Transforming Unstructured Data to Structured: Standards, Logic, and Language Models

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Web Technologies

Wayback Machine

In 1989, Sir Tim Berners-Lee invented the World Wide Web (see the original proposal). He coined the term "World Wide Web," wrote the first World Wide Web server, "httpd," and the first client program (a browser and editor), "WorldWideWeb," in October 1990.
He wrote the first version of the "HyperText Markup Language" (HTML), the document formatting language with the capability for hypertext links that became the primary publishing format for the Web. His initial specifications for URIs, HTTP, and HTML were refined and discussed in larger circles as Web technology spread.
– History | W3C

WWW Components

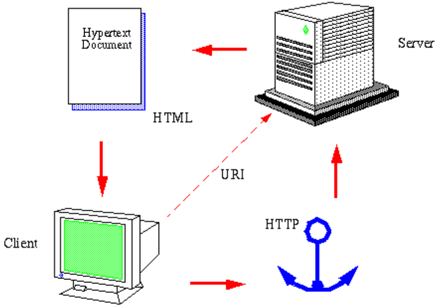


Image from Frystyk, 1994

- server (httpd)
- clients
- markup language
- protocol (HTTP)
- identifiers (URI, URL)
- navigation (hypertext)

Component: URI = Uniform Resource Identifier

- worldwide unique
- uniform = with the same syntax across object types
- resource = whatever is worth linking
  - article
  - web page
  - multimedia
  - service
  - abstract entities (e.g., the sum function)
- not necessarily accessible on the Internet

URI Syntax

```
URI = scheme ":" hier-part [ "?" query ] [ "#" fragment ]
      hier-part = "//" authority path-abempty
                  / path-absolute
                  / path-rootless
                  / path-empty
```

RFC3986, 2005

URI Example

```
foo://example.com:8042/over/there?name=ferret#nose
\_/   \______________/\_________/ \_________/ \__/
 |              |         |            |        |
scheme     authority      path        query   fragment
 |   _____________________|__
/ \ /                        \
urn:example:animal:ferret:nose
```

An image of a pet ferret. Alfredo Gutiérrez - Own work

Sidenote: URI? URL? URN? IRI?

- originally, URI = URL (Locator) or URN (Name)
- nowadays, URL stands for URI
- later, IRI = Internationalized (UTF-8 characters are allowed)

Origins of the Semantic Web

> *The Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation.*
> *For the semantic web to function, computers must have access to structured collections of information and sets of inference rules that they can use to conduct automated reasoning.*
> – *Tim Berners-Lee, 2001*

Web X.0

- 1.0 - links between **web pages** (HTML, CGI, graphics)
- 2.0 - links between **applications** (AJAX, APIs, responsivity)
- 3.0 - links between **pieces of knowledge** (semantic search, connectivity)

Sharma, 2025

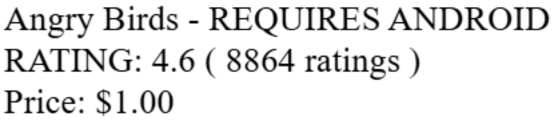
Example: Microdata in HTML

```
<div itemscope itemtype="https://schema.org/SoftwareApplication">
  <span itemprop="name">Angry Birds</span> -
  REQUIRES <span itemprop="operatingSystem">ANDROID</span>
  TYPE: <span itemprop="applicationCategory" content="GameApplication">
        Game</span>
  RATING:
  <div itemprop="aggregateRating" itemscope
        itemtype="https://schema.org/AggregateRating">
    <span itemprop="ratingValue">4.6</span> (
    <span itemprop="ratingCount">8864</span> ratings )
  </div>
  <div itemprop="offers" itemscope itemtype="https://schema.org/Offer">
    Price: $<span itemprop="price">1.00</span>
    <meta itemprop="priceCurrency" content="USD" />
  </div>
</div>
```

Example: JSON-LD

```
{ "@context": "https://schema.org",
  "@type": "SoftwareApplication",
  "name": "Angry Birds",
  "operatingSystem": "ANDROID",
  "applicationCategory": "GameApplication",
  "aggregateRating": {
    "@type": "AggregateRating",
    "ratingValue": 4.6,
    "ratingCount": 8864
  },
  "offers": {
    "@type": "Offer",
    "price": 1.00,
    "priceCurrency": "USD"
  }}
```

What is it good for?



