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Gno: Lessons in Building a Go Interpreter in Go

Background

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Tendermint 2014

- first non-PoW BFT consensus algo & impl

Cosmos 2017,

- first complete solution to “proof of stake”
- first blockchain-to-blockchain communication protocol IBC
- CosmosSDK, most popular Go framework for blockchain dev

What is Gno

Gno is a <u>deterministic</u> Go interpreter*
<u>transactional</u>
<u>persistent</u>
<u>magical</u>

* goroutines and generics planned

Why Gno?

The Gno VM enables seamless interoperability of untrusted user programs written in the Go language.

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Seamless Interoperability

```go
package alice

var x int

func GetX() int {
	return x
}

func SetX(n int) {
	x = n
}
```

```go
package bob

import "alice"

func IncrAlice() {
	x := alice.GetX()
	alice.SetX(x+1)
}
```

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Seamless Interoperability

```go
package carl

import "bob"

func RelayToBob(msg string) {
	bob.SendMessage(msg, func() {
		println("success!")
	})
}
```

State of Smart Contract Langs

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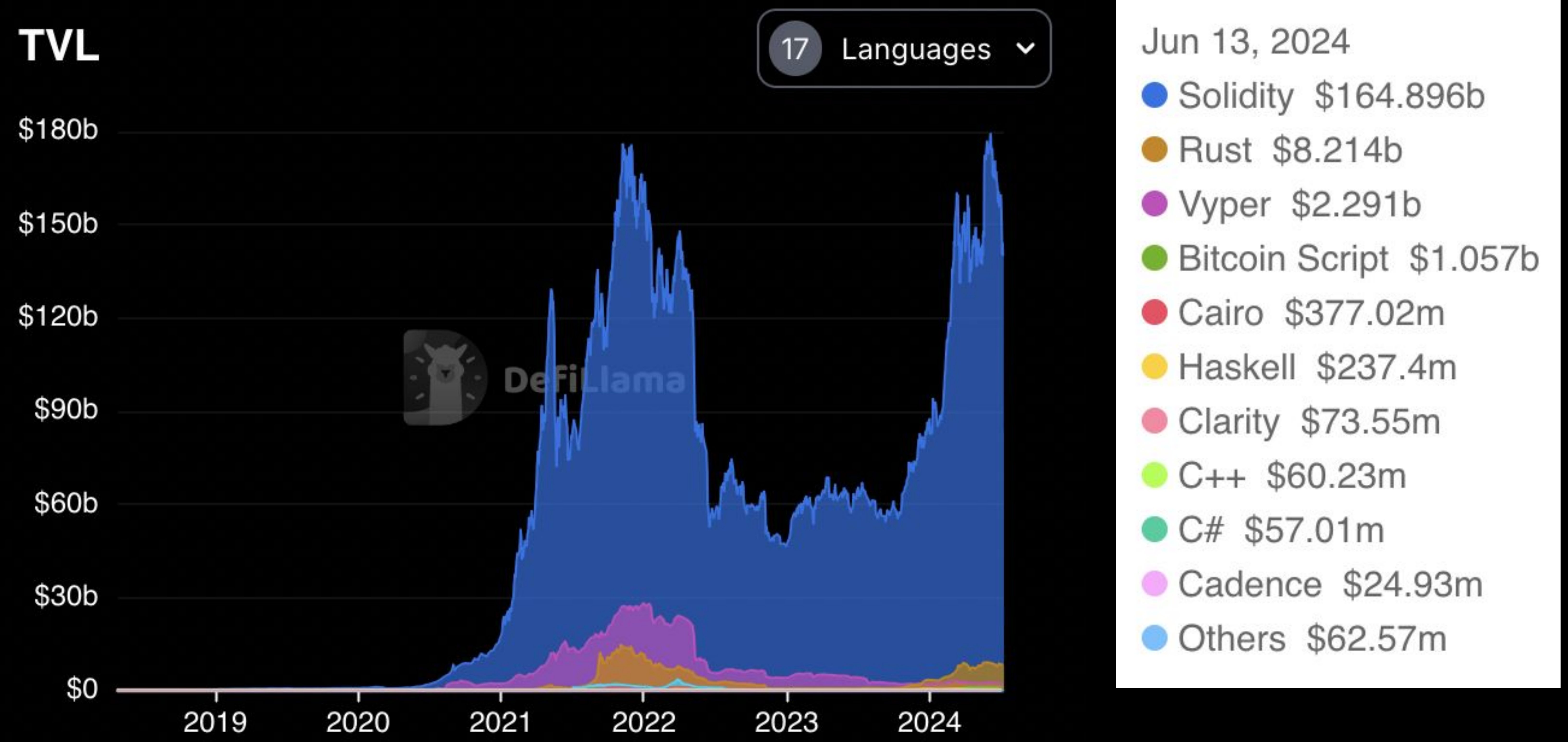

EVM/Solidity?

