Golang’s Garbage

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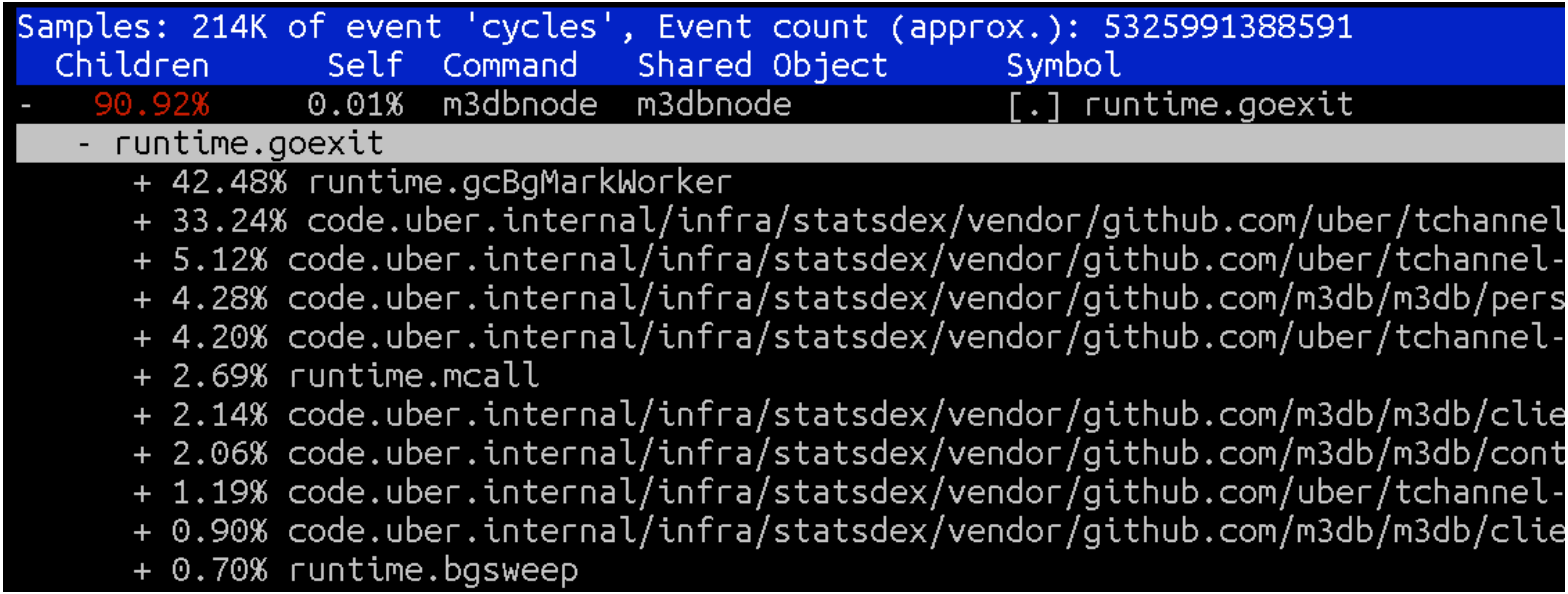
Claim of Credibility

In Uber, we run over 1700 microservices in production, written in different languages. At this scale and fanout, performance of each one of them matters.

