Chaos Engineering

Building confidence in your application and team through failure experimentation

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October 29, 2020

Administrivia

Homework 4B was due Nov 3rd, **now the 4th.**

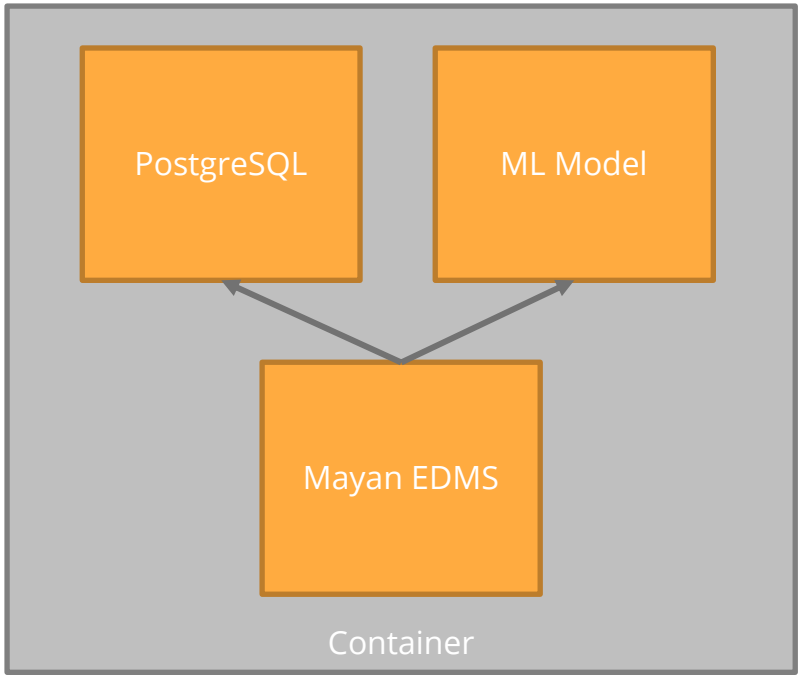
Homework 4C was due Nov 5th, **now the 6th.**

Learning Goals

Identify the need for chaos and resilience engineering

Understand the principles of chaos engineering

Exercise: Monolithic Application



What kind of failures can happen here?

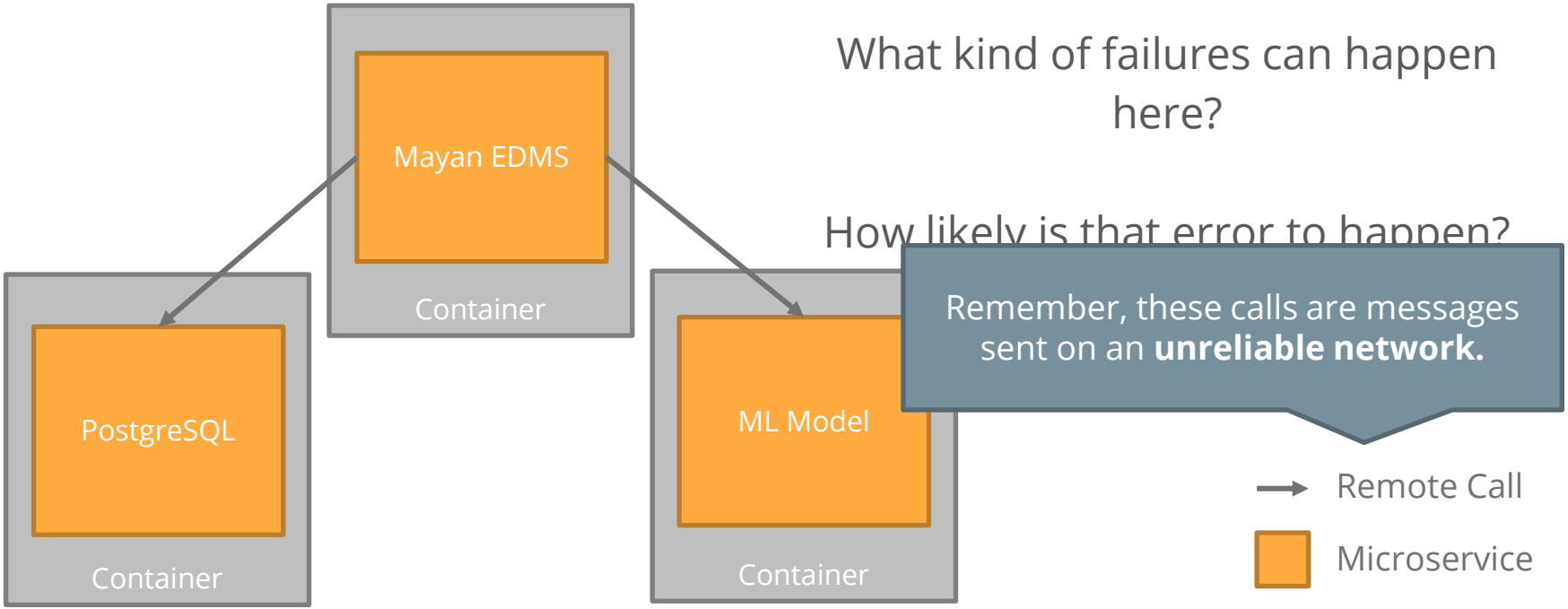
How likely is that error to happen?

