Native Histograms in Prometheus:

A Better Histogram Experience for Everyone

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KCD Zurich, June 15, 2023

All Credit Goes To…

Björn Rabenstein

Ganesh Vernekar

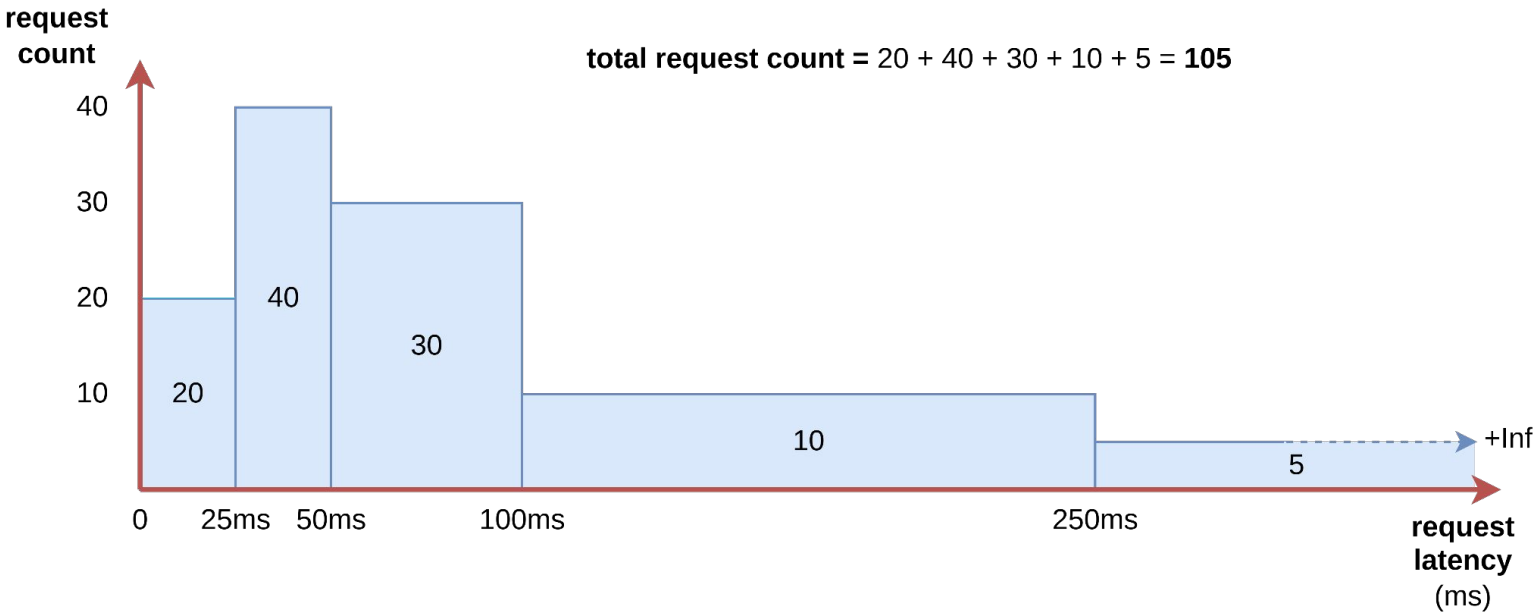
Dieter Plaetinck

…and others!

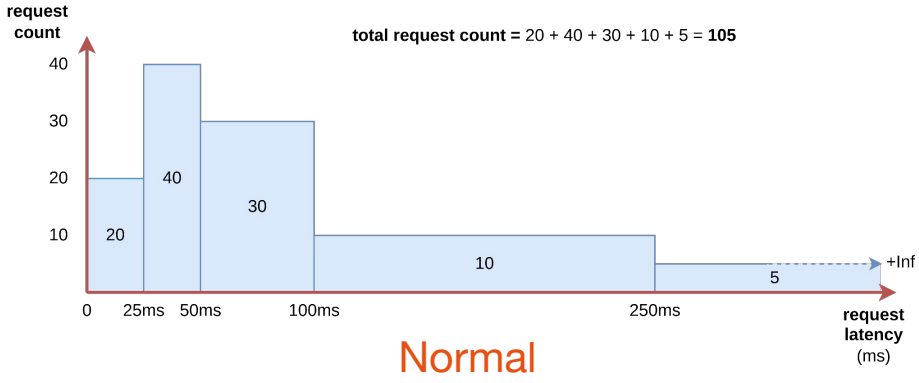
Quick Recap:
Classic Histograms

Histograms In General

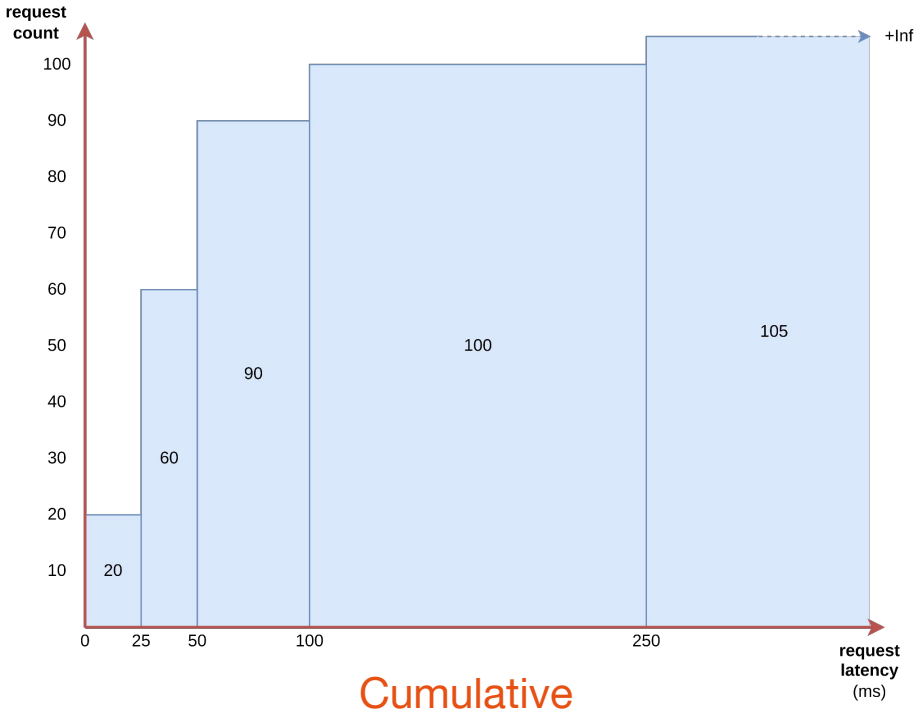
Way to track the distribution of a set of values, e.g. request durations:



