

Exploring Boto3 Events with MitmProxy

AWS Community Summit, September 22 2022



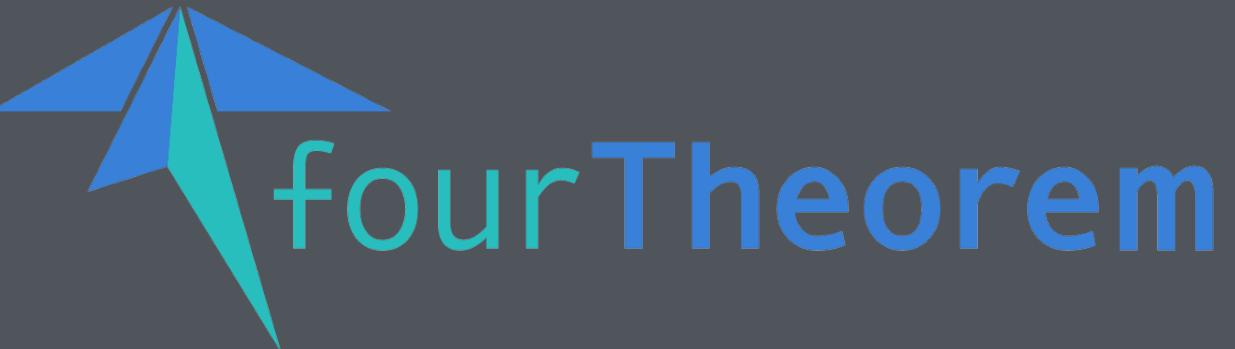
fourTheorem

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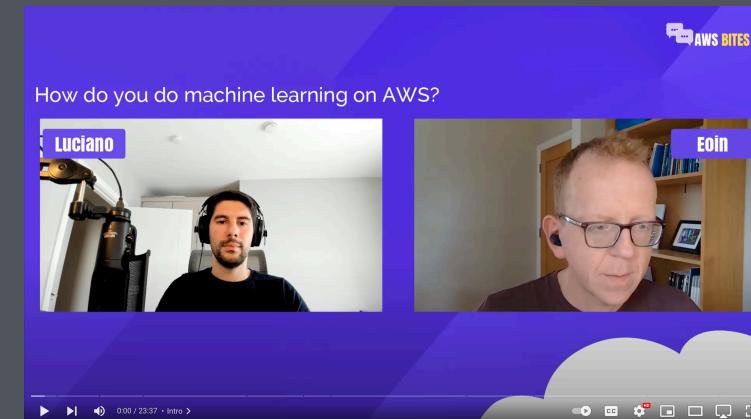
About Me

-  Senior Cloud Architect at fourTheorem
- Started my career in Sun Microsystems working on the Solaris OS in 1999 (when Y2K was a thing)
-  Been coding in Python for over 20 years
- Started kicking the tyres of AWS back when it was just S3, EC2 and SQS



<https://fourtheorem.com/>

Reach out to us at
hello@fourTheorem.com 



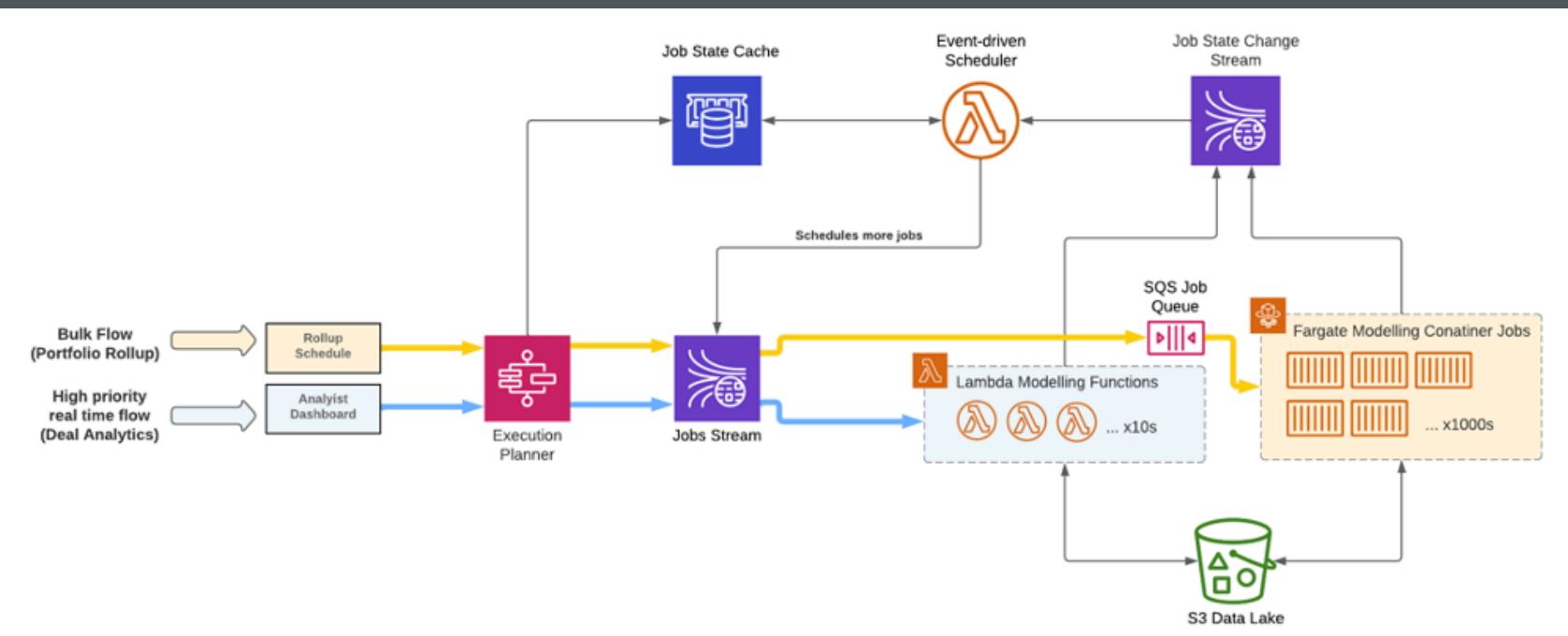
What I'll be Talking About

- A dash of AWS APIs
- Some boto3
- A bit of Python
- A pinch of HTTP
- A tiny bit of TLS
- A portion of mitmproxy



The Setup

Code base using Python and the boto3 library to talk to AWS



The core of the system runs a huge amount of computations spread over a large amount of jobs in either Lambda or Fargate containers¹

It wouldn't be unusual to have thousands of containers running many compute jobs per second.

