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What next-generation languages can teach us about HENP frameworks in the manycore era

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Abstract.
Current HENP frameworks were written before multicore systems became widely deployed. A 'single-thread' execution model naturally emerged from that environment, however, this no longer fits into the processing model on the dawn of the manycores era. Although previous work focused on minimizing the changes to be applied to the LHC frameworks (because of the data taking phase) while still trying to reap the benefits of the parallel-enhanced CPU architectures, this paper explores what new languages could bring to the design of the next-generation frameworks.

Parallel programming is still in an intensive phase of R&D and no silver bullet exists despite the 30+ years of literature on the subject. Yet, several parallel programming styles have emerged: actors, message passing, communicating sequential processes, task-based programming, data flow programming, . . . to name a few.

We present the work of the prototyping of a next-generation framework in new and expressive languages (python [4] and Go [5]) to investigate how code clarity and robustness are affected and what are the downsides of using languages younger than FORTRAN/C/C++.

1. Introduction
The “Free Lunch” is over: Moore’s law [1] does not hold anymore, computer scientists and software writers have now to be familiar with Amdahl’s law [2]. Indeed, computers are no longer getting faster: instead, they are growing more and more CPUs, each of which is no faster than the previous generation.

This increase in the number of cores evidently calls for more parallelism in HENP software. Fortunately, typical HENP applications (event reconstruction, event selection,...) are usually embarrassingly parallel, at least at the coarse-grained level: one “just” needs to parallelize the event loop.

However, the strategy devised and implemented in AthenaMP [6] where the fork system call and the Copy-On-Write (COW) mechanism were leveraged in order to save memory footprint and use multiple cores won’t probably scale up to manycores’ systems as COW’s efficiency is bounded as well as the amount of RAM available on a given machine. Indeed, the amount of physical memory associated to a core won’t scale with the increasing number of cores. A ‘one-event/one-core/one-process’ strategy, even if GNU/Linux has this codepath optimized, will bring the machine on its knees when thousands of cores will be available, especially if each of these processes perform a non-negligible amount of (possibly chaotic) I/O.
Therefore, it seems more efficient to have at least the event-level data parallel processing being performed in the same address space. In a C++ world, this means multithreading and all the issues already noted during the development of AthenaMT [6]:

- it is hard to get a multithreaded application right,
- hard to keep it right,
- hard to keep it efficient and optimized across releases.

Even if the next version of C++ (C++1x) will improve the situation with lambdas, std::future and std::thread, at least on the standardization and portability fronts, this will be achieved at the cost of complicating further the language. At this point, it would seem reasonable to ask oneself if using a new language tailored for or apter at leveraging multithreaded environments wouldn’t be more sensible.

This paper explores such a path. We will first recall the basic architecture of the GAUDI framework to identify the main components which would need modifications in a multithreaded environment. Then, after motivating why we chose Go, we will introduce some of its most relevant features with regard to concurrency and how these have been translated into a new Go-based framework, ng-go-gaudi. Finally, after having presented scalability results, we will draw some conclusions and propose ideas on future work and possible improvements to ng-go-gaudi.

2. Athena/Gaudi refresher

GAUDI [3] is an object-oriented C++-based software framework built around the Component Object Model (COM) [7]. Data objects (event data, detector data or statistical data) are recorded into and retrieved from a component: the data store. Algorithm objects are the components which manipulate this data or create new and more refined data quantities by interacting with the data store. The creation of these algorithms and proper state transitions are ensured and orchestrated by a central service, the ApplicationManager, while the in-order scheduling of the algorithms is managed by the EventLoopManager, as schematized in figure 1.

As can be seen in figure 1, the workhorse component is the Algorithm one whose (simplified) interface is reported in figure 2. The execute() method is called for each event and usually

\[i.e.: \text{contrary to e.g. a conditions-level data}]
involves retrieving data from the event store as well as recording new more refined data in that event store. Previous work [6] focused on maintaining that interface, while modifying the framework behind the scene to leverage the `fork()` and COW mechanisms to transparently parallelize the GAUDI application at the event level.