How do I fix it?

Process Call

Microservice

Exercise: Microservice Application



Failures in Microservice Architectures

1. Network may **be partitioned**
2. Server instance **may be down**
3. Communication between services may **b**
4. Server **could be overloaded** and respon
5. Server **could run out of** memory or CPU

All of these issues **can be indistinguishable** from one another!

Making the calls across the network to multiple machines makes the probability that the system is operating under failure **much higher.**

These are the problems of **latency** and **partial failure.**

Where Do We Start?

How do we even **begin to test these scenarios?**

Is there any **software** that can be used to test these types of failures?

Let's look at a **few ways** companies do this.

Game Days

Purposely **injecting failures** into critical systems in order to:

- Identify **flaws** and “latent defects”
- Identify **subtle dependencies** (which may or may not lead to a flaw/defect)
- Prepare a **response** for a disastrous event

Comes from “resilience engineering” typical in high-risk industries

Practiced by Amazon, Google, Microsoft, Etsy, Facebook, Flickr, etc.

Game Days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Our applications are built on and with **“unreliable”** components

Failure is inevitable (fraction of percent; at Google scale, ~multiple times)

Goals:

- **Preemptively trigger** the failure, observe, and fix the error
- Script testing of **previous failures** and ensure system remains resilient
- Build the necessary relationships between teams **before** disaster strikes

Example: Amazon GameDay


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Full data center destruction (Amazon EC2 region)

- ta center will be taken offline
- er will be taken offline
- Only advance notice (months) that a GameDay **will be happening**
- **Real failures in the production environment**

Not all failures can be actually performed and must be **simulated!**

Discovered **latent defect** where the monitoring infrastructure responsible for detecting errors and paging employees **was located in the zone of the failure!**


RESILIENCE TESTING

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Learning to Embrace Failure

Yes, and the exercise should be designed to make people feel a little uncomfortable. The truth is that **things often break in ways that people cannot possibly imagine.**

John Allspaw
Former CTO
Etsy

I've got a crazy story...

Kelly Sommers
Cassandra MVP

Google GameDays


RESILIENCE TESTING

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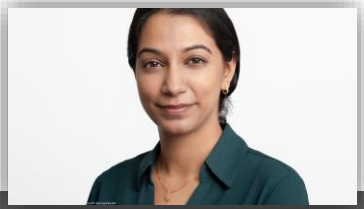
Experiments take roughly **24 – 96 hours**:

- **00 - 24h:** the **initial response**, the appearance of the ‘big’ problems.
- **24 – 48h:** team to team **testing and response**, bi-directional testing
- **72 – 96h:** exhaustion; part of the test to identify the **human response**

> …in a real emergency, you might not have the option of handing off work at the end of your shift.



