Aggregating CloudTrail log files

A data pipeline for reprocessing files in a data lake to optimize query performance.

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CHARIOT SOLUTIONS

The Problem

Lots of small files in a data lake

Small Files == Poor Query Performance

It takes ~15ms to read a 1 KB file from S3 to EC2

It takes ~20ms to read 1 MB

This translates to 67 files per second, per reader

Real-world numbers counting CloudTrail events:

Raw CloudTrail logs (1,637,376 files):	3 minutes 15 seconds
Aggregated by date (684 files):	6.3 seconds

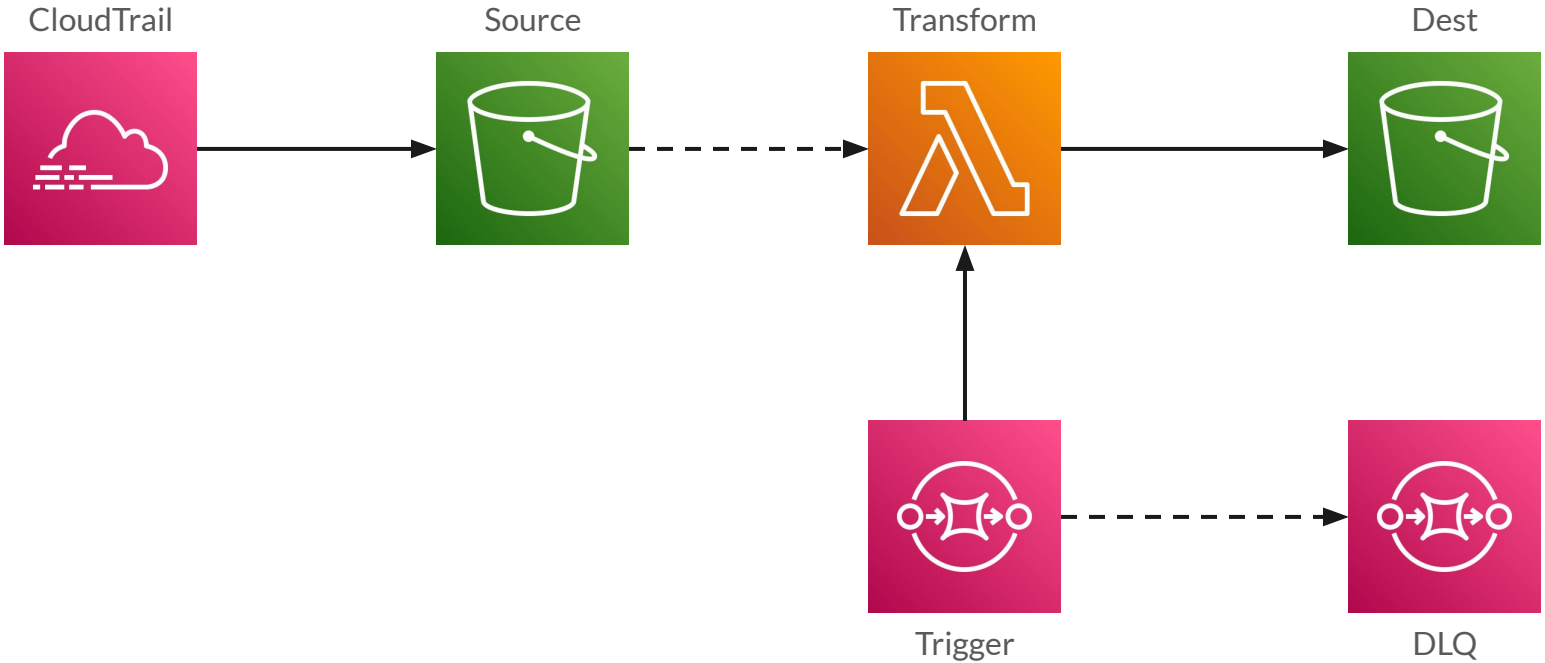
CloudTrail Writes Lots Of Small Files

- Approximately every 15 minutes, per account, per region
  - In Chariot's case, this is over 4,000 files per day
  - 4.6 million since we enabled CloudTrail
- These files often contain only a few events
  - In Chariot's case, 44% of files have 4 events or fewer (1k filesize)

The Solution

You know there had to be one, right?