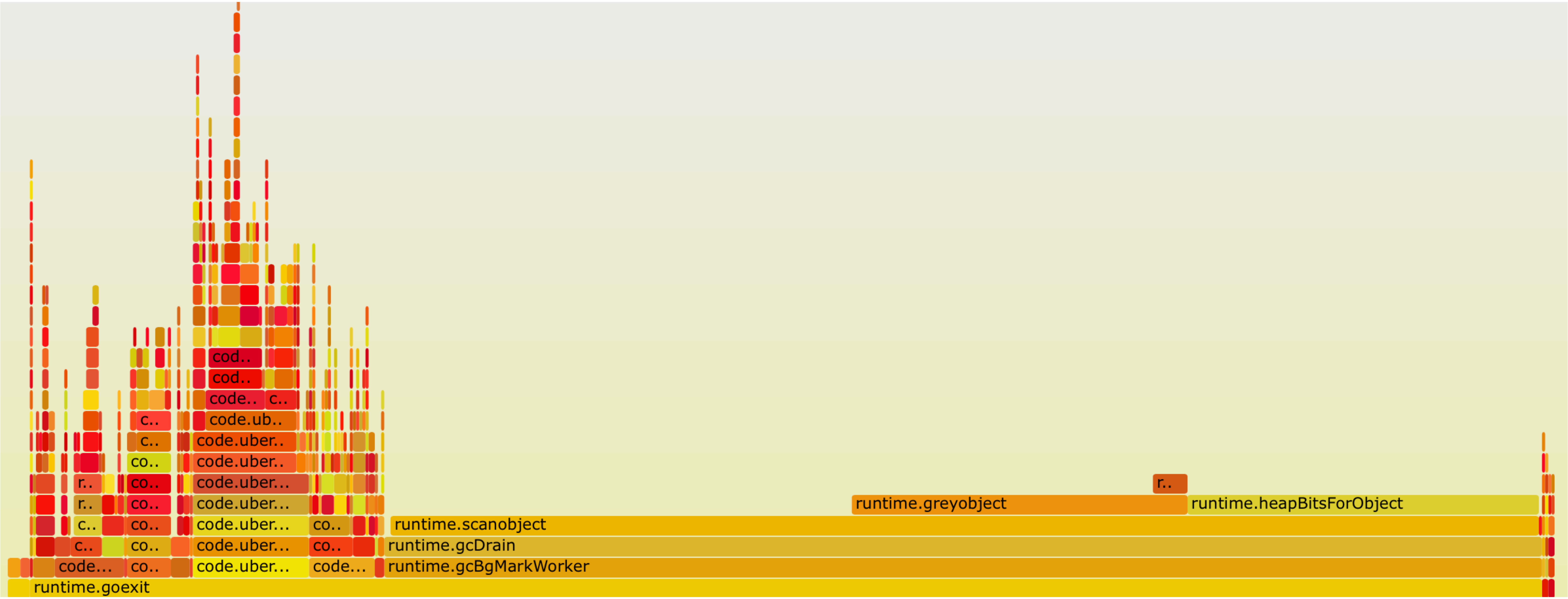
- The team I work with runs a few CPU and memory intensive Go services processing a ton of requests from all around the infrastructure.
- **Tens of millions** datapoints ingested per second.
- **Seventy five years** of time series data queried per second.

«Go is building a garbage collector **not only for 2015 but for 2025 and beyond** <…> Go 1.5’s GC ushers in a future where **stop-the-world pauses are no longer a barrier to moving to a safe and secure language**. It is a future where **applications scale effortlessly along with hardware** and as hardware becomes more powerful the GC will not be an impediment to better, more scalable software».



```
Samples: 214K of event 'cycles', Event count (approx.): 5325991388591
  Children      Self  Command   Shared Object      Symbol
-   90.92%     0.01%  m3dbnode  m3dbnode           [.] runtime.goexit
   - runtime.goexit
      + 42.48% runtime.gcBgMarkWorker
      + 33.24% code.uber.internal/infra/statsdex/vendor/github.com/uber/tchannel
      + 5.12% code.uber.internal/infra/statsdex/vendor/github.com/uber/tchannel-
      + 4.28% code.uber.internal/infra/statsdex/vendor/github.com/m3db/m3db/pers
      + 4.20% code.uber.internal/infra/statsdex/vendor/github.com/uber/tchannel-
      + 2.69% runtime.mcall
      + 2.14% code.uber.internal/infra/statsdex/vendor/github.com/m3db/m3db/clie
      + 2.06% code.uber.internal/infra/statsdex/vendor/github.com/m3db/m3db/cont
      + 1.19% code.uber.internal/infra/statsdex/vendor/github.com/uber/tchannel-
      + 0.90% code.uber.internal/infra/statsdex/vendor/github.com/m3db/m3db/clie
      + 0.70% runtime.bgsweep
```

GC scales effortlessly



GC scales even more effortlessly

Modern GC

- **Generational** – memory is divided into regions based on certain tenuring policies: no need to scan everything every time.

- **Compacting** – during each GC phase memory is defragmented: data locality improves, allocations become free.

- **Exact** – GC knows exactly what each byte of memory is: a pointer or a typed value. GC can move things around and update references.

- **Goal-based** – GC aims to keep a certain metric in user-specified bounds, e.g. pause time, heap size, etc.

