



Time series databases

COSC430—Advanced Databases

David Eyers (thanks to Paul Crane)

Learning objectives

- You should be able to **explain**:
 - Key characteristics of time series data
 - Uses for time series data
 - Why a specialised database is needed
- You should be able to **describe** existing research:
 - BTrDB—an example TSDB
 - Gorilla—the focus of our discussion today

Definitions relevant to time series databases

- Events or measurements
 - Values sampled at points in time
 - May be regular or irregular
 - Values are often tagged with metadata
- Time—many different interpretations / precisions:
 - system time, calendar time, UTC, etc.
- Time series:
 - Collection of measurements that share tag values

Data sources

- Financial & marketing—e.g., stock tickers
- Web/mobile events—e.g., click streams, notifications
- Industrial applications—e.g., safety monitoring
- Transportation & logistics—e.g., position tracking
- Datacenter & DevOps—e.g., machine metrics

Time-series analysis

- Similarity measures
 - Pearson's r
 - Spearman's rank
 - Kendall's τ
 - Kruskal's γ
- Segmentation
 - Divide the data into discrete events
- Visualisation
- Data mining, pattern discovery and clustering

Cumulative Sum
For displayed time period

Data Segmentation

Comparisons
Between series or temporally



Pattern Detection

Visualisation

Basic Statistics
(min/max/avg)
Advanced Stats
Correlations and so on

Query functions

- Aggregations (COUNT, SUM, INTEGRAL, ...)
- Selectors (BOTTOM, FIRST, LAST, TOP, ...)
- Transformation (CEILING, DERIVATIVE, ELAPSED, MOVING_AVERAGE, ...)
- For more detail you can examine the documentation of InfluxDB's time-series query language:
 - https://docs.influxdata.com/influxdb/v1.5/query_language/

Characteristics of time-series data

- Often collected from a wide range of sources
 - e.g., weather stations distributed across New Zealand
- Often collected over long durations
 - Both short- and long-histories are useful for different analyses
- Often need to store different types of data
 - e.g., different environmental sensors at one weather station
- Database should handle measurements + metadata
 - e.g., replacing a sensor device might affect values recorded

This is an old snapshot as some sensors are currently being recalibrated...



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Te Whare Wānanga o Ōtago
NEW ZEALAND

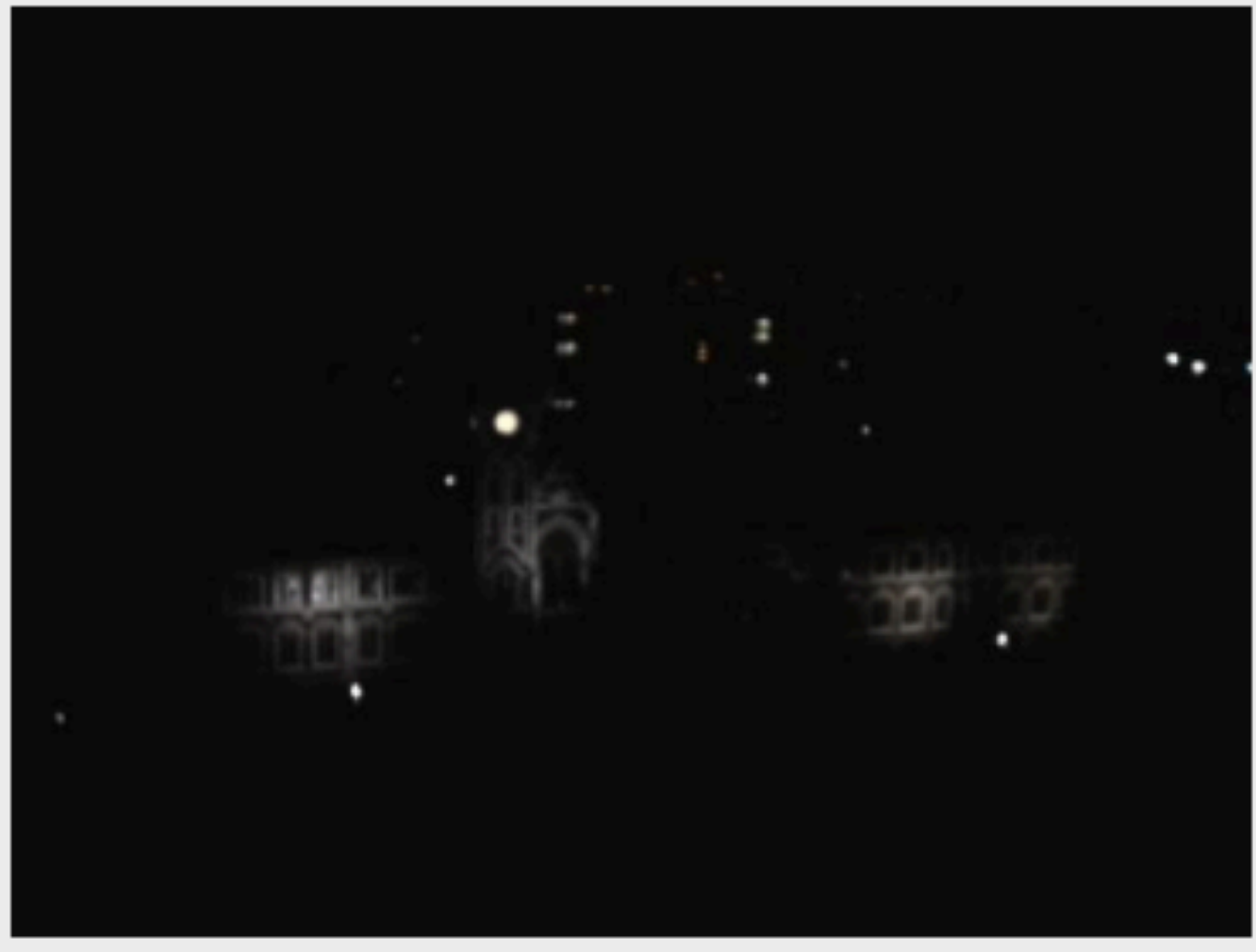
Department of Physics
WEATHER STATION MONITOR



Current Measurements
Temperature & Rain
Wind & Pressure
Solar
Seven-Day Summary
Monthly Summary

Current Measurements
Updated at 00:30, 15/04/2019 

Temperature:	10.1 °C
Today's high:	10.1 °C
Today's low:	9.8 °C
Relative humidity:	67.7 %
Total rain today:	0 mm
Global irradiance:	0 W/m ²
Pressure:	1020 hPa
Wind speed:	6.9 km/hr
Wind direction:	West
Today's max wind gust:	15.8 km/hr
Time of max wind gust:	00:00



Webcam view of the Clocktower & registry building.

Data on this page was last updated on 15/04/2019 at 00:30. More information about the weather station can be found at the [About the Weather Station](#) page on the main physics website. Archived data can be downloaded from the [Archive download](#) page.

Temperature, RH & Rain
Temperature and relative humidity over the last 24-hours

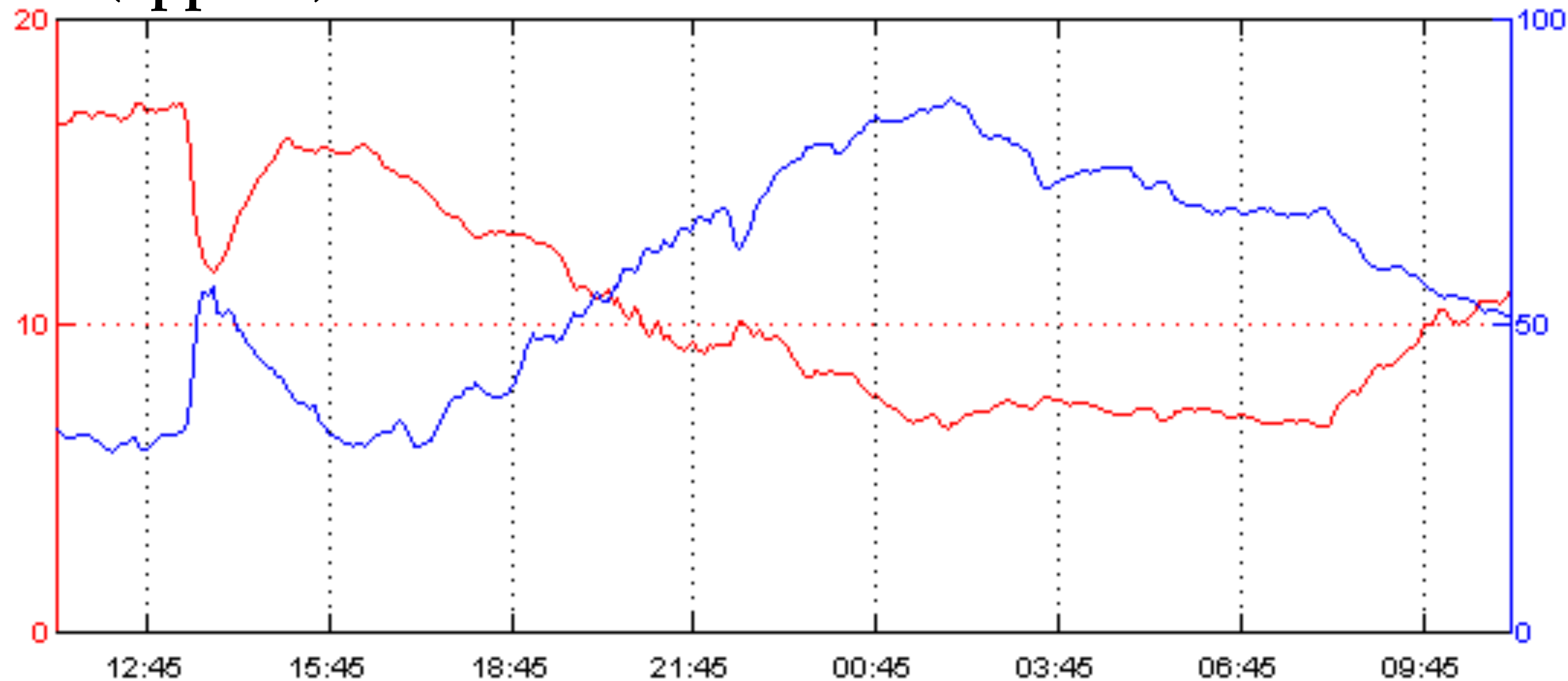
[^]

Ordered sequence of real-value variables

Measurements made
every 5 minutes (approx.)

