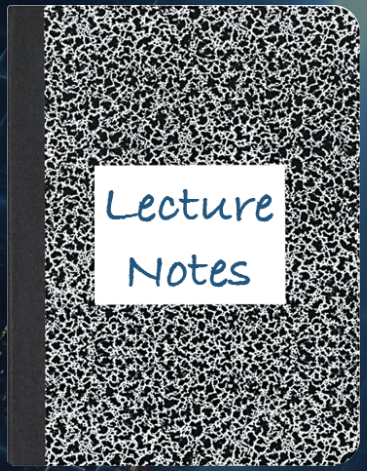


CS 417 – DISTRIBUTED SYSTEMS

Week 13: Summary

Engineering Distributed Systems

Paul Krzyzanowski

We *need* distributed systems

Handle huge data volume, transaction volume, and processing loads

- The data or request volume (or both) are too big for one system to handle
- Scale – distribute input, computation, and storage

We also want to distribute systems for

- High availability
- Parallel computation (e.g., supercomputing)
- Remote operations (e.g., cars, mobile phones, surveillance cameras, ATM systems)
- Geographic proximity (reduced latency)
- Content & Commerce: news, social, etc.
- Cloud-based storage & sharing
- Cloud services – SOA (e.g., file storage, authentication)

Designing distributed systems is not easy

Programmers tried to make it simpler

…but that also made it complicated

Apache Projects (Partial List)

Programming Languages

C++
C#
Clojure
Dart
Erlang
Elixir
Go
Haskell
Java
JavaScript
Julia
Perl
Python
Rust
Scala
…

Web

Cayenne
Cocoon
Flex
Geronimo
Isis
MyFaces
Nutch
OFBiz
Portals
Rivet
Shiro
Solr
Struts
Tapestry
Tobago
Turbine
Websh
Wicket

Data Storage

Cassandra
Cocoon
CouchDB
Curator
Derby
Empire-db
Gora
HDFS
HBase
Hive
Jackrabbit
Lucene Core
Lucene.Net
MetaModel
OFBiz
OpenJPA
ORC
Phoenix
Pig
Torque
ZooKeeper

Big Data

Accumulo
Airavata
Ambari
Avro
Beam
Bigtop
BookKeeper
Calcite
Camel
CarbonData
Crunch
Daffodil
DataFu
Drill
Edgent
Flink
Flume
Fluo
Fluo Recipes
Fluo YARN
Giraph
Helix
Kibble
Knox
Kudu
Lens
MapReduce
OODT
Oozie
ORC
Parquet
PredictionIO
REEF
Samza
Spark
Sqoop
Storm
Tajo
Tez
Trafodion
Zeppelin

Cloud

Airavata
Brooklyn
Camel
CloudStack
Helix
Ignite
jclouds
Libcloud
Mesos
Milagro
VCL

Security

Fortress
Kerby
Santuario
Syncope

Content

Annotator
Any23
Clerezza
cTAKES
FreeMarker
JSPWiki
ManifoldCF
OFBiz
Open Climate Workbench
OpenOffice
PDFBox
POI
Roller
Taverna
Tika
WhimsyVCL

Network server

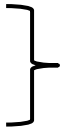
ActiveMQ
Airavata
Axis2
Camel
Cayenne
Celix
Cocoon
CouchDB
CXF
Directory
Directory Server
Felix
FtpServer
Geronimo
Guacamole
HTTP Server
HttpComponents Core
Ignite
Jackrabbit
JAMES
Karaf
MINA
mod_ftp
OFBiz
OpenMeetings
Qpid
ServiceMix
Solr
SSHD
Synapse
Thrift
Tomcat
TomEE
Vysper

Good design

Design software as a collection of services

Well-designed services are

- Well-defined & documented
- Have minimal dependencies



Can be developed and tested separately

- Easy to test
- Language independent & platform independent

Will you be able to access your Java service from a Go or Python program?
Does the service only work with an iOS app?

KISS: Keep It Simple, Stupid!

- Make services easy to use
- Will others be able to make sense of it?
- Will you understand your own service a year from now?
- Is it easy to test and validate the service?
- Will you (or someone else) be able to fix problems?

> *Everyone knows that debugging is twice as hard as writing a program in the first place. So if you're as clever as you can be when you write it, how will you ever debug it?*
>
> *– Brian Kernighan*

http://en.wikipedia.org/wiki/KISS_principle

KISS: Keep It Simple, Stupid!

