the targeted revisitation frequencies as close as possible

# Model estimation

- Create temporal model of temporal behavior of $p$
  - given samples of past content $p$ / pages similar to $p$
- Samples are often not be evenly-spaced
- Content can give hints about change frequency
  - HTTP headers, number of links, depth of page in site
- Similar pages have similar behavior
  - same site
  - similar content
  - similar link structure

# Resource allocation

## Binary Freshness model

$$f(p,t) = \begin{cases} 1 & \text{if old copy is equal to live copy} \\ 0 & \text{otherwise} \end{cases}$$

- Intuitively good strategy: proportional resource allocation
  - assign revisitation frequency proportional to change frequency
- But: uniform resource allocation achieves better average binary freshness
  - assuming equal page weights
- Reason:
  - Pages with high change frequency are stale very often regardless of crawl frequency (A)
  - Pages with lower change frequency can be kept fresh more easily (B)
  - Better to keep several pages of type B fresh than wasting resources on page of type A

# Resource allocation (continued)

## Continuous freshness model

$$age(p,t) = \begin{cases} 0 & \text{if old copy is equal to live copy} \\ a & \text{otherwise} \end{cases}$$

*a* is the amount of time between cached and live copy

- revisitation frequency increases with change frequency
  - *a* increases monotonically, crawler cannot “give up” on a page
- Instead of age, crawler can also consider content changes directly
  - distinguish between long-lived and ephemeral content

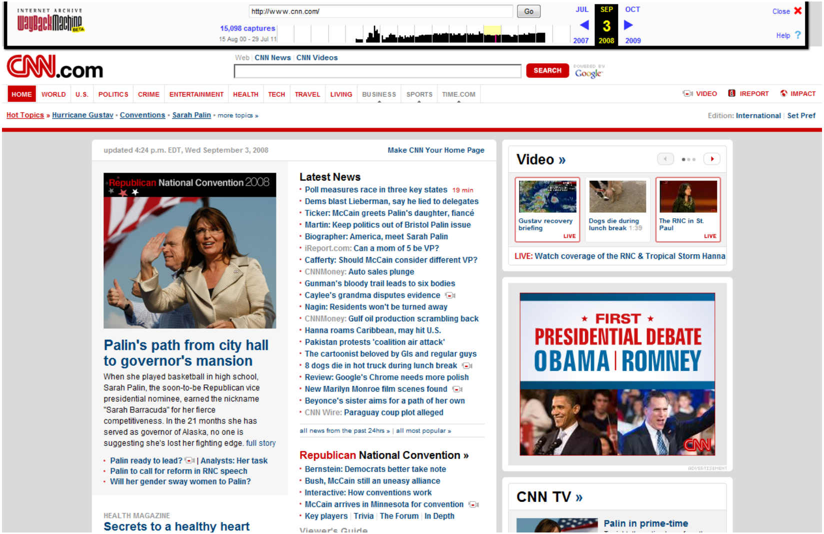
# Scheduling

Goal: Produce a crawl ordering that implements the targeted revisitation frequencies as close as possible

Uniform spacing of downloads of $p$ achieves best results.

# Temporal Coherence in Web Archives [Den+11]

- Web archives provide historical snapshots of Web pages
- Allow navigation in old versions of page
- However: Linked pages, images, scripts are crawled at different times
  - Pages show wrong images
  - Linked pages are from different points in time



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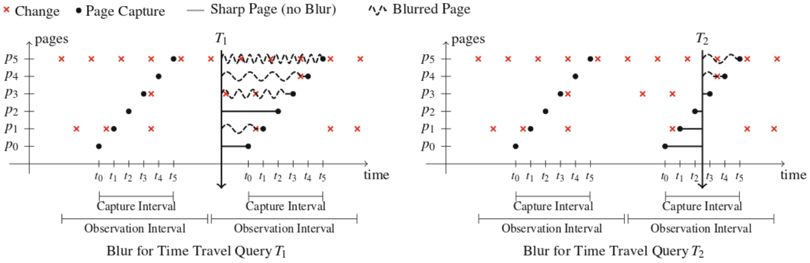
# Sharp and blurred pages



- Web Archive user accesses documents through *time-travel queries* for timepoints $T_1$ and $T_2$
- Archive is incomplete, usually retrieves documents that are temporally closest to queried time
  - *observation interval* is the time interval where a given page is returned for a query
- Retrieved pages differ from actual Web pages at that time

# Measuring Temporal Coherence

## Blur

- The blur of a Web page *pi* captured at $t_i$ is the expected number of changes between $t_i$ and query time $t$, averaged over observation interval $[0, \Delta n]$:

  $$B(p_i, t_i, n, \Delta) = \frac{1}{n\Delta} \int_0^{n\Delta} \lambda_i \cdot |t - t_i| dt = \frac{\lambda_i \omega(t_i, n, \Delta)}{n\Delta}$$

  where

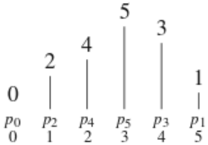
  $$\omega(t_i, n, \Delta) = t_i^2 - t_i n\Delta + \frac{(n\Delta)^2}{2}$$

  is the *download schedule penalty*.
- The blur of an Archive is the sum of the blur values of individual pages

$\omega(t_i, n, \Delta)$ can be interpreted as the penalty of downloading page $\mathrm{p_i}$ at time $\mathrm{t_i}$.

# Optimal crawl strategy

- Based on formalization of blur we can infer best crawl strategy
  - Depends on change frequency
  - Pages with highest frequency are scheduled in the middle of the crawl
  - "organ pipe" arrangement
  - Proof in paper
- Optimal strategy for known change frequencies
- Extension towards online algorithm possible



# Conclusion

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# Project

## Re-crawling strategies based on content

- Different page types have different temporal behaviors
  - Home page vs blog archive vs. news feed
- Categorize a given page into such a category
- Task: Implementation and evaluation on provided test set

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