Kripa Krishnan
Director, Cloud Ops & Site Reliability Engineering
Google

AWS Outage: April 21, 2011

EC2 **outage** in us-east-1 (Northern Virginia)

Outage **affects**:

- Foursquare
- Quora
- Reddit

Outage results in **performance problems** and in some cases **data loss**

AWS Outage: April 21, 2011

At 12:47 AM PDT on April 21st, a **network change** was performed as part of our **normal AWS scaling** activities in a single Availability Zone in the US East Region. The configuration change was to upgrade the capacity of the primary network. During the change, one of the standard steps is to shift traffic off of one of the redundant routers in the primary EBS network to allow the upgrade to happen. **The traffic shift was executed incorrectly and rather than routing the traffic to the other router on the primary network, the traffic was routed onto the lower capacity redundant EBS network.** For a portion of the EBS cluster in the affected Availability Zone, this meant that they did not have a functioning primary or secondary network because traffic was purposely shifted away from the primary network and **the secondary network couldn't handle the traffic level it was receiving.** As a result, many EBS nodes in the affected Availability Zone were completely isolated from other EBS nodes in its cluster. Unlike a normal network interruption, this change disconnected both the primary and secondary network simultaneously, leaving the affected nodes completely isolated from one another.

AWS Outage: April 21, 2011

When this network connectivity issue occurred, a large number of EBS nodes in a single EBS cluster **lost connection to their replicas.** When the incorrect traffic shift was rolled back and network connectivity was restored, **these nodes rapidly began searching the EBS cluster for available server space where they could re-mirror data.** Once again, in a normally functioning cluster, this occurs in milliseconds. In this case, because the issue affected such a large number of volumes concurrently, the **free capacity of the EBS cluster was quickly exhausted**, leaving many of the nodes "stuck" in a loop, continuously searching the cluster for free space. This quickly led to a "re-mirroring storm," where a **large number of volumes were effectively "stuck" while the nodes searched the cluster** for the storage space it needed for its new replica. At this point, about 13% of the volumes in the affected Availability Zone were in this "stuck" state.

Primary Outage

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After the initial sequence of events described above, t entered the re-mirroring storm and exhausted its avai volume API in particular) was configured with a long t plane has a regional pool of available threads it can u had no ability to service API requests and began to fa disabled all new Create Volume requests in the affecti

Two factors caused the situation in this EBS cluster to when they could not find space, but instead, continue to fail when they were concurrently closing a large nu however, during this re-mirroring storm, the volume c bug, resulting in more volumes left needing to re-mir

By 5:30 AM PDT, error rates and latencies again increa EC2 instance, the EBS nodes with the volume data, an replica and recognized by the EC2 instance as the plac of the race condition described above, the volume of calls increased as the system retried and new request team began disabling all communication between the affected Availability Zone (we will discuss recovery of

A large majority of the volumes in the degraded EBS team developed a way to prevent EBS servers in the d other essential communication between nodes in the becoming "stuck". Before this change was deployed, t becoming "stuck". However, volumes were also slowly that when this change was deployed, the total "stuck"

Customers also experienced elevated error rates until zone. This occurred for approximately 11 hours, from were able to create EBS-backed EC2 instances but were experiencing significantly-elevated error rates and latencies. New EBS-backed EC2 launches were being affected by a specific API in the EBS control plane that is only needed for attaching new instances to volumes. Initially, our alarming was not fine-grained enough for this EBS control plane API and the launch errors were overshadowed by the general error from the degraded EBS cluster. At 11:30 AM PDT, a change to the EBS control plane fixed this issue and latencies and error rates for new EBS-backed EC2 instances declined rapidly and returned to near-normal at Noon PDT.

Recovering EBS in the Affected Availability Zone

By 12:04 PM PDT on April 21st, the outage was contained to the one affected Availability Zone and the degraded EBS cluster was stabilized. APIs were working well for all other Availability Zones and additional volumes were no longer becoming "stuck". Our focus shifted to completing the recovery. Approximately 13% of the volumes in the Availability Zone remained "stuck" and the EBS APIs were disabled in that one affected Availability Zone. The key priority became bringing additional storage capacity online to allow the "stuck" volumes to find enough space to create new replicas.

ot reuse the failed node until every data replica is successfully re-
did not want to re-purpose this failed capacity until we were sure we
pacity to replace that capacity in the cluster. This required the time-
capacity into the degraded EBS cluster. Second, because of the
ed the cluster in the step described above), the team had difficulty
s to allow negotiation to occur with the newly-built servers without
as the team had to navigate a number of issues as they worked
ificant amounts of new capacity and working through the replication
ffected Availability Zone were restored by 12:30PM PDT on April
pective of the attached EC2 instances because some were blocked
nce and elect a new writable copy.