Immutable data

Write heavy workloads



Sequential appends
 t_n is added after t_{n-1}

Compressible
More recent data is more important

Deletes across large
time periods

DATE	TIME	TEMP	RH	WSP	WDIR	GBL	UVA	UVB	VISIBLE	RAIN	PRS	GUST	GTIME
dd/mm/yy	HH:MM:SS	C	%	m/s	deg	W/m2	W/m2	W/m2	mmol/m2s	mm	hPa	m/s	hhmm

01/03/2018	00:00:00	14.7	73	1.1	344	-0.1	0.0	0.01	-1	0.0	1009	1.9	2356
01/03/2018	00:05:00	14.7	74	0.7	329	-0.1	0.0	0.01	-1	0.0	1008	1.2	2
01/03/2018	00:10:00	14.9	74	0.2	357	-0.1	-0.0	0.01	-1	0.0	1008	0.6	5
01/03/2018	00:15:00	15.1	73	0.3	309	-0.1	-0.0	0.01	-1	0.0	1008	0.7	10
01/03/2018	00:20:00	15.3	74	1.2	21	-0.1	-0.0	0.01	-1	0.0	1008	1.9	18
01/03/2018	00:25:00	14.8	75	1.2	2	-0.1	0.0	0.01	-1	0.0	1008	2.0	21
01/03/2018	00:30:00	14.7	76	1.4	357	-0.1	0.0	0.01	-1	0.0	1008	2.1	27
01/03/2018	00:35:00	14.5	77	1.9	5	-0.1	0.0	0.01	-1	0.0	1008	2.7	32
01/03/2018	00:40:00	14.7	75	2.0	2	-0.1	0.0	0.01	-1	0.0	1008	2.8	38
01/03/2018	00:45:00	14.8	76	1.2	30	-0.1	0.0	0.01	-1	0.0	1008	1.8	44
01/03/2018	00:50:00	15.0	77	1.8	30	-0.1	0.0	0.01	-1	0.0	1008	2.3	48
01/03/2018	00:55:00	14.9	78	0.8	11	-0.1	0.0	0.01	-1	0.0	1008	1.5	50
01/03/2018	01:00:00	14.9	78	1.1	48	-0.1	0.0	0.01	-1	0.0	1008	1.5	100
01/03/2018	01:05:00	14.8	79	1.2	340	-0.1	-0.0	0.01	-1	0.0	1008	1.6	100
01/03/2018	01:10:00	14.9	81	1.2	65	-0.1	-0.0	0.01	-1	0.0	1008	1.8	110
01/03/2018	01:15:00	14.9	81	1.6	13	-0.1	-0.0	0.01	-1	0.0	1008	2.7	115
01/03/2018	01:20:00	14.7	82	1.1	33	-0.1	0.0	0.01	-1	0.0	1008	2.9	115
01/03/2018	01:25:00	14.7	82	0.7	354	-0.1	0.0	0.01	-1	0.0	1008	1.4	123
01/03/2018	01:30:00	14.8	83	0.8	357	-0.1	-0.0	0.01	-1	0.0	1008	1.5	127
01/03/2018	01:35:00	14.7	84	0.6	13	-0.1	0.0	0.01	-1	0.0	1008	1.0	130

- InfluxDB-specific schema:
 - key,tag=value,... field=value,... timestamp

```
temperature,location_id=42,units=c value=14.2 1524133698000000035
humidity,location_id=42,units=% value=73 1524133698000000035
wind_speed,location_id=42,units=ms-1 value=1.1 1524133698000000035
wind_dir,location_id=42,units=degrees value=344 1524133698000000035
radiation,location_id=42,units=wm-2 global=-0.1,uva=0.0,uvb=0.1 1524133698000000035
visible,location_id=42,units=mmolm-2 value=-1 1524133698000000035
rain,location_id=42,units=mm value=0.0 1524133698000000035
pressure,location_id=42,units=hPa value=1009 1524133698000000035
maxgust,location_id=42,units=ms-1 speed=1.9 1524133458000000035
```

Raw web server logs ...

```
207.46.195.225 [21/Nov/2010:09:58:09 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
207.46.195.225 [21/Nov/2010:10:09:29 +1300] "GET /publications.html HTTP/1.1" 304 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
89.149.254.75 [21/Nov/2010:10:59:25 +1300] "GET /documents/world45.ppt++++++++Result:+no+post+sending+forms+are+found; HTTP/1.0" 404 361 "http://vodca.otago.ac.nz/documents/world45.ppt++++++++Result:+no+post+sending+forms+are+found;" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
89.149.254.75 [21/Nov/2010:10:59:26 +1300] "GET / HTTP/1.0" 200 12005 "http://vodca.otago.ac.nz/" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
207.46.13.96 [21/Nov/2010:13:16:49 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
207.46.13.96 [21/Nov/2010:13:23:55 +1300] "GET / HTTP/1.1" 200 12005 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
66.249.68.204 [21/Nov/2010:17:22:08 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Mozilla/5.0 (compatible; Googlebot/2.1; +http://www.google.com/bot.html)"
66.249.68.204 [21/Nov/2010:17:22:09 +1300] "GET /patches.html HTTP/1.1" 304 "-" "Mozilla/5.0 (compatible; Googlebot/2.1; +http://www.google.com/bot.html)"
220.181.108.187 [21/Nov/2010:20:19:32 +1300] "GET / HTTP/1.1" 304 "-" "Baiduspider+(+http://www.baidu.com/search/spider.htm)"
67.195.114.240 [21/Nov/2010:20:58:02 +1300] "GET /robots.txt HTTP/1.0" 404 275 "-" "Mozilla/5.0 (compatible; Yahoo! Slurp; http://help.yahoo.com/help/us/ysearch/slurp)"
67.195.114.240 [21/Nov/2010:20:58:15 +1300] "GET / HTTP/1.0" 200 12005 "http://www.vodca.org/" "Mozilla/5.0 (compatible; Yahoo! Slurp; http://help.yahoo.com/help/us/ysearch/slurp)"
208.80.194.29 [21/Nov/2010:22:25:06 +1300] "GET / HTTP/1.0" 200 12005 "-" "Mozilla/4.0 (compatible; MSIE 7.0; Windows NT 5.1; Media Center PC 3.0; .NET CLR 1.0.3705; .NET CLR 1.1.4322; InfoPath.2)"
207.46.13.133 [22/Nov/2010:02:27:25 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
207.46.13.133 [22/Nov/2010:02:39:31 +1300] "GET /cgi-bin/vodca-regdl.cgi HTTP/1.1" 200 3605 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
123.125.66.26 [22/Nov/2010:02:59:38 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Baiduspider+(+http://www.baidu.com/search/spider.htm)"
207.46.199.47 [22/Nov/2010:05:37:09 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
207.46.199.47 [22/Nov/2010:05:48:26 +1300] "GET /patches.html HTTP/1.1" 304 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
67.195.114.235 [22/Nov/2010:08:12:24 +1300] "GET /robots.txt HTTP/1.0" 404 275 "-" "Mozilla/5.0 (compatible; Yahoo! Slurp; http://help.yahoo.com/help/us/ysearch/slurp)"
67.195.114.235 [22/Nov/2010:08:13:20 +1300] "GET /documents/world45.ppt HTTP/1.0" 200 439296 "-" "Mozilla/5.0 (compatible; Yahoo! Slurp; http://help.yahoo.com/help/us/ysearch/slurp)"
65.52.110.66 [22/Nov/2010:11:17:40 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
65.52.110.66 [22/Nov/2010:11:19:01 +1300] "GET /publications.html HTTP/1.1" 304 "-" "Mozilla/5.0 (compatible; bingbot/2.0; +http://www.bing.com/bingbot.htm)"
208.120.42.152 [22/Nov/2010:14:00:47 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Mozilla/5.0 (compatible; 008/0.83; http://www.80legs.com/webcrawler.html;) Gecko/2008032620"
208.120.42.152 [22/Nov/2010:14:00:47 +1300] "GET / HTTP/1.1" 200 12005 "-" "Mozilla/5.0 (compatible; 008/0.83; http://www.80legs.com/webcrawler.html) Gecko/2008032620"
213.5.70.204 [22/Nov/2010:16:14:18 +1300] "GET /documents/world45.ppt HTTP/1.0" 200 439296 "http://vodca.otago.ac.nz/documents/world45.ppt" "Mozilla/4.0 (compatible; MSIE 6.0; Windows NT 5.1; SV1; Crazy Browser 2.0.0 Beta 1; .NET CLR 1.0.3705; .NET CLR 1.1.4322)"
123.125.71.25 [23/Nov/2010:01:37:48 +1300] "GET /documents/main.pdf HTTP/1.1" 200 60823 "-" "Baiduspider+(+http://www.baidu.com/search/spider.htm)"
91.201.66.65 [23/Nov/2010:03:14:32 +1300] "GET /documents/world45.ppt HTTP/1.0" 200 439296 "http://vodca.otago.ac.nz/documents/world45.ppt" "Mozilla/4.0 (compatible; MSIE 6.0; Windows 98; Win 9x 4.90)"
46.118.4.66 [23/Nov/2010:03:21:08 +1300] "GET /documents/world45.ppt HTTP/1.0" 200 439296 "http://vodca.otago.ac.nz/documents/world45.ppt" "Opera/8.00 (Windows NT 5.1; U; en)"
123.125.66.106 [23/Nov/2010:07:44:37 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Baiduspider+(+http://www.baidu.com/search/spider.htm)"
66.249.71.199 [23/Nov/2010:08:24:47 +1300] "GET /robots.txt HTTP/1.1" 404 275 "-" "Googlebot/2.1 (+http://www.google.com/bot.html)"
66.249.71.199 [23/Nov/2010:08:24:48 +1300] "GET /publications.html HTTP/1.1" 200 4535 "-" "Googlebot/2.1 (+http://www.google.com/bot.html)"
```


