BEAT

Where next?

POINTERS VS VALUES

...DEBUGGED

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Using pointers or values as Method arguments

“This is how far code review can bring you!”

The Theory

***pointers**

- Allow for struct mutation
- Avoid copying overhead

But …

- Not concurrently safe
- Might escape to the heap
  - Gc overhead
  - Heap expansion cost

values

- Immutability
- Lives in the stack (escape analysis)

But …

- Processing time overhead (copying)

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The Baseline

model

```
type obj interface {
  GetI() int64
  GetF() float64
}

type tiny struct {
  a int64
  aa float64
  aaa string
}

type mini struct {
  a int64
  b int64
  c int64
  aa float64
  bb float64
  cc float64
  aaa string
  bbb string
  ccc string
}

type tera struct {
 …
}
```

methods

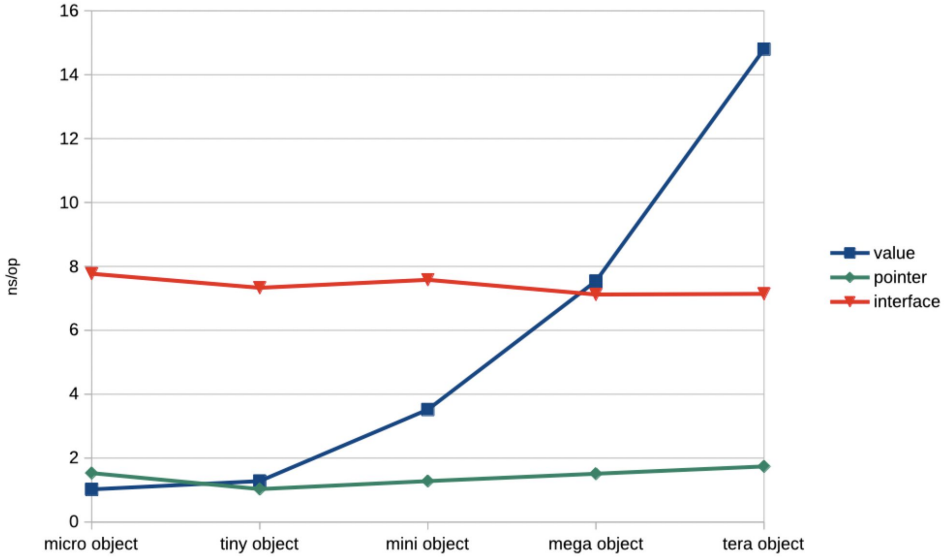
```
func calcTiny(o tiny) (float64, error) {
return float64(o.a) / o.aa, nil
}

func calcTinyP(o *tiny) (float64, error) {
 return float64(o.a) / o.aa, nil
}

func calcTera(o tera) (float64, error) {
 return float64(o.a) / o.aa, nil
}

func calcTeraP(o *tera) (float64, error) {
  return float64(o.a) / o.aa, nil
}

func calcIfc(o obj) (float64, error) {
  return float64(o.GetI()) / o.GetF(), nil
}

...
```

benchmarks

```
func BenchmarkTiny(b *testing.B) {

  o := createTiny()

  for i := 0; i < b.N; i++ {
    avoidCompilerOptimisation(calcTiny(o))
  }
}


func BenchmarkTinyP(b *testing.B) {

  o := createTiny()

  for i := 0; i < b.N; i++ {
    avoidCompilerOptimisation(calcTinyP(&o))
  }
}


// avoid compiler optimisations
var F = 0.0
func avoidCompilerOptimisation(f float64, err error) {
  F += f
}
```

ns/op

- ***Pointers*** & ***Interfaces*** seem constant in performance.
  (constant access pattern)
- ***Value*** performance is degrading “fast”.
- ***Pointer*** and ***Value*** performance is very much comparable for small object sizes *.