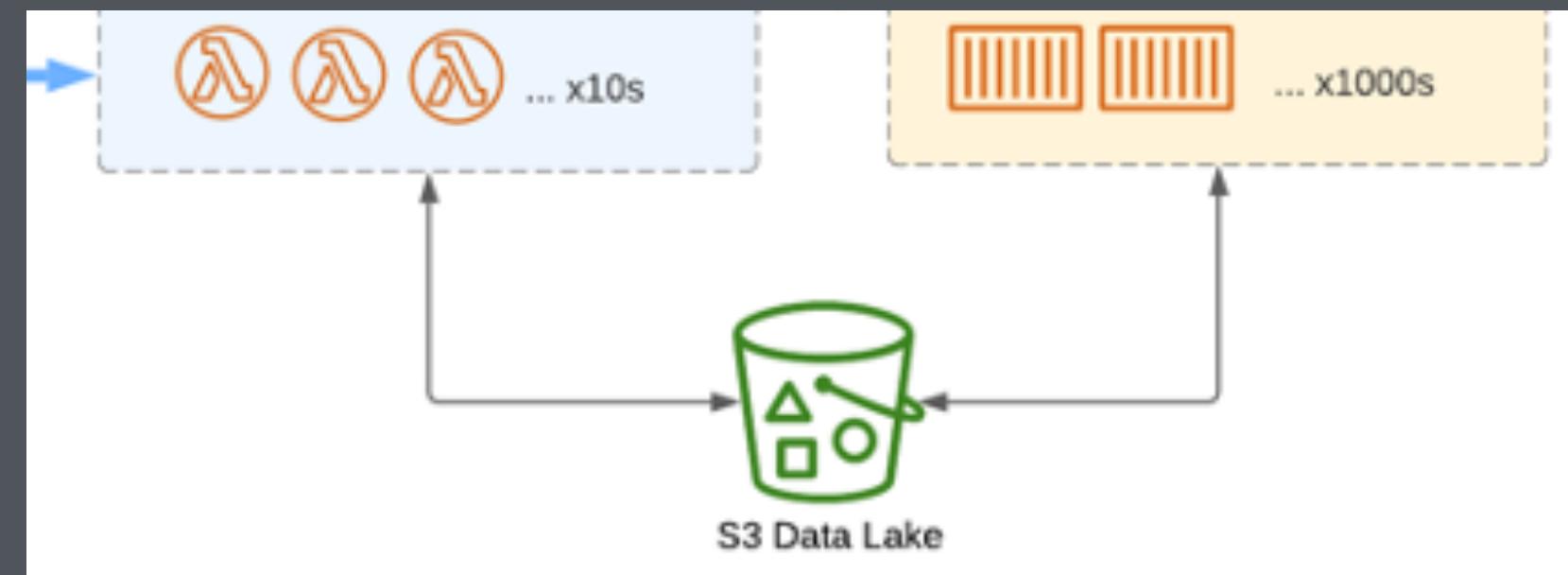
¹ For more details check out the post "A serverless architecture for high performance financial modelling" - <https://aws.amazon.com/blogs/hpc/a-serverless-architecture-for-high-performance-financial-modelling/>

The Problem

During very large job runs we would occassionally see inexplicable slow downs and sometimes rate limit errors

This prompted the question:

"Are we triggering a lot of S3 request retries?"



Request Retries?

AWS has rate limits on their APIs (sensible!)

S3 PUT object might have a rate limit of 3,500 requests per second ²

When you hit this you might get back a HTTP 429 or HTTP 503

boto3 attempts to handle this invisibly via retries³ to minimize impact on your application

² <https://docs.aws.amazon.com/AmazonS3/latest/userguide/optimizing-performance.html>

³ <https://boto3.amazonaws.com/v1/documentation/api/latest/guide/retries.html#standard-retry-mode>

Retry Mechanism

boto3's default retry handler⁴ implements the classic "retry with jitter" approach⁵:

1. For a known set of errors catch them
2. Keep count of the number of times we've tried
3. If we've hit a maximum retry count fail and allow the error to bubble up
4. Otherwise take the count and multiply by some random number and some scale factor
5. Sleep for that long
6. Retry the call

⁴ <https://github.com/boto/botocore/blob/develop/botocore/retryhandler.py>

⁵ <https://aws.amazon.com/builders-library/timeouts-retries-and-backoff-with-jitter/>

Retry Sleep Formula

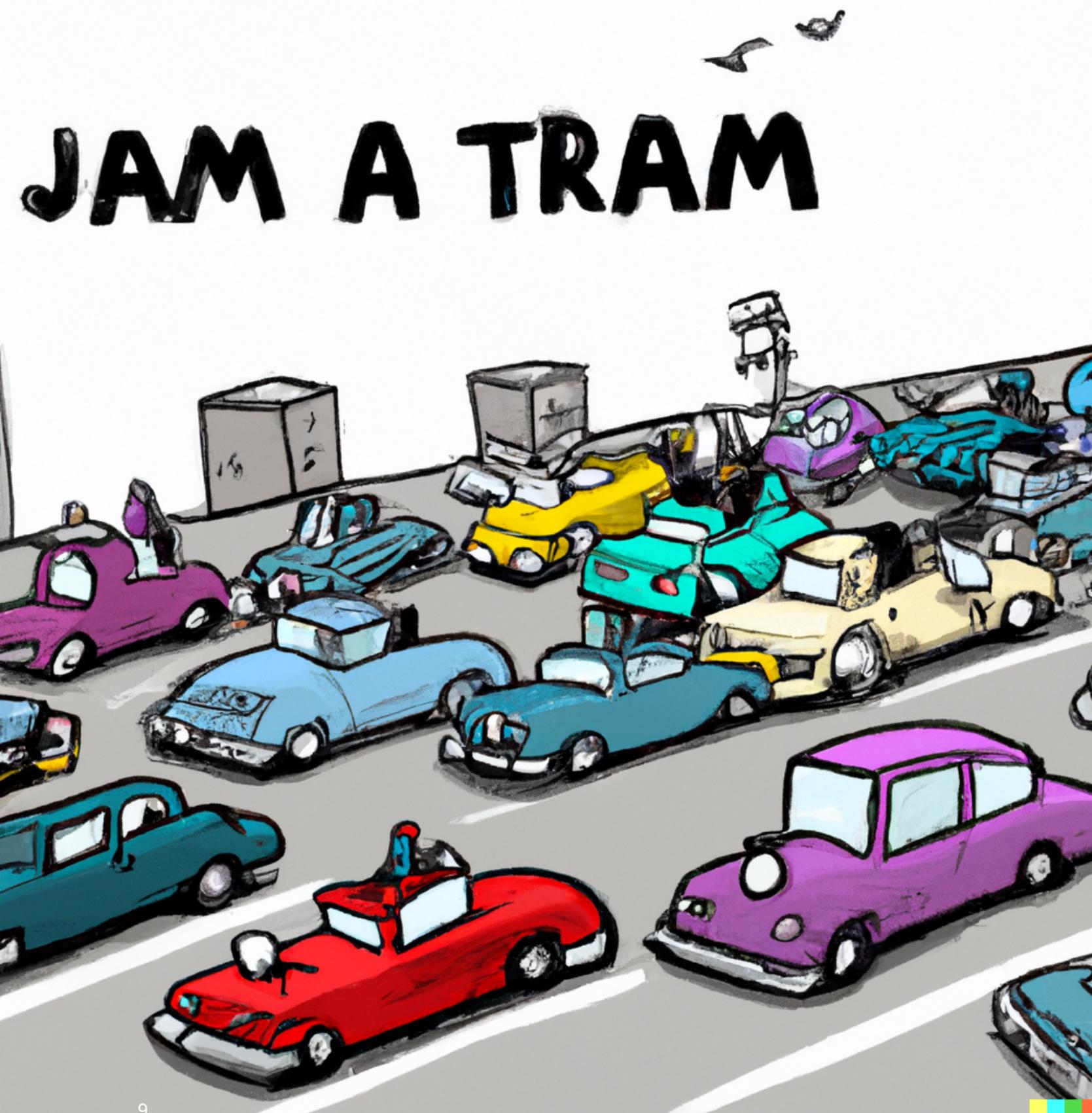
```
# From https://github.com/boto/botocore/blob/develop/botocore/retryhandler.py

base * (growth_factor ** (attempts - 1))

base = random.random() # random float between 0.0 and 1.0
growth_factor = 2
attempts = 2
random.random() * (2 ** (2 - 1))
0.75 * 2 = 1.5

attempt 1 = 1 second max
attempt 2 = 2 second max
attempt 3 = 8 second max
attempt 4 = 16 second max
attempt 5 = 32 second max

# Default of 5 retries
32 + 16 + 8 + 2 + 1 = 59 seconds max sleep total, with 5x requests
```



The Impact

Lots lots of calls per second * sleeping for a bunch of time = a big pile up

As more calls bunch up and sleep, we encounter more rate limits, leading to more calls...

Could this account for our stalls?

How Can We Figure Out The Cause?