... expressed in InfluxDB form

```
page_view,resp_code=200,path=access.log,host=www.example.com,verb=GET agent="Mozilla/5.0 (Windows; U; Windows NT 6.0; en-US) AppleWebKit/534.7 (KHTML, like Gecko) Chrome/7.0.517.44 Safari/534.7",ident="-",auth="-",client_ip="186.204.131.65",request="/",http_version=1.1,resp_bytes=12005i,referrer="http://www.vodca.org/" 1290545939000000000
```

```
page_view,path=access.log,host=www.example.com,verb=GET,resp_code=200 request="/250px-PurdueLinuxComputerCluster_neg3.jpg",client_ip="186.204.131.65",auth="-",http_version=1.1,resp_bytes=472149i,referrer="http://vodca.otago.ac.nz/",agent="Mozilla/5.0 (Windows; U; Windows NT 6.0; en-US) AppleWebKit/534.7 (KHTML, like Gecko) Chrome/7.0.517.44 Safari/534.7",ident="-" 1290545940000000000
```

```
page_view,path=access.log,host=www.example.com,resp_code=404,verb=GET  
referrer="-",client_ip="66.249.69.208",ident="-",agent="Googlebot/2.1 (+http://www.google.com/bot.html)",auth="-",resp_bytes=275i,request="/robots.txt",http_version=1.1 1290548642000000000
```

```
page_view,resp_code=200,path=access.log,host=www.example.com,verb=GET ident="-",auth="-",request="/publications.html",client_ip="66.249.69.208",http_version=1.1,resp_bytes=4535i,referrer="-",agent="Googlebot/2.1 (+http://www.google.com/bot.html)" 1290548642001000000
```

Dashboard - Overall Analyzed Requests (21/Nov/2010 - 24/Nov/2010)

Total Requests53Unique Visitors27Unique Files8Referrers6

Valid Requests53Init. Proc. Time0sStatic Files2Log Size8.61 KiB

Failed Requests0Excl. IP Hits0Unique 4044Bandwidth3.56 MiB

Log Source/Volumes/resources/scripting/access.log

> 1 - Unique visitors per day - Including spiders

Total: 4/4

Hits	h% Vis.	v%	Bandwidth	Data
11	20.75%	6 22.22%	1.32 MiB	24/Nov/2010
12	22.64%	8 29.63%	1.34 MiB	23/Nov/2010
12	22.64%	6 22.22%	874.86 KiB	22/Nov/2010
18	33.96%	7 25.93%	49.93 KiB	21/Nov/2010

2 - Requested Files (URLs)

Total: 8/8

Hits	h% Vis.	v%	Bandwidth	Mtd	Proto	Data
7	25.93%	7 26.92%	58.62 KiB	GET	HTTP/1.1	/
6	22.22%	6 23.08%	2.51 MiB	GET	HTTP/1.0	/documents/world45.ppt
4	14.81%	4 15.38%	8.86 KiB	GET	HTTP/1.1	/publications.html
4	14.81%	4 15.38%	46.89 KiB	GET	HTTP/1.0	/
3	11.11%	3 11.54%	0.0	B	GET	HTTP/1.1 /patches.html
1	3.70%	0 0.00%	293.0	B	GET	HTTP/1.1 /w00tw00t.at.ISC.SANS.DFind:)
1	3.70%	1 3.85%	3.52 KiB	GET	HTTP/1.1	/cgi-bin/vodca-regdl.cgi

3 - Static Requests

Total: 2/2

Hits	h% Vis.	v%	Bandwidth	Mtd	Proto	Data
1	50.00%	1 50.00%	59.40 KiB	GET	HTTP/1.1	/documents/main.pdf
1	50.00%	1 50.00%	461.08 KiB	GET	HTTP/1.1	/250px-PurdueLinuxComputerCluster_neg3.jpg

4 - Not Found URLs (404s)

Total: 4/4

Hits	h% Vis.	v%	Bandwidth	Mtd	Proto	Data
20	83.33%	0 0.00%	5.37 KiB	GET	HTTP/1.1	/robots.txt
2	8.33%	0 0.00%	550.0	B	GET	HTTP/1.0 /robots.txt
1	4.17%	0 0.00%	361.0	B	GET	HTTP/1.0 /documents/world45.ppt+++++++Result:+no+post+sending+forms+are+found;
1	4.17%	0 0.00%	282.0	B	GET	HTTP/1.1 http://www.mambofello.com/photos/Img14.jpg

5 - Visitor Hostnames and IPs

Total: 34/34

Hits	h% Vis.	v%	Bandwidth	Data
3	5.66%	0 0.00%	825.0	B 192.168.1.1
3	5.66%	2 7.41%	4.70 KiB	66.249.71.199
2	3.77%	1 3.70%	275.0	B 207.46.195.225
2	3.77%	1 3.70%	11.99 KiB	207.46.13.96
2	3.77%	1 3.70%	275.0	B 66.249.68.204
2	3.77%	1 3.70%	11.99 KiB	67.195.114.240
2	3.77%	1 3.70%	4.70 KiB	66.249.69.208

6 - Operating Systems

Total: 7/7

Hits	h% Vis.	v%	Bandwidth	Data
24	45.28%	16 59.26%	3.04 MiB	Windows
22	41.51%	7 25.93%	527.62 KiB	Unknown
7	13.21%	4 14.81%	9.66 KiB	Unix-like