“Copying objects within a cache line is the roughly equivalent to copying a single pointer” https://segment.com/blog/allocation-efficiency-in-high-performance-go-services/

* One thing to note though, is even if the object is less than 64 bytes, it might spread across 2 cache lines, whereas the pointer always occupies only one.

```
type micro struct {
  a int64
  aa float64
}
```

```
type tiny struct {
  a int64
  aa float64
  aaa string
}
```

```
type mini struct {
  a int64
  b int64
  c int64
  aa float64
  bb float64
  cc float64
  aaa string
  bbb string
  ccc string
}
```

```
type mega struct {
  a int64  // ( x 11 )
...
  aa float64 // ( x 11 )
...
  aaa string // ( x 11 )
...
}
```

```
type tera struct {
  a int64  // ( x 26 )
...
  aa float64 // ( x 26 )
...
  aaa string // ( x 26 )
...
}
```

Increasing Iterations

```
const iterations = 100000

func BenchmarkTiny(b *testing.B) {

  o := createTiny()

  for i := 0; i < b.N; i++ {
    for a := 0; a < iterations; a++ {
      avoidCompilerOptimisation(calcTiny(o))
    }
  }
}
```

- ***Performance*** scales consistently (almost linearly) *… as the iterations increase*
- ***Allocations*** for *pointer* and *value* are the same … for *interfaces* they become considerably more relevant

value	ns/op	B/op	allocs/op
BenchmarkTiny	1.28	0	0
BenchmarkTiny_x_100_000	219334	0	0
BenchmarkTiny_x_100_000_000	227079453	6	0
pointer			
BenchmarkTinyP	1.03	0	0
BenchmarkTinyP_x_100_000	216990	0	0
BenchmarkTinyP_x_100_000_000	218180127	6	0
interface			
BenchmarkTinyIfc	7.33	0	0
BenchmarkTinyIfc_x_100_000	723065	0	0
BenchmarkTinyIfc_x_100_000_000	716009788	32	1

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Assembly Analysis

go tool compile -S pointer_vs_value/code/* > assembly.s

MOVQ : **copy** quadrant
MOVSD : **move** doubleword
XORPS : **clear register** (usually what gcc does in C++)
PCDATA : **garbage collection** metadata

X0/X1 : registers
AX : primary accumulator (register)
SP : stack pointer

*pointer

```
"".calcMicroObjectWithPointer STEXT size=178 args=0x20 locals=0x18
(args/pointer_receiver.go:135)  TEXT    "".calcMicroObjectWithPointer(SB), ABIInternal, $24-32
(args/pointer_receiver.go:135)  MOVQ    (TLS), CX
(args/pointer_receiver.go:135)  CMPQ    SP, 16(CX)
(args/pointer_receiver.go:135)  JLS 168
(args/pointer_receiver.go:135)  SUBQ    $24, SP
(args/pointer_receiver.go:135)  MOVQ    BP, 16(SP)
(args/pointer_receiver.go:135)  LEAQ    16(SP), BP
(args/pointer_receiver.go:135)  FUNCDATA    $0, gclocals·305be4e7b0a18f2d72ac30e38ac4e7b(SB)
(args/pointer_receiver.go:135)  FUNCDATA    $1, gclocals·7d2d5fca80364273fb07d5820a76fef4(SB)
(args/pointer_receiver.go:135)  FUNCDATA    $2, gclocals·bfec7e55b3f043d1941c093912808913(SB)
(args/pointer_receiver.go:136)  PCDATA  $0, $1
(args/pointer_receiver.go:136)  PCDATA  $1, $1
(args/pointer_receiver.go:136)  MOVQ    "".o+32(SP), AX
(args/pointer_receiver.go:136)  MOVSD   8(AX), X0
(args/pointer_receiver.go:136)  XORPS   X1, X1
(args/pointer_receiver.go:136)  UCOMISD X1, X0
(args/pointer_receiver.go:136)  JNE 129
(args/pointer_receiver.go:136)  JPS 129
(args/pointer_receiver.go:137)  PCDATA  $0, $0
(<unknown line number>) NOP
```

