COMMON CRAWL

Introduction to Web Graphs

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Webgraph – Basic Concepts

- The Webgraph or Hyperlink Graph
- Example Webgraph
- Aggregation Levels
- Aggregation Levels – Host and Domain
- Aggregation Levels – Top-Level Domain
- Related Types of Graphs

The WebGraph Framework

Webgraphs At Common Crawl

Centrality Ranks as Relevance Signal for Web Crawling

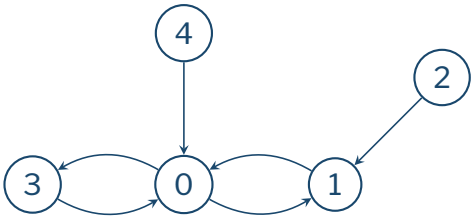
CCF Webgraph – Interactive Exploration

The Webgraph or Hyperlink Graph

- The webgraph describes the link structure between pages of the World Wide Web [1]
- Web pages correspond to the nodes (or “vertices”) of the graph
- The hyperlinks connecting the web pages are the edges (or “arcs”)
- The webgraph is a directed graph because hyperlinks are unidirectional
- Web pages are (usually) represented by URLs

Example Webgraph

A sample graph based on five Wikipedia pages:



0 https://en.wikipedia.org/wiki/Webgraph
1 https://en.wikipedia.org/wiki/PageRank
2 https://en.wikipedia.org/wiki/Popularity
3 https://en.wikipedia.org/wiki/World_Wide_Web
4 https://en.wikipedia.org/wiki/Citation_graph

Aggregation Levels

- web pages / URL
- host part of the URL
- pay-level domain, registered domain, one level below the registry suffix
- top-level domain (TLD): `org`, `uk`
- example 1: `https://en.wikipedia.org/wiki/Webgraph` page / URL
  `https://en.wikipedia.org/wiki/Webgraph` host
  `en.wikipedia.org` domain
  `wikipedia.org` TLD
- example 2: `https://libguides.ials.sas.ac.uk/az/uk-web-archive`
  `libguides.ials.sas.ac.uk`
  `libguides.ial.sas.ac.uk`

Aggregation Levels – Host and Domain

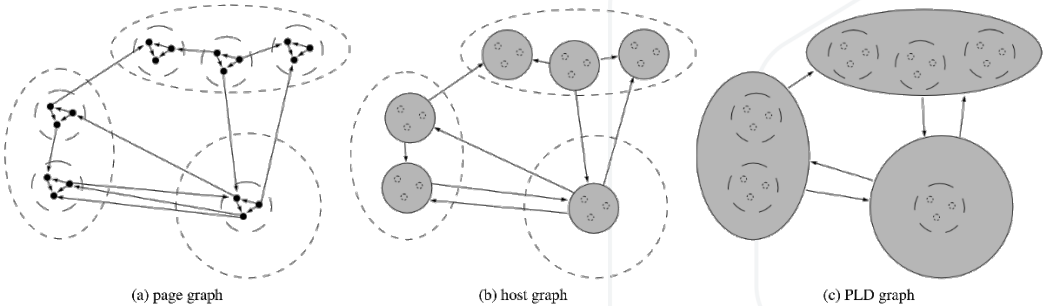
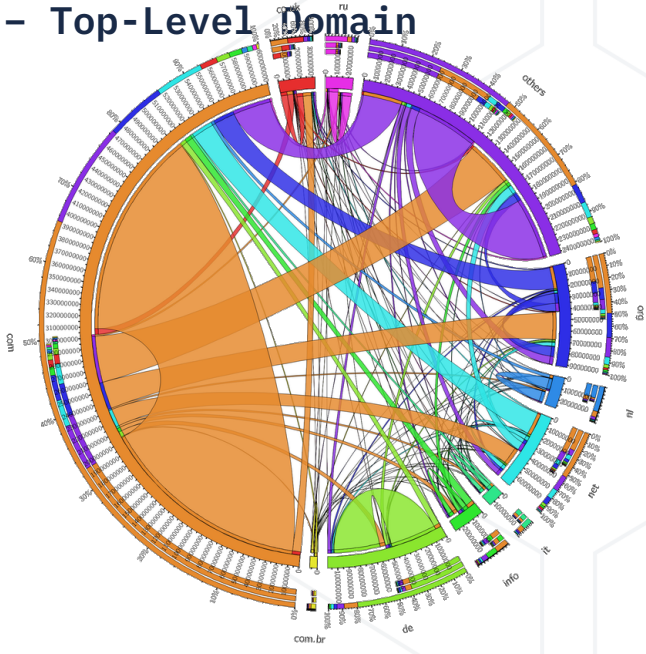


