Context
Since we are at the end
Announcements

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• Please respond to the Doodle poll to set up a 15 minute slot to meet.
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  • Must prepare a few slides. Also come prepared to demo if you are done.
• Meeting is required to get a grade for the final project.
Announcements

• Final project report is due next Wednesday at 23:59. No extensions.
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• The final project is 40% of the grade, so don’t miss this deadline.
Announcements

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  • The final project is 40% of the grade, so don’t miss this deadline.
  • Lab 2 grades will be out by Monday (probably sooner).
From Lecture 1
Three Main Reasons
Three Main Reasons

• Fault tolerance
Three Main Reasons

• Fault tolerance
  • Survive some forms of failures or bug.
Three Main Reasons

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• Scalability
Three Main Reasons

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  • Use more resources than a single computer can provide.
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• Geographic Reach
Three Main Reasons

• Fault tolerance
  • Survive some forms of failures or bug.
• Scalability
  • Use more resources than a single computer can provide.
• Geographic Reach
  • Work even when information is spread across large distances.
But Where?
Look at Three Places

Datacenters
Look at Three Places

Datacenters

Sensors/Internet of Things
## Look at Three Places

<table>
<thead>
<tr>
<th>Datacenters</th>
<th>Sensors/Internet of Things</th>
<th>The Internet</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Datacenters Image]</td>
<td>![Sensors/Internet of Things Image]</td>
<td>![The Internet Image]</td>
</tr>
</tbody>
</table>
Look at Three Places

Not in Chronological Order

Datacenters    Sensors/Internet of Things    The Internet
Same Goals Different Requirements

• Datacenter: Single administrative domain, lots of compute capacity.
Same Goals Different Requirements

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• Control and knowledge of what is running where, etc.
Same Goals Different Requirements

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- IoT: Single administrative domain, limited resources.
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Same Goals Different Requirements

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  • Control and knowledge of what is running where, etc.
• IoT: Single administrative domain, limited resources.
  • Higher failure rates (potentially). Need to limit resources.
• Internet: Different administrative domains.
  • Figure out incentives for systems to work together, align with economics, etc.
Datacenters
What Datacenters

- The Internet and the web meant lots of clients might be connecting to one service
What Datacenters

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• Question: How to scale compute to serve all of these clients?
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- In the early-1990s a few answers: mainframes, custom computers, etc.
What Datacenters

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- Question: How to scale compute to serve all of these clients?
- In the early-1990s a few answers: mainframes, custom computers, etc.
- One research idea: a network of workstations that can compute together.
What Datacenters

• What workstation? Over time differences between smaller computers blurred.
What Datacenters

• What workstation? Over time differences between smaller computers blurred.
• Now: just a building with a lot of servers in racks connected by a fast network.
What Datacenters

• What workstation? Over time differences between smaller computers blurred.
• Now: just a building with a lot of servers in racks connected by a fast network.
• How many servers? Do not know for sure, but 50,000 to 100,000 are common.
Challenges

- Where to build?
Challenges

• Where to build?
• How to build?
Challenges

• Where to build?
• How to build?
• How to maintain?
Challenges

• Where to build?
• How to build?
• How to maintain?
• How to manage infrastructure?
Challenges

• Where to build?
• How to build?
• How to maintain?
• How to manage infrastructure?
• How to effectively utilize capacity?
Challenges

• Where to build?
• How to build?
• How to maintain?
• How to manage infrastructure?
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Programming Models for Datacenter
How to Scale Programs for Datacenters

• The answer of course depends on application.
How to Scale Programs for Datacenters

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How to Scale Programs for Datacenters

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• Going to look at a few examples of how people have used datacenters
  • To serve web requests.
  • To gather and run computations on large amounts of data.
  • Combining the two.
Serving Web Requests
Defining the Problem

Clients → Cloud → Web Server → Database
Defining the Problem
Defining the Problem

Clients → Web Server → Database

Request
Defining the Problem

Clients  Web Server  Database

Request  Query
Defining the Problem

Clients -> Web Server -> Database

Request -> Result

Query
Defining the Problem

How to handle an increase in the number of clients?
Solving the Problem

Can replicate web servers and put them behind a load balancer
Solving the Problem

Can replicate web servers and put them behind a load balancer

Any problems with this strategy?
Solving the Problem

Assuming most queries are reads can cache data.

Why not just replicate databases?
Solving the Problem

Assuming most queries are reads can cache data.

Why not just replicate databases?
Solving the Problem

Can shard data (need to be aware of transactions).

Why not just replicate databases?
Solving the Problem

Can shard data (need to be aware of transactions).

Any problems with this strategy?