value

```
"".calcMicroObject STEXT size=176 args=0x28 locals=0x18
(args/pointer_receiver.go:91)   TEXT    "".calcMicroObject(SB), ABIInternal, $24-40
(args/pointer_receiver.go:91)   MOVQ    (TLS), CX
(args/pointer_receiver.go:91)   CMPQ    SP, 16(CX)
(args/pointer_receiver.go:91)   JLS 166
(args/pointer_receiver.go:91)   SUBQ    $24, SP
(args/pointer_receiver.go:91)   MOVQ    BP, 16(SP)
(args/pointer_receiver.go:91)   LEAQ    16(SP), BP
(args/pointer_receiver.go:91)   FUNCDATA    $0, gclocals·4284da0ffddacd9b3f4010ab6a9b04d6(SB)
(args/pointer_receiver.go:91)   FUNCDATA    $1, gclocals·69c1753bd5f81501d95132d08af04464(SB)
(args/pointer_receiver.go:91)   FUNCDATA    $2, gclocals·bfec7e55b3f043d1941c093912808913(SB)
(args/pointer_receiver.go:92)   PCDATA  $0, $0
(args/pointer_receiver.go:92)   PCDATA  $1, $0

(args/pointer_receiver.go:92)   MOVSD   "".o+40(SP), X0
(args/pointer_receiver.go:92)   XORPS   X1, X1
(args/pointer_receiver.go:92)   UCOMISD X1, X0
(args/pointer_receiver.go:92)   JNE 125
(args/pointer_receiver.go:92)   JPS 125

(<unknown line number>) NOP
```

- ***Pointer*** assembly code does an extra copy call
  + adds some gc overhead

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interface

```
"".calcWithPointer STEXT size=248 args=0x28 locals=0x20
    0x0000 00000 (args/pointer_receiver.go:128) TEXT    "".calcWithPointer(SB), ABIInternal, $32-40
    0x0000 00000 (args/pointer_receiver.go:128) MOVQ    (TLS), CX
    0x0009 00009 (args/pointer_receiver.go:128) CMPQ    SP, 16(CX)
    0x000d 00013 (args/pointer_receiver.go:128) JLS 238
    0x0013 00019 (args/pointer_receiver.go:128) SUBQ    $32, SP
    0x0017 00023 (args/pointer_receiver.go:128) MOVQ    BP, 24(SP)
    0x001c 00028 (args/pointer_receiver.go:128) LEAQ    24(SP), BP
    0x0021 00033 (args/pointer_receiver.go:128) FUNCDATA    $0, gclocals·b3e6cef2da4123bb4fb758b92dba3371(SB)
    0x0021 00033 (args/pointer_receiver.go:128) FUNCDATA    $1, gclocals·7d2d5fca80364273fb07d5820a76fef4(SB)
    0x0021 00033 (args/pointer_receiver.go:128) FUNCDATA    $2, gclocals·457447a82af07995fb3f7c66ee908834(SB)
    0x0021 00033 (args/pointer_receiver.go:129) PCDATA  $0, $0
    0x0021 00033 (args/pointer_receiver.go:129) PCDATA  $1, $0
    0x0021 00033 (args/pointer_receiver.go:129) MOVQ    "".o+40(SP), AX
    0x0026 00038 (args/pointer_receiver.go:129) MOVQ    24(AX), CX
    0x002a 00042 (args/pointer_receiver.go:129) PCDATA  $0, $1
    0x002a 00042 (args/pointer_receiver.go:129) MOVQ    "".o+48(SP), DX
    0x002f 00047 (args/pointer_receiver.go:129) PCDATA  $0, $0
    0x002f 00047 (args/pointer_receiver.go:129) MOVQ    DX, (SP)
    0x0033 00051 (args/pointer_receiver.go:129) CALL    CX
    0x0035 00053 (args/pointer_receiver.go:129) MOVSD   8(SP), X0
    0x003b 00059 (args/pointer_receiver.go:129) XORPS   X1, X1
    0x003e 00062 (args/pointer_receiver.go:129) UCOMISD X1, X0
    0x0042 00066 (args/pointer_receiver.go:129) JNE 145
    0x0044 00068 (args/pointer_receiver.go:129) JPS 145
    0x0046 00070 (args/pointer_receiver.go:130) PCDATA  $1, $1
    0x0046 00070 (<unknown line number>)    NOP
```