Golang GC

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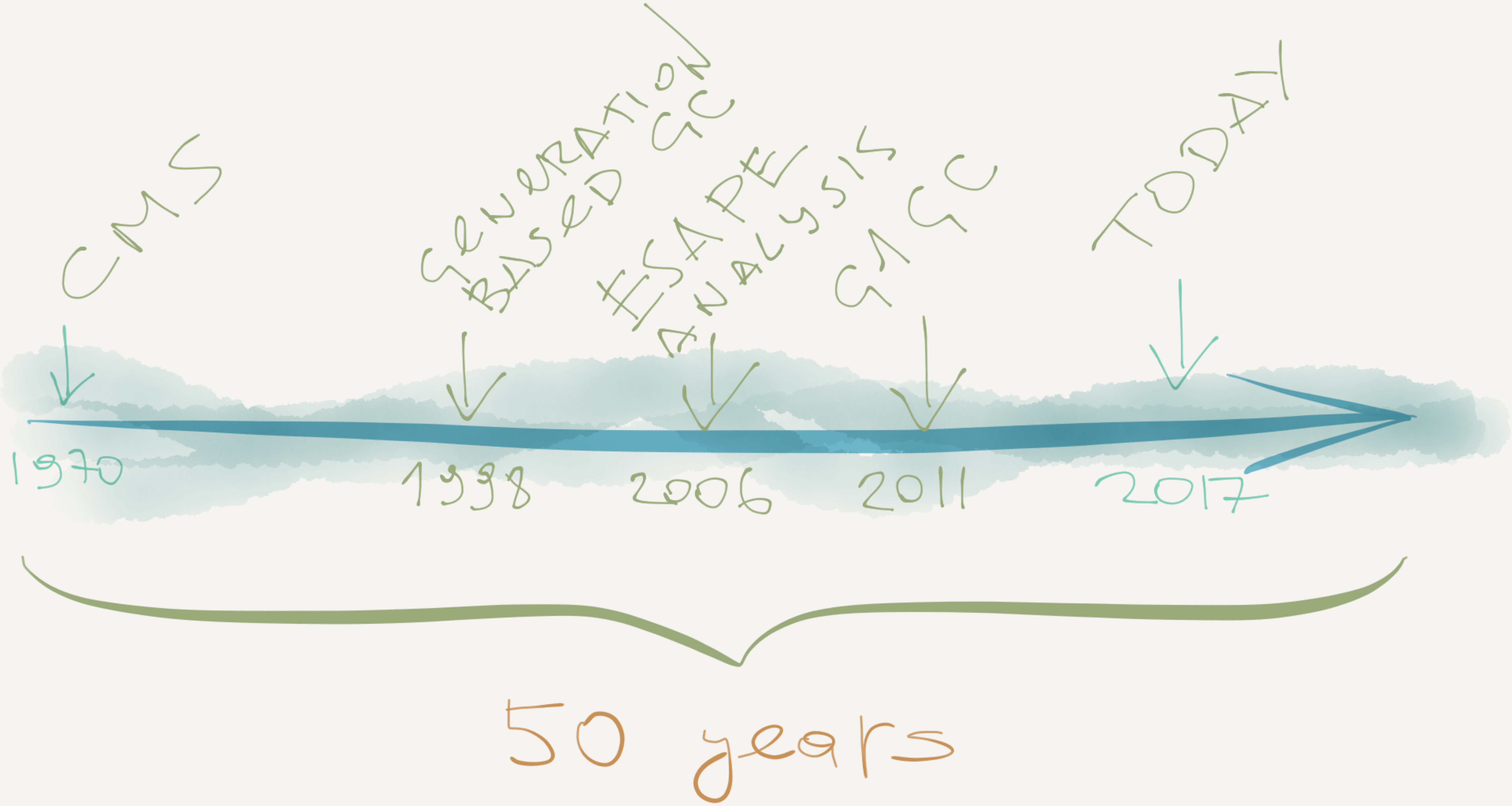

CMS
1970
GENERATION BASED GC
1998
ESAPE ANALYSIS
2006
G1GC
2011
TODAY
2017
50 years

WTF

- **Reducing stop-the-world pause times** with each Go release **has a cost** which Google's marketing people don't like to talk about.
- Background **GC CPU usage is linear with the number of pointers on the heap**.
- On a ~96GB heap populated with simple structures and interfaces, **Go spends up to 75% of total program runtime inside GC**.