Could use logging at DEBUG level

```
logging.basicConfig(level=logging.DEBUG)
```

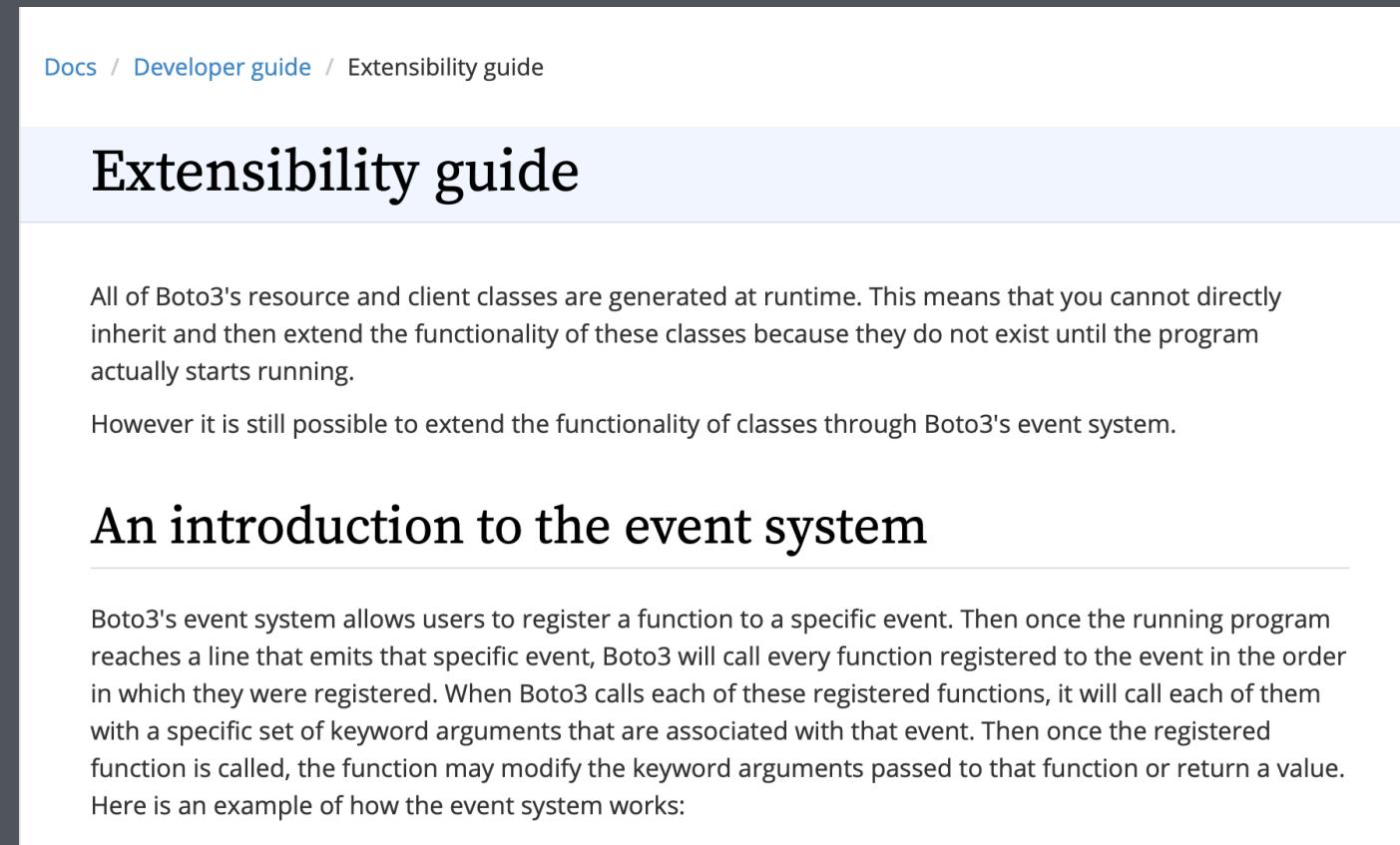
This is super verbose and logs an overwhelming level of detail

What we want is some kind of hook to increment a count or emit a metric on retry

Does boto3 offer any hooks? 🤔

boto3 Events

Events⁶ are an extension mechanism for boto3



The screenshot shows a web page from the AWS documentation. At the top left, there is a breadcrumb navigation: "Docs / Developer guide / Extensibility guide". The main title "Extensibility guide" is centered at the top of the page. Below the title, there is a paragraph of text: "All of Boto3's resource and client classes are generated at runtime. This means that you cannot directly inherit and then extend the functionality of these classes because they do not exist until the program actually starts running." Underneath this paragraph, another text block states: "However it is still possible to extend the functionality of classes through Boto3's event system." At the bottom of the visible content area, there is a section titled "An introduction to the event system" with a descriptive paragraph about how the event system works.

Docs / Developer guide / Extensibility guide

Extensibility guide

All of Boto3's resource and client classes are generated at runtime. This means that you cannot directly inherit and then extend the functionality of these classes because they do not exist until the program actually starts running.

However it is still possible to extend the functionality of classes through Boto3's event system.

An introduction to the event system

Boto3's event system allows users to register a function to a specific event. Then once the running program reaches a line that emits that specific event, Boto3 will call every function registered to the event in the order in which they were registered. When Boto3 calls each of these registered functions, it will call each of them with a specific set of keyword arguments that are associated with that event. Then once the registered function is called, the function may modify the keyword arguments passed to that function or return a value. Here is an example of how the event system works:

⁶ boto3 event docs over at <https://boto3.amazonaws.com/v1/documentation/api/latest/guide/events.html>

boto3 Events

You register a function to be called when an event matching a pattern happens.

Wildcards (*) are also allowed for patterns.

- "provide-client-params.s3.ListObjects"
- "provide-client-params.s3.*"
- "provide-client-params.*"
- "*"

```
def print_event(event_name, **kwargs):
    print(event_name)

s3 = boto3.client("s3")
s3.meta.events.register("needs-retry.*", print_event)
s3.list_buckets()

ec2 = boto3.client("ec2")
ec2.meta.events.register("needs-retry.*", print_event)
ec2.describe_instances()
```

```
import boto3
from rich import print # https://github.com/Textualize/rich

def print_event(event_name, **kwargs):
    print(event_name)

print("\nS3:")
s3 = boto3.client("s3")
s3.meta.events.register("*", print_event)
s3.list_buckets()

print("\nEC2:")
ec2 = boto3.client("ec2")
ec2.meta.events.register("*", print_event)
ec2.describe_instances()
```

S3:

```
provide-client-params.s3.ListBuckets
before-parameter-build.s3.ListBuckets
before-call.s3.ListBuckets
request-created.s3.ListBuckets
choose-signer.s3.ListBuckets
before-sign.s3.ListBuckets
before-send.s3.ListBuckets
response-received.s3.ListBuckets
needs-retry.s3.ListBuckets
after-call.s3.ListBuckets
```

EC2:

```
provide-client-params.ec2.DescribeInstances
before-parameter-build.ec2.DescribeInstances
before-call.ec2.DescribeInstances
request-created.ec2.DescribeInstances
choose-signer.ec2.DescribeInstances
before-sign.ec2.DescribeInstances
before-send.ec2.DescribeInstances
response-received.ec2.DescribeInstances
needs-retry.ec2.DescribeInstances
after-call.ec2.DescribeInstances
```

boto3 Event Args

```
import boto3
from rich import print

def print_event(event_name, **kwargs):
    print(event_name, kwargs)

s3 = boto3.client("s3")
s3.meta.events.register("*", print_event)
```

```
provide-client-params.s3.ListBuckets
{
    'params': {},
    'model': OperationModel(name=ListBuckets),
    'context': {
        'client_region': 'eu-west-1',
        'client_config': <botocore.config.Config object at 0x1078e6770>,
        'has_streaming_input': False,
        'auth_type': None
    }
}
#> s3 = provide_client_params.s3.Bucket('my-bucket')
#> s3.list()
#> s3.list().get('Contents')
#> s3.list().get('Contents')[0]
#> s3.list().get('Contents')[0].get('Key')
#> s3.list().get('Contents')[0].get('Size')
#> s3.list().get('Contents')[0].get('LastModified')
#> s3.list().get('Contents')[0].get('StorageClass')
#> s3.list().get('Contents')[0].get('Owner')
#> s3.list().get('Contents')[0].get('Owner').get('DisplayName')
#> s3.list().get('Contents')[0].get('Owner').get('ID')
#> s3.list().get('Contents')[0].get('Owner').get('Type')
#> s3.list().get('Contents')[0].get('Owner').get('UserId')
#> s3.list().get('Contents')[0].get('Owner').get('UserType')
#> s3.list().get('Contents')[0].get('Owner').get('UserName')
```