Keeping these key elements in mind, we will now investigate what a GAUDI-like framework would probably look like if it were written in a new more parallel- or concurrent-friendly language.

3. New languages

Since HEMPL and C++ met to produce (among other projects) GAUDI and ROOT [8], the language landscape greatly changed. Many new languages appeared or became “mainstream” and, while closely following the trend wasn’t achieved, some adaptations were performed. For example, most of the GAUDI configuration and steering code is nowadays written in python and most, if not all, C++ components (from ROOT and GAUDI) are also available from python.

But python (or more precisely CPython) has well-known scalability issues in a multithreaded environment because of its Global Interpreter Lock (GIL) which serializes access to python objects 2. Moreover, even if this issue can be worked around by writing C extension modules, having an event loop in an interpreted language isn’t the best bet CPU-speed wise.

Other languages such as HASKELL [9] have been considered for this study. Indeed, functional languages are a great substrate for automated code parallelization [10] thanks to their “no side effects” 3 property. However, functional programming languages are probably not yet fitting into the average physicist software toolbox, and were thus discarded from this study.

Vala [11] was considered because of its support for interfaces, which match very well the GAUDI COM architecture, as well as for its ability to asynchronously start tasks and co-routines. However, the lack of documentation and the fact that “only” GNOME is using this language, disqualified it for this study.

We were hence left with Go.

3.1. Elements of Go

Go [5] is a new open source language from Google, first released in November 2009. It is a compiled language with a garbage collector and built-in support for reflection, first-class functions, closures and object-oriented programming.

Go is lauded to bring the best of both dynamic and static worlds:

- the feel of a dynamic language, thanks to its limited verbosity, its type inference system and its fast compile-edit-run cycle,
- the safety of a static type system,
- the speed of a machine compiled language. 4

Moreover, Go support for interfaces which resemble to the duck-typing motto of python fits nicely into the GAUDI framework. Finally and more importantly, Go has language support for concurrency, modelled after the Communicating Sequential Processes (CSP) [12] model: prefixing a method or function call with the keyword go will spawn off a goroutine: the function will be executed concurrently to other codepaths. goroutines are multiplexed onto multiple OS threads so blocked goroutines because of a non-finished I/O operation won’t halt the execution of the others. Furthermore, goroutines are lightweight thanks to their variable stack size, starting small and growing as needed.

2 Other python implementations (JPython, IronPython,...) do not present this limitation.
3 this is true for the so-called pure functional languages.
4 the aim of the Go authors is to eventually bring the performances of a Go binary within 10% of C.
In Go, the typesafe mechanism to exchange data between goroutines, is called channel. Sending or receiving data on a channel is atomic and can thus be used as a synchronization mechanism. It should be noted that as of 2010, Go is lacking a few features which would probably make the current implementation of ng-go-gaudi a bit easier, such as dynamic libraries and dynamic code loading. Another set of missing features more important for efficient scientific code is the lack of generics \(^5\) and the lack of operators overloading.

4. ng-go-gaudi implementation

ng-go-gaudi is a Go implementation of a minimal framework modeled after GAUDI.

The current implementation can be found in a Mercurial repository \(^13\) and holds:

- an application manager, an event processor, and a data store service,
- base classes for algorithms with support for messaging and configuration via properties,
- a simple JSON output stream and a simple Go bytestream (gob) output stream,
- and few simple test algorithms (adder, counter, . . .).

4.1. Parallelizing the event loop

Leveraging the embarrassingly parallel nature of the typical HENP application, the event processor was parallelized, following the precepts of AthenaMP and AthenaMT. The overall architecture of this parallelization is schematized in figure 3 and the code to achieve it is reproduced in figure 4. Lines 23 to 33 setup a server goroutine which will take a buffered \(^6\) input queue of events to process and (eventually) asynchronously call an event handling function to process the events. These processed events will then be removed from the input queue and will appear on the output one. Following a typical concurrent Go pattern, a third channel, the quit one, is also created to notify clients when the event source is done, allowing to cleanly terminate the event processing.