GODEBUG=gctrace=1

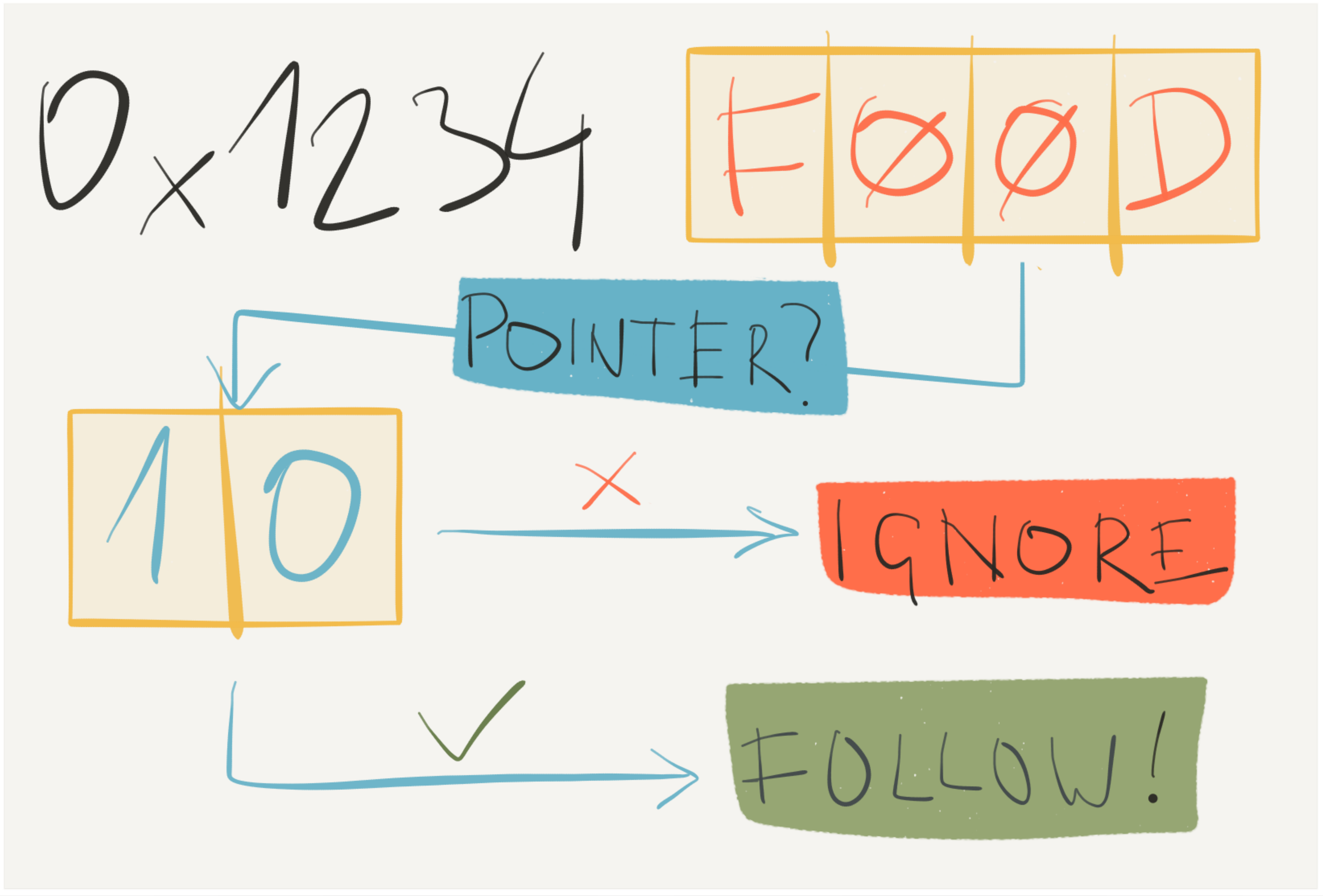
```
STF BGMSF MTF              ASST  BG    IDLE              START  END    LIVE            CPUs
1.4+17949+5.8 ms clock, 17+60052/53289/3364+69 ms cpu,   38334->39982->31776 MB, <...> 12 P
2.5+21556+3.7 ms clock, 30+5929/64643/53115+45 ms cpu,   38339->40397->32694 MB, <...> 12 P
1.8+17143+7.5 ms clock, 22+58984/50885/5663+90 ms cpu,   39817->41613->32402 MB, <...> 12 P
4.7+21064+4.3 ms clock, 57+28487/62624/21636+52 ms cpu,  38882->41093->33218 MB, <...> 12 P
1.3+18280+4.4 ms clock, 16+8069/54668/49076+53 ms cpu,   39878->41529->32903 MB, <...> 12 P
1.3+15909+3.5 ms clock, 9.2+6840/47614/53832+24 ms cpu,  40200->41653->32746 MB, <...> 12 P
1.4+16361+4.2 ms clock, 17+36463/48581/34116+50 ms cpu,  40462->41596->32379 MB, <...> 12 P
27+16683+3.9 ms clock,  223+1433/49757/63019+31 ms cpu,  39572->40527->32266 MB, <...> 12 P
```

Heap Bitmap

- Heap bitmap is a data structure that Go runtime uses to keep track of the memory's underlying **type information**. It's pre-generated by the compiler.

