DCTV: can we pose better questions to traces?

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What is DCTV?

DCTV is an experimental framework for putting complex questions to trace files and getting back reliable answers.

- Trace database
  - Custom SQL dialect for heterogeneous time series
  - Column-oriented trace-backed query engine
- SQL REPL and batch query system
  - Explore traces with SQL-DCTV queries
  - Same queries useful for debugging, batch analysis
  - Multiple input, output formats
- GUI trace viewer
  - Flexible grouping, filtering, graphing, plotting
  - Asynchronously queries traces using DB backend
  - Interactively create data views; export them as SQL traces
  - Not discussed in this talk (no time)

Why is DCTV?

- Need powerful data exploration to find "unknown unknowns"
- Existing trace ecosystem fragmented, lacking power

Inspection	• Iterative evaluation of known scenario on live system • bpftrace, ftrace histograms, counters, perf • Powerful analysis, but analysis spec needed *before* running the scenario
Retrospection	• Backward-looking "forensic" analysis • Scenario frequency not repeatable • KernelShark, Trace Compass, LTTng viewer

- Data exploration just as important as metrics crunching
  - ... but should be easy to transform explorations intro metrics

Why is DCTV? Flexible Data Analysis

- What is analysis, anyway?
  - Fundamentally: iterated induction and abstraction-building
  - Least abstract: raw trace events
  - Most abstract: answer to question in your head
- The brain is just okay at abstraction-building
  - Example: vgrep raw `sched_switch` and glean useful stuff
  - Doesn't scale: working memory is small; we're bad at sums
- DCTV allows incrementally building complex abstractions
  - Ask questions in terms of answers to previously-asked questions
  - DCTV is largely written in itself!
  - Database core doesn't know about traces
  - Data model emphasizes composition

Why is DCTV? Error Avoidance

- I'm gravely concerned about silently incorrect analysis
  - We're inclined to believe and accept the plausible, even if it's ultimately wrong
  - DCTV is designed to reject nonsense operations
  - DCTV can't stop bad statistics, but it can reject mathematical nonsense
- Comprehensive dimensional analysis
  - Every quantity tagged with physical units
  - Queries fail on dimensional errors
  - Can define new units at runtime to avoid confusion
- Carefully-designed query language
  - Geared toward physically-meaningful "pit of success"
  - Metadata-level tracking verifies operation appropriateness
  - Trace-specific ergonomics
    - For example, automatic PID and TID disambiguation

Why is DCTV? High Performance on Big Data Sets

- DCTV is a GUI backend: query latency is important
- Designed for streaming processing on larger-than-core data sets
  - Trace files can get big: 50-60GB traces are common
  - Easy for off-the-shelf analysis tools to break down at this size
  - DCTV designed for larger-than-core data sets
- Sparseness, immutability of traces suggests columnar model
  - Opportunistic caching; modern techniques like "database cracking" obviate need for explicit indexes
  - Open research problem: simultaneous optimization of multiple queries
- Embedded use is a requirement
  - Runs on desktop, maybe inside browser one day
  - Precludes some big heavyweight DBMSes

DCTV Database Design

Basic Mechanics

- Trace events are rows in event-type-specific tables
- Work with a trace file by "mounting" it in the SQL namespace
  - Can mount multiple traces at once: run queries on multiple trace files
  - Multiple formats supported
    - ftrace text
    - systrace HTML
    - ftrace binary (planned)
    - perfetto protobuf (planned)
    - LTTng?