Figure 1: Page-level webgraph and aggregations on host and domain level [2]

Aggregation Levels – Top-Level Domain



Top-level domain graph [3]

Related Types of Graphs

- Citation graph
- Social network
  - Directed: Twitter, BlueSky, Mastodon, Instagram
  - Undirected: Facebook
- Software dependencies

The WebGraph Framework

- Paolo Boldi, Sebastiano Vigna, Laboratory of Web Algorithms (LAW), University of Milano
- Framework for graph compression [4] and graph algorithms
- Java, developed over 20 years
- (in progress) Reimplementation in Rust [5]

LAW Libraries

`WebGraph` – efficiently store (compress) and work with “immutable” graphs, includes “HyperBall” to compute Harmonic Centrality

`Sux4J` – map strings to integers

`fastutil` – type-specific Java collections (small memory footprint) including big arrays (more than 2 billion items)

`dsiutils` – various utils

`law` – includes classes to compute PageRank, but also utility classes for WARC and crawling

Overview WebGraph Classes

`BVGraph` – binary, compressed graph representation

- `basename.graph` – the graph itself
- `basename.properties` – text files with graph properties, including the class name
- `basename.offsets` – required for non-sequential access
- used as pair: graph and its “transpose” (inverted direction of arcs): `basename-t.*`

`ArcListASCIIGraph` – read/write textual graph representations

- nodes are integers from 0 to $n - 1$
- one line for every arc: ⟨source⟩ ⟨target⟩
- numerically sorted by source and target

BVGraph Intro

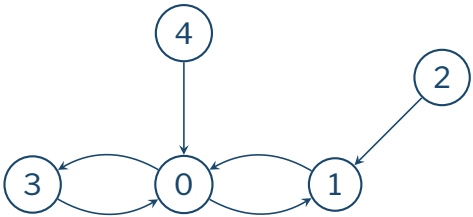
```
java it.unimi.dsi.webgraph.BVGraph -g ArcListASCIIGraph edges.txt exmpl

# Load exmpl.graph and convert it back to text (written to stdout)
java it.unimi.dsi.webgraph.ArcListASCIIGraph exmpl /dev/stdout

# Transpose of the graph
java it.unimi.dsi.webgraph.Transform transposeOffline exmpl exmpl-t

# Statistics
java it.unimi.dsi.webgraph.Stats --save-degrees exmpl
```

- instructions: `https://github.com/commoncrawl/wac2025-webgraph-workshop`
- working directory: `wac2025-webgraph-workshop/data/example-graph/`
- Java `CLASSPATH` set
- commands listed in process-example.sh)

The Wikipedia Graph – Interactive Session

```
$> jshell --class-path "$CC_WEBGRAPH_JAR"

jshell> import org.commoncrawl.webgraph.explore.GraphExplorer

jshell> GraphExplorer e = new GraphExplorer("enwiki-2024")

jshell> e.ls("Webgraph")
jshell> e.sl("Webgraph")

jshell> /exit

# A JShell script loading the graph before starting the interactive session:
$> jshell \
     --class-path "$CC_WEBGRAPH_JAR" \
     -R-Dgraph="enwiki-2024" \
     "$CC_WEBGRAPH"/src/script/webgraph_ranking/graph_explore_load_graph.jsh
```

Ranking Webgraphs – Harmonic Centrality



$$
\begin{aligned}
0: \quad & 3.5 = 3 + \tfrac{1}{2} \\
1: \quad & 3.0 = 2 + 2 \times \tfrac{1}{2} \\
2: \quad & 0 \\
3: \quad & 2.33 = 1 + 2 \times \tfrac{1}{2} + \tfrac{1}{3} \\
4: \quad & 0
\end{aligned}
$$

Ranking Webgraphs – PageRank

Paolo Boldi's explanation [8]:
https://youtu.be/cnGJtGP4gL4?t=2044

WebGraph Classes For Ranking

```
# PageRank
java it.unimi.dsi.law.rank.PageRankParallelGaussSeidel \
     --alpha .85 --threads 2 --mapped exmpl-t exmpl-pr
java it.unimi.dsi.law.io.tool.DataInput2Text --type double exmpl-pr.ranks

# Harmonic Centrality via HyperBall
java it.unimi.dsi.webgraph.algo.HyperBall --threads 2 --offline --log2m 12 \
     --harmonic-centrality exmpl-hc.bin exmpl-t exmpl
java it.unimi.dsi.law.io.tool.DataInput2Text --type float exmpl-hc.bin
```

Webgraphs Based on Common Crawl Data

2013—2015 Web Data Commons, University of Mannheim: hyperlink graphs and rankings [10, 11, 3, 2]

- Page/host/domain-level hyper-link graphs
- Host-level site ranking by harmonic centrality, pagerank, indegree centrality, Katz centrality [12]

2016 Common Search: host-level webgraph and pagerank [13, 14]

2017— "In-house" host/domain-level webgraph datasets by CCF [15, 16]

Why the WebGraph Framework?