Cumulative Representation

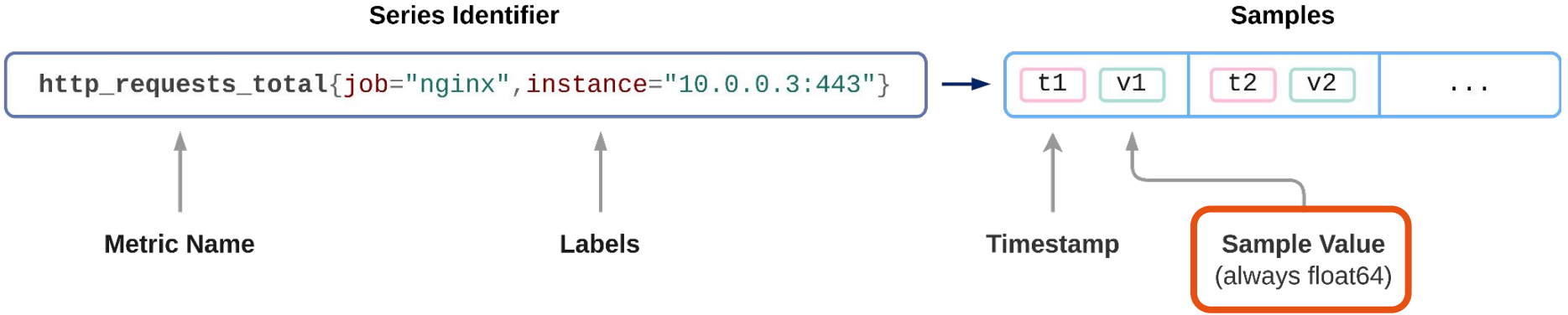


Normal



Cumulative

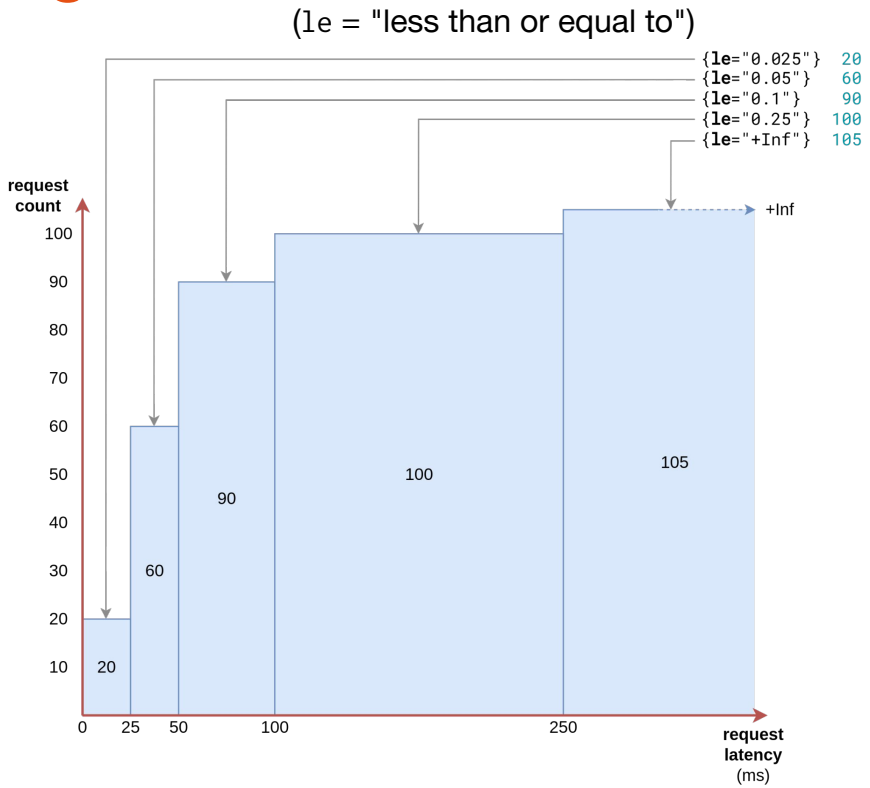
Classic Prometheus Data Model



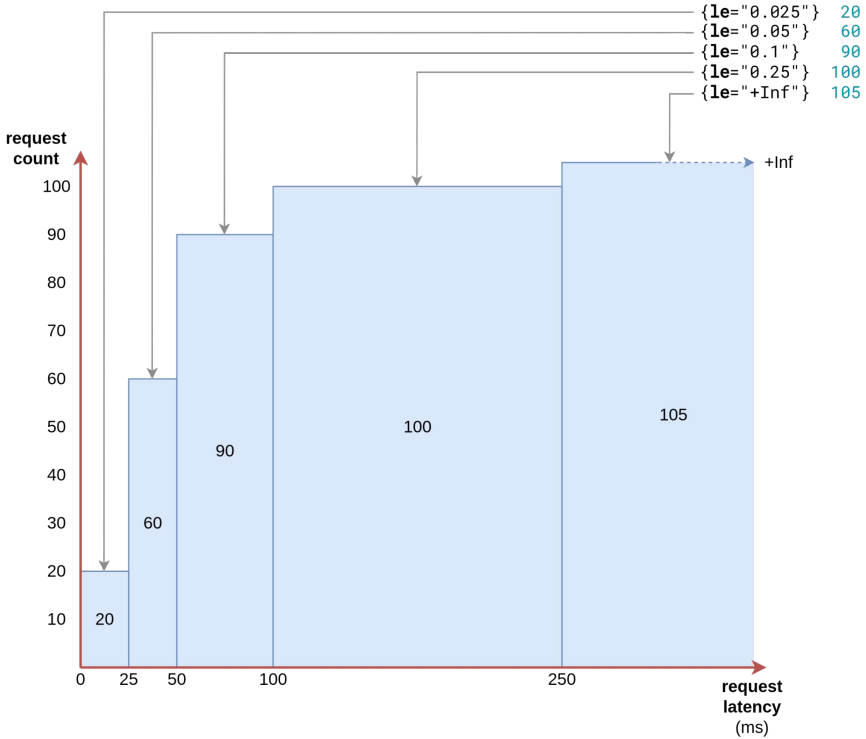
How to squeeze histograms into this data model?

Classic Histograms

- Cumulative histogram
- One counter series per bucket
- Manual bucket configuration



Serializing Classic Histograms




```
# le = "less than or equal"
foo_bucket{le="0.025"} 20
foo_bucket{le="0.05"} 60
foo_bucket{le="0.1"} 90
foo_bucket{le="0.25"} 100
foo_bucket{le="+Inf"} 105
foo_sum 21.322
foo_count 105
```

What's Great About Classic Histograms?

- Efficient at **high-frequency** observations
- Computing **percentages / ratios / averages**
- Computing **percentiles**
- **Partitioning** by dimensions (with caveats!)
- **Aggregating** over dimensions

What Sucks About Classic Histograms?

- **Expensive!** (one series per bucket)
- **Manual + static** bucket configuration

In practice, **huge tradeoff** between **cost** and **resolution / dimensional partitioning**.

Lots of overloaded Prometheus servers :(

Can We Improve That While Keeping the Great Features?

Enter: Native Histograms!