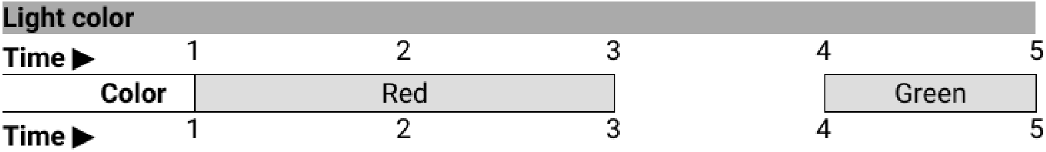
Example: basic trace mounting

```
~/dctv
$ ./dctv repl
Type .help for help.
DCTV> MOUNT TRACE 'local-data/dragonball.mini.trace' AS mytrace
DCTV> SELECT COUNT(next_comm) FROM mytrace.raw_events.sched_switch
COUNT(next_comm)
           32370
DCTV>
```

Data Model: SQL Superset

- SQL essence: set operations on high-dimensional points
- Query language supports "shape" as well as "point" operations
    - Data and *syntactic* support for intervals along the time axis
    - Each interval is called a "span"
    - Special table types: span tables and event tables
        - Optionally "partitioned" to capture higher dimensions
    - Special operators for working on span, event tables
        - `SPAN JOIN`
        - `SPAN GROUP`
        - `SPAN BROADCAST`
        - `EVENT BROADCAST`

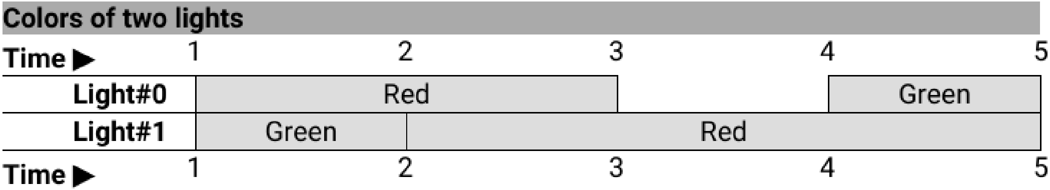
Example: span table



Light color (span table representation)

_ts	_duration	color
1	2	red
4	1	green

Example: partitioned span table



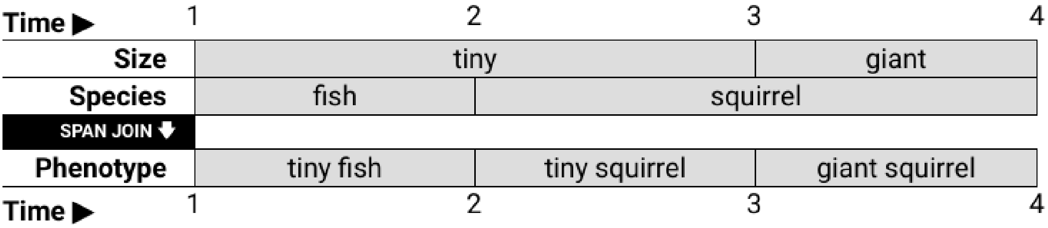
Colors of two lights (span table representation)

_ts	_duration	lightno	color
1	2	0	red
1	1	1	green
2	3	1	red
4	1	0	green

Span join

- `SPAN JOIN` aligns spans from different span tables
  - Output has a span boundary anywhere an input had a span boundary
- Comes in the usual SQL `INNER JOIN`, `OUTER JOIN`, etc. varieties
- Useful for asking questions of two time series with changes are different points.
- A regular, non-`SPAN JOIN` of a span table with a non-span table produces a span table partitioned by the join column of the unpartitioned table!

Span Join Diagram



Span Join Query: CPU times, frequency

```
DCTV> SELECT * FROM mytrace.scheduler.timeslices_p_cpu LIMIT 2;
_ts [ns] | _duration [ns] | cpu | comm       | pid   | prio
       0 |         164000 |   5 | swapper/5  |     0 |  120
   27000 |           7000 |   4 | trace-cmd  | 12202 |  120
DCTV> SELECT * FROM mytrace.scheduler.cpufreq_p_cpu LIMIT 2;
_ts [ns] | _duration [ns] | cpu | frequency [kcpu_cycle/s]
15035000 |         957000 |   0 |                  1171200
15051000 |         954000 |   1 |                  1171200
DCTV> SELECT _ts, _duration, frequency * _duration AS cycles FROM mytrace.scheduler
      cpufreq_p_cpu SPAN INNER JOIN mytrace.scheduler.timeslices_p_cpu LIMIT 2;
_ts [ns] | _duration [ns] | cycles [kcpu_cycle]
15035000 |         131000 |            153.4272
15051000 |         140000 |   163.96800000000002
DCTV>
```