value

```
1  "".calcMicroObject STEXT size=176 args=0x28 locals=0x18
2  (args/pointer_receiver.go:91)   TEXT    "".calcMicroObject(SB), ABIInternal, $24-40
3  (args/pointer_receiver.go:91)   MOVQ    (TLS), CX
4  (args/pointer_receiver.go:91)   CMPQ    SP, 16(CX)
5  (args/pointer_receiver.go:91)   JLS 166
6  (args/pointer_receiver.go:91)   SUBQ    $24, SP
7  (args/pointer_receiver.go:91)   MOVQ    BP, 16(SP)
8  (args/pointer_receiver.go:91)   LEAQ    16(SP), BP
9  (args/pointer_receiver.go:91)   FUNCDATA    $0, gclocals·4284da0ffddacd9b3f4010ab6a9b04d6(SB)
10 (args/pointer_receiver.go:91)   FUNCDATA    $1, gclocals·69c1753bd5f81501d95132d08af04464(SB)
11 (args/pointer_receiver.go:91)   FUNCDATA    $2, gclocals·bfec7e55b3f043d1941c093912808913(SB)
12 (args/pointer_receiver.go:92)   PCDATA  $0, $0
13 (args/pointer_receiver.go:92)   PCDATA  $1, $0
14
15
16
17
18
19
20
21 (args/pointer_receiver.go:92)   MOVSD   "".o+40(SP), X0
22 (args/pointer_receiver.go:92)   XORPS   X1, X1
23 (args/pointer_receiver.go:92)   UCOMISD X1, X0
24 (args/pointer_receiver.go:92)   JNE 125
25 (args/pointer_receiver.go:92)   JPS 125
26
27 (<unknown line number>) NOP
```

- ***Interfaces*** need by default 2 pointers
  See the “iface” struct https://github.com/golang/go/blob/bf86aec25972f3a100c3aa58a6abcbcc35bdea49/src/runtime/runtime2.go#L143-L146
- ***Pointer*** handling for interfaces must be “by the book”

