# Go, tasks and dataflow from Athena

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# Introduction

- Moore's law ceased to provide the traditional single-threaded performance increases
  - clock-frequency wall of 2003
  - still deliver increases in transistor density
- multicore systems become the norm
- need to "go parallel" to get scalability

# In a C++ world...

- parallel programming in C++ is doable:
  - C/C++ "locking + threads" (`pthreads`, `WinThreads`)
    - ★ excellent performance
    - ★ good generality
    - ★ relatively low productivity
  - multi-threaded applications...
    - ★ hard to get right
    - ★ hard to keep right
    - ★ hard to keep efficient and optimized across releases
  - multi-process applications...
    - ★ à la `AthenaMP/GaudiMP`
    - ★ leverage `fork+COW` on `GNU/Linux`
    - ★ event-level based parallelism

Parallel programming in C++ is doable,
but *no panacea*

# In a C++ world...

- in C++03, we have libraries to help with parallel programming
  - `boost::lambda`
  - `boost::MPL`
  - `boost::thread`
  - Threading/Array Building Blocks (TBB/ArBB)
  - Concurrent Collections (CnC)
  - `OpenMP`
  - ...

# In a C++11 world...

- in C++11, we get:
  - $\lambda$ functions (and a new syntax to define them)
  - `std::thread`,
  - `std::future`,
  - `std::promise`

Helps taming the beast
... at the price of sprinkling templates everywhere...
... and complicating further a not so simple language...

# In a C++11 world...

yay! for C++11, but old problems are still there...

- build scalability
  - templates
  - headers system
  - still no module system (WG21 - N2073)
    - ★ maybe in the next Technical Report ?
- code distribution
  - no CPAN like readily available infrastructure (and cross-platform) for C++
  - remember ROOT/BOOT ? (CHEP-06)

# Time for a new language ?

*"Successful new languages build on existing languages and where possible, support legacy software. C++ grew our of C. java grew out of C++. To the programmer, they are all one continuous family of C languages." (T. Mattson)*

- notable exception (which confirms the rule): python

Can we have a language:

- as easy as python,
- as fast (or nearly as fast) as `C/C++/FORTRAN`,
- with none of the deficiencies of `C++`,
- and is multicore/manycore friendly ?

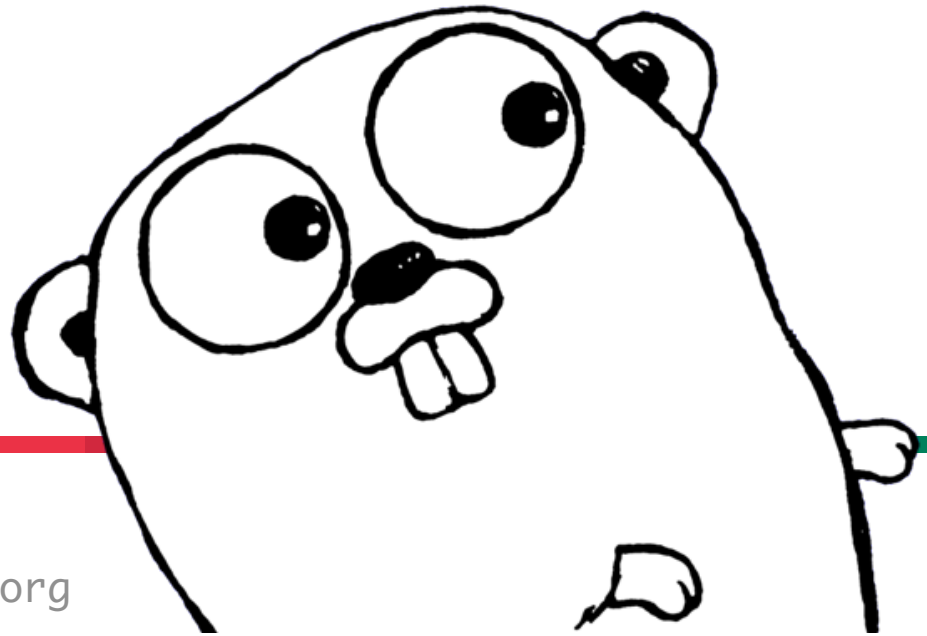
Why not Go ?