Some Observations

- That's a lot of different inputs for different events!
 - The list of events isn't explicitly documented
 - The args each event can receive isn't explicitly documented
- => It's hard to guess what code you'll need to implement without triggering the behaviour you want

Side track: Extending Libraries in Python

There are a few "classic" approaches to extending code in Python:

1. Inheritance
2. Callbacks
3. Events

Inheritance

```
class MyLibrary:  
    def do_something(self, arg1: int, arg2: float):  
        ... library does something here ...  
  
class MyModifiedLibrary(MyLibrary):  
    def do_something(self, arg1: int, arg2: float):  
        ... your stuff happens ...  
        # call the original code too:  
        super().do_something(arg1, arg2)
```

- Works best with libraries written as a bunch of classes
- Can be very clunky and hard to predict how code will interact
- Usually needs explicit hooks for cleanly overriding functionality

Callbacks

```
def add_handler(handler: Callable[[int, float], str]):  
    pass  
  
def my_handler(arg1: int, arg2: float) -> str:  
    pass  
  
def my_broken_handler(arg1: str, arg2: str) -> str:  
    pass  
  
add_handler(my_handler)  
  
# error: Argument 1 to "add_handler"  
# has incompatible type "Callable[[str, str], str]";  
# expected "Callable[[int, float], str]"  
add_handler(my_broken_handler)
```

- Generally `add_handler` keeps a list of functions to call somewhere
- This approach allows for typing hints to guide the developer
- Generally easy to document

Events

```
def add_handler(event: str, handler: Callable):  
    pass  
  
def my_handler(arg1: int, arg2: float):  
    pass  
  
def my_other_handler(arg1: str):  
    pass  
  
add_handler("x.*", my_handler)  
add_handler("y.*", my_other_handler)  
  
# This will probably break  
add_handler("y.*", my_handler)
```

- Events usually used for generic hooks in libraries
- Ideally should have a consistent set of args for your handlers
- Requires more documentation to guide the programmer

boto3 Uses Events

Generic event hooks much easier to integrate to library, especially when dynamically generated like boto3

Drawback: can be very hard for the developer to know what events exist and how they behave

Solution: Lets watch them play out!

 Now, how do we trigger rate limits?

Triggering a rate limit

There are many ways to trigger problems:

- Hacking the library 
- Hacking Python 
- Hacking the OS 
- Hacking the network 
- Triggering the problem for real 

I chose to mess with the network

Why? This is close to what would be seen in real life and cheaper than calling for real!

HTTP

We can mess with the HTTP responses boto3 gets

In particular:

- For a rate limit I'm betting boto3 looks at the HTTP response code
- I'm also betting it'll be HTTP 429
- I'm also betting the code doesn't care about the payload too much once it's a 429
- Finally I'm betting boto3 doesn't verify a response checksum

=> Lets change the response code!

From this

```
HTTP/1.1 200 OK
Content-Length: 34202
Content-Type: application/json
...
{
  ...
}
```

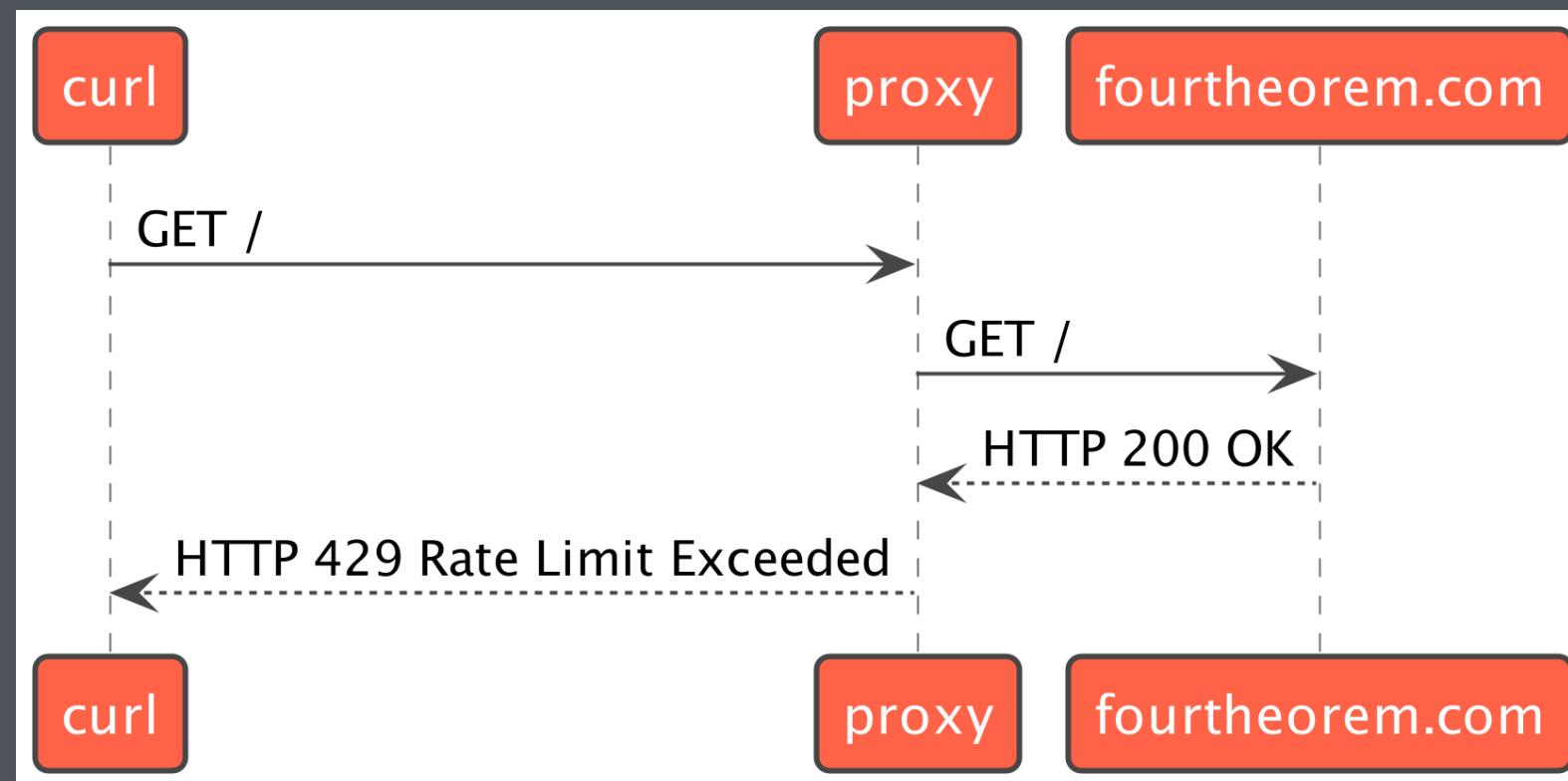
To this

```
HTTP/1.1 429 Rate limit exceeded
Content-Length: 34202
Content-Type: application/json;
...
{
  ...
}
```

How do we achieve this?