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interface

```
0x006a 00106 ($GOROOT/src/errors/errors.go:59)  PCDATA  $0, $2
0x006a 00106 ($GOROOT/src/errors/errors.go:59)  MOVQ    CX, (AX)
0x006d 00109 (args/pointer_receiver.go:130) XORPS   X0, X0
0x0070 00112 (args/pointer_receiver.go:130) MOVSD   X0, ""..~r1+56(SP)
0x0076 00118 (args/pointer_receiver.go:130) PCDATA  $0, $3
0x0076 00118 (args/pointer_receiver.go:130) PCDATA  $1, $2
0x0076 00118 (args/pointer_receiver.go:130) LEAQ    go.itab.*errors.errorString,error(SB), CX
0x007d 00125 (args/pointer_receiver.go:130) PCDATA  $0, $2
0x007d 00125 (args/pointer_receiver.go:130) MOVQ    CX, ""..~r2+64(SP)
0x0082 00130 (args/pointer_receiver.go:130) PCDATA  $0, $0
0x0082 00130 (args/pointer_receiver.go:130) MOVQ    AX, ""..~r2+72(SP)
0x0087 00135 (args/pointer_receiver.go:130) MOVQ    24(SP), BP
0x008c 00140 (args/pointer_receiver.go:130) ADDQ    $32, SP
0x0090 00144 (args/pointer_receiver.go:130) RET
0x0091 00145 (args/pointer_receiver.go:132) PCDATA  $1, $0
0x0091 00145 (args/pointer_receiver.go:132) MOVQ    ""..o+40(SP), AX
0x0096 00150 (args/pointer_receiver.go:132) MOVQ    32(AX), CX
0x009a 00154 (args/pointer_receiver.go:132) PCDATA  $0, $1
0x009a 00154 (args/pointer_receiver.go:132) MOVQ    ""..o+48(SP), DX
0x009f 00159 (args/pointer_receiver.go:132) PCDATA  $0, $0
0x009f 00159 (args/pointer_receiver.go:132) MOVQ    DX, (SP)
0x00a3 00163 (args/pointer_receiver.go:132) CALL    CX
0x00a5 00165 (args/pointer_receiver.go:132) MOVQ    8(SP), AX
0x00aa 00170 (args/pointer_receiver.go:132) MOVQ    AX, ""..autotmp_12+16(SP)
0x00af 00175 (args/pointer_receiver.go:132) MOVQ    ""..o+40(SP), CX
0x00b4 00180 (args/pointer_receiver.go:132) MOVQ    24(CX), CX
0x00b8 00184 (args/pointer_receiver.go:132) PCDATA  $0, $1
0x00b8 00184 (args/pointer_receiver.go:132) PCDATA  $1, $1
0x00b8 00184 (args/pointer_receiver.go:132) MOVQ    ""..o+48(SP), DX
0x00bd 00189 (args/pointer_receiver.go:132) PCDATA  $0, $0
0x00bd 00189 (args/pointer_receiver.go:132) MOVQ    DX, (SP)
0x00c1 00193 (args/pointer_receiver.go:132) CALL    CX
0x00c3 00195 (args/pointer_receiver.go:132) MOVQ    ""..autotmp_12+16(SP), AX
0x00c8 00200 (args/pointer_receiver.go:132) XORPS   X0, X0
0x00cb 00203 (args/pointer_receiver.go:132) CVTSQ2SD    AX, X0
0x00d0 00208 (args/pointer_receiver.go:132) DIVSD   8(SP), X0
0x00d6 00214 (args/pointer_receiver.go:132) MOVSD   X0, ""..~r1+56(SP)
0x00dc 00220 (args/pointer_receiver.go:132) PCDATA  $1, $2
0x00dc 00220 (args/pointer_receiver.go:132) XORPS   X0, X0
0x00df 00223 (args/pointer_receiver.go:132) MOVUPS  X0, ""..~r2+64(SP)
0x00e4 00228 (args/pointer_receiver.go:132) MOVQ    24(SP), BP
0x00e9 00233 (args/pointer_receiver.go:132) ADDQ    $32, SP
0x00ed 00237 (args/pointer_receiver.go:132) RET
0x00ee 00238 (args/pointer_receiver.go:132) NOP
0x00ee 00238 (args/pointer_receiver.go:128) PCDATA  $1, $-1
0x00ee 00238 (args/pointer_receiver.go:128) PCDATA  $0, $-1
0x00ee 00238 (args/pointer_receiver.go:128) CALL    runtime.morestack_noctxt(SB)
0x00f3 00243 (args/pointer_receiver.go:128) JMP 0
```

value

```
($GOROOT/src/errors/errors.go:59)   PCDATA  $0, $1
($GOROOT/src/errors/errors.go:59)   MOVQ    CX, (AX)
(args/pointer_receiver.go:93)   XORPS   X0, X0
(args/pointer_receiver.go:93)   MOVSD   X0, ""..~r1+48(SP)
(args/pointer_receiver.go:93)   PCDATA  $0, $2
(args/pointer_receiver.go:93)   PCDATA  $1, $1
(args/pointer_receiver.go:93)   LEAQ    go.itab.*errors.errorString,error(SB), CX
(args/pointer_receiver.go:93)   PCDATA  $0, $1
(args/pointer_receiver.go:93)   MOVQ    CX, ""..~r2+56(SP)
(args/pointer_receiver.go:93)   PCDATA  $0, $0
(args/pointer_receiver.go:93)   MOVQ    AX, ""..~r2+64(SP)
(args/pointer_receiver.go:93)   MOVQ    16(SP), BP
(args/pointer_receiver.go:93)   ADDQ    $24, SP
(args/pointer_receiver.go:93)   RET
(args/pointer_receiver.go:95)   PCDATA  $1, $0
(args/pointer_receiver.go:95)   MOVQ    ""..o+32(SP), AX
(args/pointer_receiver.go:95)   XORPS   X1, X1
(args/pointer_receiver.go:95)   CVTSQ2SD    AX, X1
(args/pointer_receiver.go:95)   DIVSD   X0, X1
(args/pointer_receiver.go:95)   MOVSD   X1, ""..~r1+48(SP)
(args/pointer_receiver.go:95)   PCDATA  $1, $1
(args/pointer_receiver.go:95)   XORPS   X0, X0
(args/pointer_receiver.go:95)   MOVUPS  X0, ""..~r2+56(SP)
(args/pointer_receiver.go:95)   MOVQ    16(SP), BP
(args/pointer_receiver.go:95)   ADDQ    $24, SP
(args/pointer_receiver.go:95)   RET
(args/pointer_receiver.go:95)   NOP
(args/pointer_receiver.go:91)   PCDATA  $1, $-1
(args/pointer_receiver.go:91)   PCDATA  $0, $-1
(args/pointer_receiver.go:91)   CALL    runtime.morestack_noctxt(SB)
(args/pointer_receiver.go:91)   JMP 0
```

