Go optimizations in VictoriaMetrics

Aliaksandr Valialkin, CTO at VictoriaMetrics

About me

- https://github.com/valyala
- I’m fond of Go and performance optimizations
- Fasthttp author
- VictoriaMetrics core developer

Agenda

- What is VictoriaMetrics?
- What is time series?
- What does time series database do?
- Time series database architecture
- Inverted index implementations, issues and optimizations
- Specialized bitset implementation in Go

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  - MergeTree data structure
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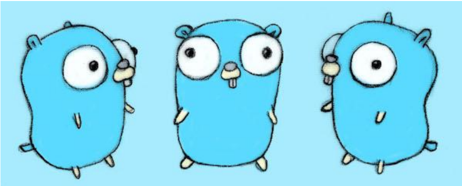

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- A key contains non-empty set of (label=value) pairs
- Example:

  {__name__=”cpu_usage”, instance=”my-server”, datacenter=”us-east”}

  (t1, 10), (t2, 20), (t3, 12), …. (tN, 15)

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- Healthcare - cardiogram, blood pressure

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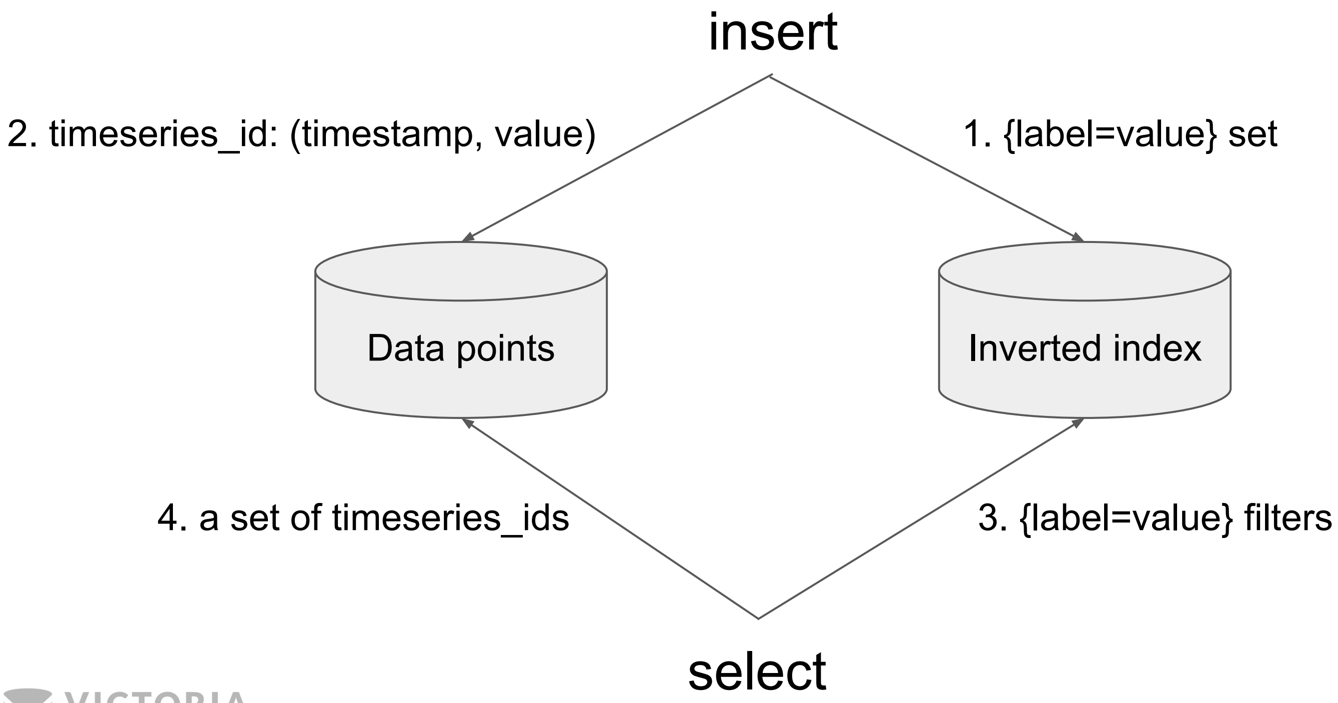
  - Example: **{__name__=”cpu_usage”, datacenter=~”us-.+”}** would select all the **cpu_usage** time series for all the datacenters in US
- Provides query language for time series data: PromQL, InfluxQL, Flux, Q

