Lessons Learned While Building Infrastructure Software at Google

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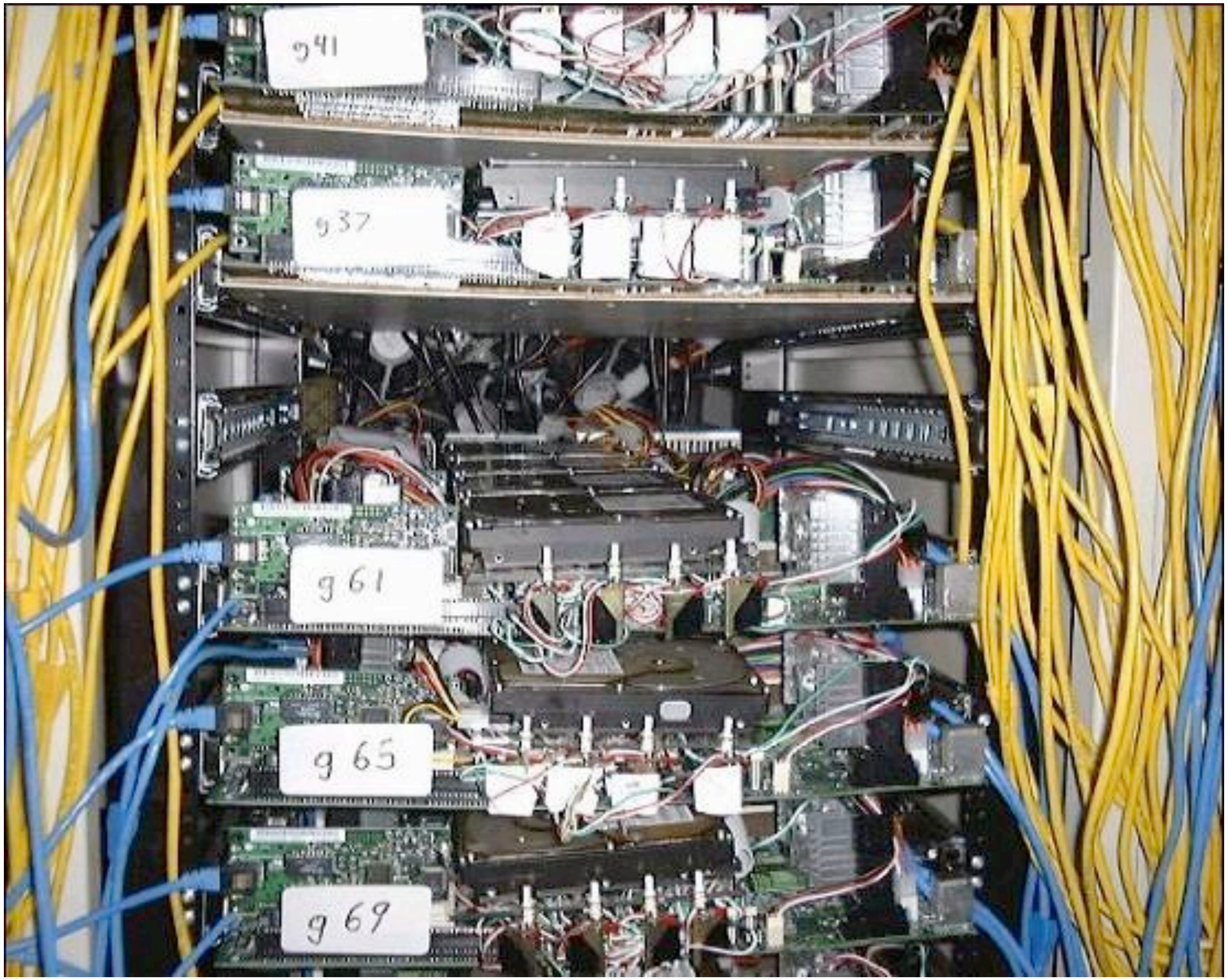
“Google” Circa 1997 (google.stanford.edu)

“Corkboards” (1999)



Google Data Center (2000)

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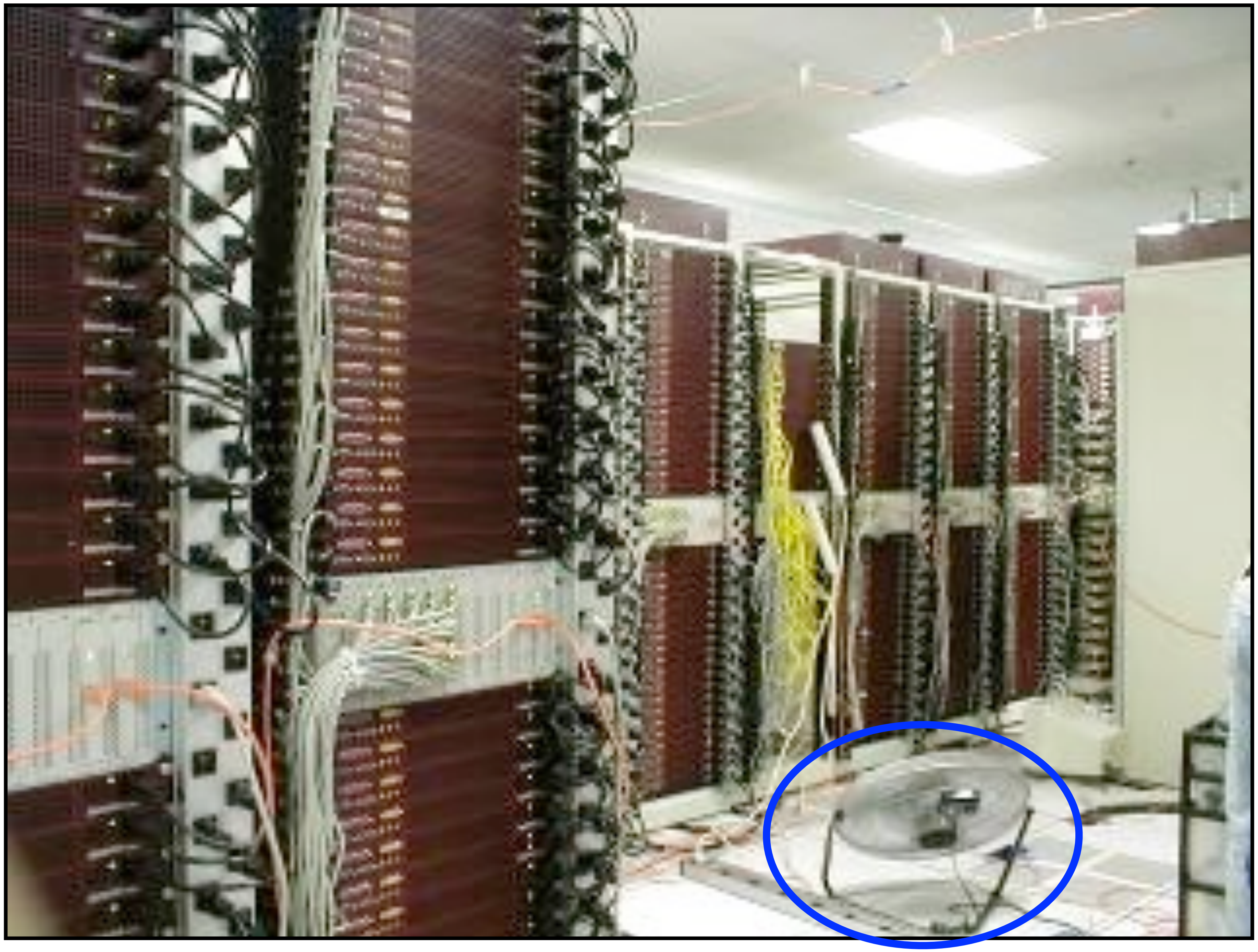
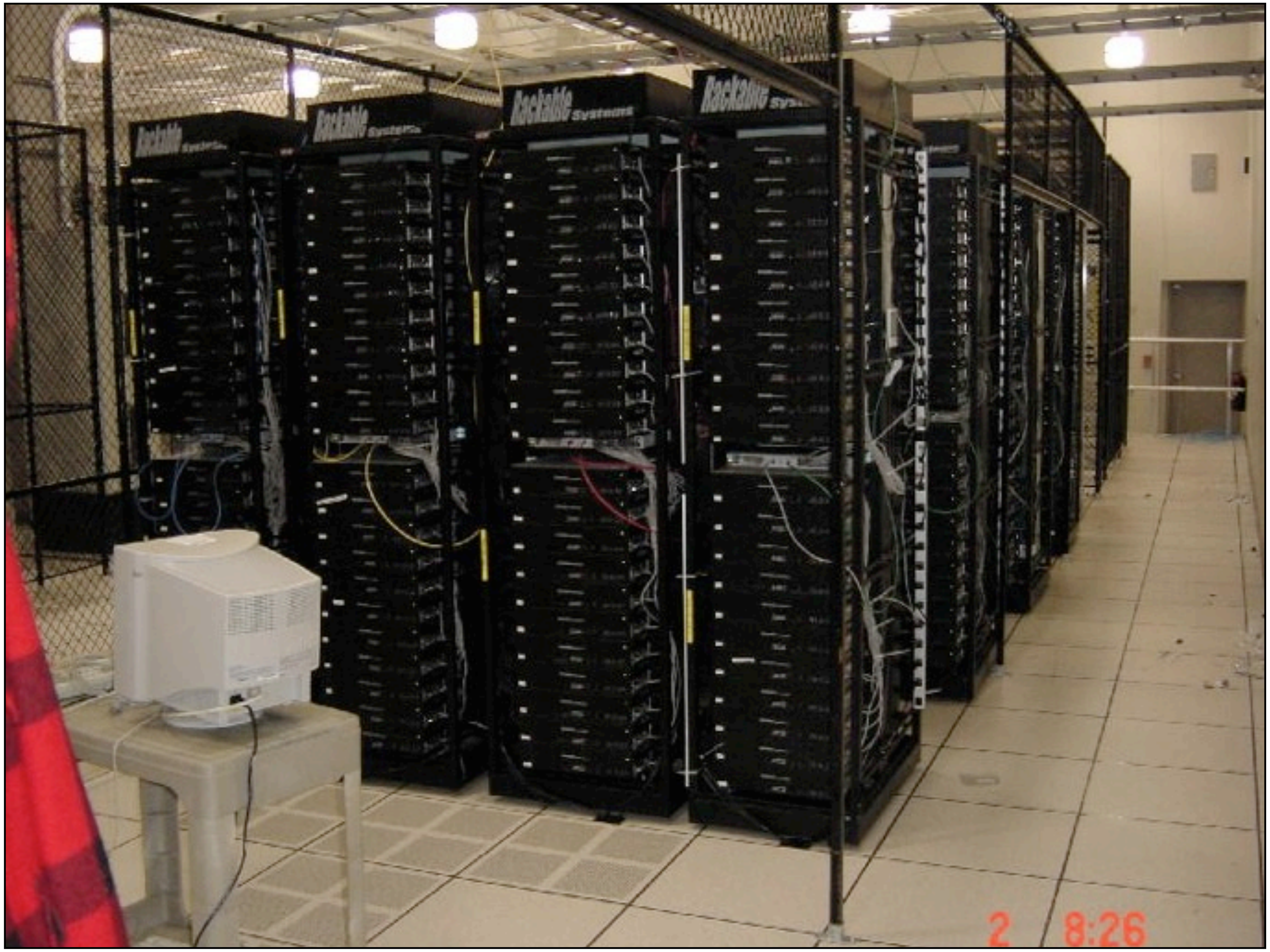