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* EVM limitations
* Solidity limitations
* No garbage collector
* Max 16 variables per function
* No closures
* No self-referential structs
* ...

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Near/WASM/Rust?

CROSS-CONTRACT CALLS ARE INDEPENDENT

You will need two independent functions: one to make the call, and another to receive the result

CROSS-CONTRACT CALLS ARE ASYNCHRONOUS

There is a delay between the call and the callback execution, usually of **1 or 2 blocks**. During this time, the contract is still active and can receive other calls.

Near/WASM/Rust?

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```
#[ext_contract(external_trait)]
trait Contract {
    fn function_name(&self, param1: T, param2: T) -> T;
}

external_trait::ext("external_address")
.with_attached_deposit(DEPOSIT)
.with_static_gas(GAS)
.function_name(arguments)
.then(
  // this is the callback
  Self::ext(env::current_account_id())
  .with_attached_deposit(DEPOSIT)
  .with_static_gas(GAS)
  .callback_name(arguments)
);
```

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Near/WASM/JS?

```
NearPromise.new("external_address").functionCall("function_name", JSON.stringify(arguments), DEPOSIT, GAS)
.then(
  // this function is the callback
  NearPromise.new(near.currentAccountId()).functionCall("callback_name", JSON.stringify(arguments), DEPOSIT,
);
```

Solana/WASM/Rust?

CPI call depth - `CallDepth` error

Cross-program invocations allow programs to invoke other programs directly, but the depth is constrained currently to `4`.

When a program exceeds the allowed cross-program invocation call depth, it will receive a `CallDepth` error

WASM/Go?

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knqyf263/go-plugin

* Choose the interface(s) you want to expose for plugins.
  - Define Messages and Services in a proto file.
* Generate SDK for a host and plugin by go-plugin.
* Implement the Go interface defined in the plugin SDK.
* Compile your plugin to Wasm.
* Load the plugin and call the defined methods.

Why not WASM?

Solved: loading/unloading modules.

Solved: memory limitations

Solved: determinism (sort of)

Solved: CPU limitations

Unsolved: complex frameworks

Unsolved: relies on actor model (message passing)

Gno VM

* Language-level interoperability

* Fine-grained memory/cpu/storage limitations

* Automatic persistence

* Determinism for replicability

* Simple, < 30k lines of code

* Interprets the Go language

Gno VM - Stack-based AST VM

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```go
type Machine struct {

	// State
	Ops        []Op          // operations stack
	Values     []TypedValue  // buffer of values to be operated on
	Exprs      []Expr        // pending expressions
	Stmts      []Stmt        // pending statements
	Blocks     []*Block      // block (scope) stack
	Frames     []*Frame      // func call stack
	Package    *PackageValue // active package
	Realm      *Realm        // active realm
	Alloc      *Allocator    // memory allocations
	Exceptions []Exception   // exceptions stack
	NumResults int           // number of results returned
	Cycles     int64         // number of "cpu" cycles performed

	// Configuration
	...
}
```

Gno VM - Op codes

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```
/* Control operators */
OpHalt                Op = 0x01 // halt (e.g. last statement)
OpNoop                Op = 0x02 // no-op
OpExec                Op = 0x03 // exec next statement
OpPrecall             Op = 0x04 // sets X (func) to frame
OpCall                Op = 0x05 // call(Frame.Func, [...])
OpReturn              Op = 0x07 // return ...
...

/* Unary & binary operators */
OpUpos   Op = 0x20 // + (unary)
OpLor    Op = 0x26 // ||
OpLand   Op = 0x27 // &&
OpEql    Op = 0x28 // ==
...

/* Other expression operators */
OpEval          Op = 0x40 // eval next expression
OpBinary1       Op = 0x41 // X op ?
OpIndex1        Op = 0x42 // X[Y]
OpIndex2        Op = 0x43 // (_, ok :=) X[Y]
OpSelector      Op = 0x44 // X.Y
OpSlice         Op = 0x45 // X[Low:High:Max]
...
```

```
/* Type operators */
OpFieldType       Op = 0x70 // Name: X `tag`
OpArrayType       Op = 0x71 // [X]Y{}
OpSliceType       Op = 0x72 // []X{}
OpPointerType     Op = 0x73 // *X
...

/* Statement operators */
OpAssign       Op = 0x80 // Lhs = Rhs
OpAddAssign    Op = 0x81 // Lhs += Rhs
OpDefine       Op = 0x8C // X... := Y...
OpInc          Op = 0x8D // X++
...