One way to mess with HTTP is using a HTTP proxy

One tool which implements this is mitmproxy



mitmproxy

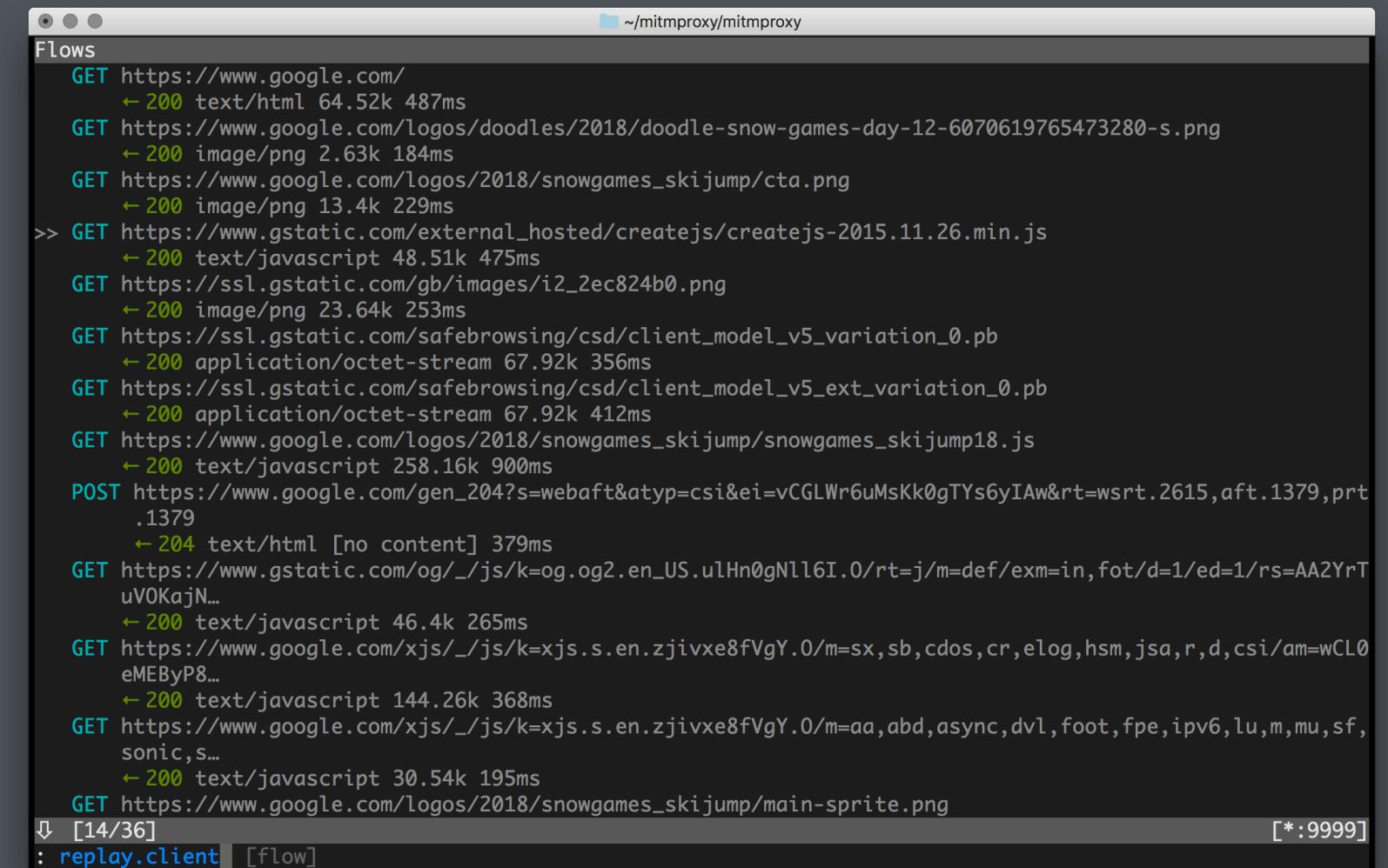
<https://mitmproxy.org>

mitmproxy is a free and open source interactive HTTPS proxy.

What?

Let's you mess with the HTTP requests and responses from programs

Bit like Chrome Dev Tools for all your HTTP speaking commands



The screenshot shows the mitmproxy application window titled 'Flows'. It displays a list of network requests and responses. The requests are color-coded by method: GET (blue), POST (red), and others (green). The responses are color-coded by status code: 200 (green), 204 (light green), and others (yellow). The traffic is primarily from Google's servers, including requests for Google's homepage, a doodle, and various JavaScript files used in their search interface. The interface includes a sidebar with navigation buttons and a bottom status bar indicating 14/36 flows and a replay client.

```
GET https://www.google.com/
    ← 200 text/html 64.52k 487ms
GET https://www.google.com/logos/doodles/2018/doodle-snow-games-day-12-6070619765473280-s.png
    ← 200 image/png 2.63k 184ms
GET https://www.google.com/logos/2018/snowgames_skijump/cta.png
    ← 200 image/png 13.4k 229ms
>> GET https://www.gstatic.com/external_hosted/createjs/createjs-2015.11.26.min.js
    ← 200 text/javascript 48.51k 475ms
GET https://ssl.gstatic.com/gb/images/i2_2ec824b0.png
    ← 200 image/png 23.64k 253ms
GET https://ssl.gstatic.com/safefetch/csd/client_model_v5_variation_0.pb
    ← 200 application/octet-stream 67.92k 356ms
GET https://ssl.gstatic.com/safefetch/csd/client_model_v5_ext_variation_0.pb
    ← 200 application/octet-stream 67.92k 412ms
GET https://www.google.com/logos/2018/snowgames_skijump/snowgames_skijump18.js
    ← 200 text/javascript 258.16k 900ms
POST https://www.google.com/gen_204?s=webaft&atyp=csi&ei=vCGLWr6uMsKk0gTYs6yIAw&rt=wsrt.2615,aft.1379,prt
    .1379
    ← 204 text/html [no content] 379ms
GET https://www.gstatic.com/og/_/js/k=og.og2.en_US.ulHn0gNl16I.0/rt=j/m=def/exm=in,fot/d=1/ed=1/rs=AA2YrT
    uV0KajN...
    ← 200 text/javascript 46.4k 265ms
GET https://www.google.com/xjs/_/js/k=xjs.s.en.zjivxe8fVgY.0/m=sx,sb,cdos,cr,elog,hsm,jsa,r,d,csi/am=wCL0
    eMEByP8...
    ← 200 text/javascript 144.26k 368ms
GET https://www.google.com/xjs/_/js/k=xjs.s.en.zjivxe8fVgY.0/m=aa,abd,async,dvl,foot,fpe,ipv6,lu,m,mu,sf,
    sonic,s...
    ← 200 text/javascript 30.54k 195ms
GET https://www.google.com/logos/2018/snowgames_skijump/main-sprite.png
    ← 200 image/png 1.12k 11ms
[14/36]
: replay.client [flow]
```

Basic usage

1. Run mitmproxy (or mitmweb for a fancier web interface)
2. Set the HTTP proxy settings to mitmproxy's (defaults to http://localhost:8080)
3. Run your program
4. Watch in mitmproxy

```
export http_proxy=localhost:8080  
export https_proxy=localhost:8080
```

```
python my_app.py
```

Easy right?