- ***Interfaces*** also must do more work at runtime while their methods are being invoked. This seems to be the main differentiator.

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Escape Analysis

go test pointer_vs_value/code/* -gcflags "-m -m" -run none -benchmem -memprofile mem.out &> escape.out

- ***Pointers*** do not escape to the heap in this implementation
- ***Interfaces*** always do ...

```
// value
func calcTera(o tera) (float64, error) {                    // calcTera o does not escape
  return float64(o.a) / o.aa, nil
}

// interface
func calcIfc(o obj) (float64, error) {                      // leaking param: o
  return float64(o.GetI()) / o.GetF(), nil
}

// pointer
func calcTeraP(o *teraObject) (float64, error) {            // calcTeraP o does not escape
  return float64(o.a) / o.aa, nil
}
```

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Garbage Collection

… measuring with un-certainty

```
func trackGC(caller string) {

  runtime.GC()

  stats := debug.GCStats{}
  debug.ReadGCStats(&stats)

  println(fmt.Sprintf("\n%s , %v , %v , %v , %v\n",
                      caller,
                      stats.NumGC,
                      sum(stats.Pause),
                      stats.PauseQuantiles,
                      stats.PauseTotal))
   //debug.FreeOSMemory() // consider cleaning up for the upcoming test
}

func sum (durations []time.Duration) int64 {
  var f int64 = 0
  for _ , d := range durations {
     f += d.Microseconds()
  }
  return f
}
```

```
const timeout = 100 * time.Second

func runRoutine(exec func(o tera),name string) {
  ch := make(chan tera, 1)
  ctx, cnl := context.WithCancel(context.Background())

  go func() {
     <-time.After(timeout)
     cnl()
  }()

  go func() {
     start := time.Now()
     for {
        select {
        case <-ctx.Done():
           duration := time.Now().Sub(start).Milliseconds()
           fmt.Println(fmt.Printf("Time passed [%v]", duration))
           close(ch)
           return
        default:
           ch <- createTeraObject()
        }
     }
  }()

  i := 0
  for o := range ch {
     exec(o)
     i++
  }

  println(fmt.Sprintf("invocations = %v", i))
  trackGC(name)
}
```

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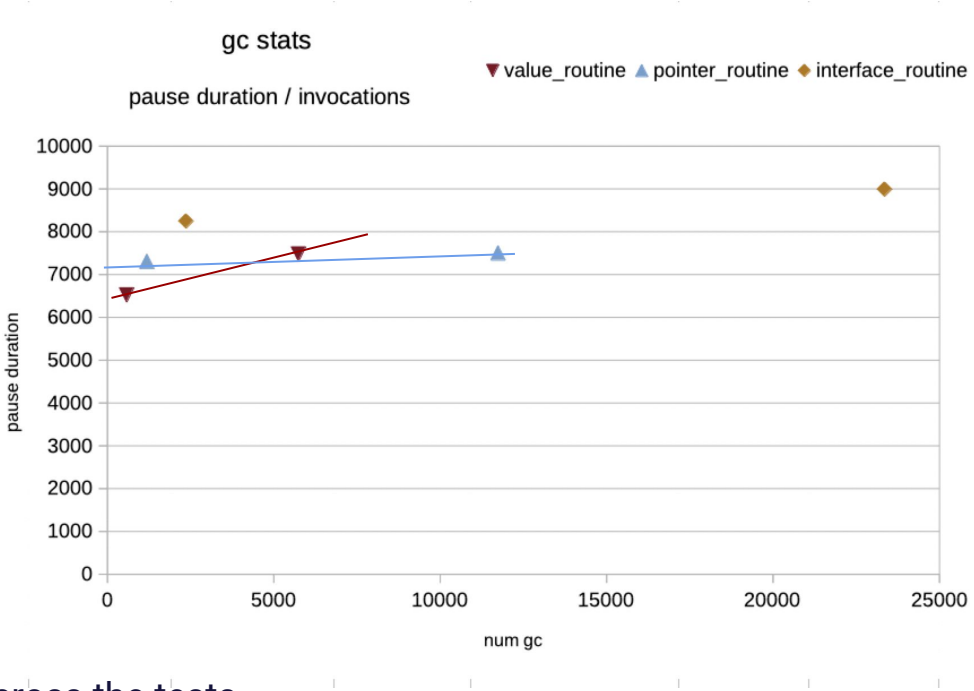
Test duration (sec)	method	time passed	invocations	num GC	pause duration (ms)
10	value	10001	2723703	580	6522
100	value	100001	26778210	5742	7476
10	pointer	10001	2835459	1188	7308
100	pointer	100000	27850534	11740	7503
10	interface	10000	2604248	2362	8249
100	interface	100000	25550879	23350	8994