Angry Birds - REQUIRES ANDROID
RATING: 4.6 (8864 ratings)
Price: $1.00

Figure: Rendered code from previous page

Search Engine point-of-view: rich results

- Microdata
- JSON-LD

  Google uses structured data to understand the content on the page and show that content in a richer appearance in search results, which is called a rich result.
  – Google, 2025

Search results: article, breadcrumb, carousel, course list, dataset, discussion forum, education Q&A, event, FAQ, image metadata, job posting, local business, math solver, movie, organization, practice problem, product, profile page, Q&A, recipe, review snippet, software app, speakable, subscription and paywalled content, vacation rental, video

Back to the JSON-LD Example

```
{ "@context": "https://schema.org",
  "@type": "SoftwareApplication",
  "name": "Angry Birds",
  "operatingSystem": "ANDROID",
  "applicationCategory": "GameApplication",
  "aggregateRating": {
    "@type": "AggregateRating",
    "ratingValue": 4.6,
    "ratingCount": 8864
  }}
```

Where are these entities from?

- SoftwareApplication
- GameApplication
- AggregateRating

Are Structured Data Used?

Check the stats

The Four Rules for Linked Data

1. Use URIs as names for things
2. Use HTTP URIs so that people can look up those names.
3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL)
4. Include links to other URIs, so that they can discover more things.

Berners-Lee, 2006

The Five Stars of Linked Open Data (LOD)

*	Available on the web (whatever format) but with an open licence, to be Open Data
**	Available as machine-readable structured data (e.g. excel instead of image scan of a table)
***	As (2) plus non-proprietary format (e.g. CSV instead of excel)
****	All the above plus, Use open standards from W3C (RDF and SPARQL) to identify things, so that people can point at your stuff
*****	All the above, plus: Link your data to other people's data to provide context

Berners-Lee, 2006

FAIR Data

- **F**indable - machine-readable metadata that allow discovery
- **A**ccessible - authentication, authorization, accessibility of the metadata
- **I**nteroperable - shared vocabularies, shared language for knowledge representation
- **R**eusable - richly described data, released with clear licence and clear provenance

Wikipedia

FAIR and LOD

- LOD → data interoperability
- FAIR → data reusability

FAIR data does not have to be *open*. FAIR can use other identifiers than *URIs*.

> *Both FAIR and LOD are a high-level guide for data producers and publishers.*
> *Avanco, 2021*

Semantic Web technologies

The Triple

```
statement: <subject> <predicate> <object> .
```

Conditions

1. everything is a resource
2. resources have URLs
3. the `<object>` can be a literal

Statements

about individuals

```
<TimBernersLee> <isA> <inventor> .
```

about classes

```
<inventor> <isA> <human> .
```

The Tendency to Re-Use

- reuse subjects and objects → increase the graph density
- reuse predicates → minimize the number of types of edges
- reuse definitions → what is LOV?

How about complex statements?

```
<TimBernersLee> <isA> <inventor> <ofTheWWW> .
```

- create complex nodes
  - `inventorOfTheWWW`
- reification
  - rotate 90 degrees :-)

Complex Concepts

```
<TimBernersLee> <isA> <inventorOfTheWWW> .
<inventorOfTheWWw> <isA> <inventor> .
<inventorOfTheWWw> <hasTopic> <WorldWideWeb> .
```

The `<inventorOfTheWWW>` is a complex concept. It's less reusable than simpler complex.

Reification

```
<statement> <hasSubject> <TimBernersLee> .
<statement> <hasPredicate> <isA> .
<statement> <hasObject> <inventor> .
<statement> <hasTopic> <WorldWideWeb> .
```

Technical Note

RDF Triples can be **serialized** in several forms:

- XML (RDF/XML)
- Turtle
- N-Triples
- N-Quads

Let's check on RDF Grapher

Summary

- although the initial idea of the semantic web has not been realized, a lot of technologies and ideas were adopted:
    - worldwide unique identifiers
    - link as much as possible
    - standardization of data
- knowledge graphs are part of modern search engines
    - to directly answer users questions
    - machines interchange information about goods, events, and other searchable things
- data producers can use high-level frameworks
    - linked data
    - linked open data
    - FAIR data