ess to the affected Availability Zone and restoring access to the
raded EBS nodes to the EBS control plane and vice versa. This effort
API access online to the impacted Availability Zone centered on
instance of the EBS control plane, one we could keep partitioned to
og. We rapidly developed throttles that turned out to be too coarse-
the morning of April 23rd, we worked on developing finer-grain
s. Initial tests of traffic against the EBS control plane demonstrated
finished enabling access to the EBS control plane to the degraded
negotiate which replica would be writable, to once again be usable
Availability Zone.

nes in the Region. The recovery of the remaining 2.2% of affected
the event as an extra precaution against data loss while the event
and began processing batches through the night. At 12:30 PM PDT
ected volumes. At this point, the team began forensics on the
0 PM PDT, the team began restoring these. Ultimately, 0.07% of the

"RDS"). RDS depends upon EBS for database and log storage, and as

ultiple Availability Zones ("multi-AZ"). Single-AZ database instances
d if one of the EBS volumes it was relying on got "stuck". In the
elatively-bigger portion of the RDS population than the
ases aggregate I/O capacity for database workloads under normal
l the volume is restored. The percentage of "stuck" single-AZ
d. The percentage of "stuck" single-AZ database instances in the
hours, and the rest recovered throughout the weekend. Though we
lity Zone had an underlying EBS storage volume that was not
option to initiate point-in-time database restore operations.

RDS multi-AZ deployments provide redundancy by synchronously replicating data between two database replicas in different Availability Zones. In the event of a failure on the primary replica, RDS is designed to automatically detect the disruption and fail over to the secondary replica. Of multi-AZ database instances in the US East Region, 2.5% did not automatically failover after experiencing "stuck" I/O. The primary cause was that the rapid succession of network interruption (which partitioned the primary from the secondary) and "stuck" I/O on the primary replica triggered a previously un-encountered bug. This bug left the primary replica in an isolated state where it was not safe for our monitoring agent to automatically fail over to the secondary replica without risking data loss, and manual intervention was required. We are actively working on a fix to resolve this issue.

Cornerstones of Resilence

"[resilient is the] **ability to sustain operations before, during, and after** an unexpected disturbance"

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1. **Anticipation:** know what to expect
2. **Monitoring:** know what to look for
3. **Response:** know what to do
4. **Learning:** know what just happened (e.g, postmortems)

Anticipation


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"[…] get people throughout the organization to start building their anticipation muscles by **thinking about what might possibly go wrong.**"

These experiments form a cycle where developers **begin to anticipate what might possibly go wrong** during development, which adds to the overall resilience of the system.

Response: Etsy's Substitution Test


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Developer runs command that brings down the site

- Grab another engineer who had no involvement in the incident
- Explain the context of the problem
- Fill developer in on the details known by the developer at the time
- Ask what they would do

Developer says they would run the same command almost every time

Identify the reasons for why this seemed the right decision at the time

Some Example Google Issues


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Learning to Embrace Failure

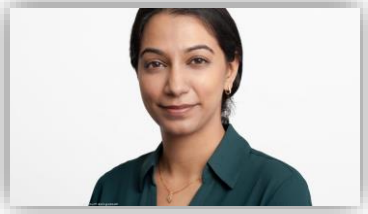
Terminate network in Sao Paulo for testing:

- Hidden dependency takes down links in Mexico which would have remained undiscovered without testing

Turn of data center to find that machines won't come back:

- Ran out of DHCP leases (for IP address allocation) when a large number of machines come back online unexpectedly.

Complexities are introduced as new capabilities are developed. […] It gets progressively **harder to see where our dependencies are and what might lead to cascading failures.**



Netflix: Background


FOCUS: DEVOPS

Chaos Engineering

Started as a **DVD-by-mail business** because Reed Hastings was annoyed with Blockbuster late fees

Problem: when new movies come out, there's **only hundreds** of DVDs to **service multiple thousands of demand**

Stream movies instead of purchasing and mailing DVDs out to customers

Problem: must **purchase enough compute to handle peaks** (7pm+ weekends) vs valleys (noon, weekday)

Netflix: Cloud Computing


Chaos Engineering

Significant deployment in Amazon Web Services in order to remain **elastic** in times of high and low load (first public, 100% w/o content delivery.)