- Don’t over-engineer or over-optimize
  … at least not initially
- Understand where potential problems may be
- Redesign what’s needed

Good API and protocol design is crucial

- Interfaces stick around for a long time
  - You can re-engineer everything under them if you have to
- Interfaces should make sense

Communication

- Sockets are still the core of interacting with services
- RPC (& remote objects) great for local, non-web services

  … but think about what happens when things fail

  - Will the service keep re-trying?
  - How long before it gives up?
  - Was any state lost on the server?
  - Can any failover happen automatically?
- Are you using something that only works with Python or Windows?

Interface Mechanisms

- Efficiency & interoperability
  … and avoid writing your own parser
- REST/JSON popular for web-based services
  - XML is still out there … but not efficient and used less and less
  - REST/JSON great for public-facing & web services … but still not efficient
- But you don't need to use web services for all interfaces
  - There are benefits … but also costs
- Use automatic code generation from interfaces (if possible)
  - It's easier and reduces bugs

Efficient & portable marshaling

- Google Protocol Buffers gaining in lots of places
  - Self-describing schemas – defines the service interface
  - Versioning built in
  - Supports multiple languages
  - Really efficient and compact
- Investigate successors … like Cap'n Proto (capnproto.org)
  - Pick something with staying power –
    You don't want to rewrite a lot of code when your interface generator is no longer supported
- Lots of RPC and RPC-like systems out there – many use JSON for marshaling
  - Supported by C, C++, Go, Python, PHP, etc.

Fundamental Issues

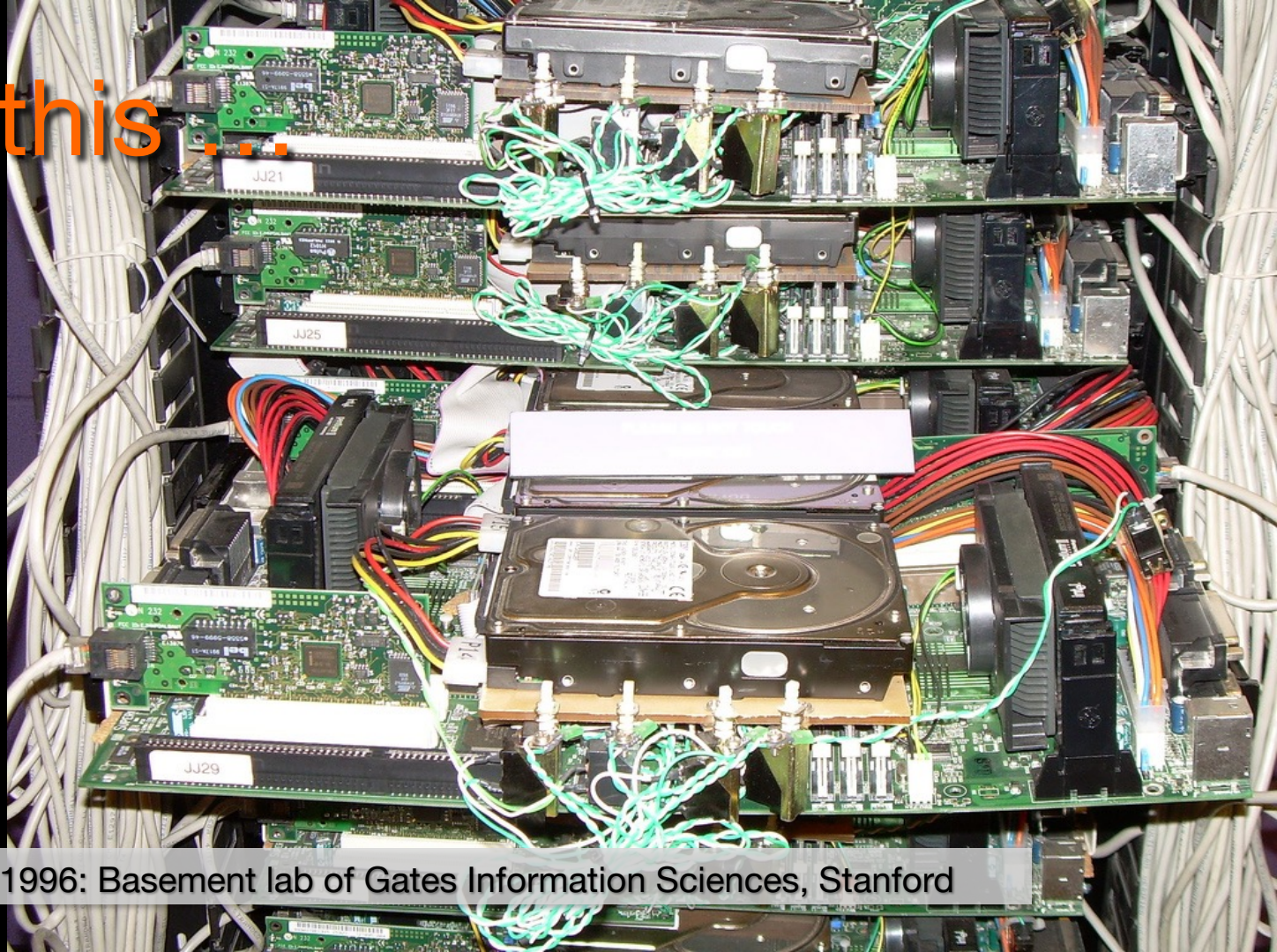
- Partial failure
- Concurrency
- Consistency
- Latency
- Security