Time series database architecture



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- Select all the timeseries_ids from inverted index that match the given set of (label=value or regexp) pairs
- Select all the data points for the given timeseries_ids set in the given time range
- Perform additional processing for the selected data points

Inverted index

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- Quickly finds all the timeseries_ids for the given set of (label=value) pairs

Inverted index implementations

Inverted index: naive implementation

```go
var invertedIndex = make(map[string][]int)

func getMetricIDs(labelValues []string) []int {
    metricIDs := invertedIndex[labelValue[0]]
    for _, labelValue := range labelValues[1:] {
        newMetricIDs := invertedIndex[labelValue]
        metricIDs = intersectInts(metricIDs, newMetricIDs)
    }
    return metricIDs
}
```

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- Inverted index must fit RAM - doesn’t scale to big number of time series

Inverted index: LevelDB

- Store **{(label=value): timeseries_id}** rows in LevelDB
- Extract all the timeseries_ids from all the rows for the given (label=value) pair

Inverted index: LevelDB

```
var invertedIndex *LevelDB

func getMetricIDs(labelValues []string) []int {
    metricIDs := invertedIndex.GetValues(labelValue[0])
    for _, labelValue := range labelValues[1:] {
        newMetricIDs := invertedIndex.GetValues(labelValue)
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    }
    return metricIDs
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```

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- Cgo overhead for LevelDB and RocksDB

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- The API is similar to LevelDB or RocksDB