Pushes code into production and modifies runtime configuration hundreds of times a day

Key metric: **availability**

a customer who can't watch a video because of a service outrage **might not be a customer for long.**

"Chaos Engineering"
Basiri *et al., IEEE Software 2016*

Chaos Engineering: The History


Chaos Engineering

Experimentation to **build confidence** around a system to **withstand turbulent conditions** in pr

Chaos Monkey has **proven successful**; today all Netflix engineers **design their services to handle instance failures as a matter of course.**

Netflix's Simian Army

- *(the original)* Chaos Monkey:
  Randomly **terminates** EC2 instances in production
- Chaos Kong:
  Simulates the failure of an entire EC2 region in AWS
- Latency Monkey:
  Injects latency to simula
  services react appropriately

Have Chaos Monkey crash development instances, too!

Netflix UI: AppBoot

What happens if the bookmark service **is down?**

My List

Bookmarks

User Profiles

Ratings

Recommendations

Search

AppBoot

Remote Call

Microservice

Principles of Chaos Engineering

1. Build a **hypothesis** around steady state behavior

2. Vary **real-world events**
   experimental events, crashes, etc.

3. Run **experiments** in production
   control group vs. experimental group
   draw conclusions, invalidate hypothesis

4. **Automate experiments** to run continuously

Does everything seem to be **working properly?**

Are users **complaining?**

However, **"works properly" is too vague** a basis for designing experiments.

Graceful Degradation: Anticipating Failure

Allow the system to degrade in a way it's still usable

Fallbacks:

- Cache miss due to failure of cache;
- Go to the bookmarks service and use value at possible latency penalty

Personalized content, use a reasonable default instead:

- What happens if **recommendations** are unavailable?
- What happens if **bookmarks are unavailable?**

…default to starting videos at the beginning rather than providing a "resume from previous location" option.

Steady State Behavior

Back to **quality attributes: availability!**

SPS is the **primary indicator** of the system's overall health.

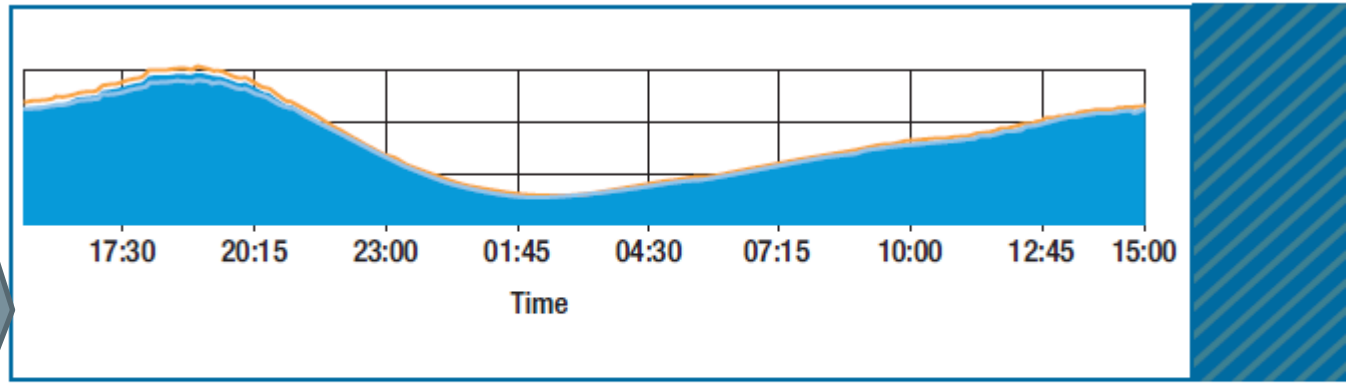


FIGURE 2. A graph of SPS ([stream] starts per second) over a 24-hour period. This metric varies slowly and predictably throughout a day. The orange line shows the trend for the

Ultimately, what we care about is whether users can **find content to watch and successfully watch it.**

Netflix UI: AppBoot

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Microservice

AppBoot: Bookmarks Down Scenario (Imaginary)

SPS as **core metric.**

Experiment 1:
Outage of bookmarks service causes UI to fail to load, SPS decreases. Code fixed to hide bookmarks if call fails.

Experiment 2:
Outage of bookmarks service hides booksmarks on UI, SPS stays normal.

Exercise: Quality Attributes

1. What would a quality attribute be for an **e-commerce website** to characterize the stead-state behavior of the system?