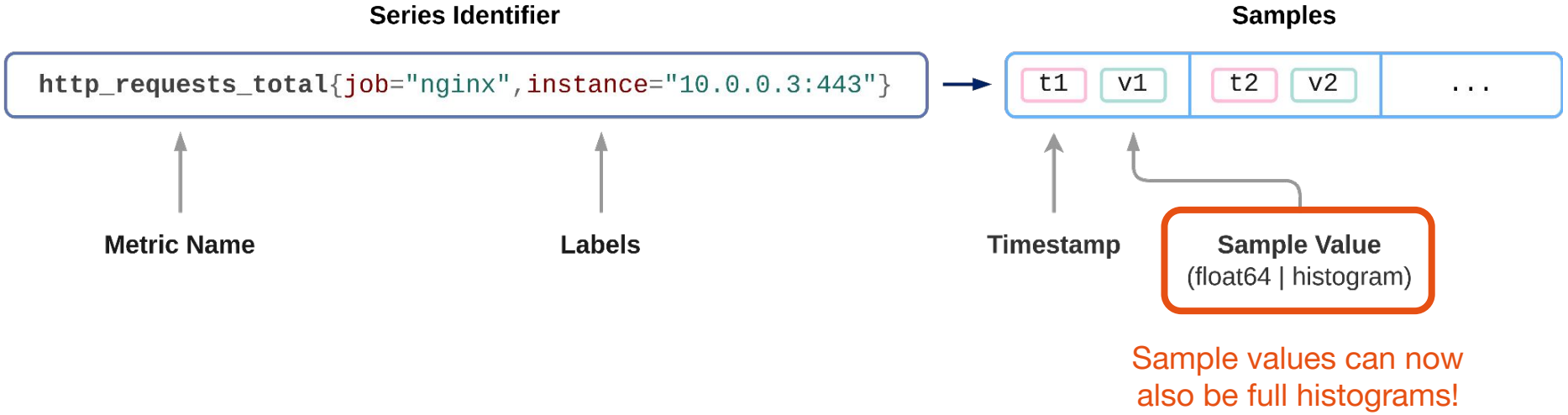
First Question

One series per bucket is expensive.

Can we store an **entire histogram**

in the **sample value** of a single series?

Yes! New Prometheus Data Model:



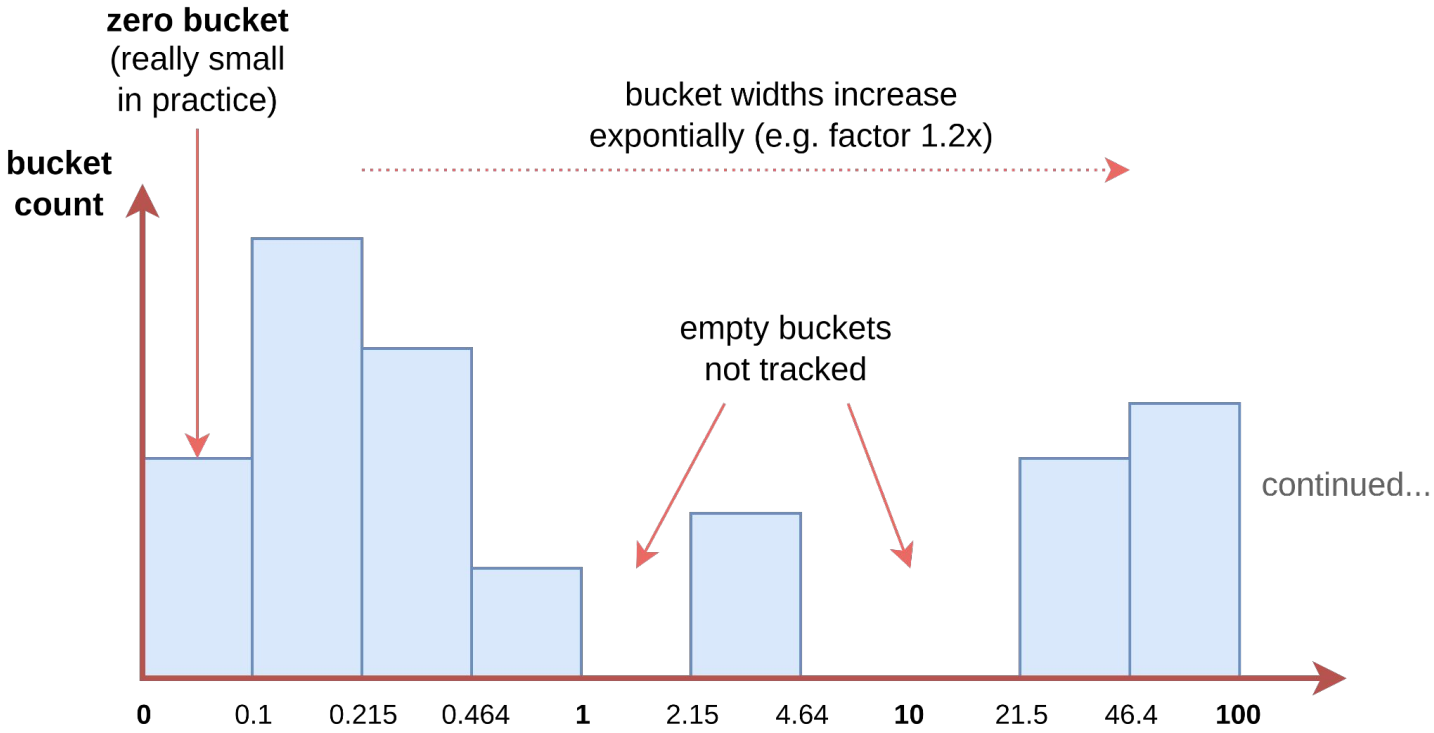
Sample values can now also be full histograms!

Second Question

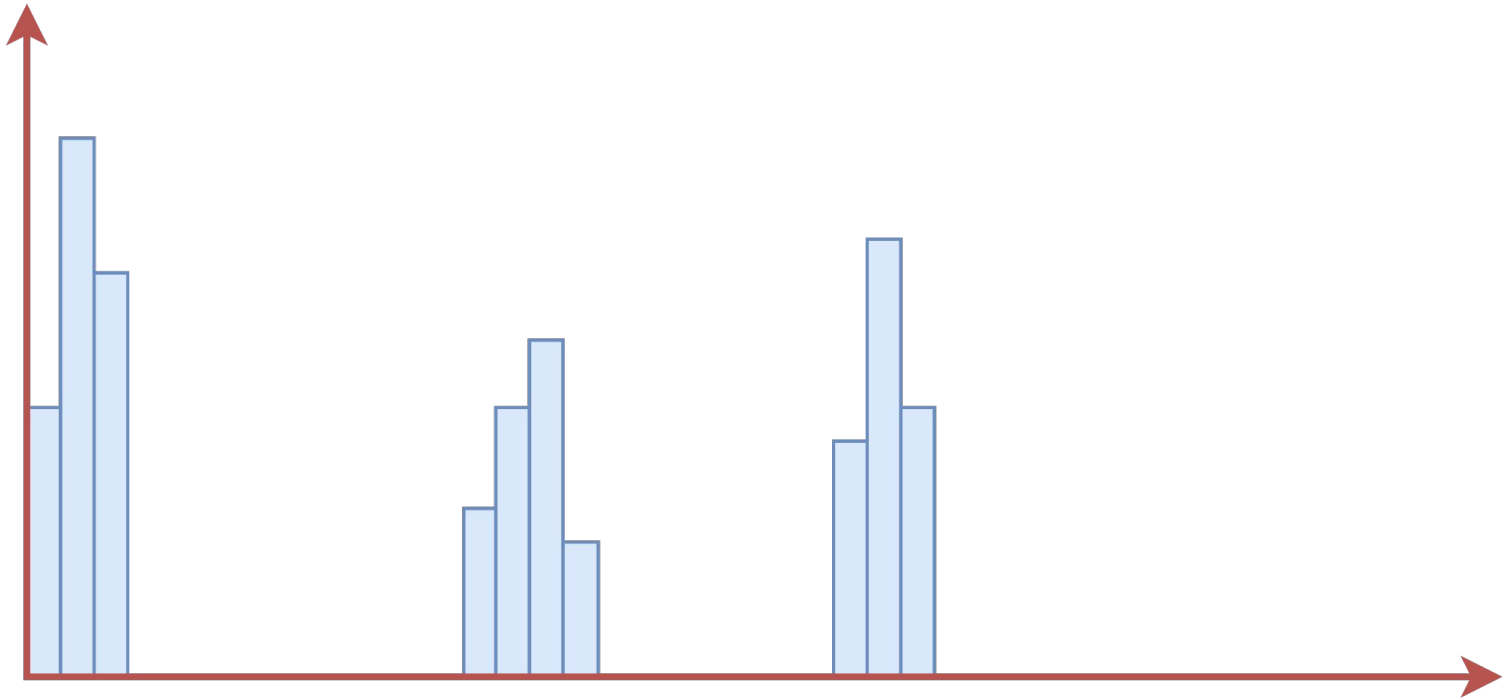
Can we have **sparse**, **high-resolution** histograms with no **manual bucket config**?

