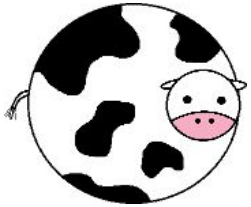


Do You Want to Retry?

Anton Marchukov

About Me

- I am a **Software Engineer** at **Red Hat**.
- I am a member of **RHV DevOps** and **oVirt Community Infra** teams.
- We are in charge of doing **CI** and related **infrastructure** for the projects.
- We write a lot of **automation** and **Python** is our primary language.
- I am **DevOps** advocate and enjoy combining different IT areas together.

oVirt is free, open-source virtualization management platform based on the KVM hypervisor.

Red Hat Virtualization (RHV) is an enterprise virtualization product based on oVirt and supported by Red Hat.

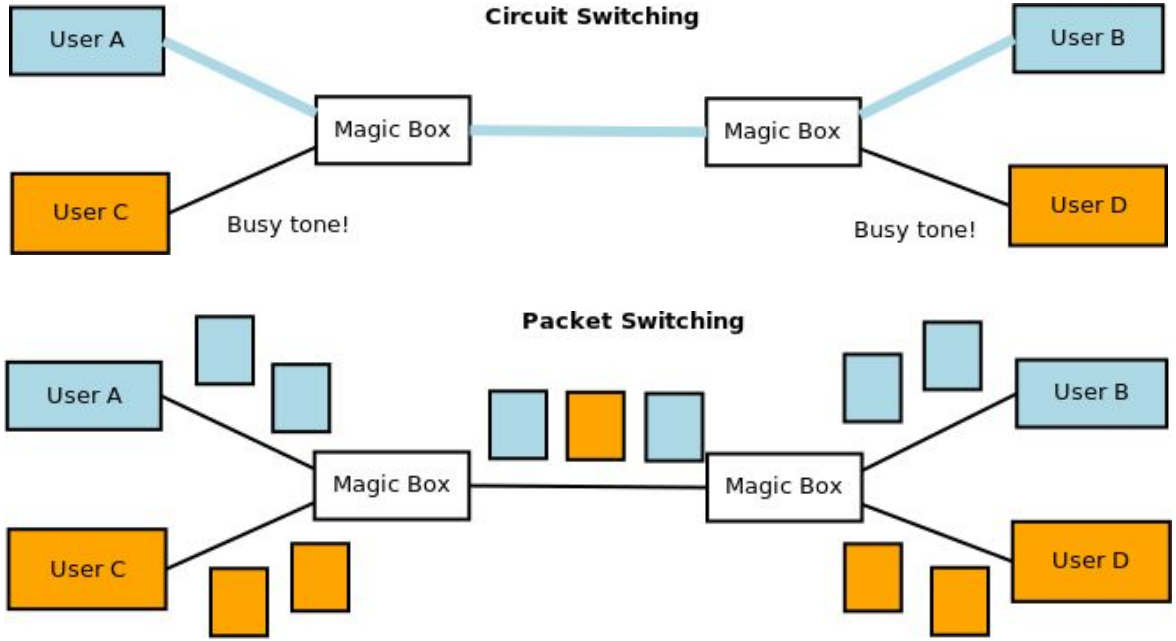
About This Talk

- Follows a real story
- The battle is not over yet
- All simulations are reproducible (should be)

Your feedback will make it better. Try it yourself and share:

https://github.com/marchukov/talk-network-retries

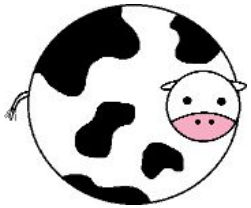
Why Do We Care? Overbooking in TCP/IP Networks

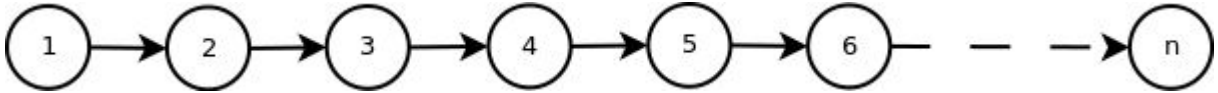


- Due to statistical multiplexing “failures” are built into TCP/IP networks.
- Protocols are designed to just drop packets or give you an error (if you receive it) under the load.

This means that occasional network “failures” are not failures in fact, but “as designed” behaviour.

Why Do We Care? Rare is Not Always Rare





Assuming independence and if **f** is a probability of failure in one part of the chain, we can calculate the probability of success of one part of a chain **s** and then the probability of **n**-parts chain success **S**:

$$S = s^n = (1 - f)^n$$

Now if we want to run the chain **k** times and have all runs be successful, we essentially prolong the chain **k** times:

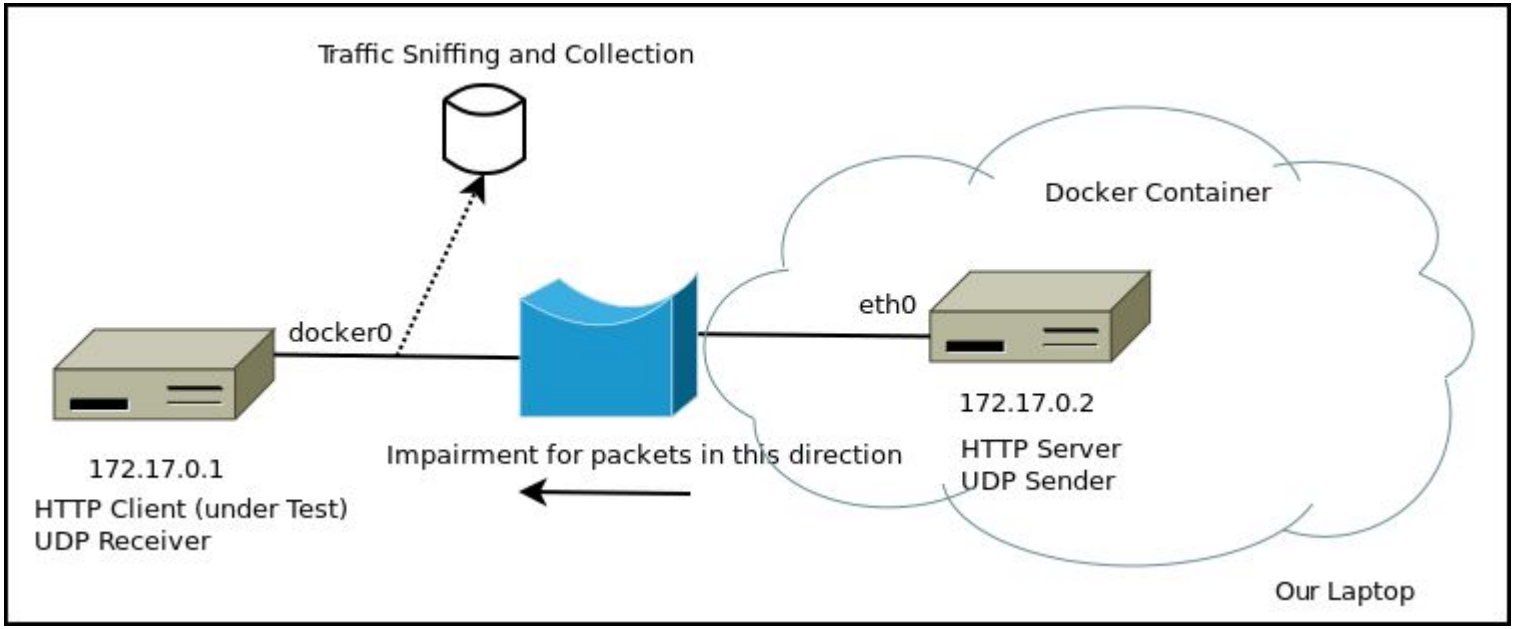
$$S_k = S^k = (1 - f)^{nk}$$

This “amplify” rare failures and we start seeing them more often when we have more runs:

f	**n**	**k**	**S(k) ≈**
0.000001	1	1	1
0.000001	10	1000	0.99
0.000001	100	1000	0.90
0.000001	100	10000	0.37

A spherical cow metaphor https://en.wikipedia.org/wiki/Spherical_cow. Cow image from http://abstrusegoose.com/406 under CC by-nc-sa license.