- Invocation count and duration are consistent across the tests
- Value receivers seem to degrade in performance faster (slope)
- Although invocations of gc rise fast, total pause duration stays under control
- Need a broader result set

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So… who won?

… It's all about the implementation

Design

Interfaces provide abstraction (no tight coupling)
But harm performance …
NOTE : With large amount of data and longer running processes, this penalty is amortised well enough.

Escape analysis

Not all pointers escape to the heap.
It depends on invocation details and object sizes.
(Even value receivers can escape to the heap)
see https://golang.org/doc/faq#stack_or_heap

Performance

Pointers seem to behave optimally regarding performance.
Due to modern cpu optimizations (pre-fetch etc...).
see https://github.com/teh-cmc/go-internals/tree/master/chapter2_interfaces#overhead

Assembly correlation

There are some expected differences.
But in the end, it all boils down to the cpu intrinsics.
see https://segment.com/blog/allocation-efficiency-in-high-performance-go-services/

Garbage collection

The garbage collector is "far too sophisticated" to care
… in the end.
see https://blog.golang.org/ismmkeynote

Additional Considerations

skipped points ...

- Avoid compiler optimisations

  `gcflags "-n"`

  => No considerable difference
- Avoid compiler inlining

  `gcflags "-l"`

  => No considerable difference

  (mostly regarding the error handling code)
- Track gc on benchmarks

  => Inconclusive results

Where next?

Further investigation ...

- Simplify benchmark code by using arrays
  (Thanks to Erik for the tip 😉)
- Investigate with different method bodies
  (See Appendix A)
- Investigate breaking conditions i.e. OOM boundary
  (TBD in Appendix B)
- Compare detailed escape analysis output
  `gcflags "-m -m -m -m"`
- Run benchmarks on different cpus
- Investigate the same for method return elements

References & Further Readings

[The code]

- https://github.com/drakos74/go-bench/tree/master/pointer_vs_value

Benchmarks

- https://dave.cheney.net/2013/06/30/how-to-write-benchmarks-in-go
- https://stackimpact.com/blog/practical-golang-benchmarks/

Go assembly

- https://www.tutorialdocs.com/article/go-assembly-code.html
- https://github.com/teh-cmc/go-internals/blob/master/chapter1_assembly_primer/README.md
- https://class.ece.uw.edu/469/hauck/lectures/02_Assembly.pdf

Escape Analysis & Memory Allocation 👍🏾

- http://www.agardner.me/golang/garbage/collection/gc/escape/analysis/2015/10/18/go-escape-analysis.html
- https://www.ardanlabs.com/blog/2017/05/language-mechanics-on-escape-analysis.html
- https://segment.com/blog/allocation-efficiency-in-high-performance-go-services/
- https://blog.learngoprogramming.com/a-visual-guide-to-golang-memory-allocator-from-ground-up-e132258453ed