Design for Scale

Prepare to go from this…

1996: Basement lab of Gates Information Sciences, Stanford

… and this …



1996: Basement lab of Gates Information Sciences, Stanford

Google Data Center: Douglas County, Georgia

http://www.google.com/about/datacenters/gallery/

… and this

Google Data Center: Council Bluffs, Iowa

http://www.google.com/about/datacenters/gallery/

Facebook's Data Center: Prineville, Oregon

Photo by Katie Fehrenbacher. From "A rare look inside Facebook's Oregon data center", Aug 17, 2012, © 2012 GigaOM. Used with permission
http://gigaom.com/cleantech/a-rare-look-inside-facebooks-oregon-data-center-photos-video/

Scalability

- Design for scale
  - Be prepared to re-design … but start off in the right direction
- Something that starts as a collection of three machines might grow
  - Will the algorithms scale?
- Don’t be afraid to test alternate designs
  - Easier to do sooner than later

Design for scale & parallelism

- Figure out how to partition problems for maximum parallelism
  - Shard data
  - Concurrent processes with minimal or no IPC
  - Do a lot of work in parallel and then merge results
- Design with scaling in mind – even if you don't have a need for it now
  - E.g., MapReduce works on 2 systems or 2,000
- Consider your need to process endless streaming data vs. stored data
- Partition data for scalability
  - Distribute data across multiple machines (e.g., Dynamo, Bigtable, HDFS)
- Use multithreading
  - It lets the OS take advantage of multi-core CPUs

Design for High Availability

Availability

- Everything breaks: hardware and software *will* fail
  - Disks, even SSDs
  - Routers
  - Memory
  - Switches
  - ISP connections
  - Power supplies; data center power, UPS systems
- Even amazingly reliable systems will fail
  - Put together 10,000 systems, each with 30 years MTBF
  - Expect an average of a failure per day!

Building Software Systems at Google and Lessons Learned, Jeff Dean, Google
http://static.googleusercontent.com/external_content/untrusted_dlcp/research.google.com/en/us/people/jeff/Stanford-DL-Nov-2010.pdf

Availability

- Google's experience
  - 1-5% of disk drives die per year (300 out of 10,000 drives)
  - 2-4% of servers fail – servers crash at least twice per year
- Don't underestimate human error
  - Service configuration
  - System configuration
  - Router, switches, cabling
  - Starting/stopping services

Building Software Systems at Google and Lessons Learned, Jeff Dean, Google
http://static.googleusercontent.com/external_content/untrusted_dlcp/research.google.com/en/us/people/jeff/Stanford-DL-Nov-2010.pdf

It's unlikely *everything* will fail at once

- Software must be prepared to deal with partial failure
- Can your program handle a spontaneous loss of a socket connection?
- Watch out for default behavior on things like RPC retries
  - Is retrying what you really want … or should you try alternate servers?
  - Failure breaks function-call transparency – RPC isn't always as pretty as it looks in demo code
  - Handling errors often makes code big and ugly
  - What happens if a message does not arrive?
    - Easier with designs that support asynchronous sending and responses and handle timeouts

Replication addresses availability

- Replicated state machines provide same-sequence updates
  - We use protocols like Raft or Paxos to help with this
- Partitions *will* happen – design with them in mind
  - You cannot violate the CAP theorem: choose availability or consistency!
- Decide on stateful vs. stateless services
  - Stateful services mean keeping track of past requests

Fault Detection

- Detection
  - Heartbeat networks: watch out for high latency & partitions
  - Software process monitoring
  - Software heartbeats & watchdog timers
  - How long is it before you detect something is wrong and do something about it?
- What if a service is not responding?
  - You can have it restarted … but a user may not have patience
    - Maybe fail gracefully
    - Or, better yet, have an active backup
- Monitoring, logging, and notifications
  - It may be your only hope in figuring out what went wrong with your systems or your software
  - But make it useful and easy to find

