A third look at the health of the Go ecosystem

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1 Background

The root inspiration for this investigation and report was trying to use Athens, with a validating web-hook, for a company concerned with what is brought in from external sources.

In the initial setup, there were three intentional (and one non-intentional) way a package could fail validation. It could have file(s) that triggered a vulnerability scanner, it could fail to build, it could have failing unit tests. Or, unintended, either `go mod download` or `go list -json`[1] could fail.

It soon became evident that "has failing unit tests" was not a feasible[2] criterion. It eventually became evident that "has failing build targets" was also not feasible.

This raised a question in the author's mind. What is the current state of health of the Go eco-system? A previous investigation answered some of these questions, but it left sufficient scope for more questions to be asked (and refining the previous answers).

2 Methodology

In order to investigate the current state of health of the Go eco-system, you need to compile a lot of Go packages. You also need to do some statistics on them.

In order to more easily get multiple modules, at various versions, compiled through an instrumented build environment, the author built an environment consisting of a validator (custom Go code), Athens (pre-existing Docker container), and an instrumented build environment (custom Python, in a Docker container).

The validator considers all module/version tuples as valid. If the specific module/version tuple has not been seen before, a build of that is started[3]. The validator limits builds to at most five concurrent ones, this is to preserve some responsitivity on the test machine. It is possible to increase the build parallelism by having more "build workers". The number of build workers is set at compile time.

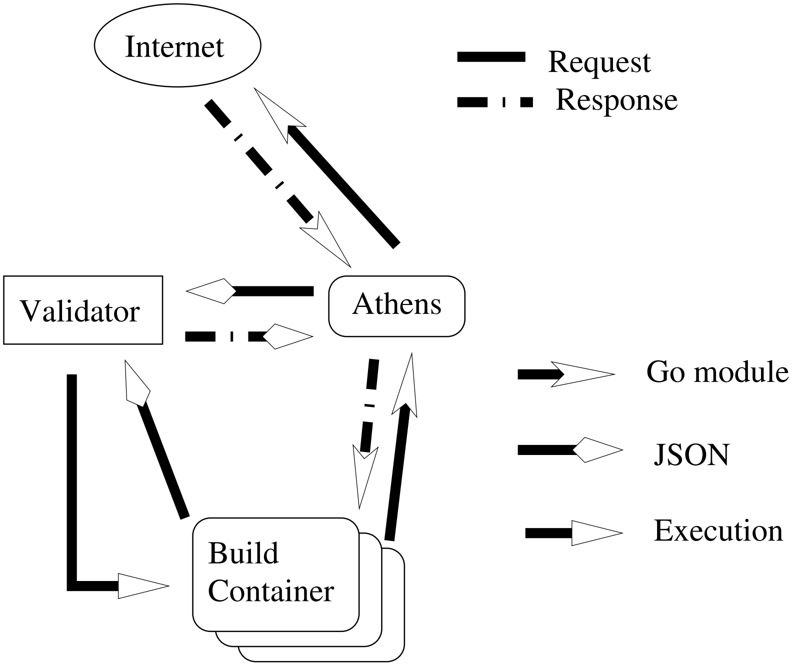
The custom build environment then reports back some general statistics (did "go mod download" work, could we list all targets in the downloaded code, did

[1] One possible reason for this is that the GitHub repo has been moved, causing a skew between the downloaded URL and that in the go.mod file

[2] Part of this is that over time, multiple "go vet" errors have been promoted test errors

[3] Technically, placed in a build queue

Fig. 1: Rough system architecture, depicting JSON requests, module requests and execution with different arrows



all builds succeed, did all tests succeed, how many build/test targets, did go vet pass[4], and (on failure) what build/test targets failed). The build environment is set up to use the Athens instance as its GOPROXY, making it much easier to get a wide spectrum of code scanned, as all transitive dependencies from the seed modules end up being processed.

The validator periodically writes its current data set to disk. There is also a web endpoint that triggers a save when accessed. The validator will only create a new save file if there's been any changes[5] since the last save.

To seed the scan, a few packages were manually started within the build container, using the same environment as that set up by the validator. For more details, see the section on seed packages.

The source code for the tabulator, the validation web-hook framework and the build instrumentation can be found at https://github.com/vatine/gochecker/ .

2.1 Methodology changes for the latest report

2.1.1 Downloads

Due to various changes in how Go modules are fetched, the wrapper has been intrsumented to report "module that can be downloaded, but has one or more immediate missing dependencies" as "download succeeded, build error", whereas

[4] This is a new test for this report

[5] Note, a "change" really means "there has been build results reported", in practice this is enough in the early stages of data gathering.

in previous versions that may have been reported as a download error.

2.1.2 Data cleaning

The latest report also has a “data cleaning” component, that deletes names tha can definitely not be module names (bare host names, github users or organisations, golang.org/x and a few others, specific details will be in source code). Only module-version tuples flagged as “download failed” are eligible for being cleaned from the data set.