Flows

↓ [0/0] [*:8080]

21:04:56

curl -X POST -d "text=Hello World" http://localhost:8080/hello

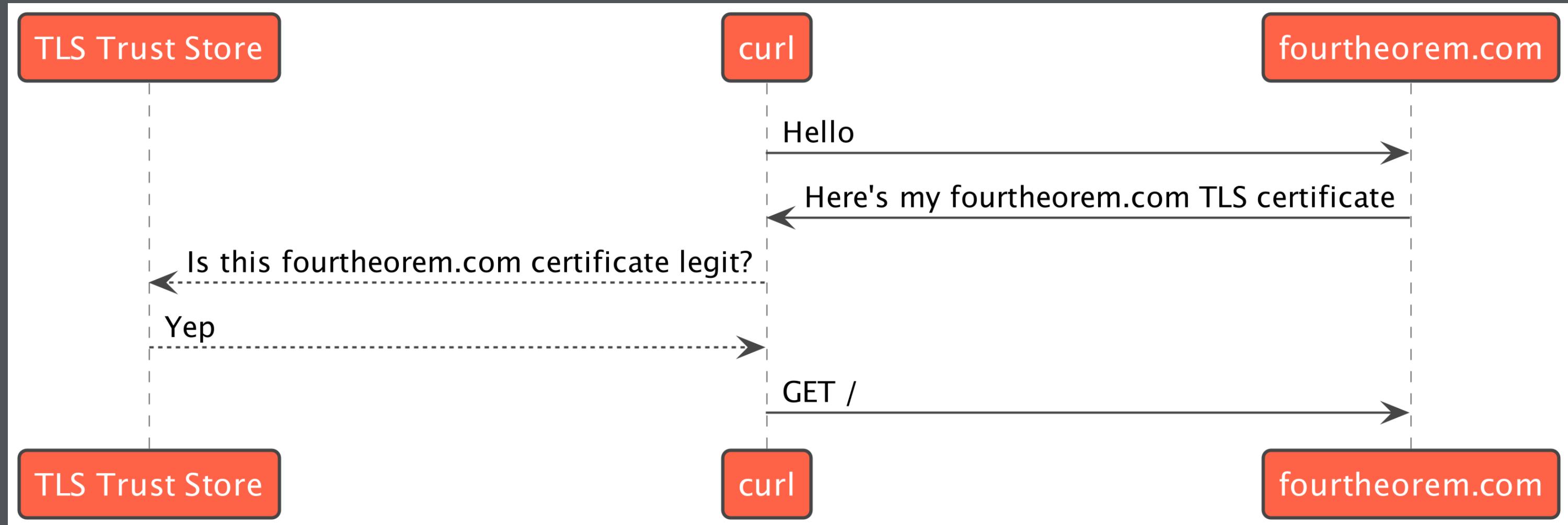
curl

```
> https_proxy=localhost:8080 curl -I https://www.fourtheorem.com  
curl: (60) SSL certificate problem: unable to get local issuer certificate  
More details here: https://curl.se/docs/sslcerts.html
```

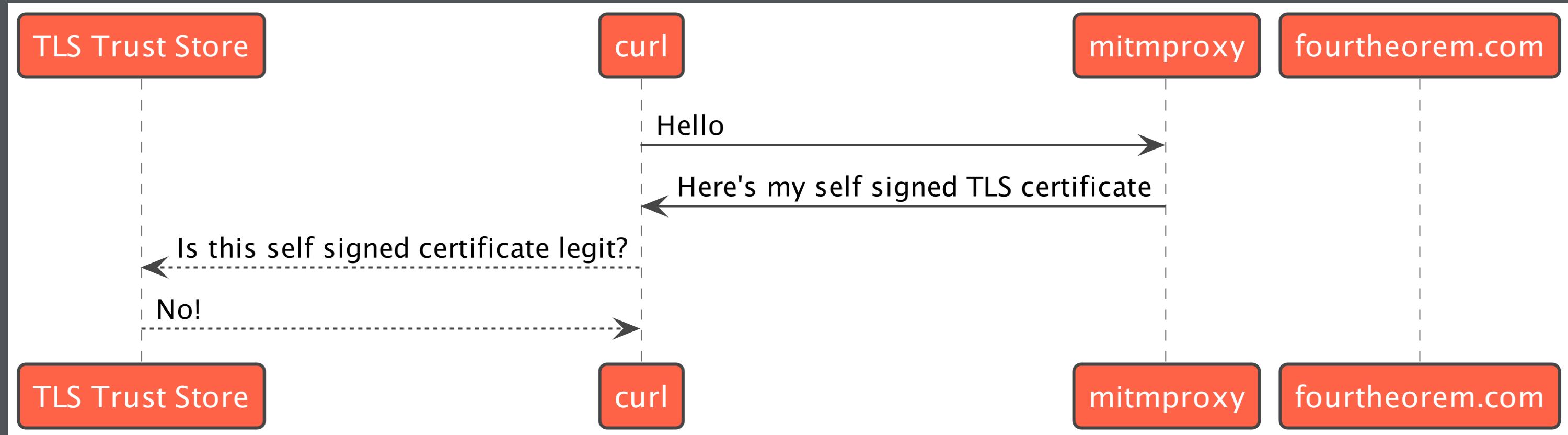
curl failed to verify the legitimacy of the server and therefore could not establish a secure connection to it. To learn more about this situation and how to fix it, please visit the web page mentioned above.

Not so easy after all!

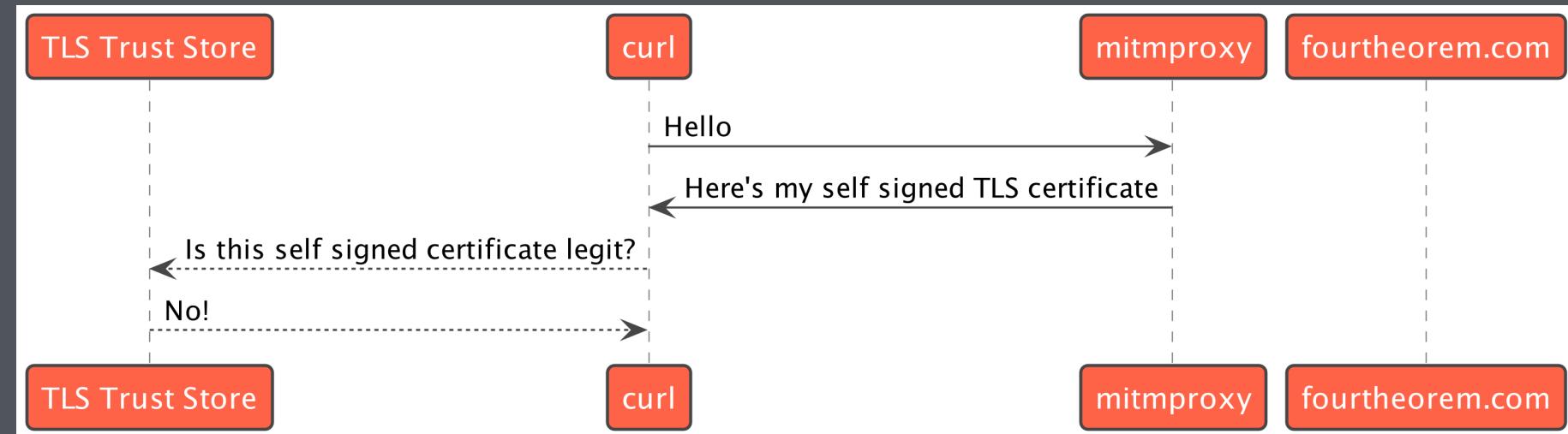
Normal Working TLS



Our Broken TLS



What's Going Wrong?



What's happening?

1. We tell curl to connect via mitmproxy to www.fourtheorem.com using HTTPS
2. curl connects to mitmproxy and tries to verify the TLS certificate
3. curl decides the certificate in the proxy isn't to be trusted and rejects the connection

MITM

curl (and TLS) is doing its job: preventing someone from injecting themselves into the HTTP connection and intercepting traffic.

A man in the middle attack (or MITM) was prevented!

Unfortunately that's what we want to do!

mitmproxy has an answer

Luckily mitmproxy generates TLS certificates for you to use:

```
> ls -l ~/.mitmproxy/
total 48
-rw-r--r--  1 mick  staff  1172 Sep  4 19:26 mitmproxy-ca-cert.cer
-rw-r--r--  1 mick  staff  1035 Sep  4 19:26 mitmproxy-ca-cert.p12
-rw-r--r--  1 mick  staff  1172 Sep  4 19:26 mitmproxy-ca-cert.pem
-rw-----  1 mick  staff  2411 Sep  4 19:26 mitmproxy-ca.p12
-rw-----  1 mick  staff  2847 Sep  4 19:26 mitmproxy-ca.pem
-rw-r--r--  1 mick  staff   770 Sep  4 19:26 mitmproxy-dhparam.pem
```

If you can somehow tell your command to trust these it will talk via mitmproxy!