2. What would a quality attribute be for an **advertisement platform** to characterize the stead-state behavior of the system?

3. What would a quality attribute be for an **admissions system** to characterize the stead-state behavior of the system?

Making Hypotheses

No **trivial** hypotheses

- Overloading the system will increase the CPU, etc.
- Hypothesis should be made w.r.t overall system health metric

Monitor finer-grained metrics

- Monitor the CPU, other resources
- Indicators of degraded mode operation, etc.
- Use alerting to identify these issues to catch them early and anticipate

Varying Real-World Events

1. Clients send malformed requests
2. Servers may send malformed responses
3. Servers die
4. Hard disks fill up
5. Memory is exhausted
6. CPU is overloaded
7. Latencies spike
8. **Load from clients can spike**

A recent study reported that 92% of catastrophic system failures **resulted from incorrect handling of nonfatal errors.**

Sampling of Netflix's Candidate Faults

1. **Terminate** virtual machine instances
2. **Inject latency** into requests between different services
3. **Fail requests** between services
4. **Fail an entire service**
5. Make an entire Amazon **region unavailable**

Two Example Netflix Errors


FOCUS: DEVOPS

Chaos Engineering

1. Server is overloaded and takes longer and longer to respond
   Clients requests are placed in a queue to be serviced
   Local queue becomes exhausted, run out of memory
   Client service crash

2. Client makes a request to a server that uses a cache
   Error *(transient)* is returned to the client
   Server caches the error
   Future clients read the cached error value

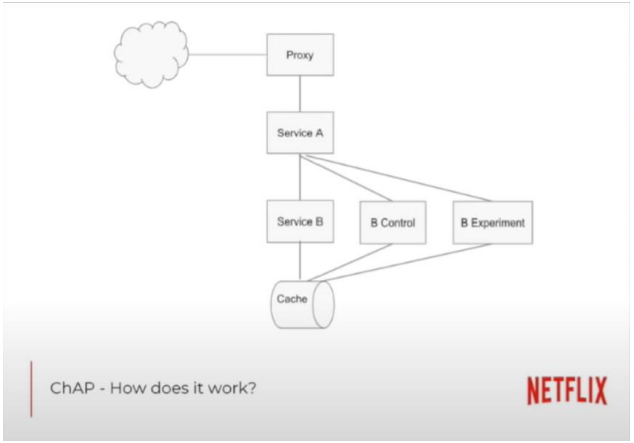
Chaos Engineering as Continuous Process

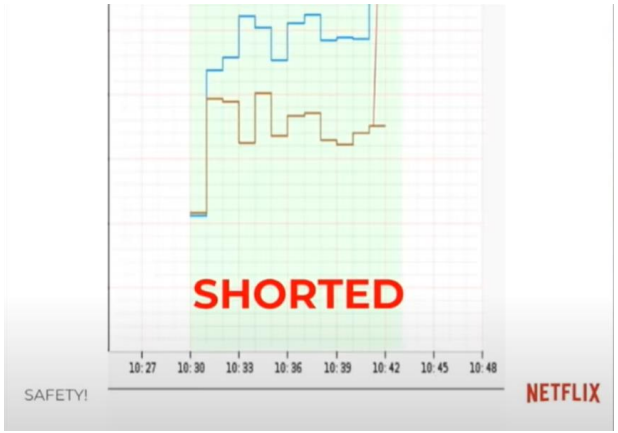
Our system at Netflix changes **continuously.**

Because of these changes, our confidence in past experiments' results **decreases over time.**

Chaos Monkey **runs continuously** during weekdays, and we run Chaos Kong exercises monthly. (2016)

Netflix Today: CHaP





Automatic experimentation and failure injection with FIT → **Automatic instrumentation** of key performance metrics → **Automatic termination** based on key metrics

Automatic experiment design with Monocle

reference: https://www.youtube.com/watch?v=3WRVgC8SiGc

How to run a Chaos Experiment

1. Define steady-state as some **measurable output of a system** that indicates normal behavior

2. Hypothesize that this steady state will continue in both the **control group** and **experimental group**

3. Introduce variables that **reflect real-world events** such server crashes, hard drives malfunctioning, and network connections being severed

4. Try to **disprove the hypothesis** by looking for a difference in steady state between the control group and the experimental group.