A Lambda to Aggregate Files



Triggered from SQS

- Simple integration with Lambda
- Retry on failure, with persistent failures sent to dead-letter queue
- Supports both manual and programmatic invocation

Code Sample: Sending Messages to SQS

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

import boto3
import json

from datetime import date, timedelta

QUEUE_URL = "https://sqs.us-east-1.amazonaws.com/123456789012/cloudtrail-aggregation-trigger"

client = boto3.client('sqs')

dd = date(2023, 12, 1)
while dd <= date(2023, 12, 31):
    msg = json.dumps({"month": dd.month, "day": dd.day, "year": dd.year})
    client.send_message(QueueUrl=QUEUE_URL, MessageBody=msg)
    dd += timedelta(days=1)
```

Scaling the Transform

SQS invokes concurrent Lambdas to process queue

Quickly scales to configured limit or account quota

This can crush a database server!

May cause starvation for other Lambda jobs!

List One Day's Files

CloudTrail has a complex naming scheme:

```
AWSLogs/o-x7q8b22ufe/123456789012/CloudTrail/us-east-1/2
024/01/05/123456789012_CloudTrail_us-east-1_20240105T113
0Z_sKZpDSwJukKLNIFI.json.gz
```

S3 isn't a filesystem

But `ListObjectsV2` can make it act like one, using repeated calls with successively longer prefixes

Code Sample: Retrieving Prefixes

```
# src_bucket = "com-chariotsolutions-cloudtrail"
# src_prefix = "AWSLogs/o-x7q8b22ufe/"


def retrieve_accounts():
    return retrieve_child_prefixes(src_prefix)


def retrieve_regions_for_account(account_id):
    return retrieve_child_prefixes(f"{src_prefix}{account_id}/CloudTrail/")


def retrieve_child_prefixes(parent_prefix):
    resp = s3_client.list_objects_v2(Bucket=src_bucket, Prefix=parent_prefix, Delimiter="/")
    result = []
    for prefix in [x['Prefix'] for x in resp.get('CommonPrefixes', [])]:
        trimmed = prefix.replace(parent_prefix, "").replace("/", "")
        result.append(trimmed)
    return result
```

Code Sample: Listing Files

```
# src_bucket = "com-chariotsolutions-cloudtrail"
# src_prefix = "AWSLogs/o-x7q8b22ufe/"


def retrieve_file_list_for_account_region_and_date(account_id, region, month, day, year):
    result = []
    prefix = f"{src_prefix}{account_id}/CloudTrail/{region}/{year:04d}/{month:02d}/{day:02d}/"
    req_args = {
        "Bucket": src_bucket,
        "Prefix": prefix
    }
    while True:
        resp = s3_client.list_objects_v2(**req_args)
        for item in resp.get('Contents', []):
            result.append(item['Key'])
        if not resp.get('IsTruncated'):
            return result
        req_args['ContinuationToken'] = resp['NextContinuationToken']
```

Aggregate Files In-Memory

Historically, Lambda provided only 512 MB disk

Still much easier to let the garbage collector reclaim memory

Code Sample: Aggregating Records

```
def retrieve_log_records(file_list):
    for file in file_list:
        parsed = json.loads(read_file(file))
        for rec in parsed['Records']:
            yield json.dumps(rec)

def aggregate_and_output(file_list, month, day, year, desired_size = 64 * 1024 * 1024):
    file_number = 0
    cur_recs = []
    cur_size = 0
    for rec in retrieve_log_records(file_list):
        cur_recs.append(rec)
        cur_size += len(rec)
        if cur_size >= desired_size:
            write_file(cur_recs, month, day, year, file_number)
            file_number += 1
            cur_recs = []
            cur_size = 0
    if len(cur_recs) > 0:
        write_file(cur_recs, month, day, year, file_number)
```

Code Sample: Writing Files