⚠ Danger! ⚠ Here be Dragons!



To work mitmproxy requires clients to trust these certificates

This potentially opens up a massive security hole on your machine depending how this is set up

Recommendation: if possible restrict to one off command line invocations rather than install system wide

Luckily we can override on a per invocation basis in curl and boto3

Full guide: <https://docs.mitmproxy.org/stable/concepts-certificates/>

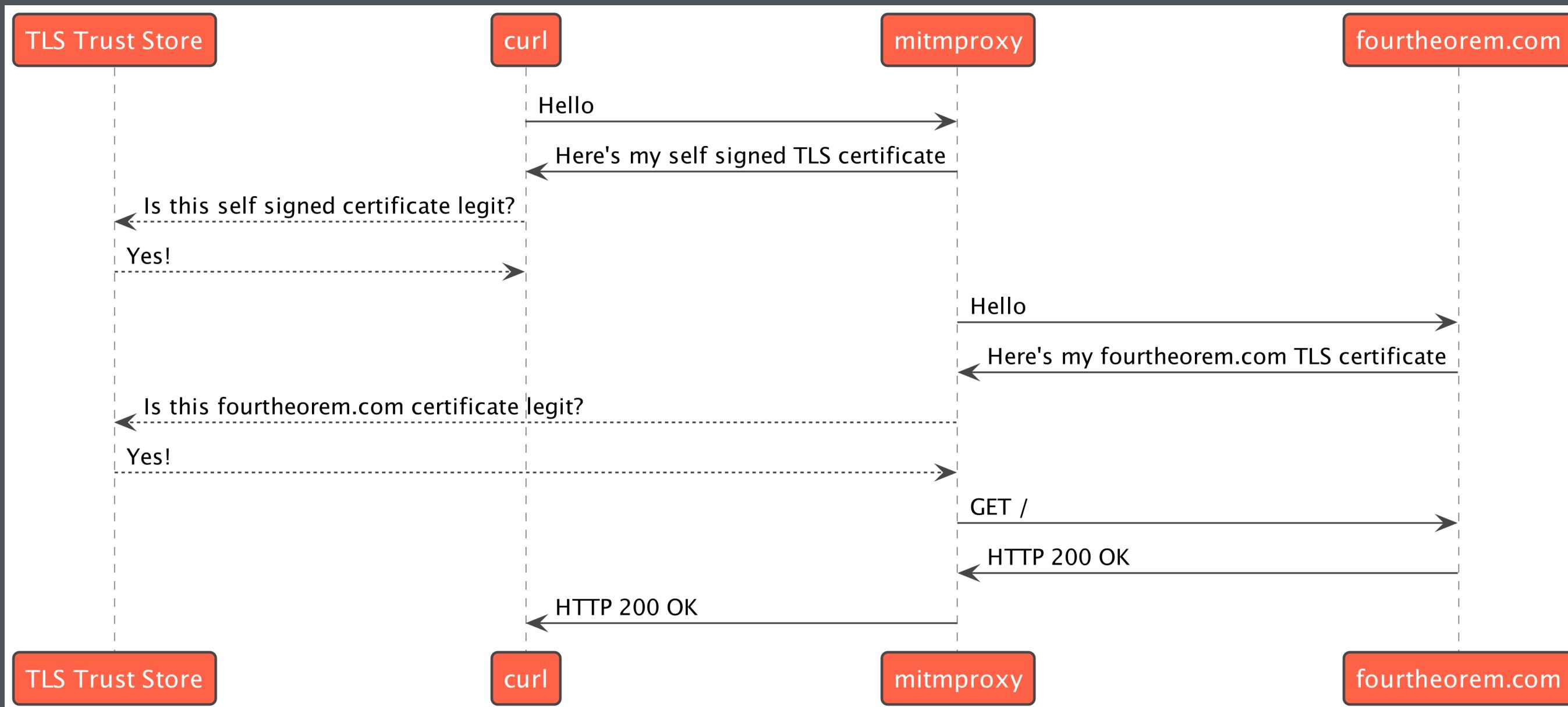
Overriding the cert bundle

curl offers a simple way to trust a cert: `--cacert`

```
> https_proxy=localhost:8080 curl --cacert ~/.mitmproxy/mitmproxy-ca-cert.pem -I https://www.fourtheorem.com
HTTP/1.1 200 Connection established
```

```
HTTP/1.1 200 OK
Server: openresty
Date: Sun, 04 Sep 2022 20:09:03 GMT
Content-Type: text/html; charset=utf-8
Content-Length: 520810
Connection: keep-alive
...
...
```

Working mitmproxy



```
* Uses proxy env variable https_proxy == 'localhost:8080'  
* Trying 127.0.0.1:8080...  
* Connected to localhost (127.0.0.1) port 8080 (#0)  
* allocate connect buffer!  
* Establish HTTP proxy tunnel to www.google.ie:443  
...  
* Proxy replied 200 to CONNECT request  
...  
* successfully set certificate verify locations:  
* CAfile: /Users/mick/.mitmproxy/mitmproxy-ca-cert.pem  
* CApth: none  
* (304) (OUT), TLS handshake, Client hello (1):  
* (304) (IN), TLS handshake, Server hello (2):  
* (304) (IN), TLS handshake, Unknown (8):  
* (304) (IN), TLS handshake, Certificate (11):  
* (304) (IN), TLS handshake, CERT verify (15):  
* (304) (IN), TLS handshake, Finished (20):  
* (304) (OUT), TLS handshake, Finished (20):  
* SSL connection using TLSv1.3 / AEAD-AES256-GCM-SHA384  
* ALPN, server accepted to use h2  
* Server certificate:  
* subject: CN=*.google.ie  
* start date: Sep 17 11:58:59 2022 GMT  
* expire date: Sep 19 11:58:59 2023 GMT  
* subjectAltName: host "www.google.ie" matched cert's "*.google.ie"  
* issuer: CN=mitmproxy; O=mitmproxy  
* SSL certificate verify ok.  
...
```

Flows

↓ [0/0] [*:8080]

mac ~ ➔ x 60 21:05:52
↳ https://copy-free-test-123.com - a cool website you can use to copy free images from the internet.

boto3

We can do something similar with boto3:

```
> https_proxy=localhost:8080 \
  AWS_CA_BUNDLE=$HOME/.mitmproxy/mitmproxy-ca-cert.pem \
  python examples/print_events.py
```

S3:

```
provide-client-params.s3.ListBuckets
before-parameter-build.s3.ListBuckets
before-call.s3.ListBuckets
request-created.s3.ListBuckets
...

```

We tell boto3 to use a different cert bundle (AWS_CA_BUNDLE)

Figure 2: The effect of social media

Panel A: Social media

Panel B: Social media

Panel C: Social media

Panel D: Social media

Panel E: Social media

Panel F: Social media

Panel G: Social media

Panel H: Social media

Panel I: Social media

Panel J: Social media

Panel K: Social media

Panel L: Social media

Panel M: Social media

Panel N: Social media

Panel O: Social media

Panel P: Social media

Panel Q: Social media

Panel R: Social media

Panel S: Social media

Panel T: Social media

Panel A: Social media

Panel B: Social media

Panel C: Social media

Panel D: Social media

Panel E: Social media

Panel F: Social media

Panel G: Social media

Panel H: Social media

Panel I: Social media

Panel J: Social media

Panel K: Social media

Panel L: Social media

Panel M: Social media

Panel N: Social media

Panel O: Social media

Panel P: Social media

Panel Q: Social media

Panel R: Social media

Panel S: Social media

What Were We Trying to Do Again?

