Chaos Engineering

Building confidence in your application and team through failure experimentation

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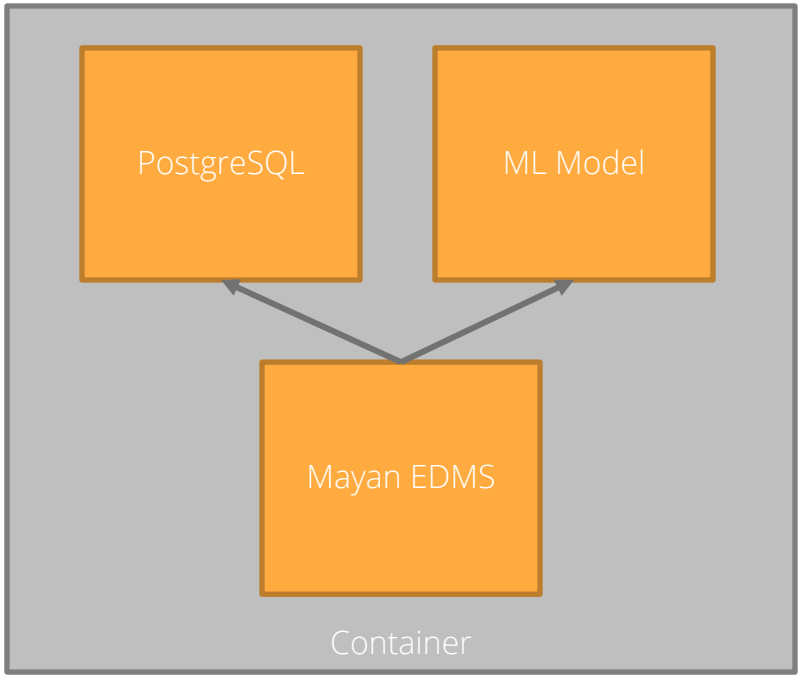
Exercise: Monolithic Application



What kind of failures can happen here?

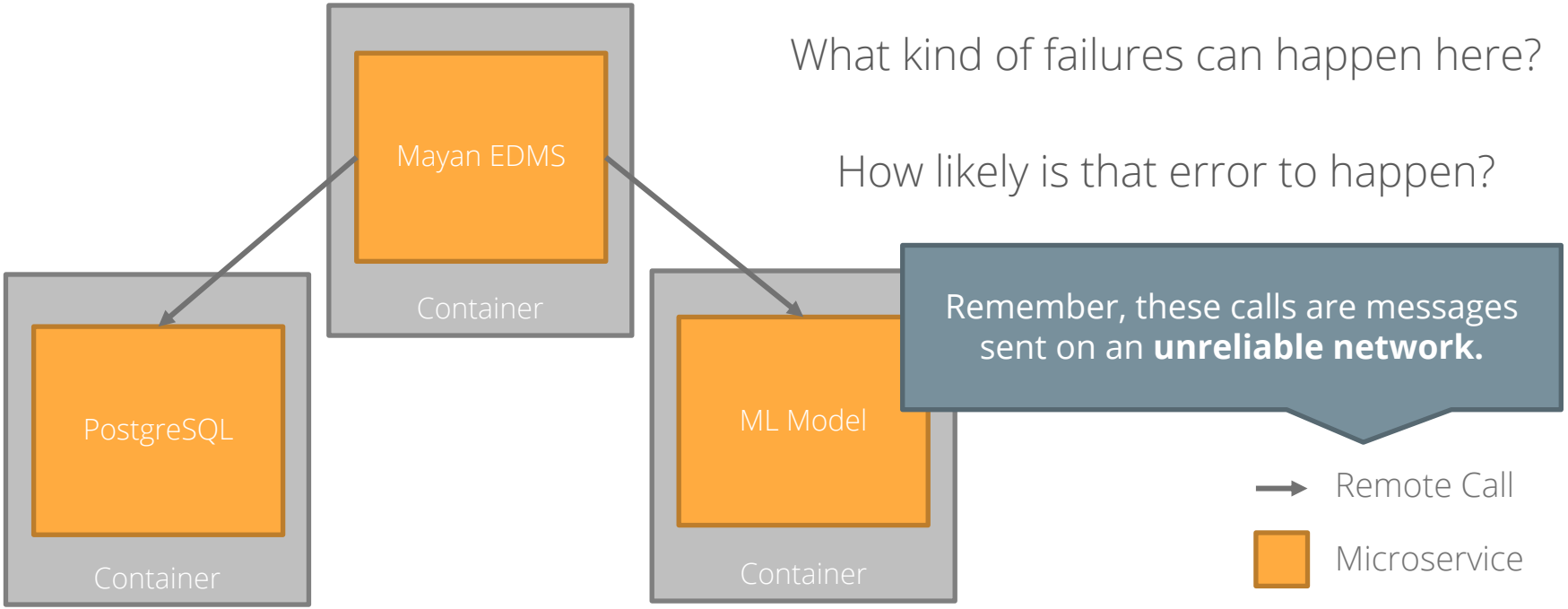
How likely is that error to happen?