3 Recommendations based on this research

The conclusions in this section remain mostly unchanged from the first iteration of this line of investigation.

3.1 Modules

By all means make your code into a module, it improves the situation for any user of your code, and may also make your life easier (although in some cases it may make it harder).

At least a few of the build errors seen can be directly traced to not having go modules enabled, so as a general recommendation, it is probably something that should be done.

3.2 Renaming

It is recommended to never rename a Go module. If you want it available under a new name, consider the new name a “new module” and leave releases up to the point in time where the changed version still available under the old name. If necessary, archive the repository, so that no further accidental modifications are possible. Probably after leaving a link in a README pointing to the new location.

Otherwise, the renaming has suddenly broken previously-fine packages. If nothing else, the name change is putting a burden on any user of your library and should ideally be followed up with a pull request[6] to bring users of the library back to a building state.

Note that prior to the introduction of the module system, renames were (to some extent) transparent to code, which is probably why the practise continues even in a “we should all be using modules now” world.

The main reason I am recommending “don’t rename” is that the name of a module is (part of) its unique identifier, and with that changing, on some level it is no longer “the same module”. If nothing else, it now has another name.

3.3 Testing

It is recommended to have pull requests checked against all (or at least all relevant) test targets as part of the review process. Ideally, this should be done by automation, posting status back to the project.

[6] The use of github.com as a platform is quite prevalent, other version control systems have different names for “this is a unit of change”.

It is strongly recommended to not cut a release if there are any failing unit tests.

It may also be useful having periodic (daily? weekly? monthly?) builds running with the latest toolchain, even if that's not the primary concern while developing. Sooner or later, your library will end up in a newer toolchain. And while the Go backwards compatibility guarantees are pretty good, this report shows that sometimes things change subtly.

4 The numbers

Here are some numbers distilled from the investigation. For the breakdown on failing build/test cases, the mean has only been done for module/versions with at least one failure. The number of packages with download problems is over-reported, as it includes: packages with a name that differs from the requested in their go.mod, packages with a version number that doesn't parse, and packages that simply do not exist at this point in time.

Tab. 1: Build target statistics

Packages processed	4326
Packages failed to download	1535
No build failures	2604 (60.194175%)
No vet failures	1789 (41.354600%)
No fmt failures	4326 (100.000000%)
No test targets	748 (17.290800%)
Mean build targets (all modules)	32.659270
stddev	153.801803
Median build targets	2
75th percentile # of build targets	10
90th percentile # of build targets	49
95th percentile # of build targets	185
99th percentile # of build targets	412
Max # of build targets	2674
Mean build targets (at least one buildable)	35.276904
stddev	159.558912
Mean failed build targets (all modules)	20.178687
stddev	147.212632
Mean failed build targets (at least one failed)	58.040559
stddev	245.280695
Mean failed vet targets (all modules)	22.294267
stddev	147.749693
Mean failed vet targets (at least one failed)	43.522112
stddev	204.207778

4.1 Download problems

The number of packages that failed to download has increased dramatically from the previous report, now standing at 1535, up from last report's 340. Some of

Tab. 2: Test target statistics

Packages seen	4326
No test failures	2165 (50.046232%)
No test failures (with tests)	1417 (39.603130%)
No build failures, but test failures	670 (15.487748%)
No tests	748 (17.290800%)
Mean failed test targets for passed builds (all)	1.356716
stddev	1.128344
Mean failed test targets for passed builds (at least one fail)	1.356716
stddev	1.128344
Mean failed test targets, all packages	7.093012
stddev	14.636305
Mean failed test targets, packages with at least one test failure	7.888832
stddev	15.231140

Tab. 3: Most versions per module that download

golang.org/x/sys	169
golang.org/x/tools	139
google.golang.org/genproto	130
golang.org/x/net	109
google.golang.org/api	62
cloud.google.com/go	47
golang.org/x/crypto	42
github.com/Azure/go-autorest/autorest	31
google.golang.org/grpc	28
github.com/prometheus/common	27

this is due to redirection domain names no longer existing, some of this is down to more aggressive "there are missing dependencies" in the toolchain.

Some of the download problems may stem from automatic "try fetching a shortened module path"[7].

At this point, the clean-up is somewhat ad-hoc, addressing issues that have been manually spotted and (in a limited number of cases) extended to cover more incorrect import paths following the same pattern.

4.2 Building

Of the downloaded 4326 packages, 2604 (60.19%) had no build failures. This is a dramatic drop from the previous report, where 4598 out of 5108 (90.02%) had no build failures.

At the time of writing this, no exhaustive investigation to find common sources of these has been done.