Test Environment Setup (Virtual)



#docker #container #wiretapping #python #rest #json #cloud #modern #setup #cutting #edge

Test Setup: HTTP Server with Test JSON File

```
mkdir -p ~/tmp/webroot

vi ~/tmp/webroot/test.json # Put random json from http://www.json-generator.com/ (around 7 KB)

sudo docker run --name nginx-test -v ~/tmp/webroot:/usr/share/nginx/html:ro --privileged -d nginx

sudo docker inspect nginx-test | grep IPAddress # "IPAddress": "172.17.0.2",
```

Now the test json file is exposed over HTTP:

http://172.17.0.2/test.json

Test Setup: Network UDP Probe Using netcat

```
# Probe Receiver
ip addr | grep docker0 # inet 172.17.0.1/16 scope global docker0
nc -l -u -p 65535 > /dev/null
```

```
# Probe Sender
sudo docker exec -i -t nginx-test apt-get update
sudo docker exec -i -t nginx-test apt-get -y install netcat
sudo docker exec -i -t nginx-test bash -c 'cat /dev/urandom | nc -u 172.17.0.1 65535'
```

Capturing with WireShark (dumpcap / tshark)

```
# We run naive download in separate terminal after dumpcap is started
# And abort dumpcap with ^C when download finishes - as easy as that

sudo dumpcap -i docker0 -w /tmp/traffic.pcap -s 100 -f 'host 172.17.0.2'

tshark -r /tmp/traffic.pcap -T fields -E separator=, -e _ws.col.Time -e _ws.col.Length udp.port eq 65535
> naive_probe.csv
tshark -r /tmp/traffic.pcap -T fields -E separator=, -e _ws.col.Time -e _ws.col.Length tcp.port eq 80
> naive_download.csv

# Now we have CSV files we can load into any math system like Octave and play with
head -n 1 naive_download.csv
0.000000000,74
# _ws.col.Time, _ws.col.Length
```

GET JSON: Naïve

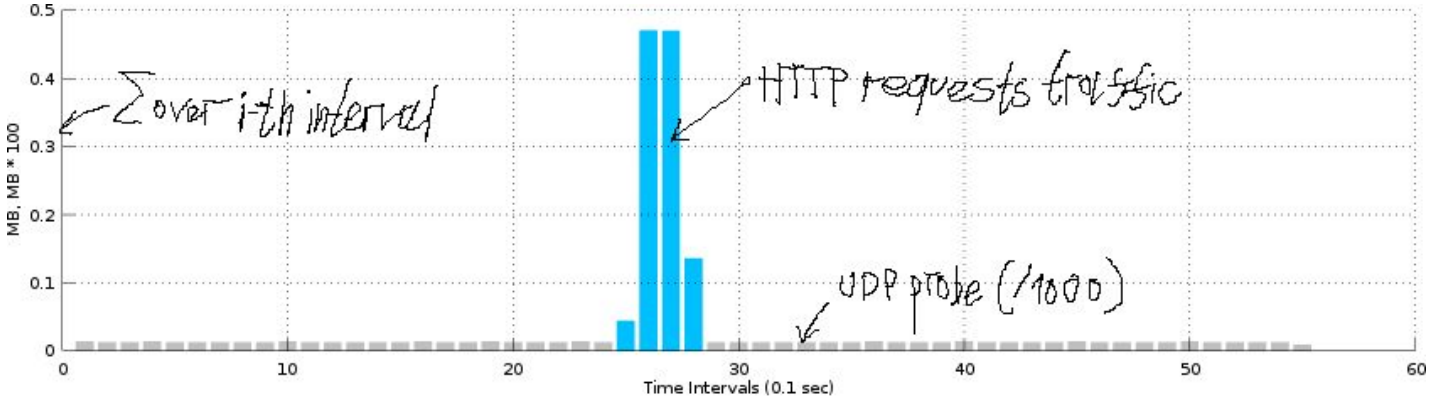
```
#!/usr/bin/env python3
import requests



URL = 'http://172.17.0.2/test.json'



r = requests.get(URL)
r.raise_for_status()

res = r.json()
```

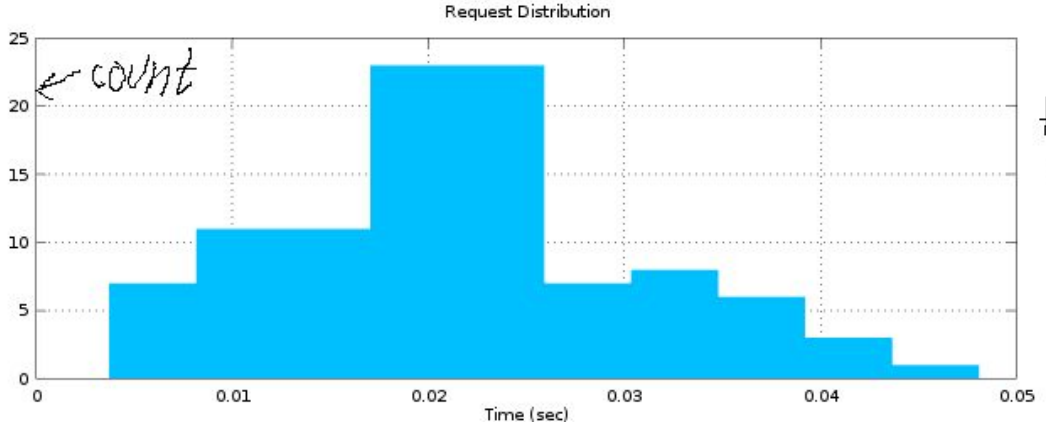
Sampler: Repeat Module Method N Times

```
# Run naive_get_json from get_json 100 times in a thread pool of 10 and output CSV statistics
./sampler.py 100 10 get_json naive_get > naive_get.csv

head -n 3 naive_get_json.csv
0,0.009381771087646484
0,0.0030426979064941406
0,0.002211332321166992
# Success flag (0 - ok, 1 - error), run time in seconds
```

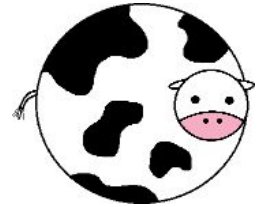
```
from concurrent.futures import ThreadPoolExecutor

def sampler(num_samples, num_workers, func):
    writer = csv.writer(sys.stdout)
    with ThreadPoolExecutor(max_workers=num_workers) as executor:
        for _ in range(num_samples):
            executor.submit(sample, func, writer)
```

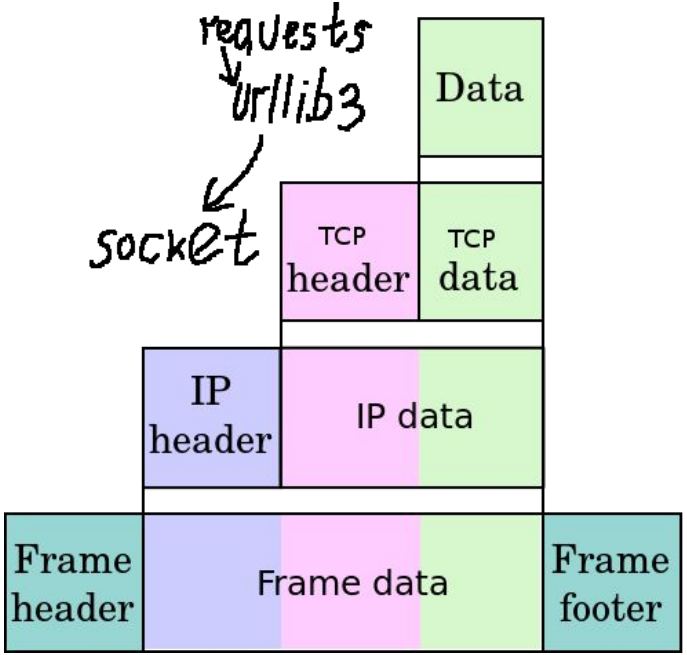
100 x 7 kB GET and Ideal Network





Simulation Scope and Strategy



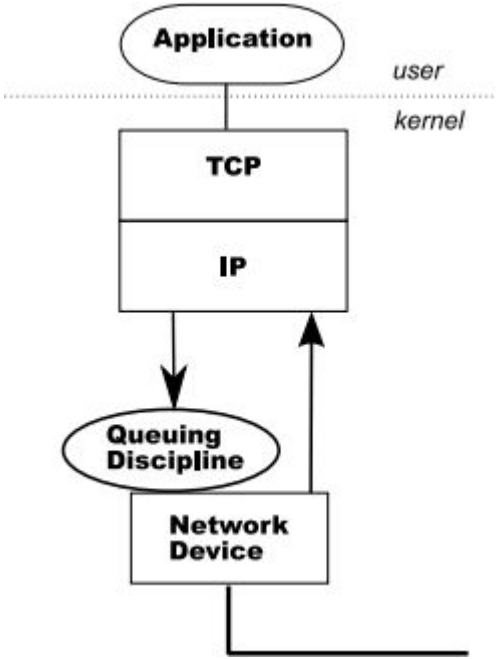


Assumptions and Scope:

1. We test our HTTP GET request code for json file against simulated poor network using NetEm.
2. All failures happening downstream in the stack will look to us as either:
   a. Data coming
   b. No data coming
   c. We get an exception
3. No library hacking (yet).