We can now:

1. Run some requests from boto3 to AWS
2. Intercept and inspect these requests in mitmproxy

How does this help us?

More than a HTTP debugger

mitmproxy offers the ability to intercept and change HTTP requests

(It also offers a full API and the ability to replay requests)

<https://docs.mitmproxy.org/stable/mitmproxytutorial-interceptrequests/>

<https://docs.mitmproxy.org/stable/mitmproxytutorial-modifyrequests/>

Intercepting

1. Hit i to create an intercept
2. ~d s3.eu-west-1.amazonaws.com & ~s
3. Run the command
4. In the UI go into the response and hit e
5. Change the response code to 429
6. Hit a to allow the request to continue
7. Watch what happens in the command

Modified code to focus on retry mechanism for brevity

```
import boto3
from rich import print
import time

def print_event(event_name: str, attempts: int, operation, response, request_dict, **_):
    print(
        event_name,
        operation,
        attempts,
        response[1]["ResponseMetadata"]["HTTPStatusCode"],
        request_dict["context"]["retries"],
    )

s3 = boto3.client("s3")
s3.meta.events.register("needs-retry.s3.ListBuckets", print_event)
s3.list_buckets()
```

mac ~

14m 3s 22:08:53

➤ mitmproxy

mac ~ /src/github.com/micktwomey/exploring-boto3-events-with-mitmproxy git main !9 ?6
➤ https_proxy=localhost:8080 AWS_CA_BUNDLE=\$HOME/.mitmproxy/mitmproxy-ca-cert.pem python examples/intercepting.py

exploring-boto3-events-with-mitmproxy-U4wvGYlF 22:08:46

```
> https_proxy=localhost:8080 \
  AWS_CA_BUNDLE=$HOME/.mitmproxy/mitmproxy-ca-cert.pem \
  python examples/intercepting.py

needs-retry.s3.ListBuckets OperationModel(name=ListBuckets) 1 429
{'attempt': 1, 'invocation-id': '...'}
needs-retry.s3.ListBuckets OperationModel(name=ListBuckets) 2 429
{'attempt': 2, 'invocation-id': '...', 'max': 5, 'ttl': '20220904T211601Z'}
needs-retry.s3.ListBuckets OperationModel(name=ListBuckets) 3 200
{'attempt': 3, 'invocation-id': '...', 'max': 5, 'ttl': '20220904T211623Z'}
```

Observations:

1. The retry counter starts at 1
2. It increments every time there's a retried call
3. Can test for attempt > 1

Finally! Can emit metrics!

```
import boto3
from rich import print

def increment_metric(name):
    print(f"{name}|increment|count=1")

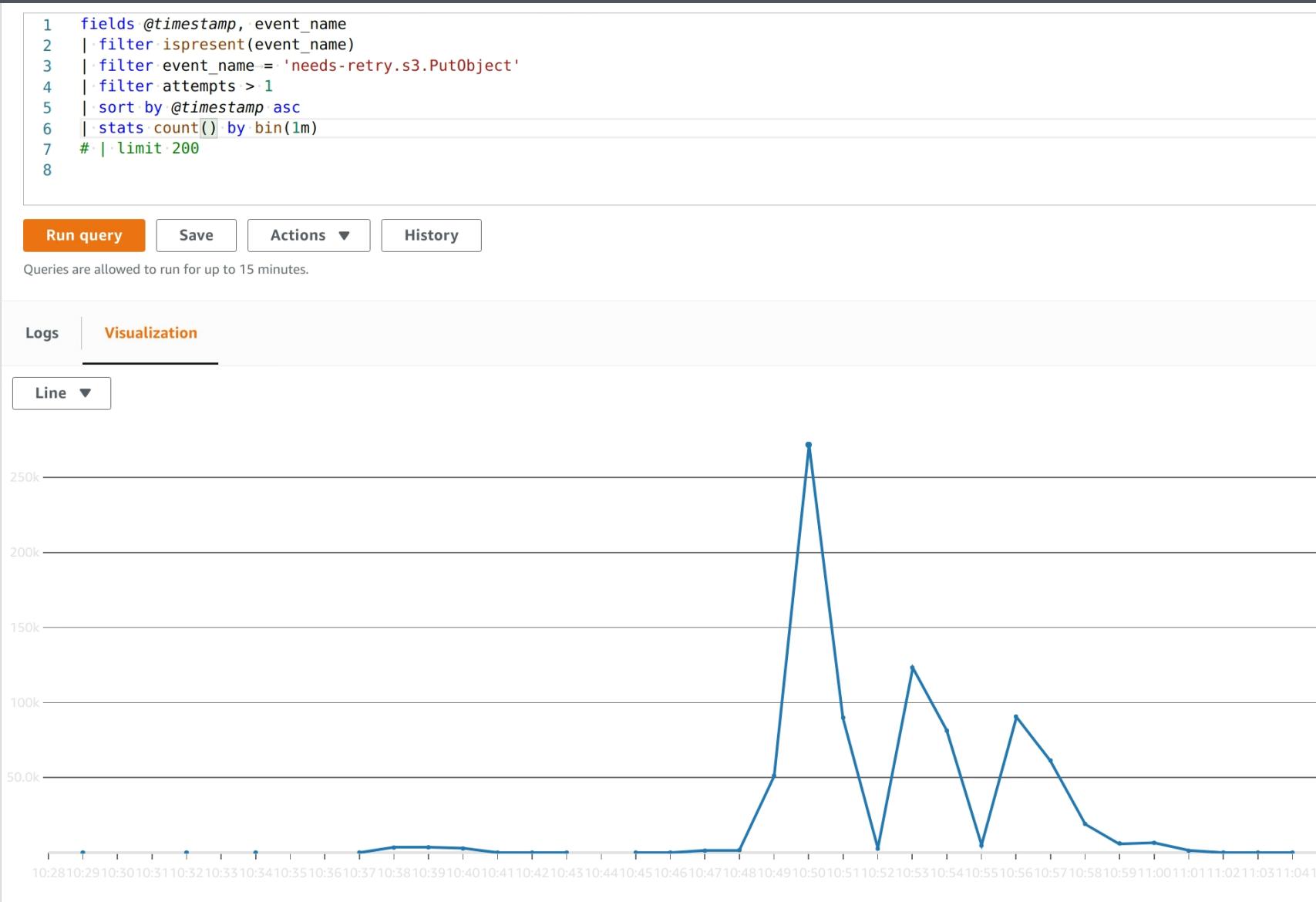
def handle_retry(event_name: str, attempts: int, *_):
    if attempts > 1:
        increment_metric(event_name)

s3 = boto3.client("s3")
s3.meta.events.register("needs-retry.s3.*", handle_retry)
s3.list_buckets()
print("All done!")
```

```
22:37:58
❯ mitmproxy --intercept "~d s3.eu-west-1.amazonaws.com & ~s"
```

```
22:37:07
❯ INT x 1m 14s * exploring-boto3-events-with-mitmproxy-U4wvGYlF 22:37:07
❯ https_proxy=localhost:8080 AWS_CA_BUNDLE=$HOME/.mitmproxy/mitmproxy-ca-cert.pem python examples/retry_metrics.py
```

So What Was the Point of All That?



What We Covered

- AWS API limits
 - <https://docs.aws.amazon.com/AmazonS3/latest/userguide/optimizing-performance.html>
- boto3's event system
 - <https://boto3.amazonaws.com/v1/documentation/api/latest/guide/events.html>
- How request retries behave
 - <https://boto3.amazonaws.com/v1/documentation/api/latest/guide/retries.html#standard-retry-mode>
- mitmproxy
 - <https://mitmproxy.org>

Thank You! 🎉

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Slides & Code: <https://github.com/micktwomey/exploring-boto3-events-with-mitmproxy>