```
def write_file(records, month, day, year, file_number):
    out = io.StringIO()
    for rec in records:
        print(rec, file=out)
    data = out.getvalue().encode('utf-8')
    data = gzip.compress(data)
    key = f"{dst_prefix}{year:04d}/{month:02d}/{day:02d}/{file_number:06d}.ndjson.gz"
    logger.info(f"writing {len(records)} records to s3://{dst_bucket}/{key}")
    s3_client.put_object(Bucket=dst_bucket, Key=key, Body=data)
```

Resiliency

Pipelines fail, be prepared

Do or Do Not, There is No “Try”

- It’s better to fail than partially succeed
  - Don’t catch exceptions unless you know that you can handle them
- Fail loudly
  - Nobody looks at logs unless they know there’s a problem
  - But capture enough information to allow debugging!
- Make transformer idempotent: invoke many times, produce same output

CloudWatch Metrics / Alarms

- Built-in metrics:
  - Alarm if anything in dead-letter queue
  - Alarm if messages remain in trigger queue
- Custom metrics to report file count, number of records
  - Alarm when out of bounds, or if missing data
- Dashboards only useful if people look at them

Logging

INFO-level to report high-level activity

```
2024-01-23T22:39:03.789Z retrieving files for 2024-01-12
2024-01-23T22:39:16.743Z 4002 total files
2024-01-23T22:42:41.953Z writing 18698 records to
s3://example/cloudtrail/2024/01/12/000000.ndjson.gz
```

DEBUG-level for detailed actions