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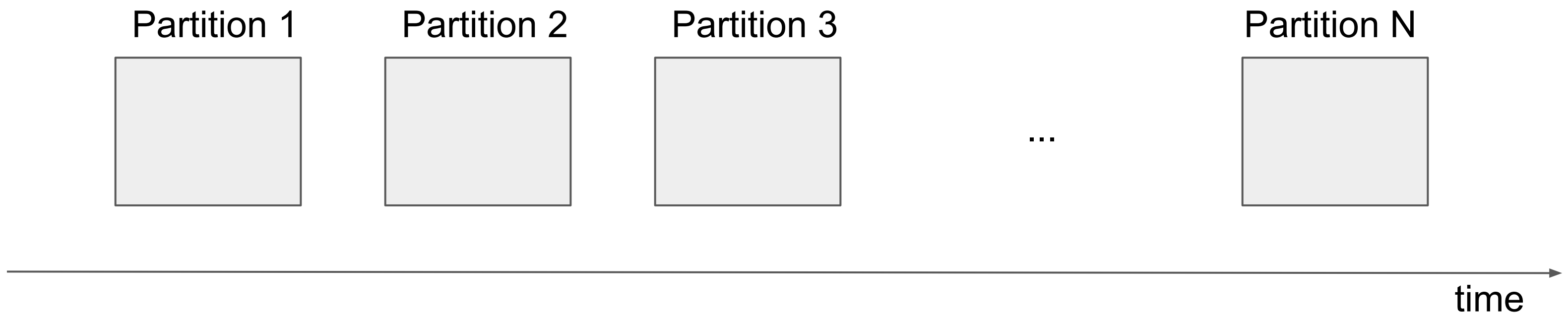
- The number of **{datacenter="us-east"}** time series grows over time
- But the number of **{datacenter="us-east"}** time series for **the last day** remains constant
- How to provide constant speed for selecting **{datacenter="us-east"}** time series for **the last day**?

High churn rate solutions

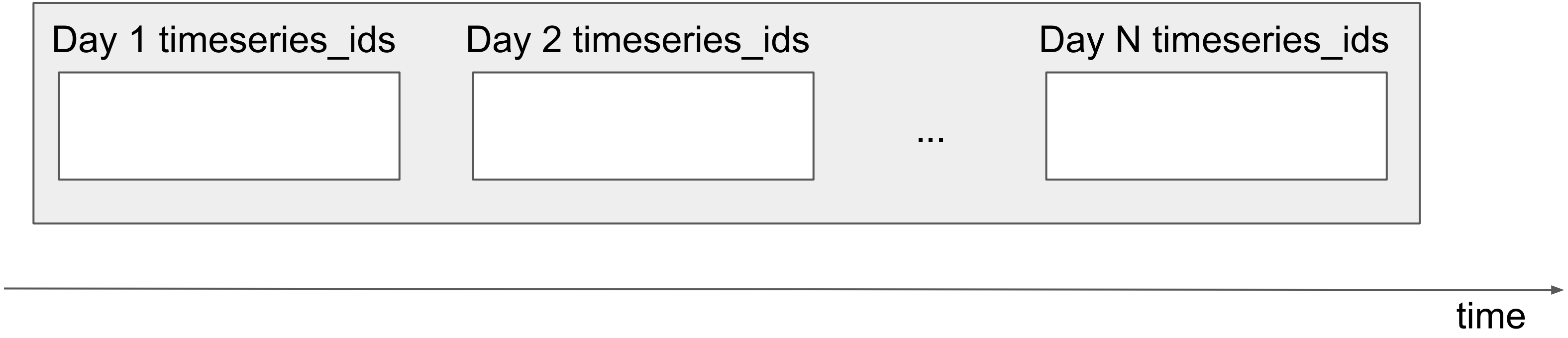
Partition inverted index by time

- Pros:
  - Simple
  - Fast
- Cons:
  - duplicates inverted index data for long-living time series



Per-day timeseries_ids sets for active time series

- Pros:
  - Index for long-living time series is stored only once
- Cons:
  - harder to implement
  - needs to scan bigger timeseries_ids sets



Solutions for high number of time series matching (label=value)

Store multiple timeseries_ids per mergeset row

- Pros:
  - requires less memory (especially for long (label=value) pairs)
  - improves scan speed
- Cons:
  - hard to implement
  - hard to debug

Original rows:

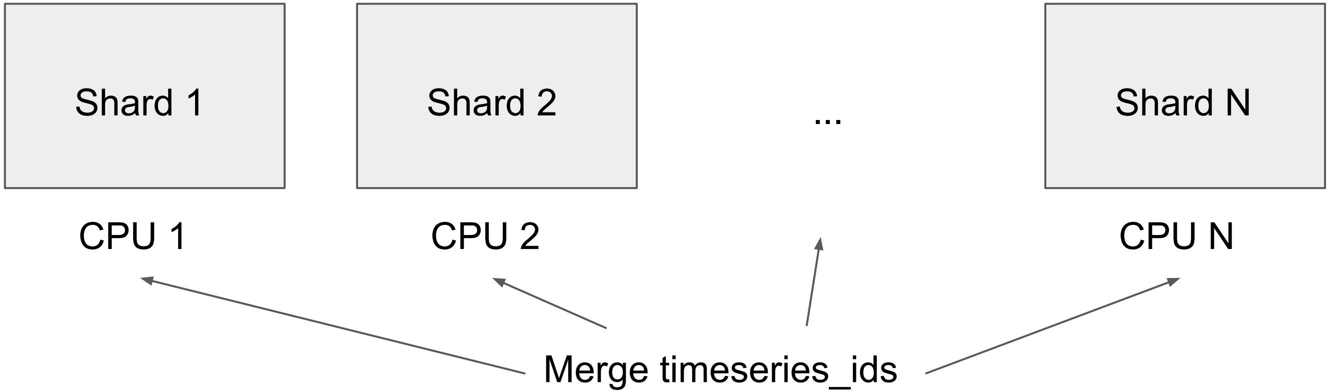
(label=value) timeseries_id1
(label=value) timeseries_id2
…
(label=value) timeseries_idN

Optimized row:

(label=value) timeseries_id1, timeseries_id2, … timeseries_idN

Shard inverted index by time series key (a set of (label=value) pairs)

- Pros:
  - scales to multiple CPUs
- Cons:
  - requires more CPU resources



Optimizations for timeseries_ids sets intersection

- **{datacenter=”us-east”, job=”my-app”, instance=”my-host”}** requires intersection of three timeseries_ids sets:
  - (datacenter=”us-east”)
  - (job=”my-app”)
  - (instance=”my-host”)
- How to quickly intersect timeseries_ids sets?

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Timeseries_ids sets intersection: naive approach