Google (new data center 2001)

Google Data Center (3 days later)



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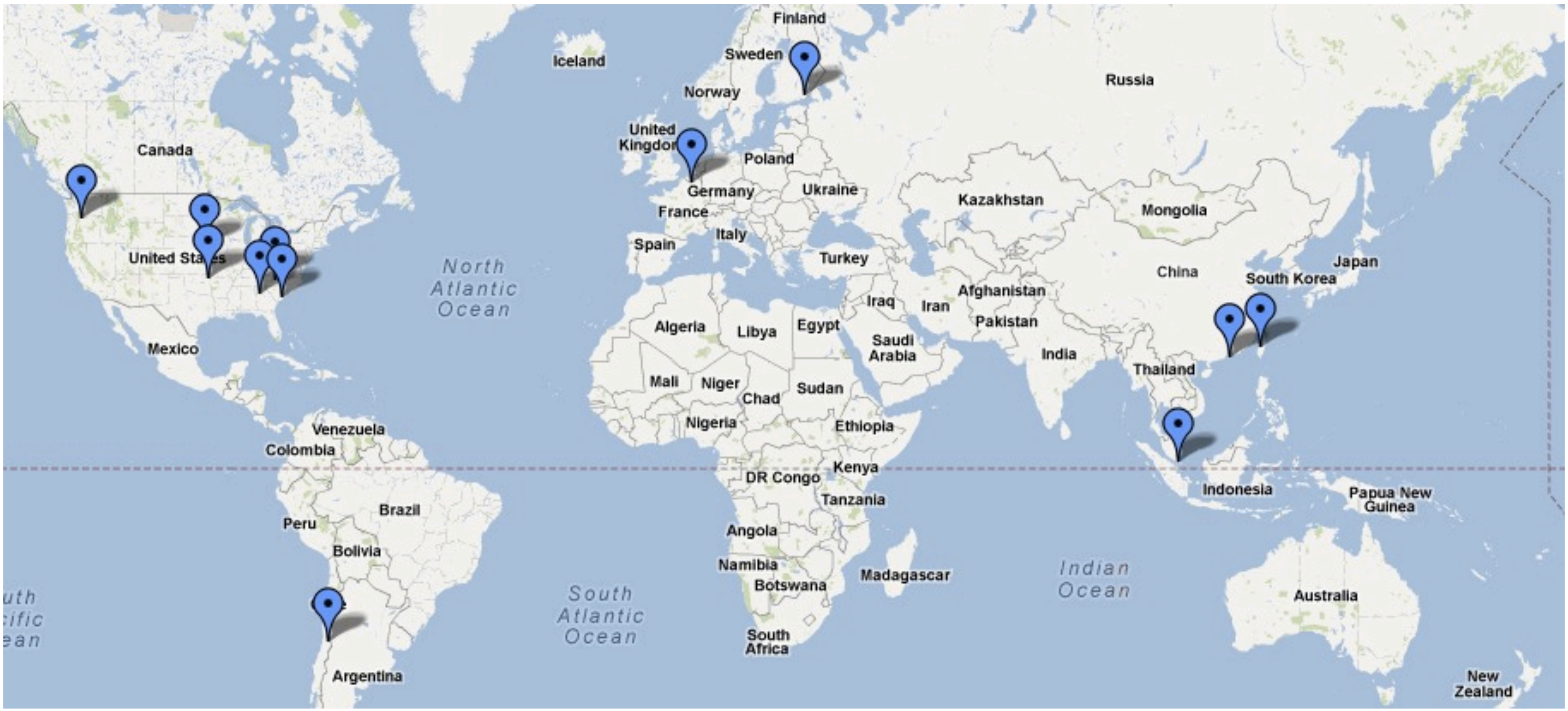
Google's Computational Environment Today

- Many datacenters around the world



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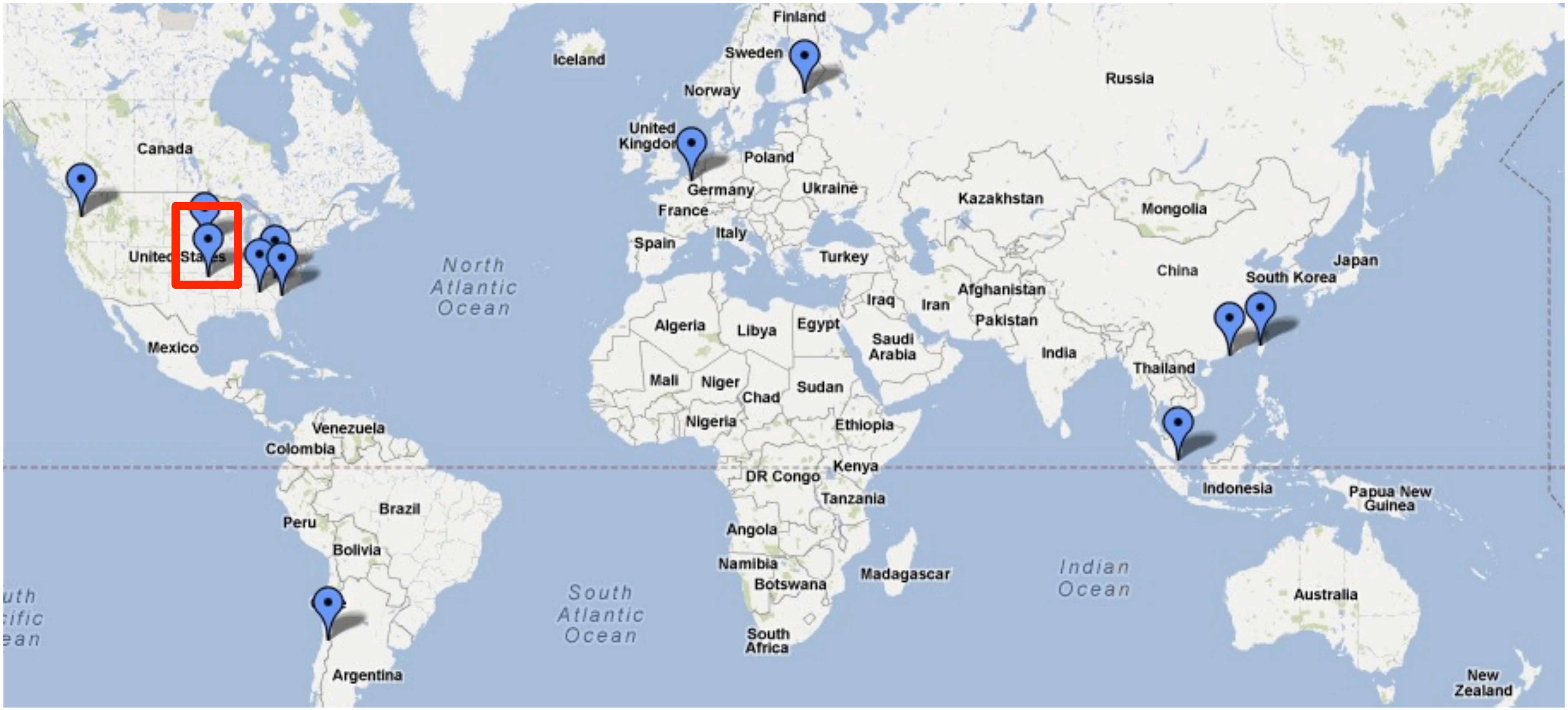