These exist in other systems, but how to make these work with Prometheus' **pull model**?

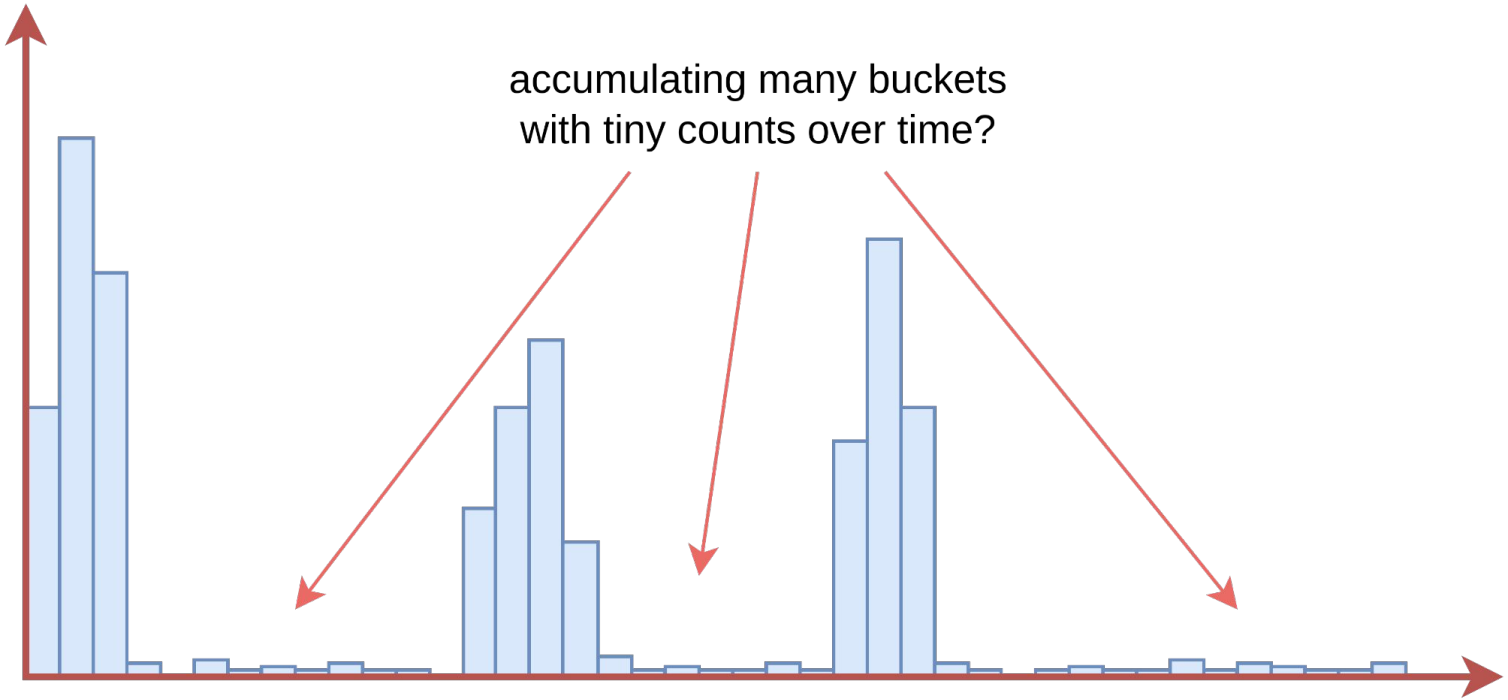
Native Histograms



Sparse Bucket Usage



Accumulating Entropy Over Time?



Solution: Resets!

- Buckets are counters.
- Counters should always be rate-ed before use.
- Counters may occasionally reset anyway.
- `rate()` and friends deal fine with resets.

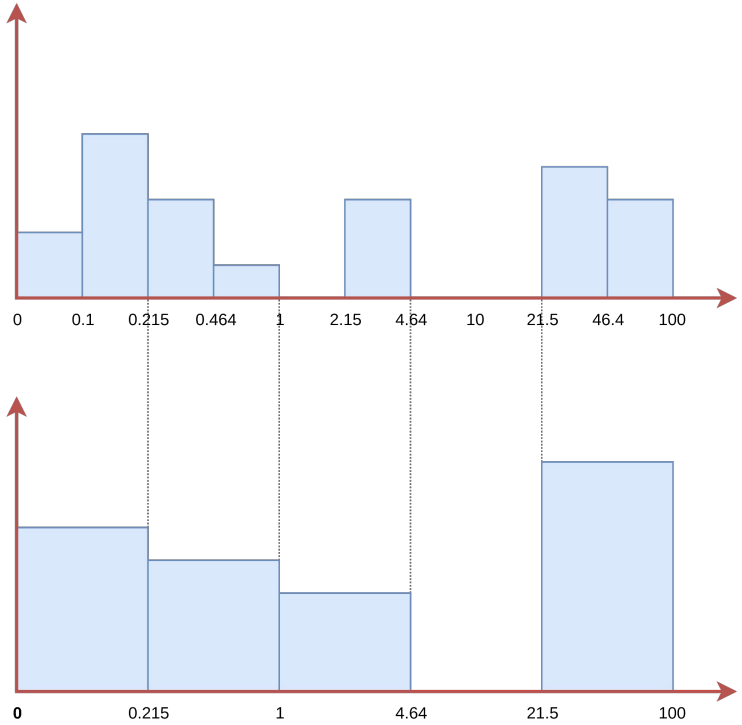
Just **reset the histogram** completely once in a while!

Resolution Downgrade + Aggregatability

Real bucket factors are always $2^{2^{\wedge}-n}$.