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 be
4. Server could be overloaded and response
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


RESILIENCE TESTING 6

acmqueue Case Study
Learning to Embrace Failure

A discussion with Jesse Robbins, Kripa Krishnan, John Allspaw, and Tom Limoncelli

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In the early 2000s, Amazon created GameDay, a program designed to increase resilience by purposely injecting major failures into critical systems semi-regularly to discover flaws and subtle dependencies. Discovery of these problems led to a company's systems, software, and people in the course of preparing for a response to a disastrous event. Widespread acceptance of the GameDay concept has taken a few years, but many companies now see its value and have started to adapt their own versions. This discussion considers some of those experiences.

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- 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.

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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

Full data center destruction (Amazon EC2 region)

- center will be taken offline
- will be taken offline
- Only a[illegible] 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!


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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…

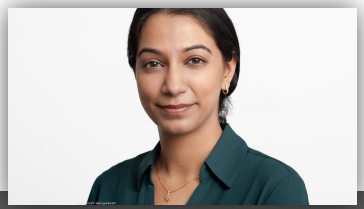
Kelly Sommers
Cassandra MVP

Google GameDays

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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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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cluster, this occurs in milliseconds. In this case, becau
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while the nodes searched the cluster for the storage s

After the initial sequence of events described above, t
entered the re-mirroring storm and exhausted its ava
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 affect

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, ar
replica and recognized by the EC2 instance as the pla
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
egotiate 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

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


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In the early 2000s, Amazon created GameDay, a program designed to increase resilience by purposely injecting major failures into critical systems semi-regularly to discover flaws and subtle dependencies. GameDay combines knowledge of how to fix a company's systems, software, and people in the course of preparing for a response to a disastrous event. Widespread acceptance of the GameDay concept has taken a few years, but many companies now see its value and have started to adapt their own versions. This discussion considers some of those experiences.

Participants include Jesse Robbins, the architect of GameDay at Amazon, where he was officially called the Master of Disaster. Robbins used his training as a firefighter in developing GameDay, following similar principles of incident response. He left Amazon in 2006 and founded the Velocity Web Performance and Operations Conference, the annual O'Reilly meeting for people building at Internet scale. In 2008, he founded Opscode, which makes Chef, a popular framework for infrastructure automation. Running GameDay operations on a slightly smaller scale is John Allspaw, senior vice president of technological operations at Etsy. Allspaw's experience includes stints at Salon.com and Friendster before joining Flickr as engineering manager in 2005. He moved to Etsy in 2010. He also recently took over as chair of the Velocity conference from Robbins.

Google's equivalent of GameDay is run by Kripa Krishnan, who has been with the program almost from the time it started six years ago. She also works on other infrastructure projects, most of which are focused on the protection of users and their data.

Moderating this discussion is a Google colleague, Tom Limoncelli, who is a site reliability engineer (SRE)—Google's version administrator circle, he started out at Bell Labs and has written four books, most notably Time Management for System Administrators and The Practice of System and Network Administration.

TOM LIMONCELLI: Jesse, you've probably been involved in more GameDay exercises than anybody. What's the most important lesson you've taken away from that?

1

Some Example Google Issues


RESILIENCE TESTING 6

acmqueue Case Study
Learning to Embrace Failure

A discussion with Jesse Robbins, Kripa Krishnan, John Allspaw, and Tom Limoncelli

It's very nearly the holiday shopping season and something is very wrong at a data center handling transactions for one of the largest online retail operations in the country. Some systems have failed, and no one knows why. Stress levels are off the charts while teams of engineers work around the clock for three days trying to recover.

The good news is that it's not a real disaster—though it could have been. Instead, it's an exercise designed to teach a company how to adapt to the inevitable: system failure. Things break, disaster happens; failure is real. Although no one—perhaps least of all software developers and systems engineers—likes to believe they can't prevent failure, the key to preparing for it is first to accept it.

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1

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


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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

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**


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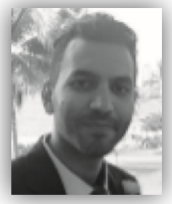
a customer who can't watch a video because of a service outrage **might not be a customer for long.**

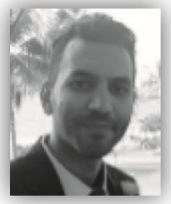


"Chaos Engineering"
Basiri *et al., IEEE Software 2016*

Chaos Engineering: The History

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

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 simulate
  react appropriately

Have Chaos Monkey crash development instances, too!