[?] Help [Enter] Exp. Panel 0 - Tue Mar 20 10:20:29 2018

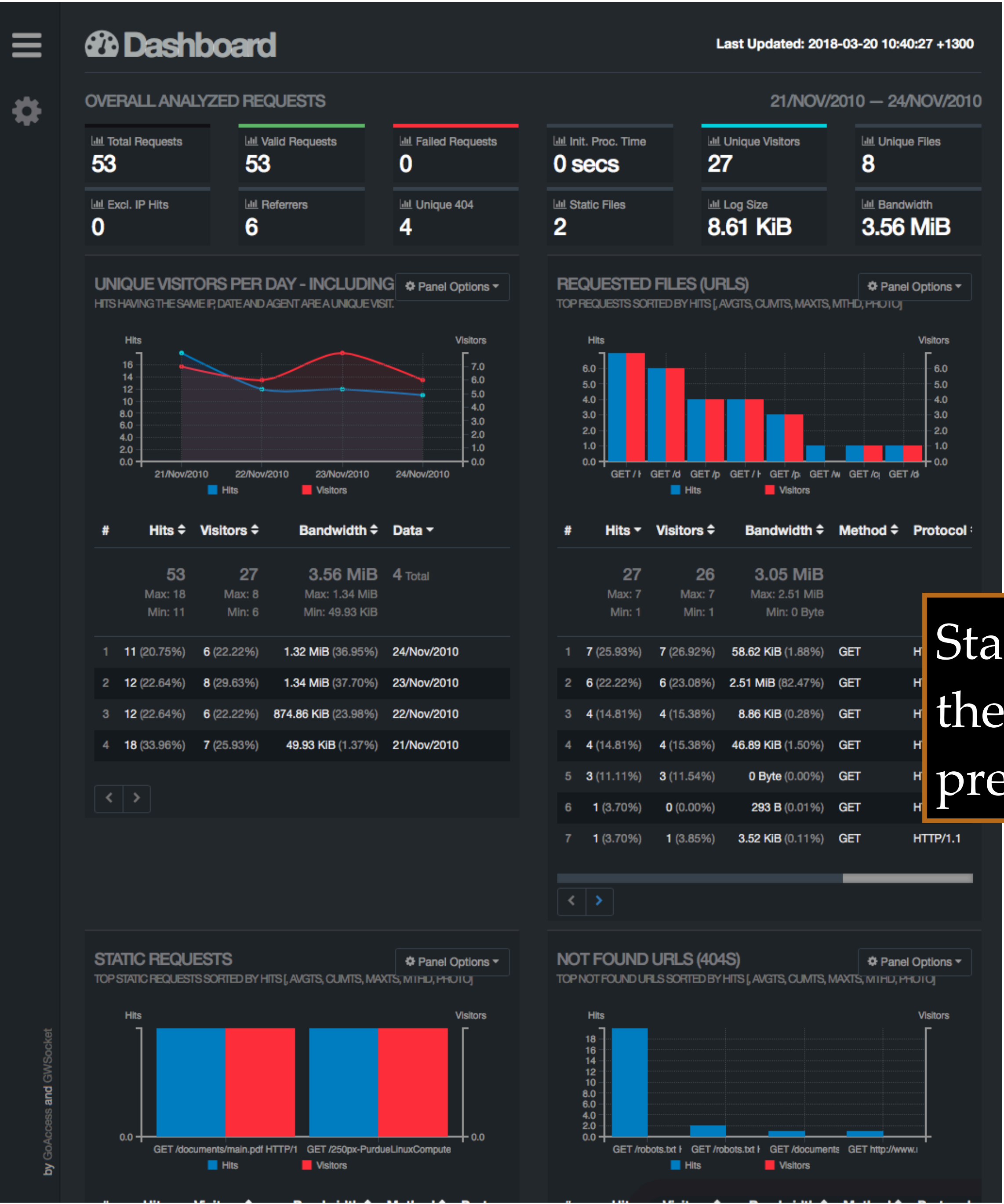
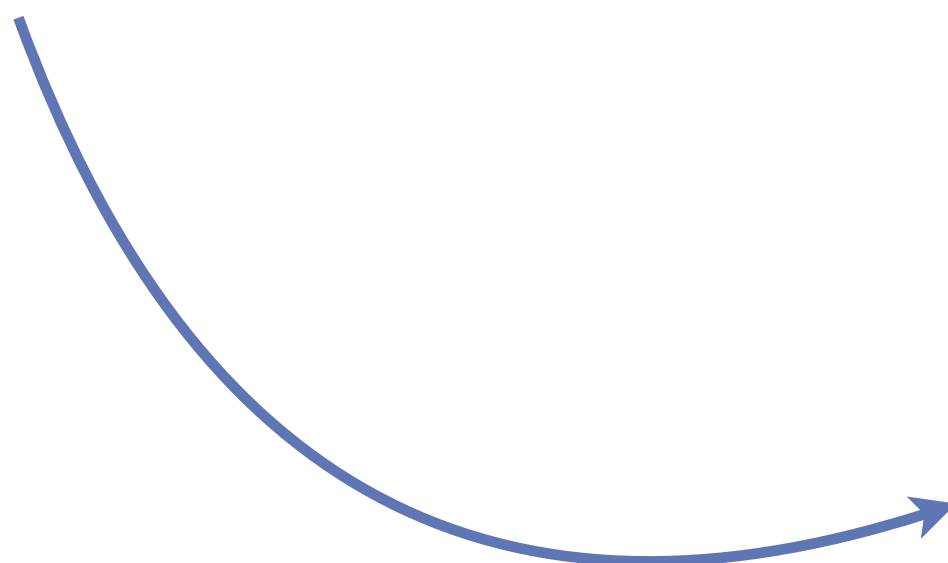
[Q]uit GoAccess 1.2

Command line interface,
generated from the web
log shown previously

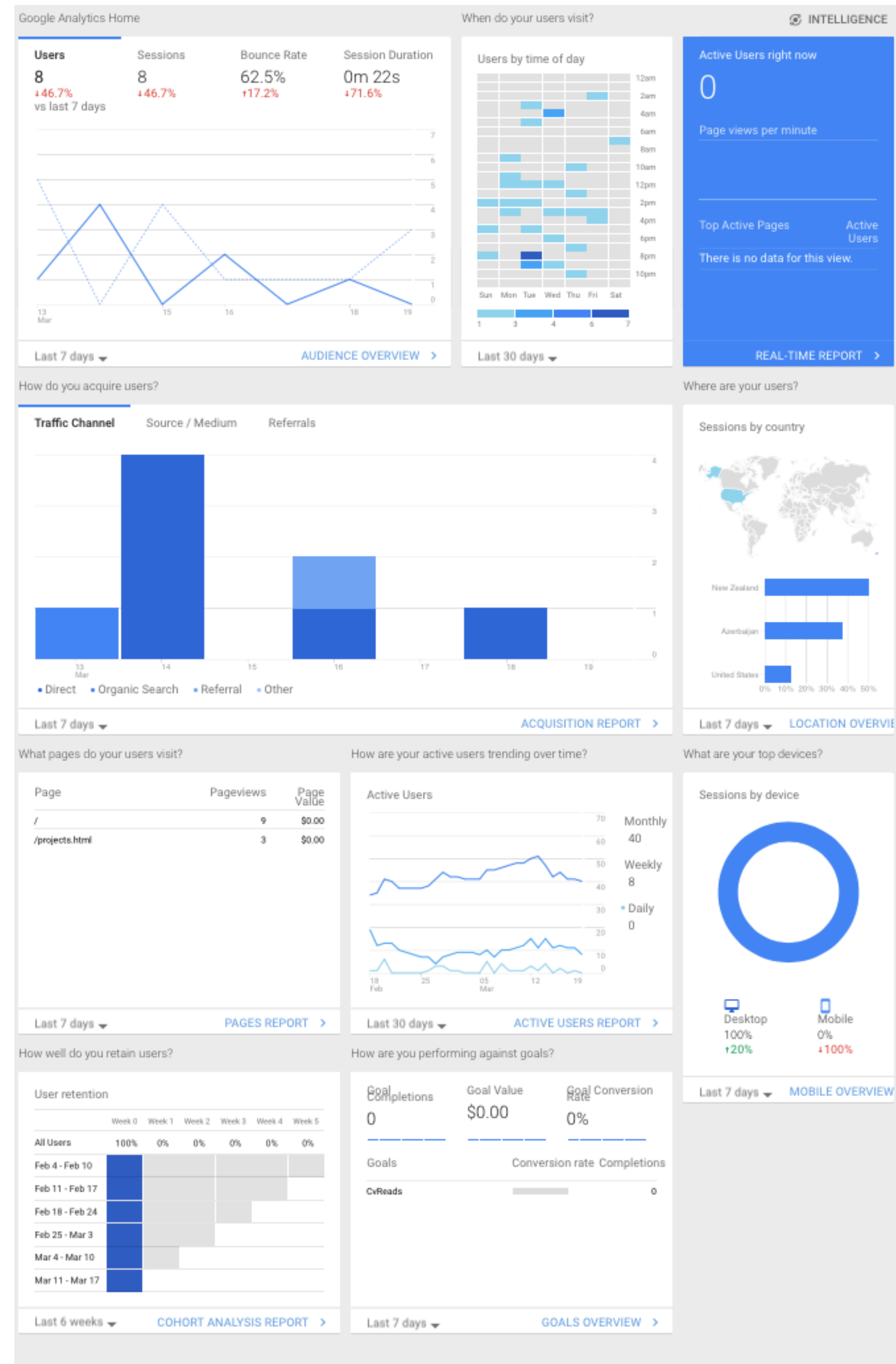
COSC430 Lecture 8, 2020

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Example statistics
from a fileserver
that used to
support COSC301