⇒ All possible schemas vary by multiples of 2 in their bucket density, so can be downgraded / aggregated!

n	Factor
8	1.002711275
7	1.005429901
6	1.010889286
5	1.021897149
4	1.044273782
3	1.090507733
2	1.189207115
1	1.414213562
0	2
-1	4
-2	16
-3	256
-4	65536



Native Histogram Advantages

- Way fewer time series
- Much better bucket encoding
- Sparse - Unused buckets are free
- Much higher resolution possible
- All schemas aggregatable
- Easier configuration

Enabling Native Histograms in Prometheus

Still experimental!

Enable content negotiation + ingestion using:

```
./prometheus --enable-feature=native-histograms
```

Scraping Native Histograms

No text format support yet, currently requires new **protobuf-based scrape format** (implemented in Go client library).

Server negotiates format:

```
Accept: application/vnd.google.protobuf;proto=io.prometheus.client.MetricFamily;encoding=delimited,application/openmetrics-text;version=1.0.0;q=0.8,application/openmetrics-text;version=0.0.1;q=0.75,text/plain;version=0.0.4;q=0.5,*/*;q=0.1
```

Native Histograms In Instrumentation

Classic histograms:

```
requestDurations := prometheus.NewHistogram(prometheus.HistogramOpts{
  Name:    "http_request_duration_seconds",
  Help:    "A histogram of the HTTP request durations in seconds.",
  // Manual configuration of upper bucket bounds.
  Buckets: []float64{0.05, 0.1, 0.25, 0.5, 1, 2.5, 5, 10},
})
```

Native Histograms In Instrumentation

Native histograms:

```
requestDurations := prometheus.NewHistogram(prometheus.HistogramOpts{
  Name:    "http_request_duration_seconds",
  Help:    "A histogram of the HTTP request durations in seconds.",
  // Increase each subsequent bucket width by a factor of ~1.1x.
  NativeHistogramBucketFactor: 1.1,
})
```

Optional Settings

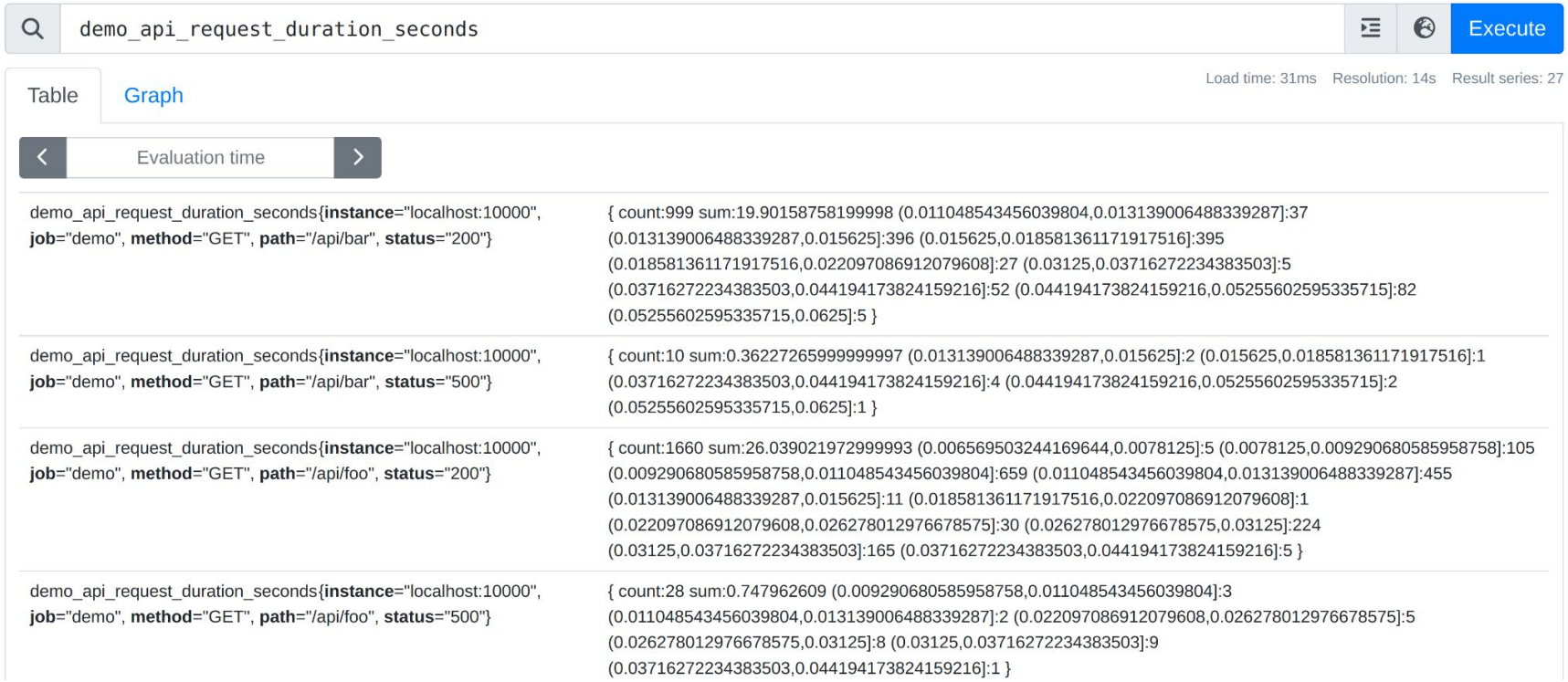
Optional settings to configure details:

```
// Zero bucket upper bound.
NativeHistogramZeroThreshold float64
// Max bucket number.
NativeHistogramMaxBucketNumber uint32
// Minimum duration before resetting buckets.
NativeHistogramMinResetDuration time.Duration
// Maximum upper bound to increase zero bucket to (when >max buckets).
NativeHistogramMaxZeroThreshold float64
```

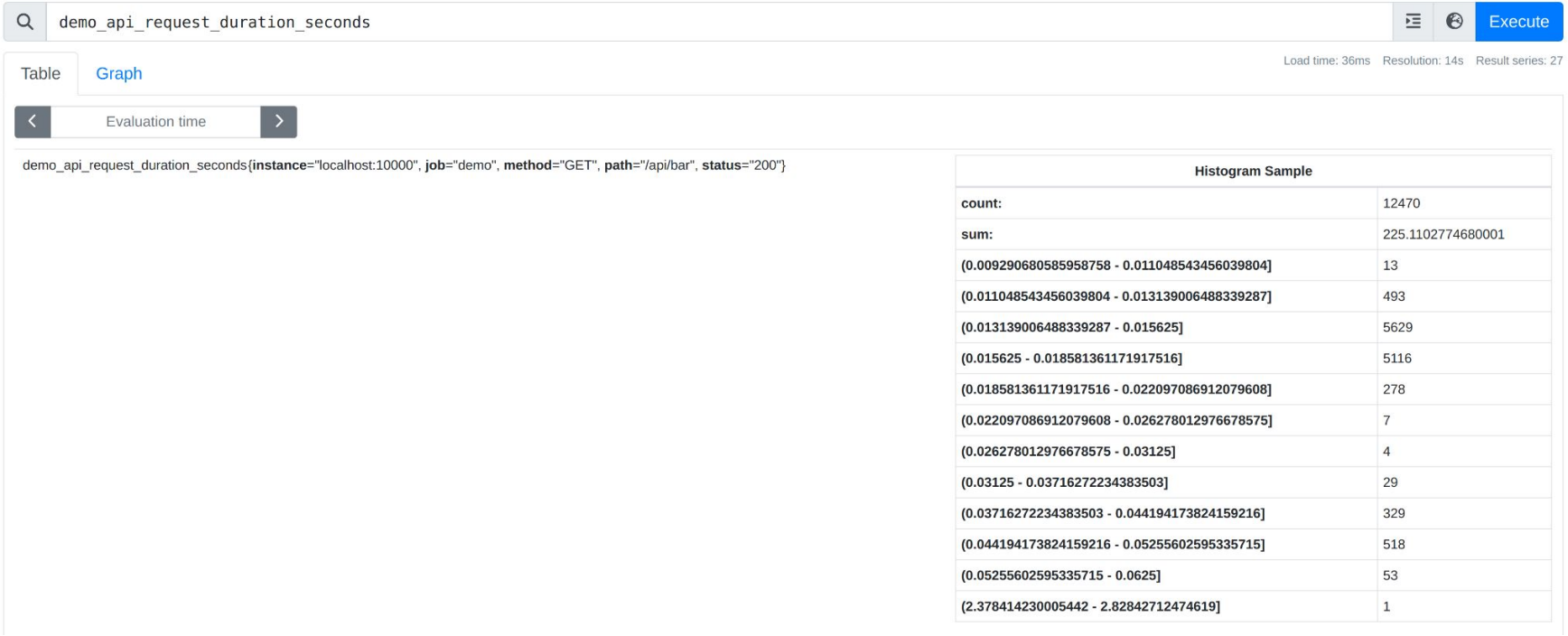
Very simplified! For full details, see:
https://pkg.go.dev/github.com/prometheus/client_golang/prometheus#HistogramOpts