- Proven to work for ranking the Web Data Commons hyperlink graphs
- Main goal of the CCF webgraphs: graph-based rankings as relevance signal for the web crawls
- Frank McSherry [17, 18]: “throwing more machines at a problem isn’t necessarily the best approach. A laptop can outperform clusters when used effectively.”
- Same experience while evaluation and comparing Spark’s GraphX and the WebGraph framework

Common Crawl Webgraph Datasets

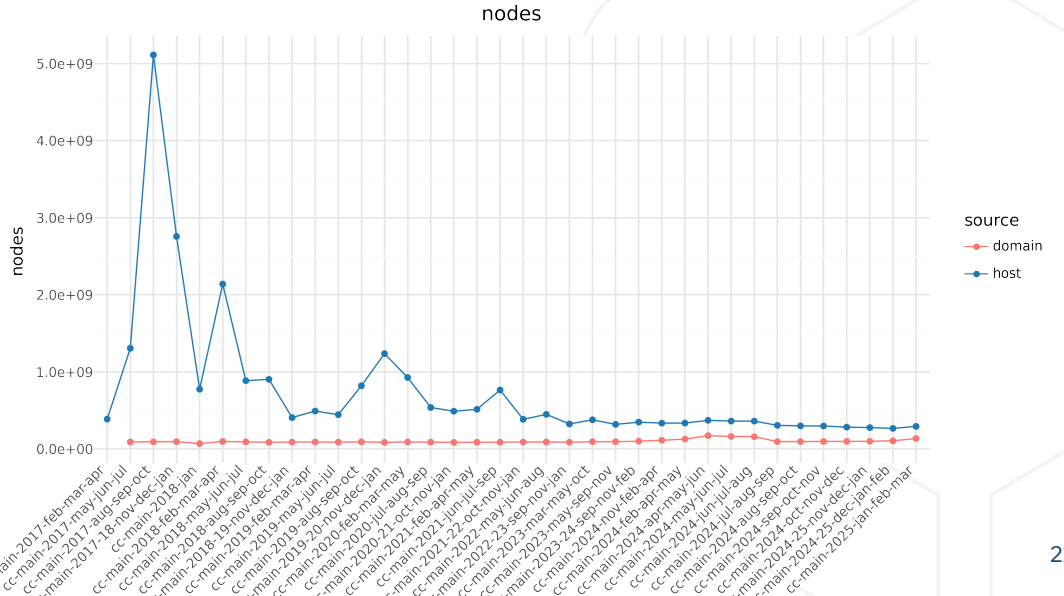
- One graph dataset combines three “monthly” crawl datasets
- Initially released quarterly
- Since monthly using a sliding window of the three latest crawls

- Only host and domain-level aggregations

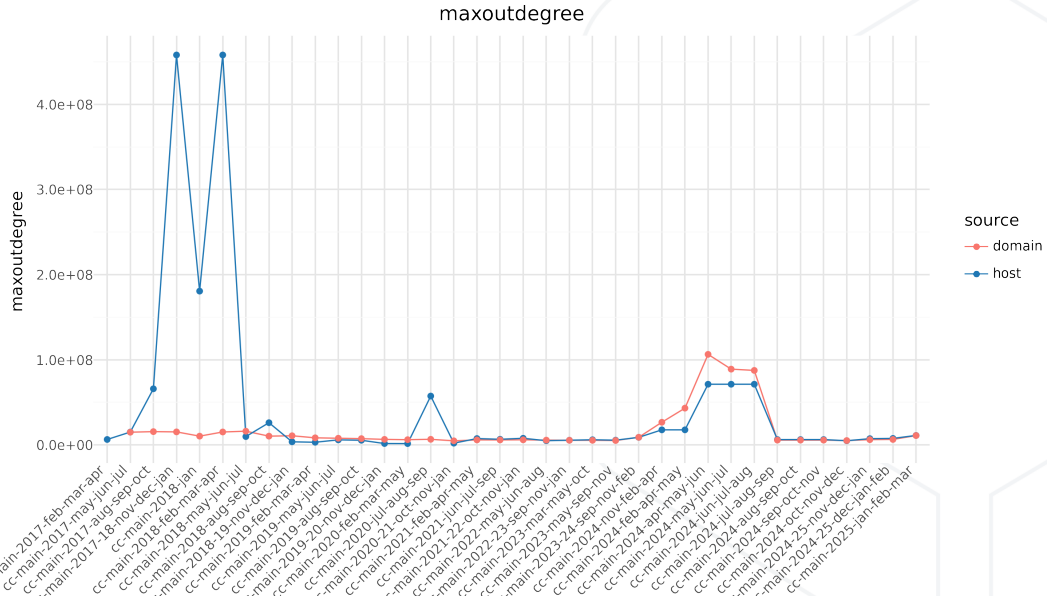
! A page-level graph would be too large and costly to build and rank