Span Group

- `SPAN GROUP` is the "opposite" of `SPAN JOIN`
- Grouping puts spans together instead of breaking them apart
- Two kinds
  - Group by partition: collapse partitions, grouping payloads
    - Example: collapse per-CPU time series into system-wide time series
    - Example: collapse per-disk queue lengths into maximum queue length anywhere over time
  - Group by spans: force a span table into periods defined by another span table

Span Group Diagram

Time ▶	1	2	3	4	5	6	7	8	9
Number arms	2	5	0	7	2	4	9	0	
Periods	A		B		C		D		
Span group 🡇									
`MAX(arms)`	5		7		4		9		
`MIN(arms)`	2		0		2		0		
Time ▶	1	2	3	4	5	6	7	8	9

Complex example queries

Overall System Cpu Use Over Time

```
DCTV> WITH idle_by_span AS (
          SELECT SPAN SUM(_duration) AS total_time,
                      SUM(IF(pid=0, _duration, 0ns)) AS idle_time
                      FROM dctv.with_all_partitions(
                        mytrace.scheduler.timeslices_p_cpu) AS tscl
                      WHERE cpu=0
                      GROUP SPANS USING PARTITIONS)
      SELECT SPAN SUM(idle_time) / SUM(total_time)
      FROM idle_by_span
      GROUP AND INTERSECT SPANS INTO SPANS mytrace.quantize(1000us)
      LIMIT 5
 _ts [ns] | _duration [ns] | (SUM(idle_time) / SUM(total_time))
11000000  |        1000000 |                  0.945140131186642 9
12000000  |        1000000 |                                1.0
13000000  |        1000000 |                 0.9422283356258597
14000000  |        1000000 |                 0.8962510897994769
15000000  |        1000000 |                 0.7383268482490273
```

Frame Deadline Miss Attribution

```
DCTV> WITH frames AS (SELECT SPAN * FROM dctv.time_series_to_spans(
                      sources=>[{source=>(
                           SELECT * FROM trace.raw_events.`print|B`
                           WHERE name='eglBeginFrame'),
                      }],
                      columns=>[])),
           bad_frames AS (SELECT SPAN * FROM frames WHERE _duration > 17ms),
           bad_timeslices AS (SELECT SPAN * FROM bad_frames
                               SPAN BROADCAST INTO SPAN PARTITIONS
                               trace.scheduler.timeslices_p_cpu)
      SELECT comm, cpu, SUM(_duration) AS totdur FROM bad_timeslices
      WHERE pid != 0
      GROUP BY comm, cpu
      ORDER BY totdur DESC
      LIMIT 20
```

Development Status

- 40kLOC of Python, C++ and growing
- Includes object-based variant of Python multiprocessing that allows for concurrent query execution
- Interface still experimental
  - No guarantees about stability of the query language or other APIs
  - Patches welcome
- Perfetto includes a SQL-based "trace processor" as well
  - Perfetto's is SQLite-based: less powerful, less experimental
  - DCTV more focused on experimentation
  - Some ideas from DCTV imported into Perfetto
    - Columnar storage for trace data
    - Subset of span join operations

Future directions

- Incorporate perf events, system log events
- SQL/PL imperative query support
- Expanded "standard library" of trace building blocks
- Automatic slurping of ftrace event stacks
- Apache Arrow representation of result rows
  - Easier integration into SciPy ecosystem
- IPython notebook integration
- Collaborative annotation
- "Time table" spelling of span operations

Thank you for listening!
Questions welcome.