Garbage collector

- https://dave.cheney.net/high-performance-go-workshop/dotgo-paris.html
- https://medium.com/@vCabbage/go-are-pointers-a-performance-optimization-a95840d3ef85

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Appendix A

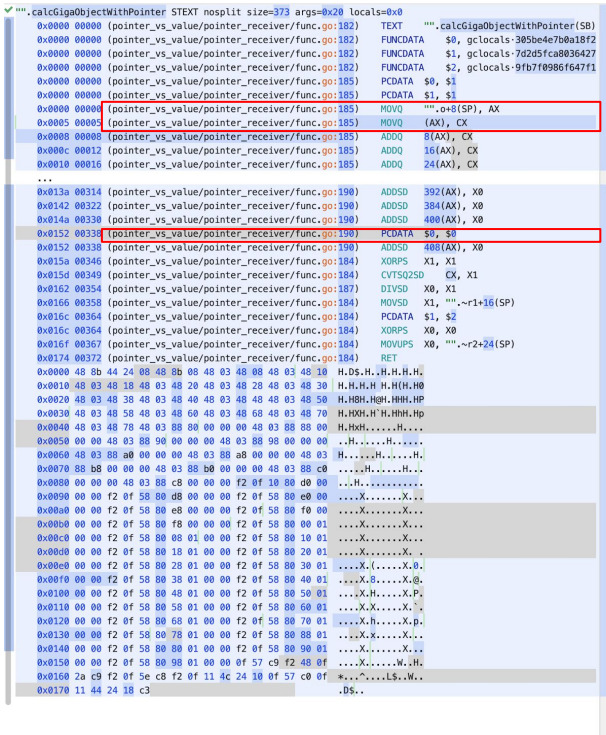
Extend implementation to access more object properties

```
// access ALL object properties

func calcGiga(o giga) (float64, error) {
  return float64(
     o.a+o.b+o.c+o.d+o.e+o.f+o.g+o.h+o.i+
       o.j+o.k+o.l+o.m+o.n+o.o+o.p+o.q+
       o.r+o.s+o.t+o.u+o.v+o.y+o.x+o.w+o.z) /
     (o.aa+o.bb+o.cc+o.dd+o.ee+o.ff+o.gg+o.hh+
      o.ii+o.jj+o.kk+o.ll+o.mm+o.nn+o.oo+o.pp+o.qq+
      o.rr+o.ss+o.tt+o.uu+o.vv+o.yy+o.xx+o.ww+o.zz),
nil
}

func calcGigaP(o *giga) (float64, error) {
  // we skip error checking here for simplicity
  return float64(
     o.a+o.b+o.c+o.d+o.e+o.f+o.g+o.h+o.i+
       o.j+o.k+o.l+o.m+o.n+o.o+o.p+o.q+
       o.r+o.s+o.t+o.u+o.v+o.y+o.x+o.w+o.z) /
     (o.aa+o.bb+o.cc+o.dd+o.ee+o.ff+o.gg+o.hh+o.ii+
       o.jj+o.kk+o.ll+o.mm+o.nn+o.oo+o.pp+o.qq+
      o.rr+o.ss+o.tt+o.uu+o.vv+o.yy+o.xx+o.ww+o.zz),
nil
}
```

*pointer



value

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Extended Results

What does it mean?

- Difference in performance becomes much more balanced.
- Value implementation beats interfaces.

Extra Tip!

- If you won't access many of your object's properties consider seriously using pointers or interfaces!

```
goos: darwin
goarch: amd64
pkg: go-bench/pointer_vs_value/pointer_receiver
BenchmarkTera_Calc-16          77776372          14.8 ns/op
BenchmarkTeraP_Calc-16        678546289          1.74 ns/op
BenchmarkTeraIfc_Calc-16      166455222          7.14 ns/op
PASS
```



```
goos: darwin
goarch: amd64
pkg: go-bench/pointer_vs_value/pointer_receiver
BenchmarkGiga_Calc-16          46147950          29.9 ns/op
BenchmarkGigaP_Calc-16         57532897          19.2 ns/op
BenchmarkGigaIfc_Calc-16       10571948          98.9 ns/op
PASS
```

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THANK YOU!

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