Why not just replicate databases?
Sharding is Hard
Why not just replicate databases?
Gathering and Running Computation
PageRank

- Need to discover and rank pages on the web.
PageRank

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- Was done manually for a while.
PageRank

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PageRank

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• Task: Find number of links to each page.
• Challenge: 30 trillion (and growing) pages today.
Web Crawlers
Web Crawlers

Output
a.com/i -> a.com/j
Web Crawlers

Output
a.com/i -> a.com/j
a.com/i -> a.com/k
Web Crawlers

Output
a.com/i -> a.com/j
a.com/i -> a.com/k
a.com/i -> d.com/a
Web Crawlers

tape:

a.com/i

Output

a.com/i -> a.com/j
a.com/i -> a.com/k
a.com/i -> d.com/a
Web Crawlers

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a.com/i -> a.com/j
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...
Web Crawlers

Output
a.com/i -> a.com/j
a.com/i -> a.com/k
a.com/i -> d.com/a
Scaling Web Crawling

- Why independent outputs?
Scaling Web Crawling

- Why independent outputs?
- Is starting from independent pages sufficient?
Scaling Web Crawling

• Why independent outputs?
• Is starting from independent pages sufficient?
• For correctness?
Scaling Web Crawling

- Why independent outputs?
- Is starting from independent pages sufficient?
  - For correctness?
  - For scalability?
Scaling Web Crawling

- Why independent outputs?
- Is starting from independent pages sufficient?
  - For correctness?
  - For scalability?
- How to address any issues?
Computing PageRank
Computing PageRank

Output 1
a→b
c→b
d→c
y→a
x→j

Output 2

Output 3

Output 4

Count # of unique links
Count # of unique links
Count # of unique links
Count # of unique links
Computing PageRank

```
a->b
c->b
da->c
y->a
x->j
```

Count # of unique links

Map
Computing PageRank

Output 1
Output 2
Output 3
Output 4

Map
Shuffle

Count # of unique links
Count # of unique links
Count # of unique links
Count # of unique links

a->b  c->b  y->a
a->b  c->b  y->a
a->b  c->b  y->a
a->b  c->b  y->a

a->b  c->b  y->a
a->b  c->b  y->a
a->b  c->b  y->a
a->b  c->b  y->a
Computing PageRank

Map | Shuffle | Reduce

Count # of unique links

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Map Reduce as a Computational Paradigm

- Generalized into a programming framework used to implement
Map Reduce as a Computational Paradigm

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- Running aggregation queries (e.g., on large amounts of data).
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- Machine learning jobs of some kind.
Map Reduce as a Computational Paradigm

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  - Running aggregation queries (e.g., on large amounts of data).
  - Machine learning jobs of some kind.
  - Various other things...
Map Reduce Challenges

• Fault tolerance: need to replicate data and remember locations.
• Scheduling: minimize time and resources used.
• Sharing the cluster across jobs.
• Minimizing compute and network transfer time.
Sensors or IoT
Many Variants, Main Differences

• Usually consider the case of sensors producing data.
Many Variants, Main Differences

• Usually consider the case of sensors producing data.
  • Want to compute on the aggregate data from sensors.
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  • ...
Challenges

- Sensors have limited compute and power resources.
Challenges

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Challenges

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  • Might not always be on, might be able to do a limited number of tasks.
  • Communicate over wireless networks which might not always work reliably.
  • Interference or change in distance might disconnect individual sensors.
Thoughts on solutions?
The Internet
Many Problems, Focusing on One

• There are many problems here.
Many Problems, Focusing on One

- There are many problems here.
- A wide variety of requirements and tradeoffs.
Many Problems, Focusing on One

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- Focusing on one specific problem here.
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• Why? Seems like a problem that generalizes.
Many Problems, Focusing on One

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- A wide variety of requirements and tradeoffs.
- Focusing on one specific problem here.
- Why? Seems like a problem that generalizes.
- Also a problem I like.
What is the Internet

A set of networks, each of which is owned by a different entity.
What is the Internet

Must cooperate to get packets to a particular destination
How to Get Cooperation

- What is great about this model:
How to Get Cooperation

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  • Grows organically to include new areas, don’t need a central authority.
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  • ...
How it Works Today

Have path to M: B->M
Have path to S: B->S
How it Works Today

Have path to M: B→M
Have path to S: B→S

Have path to B: M→B
Have path to S: M→B→S
How it Works Today
How it Works Today

Do not consider paths from B.

Prefer paths from D over paths from B.
How it Works Today

Do not consider paths from S.
Prefer paths from D over paths from B.
Prefer paths from M over paths from S.
Do not consider paths from F.
How it Works Today

Combine policies and announcements to compute path.
Problems

- How to ensure paths are stable?
Problems

• How to ensure paths are stable?
• How to ensure quick response after failure?
Benefits

• Range of policies that can be implemented?
How to do better?
Final Thoughts (of the semester)
Final Thoughts

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  • If you write programs, very likely to be targeting distributed systems.
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  • If you write programs, very likely to be targeting distributed systems.
  • Probably hidden behind a few layers of abstraction.
• Given this remember just a few rules as you build systems.
  • Avoid coordination when possible, coordination is often slow.
  • But do not shun coordination in exchange for increased complexity.
The End

Please stay to fill out evaluation forms.