Native Histograms in PromQL

Querying a Native Histogram

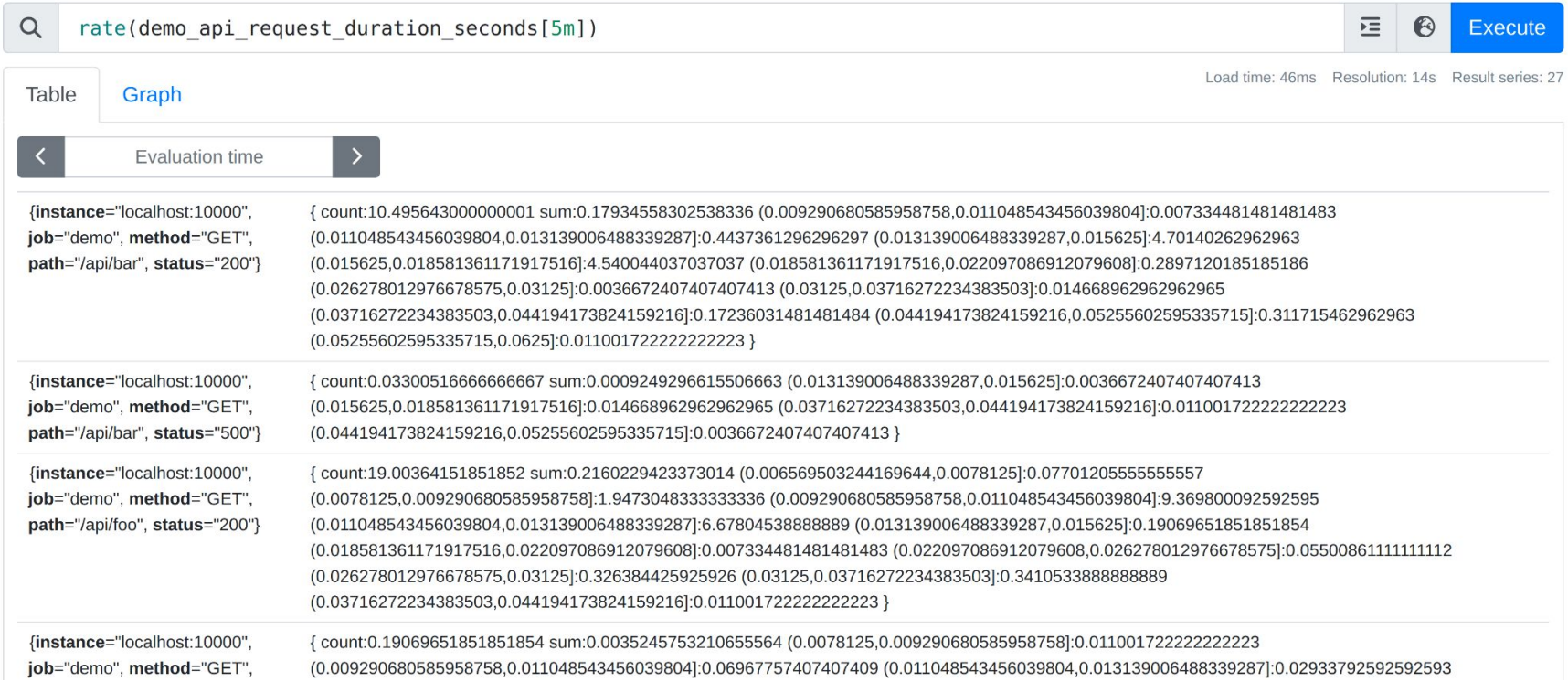


Working on a Better Visualization…



Histogram Sample	
count:	12470
sum:	225.1102774680001
(0.009290680585958758 - 0.011048543456039804]	13
(0.011048543456039804 - 0.013139006488339287]	493
(0.013139006488339287 - 0.015625]	5629
(0.015625 - 0.018581361171917516]	5116
(0.018581361171917516 - 0.022097086912079608]	278
(0.022097086912079608 - 0.026278012976678575]	7
(0.026278012976678575 - 0.03125]	4
(0.03125 - 0.03716272234383503]	29
(0.03716272234383503 - 0.044194173824159216]	329
(0.044194173824159216 - 0.05255602595335715]	518
(0.05255602595335715 - 0.0625]	53
(2.378414230005442 - 2.82842712474619]	1

Calculating Rates



Aggregating Over Dimensions

```
sum by(path, method) (rate(demo_api_request_duration_seconds[5m]))
```