Statically generated from
the web log shown
previously

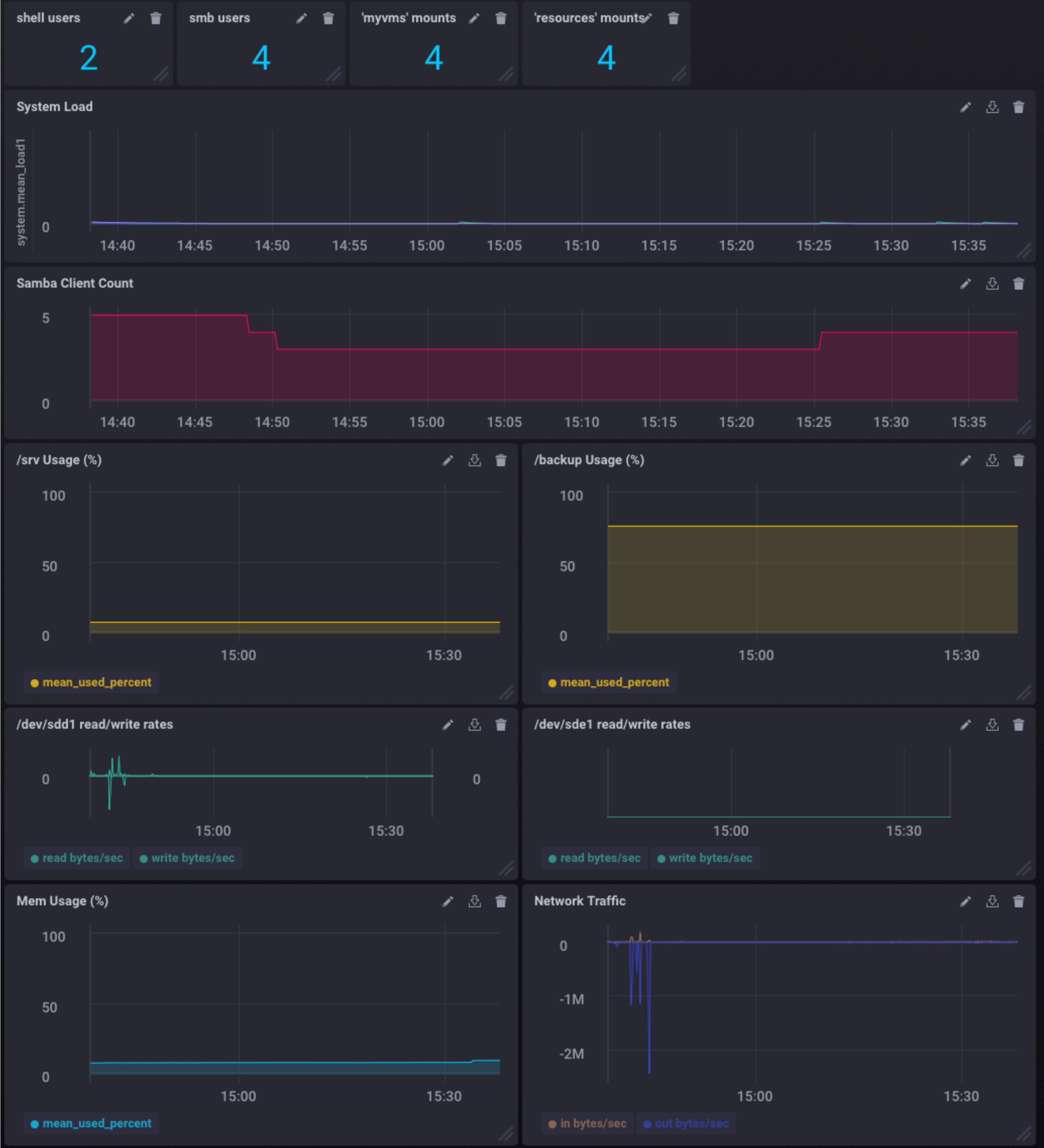
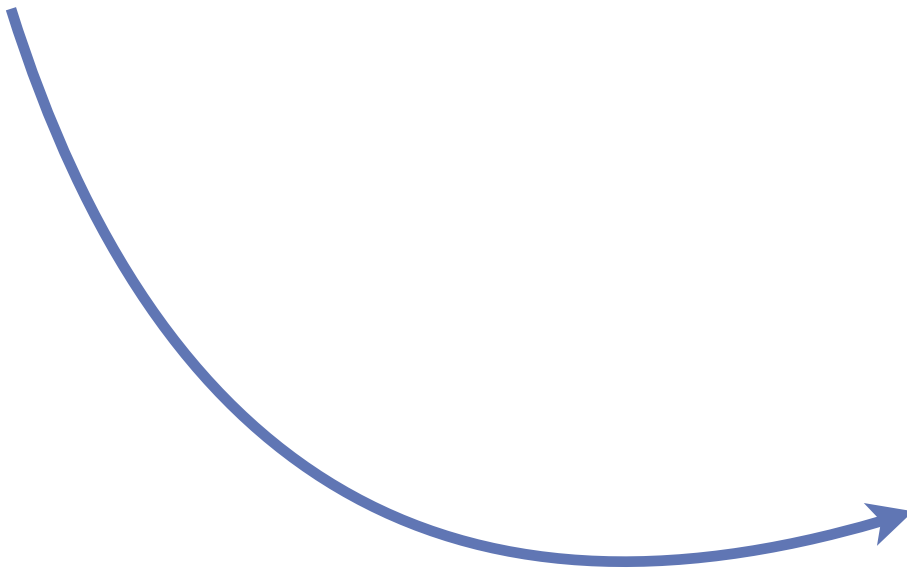


This is not actually from
a server log, but some
JavaScript that runs in
the browser

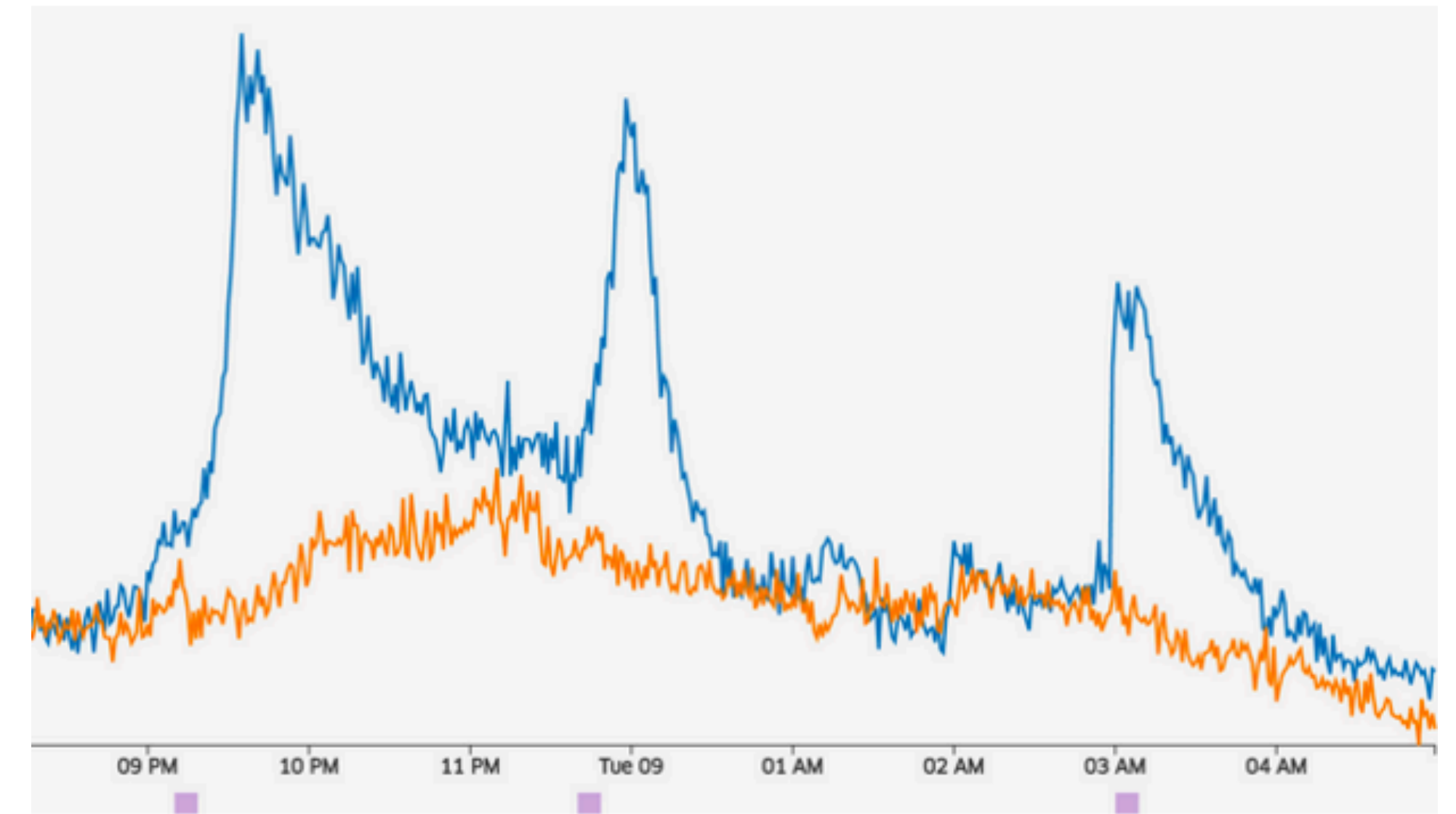
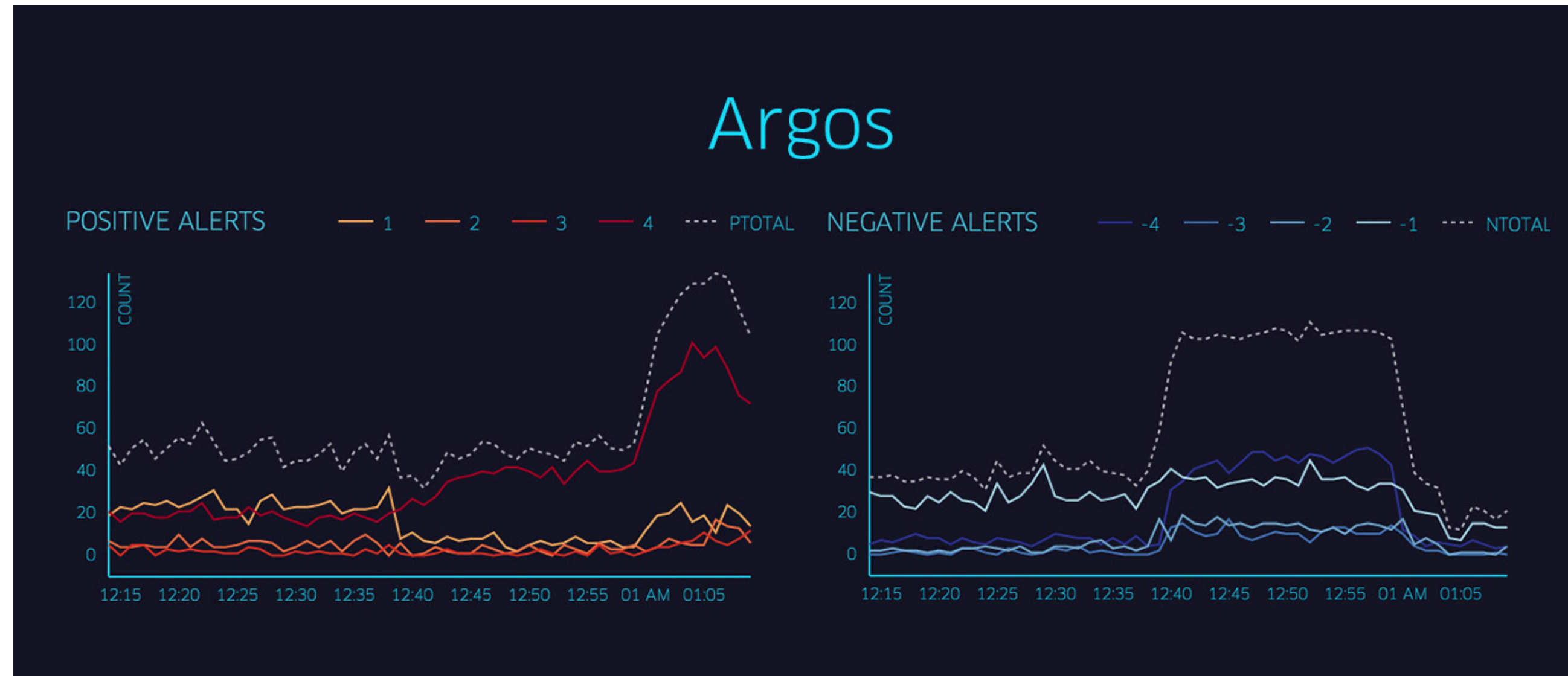
DevOps