Think about the worst case

- Deploy across multiple Availability Zones (AZs)
  - Handle data center failure
- Don’t be dependent on any one system for the service to function
- Prepare for disaster recovery
  - Periodic snapshots
  - Long-term storage of data (e.g., Amazon Glacier)
  - Recovery of all software needed to run services (e.g., via Amazon S3)

Design for High Performance & Low Latency

Design for Low Latency

- Users hate to wait
  - Amazon: every 100ms latency costs 1% sales
  - Google: extra 500ms latency reduces traffic by 20%
  - Sometimes, milliseconds really matter, like high frequency trading

    E.g., 2010: Spread Networks built NYC-Chicago fiber: reduced RTT from 16 ms to 13 ms
- Avoid moving unnecessary data
- Reduce the number of operations through clean design
  - Particularly number of API calls

Design for Low Latency

- Reduce amount of data per remote request
  - Efficient RPC encoding & compression (if it makes sense)
- Avoid extra hops
  - E.g., Dynamo vs. CAN or finger tables
- Do things in parallel
- Load balancing, replication, geographic proximity
- CPU performance scaled faster than networks or disk latency
- You cannot defeat physics

  It's 9,567 miles (15,396 km) from New Jersey to Singapore

  = 75 ms via direct fiber … but you don't have a direct fiber!

Asynchronous Operations

Some things are best done asynchronously

- Provide an immediate response to the user while still committing transactions or updating files
- Replicate data eventually
  - Opportunity to balance load by delaying operations
  - Reduce latency: *the delay to copy data does not count in the transaction time!*
  - But watch out for consistency problems (*can you live with them?*)
- But if you need consistency, use frameworks that provide it
  - Avoid having users reinvent consistency solutions

Know the cost of everything

Don’t be afraid to profile!

- CPU overhead
- Memory usage of each service
- RPC round trip time
- UDP vs. TCP
- Time to get a lock
- Time to read or write data
- Time to update all replicas
- Time to transfer a block of data to another service
  … in another datacenter?

Systems & software change frequently

- Don’t trust the web … find out for yourself

Testing, profiling, and optimization

- Continuously benchmark and test
  - Avoid future surprises
- Optimize critical paths
  - Watch out for overhead of interpreted environments
  - Consider languages that compile, such as go

Understand what you're working with

- Understand underlying implementations
  - The tools you're using & their repercussions
  - Scalability
  - Data sizes
  - Latency
  - Performance under various failure modes
  - Consistency guarantees
- Design services to hide the complexity of distribution from higher-level services
  - E.g., MapReduce, Pregel, Dynamo

Don’t do everything yourself

- There’s a lot of stuff out there
  - Use it if it works & you understand it

Security

Security is *really* difficult to get right

- Authentication, encryption, key management, protocols
- Consider using API gateways for service authorization
- Secure, authenticated communication channels
- Authorization service via OAuth OpenID Connect
- Pay attention to how & where keys are stored and managed
- Employ Zero Trust – don't assume you can protect the perimeter of your network

Security should not be an afterthought!

Design for Test & Deployment

Test & deployment

- Test partial failure modes
  - What happens when some services fail?
  - What if the network is slow vs. partitioned?
- Unit tests & system tests
  - Unit testing
  - Integration & smoke testing (build verification): see that the system seems to work
  - Input validation
  - Scale: add/remove systems for scale
  - Failure
  - Latency
  - Load
  - Memory use over time

Infrastructure as code

- Version-managed & archived configurations
- Never a need for manual configuration
- Create arbitrary number of environments
- Deploy development, test, & production environments
- E.g., TerraForm

Blue/Green deployment

- Run two identical production environments
- Two versions of each module of code: *blue* & *green*
  - One is live and the other idle
- Production points to code versions of a specific color
- Staging environment points to the latest version of each module
  - Deploy new code to non-production color
  - Test & validate
  - Switch to new deployment color
- Simplifies rollback

Eight Fallacies of Distributed Computing

1. The network is reliable
2. Latency is zero
3. Bandwidth is infinite
4. The network is secure
5. Topology doesn't change
6. There is one administrator
7. Transport cost is zero
8. The network is homogeneous

By L. Peter Deutsch et al. @ Sun Microsystems c. 1994+

A Few More Fallacies of Distributed Computing

9. Clocks are synchronized
10. Test environment is the same as the production environment
11. Users will use your interfaces correctly
12. All systems will run the same version of the software
13. Your service will never be a target of security attacks

Paul Krzyzanowski c. 2021

A couple more fallacies

- Clocks are synchronized
- Test environment is the same as the production environment
- Users will use your interfaces correctly
- All systems will run the same version of the software
- Your service will never be a target of security attacks

The End