golang.org

# Elements of go

- obligatory `hello world` example...

```
package main
import "fmt"
func main() {
    fmt.Println("Hello, World")
}
```



http://golang.org

Google

# Elements of go - II

- founding fathers:
  - Russ Cox, Robert Griesemer, Ian Lance Taylor
  - Rob Pike, Ken Thompson
- concurrent, compiled
- garbage collected
- an open-source general programming language
- best of both 'worlds':
  - feel of a dynamic language
    - ⋆ limited verbosity thanks to **type inference system**, map, slices
  - safety of a static type system
  - compiled down to machine language (so it is fast)
    - ⋆ goal is within 10% of C
- object-oriented (but w/o classes), builtin reflection
- first-class functions with closures
- duck-typing à la `python`

# Elements of go - III

2 open source compilers:

- gc, modeled after the C compiler infrastructure from Plan9
  - fast compilation
  - more naive optimizations
- gccgo, front-end to GCC
  - reasonnably fast compilation
  - good optimizations
  - not as good as gc for concurrency (goroutines multiplexing)

Supported architectures:

- linux 32/64
- darwin 32/64
- ARM
- win 32 (win 64 on the way)
- FreeBSD, OpenBSD, Plan9, Solaris: WIP

# Go concurrent

## goroutines

- a function executing concurrently as other goroutines in the same address space
- starting a goroutine is done with the go keyword
  - `go myfct(arg1, arg2)`
- growable stack
  - lightweight threads
  - starts with a few kB, grows (and shrinks) as needed
    - ⋆ now, also available in GCC 4.6 (thanks to the GCC-Go front-end)
  - no stack overflow
- goroutines can be multiplexed onto multiple real OS threads
  - only available (for now) with the gc compiler
  - gccgo should get this feature pretty soon (TM)

# Go concurrent - II

## channels

- provide (type safe) communication and synchronization

```
// create a channel of mytype
my_chan := make(chan mytype)
my_chan <- some_data     // sending data
some_data = <- my_chan   // receiving data
```

- send and receive are atomic

*"Do not communicate by sharing memory; instead, share memory by communicating"*

# Go concurrent with ng-go-gaudi

- very minimal implementation of Gaudi in Go:
  - appmgr
  - evtproc
  - datastoresvc
  - algorithm, messages, tools, services, properties
  - simple JSON output stream
  - simple go bytestream (gob) output stream
  - simple test algorithms (adder, counter, ...)

# Go concurrent - III

```
package evtproc
import "gaudi/kernel"

// --- evt state ---
type evtstate struct {
        idx  int
        sc   kernel.Error
        data kernel.DataStore
}

// --- evt processor ---
type evtproc struct {
        kernel.Service
        algs []kernel.IAlgorithm
        nworkers int
}

func (self *evtproc)
NextEvent(evtmax int) kernel.Error {

        if self.nworkers > 1 {
                return self.mp_NextEvent(evtmax)
        }
        return self.seq_NextEvent(evtmax)
}
```

# Go concurrent - IV

```
import "gaudi/kernel"

func (self *evtproc) mp_NextEvent(evtmax int) kernel.Error {
        // ... setup event server ...
        in_queue, out_queue, quit := start_evt_server(self.nworkers)
        for i := 0; i < evtmax; i++ {
                in_queue <- new_evtstate(i)
        }

        for evt := range out_queue {
                if !evt.sc.IsSuccess() {
                        n_fails++
                }
                n_processed++
                if n_processed == evtmax {
                        quit <- true
                        close(out_queue)
                        break
                }
        }
        if n_fails != 0 {
                return kernel.StatusCode(1)
        }
```