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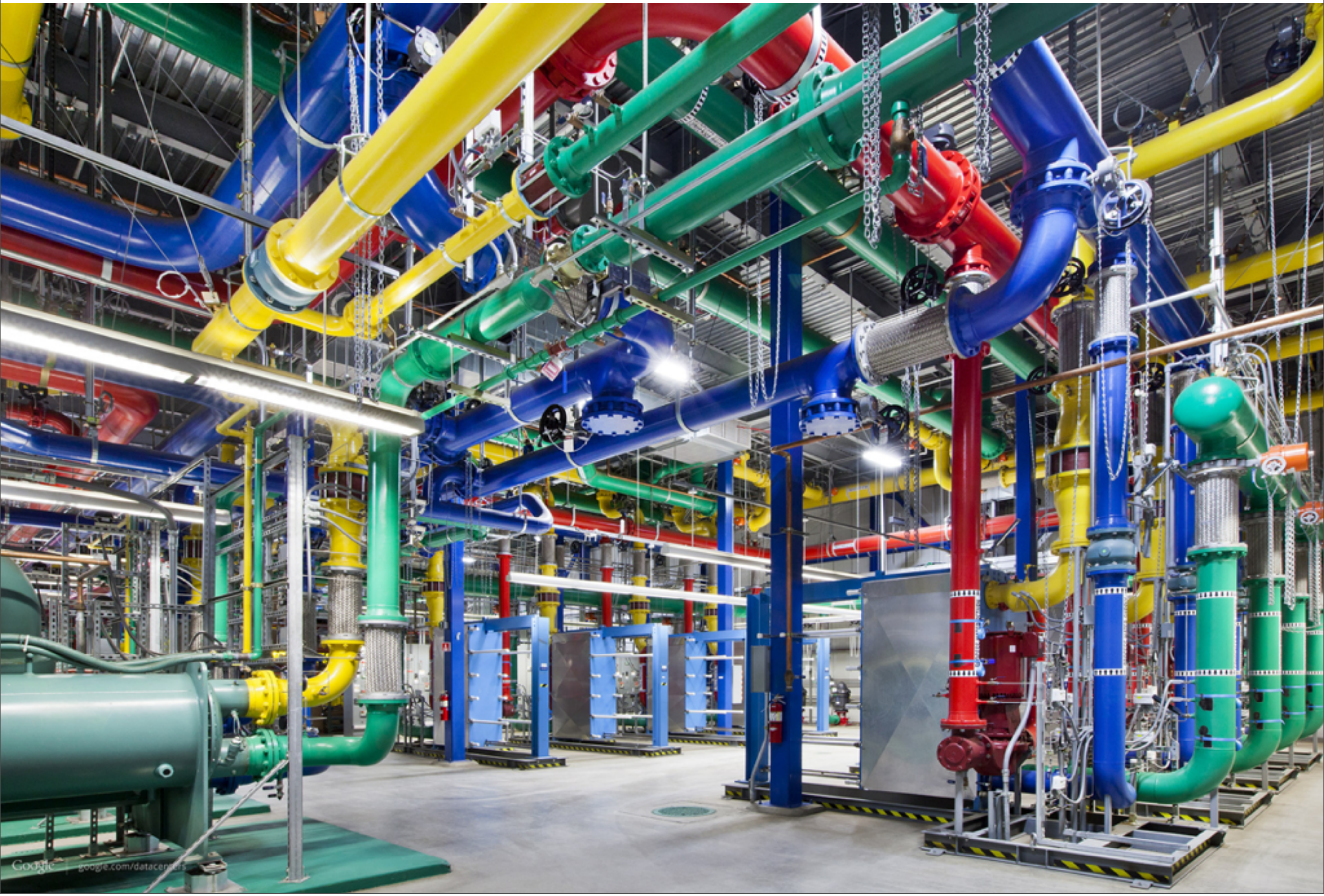
Zooming In…

Lots of machines...

Cool...



Low-Level Systems Software Desires

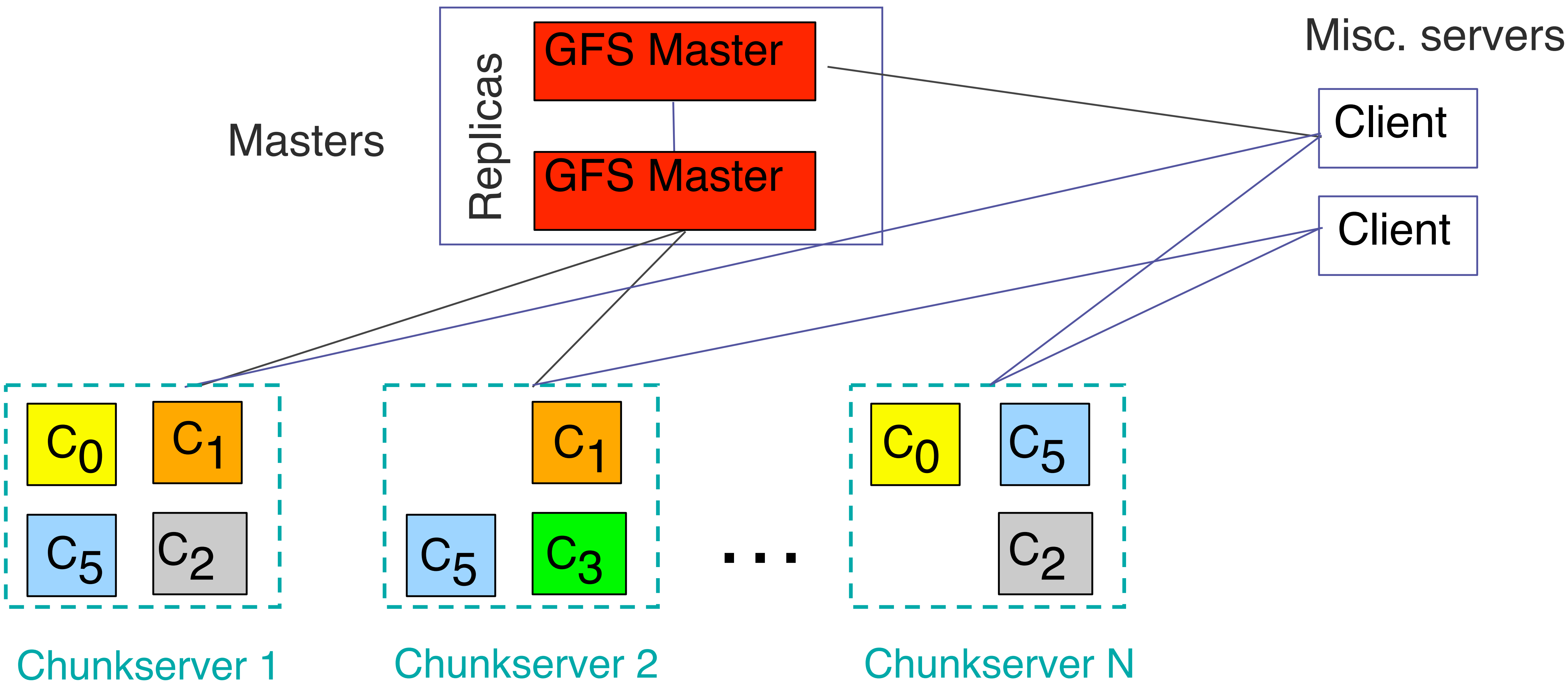
- If you have lots of machines, you want to:

- Store data persistently
  - w/ high availability
  - high read and write bandwidth

- Run large-scale computations reliably
  - without having to deal with machine failures

- GFS, MapReduce, BigTable, Spanner, ...