Execute

Table | Graph

Load time: 38ms Resolution: 14s Result series: 5

Evaluation time

{**method**="GET", **path**="/api/bar"}	{ count:45.5788413673182 sum:0.8028927489200216 (0.0078125,0.009290680585958758]:0.003508771929824561 (0.009290680585958758,0.011048543456039804]:0.07017534010533874 (0.011048543456039804,0.013139006488339287]:1.9263114066173985 (0.013139006488339287,0.015625]:20.122760061886915 (0.015625,0.018581361171917516]:19.242061262235524 (0.018581361171917516,0.022097086912079608]:1.1719267467128884 (0.022097086912079608,0.026278012976678575]:0.003508771929824561 (0.026278012976678575,0.03125]:0.003508747307036442 (0.03125,0.03716272234383503]:0.08421030471069639 (0.03716272234383503,0.044194173824159216]:1.042102800879083 (0.044194173824159216,0.05255602595335715]:1.719293936626114 (0.05255602595335715,0.0625]:0.18947321637755205 }
{**method**="GET", **path**="/api/foo"}	{ count:83.47348971512295 sum:0.9728647667771257 (0.006569503244169644,0.0078125]:0.31227988920237804 (0.0078125,0.009290680585958758]:7.999980720356901 (0.009290680585958758,0.011048543456039804]:40.715695193028495 (0.011048543456039804,0.013139006488339287]:29.26659863390309 (0.013139006488339287,0.015625]:0.7859630901943808 (0.018581361171917516,0.022097086912079608]:0.01754378578075845 (0.022097086912079608,0.026278012976678575]:0.29473607879883146 (0.026278012976678575,0.03125]:2.2315739489424327 (0.03125,0.03716272234383503]:1.7894693998453937 (0.03716272234383503,0.044194173824159216]:0.05964897507028882 }
{**method**="GET", **path**="/api/nonexistent"}	{ count:2.5157836134606377 sum:0.00008186569528666895 (0.000045364651298626 75,0.000053947966093944 36]:0.003508747307036442 (0.000064155305118844 18,0.00007629394531 25]:0.003508771929824561 (0.00007629394531 25,0.000090729302597 2535]:0.003508771929824561 (0.000128310610237688 35,0.00015258789062 5]:0.02105258233337113 (0.00015258789062 5,0.000181458605194507]:0.08421045244742512 (0.000181458605194507,0.000215791864375777 42]:0.18596432133378688 (0.000215791864375777 42,0.000256621220475376 7]:0.22105213912318494

Calculating Quantiles

```
histogram_quantile(
  0.9,
  sum by(method, path) (
    rate(demo_api_request_duration_seconds[5m])
  )
)
```

Execute

Table | Graph

Load time: 21ms Resolution: 3s Result series: 5

Evaluation time

{**method**="GET", **path**="/api/bar"}	0.0197084802952615
{**method**="GET", **path**="/api/foo"}	0.012671338816069253
{**method**="GET", **path**="/api/nonexistent"}	0.00004158369478303058
{**method**="POST", **path**="/api/bar"}	0.06001322530904167
{**method**="POST", **path**="/api/foo"}	0.0243032422412312

Calculating Quantiles (Classic vs. Native)

Fraction of Observations Within Range

```
# Within the last 5 minutes, which fraction of
# my requests finished within 50ms (interpolated)?
histogram_fraction(
  0,
  0.05,
  sum by(method, path) (
    rate(demo_api_request_duration_seconds[5m])
  )
)
```

Execute

Load time: 36ms Resolution: 3s Result series: 5

Table Graph

Evaluation time

{**method**="GET", **path**="/api/bar"}	0.9860660782306007
{**method**="GET", **path**="/api/foo"}	1
{**method**="GET", **path**="/api/nonexistent"}	1
{**method**="POST", **path**="/api/bar"}	0.4352938236934613
{**method**="POST", **path**="/api/foo"}	1

Accessing the Count and Sum Fields

```
# Extract the "count" field, which is equivalent
# to the per-(path/method) request rate in this case.
histogram_count(
  sum by(path, method) (
    rate(demo_api_request_duration_seconds[5m])
  )
)
```

Execute

Table Graph

Load time: 21ms Resolution: 3s Result series: 5

Evaluation time

{**method**="GET", **path**="/api/bar"}	63.3436370106538
{**method**="GET", **path**="/api/foo"}	112.72241064129149
{**method**="GET", **path**="/api/nonexistent"}	4.059634829328666
{**method**="POST", **path**="/api/bar"}	15.077139982090676
{**method**="POST", **path**="/api/foo"}	12.361360000457982

Accessing the Count and Sum Fields

```
# Average request handling duration.
  histogram_sum(rate(demo_api_request_duration_seconds[5m]))
/
  histogram_count(rate(demo_api_request_duration_seconds[5m]))
```

Execute

Table | Graph

Load time: 51ms Resolution: 3s Result series: 27

Evaluation time

{**instance**="localhost:10000", **job**="demo", **method**="GET", **path**="/api/bar", **status**="200"}	0.017171290258045088
{**instance**="localhost:10000", **job**="demo", **method**="GET", **path**="/api/bar", **status**="500"}	0.029652652590909063
{**instance**="localhost:10000", **job**="demo", **method**="GET", **path**="/api/foo", **status**="200"}	0.0123609184425159
{**instance**="localhost:10000", **job**="demo", **method**="GET", **path**="/api/foo", **status**="500"}	0.02237244111320752
{**instance**="localhost:10000", **job**="demo", **method**="GET", **path**="/api/nonexistent", **status**="404"}	0.0000352882634989 2014
{**instance**="localhost:10000", **job**="demo", **method**="POST", **path**="/api/bar", **status**="200"}	0.06115579723658063
{**instance**="localhost:10000", **job**="demo", **method**="POST", **path**="/api/bar", **status**="500"}	0.09069541970000003
{**instance**="localhost:10000", **job**="demo", **method**="POST", **path**="/api/foo", **status**="200"}	0.026676985996028392
{**instance**="localhost:10000", **job**="demo", **method**="POST", **path**="/api/foo", **status**="500"}	0.047206546692307644
{**instance**="localhost:10001", **job**="demo", **method**="GET", **path**="/api/bar", **status**="200"}	0.01718281653899948

Binary Operators

```
  rate(demo_api_request_duration_seconds{method="GET"}[5m])
+ ignoring(method)
  rate(demo_api_request_duration_seconds{method="POST"}[5m])
```

Execute

Table | Graph

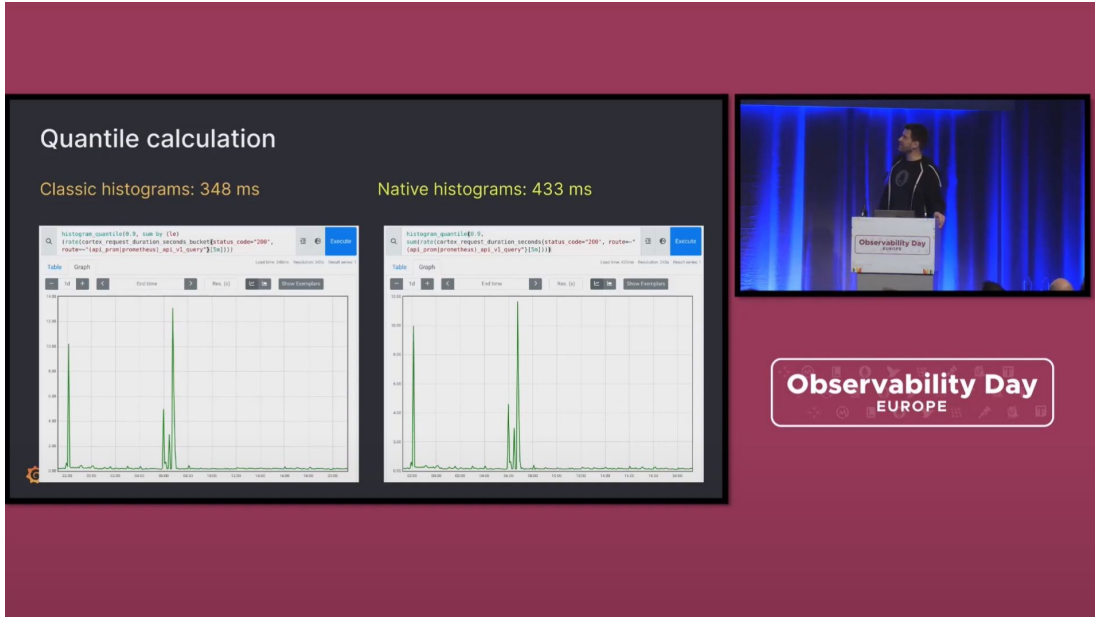
Load time: 38ms Resolution: 14s Result series: 12