- Includes server Monitoring
- Consider operating at Google-scale
 - ~2015 ratio of SREs to machines ~1:3000
 - Too many to manage individually
- Need automated trend and anomaly detection

Example statistics
from a fileserver
that used to
support COSC301



Anomaly Detection



Positive alerts are for metric counts that are higher than expected, while negative alerts are for metrics counts that are lower than expected (compared to normal business conditions).

Weather events, concerts, sporting events and promotions greatly affect Uber's ride demand (blue). Purple markers indicate the onset of local thunderstorms on a June 2015 evening in Chicago. For reference, the previous week's ride demand is overlaid in orange

Need for TSDBs—DevOps example

- Every 10s collect measurements from a server with:
 - 8-core CPU, 16GiB RAM, 4 disks (2 RAID arrays), 1 NIC
- Could easily choose to record:
 - 10 metrics for each CPU core; 11 memory metrics; 7 metrics per disk; 8 network metrics; 11 process metrics; 7 system load
 - That's ~200 metrics every 10s or ~20 INSERTs per second
- But if you raise the number of machines?
 - Spotify: ~10K physical machines, so 200K INSERTs per second
 - Netflix: would have 100M metrics

Need for TSDBs—Smart electricity monitoring

- Phasor measurement units analyse power waveforms
 - Micro-synchrophasors are PMUs that sync up, e.g., to GPS time
- Diagnostics & control use
 - High-precision, high-resolution data streams
 - High write workload
 - Higher read workload

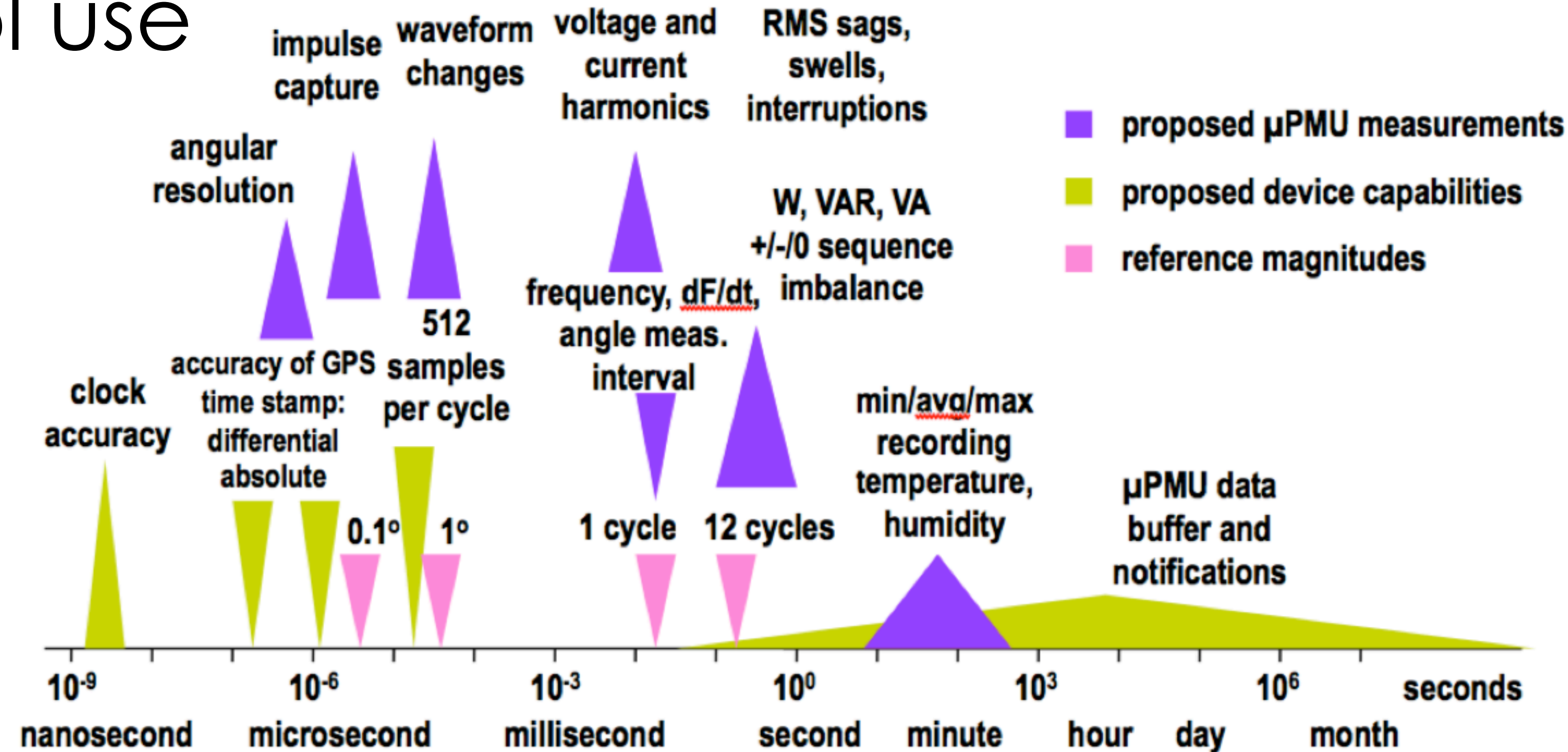


Figure 1. Time Scale for μPMU Performance

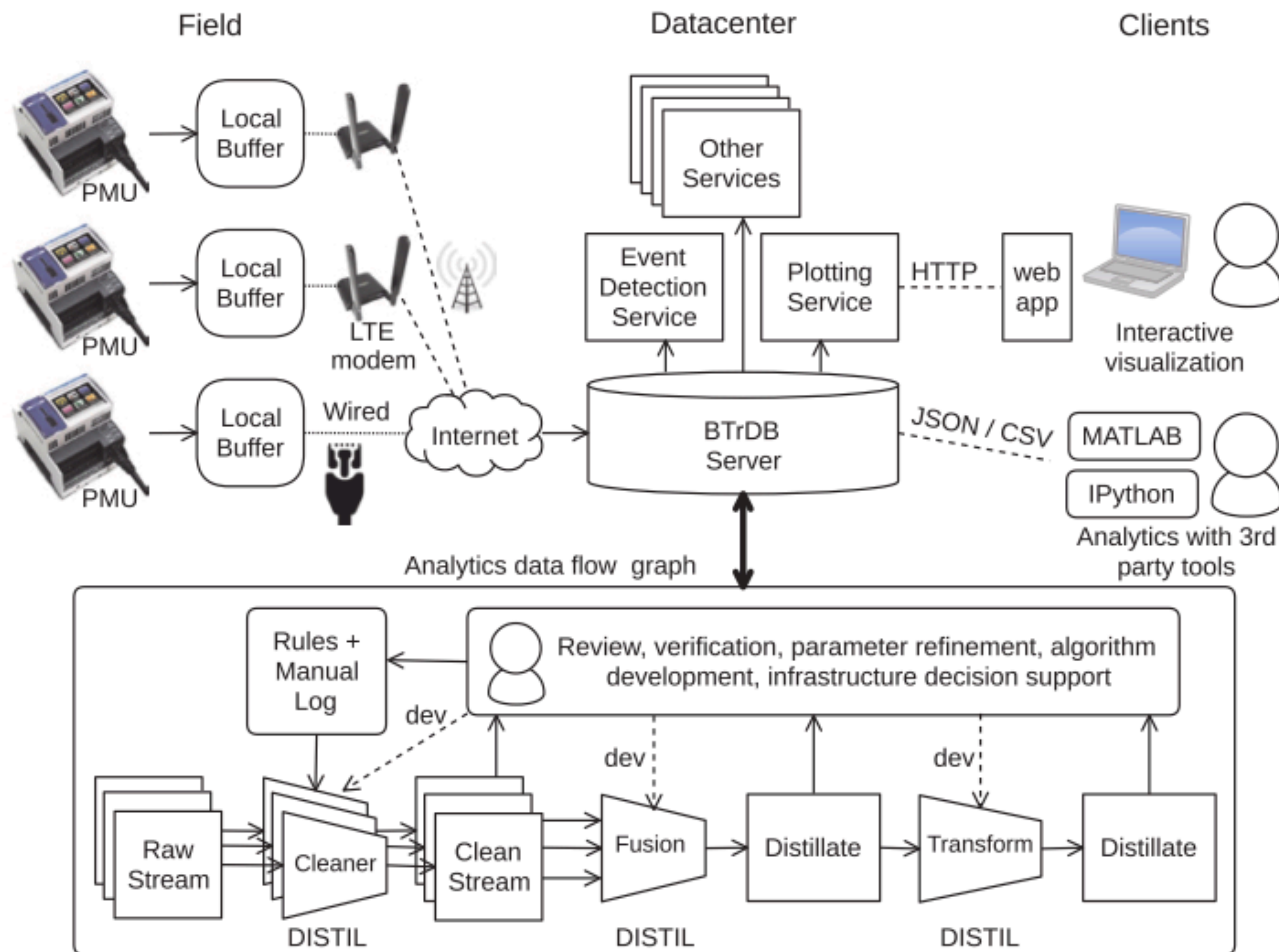


Figure 2: uPMU network storage and query processing system

Requirements on database nodes

- Each device produces:
 - 12 streams of high precision values at 120Hz
 - timestamps accurate to 100ns
- Need to support 1000 devices per database node
- Close to 1TB of data per day per node!