# Go concurrent - V

```
func (self *evtproc) mp_NextEvent(evtmax int) kernel.Error {

        start_evt_server := func(nworkers int) (in_evt_queue,
                                                out_evt_queue chan *evtstate,
                                               quit chan bool) {
                in_evt_queue = make(chan *evtstate, nworkers)
                out_evt_queue = make(chan *evtstate)
                quit = make(chan bool)
                go serve_evts(in_evt_queue, out_evt_queue, quit)
                return in_evt_queue, out_evt_queue, quit
        }

        // ...
        return kernel.StatusCode(0)
}
```

# Go concurrent - VI

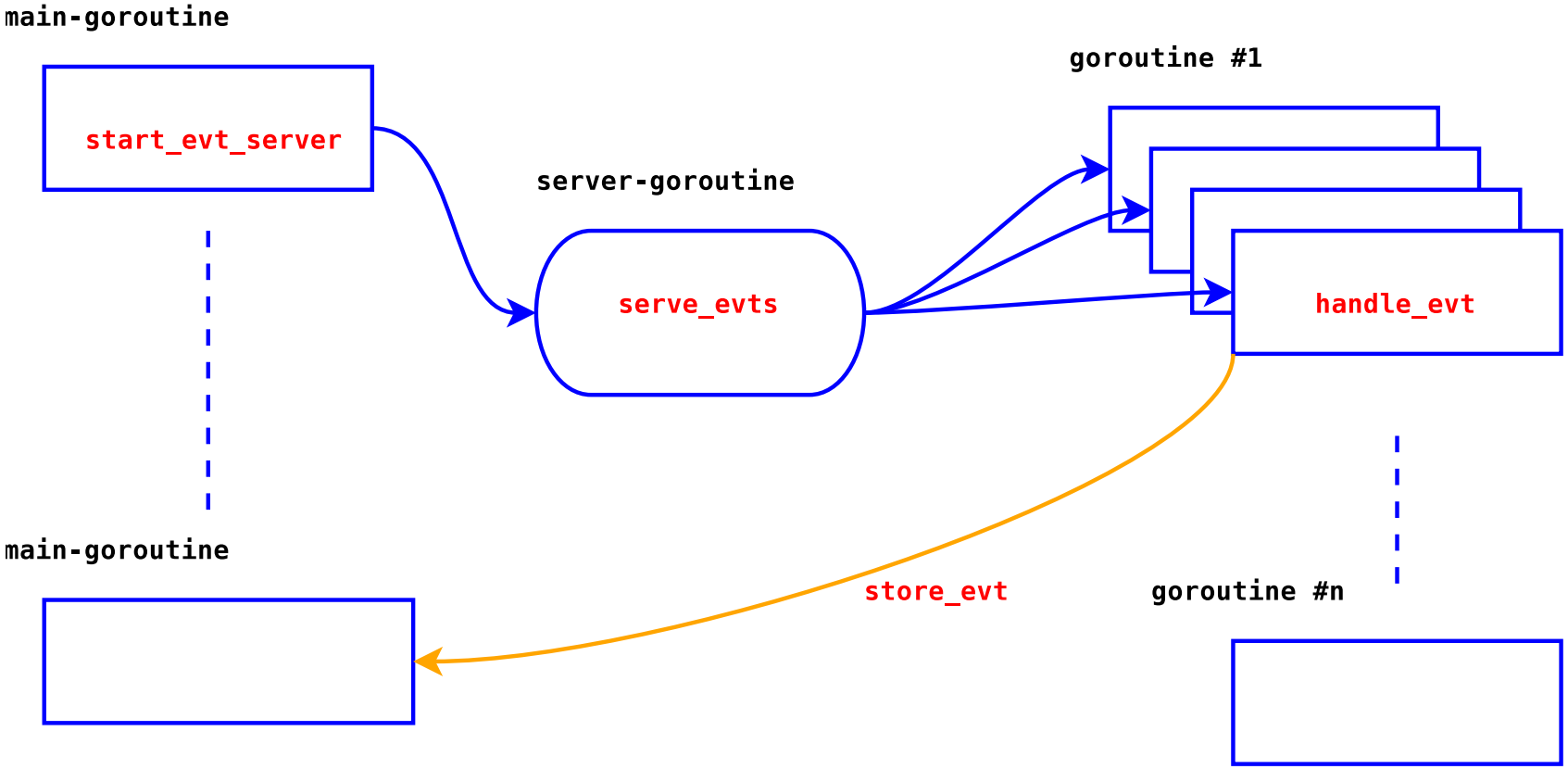
```
func (self *evtproc) mp_NextEvent(evtmax int) kernel.Error {

        handle := func(evt *evtstate, out_queue chan *evtstate) {
                self.MsgInfo("nextEvent[%v]...\n", evt.idx)
                evt.sc = self.ExecuteEvent(evt)
                out_queue <- evt
        }

        serve_evts := func(in_evt_queue, out_evt_queue chan *evtstate,
                           quit chan bool) {
                for {
                        select {
                        case ievt := <-in_evt_queue:
                                go handle(ievt, out_evt_queue)
                        case <-quit:
                                return
                        }
                }
        }

        // ...
        return kernel.StatusCode(0)
}
```