```
2024-01-23T22:39:27.112Z 284 files for account 123456789012,
region us-west-2
```

Configure logging level via environment variable

Performance

How slow is slow, and what can we do about it?

It Takes Four Minutes to Run!

Number of source files:	4,002
Number of records:	18,698
Time breakdown from logs:	
Select list of files:	12.954 sec
Read files and aggregate records:	205.501 sec
Total execution time:	218.455 sec

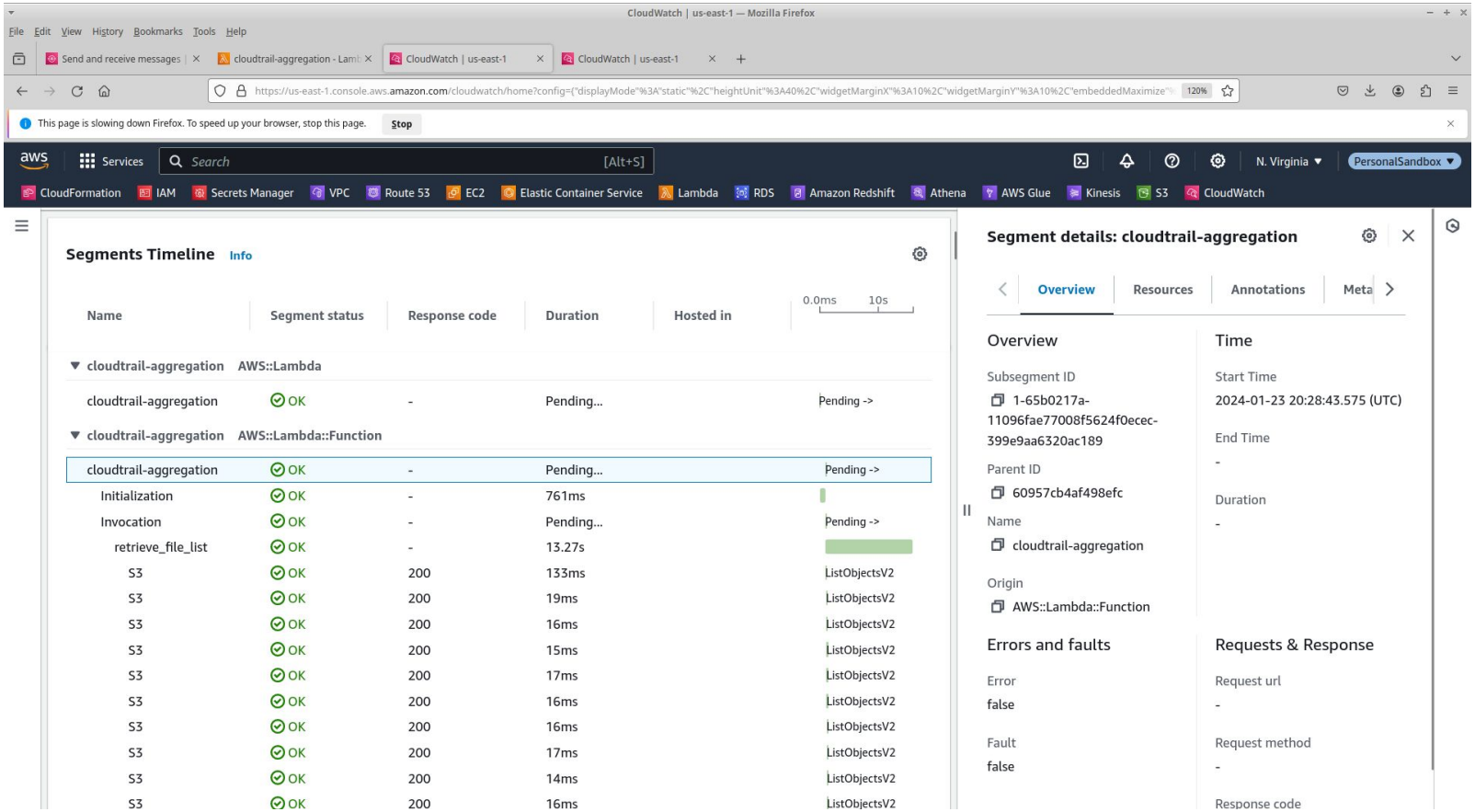
Will More Memory Help?

- Provisioned memory determines CPU
  - 1,769 MB == 1 vCPU
  - 128 MB (default for Python) == 1/14th vCPU
- This is primarily a problem for cold starts
  - Especially for scripts that load a lot of modules and/or perform CPU-intensive tasks at startup (including boto3 client creation)

Can X-Ray Give Us More Information?

- Distributed tracing service provided by AWS
  - Reports “trace segments” to central service
- Allows patching libraries (including boto3) to trace calls to external services
- Tightly integrated with Lambda
  - Custom segments requires the X-Ray SDK; attach as layer

X-Ray Isn't Designed For This!



How About the Python Profiler?

Tracing profiler built-in to the CPython runtime

Lambda throws when using `cProfile.run()`

Instead, must explicitly create, enable, disable:

```
profiler = cProfile.Profile()
profiler.enable()
aggregate_and_output(all_files, month, day, year)
profiler.disable()
pstats.Stats(profiler).sort_stats('tottime').print_stats()
```

Function Calls by Cumulative Time