Example tools

- InfluxDB
- TimescaleDB
- Spotify (Heroic)
- RedHat (Hawkular)
- Facebook (Gorilla)
- BTrDb
 - We'll explore BTrDb...

Table 1. A Summary of Time-series Databases Storage Engines and Querying Support

Database	Storage Engine	Read	Query Support ^a			
			Π	σ	$\bowtie$	Γ
Heroic [54]	Cassandra [29]	HQL	✓	✓	×	✓
KairosDB [27]		JSON	×	<i>t</i>	×	✓
Hawkular [44]		REST	×	<i>t</i>	×	✓
Blueflood [43]			×	<i>t</i>	×	×
OpenTSDB [56]	HBase [60]	REST	×	✓	×	✓
Cube [55]	MongoDB [3]	REST	×	<i>t</i>	×	✓
InfluxDB [25]	Native	LSM-based	✓	✓	×	✓
Vulcan/Prometheus [42]		Chunks-on-FS	✓	✓	×	✓
Gorilla/Beringei [38]		In-memory	×	<i>t</i>	×	×
BTrDb [2]		COW-tree	×	<i>t</i>	×	✓
Akumuli [30]		Numeric-B+-tree	×	<i>t</i>	×	✓
DalmatinerDB [41]	Riak	DQL	✓	✓	×	✓
Riak-TS [5]		SQL	✓	✓	×	✓
Timescale [57]	Postgres	SQL	✓	✓	✓	✓
Tgres [58]			✓	✓	✓	✓

^a Π = Projection, σ = Selection, where *t* is selection by time only, $\bowtie$ = Joins, Γ = Aggregation functions

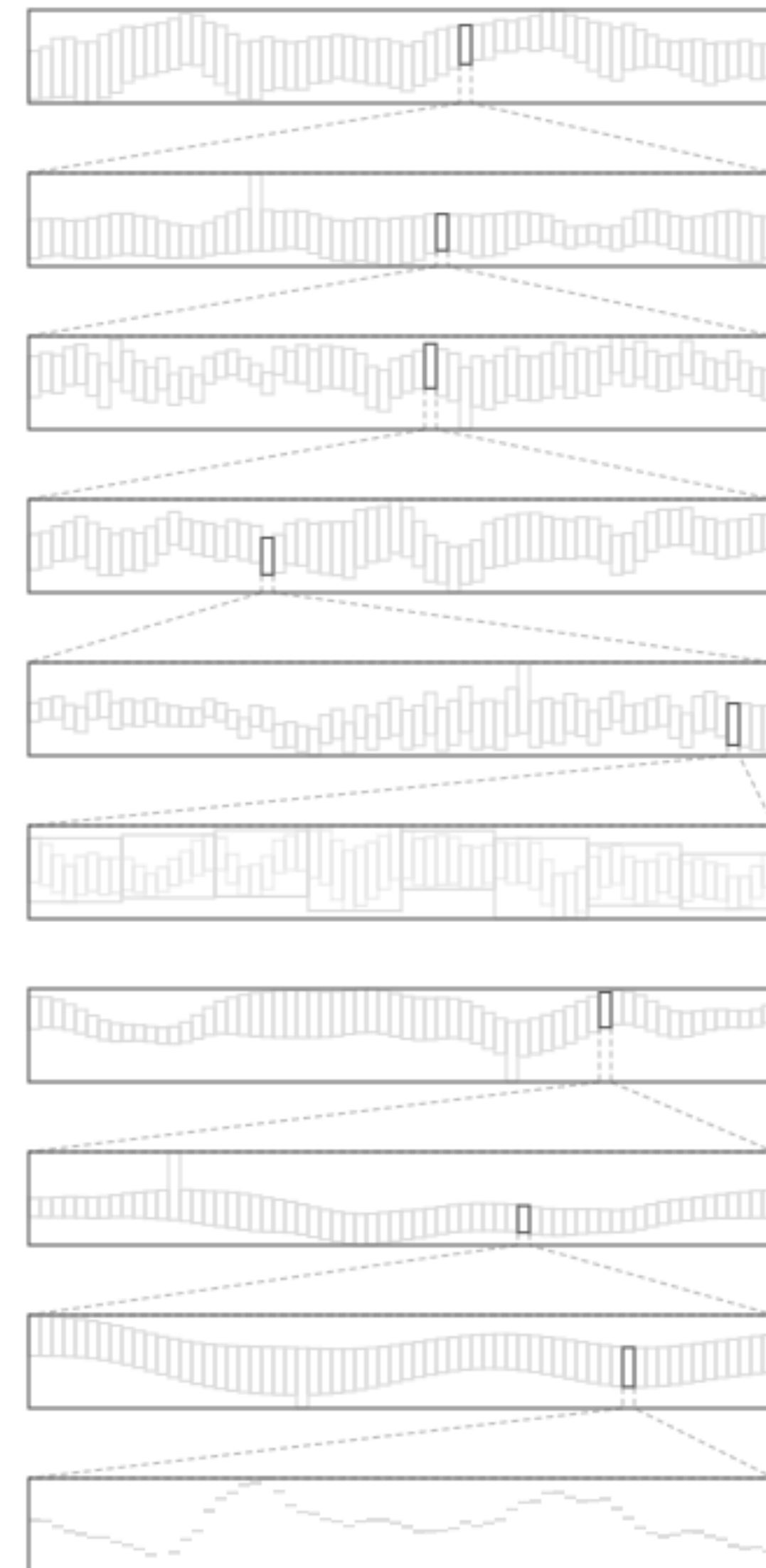
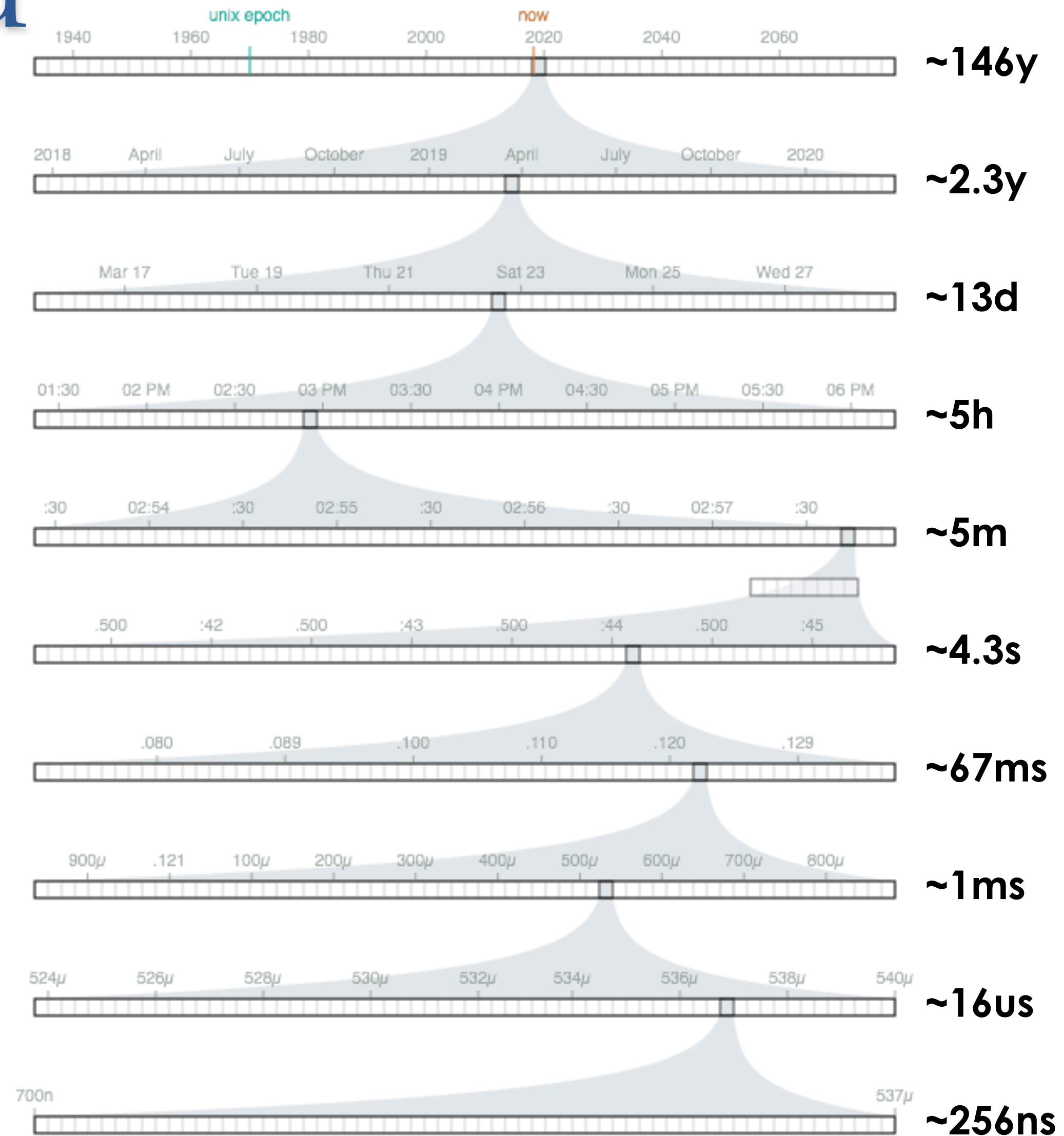
Time partitioned tree