As shown in figure 3, each event is processed by a dedicated goroutine, so the event processing is concurrent. This means each goroutine needs its own data store and thus each algorithm needs to know which data store it should interact with. To fulfill that requirement, the GAUDI algorithm interface had to be extended to encode the data provenance and make the event context explicit, as shown in figures 6 and 7.

4.2. Parallel I/O

JSON and gob output streams have been implemented to study the feasibility of a parallel I/O persistency system. In each case, the data is transferred from the data store to the concrete output stream via channels, that data is then owned by the goroutine committing it to disk.

The JSON service implementation of the NewOutputStream method of figure 5 follows the typical Go pattern already described for the parallel event loop where 3 channels are created (input, errors and quit) and a goroutine which polls on each of these channels. The JSON output handle is then handed these 3 channels to pump data in, as shown in figure 8.

4.3. Job configuration and results

As mentioned previously, current (2010) Go does not support dynamic code loading \(^7\). This can be worked around by leveraging the fast compilation of Go code. Indeed, ng-go-gaudi job

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\(^5\) also called templates in C++.

\(^6\) The input queue is buffered to limit the number of in-flight events. This can of course be configured at the command line level.

\(^7\) This limitation should be lifted in a future Go version.
configuration is performed by running a python script which will generate Go code compiled down to an executable holding the concrete list of all components to be used at runtime.\footnote{In C++ GAUDI, this is done via dlopen and a plugin manager.}

An excerpt of such a job configuration, scheduling 1000 algorithms (incrementing integers and displaying them) multiplexed on 5000 goroutines, can be seen in figure 9 which, by varying the number of cores being used at runtime leads to the performance plot in figure 10. The scalability problem which can be observed has been attributed after inspection of the goroutines profiles to mutex bottlenecks mainly at the messaging layer: each component can print messages on screen

```
package kernel

// type IAlgorithm interface
func (self *myalg) Execute(ctx IEvtCtx) kernel.Error { return kernel.StatusCodeWithErr(1, e) }

func (self *myalg) Finalize() Error { return kernel.StatusCode(0) }

```

Figure 6. Extended IAlgorithm interface.

```
package outstream

import "json"

// an output stream using JSON as a format
// writes the data to the stream
Write(data interface{}) Error

// interface to a concurrent output
interface IOutputStream interface {
    // write (and possibly commit)
    Write(data interface{}) Error
    // closes and flushes the output stream
    Close() Error
}

```

Figure 7. Example of accessing a particular data store in client code.

```
package kernel

// type IAlgorithm interface
func (self *myalg) Execute(ctx IEvtCtx) kernel.Error { return kernel.StatusCodeWithErr(1, e) }

func (self *myalg) Finalize() Error { return kernel.StatusCode(0) }

```

Figure 8. JSON concrete backend.
at various verbosity levels, but as the standard output is shared between all these components, a contention appears on this resource.

```
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/datasstore:datasstoresvc", "det-store")
app.svcs += Svc("gaudi/kernel/datasstore:datasstoresvc", "det-store")
for i in xrange(500):
    app.algs += Alg("gaudi/test/pkg2:alg_adder", "addr-%04i"%i, SimpleCounter="my_counter")
    app.algs += Alg("gaudi/test/pkg2:alg_dumper", "dump-%04i"%i, SimpleCounter="my_counter", ExpectedValue=i+1)
```

Figure 9. python code used to configure an ng-go-gaudi job.

5. Conclusions
We presented a prototype of a GAUDI-like framework written in Go to investigate what next generation frameworks could look like when leveraging new languages better tailored at exploiting concurrency and parallelism. A concurrent event loop manager and concurrent output streams were implemented for this study.

Even if some performance problems were uncovered - but could easily be addressed by redesigning the gaudi/msgstream to reduce contention on stdout or by reducing the garbage collector pressure through a tighter integration with the event loop model of GAUDI - the implementation of concurrent patterns and the ability to compose them was greatly eased by Go primitives and builtin support.

We propose to further continue the prototyping of ng-go-gaudi and address its shortcomings. Future work will also investigate the feasibility to develop sub-event concurrency and explore ways to improve the memory locality of our big software framework applications - an obvious way would be to break the single application into a flock of smaller more specialized ones.

References