Google File System (GFS) Design



- Master manages metadata
- Data transfers are directly between clients/chunkservers
- Files broken into chunks (typically 64 MB)
- Chunks replicated across multiple machines (usually 3)

GFS Motivation and Lessons

- Indexing system clearly needed a large-scale distributed file system
  - wanted to treat whole cluster as single file system
- Developed by subset of same people working on indexing system
- Identified minimal set of features needed
  - *e.g.* Not POSIX compliant
  - actual data was distributed, but kept metadata centralized
    - Colossus: Follow-on system developed many years later distributed the metadata
- Lesson: Don't solve everything all at once

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MapReduce History

- 2003: Sanjay Ghemawat and I were working on rewriting indexing system:
  - starts with raw page contents on disk
  - many phases:
    - (near) duplicate elimination, anchor text extraction, language identification, index shard generation, etc.
  - end result is data structures for index and doc serving

- Each phase was hand written parallel computation:
  - hand parallelized
  - hand-written checkpointing code for fault-tolerance

MapReduce

- A simple programming model that applies to many large-scale computing problems
  - allowed us to express all phases of our indexing system
  - since used across broad range of computer science areas, plus other scientific fields
  - Hadoop open-source implementation seeing significant usage

- Hide messy details in MapReduce runtime library:
  - automatic parallelization
  - load balancing
  - network and disk transfer optimizations
  - handling of machine failures
  - robustness
  - **improvements to core library benefit all users of library!**

Google

Typical problem solved by MapReduce

- Read a lot of data
- Map: extract something you care about from each record
- Shuffle and Sort
- Reduce: aggregate, summarize, filter, or transform
- Write the results

Outline stays the same,
User writes Map and Reduce functions to fit the problem

Google

MapReduce Motivation and Lessons

- Developed by two people that were also doing the indexing system rewrite
  - squinted at various phases with an eye towards coming up with common abstraction
- Initial version developed quickly
  - proved initial API utility with very simple implementation
  - rewrote much of implementation 6 months later to add lots of the performance wrinkles/tricks that appeared in original paper
- Lesson: Very close ties with initial users of system make things happen faster
  - in this case, we were both building MapReduce and using it simultaneously

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BigTable: Motivation

- Lots of (semi-)structured data at Google
  - URLs: Contents, crawl metadata, links, anchors, pagerank, …
  - Per-user data: User preferences, recent queries, …
  - Geographic locations: Physical entities, roads, satellite image data, user annotations, …
- Scale is large
- Want to be able to grow and shrink resources devoted to system as needed

BigTable: Basic Data Model

- Distributed multi-dimensional sparse map

  (row, column, timestamp) → cell contents

Columns

Rows

- Rows are ordered lexicographically
- Good match for most of our applications

BigTable: Basic Data Model

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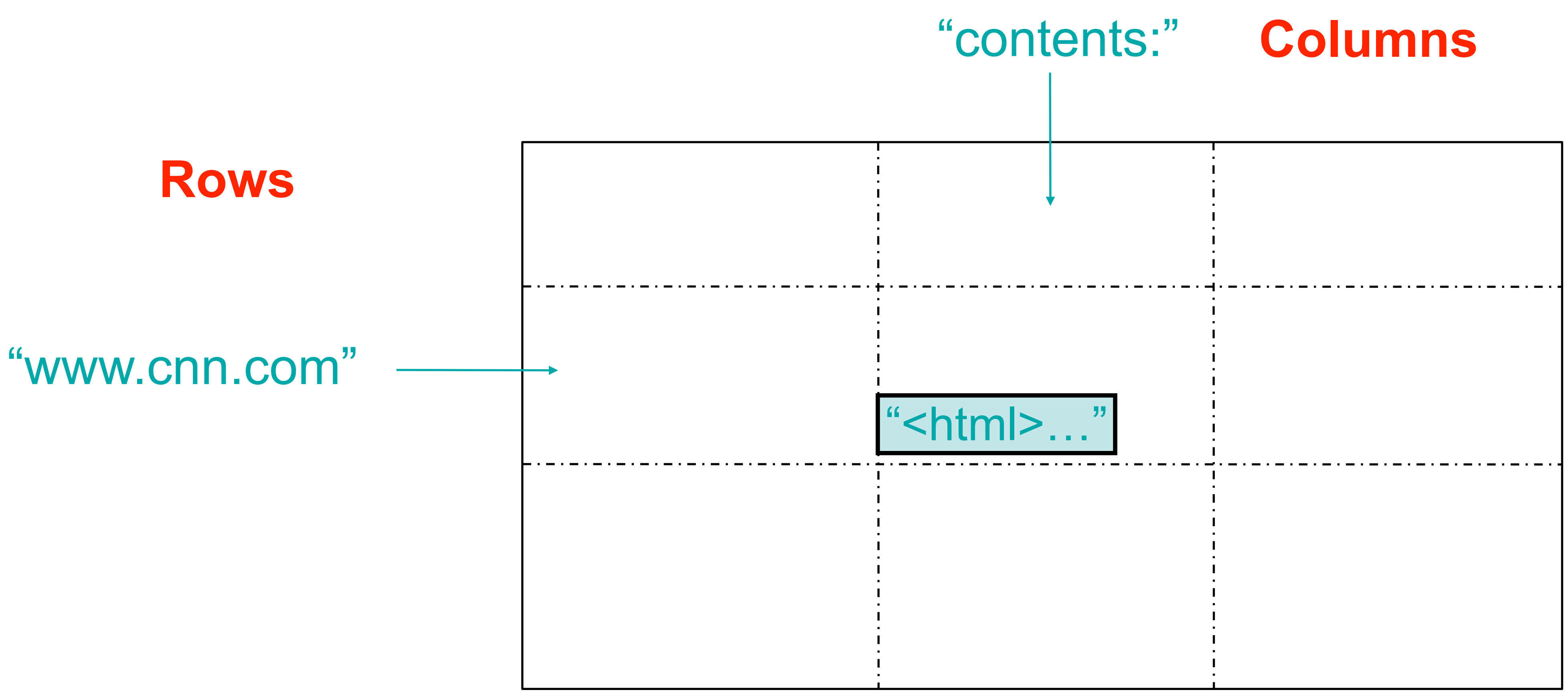

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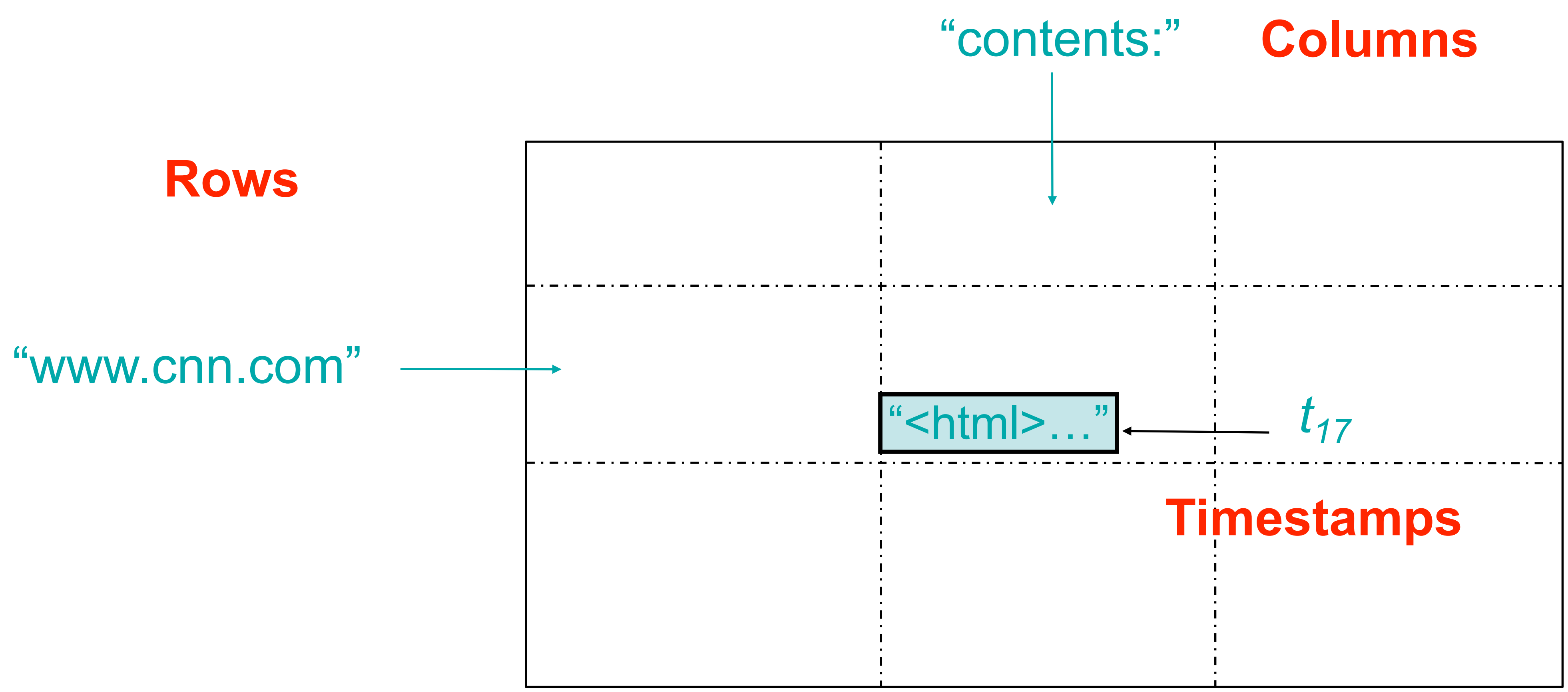