- **For each word** in memory, it keeps **two bits of metadata** — in most cases, whether it's a pointer or not and a debug bit.

- GC uses this bitmap to populate its working set for each cycle by **recursively adding all pointers** starting from those found in root objects — globals and stacks.


0x1234
F00D
POINTER?
10
IGNORE
FOLLOW!

More Pointers = Slower Code

Easy Tricks

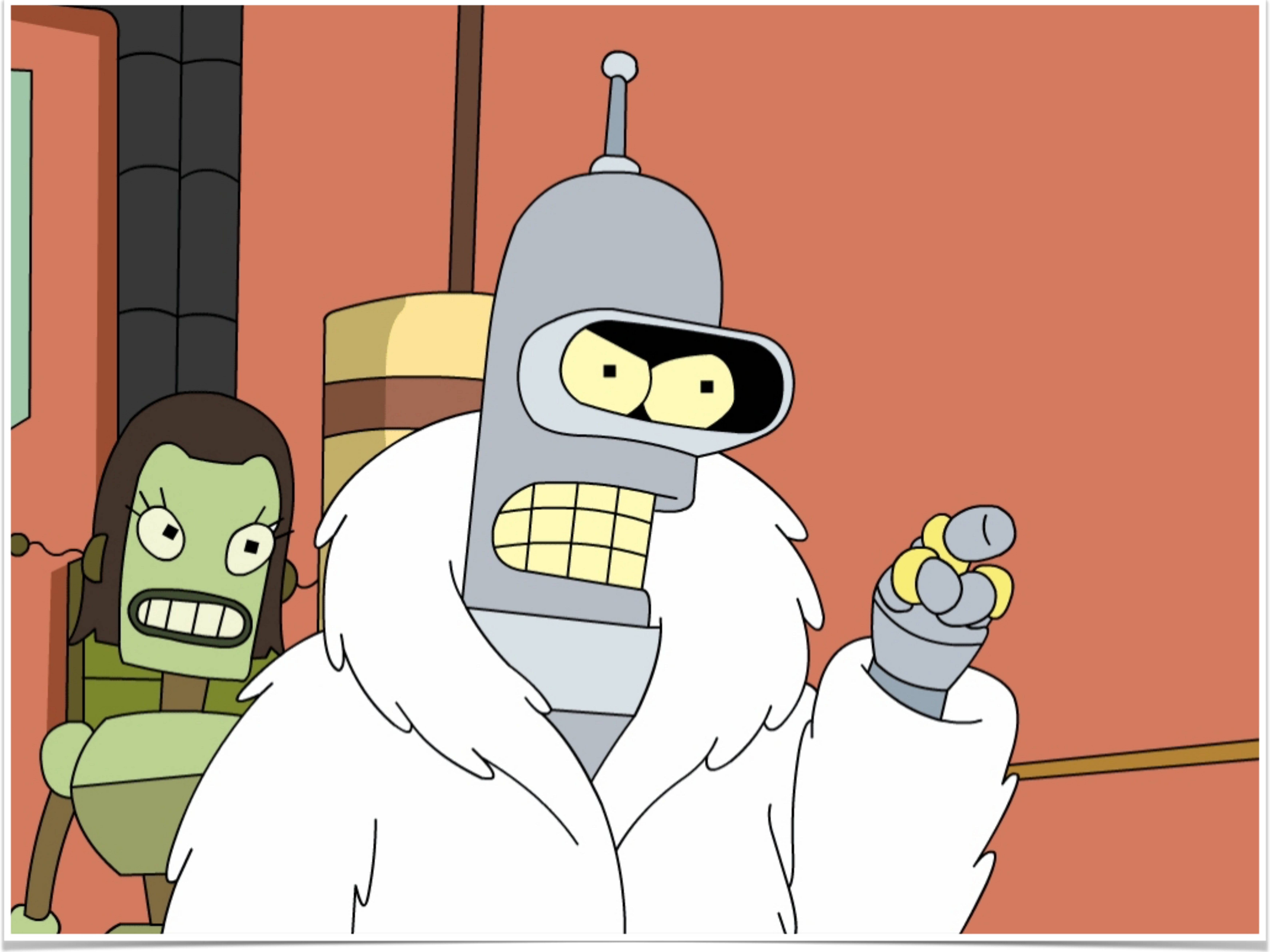
- **Channels** of pointerless structures or plain values are allocated as a single block and marked as non-scannable.
- **Maps** where both keys and values are pointerless structures are marked as non-scannable.
- **Pointers** can be stored as *uintptrs* and casted to actual types via *unsafe.Pointer* to also be marked as non-scannable.
- **Closures** force all stack variables of the enclosing function to escape to the heap. Don’t use closures – use functors.