```go
// intersectInts returns the intersection of a and b sets
func interesectInts(a, b []int) []int {
	var result []int
	for _, x := range a {
		for _, y := range b {
			if x == y {
				result = append(result, x)
				break
			}
		}
	}
	return result
}
```

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What’s wrong with the naive approach?

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What’s wrong with the naive approach?

- It works slowly with big sets
- It has O(N^2) complexity
- Let len(a) == 1M, len(b) == 1M
- Then the max number of iterations equals to **len(a)*len(b)=1M*1M=1 trillion**

Timeseries_ids intersection: map

```go
// intersectInts returns the intersection of a and b sets
func interesectInts(a, b []int) []int {
	m := make(map[int]bool)
	for _, x := range a {
		m[x] = true
	}
	var result []int
	for _, y := range b {
		if m[y] {
			result = append(result, y)
		}
	}
	return result
}
```

Set intersection with map

- Pros:
  - Has O(N) complexity
- Cons:
  - Has high overhead on hashing

Timeseries_ids intersection: customized bitset

```
// intersectInts returns the intersection of a and b sets
func interesectInts(a, b []uint64) []uint64 {
	s := &uint64set.Set{}
	for _, x := range a {
		s.Add(x)
	}
	var result []uint64
	for _, y := range b {
		if s.Has(y) {
			result = append(result, y)
		}
	}
	return result
}
```

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Set intersection with customized bitset

- Pros:
  - Up to 10x better performance comparing to map-based intersection
  - Lower memory usage for big sets (>1M items)
- Cons:
  - Non-trivial implementation
  - Memory usage can explode if improperly used

Customized bitset: implementation details

- Located at lib/uint64set
- Optimized for dense serial timeseries_ids where higher 32 bits are constant
- Doesn’t provide data persistence

lib/uint64set API

```
package uint64set // import "github.com/VictoriaMetrics/VictoriaMetrics/lib/uint64set"

type Set struct {
        // Has unexported fields.
}
    Set is a fast set for uint64.

    It should work faster than map[uint64]struct{} for semi-sparse uint64 values
    such as MetricIDs generated by lib/storage.

    It is unsafe calling Set methods from concurrent goroutines.

func (s *Set) Add(x uint64)
func (s *Set) AppendTo(dst []uint64) []uint64
func (s *Set) Clone() *Set
func (s *Set) Del(x uint64)
func (s *Set) Has(x uint64) bool
func (s *Set) Len() int
```

lib/uint64set internals

```
type Set struct {
        itemsCount int
        buckets    []*bucket32
}
type bucket32 struct {
        hi      uint32
        b16his  []uint16
        buckets []*bucket16
}
type bucket16 struct {
        bits [wordsPerBucket]uint64
}
const (
        bitsPerBucket  = 1 << 16
        wordsPerBucket = bitsPerBucket / 64
)
```

lib/uint64set internals: Set.Add

```go
// Add adds x to s.
func (s *Set) Add(x uint64) {
	hi := uint32(x >> 32)
	lo := uint32(x)
	for _, b32 := range s.buckets {
		if b32.hi == hi {
			if b32.add(lo) {
				s.itemsCount++
			}
			return
		}
	}
	s.addAlloc(hi, lo)
}
```

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lib/uint64set internals: bucket32.add

```go
func (b *bucket32) add(x uint32) bool {
	hi := uint16(x >> 16)
	lo := uint16(x)
	if len(b.buckets) > maxUnsortedBuckets {
		return b.addSlow(hi, lo)
	}
	for i, hi16 := range b.b16his {
		if hi16 == hi {
			return b.buckets[i].add(lo)
		}
	}
	b.addAllocSmall(hi, lo)
	return true
}
```

lib/uint64set internals: bucket16.add

```go
func (b *bucket16) add(x uint16) bool {
        wordNum, bitMask := getWordNumBitMask(x)
        word := &b.bits[wordNum]
        ok := *word&bitMask == 0
        *word |= bitMask
        return ok
}
```

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- There are many more optimizations in the code
- The majority of these optimizations are applied after `go tool pprof` analysis
- Investigate VictoriaMetrics Go code - it is free and open source:
  https://github.com/VictoriaMetrics/VictoriaMetrics

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Questions?

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