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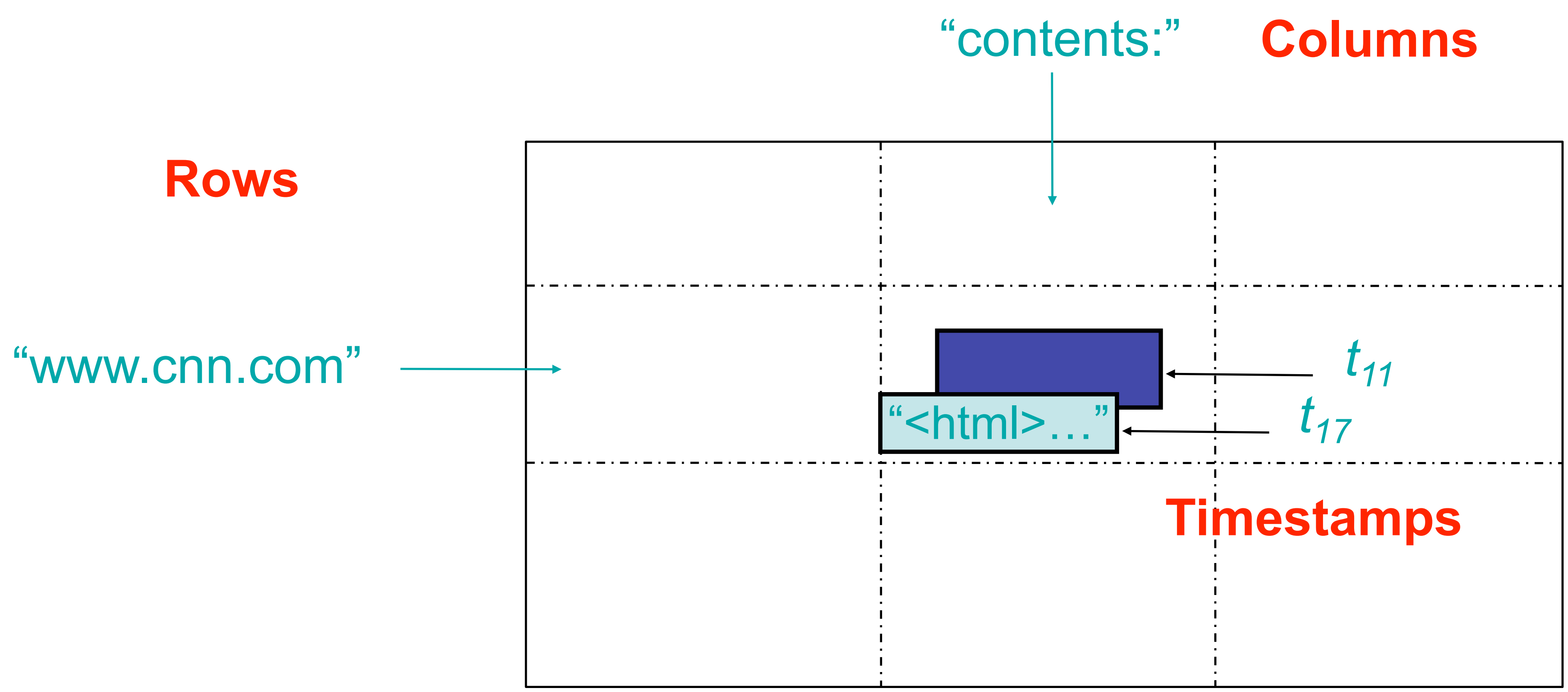

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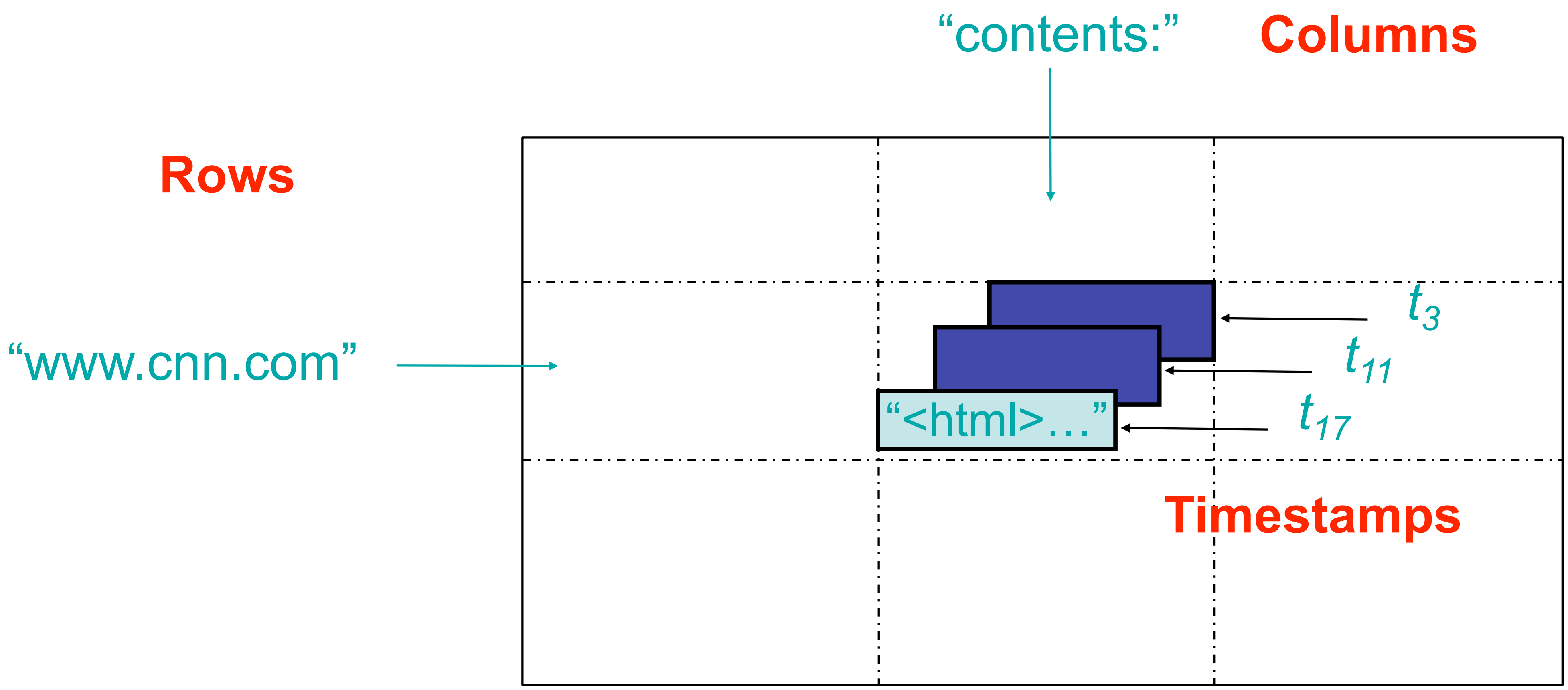