Pooling

sync.Pool	ObjectPool
unbounded	bounded
separate per-P pools	one shared pool
purged on GC	retained on GC
lazily populated	eagerly populated

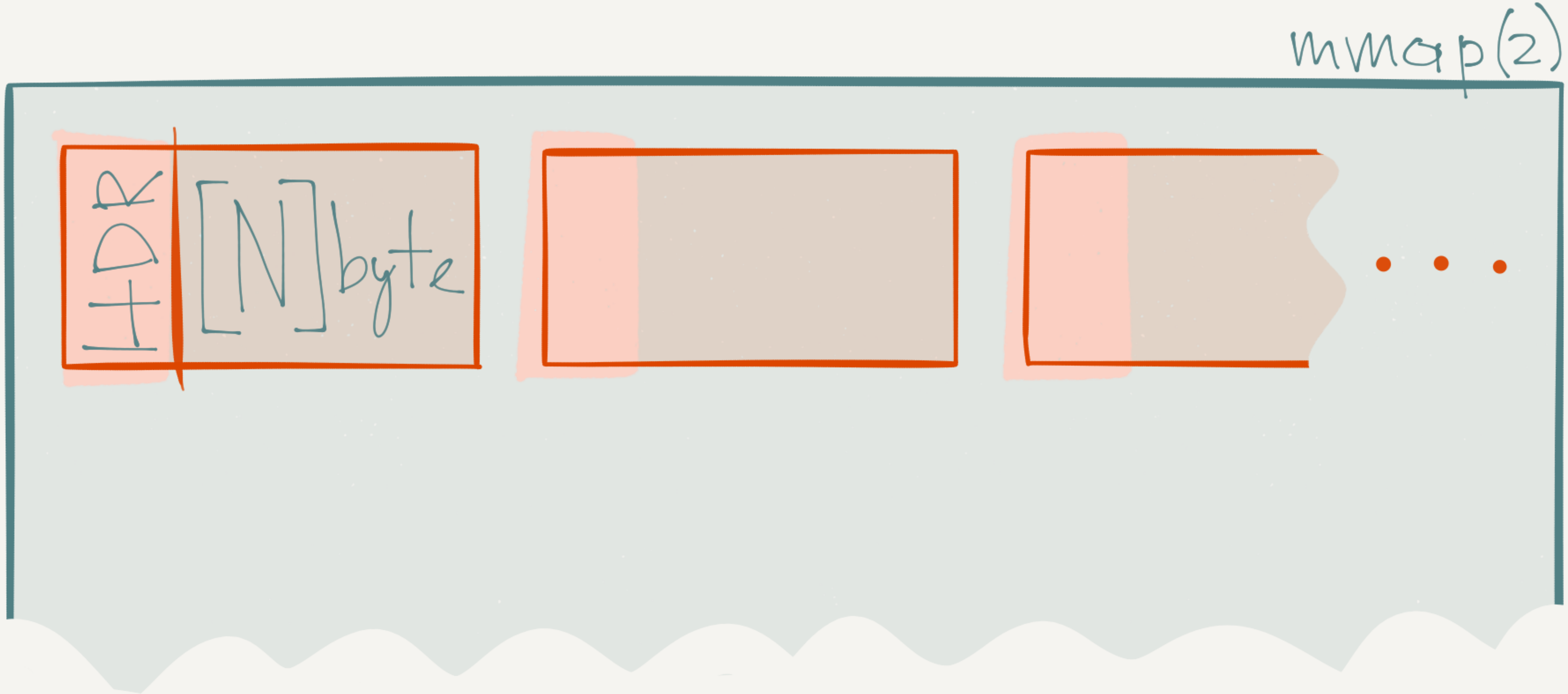
Uneasy Tricks

How can we dramatically reduce the number of pointers on the heap?



Native Heap

- **Step 1**: Allocate a huge block of memory via *mmap(2)*.
- **Step 2**: Slice it into chunks of the specified type's size and a little bit extra for the header.
- **Step 3**: ???
- **Step 4**: Profit!


mmap(2)
HDR
[N]byte
...