/* Decl operators */
OpValueDecl Op = 0x90 // var/const ...
OpTypeDecl  Op = 0x91 // type ...

/* Loop (sticky) operators (>= 0xD0) */
OpSticky            Op = 0xD0 // not a real op.
OpBody              Op = 0xD1 // if/block/switch/select.
OpForLoop           Op = 0xD2
OpRangeIter         Op = 0xD3
...
```

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Gno VM - Persistence

There are two types of packages

* Pure packages - immutable, stateless
* Realm packages - mutable, stateful

Any changes to Realm packages are persisted

(at the end of a transaction boundary)

Gno VM - Persistence

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```go
// gno.land/r/alice/arealm
package arealm

var x int

func GetX() int {
	return x
}

func SetX(n int) {
	x = n
}
```

```go
// gno.land/r/bob/brealm
package brealm

import "gno.land/r/alice/arealm"

func IncrAlice() {
	x := arealm.GetX()
	arealm.SetX(x+1)
}
```

Gno VM - Persistence

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A transaction is just function call (that crosses realm boundaries).

```
Frame3: Pkg   = gno.land/p/avl,           Func = Set
Frame2: Realm = gno.land/r/alice/alream, Func = SetItem
Frame2: Realm = gno.land/r/alice/alream, Func = SetX        v__ realm boundary
Frame1: Realm = gno.land/r/bob/brealm,   Func = IncrAlice   ^
```

Lessons learned

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Interpreter VMs need memory management for performance.

* e.g. each for/if/range/select/switch/call creates a *Block
* `go tool pprof`
* `go tool pprof --alloc_space --alloc_counts`
* `go tool compile -S`
* pool.Get()/pool.Put()

Lessons learned

Primitive types as interface values allocate pointers.

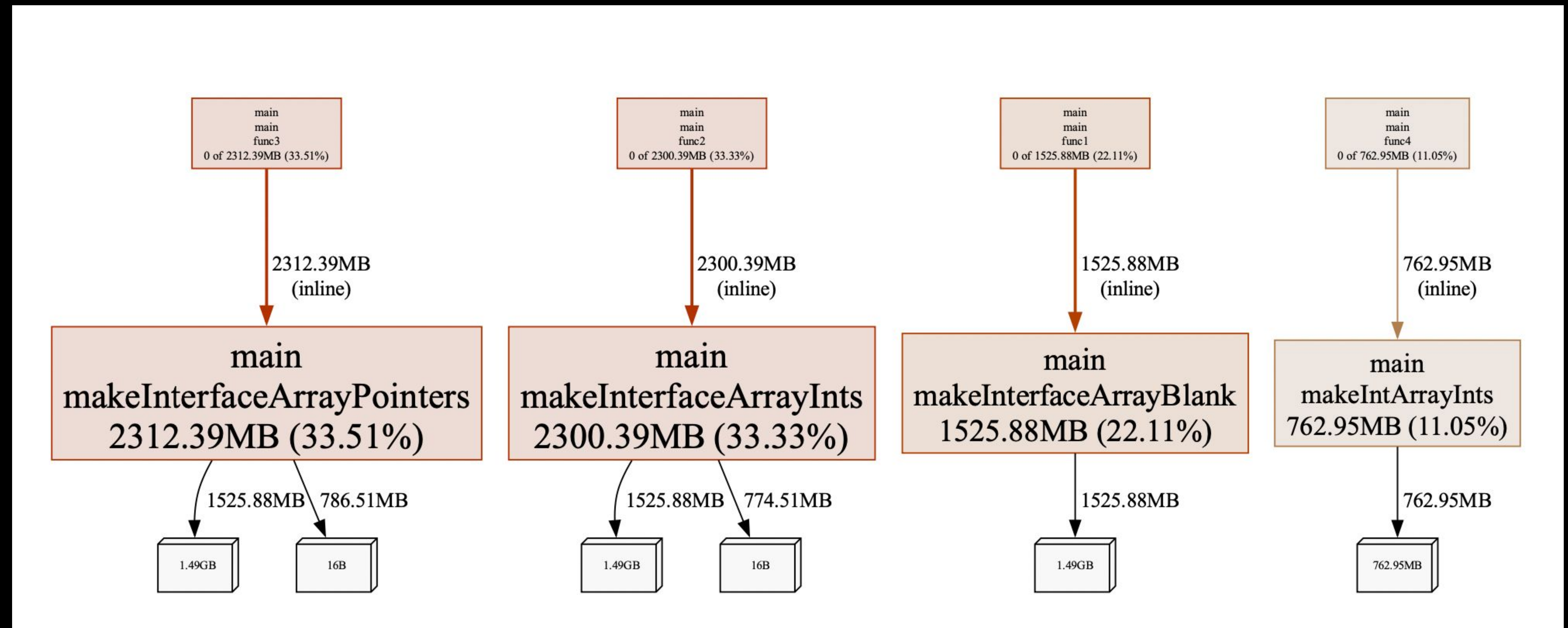
Lessons learned

```go
func makeInterfaceArrayBlank(N int) {
	x := make([]interface{}, N)
}

func makeInterfaceArrayInts(N int) {
	x := make([]interface{}, N)
	for i := 0; i < N; i++ {
		x[i] = i
	}
}

func makeInterfaceArrayPointers(N int) {
	x := make([]interface{}, N)
	for i := 0; i < N; i++ {
		p := &i
		x[i] = p
	}
}

func makeIntArrayInts(N int) {
	x := make([]int, N)
	for i := 0; i < N; i++ {
		x[i] = i
	}
}
```