```
31596718 function calls (31400363 primitive calls) in 252.702 seconds
Ordered by: cumulative time
ncalls  tottime  percall  cumtime  percall filename:lineno(function)
1        0.043    0.043   252.764  252.764 /var/task/index.py:99(aggregate_and_output)
18699    0.170    0.000   248.831    0.013 /var/task/index.py:119(retrieve_log_records)
4002     0.061    0.000   247.582    0.062 /var/task/index.py:129(read_file)
4003     0.028    0.000   246.635    0.062 /opt/python/botocore/client.py:544(_api_call)
(a bunch of functions in the boto3 call chain)
8324   210.584    0.025   210.584    0.025 {method 'read' of '_ssl._SSLSocket' objects}
```

Is there an issue with buffer size?

Possible Implementation Changes

Multi-threading?

- Can give performance boost when IO overlaps with CPU
- Python GIL means that Amdahl's Law limits speedup
- Adds complexity: need to coordinate threads

Use a different language?

- A "faster" language won't reduce IO times
- But other languages have better support for concurrency

Is This a Problem That Needs Solving?

- This Lambda typically runs when nobody's watching
- 4 minutes, 512 MB == 120 GB/sec == $0.002
  - Run daily, that's $0.78 / year
- Scale horizontally to process an entire dataset
  - With 8 concurrent executions, a month of data takes < 15 minutes

But Wait, There's More

Because friends don't let friends use JSON in their data lake

Reasons to stop here

CloudTrail data is complex, changing, impossible to accurately represent in a fixed format like Parquet

A few thousand files is sufficiently performant

Each file is ~6 MB; too small for Parquet

A Second Aggregation Step

- We process data by month this time
  - Reads data produced by first step
  - Lambda would timeout if we gave it a whole month of raw data
- Question: do we need to retain that first aggregation?
  - Idempotency says the files *should not* be deleted by the Lambda
- Nested fields will be stored as JSON strings

PyArrow

- Python wrapper over native Arrow library
- Better-documented than the Java Parquet library
  - And it doesn't have hundreds of dependencies!
- API is designed for bulk activities
  - This means staging data as Python lists/dicts, then writing

Code Sample: Schema

```
SCHEMA = pa.schema([
    pa.field('eventID', pa.string()),
    pa.field('requestID', pa.string()),
    pa.field('sharedEventID', pa.string()),
    pa.field('eventTime', pa.timestamp('ms')),
    pa.field('eventName', pa.string()),
    pa.field('eventSource', pa.string()),
    pa.field('eventVersion', pa.string()),
    pa.field('awsRegion', pa.string()),
    pa.field('sourceIPAddress', pa.string()),
    pa.field('recipientAccountId', pa.string()),
    pa.field('userIdentity', pa.string()),
    pa.field('requestParameters', pa.string()),
    pa.field('responseElements', pa.string()),
    pa.field('additionalEventData', pa.string()),
    pa.field('resources', pa.string()),
])
```

Code Sample: Record Conversion

```
def transform_record(src_rec):
    rec = json.loads(src_rec)
    xformed = {
        'eventID': rec.get('eventID'),
        'requestID': rec.get('requestID'),
        'sharedEventID': rec.get('sharedEventID'),
        'eventTime': datetime.fromisoformat(rec.get('eventTime')),
        # ...
        'recipientAccountId': rec.get('recipientAccountId'),
    }
    for nested_key in ['userIdentity', 'requestParameters', 'responseElements',
                       'additionalEventData', 'resources']:
        if rec.get(nested_key):
            xformed[nested_key] = json.dumps(rec.get(nested_key))
        else:
            xformed[nested_key] = None
    return xformed
```

Code Sample: Writing the File

```
def write_file(records, month, year, file_number):
    s3_url = f"s3://{dst_bucket}/{dst_prefix}{year:04d}/{month:02d}/{file_number:06d}.parquet"
    logger.info(f"writing {len(records)} records to {s3_url}")
    table = pa.Table.from_pylist(records, schema=SCHEMA)
    pq.write_table(table, s3_url, compression='SNAPPY')
```

A “Big” Problem

PyArrow + NumPy > 50 MB

Layers to the rescue!

Must use two: NumPy is 23M, PyArrow is 39 MB

Fortunately, there aren’t any transitive dependencies

```
pip install -t python pyarrow
zip -r /tmp/pyarrow.zip python/pyarrow*
zip -r /tmp/numpy.zip python/numpy*
```

A Bigger Problem

PyArrow library is specific to Python version, processor architecture

If you get this wrong: `No module named 'pyarrow.lib'`

Solution #1: create using AWS Docker image

```
docker run -it --rm \
       --entrypoint /bin/bash -v /tmp:/build \
       amazon/aws-lambda-python:3.11
```

Solution #2: deploy as a Lambda Container Image

Questions?

I have answers, some of them might even be correct

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