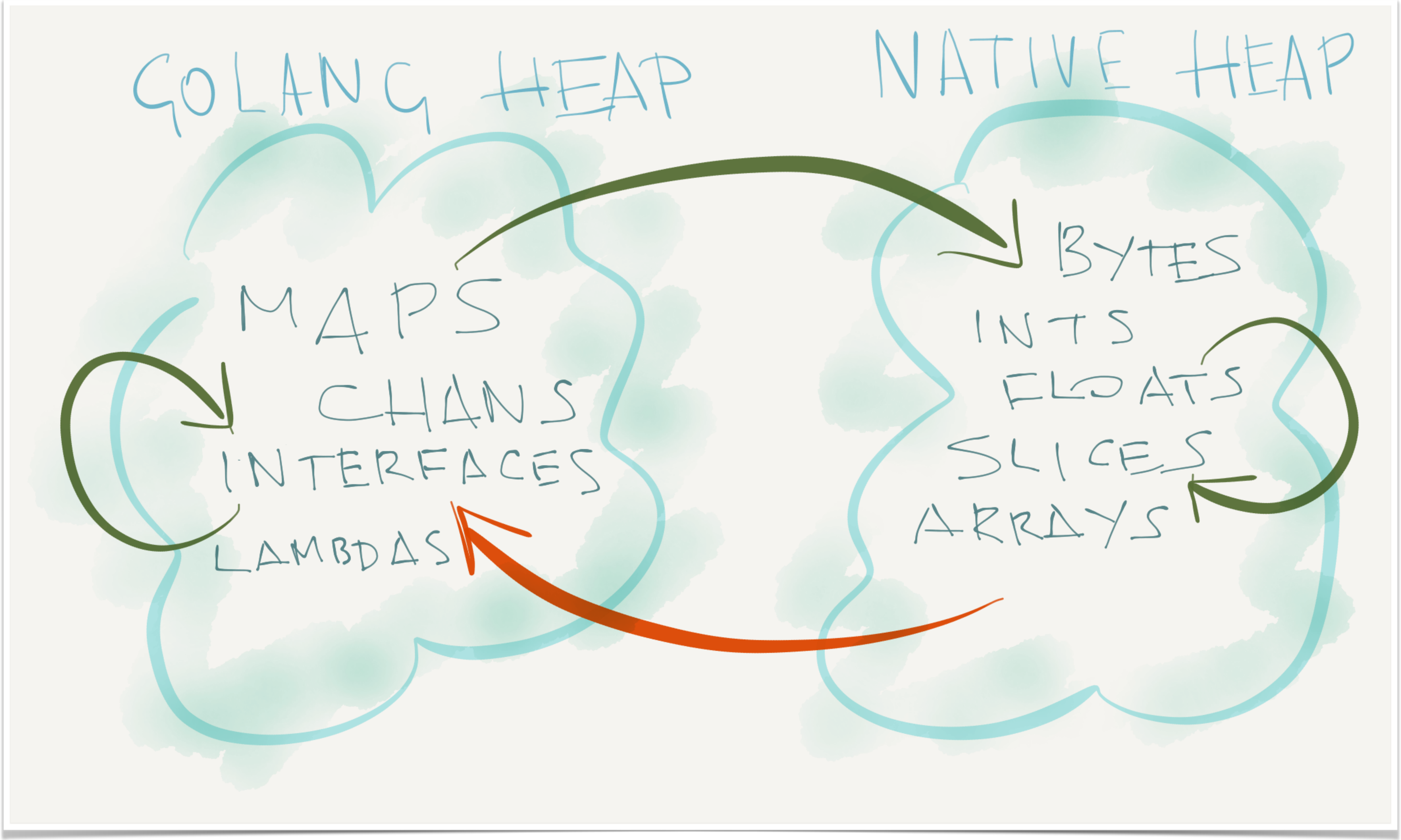
Native Heap

- The **native heap is invisible to the Go runtime**, so GC ignores it even if it sees a pointer into it. This also means that *free(3)* is back.

- For the same reason, **native heap pointers cannot keep objects on the GC heap alive** (think weak pointers).

- It means **all pointers** in objects on the native heap **must point to the native heap**, unless there's another root somewhere.

- Since the internal structure of builtin types is not available to the user code, **maps, channels and other builtins won't work**.