# Go concurrent - VII



# ng-go-gaudi - concurrent event loop

- a concurrent event loop in a few lines
- same pattern than in AthenaMP
  - but with goroutines rather than multiple forked processes
  - also modified slightly the main Algorithm API to make the event context explicit:

```
package kernel

type IAlgorithm interface {
        Initialize() Error
        Execute(ctx IEvtCtx) Error
        Finalize() Error
}
```

```
package testalg

import "gaudi/kernel"

type myalg struct {
  kernel.Algorithm
}

func (self *myalg)
Execute(ctx kernel.IEvtCtx) kernel.Error {
    store := self.EvtStore(ctx)
    store.Put("foo", 42)
    return kernel.StatusCode(0)
}
```

# Handling I/O

- implement an asynchronous output stream service
  - `JSON` backend (easier for validation)
  - `Gob` backend (binary `Go` specific data format)
- commit of data is performed by a dedicated `goroutine`
- data is transfered from the 'worker' `goroutine` to the I/O `goroutine` via channels

# Handling I/O - interfaces

```
package kernel

/// handle to a concurrent output stream
type IOutputStream interface {
        /// writes (and possibly commit) data to the stream
        Write(data interface{}) Error
        /// closes and flushes the output stream
        Close() Error
        /// returns the name of the output stream (ie: URI)
        Name() string
        /// returns the file-descriptor associated to that output stream
        Fd() int
}

/// interface to a concurrent output stream server
type IOutputStreamSvc interface {
        /// returns a new output stream
        NewOutputStream(stream_name string) IOutputStream
}
```

# A simple jobo.py example

- create 500 adder algorithms, 500 dumper algorithms
- process 10000 events, spawn off 5000 concurrent workers