Encapsulation diagram https://en.wikipedia.org/wiki/Internet_protocol_suite#/media/File:UDP_encapsulation.svg under CC-BY-SA license

Linux Network Emulator (NetEm)



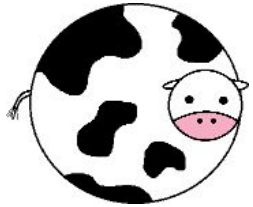
Current impairment capabilities:

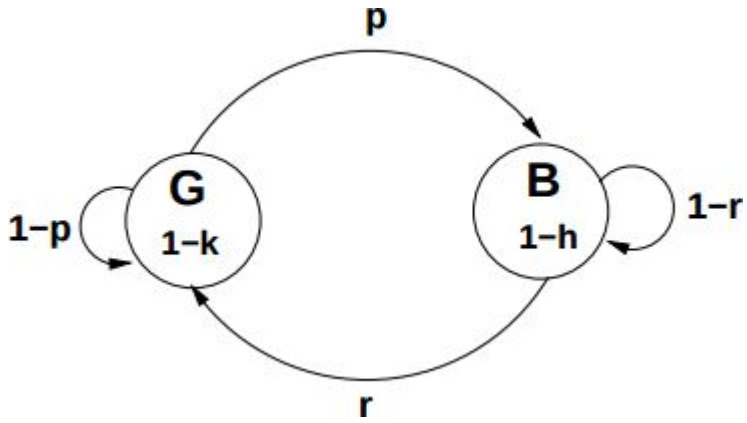
- Delay
- **Loss - we choose just this**
- Corrupt
- Duplicate
- Reorder
- Rate

Note: applied to **outgoing packets only**. Enough to get failures for us.

Image from Hemminger S. "Network Emulation with NetEm", Open Source Development Lab, April 2005.
NetEm https://wiki.linuxfoundation.org/networking/netem
Man netem(8) (usually part of iproute2 package)

Gilbert-Elliott Loss Model





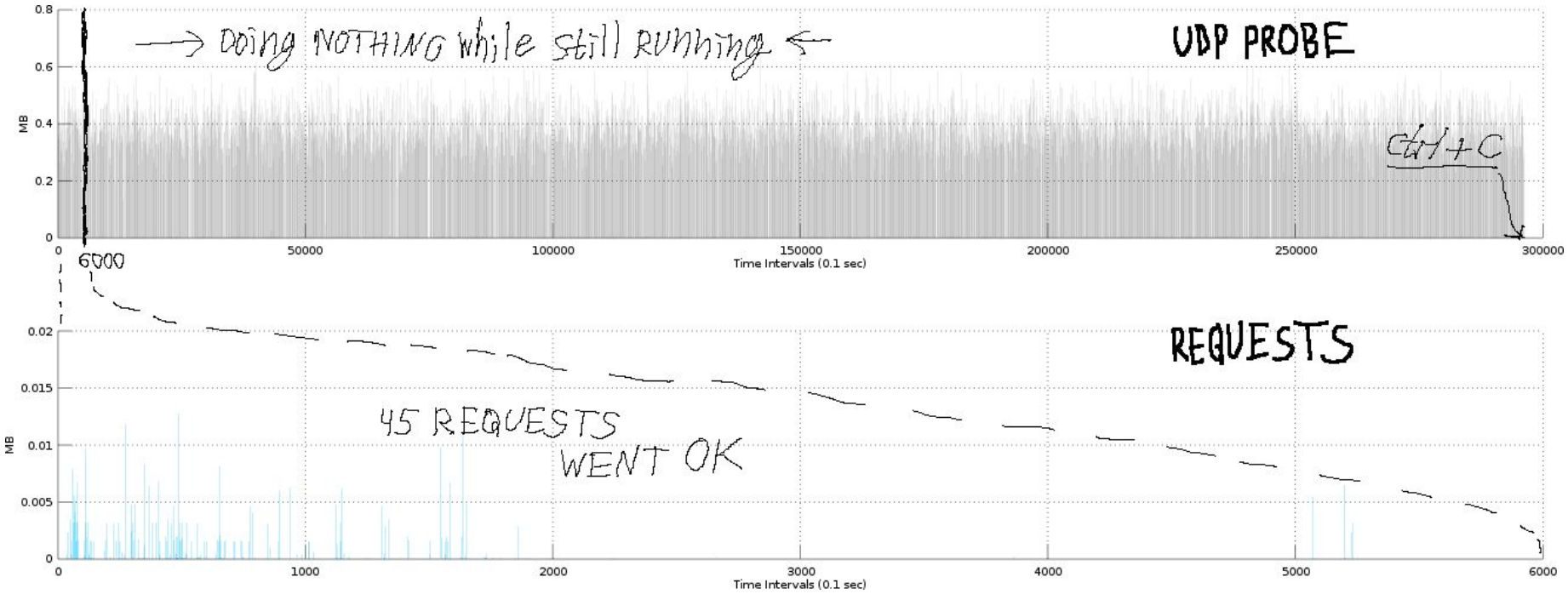
Model	Parameter	Training Complexity	Simplification
Simple Gilbert	p, r	simple	$k = 1$, $h \in \{0, 0.5\}$
Gilbert	p, r, h	medium	$k = 1$
Gilbert-Elliott	p, r, h, k	high	/

From G.Hassingler, O.Hohlfeld. The Gilbert-Elliott Model for Packet Loss in Real Time Services on the Internet. Measuring, Modelling and Evaluation of Computer and Communication Systems (MMB), 2008 14th GI/ITG Conference

Setting Up an Impairment Using tc

```
# Inside our nginx container (that should run as privileged):

# To add
sudo tc qdisc add dev eth0 root netem loss gemodel 50 20

# To show
sudo tc qdisc show dev eth0
qdisc netem 8001: root refcnt 2 limit 1000 loss gemodel p 50% r 20% 1-h 100% 1-k 0%

# To change when it is added previously
sudo tc qdisc change dev eth0 root netem loss gemodel 50 20
```

7 kB GET Run Overnight with Gilbert Loss (0.5, 0.2)



The network was somehow working (UDP packets coming) all the time with some gaps, but we did only 45 requests at first 600 seconds and then stucked. Sampler run was manually aborted by Ctrl+C.

Missing Timeout: Great Way Not to Fail

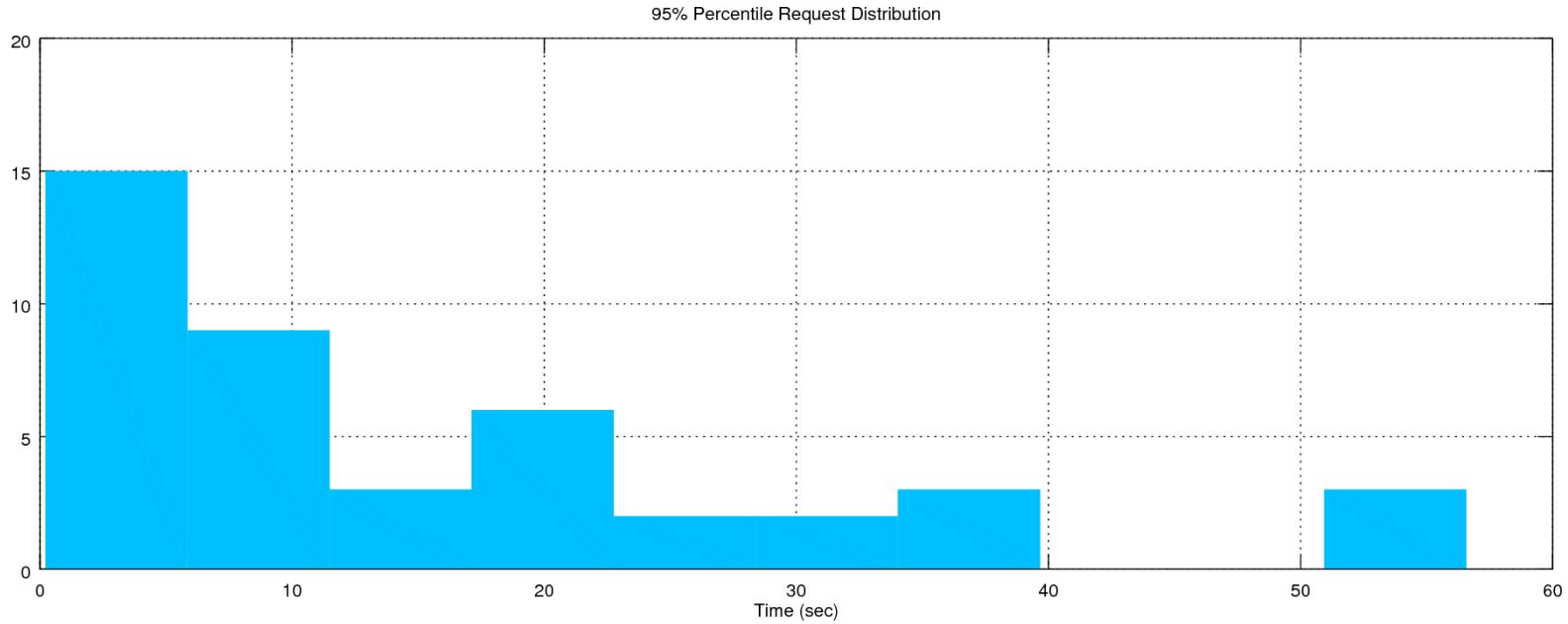
And also **do nothing** over **long period** of time…

> **Note**
>
> `timeout` is not a time limit on the entire response download; rather, an exception is raised if the server has not issued a response for `timeout` seconds (more precisely, if no bytes have been received on the underlying socket for `timeout` seconds). **If no timeout is specified explicitly, requests do not time out.**

Do you know your required **Service Level**?