Evaluation time

{**instance**="localhost:10000", **job**="demo", **path**="/api/bar", **status**="200"}	{ count:16.5859649122807 sum:0.4376887746035095 (0.009290680585958758,0.011048543456039804]:0.021052631578947364 (0.011048543456039804,0.013139006488339287]:0.5929824561403508 (0.013139006488339287,0.015625]:6.028070175438596 (0.015625,0.018581361171917516]:5.368421052631579 (0.018581361171917516,0.022097086912079608]:0.3157894736842105 (0.03125,0.03716272234383503]:0.024561403508771933 (0.03716272234383503,0.044194173824159216]:0.6912280701754385 (0.044194173824159216,0.05255602595335715]:2.1929824561403506 (0.05255602595335715,0.0625]:0.975438596491228 (0.0625,0.07432544468767006]:0.017543859649122806 (0.1051120519067143,0.125]:0.010526315789473682 (0.125,0.14865088937534013]:0.15087719298245614 (0.14865088937534013,0.17677669529663687]:0.17894736842105263 (0.17677669529663687,0.2102241038134286]:0.017543859649122806 }
{**instance**="localhost:10000", **job**="demo", **path**="/api/bar", **status**="500"}	{ count:0.10175438596491226 sum:0.007497379919298239 (0.013139006488339287,0.015625]:0.010526315789473682 (0.015625,0.018581361171917516]:0.017543859649122806 (0.018581361171917516,0.022097086912079608]:0.007017543859649122 (0.03716272234383503,0.044194173824159216]:0.007017543859649122 (0.044194173824159216,0.05255602595335715]:0.017543859649122806 (0.05255602595335715,0.0625]:0.003508771929824561 (0.0625,0.07432544468767006]:0.003508771929824561 (0.125,0.14865088937534013]:0.010526315789473682 (0.14865088937534013,0.17677669529663687]:0.021052631578947364 (0.17677669529663687,0.2102241038134286]:0.003508771929824561 }
{**instance**="localhost:10000", **job**="demo", **path**="/api/foo"	{ count:27.47719298245614 sum:0.352869677592981 (0.006569503244169644,0.0078125]:0.09473684210526315 (0.0078125,0.009290680585958758]:2.459649122807017 (0.009290680585958758,0.011048543456039804]:12.235087719298244

Real-World Results

Detailed Talk by Björn



[Prometheus Native Histograms in Production] - Björn Rabenstein

(Very) Rough Bottom Line

Storage: 10x resolution for half the price!

Query time: Roughly the same, some things a tad slower

Bucket entropy and resets were reasonable.

Grafana Heatmap Comparison

Still Experimental!

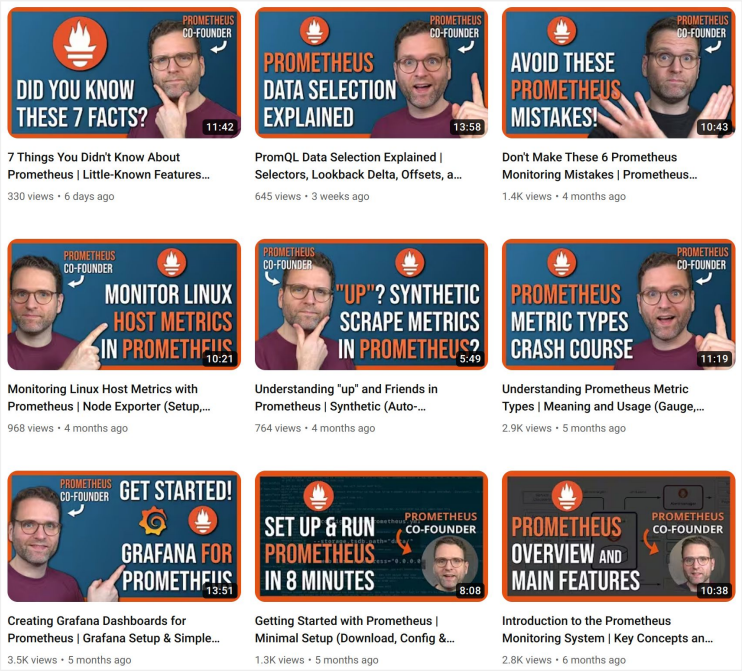
Try It Out and Give Feedback!

More Native Histogram Talks

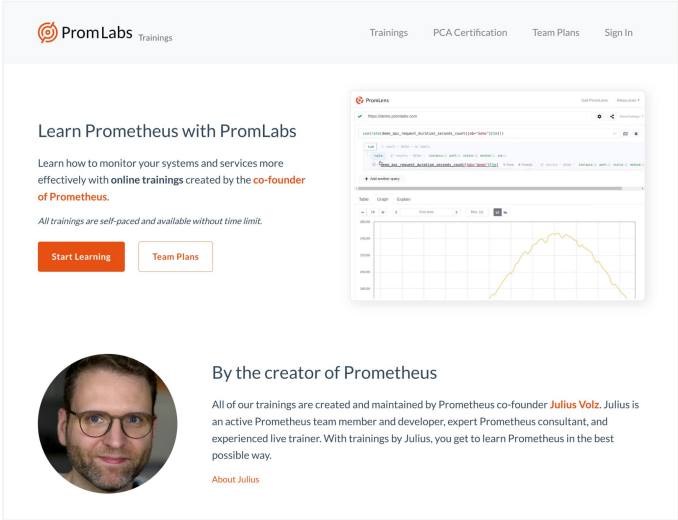
- **Prometheus Native Histograms in Production**, Björn Rabenstein, Observability Day Amsterdam 2023
  https://www.youtube.com/watch?v=TgINvIK9SYc
- **Native Histograms in Prometheus**, Ganesh Vernekar, PromCon EU 2022
  https://www.youtube.com/watch?v=AcmABV6NCYk
- **PromQL for Native Histograms**, Björn Rabenstein, PromCon EU 2022
  https://www.youtube.com/watch?v=fikCqhIUOmQ
- **Prometheus Sparse High-Resolution Histograms in Action**, Ganesh Vernekar, KubeCon NA 2022
  https://www.youtube.com/watch?v=T2GvcYNth9U
- **A New Kid in Histogram Town**, Björn Rabenstein, KubeCon NA 2021
  https://www.youtube.com/watch?v=rM8tR2SPJ4M
- **Better Histograms in Prometheus**, Björn Rabenstein, KubeCon NA 2020
  https://www.youtube.com/watch?v=HG7uzON-IDM
- **Prometheus Histograms – Past, Present, and Future**, Björn Rabenstein, PromCon EU 2019
  https://www.youtube.com/watch?v=7sQFkaMCyEI

Thanks! Learn More:

YouTube Channel:
https://youtube.com/@PromLabs



Self-Paced Prometheus Courses:
https://training.promlabs.com/



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