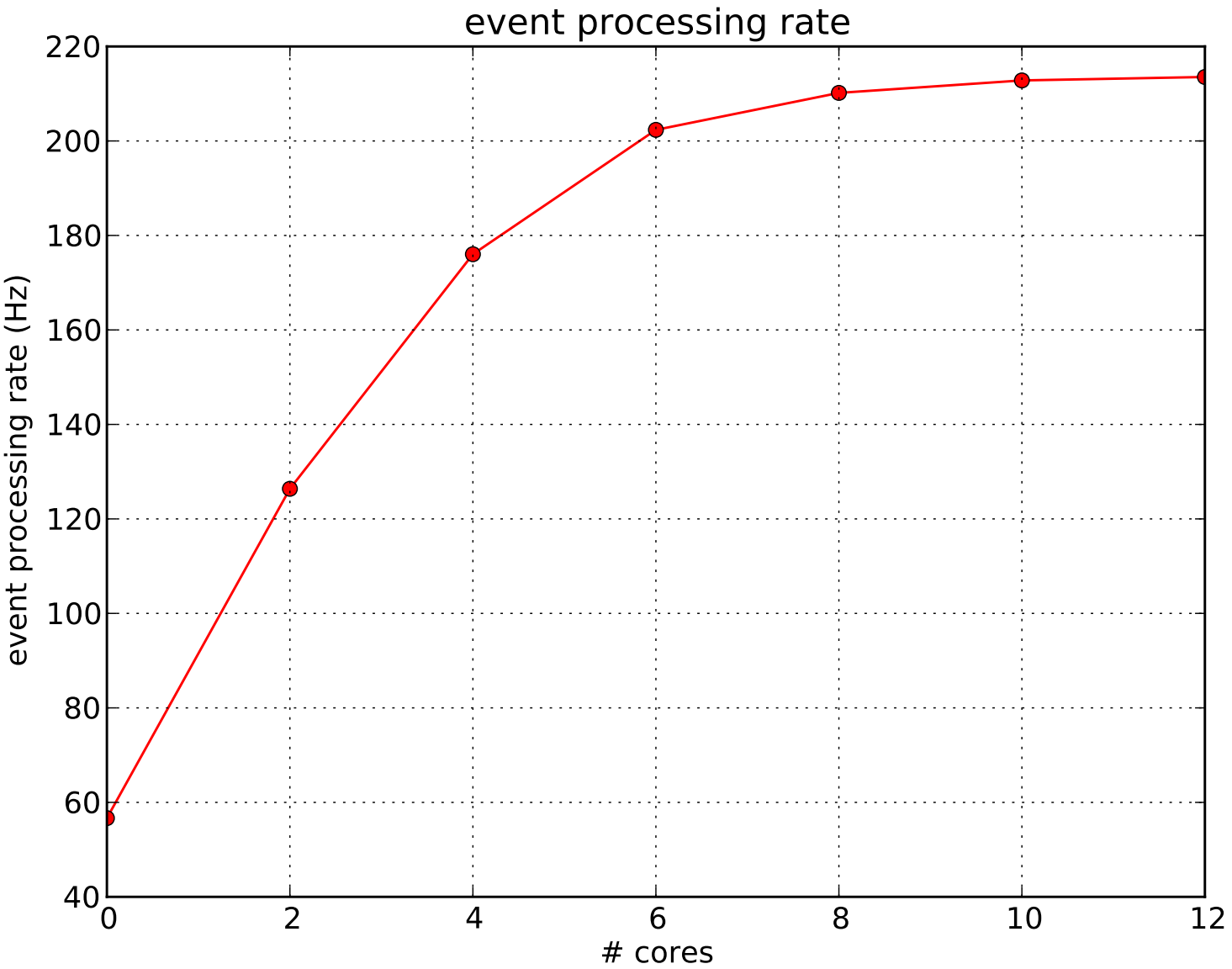
```
app.props.EvtMax = 10000
app.props.OutputLevel = 1

app.svcs += Svc("gaudi/kernel/evtproc:evtproc",
                "evt-proc",
                OutputLevel=Lvl.INFO,
                NbrWorkers=5000)

app.svcs += Svc("gaudi/kernel/datastore:datastoresvc", "evt-store")
app.svcs += Svc("gaudi/kernel/datastore:datastoresvc", "det-store")

for i in xrange(500):
    app.algs += Alg("gaudi/tests/pkg2:alg_adder",
                    "addr--%04i" % i,
                    SimpleCounter="my_counter")
    app.algs += Alg("gaudi/tests/pkg2:alg_dumper",
                    "dump--%04i" % i,
                    SimpleCounter="my_counter",
                    ExpectedValue=i+1)
```