Netflix UI: AppBoot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Chaos Engineering

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

My List

Bookmarks

User Profiles

Ratings

Recommendations

Search

AppBoot

Remote Call

Microservice

Principles of Chaos Engineering


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Chaos Engineering

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

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

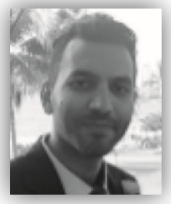
3. Run **experiments** in production
   control group vs. experimental group
   draw conclusions, invalidate hypothesis

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

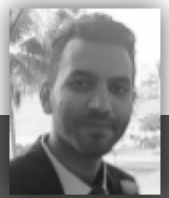
Fallbacks:

- 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.

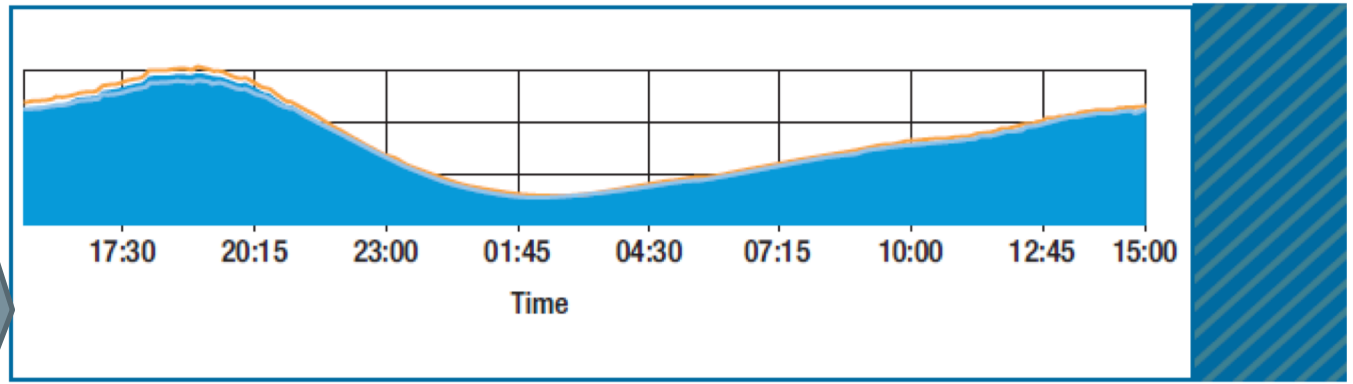


FIGURE 2. A graph of SPS ([stream] starts per second) over a 24-hour period. This metric varies slowly and predictably throughout a day. The orange line shows the trend for the

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

Exercise: Quality Attributes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1. What would a quality attribute be for an **e-commerce website** to chara 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


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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


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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**


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Chaos Engineering

Ali Basiri, Niosha Behnam, Ruud de Rooij, Lorin Hochstein, Luke Kosewski, Justin Reynolds, and Casey Rosenthal, Netflix

Modern software-based services are implemented as distributed systems with complex behavior and failure modes. Chaos engineering uses experimentation to ensure system availability. Netflix engineers have developed principles of chaos engineering that describe how to design and run experiments.

Two Example Netflix Errors


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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

Testing Timeouts

Request to service **waits 10 seconds** before **returning error** to the user

Which messages do we delay?

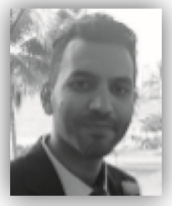
- There are two options: the **request** or the **response**
- **Which** do we delay and **why?**

How **long** do we delay the message?

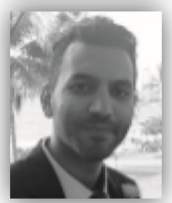
- There are **multiple correct answers** when choosing how long to delay

Chaos Engineering is a Continuous Process

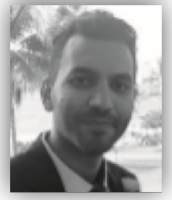
Our system at Netflix changes **continuously.**



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.

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How to run a Chaos Experiment


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Chaos Engineering

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.

Recitation

Run a **chaos experiment** using Mayan EDMS.
Come up with a hypothesis.
Run a chaos experiment for real using Gremlin!

My Favorite Bug: Doomstones

1. Cassandra is a **highly-available, eventually consistent** database
   Accepts writes during **network partitions**

2. To determine what value to keep when **nodes disagree after the network has healed**, the client **provides a clock** with each write
   and **the object with the newest recent clock wins.**

3. To delete a value, **you write a tombstone.**

4. **What happens when if delete a value and your computers clock is wrong?** (it's incorrectly set in the future.)