Requests 2.11.1 documentation. Quickstart. http://docs.python-requests.org/en/latest/user/quickstart/#timeouts

45 Out of 100 Requests Managed to Finish

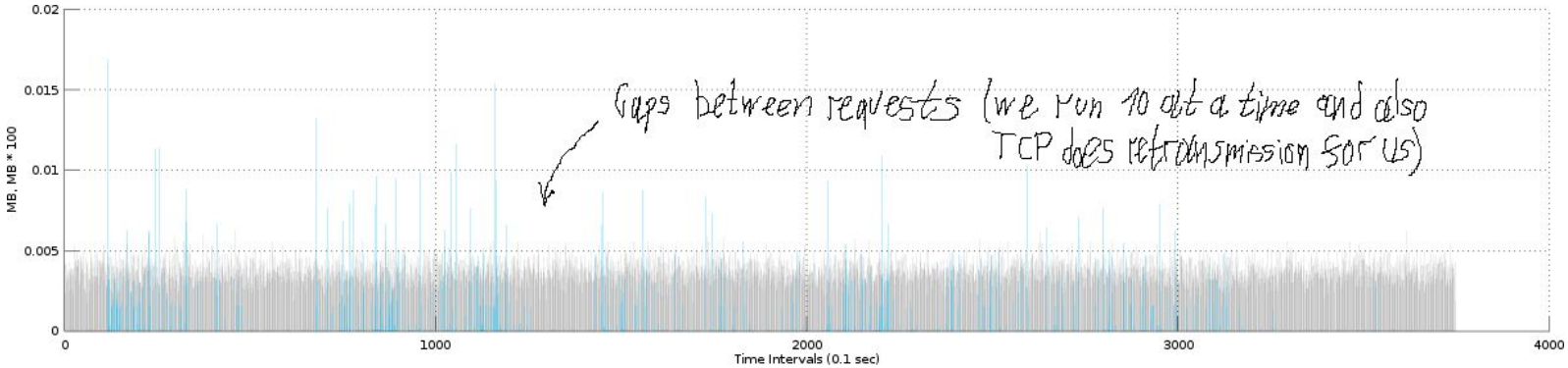


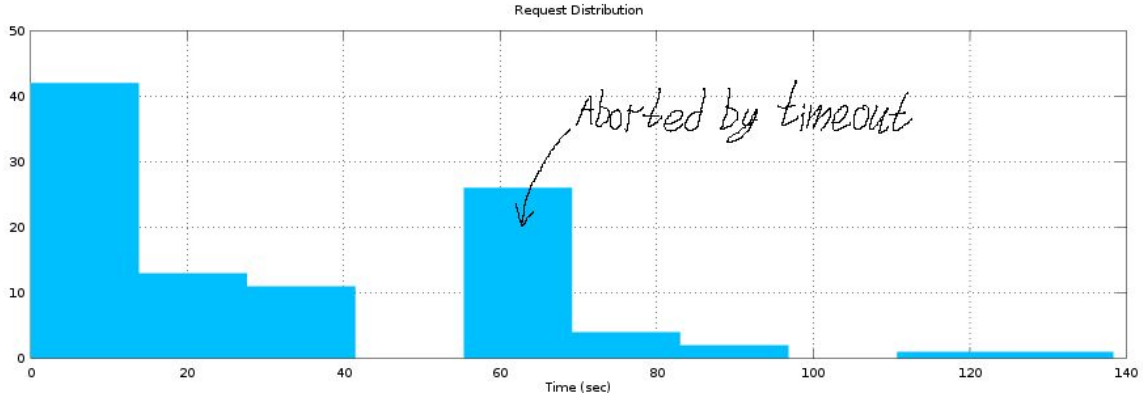
We removed outliers by leaving requests within **95% percentile**. They all finished within **60** seconds.

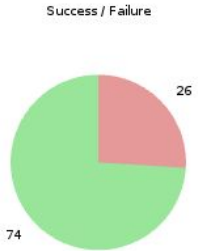
GET JSON: Less Naïve (with Timeout)

```
#!/usr/bin/env python3
import requests



URL = 'http://172.17.0.2/test.json'
TIMEOUT = 60  # Seconds



r = requests.get(URL, timeout=TIMEOUT)
r.raise_for_status()

res = r.json()
```

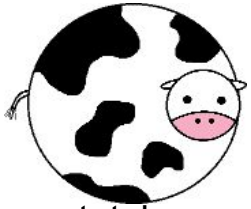
100 x 7 kB GET with G(0.5, 0.2) and Timeout 60 Sec





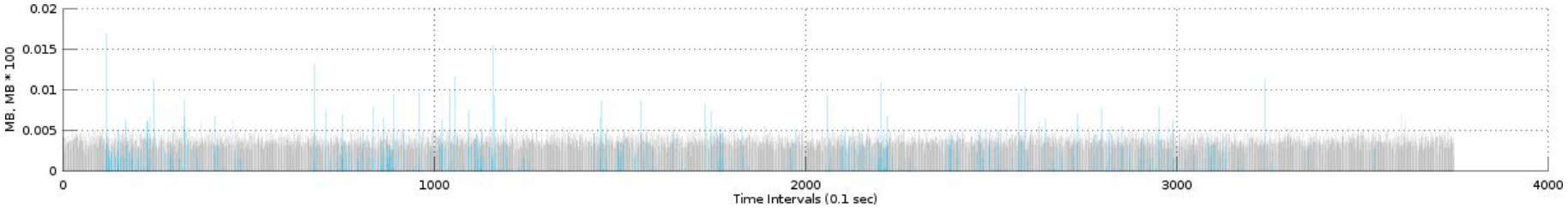


Does It Make Sense to Retry?



74 request finished. They were lucky. If we retry we try our luck one more time and increase our total success probability:

$$P(A \text{ or } B) = P(A) + P(B)$$



TCP does retries (retransmissions) for us within the timeout set, but will not help with the following:

- HTTP specific failures (are not simulated here, but retry code works for them too).
- Failures when connection is not established (e.g. DNS errors, no route to host, etc).

Is It Safe To Retry?

General case:

- **Idempotent requests** $f(f(x)) = f(x)$.
- **Nothing happened** (did not reach the server or the server did nothing).

Our case:

- **HTTP standard** defines idempotency of the methods and status codes (GET call is idempotent). Requests library uses urllib3 library that has an implementation of retry working with **any RFC compliant HTTP service**.