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Lessons learned

```go
type TypedValue struct {
	T Type    `json:",omitempty"` // never nil
	V Value   `json:",omitempty"` // an untyped value
	N [8]byte `json:",omitempty"` // numeric bytes
}
```

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Lessons learned

Avoid switching on interface values.

```go
type PointerType struct {...}
type ArrayType struct {...}
type SliceType struct {...}
type StructType struct {...}
type FuncType struct {...}
type MapType struct {...}
type InterfaceType struct {...}
type TypeType struct {...}
type DeclaredType struct {...}
type PrimitiveType int
```

```go
const (
	InvalidType PrimitiveType = 1 << iota
	UntypedBoolType
	BoolType
	UntypedStringType
	StringType
	IntType
	Int8Type
	Int16Type
	UntypedRuneType
	Int32Type
	Int64Type
	UintType
	Uint8Type
	DataByteType
```

Lessons learned

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```go
var lv, rv TypedValue
...
switch baseOf(lv.T) {
case StringType, UntypedStringType:
        lv.V = alloc.NewString(lv.GetString() + rv.GetString())
case IntType:
        lv.SetInt(lv.GetInt() + rv.GetInt())
case Int8Type:
        lv.SetInt8(lv.GetInt8() + rv.GetInt8())
case Int16Type:
        lv.SetInt16(lv.GetInt16() + rv.GetInt16())
case Int32Type, UntypedRuneType:
        lv.SetInt32(lv.GetInt32() + rv.GetInt32())
case Int64Type:
        lv.SetInt64(lv.GetInt64() + rv.GetInt64())
case UintType:
```

Lessons learned

Scope != Allocation

```
var ptrs []*int
for {
        i := 0
        ptrs = append(ptrs, &i)
}
```

Lessons learned

Scope != Allocation

```
	var ptrs []*int
LABEL1:
	i := 0
LABEL2:
	i += 1
	ptrs = append(ptrs, &i)

	// goto LABEL1, then LABEL2, then break
	switch len(ptrs) {
	case 1:
		goto LABEL1
	case 2:
		goto LABEL2
	}

	// print pointers
	for _, ptr := range ptrs {
		println(ptr, *ptr)
	}
```

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Lessons learned

Go reflection is limited

* cannot create named types
→ cannot make recursive types
* cannot create interfaces

→ limited/hacky "go-native" support, will be removed.

Future Work

Upgrading (runtime) logic will be a challenge.

Bugs happen. What then?

Future Work

* Replacing a function or method w/ same signature is OK.
  → like iOS "swizzle".
* Appending fields to a struct:
  → will break old logic w/ use of reflection.
  → will break old logic w/ use of .(type) checks.
* Appending methods is almost OK,
  → but will break old logic w/ use of .(type) checks.
* User-land upgrade patterns preferred.

Future Work

intra-transaction GC

* piggy back on Go's runtime GC (today)
* but Go’s GC doesn’t make free memory available (yet)

→ increment memory counter for every value allocation

→ when memory limit is reached, count everything reachable

Future Work

global persistent GC

* after a transaction, all reachable objects are saved to disk.
* cycles will lead to persistent-memory-leaks.
* PLAN 0: don't create post-transaction cycles.
* PLAN 1: implement a GC for persistent objects.
* PLAN 2: extend the language with ownership rules.

Gno.land is...

* a distributed multi-user language-based operating system.
* the Go lover's answer to Ethereum.
* a repository of open auditable Gno code.

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/r/gnoland/home

[source] [help]

Welcome to gno.land

We’re building gno.land, the first open-source smart contract system, using Gno, an interpreted and fully deterministic variation of the Go programming language for succinct and composable smart contracts.

Thank you!

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Website

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Gno Docs

docs.gno.land

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We’re hiring!

@jaekwon