- A small dataset (only Gigabytes) but a good representation of the sample crawled by CCBot

CCF Webgraph Datasets: Number of Nodes



CCF Webgraph Datasets: Max Outdegree



The Need for Sampling

Why sampling and prioritization are necessary? Why not just follow links?

- An average “monthly” crawl includes 3 billion page captures with
  - 500+ billion links
  - 25+ billion unique URLs linked
- Up to 2.5 billion URLs listed in a single sitemap (sitemap index) [19]

Need to select a diverse and representative sample given

- Limited resources
- Requirements for crawler politeness: do not overload a single web site
- It’s easy to get lost in the wrong corner of the web!

Stratified Domain-Level Sampling

Domain-level harmonic centrality ranks

- Define a “budget” [20] per registered domain
  - How many URLs/pages are sampled per domain
  - Domain: one level below the registry suffix, e.g. `w.org`, `data.gov.uk`)
- Are used during URL discovery to sample sitemaps or home pages (top-ranking domains: always, decreasing likelihood for lower ranks)
- Are “projected” to the page-level by inlink count or OPIC [21]
  - Rank the pages within a domain
  - ! We have no absolute “page quality metrics” comparing two pages from two different domains

Domain-Level Graph-Based Ranking Example

- Top-N `.edu` domains ranked by harmonic centrality (or pagerank) calculated on CC's domain-level hyperlink graphs [22]
- Reverse domain name notation [23]
- Order by harmonic centrality ("hc") [7, 8]
  - ranks are shown not scores
  - PageRank rank [24], too
  - global ranks over domains below all top-level domains, not only `.edu`
- Includes not only universities (*)
- Compared with university rankings by QS World [25] and Forbes [26]

Domain-Level Graph-Based Ranking Example

pos	hc	pr	rev. domain
1	71	297	edu.stanford
2	78	285	edu.harvard
3	90	392	edu.mit
4	135	588	edu.berkeley
5	157	757	edu.psu
6	167	515	edu.cornell
7	203	522	edu.cmu
8	213	978	edu.princeton
9	228	998	edu.utexas
10	236	818	edu.columbia
11	239	1011	edu.yale
12	249	1063	edu.wisc
13	268	1050	edu.washington
14	292	1358	edu.brookings*
15	300	1405	edu.usc
16	349	2076	edu.ncsu
17	352	1243	edu.si*
18	391	1824	edu.georgetown
19	397	1248	edu.academia*
20	398	1010	edu.uchicago

rank	QS World [25]
1	MIT
4	Harvard
6	Stanford
10	Caltech
11	U. Pennsylvania
12	Berkeley (UCB)
16	Cornell
21	Chicago
22	Princeton
23	Yale
32	Johns Hopkins
34	Columbia
42	UCLA
43	NYU
44	Michigan-Ann Arbor
50	Northwestern
58	Carnegie Mellon
61	Duke
66	Texas at Austin
69	Illinois

rank	Forbes [26]
1	Princeton
2	Stanford
3	MIT
4	Yale
5	Berkeley
6	Columbia
7	U. Pennsylvania
8	Harvard
9	Rice
10	Cornell
11	Northwestern
12	Johns Hopkins
13	UCLA
14	Chicago
15	Vanderbilt
16	Dartmouth College
17	Williams College
18	Brown
19	Claremont McKenna
20	Duke

CCF Domain-Level Graph – Interactive Session

```
$> jshell \
     --class-path "$CC_WEBGRAPH_JAR" \
     -R-Dgraph="cc-main-2025-jan-feb-mar-domain" \
     "$CC_WEBGRAPH"/src/script/webgraph_ranking/graph_explore_load_graph.jsh
```

- instructions: `https://github.com/commoncrawl/wac2025-webgraph-workshop`
- see also: `https://github.com/commoncrawl/cc-webgraph/blob/main/graph-exploration-README.md`

Questions?

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