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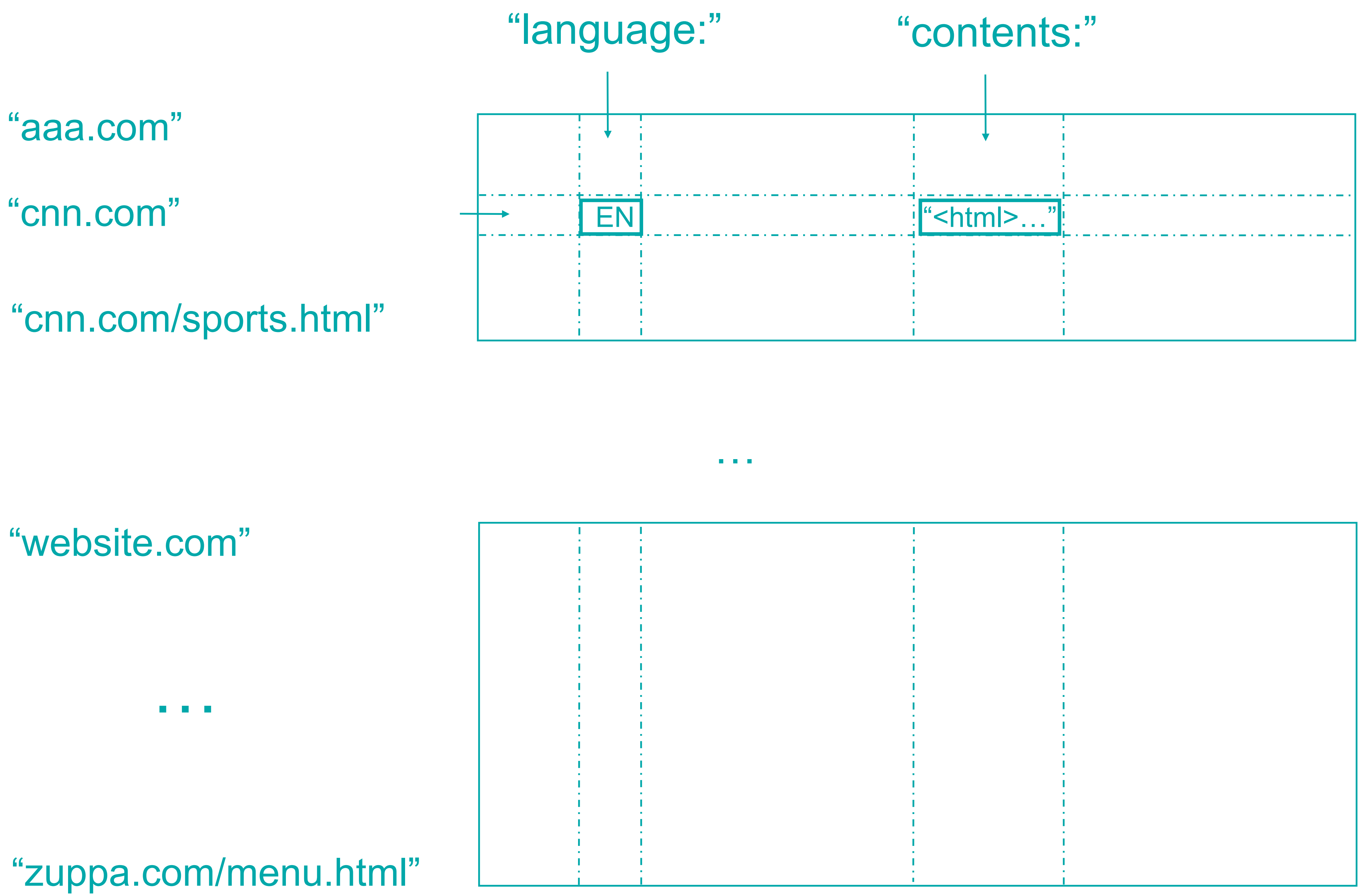
Tablets & Splitting



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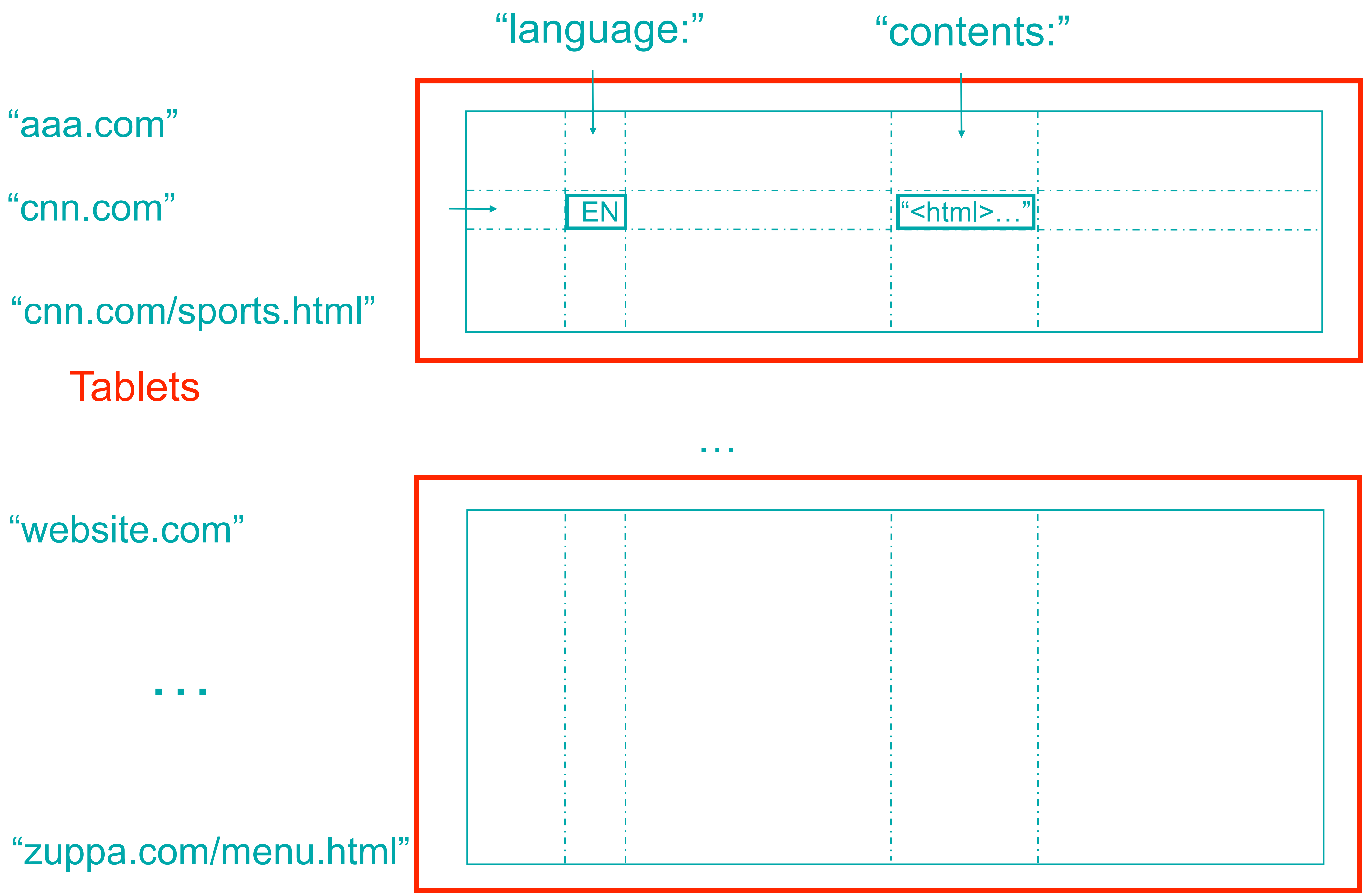

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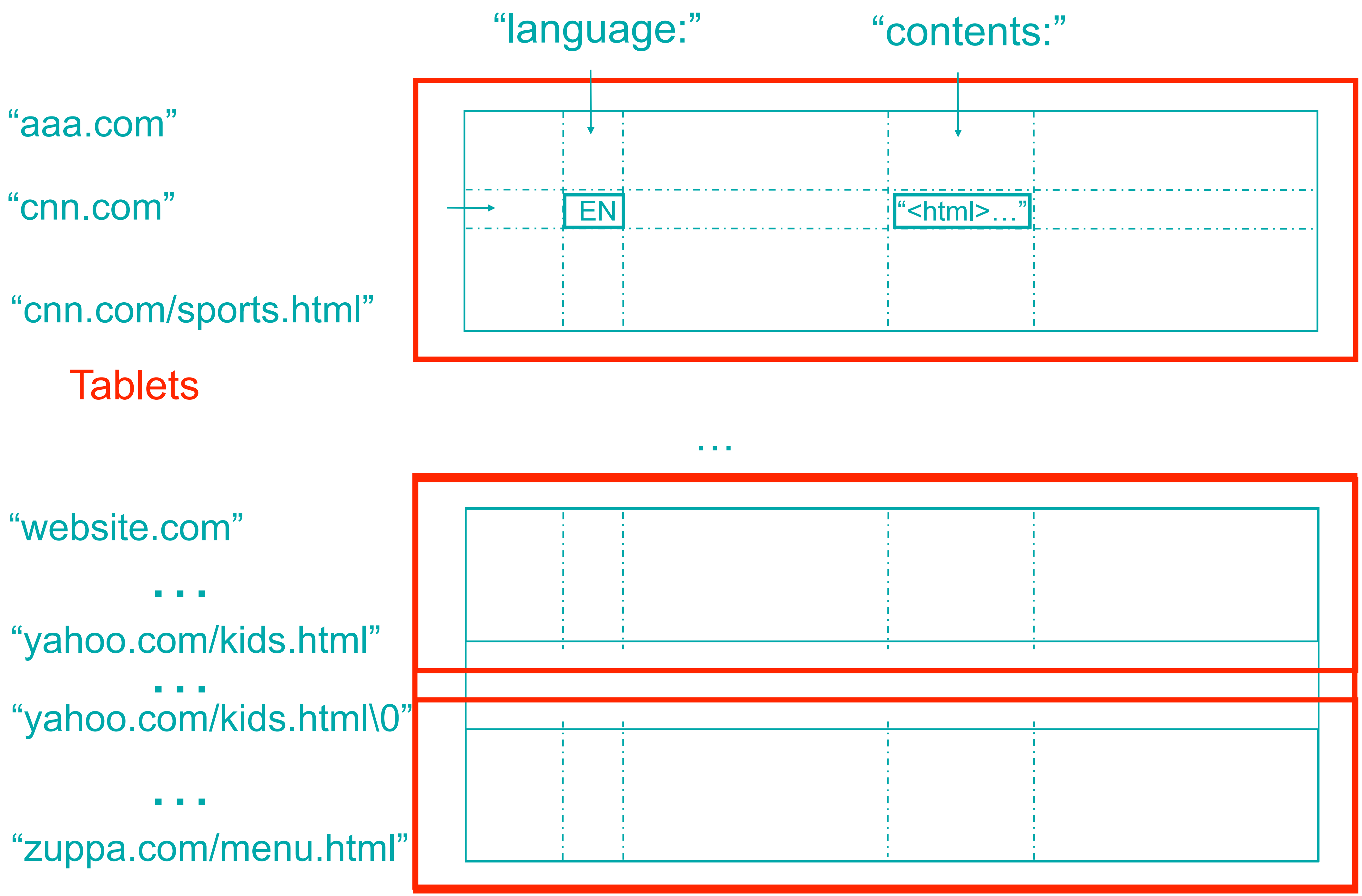