Your case:

HTTP protocol designers thought about it. **What about you?**

```
# Idempotence example

A = 1

def set_a(value):
    global A
    A = value

A         # 1
set_a(2)  # 2
set_a(2)  # 2
set_a(2)  # 2
# …       # 2
```

Kevin Burke. A look at the new retry behavior in urllib3. https://kev.inburke.com/kevin/urllib3-retries/
What are idempotent and/or safe methods? REST Cookbook. http://restcookbook.com/HTTP%20Methods/idempotency/

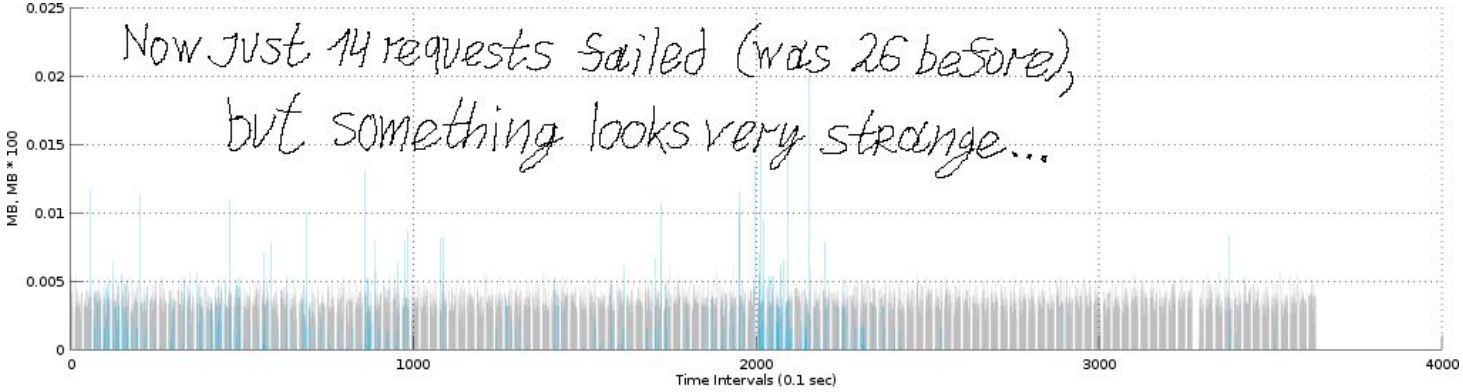
Retry Support in Python HTTP Libraries

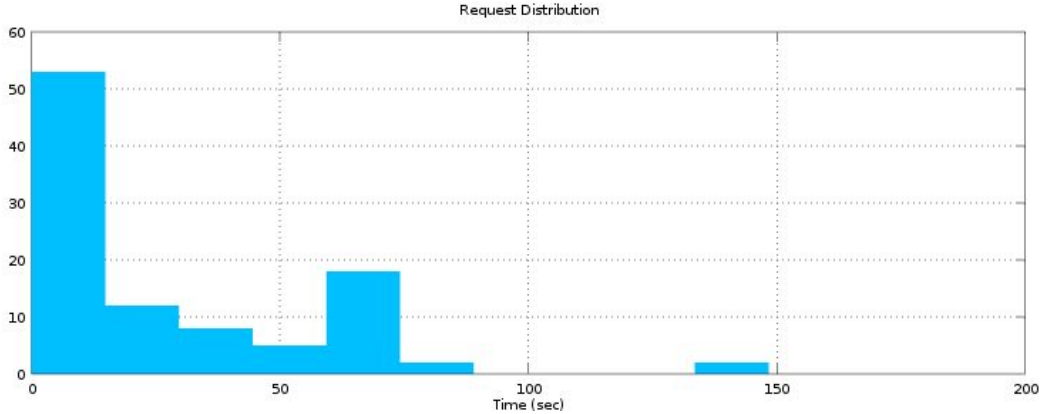
Library	Included?	Retry?	Comments
http	Yes	No	
urllib	Yes	No	Same for urllib2
urllib3	No	Yes	New behaviour merged on Jul 2, 2014. Best I've found
requests	No	Yes	Uses urllib3, does not yet expose all functionality
Your Library	?	?!	Something to consider

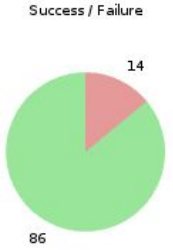
GET JSON: with Retry

```
import requests



RETRY_PREFIX = 'http://'  # Protocol to retry
MAX_RETRIES = 3  # Number of retries



session = requests.Session()
adapter = requests.adapters.HTTPAdapter(max_retries=MAX_RETRIES)
session.mount(RETRY_PREFIX, adapter)
r = session.get(URL, timeout=TIMEOUT)
r.raise_for_status()

res = r.json()
```

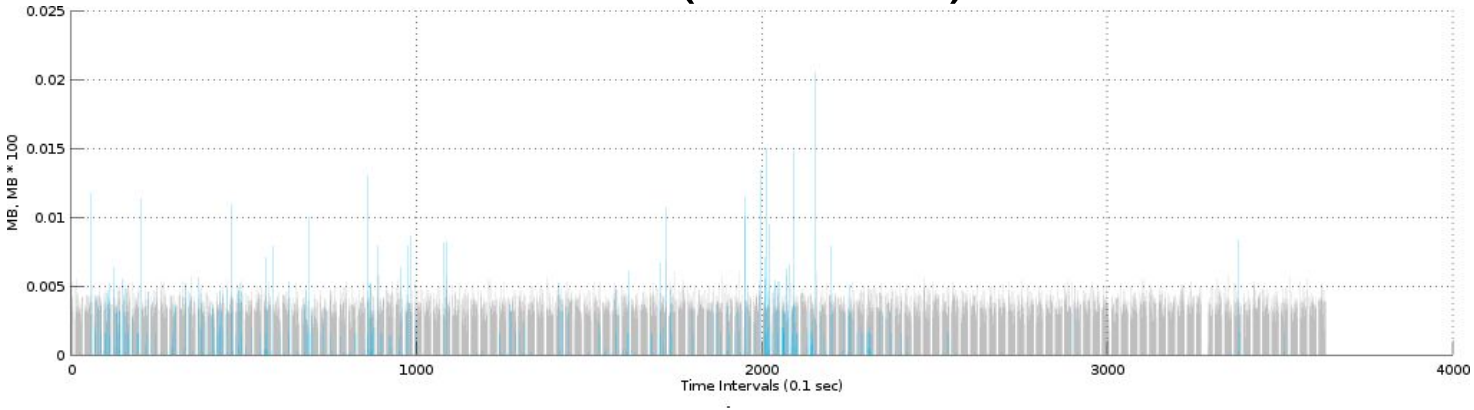
100 x 7 kB GET with G(0.5, 0.2) and 3 Retries

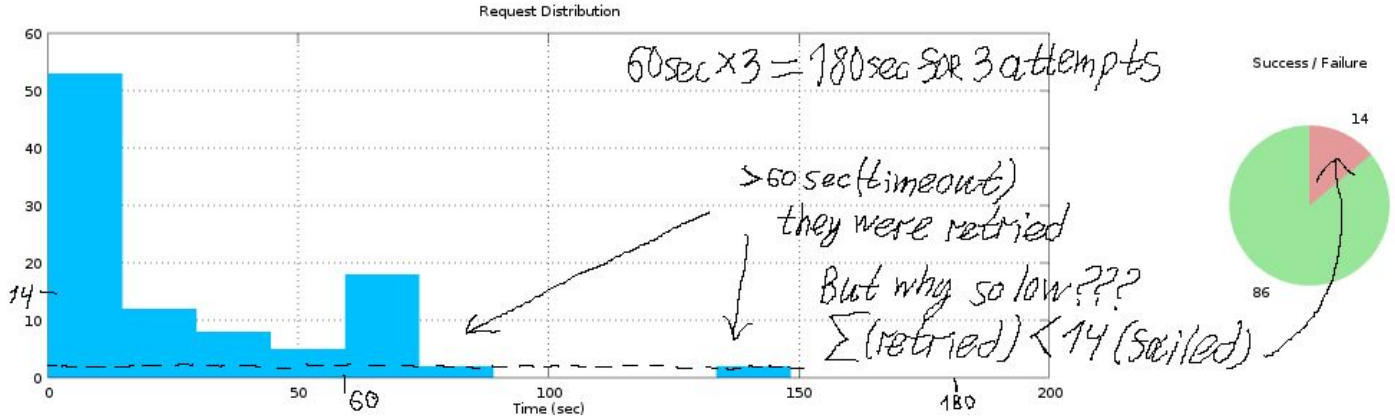






100 x 7 kB GET with G(0.5, 0.2) and 3 Retries





Let’s See What It Does: Enable Protocol Debug

```
import http
import logging



logging.basicConfig()
logging.getLogger().setLevel(logging.DEBUG)



http.client.HTTPConnection.debuglevel = 1



requests_logger = logging.getLogger('requests.packages.urllib3')
requests_logger.setLevel(logging.DEBUG)
requests_logger.propagate = True
```

Switch Off The Network in Test Environment

Gilbert-Elliott model with loss probability in bad **B** state **1 - k = 1**

This makes **100%** loss in both states - no network at all.

```
root@8b256f70b26b:/# sudo tc qdisc change dev eth0 root netem loss gemodel 50 20 100 100; sudo tc qdisc
show dev eth0;
qdisc netem 803c: root refcnt 2 limit 1000 loss gemodel p 50% r 20% 1-h 100% 1-k 100%
```

Now let’s see how retry works.