- Core nodes

- Store statistical summaries for all child nodes
- Each core node stores 64 statistical points
- Each statistical point stores min, max, count, mean for 1/64th of the children

- Vector node

- Stores raw data
- Each vector node contains 1024 raw points, and represents ~4ns



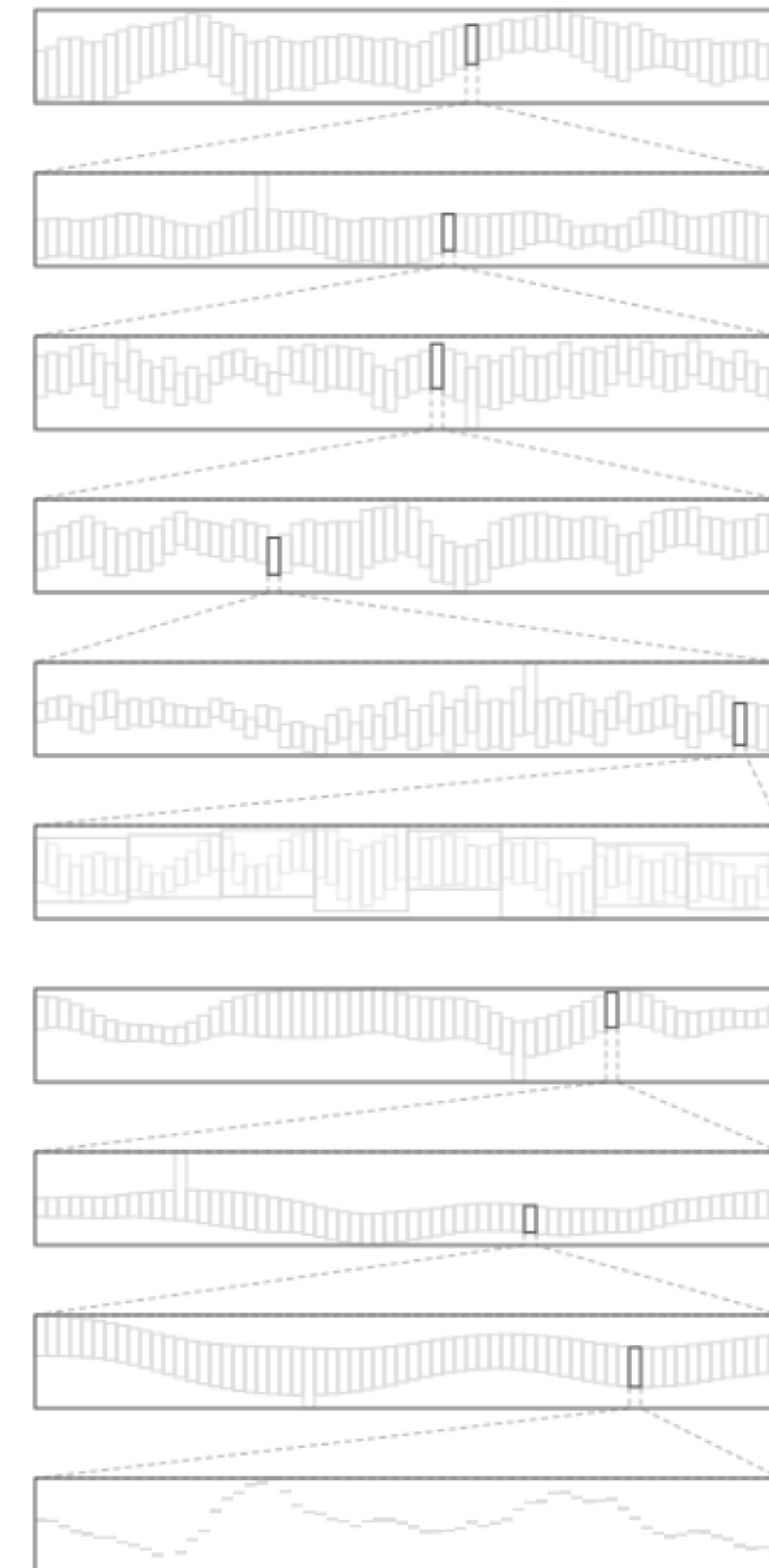
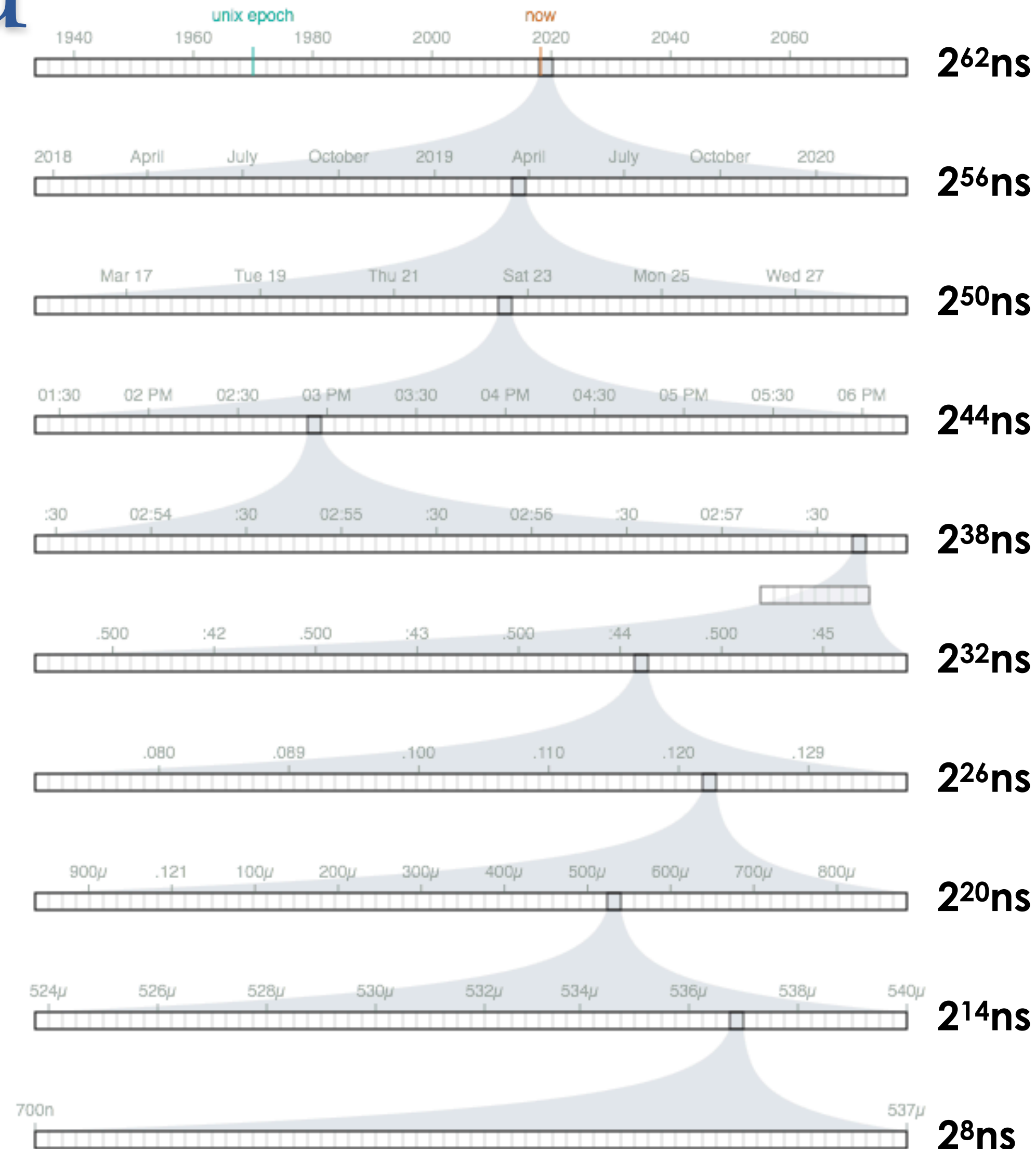
Time partitioned tree

- Core nodes

- Store statistical summaries for all child nodes
- Each core node stores 2^6 statistical points
- Each statistical point stores min, max, count, mean for $1/2^6$ th of the children

- Vector node

- Stores raw data
- Each vector node contains 1024 raw points, and represents 2^2 ns



Gorilla—paper review

- Key problem under investigation?
- Key idea of the proposed solution?
- How does it solve the problem?
- Evaluation?
- Drawbacks?