# Results


event processing rate
event processing rate (Hz)
# cores
220
200
180
160
140
120
100
80
60
40
0
2
4
6
8
10
12

# Investigating sub-event parallelism

- extracted list of algorithms from `Athena` reconstruction
- extracted list of dependencies
  - which algorithm produces which container(s)
  - which algorithm reads which container(s)
  - infer a dependency graph in terms of algorithm dependencies
    - NOT in terms of containers
    - `algorithm` is the elementary chunk of sequential work
- extracted `CPU` timings from the same reconstruction job
  - averaged over 50 events, first event discarded
- inject into a mockup framework of the framework

# Investigating sub-event parallelism - II

```
// closure to re-initialize dependency-graph scheduler
// state and datastore content
reinit_fct := func() {
    // re-init depg
    for k, _ := range depg {
        depg[k] = make(chan int, 1)
    }
    // re-init store
    for k, _ := range store {
        store[k] = nil
    }
}
```

# Investigating sub-event parallelism - III

```
for ievt := 0; ievt < *g_evtmax; ievt++ {
    var seq sync.WaitGroup
    seq.Add(len(algs))
    for i, _ := range algs {
        go func(ievt, ialg int) {
            a := algs[ialg]
            if err := a.Execute(ievt); err != nil {
                panic(err)
            }
            seq.Done()
        }(ievt, i)
    }
    seq.Wait() // <-- barrier
    reinit_fct()
}
```

# Investigating sub-event parallelism - IV

```
func (a *alg) Execute(ctx int) error {
    for _, dep := range a.deps {
        fmt.Printf(
            ":: [%s] waiting for [%s] (evt: %d)...\n",
            a.name, dep, ctx)
        v := <-a.depg[dep]
        a.depg[dep] <- v
    }

    // simulate work...
    <-time.After(int64(a.sleep * 1e9))

    // tell dep-graph scheduler we are done
    a.depg[a.name] <- 1
    return nil
}
```

# (very preliminary) results

```
::: flat-sequence :::

::: nprocs:  0
real    13m22.236s
user     0m0.861s
sys      0m0.635s

::: nprocs: 16
real    13m23.110s
user    0m1.031s
sys     0m0.932s
```

```
::: parallel-sequence :::

::: nprocs:  0
real    4m50.205s
user    0m1.876s
sys     0m1.541s

::: nprocs: 16
real    4m49.637s
user    0m1.847s
sys     0m1.519s
```

# Non-elements of Go

- no dynamic libraries (frown upon)
- no dynamic loading (yet)
  - but can either rely on separate processes
    - IPC is made easy *via* the `netchan` package
  - or rebuild executables on the fly
    - compilation of Go code is fast
    - even faster than FORTRAN and/or C
- no templates/generics
  - still open issue
  - looking for the proper Go -friendly design
- no operator overloading

# Go from anywhere to everywhere

- code compilation and distribution are (*de facto*) standardized
- put your code on some repository
  - `bitbucket`, `launchpad`, `googlecode`, `github`, ...
- check out, compile and install in one go with goinstall:
  - `goinstall bitbucket.org/binet/igo`
  - no `root` access required
  - automatically handle dependencies
- `goinstall` -able packages are listed on the dashboard:
  - godashboard.appspot.com

# Go and C/C++

Interfacing with C:

- done with the CGo foreign function interface
- #include the header file to the C library to be wrapped
- access the C types and functions under the artificial "C" package

```
package myclib
// #include <stdio.h>
// #include <stdlib.h>
import "C"
import "unsafe"

func foo(s string) {
  c_str := C.CString(s)  // create a C string from a Go o
  C.fputs(c_str, C.stdout)
  C.free(unsafe.Pointer(c_str))
}
```

# Go and C/C++

Interfacing with C++:

- a bit more involved
- uses SWIG
  - you write the SWIG interface file for the library to be wrapped
  - SWIG will generate the C stub functions
  - which can then be called using the CGo machinery
  - the Go files doing so are automatically generated as well
- handles overloading, multiple inheritance
- allows to provide a Go implementation for a C++ abstract class

## Problem

SWIG doesn't understand all of C++03

- *e.g.* can't parse `TObject.h`

# Go and FORTRAN

Two cases:

- lucky enough to wrap "legacy" `Fortran 03` code with the `ISO C` interface:
  - just use `CGo`
- wrapping legacy `F77` code:
  - write the `C` interface code
  - use `CGo` to call this interface code
- examples:
  - http://bitbucket.org/binet/go-hepevt
  - http://bitbucket.org/binet/go-herwig
- no automatic press-button solution
  - although there is no technical blocker to write such a thing
  - this has been done for `python` (*e.g.:* `fwrap`)

# Go and ROOT

- step 1 of evil plan for (HENP) world domination:
  - Go bindings to ROOT
- http://bitbucket.org/binet/go-croot
  - hand written CGo bindings to a hand written library exposing a C interface to (a subset of) ROOT
    - TFile, TTree/TChain
    - Reflex, Cint
    - TRandom
  - handles automatic conversion of Go structs into their C counter-part
  - and *vice versa*
    - two-way conversion is done by connecting the C++ introspection library (Reflex) with its Go counter-part (the reflect package)

# Go and ROOT

- running the ROOT TTree example, in C++, via the C API and through go-croot over 10000000 events:

```
29.04s user  1.03s system 86% cpu 34.83 total (C++)
29.12s user  1.09s system 85% cpu 35.48 total (CRoot)
44.83s user  1.24s system 87% cpu 54.36 total (go-croot)
```

```
$ uname -a
Linux farnsworth 3.0-ARCH #1 SMP PREEMPT
x86_64 Intel(R) Core(TM)2 Duo
CPU T9400 @ 2.53GHz GenuineIntel GNU/Linux
```

additional overhead *w.r.t.* CRoot

- different calling conventions (b/w C and Go) need to be handled
- *Note:* for such loopy-code, using GCC-Go would be better

# Conclusions

Can `Go` address the (non-) multicore problems of yesterday ?

- yes:
  - productivity (dev cycle of a scripting language)
  - build scalability (package system)
  - deployment (goinstall)
  - support for "legacy" `C/C++/Fortran` software (cgo+swig)

Can `Go` address the multicore issues of tomorrow ?

- yes:
  - easier to write concurrent code with the builtin abstractions (goroutines, channels)
  - easier to have efficient concurrent code (stack management)
  - still have to actually write efficient concurrent code, though...
    - ⋆ work partitioning, load balancing, ...
  - cloud-enabled: runnable on `AppEngine` (and its open source cousin)
- **but:** no such thing as a magic wand for multicores/manycores

# Prospects - what's missing in `ng-go-gaudi` ?

- backport sub-event concurrency event loop into `ng-go-gaudi`
- use actual `C++` components *via* `cgo` from `ng-go-gaudi`
- implement more dataflow use cases (i/o bound, cpu bound, ...)
- test dataflow with `CMS` data

# Prospects - what's missing in Go ?

- better support for C++ libraries
  - building on ROOT C++ dictionary infrastructure
    - now using GCC-Xml + a modified version of genreflex
    - tomorrow using LLVM/CLang
  - automatically generate the Go bindings
- bind more HEP libraries ?
- provide a Go interpreter ?
  - bitbucket.org/binet/igo

# Resources

- golang.org
- root.cern.ch
- swig.org
- godashboard.appspot.com
- bitbucket.org/binet/go-hepevt
- bitbucket.org/binet/go-herwig
- bitbucket.org/binet/go-croot
- bitbucket.org/binet/ng-go-gaudi
- fwrap
- LLVM
- CLang