Does Not Look Like It Works At All...

```
./get_json.py
DEBUG:requests.packages.urllib3.util.retry:Converted retries value: 3 -> Retry(total=3, connect=None,
read=None, redirect=None)
INFO:requests.packages.urllib3.connectionpool:Starting new HTTP connection (1): 172.17.0.2
Traceback (most recent call last):
  File "/usr/lib/python3/dist-packages/urllib3/connection.py", line 137, in _new_conn
    (self.host, self.port), self.timeout, **extra_kw)
  File "/usr/lib/python3/dist-packages/urllib3/util/connection.py", line 91, in create_connection
    raise err
  File "/usr/lib/python3/dist-packages/urllib3/util/connection.py", line 81, in create_connection
    sock.connect(sa)
OSError: [Errno 113] No route to host
#
# ... and more tracebacks below … but no traces of any new connection attempts
#
```

urllib3 Retry Object (Encapsulates HTTP Retry Behaviour)

```
retries = Retry(connect=5, read=2, redirect=5)
http = PoolManager(retries=retries)
response = http.request('GET', 'http://example.com/')
```

total	Total number of retries to allow. Takes precedence over other counts.
connect	How many connection-related errors to retry on (errors raised before the request is sent to the remote server).
read	How many times to retry on read errors (errors are raised after the request was sent to the server).
redirect	How many redirects to perform. Limit this to avoid infinite redirect loops.
And many more customization parameters. Check urllib3 documentation. Not enough? Subclass and override with your code.	

Kevin Burke. A look at the new retry behavior in urllib3. https://kev.inburke.com/kevin/urllib3-retries/
urllib3.util.retry documentation. http://urllib3.readthedocs.io/en/latest/reference/urllib3.util.html#module-urllib3.util.retry

Is It Safe To Retry Using urllib3 Retry Object?

1. All is **disabled by default**.
2. **connect**: did not reach remote server.
3. **read**: may have side-effects, request reached remote server.
4. **method_whitelist**: by default, we only retry on methods which are considered to be idempotent:

```
DEFAULT_METHOD_WHITELIST = frozenset([ 'HEAD', 'GET', 'PUT', 'DELETE', 'OPTIONS', 'TRACE'])
```

5. **status_forcelist**: a set of integer HTTP status codes that we should force a retry on. Default is (**Payload Too Large**, **Too Many Requests**, **Service Unavailable**):

```
RETRY_AFTER_STATUS_CODES = frozenset([413, 429, 503])
```

urllib3.util.retry documentation. http://urllib3.readthedocs.io/en/latest/reference/urllib3.util.html#module-urllib3.util.retry
urllib3.util.retry source code. https://github.com/shazow/urllib3/blob/master/urllib3/util/retry.py

GET JSON: With Fixed Retry

```
MAX_RETRIES = 3  # Number of retries

session = requests.Session()
retry = urllib3.util.Retry(total=MAX_RETRIES,
                           connect=MAX_RETRIES,
                           read=MAX_RETRIES)
adapter = requests.adapters.HTTPAdapter(max_retries=retry)
session.mount(RETRY_PREFIX, adapter)
r = session.get(URL, timeout=TIMEOUT)
r.raise_for_status()

res = r.json()
```

Still Does Not Work! Although Now It Does Retry

```
./get_json.py
INFO:requests.packages.urllib3.connectionpool:Starting new HTTP connection (1): 172.17.0.2
DEBUG:requests.packages.urllib3.util.retry:Incremented Retry for (url='/test.json'): Retry(total=2, connect=2, read=None,
redirect=None)
WARNING:requests.packages.urllib3.connectionpool:Retrying (Retry(total=2, connect=2, read=None, redirect=None)) after
connection broken by 'NewConnectionError('<requests.packages.urllib3.connection.HTTPConnection object at 0x7ff82206dbe0>:
Failed to establish a new connection: [Errno 113] No route to host',)': /test.json
INFO:requests.packages.urllib3.connectionpool:Starting new HTTP connection (2): 172.17.0.2
# ... skipped two more connection attempts ...
WARNING:requests.packages.urllib3.connectionpool:Retrying (Retry(total=0, connect=0, read=None, redirect=None)) after
connection broken by 'NewConnectionError('<requests.packages.urllib3.connection.HTTPConnection object at 0x7ff82206df60>:
Failed to establish a new connection: [Errno 113] No route to host',)': /test.json
INFO:requests.packages.urllib3.connectionpool:Starting new HTTP connection (4): 172.17.0.2
Traceback (most recent call last):
# ... skipped traceback …
OSError: [Errno 113] No route to host
# ... no more retries below. It just fails … and fails all attempts quite fast in fact ...
```

Just Kidding. We Switched the Network Off

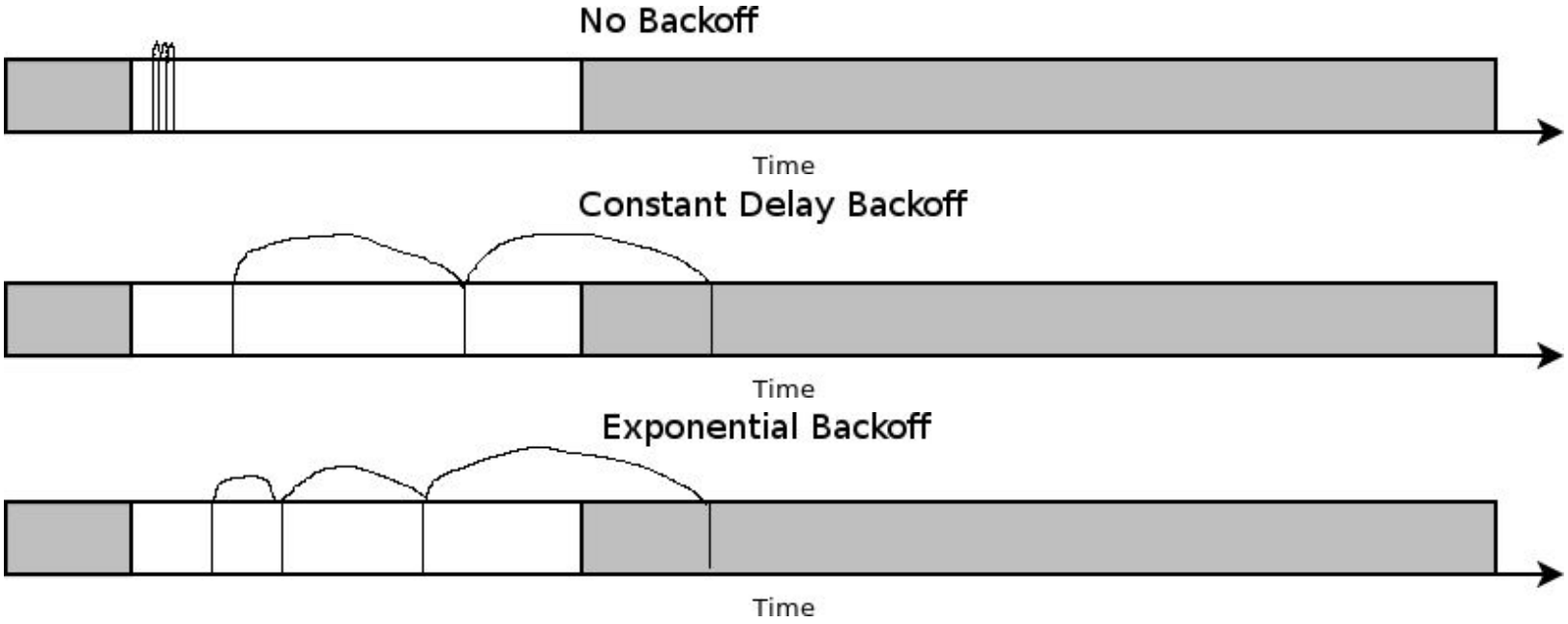
```
qdisc netem 803c: root refcnt 2 limit 1000 loss gemodel p 50% r 20% 1-h 100% 1-k 100%
```

But… Wait a minute…

Can it happen in real life too?

Yes.