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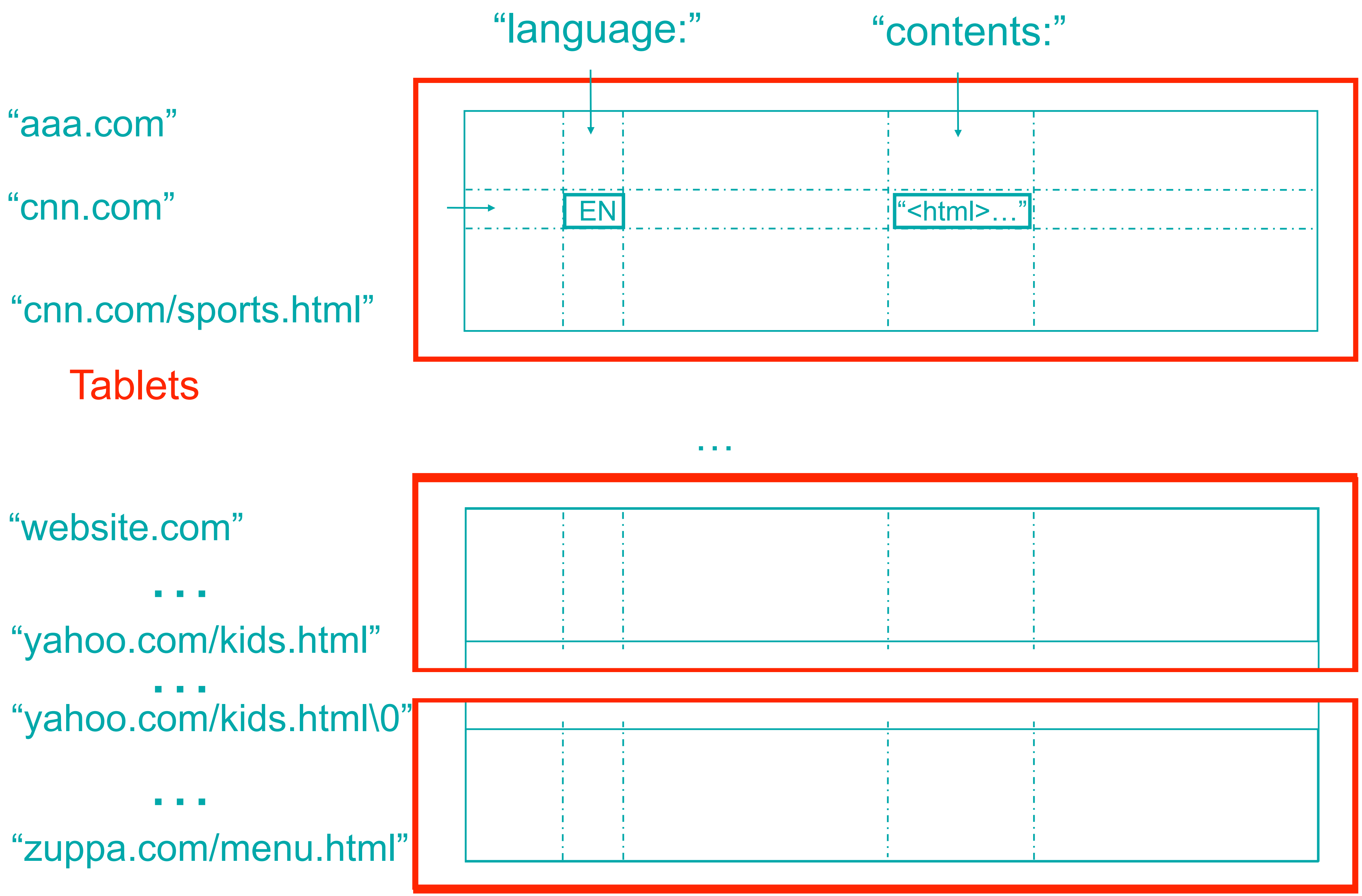

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BigTable System Structure

Bigtable Cell

Bigtable master

Bigtable tablet server   Bigtable tablet server   …   Bigtable tablet server

BigTable System Structure

Bigtable Cell

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performs metadata ops +
load balancing

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BigTable System Structure

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Bigtable tablet server | Bigtable tablet server | … | Bigtable tablet server

serves data | serves data | serves data

Google

BigTable System Structure

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Bigtable tablet server	Bigtable tablet server	…	Bigtable tablet server
serves data	serves data		serves data

Cluster scheduling system

Cluster file system

Lock service

BigTable System Structure

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Bigtable tablet server — serves data

Bigtable tablet server — serves data

…

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schedules tasks onto machines

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schedules tasks onto machines

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holds tablet data, logs

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performs metadata ops + load balancing

Bigtable tablet server	Bigtable tablet server	…	Bigtable tablet server
serves data	serves data		serves data

Cluster scheduling system	Cluster file system	Lock service
schedules tasks onto machines	holds tablet data, logs	holds metadata, handles master-election

Google

BigTable System Structure

Bigtable Cell

Bigtable client

Bigtable client library

Bigtable master

performs metadata ops + load balancing

Bigtable tablet server

serves data

Bigtable tablet server

serves data

…

Bigtable tablet server

serves data

Cluster scheduling system

schedules tasks onto machines

Cluster file system

holds tablet data, logs

Lock service

holds metadata, handles master-election

BigTable System Structure

Bigtable client

Bigtable client library

Bigtable Cell

Bigtable master

performs metadata ops + load balancing

Open()

Bigtable tablet server

serves data

Bigtable tablet server

serves data

…

Bigtable tablet server

serves data

Cluster scheduling system

schedules tasks onto machines

Cluster file system

holds tablet data, logs

Lock service

holds metadata, handles master-election

BigTable System Structure

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Bigtable client library

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performs metadata ops + load balancing

read/write

Open()