GOLANG HEAP
NATIVE HEAP
MAPS
CHANS
INTERFACES
LAMBDAS
BYTES
INTS
FLOATS
SLICES
ARRAYS

Native Slices

```go
// Make a heap of 1024 16-byte blocks.
h := heap.New(1024,
    reflect.ArrayOf(16, reflect.TypeOf((byte)(0))))

// Allocate a ninja slice.
v := *(*[]byte)(unsafe.Pointer(&reflect.SliceHeader{
    Data: reflect.ValueOf(h.get()).Pointer(),
    Len:  0,
    Cap:  16,
}))
```

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```

Native Slices

```go
type SliceHeader struct {
        Data uintptr
        Len  int
        Cap  int
}
```

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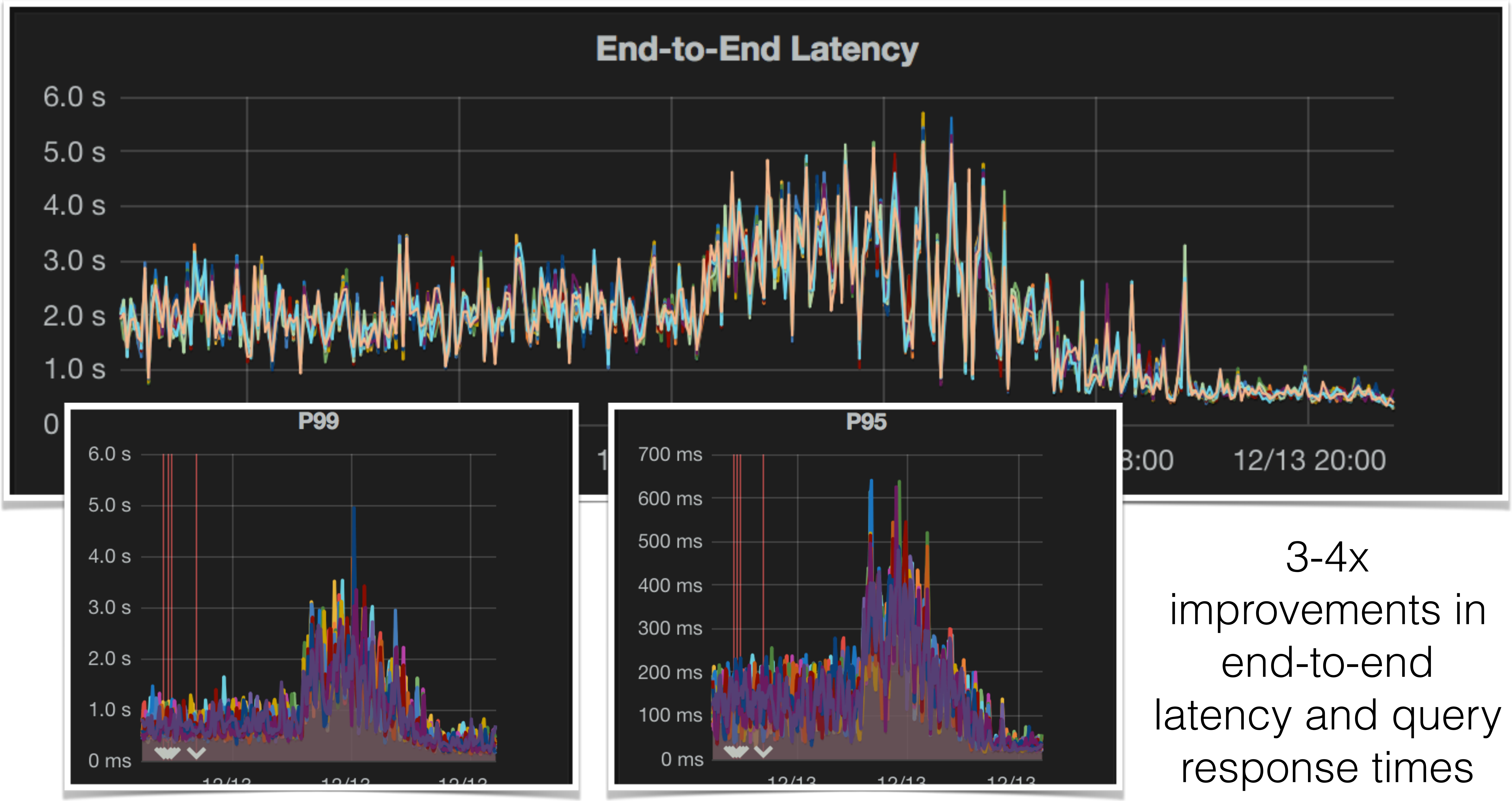

3-4x improvements in end-to-end latency and query response times

What’s Next?

- Figuring out more ways to have less objects or move more objects to the **Native Heap**.
- **ROC** – Request Oriented Collector. It’s a generational CMS with a special tenuring policy based on request-response hypothesis. It’s nineties all over again!
- Porting performance-critical code paths to **C++** or **Rust** and calling into it via CGo or local IPC.

Thank you!

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