Missing Backoff: Great Way to Retry and Do Not Retry



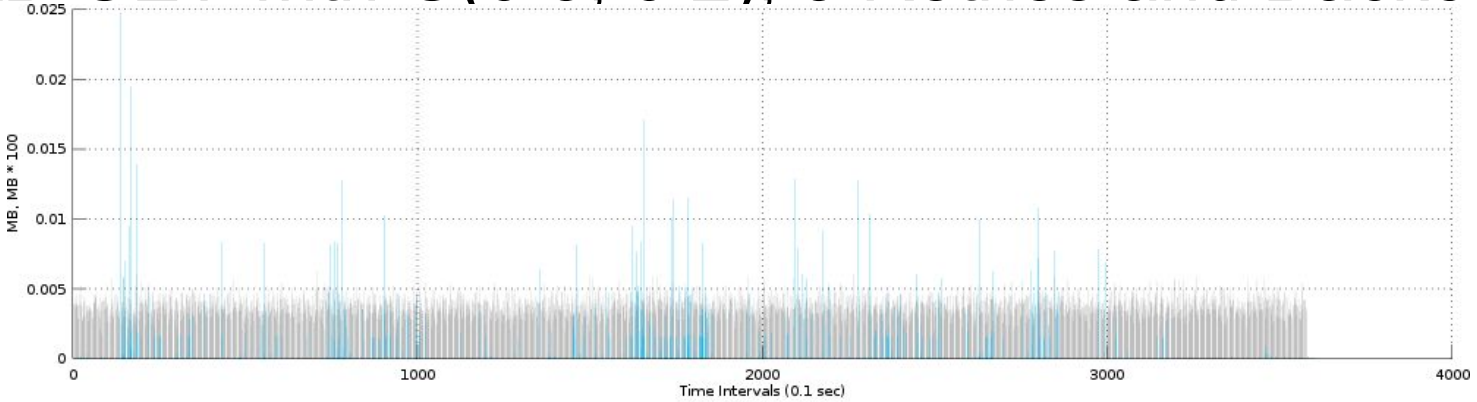

```
# For backoff_factor=1: 0 1 2 4 8 ...
backoff_value = self.backoff_factor * (2 ** (consecutive_errors_len - 1))
```

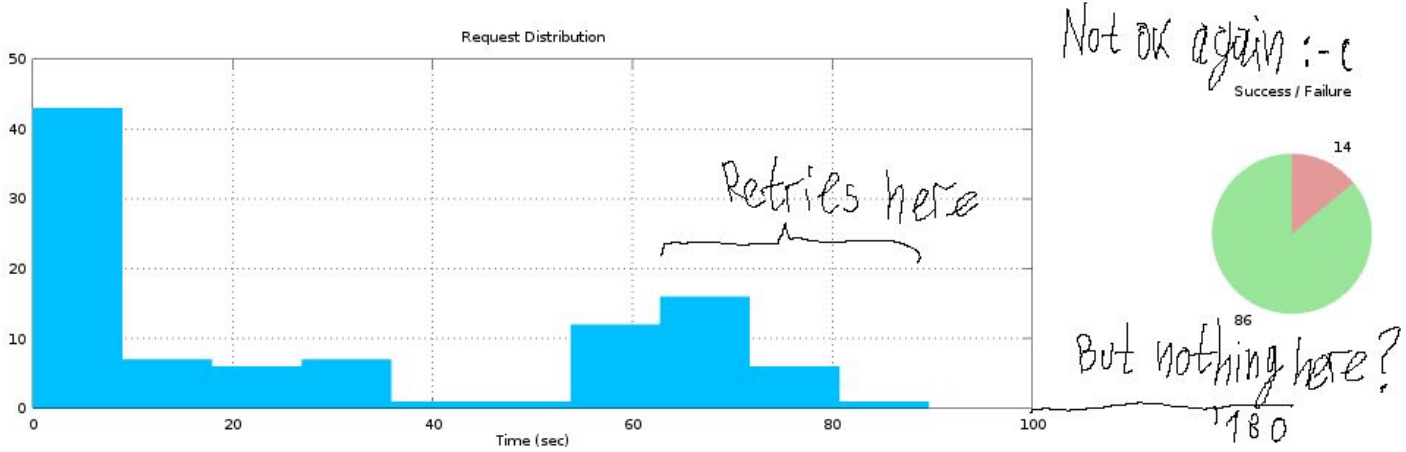
urllib3.util.retry source code. https://github.com/shazow/urllib3/blob/master/urllib3/util/retry.py
Exponential Backoff And Jitter. AWS Architecture Blog. https://www.awsarchitectureblog.com/2015/03/backoff.html

GET JSON: With Backoff Factor 25 sec (25% of Timeout)

```
BACKOFF_FACTOR = 25  # Seconds

session = requests.Session()
retry = urllib3.util.Retry(total=MAX_RETRIES,
                           connect=MAX_RETRIES,
                           read=MAX_RETRIES,
                           backoff_factor=BACKOFF_FACTOR)

adapter = requests.adapters.HTTPAdapter(max_retries=retry)
session.mount(RETRY_PREFIX, adapter)
r = session.get(URL, timeout=TIMEOUT)
r.raise_for_status()

res = r.json()
```

7 kB GET with G(0.5, 0.2), 3 Retries and Backoff





Read Timeout Exceptions: Handled and Unhandled

```
WARNING:requests.packages.urllib3.connectionpool:Retrying (Retry(  total=2, connect=3, read=2, redirect=None)) after connection broken
by 'ReadTimeoutError("HTTPConnectionPool(host='  172.17.0.2', port=80): Read timed out. (read timeout=60)",)'  : /test.json
```

```
ERROR:root:ConnectionError(ReadTimeoutError( "HTTPConnectionPool(host='172.17.0.2', port=80): Read timed out."  ,),)
ERROR:root:  File  "./sampler.py", line 15, in sample
    func()
  File "/home/amarchuk/tmp/pyconcz2016-net-failures/python/get_json.py"  , line 45, in get_retry
    r = session.get(URL,  timeout=TIMEOUT)
  File "/usr/lib/python3/dist-packages/requests/sessions.py"  , line 480, in get
    return self.request('GET', url, **kwargs)

  File "/usr/lib/python3/dist-packages/requests/sessions.py"  , line 468, in request
    resp = self.send(prep,  **send_kwargs)
  File "/usr/lib/python3/dist-packages/requests/sessions.py"  , line 608, in send
    r.content
  File "/usr/lib/python3/dist-packages/requests/models.py"  , line 737, in content
    self._content = bytes().join( self.iter_content(CONTENT_CHUNK_SIZE))  or bytes()
  File "/usr/lib/python3/dist-packages/requests/models.py"  , line 667, in generate
    raise ConnectionError(e)
```

GET JSON: With Our Own Retry

```
retry = urllib3.util.Retry( total=MAX_RETRIES, connect=MAX_RETRIES, read=MAX_RETRIES, backoff_factor=BACKOFF_FACTOR)

def attempt(url, retry=retry):
    try:
         # this essentially creates a new connection pool per request :-(
         session = requests.Session()
         adapter = requests.adapters.HTTPAdapter( max_retries=retry)
         session.mount(RETRY_PREFIX, adapter)
         req = requests.Request( 'GET', url).prepare()
         # would be nice just to pass retry here, but we cannot :-(
         r = session.send(req, timeout=TIMEOUT)
         r.raise_for_status()
#        except MaxRetryError:
#            raise
    except ConnectionError as e:
        #  increment() will return a new Retry() object
        retry = retry.increment(req.method, url, error=e)
        retry.sleep()  #  backoff is happening here
        logging.warning( "Retrying (%r) after connection broken by ' %r': '%s'", retry, e, url)
        return attempt(url, retry=retry)
    return r
res = attempt(URL).json()
```

urllib3 Retry Object in Response

Previous code can retry at maximum:

MAX_RETRIES * MAX_RETRIES > MAX_RETRIES

Latest urllib3 (**not yet in requests**) passes Retry() object used as part of the response, so we would do:

```
r = None
try:
    # ... skipped ...
    adapter = requests.adapters.HTTPAdapter(max_retries=retry)
    # ... skipped ...
    r = session.send(req, timeout=TIMEOUT)
    r.raise_for_status()
except ConnectionError as e:
    retry = r.raw.retries if r else retry #  May skip this if we are sure r is defined (e.g. from exception type)
    retry = retry.increment(req.method, url, error=e)
    # ... skipped ...
```

`urllib3.response.HTTPResponse:`

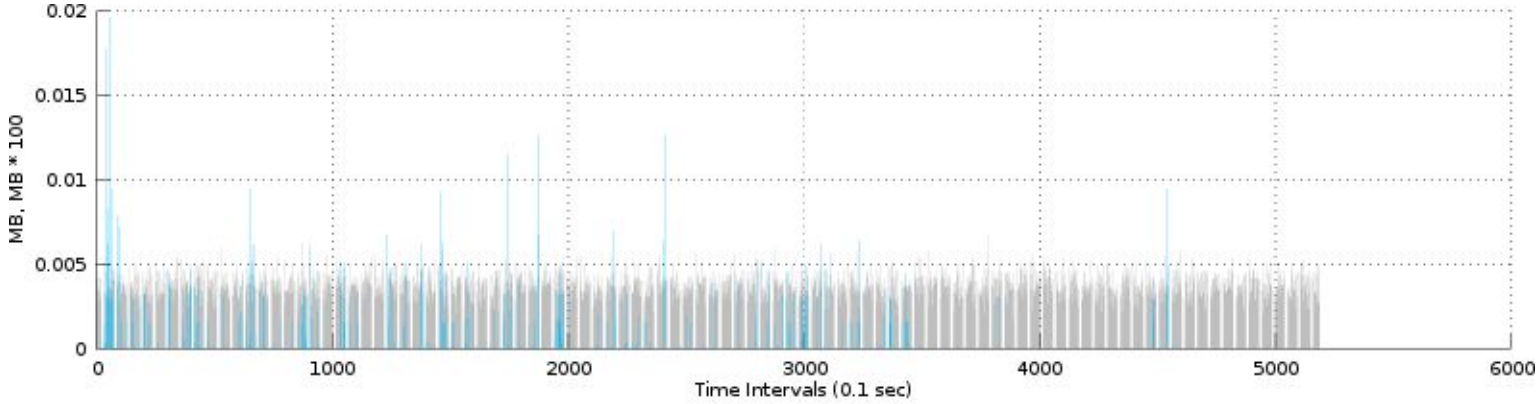
- **retries** – The retries contains the last `Retry` that was used during the request.