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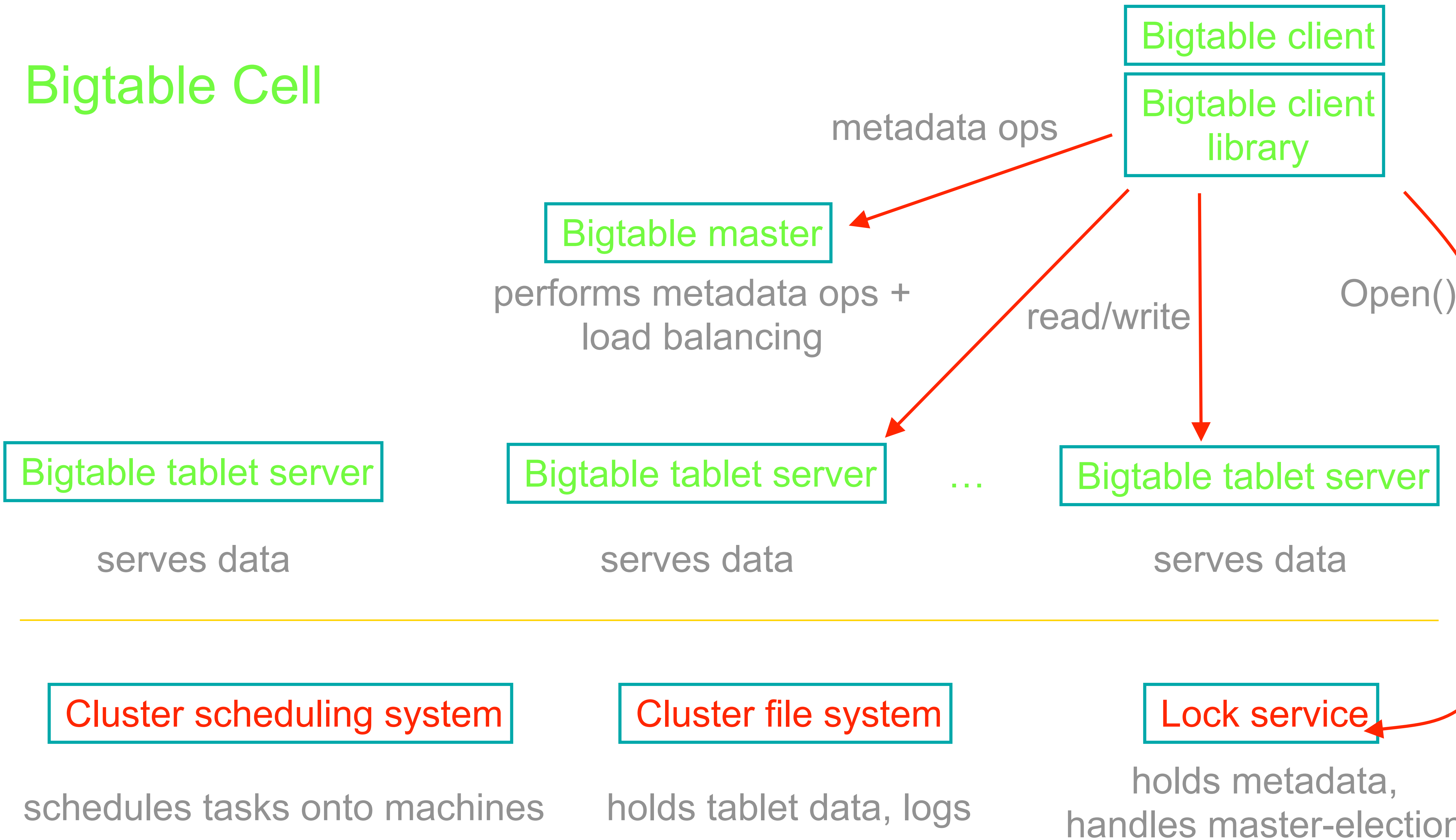
BigTable System Structure



BigTable Status

- Production use for 100s of projects:
  - Crawling/indexing pipeline, Google Maps/Google Earth/Streetview, Search History, Google Print, Google+, Blogger, ...
- Currently 500+ BigTable clusters
- Largest cluster:
  - 100s PB data; sustained: 30M ops/sec; 100+ GB/s I/O
- Many asynchronous processes updating different pieces of information
  - no distributed transactions, no cross-row joins
  - initial design was just in a single cluster
  - follow-on work added eventual consistency across many geographically distributed BigTable instances

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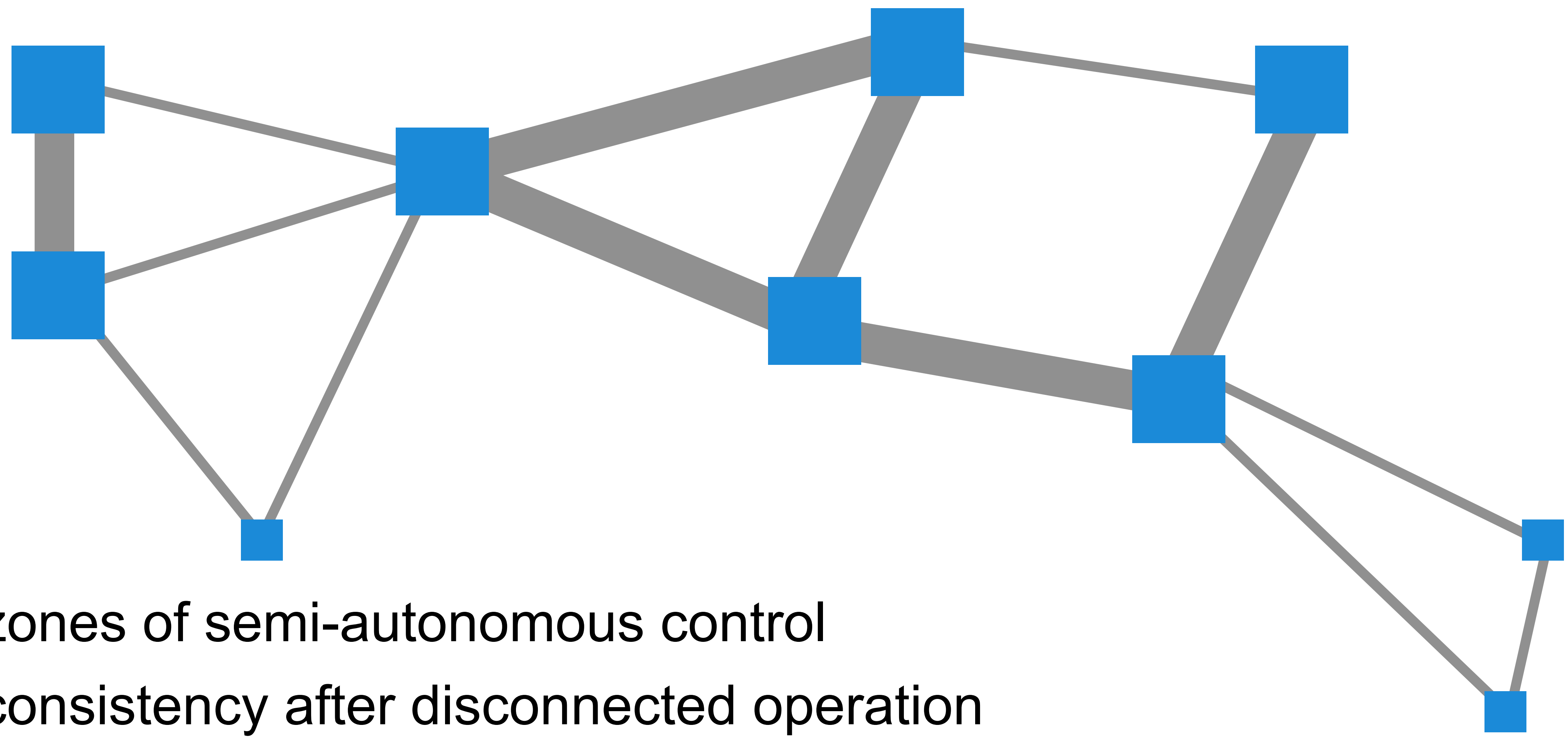
Spanner

- Storage & computation system that runs across many datacenters
  - single global namespace
    - names are independent of location(s) of data
    - fine-grained replication configurations
  - support mix of strong and weak consistency across datacenters
    - Strong consistency implemented with Paxos across tablet replicas
    - Full support for distributed transactions across directories/machines
  - much more automated operation
    - automatically changes replication based on constraints and usage patterns
    - automated allocation of resources across entire fleet of machines

Design Goals for Spanner

- Future scale: ~10^5 to 10^7 machines, ~10^{13} directories, ~10^{18} bytes of storage, spread at 100s to 1000s of locations around the world



  - zones of semi-autonomous control
  - consistency after disconnected operation
  - users specify high-level desires:

    “99%ile latency for accessing this data should be <50ms”

    “Store this data on at least 2 disks in EU, 2 in U.S. & 1 in Asia”

Spanner Lessons

- Several variations of eventual client API
- Started to develop with many possible customers in mind, but no particular customer we were working closely with

- Eventually we worked closely with Google ads system as initial customer
  - first real customer was very demanding (real $$): good and bad

- Different API than BigTable
  - Harder to move users with existing heavy BigTable usage

Designing & Building Infrastructure

Identify common problems, and build software systems to address them in a general way

- Important to not try to be all things to all people
  - Clients might be demanding 8 different things
  - Doing 6 of them is easy
  - …handling 7 of them requires real thought
  - …dealing with all 8 usually results in a worse system
    - more complex, compromises other clients in trying to satisfy everyone

Designing & Building Infrastructure (cont)

Don't build infrastructure just for its own sake:

- Identify common needs and address them
- Don't imagine unlikely potential needs that aren't really there

Best approach: use your own infrastructure (especially at first!)

- (much more rapid feedback about what works, what doesn't)

If not possible, at least work very closely with initial client team

- ideally sit within 50 feet of each other
- keep other potential clients needs in mind, but get system working via close collaboration with first client first

Google

Thanks!

Further reading:

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