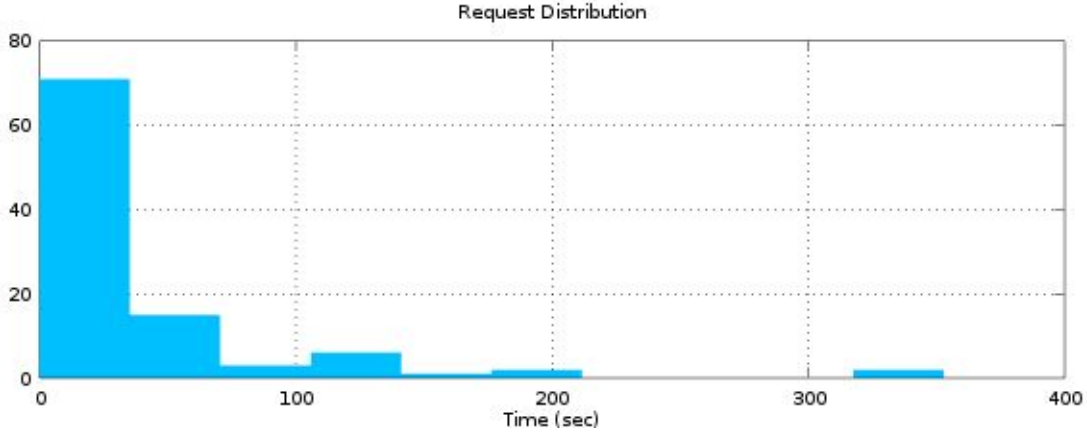
urllib3.response.HTTPResponse documentation. https://urllib3.readthedocs.io/en/latest/reference/index.html#module-urllib3.response

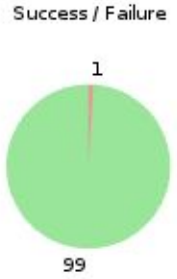
urllib3 Even Allows to Set Retry Per Request

```
import json
import urllib3

retry = urllib3.util.Retry(total=MAX_RETRIES, connect=MAX_RETRIES, read=MAX_RETRIES, backoff_factor=BACKOFF_FACTOR)
http = urllib3.PoolManager(retries=retry, timeout=TIMEOUT)

def attempt(url, http=http, retry=retry):
    r = None
    try:
        r = http.request('GET', url, retries=retry)
    except FooBarException as e:
        retry = r.retries if r else retry
        retry = retry.increment('GET', url, error=e)
        retry.sleep()
        logging.warning("Retrying (%r) after connection broken by '%r': '%s'", retry, e, url)
        return attempt(url, retry=retry)
    return r

return json.loads(attempt(URL, http).data.decode('utf-8'))
```

7 kB GET with G(0.5, 0.2) and Our Own Retry Catch







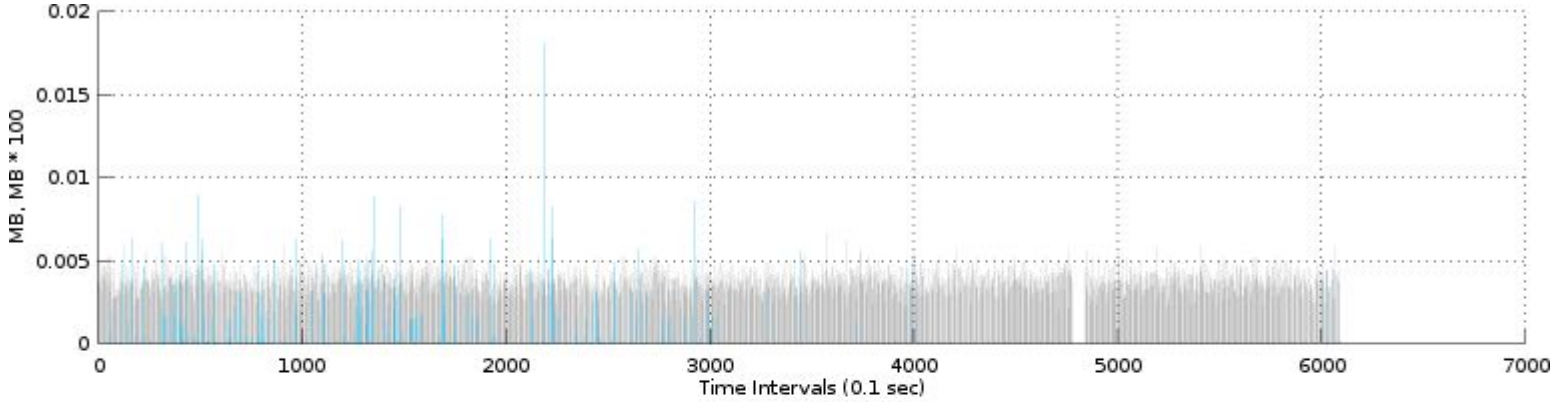
Still 1 Request Failed. Can We Do Even Better?

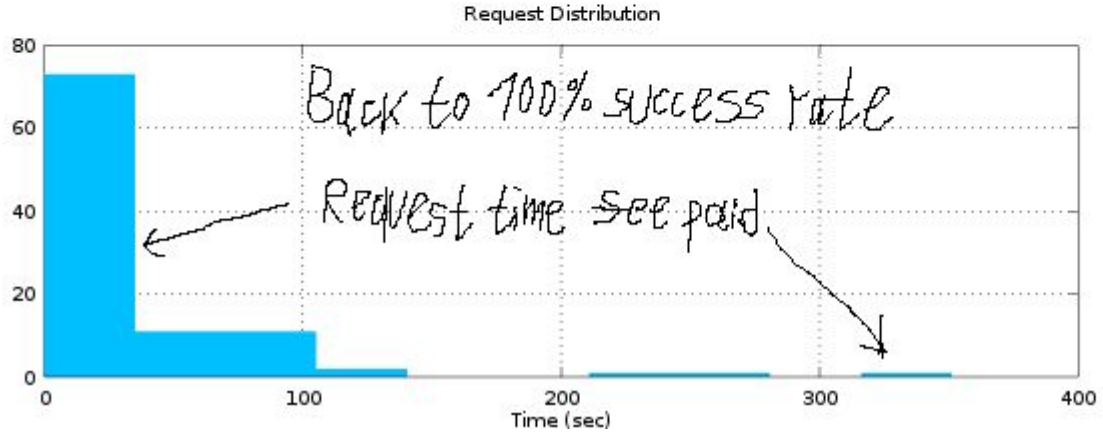
```
ERROR:root:object of type 'NoneType' has no len()
ERROR:root:  File "./sampler.py", line 15, in sample
    func()
  File "/home/amarchuk/tmp/pyconcz2016-net-failures/python/get_json.py", line 88, in get_retry_extended
    return attempt(URL).json()
  File "/usr/lib/python3/dist-packages/requests/models.py", line 791, in json
    if not self.encoding and len(self.content) > 3:
```

GET JSON: Retry With Content Awareness

```
def attempt(url, retry=retry):
    try:
        session = requests.Session()
        adapter = requests.adapters.HTTPAdapter(max_retries=retry)
        session.mount(RETRY_PREFIX, adapter)
        req = requests.Request('GET', url).prepare()
        r = session.send(req, timeout=TIMEOUT)
        r.raise_for_status()
        j = r.json()
    # DEMO ONLY. TypeError is too wide to handle here
    except (ConnectionError, TypeError) as e:
        retry = retry.increment(req.method, url,error=e)
        retry.sleep()
        logging.warning"Retrying (%r) after connection broken by %r': '%s'", retry, e, url)
        return attempt(url, retry=retry)
    return j
res = attempt(URL)
```

7 kB GET with G(0.5, 0.2) and Content Aware Retry





Conclusion

1. We can emulate network good enough.
2. Testing on “localhost” network does not work.
3. Testing on local network also might not work.
4. Implementing a retry is not easy. Use existing solutions when possible.
5. If you do your network library or protocol consider standard retries built in.
6. But, provide users ability to customize and override based on their use case.

And all this is possible!

Questions?

https://github.com/marchukov/talk-network-retries

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or just google for other contacts...