Like in previous reports, this time we see a very skewed distribution of build targets, with a few modules having may build targets massively skewing the

[7] an example would be starting with "golang.org/x/module@vx.y.z", when that fails re-try with "golang.org/x@vx.y.z", and finally "golang.org@vx.y.z", if you start with an import that is in a deep-ish path within a module that has a problem, this can cause multiple counts of download failures

Tab. 4: Most versions per module that fail to download

github.com/hashicorp/consul	72
golang.org/x/tools	54
github.com/Azure/go-autorest	53
google.golang.org/grpc	40
github.com/hashicorp/vault	37
contrib.go.opencensus.io/exporter	36
golang.org/x/crypto	34
github.com/aws/aws-sdk-go	33
golang.org/x/exp	21
github.com/Azure/go-autorest/autorest	21

distribution. The median number of build targets in a module is 2, the 75th percentile is 10, and the maximum number of build targets seen is 2674. These numbers are lower than in the last report, but MAY be influenced by multiple modules having downloaded but in such a way that no target introspection can succeed.

4.3 Go vet checks

The Go toolchain has a built-in tool for reporting on possible problems with the code that aren't wrong, per se, but have been found to be problematic. This is invokable as `go vet` *target* and exits with a "failure"[8] status if there was anything to report.

This check has NOT been performed for packages that downloaded successfully, but had one or more missing dependedncies.

4.4 Go fmt checks

New for this report is checking downloaded packages for conformance to the `go fmt` tool. This check has NOT been done for packages with one or more missing dependencies, so may be artificially inflated.

4.5 Tests

The Go toolchain has a built-in test framework (accessible by running `go test` *target*) and it exits with a failure if any specific test for that target fails. This does not give us a "number of failed tests" (multiple failing tests within a single testable target will only be counted once), but does give us an indication of to what extent things are released (and used) with failing tests.

This round of testing was done with the Go 1.16.3 release. It started with Go 1.16.0, then was re-done with 1.16.3 when there were what seemed like anomalies in the data. This turns out to be a combination of more aggressive "nope, there are missing dependencies, so this download has now failed" and a few other small things.

Of the test failure numbers, the two that are probably most interesting to compare are the "no test failures (with tests)" (that is, at least one test

[8] non-zero, in the case of unix

target, and all tests pass), which distressingly has dropped dramatically from the previous report (now 39.6%, previously 55.25%) and the "No build failures, but at least one failing test" (15.49%, down from 30.38%). Now, there's no further breakdown than that, but we can at least assume that "build failure" would at least potentially cause "test failure" and there's a decent margin between the two.

Slighly discouraging, 17.29% of the packages had no test targets at all, this is a combination both of "a higher number of packages had no tests" (728 in the last report, 748 in this report) and "a larger proportion of modules failed to download".

5 Investigation of (some) download errors

A module at a specific version is counted as "has download error" if both a `go mod download ...` and a `go get ...` fail. This is usually down to a discrepancy between the path of the module as requested, and the name in the go.mod file. Not all errors have been exhaustively investigated, but a few are investigated in more detail below.

It is also counted as a "download error" if it is not possible to list the contents of the package, this is a rather generous definition of "download error", but from the background of "go proxy for a walled garden, wanting some assurance of what comes in", it makes some level of sense.

The 192.168.1.2:3000 you will see in a few error messages is simply the Athens proxy that is part of the test environment.

5.1 cloud.google.com/go/bigquery@v1.0.0

This module/version combo fails with the following error:

```
go: downloading cloud.google.com/go/bigquery v1.0.0
go: downloading cloud.google.com/go v0.44.1
go: downloading cloud.google.com/go/bigquery v1.18.0
go: downloading cloud.google.com/go v0.82.0
cloud.google.com/go/bigquery: ambiguous import: found package cloud.google.com/go/bigquery
cloud.google.com/go v0.44.1 (/go/pkg/mod/cloud.google.com/go@v0.44.1/bigquery)
cloud.google.com/go/bigquery v1.0.0 (/go/pkg/mod/cloud.google.com/go/bigquery@v1.0.0)
```

This seems to be a new behaviour of the tool chain from 1.16 onwards.

5.2 cloud.google.com/go/pubsub@v1.0.1-beta.ordered.keys

This module/version fails with the following error:

```
go: downloading cloud.google.com/go/pubsub v1.0.1-beta.ordered.keys
go get: cloud.google.com/go/pubsub@v1.0.1-beta.ordered.keys requires cloud.google.com/go/p
```

This seems to be some weird circular reference, that I have not investigated deeper.

6 cloud.google.com/go@v0.26.0

Another case of "transitive dependencies failing to download" that the existing tooling doesn't take into account.

```
go: downloading cloud.google.com/go v0.23.0
go: downloading github.com/golang/protobuf v1.5.2
go: downloading github.com/googleapis/gax-go v1.0.3
go: downloading go.opencensus.io v0.23.0
go: downloading golang.org/x/net v0.0.0-20210521195947-fe42d452be8f
go: downloading golang.org/x/oauth2 v0.0.0-20210514164344-f6687ab2804c
go: downloading golang.org/x/sync v0.0.0-20210220032951-036812b2e83c
go: downloading google.golang.org/api v0.47.0
go: downloading google.golang.org/genproto v0.0.0-20210521181308-5ccab8a35a9a
go: downloading google.golang.org/grpc v1.38.0
go: downloading google.golang.org/api v0.0.0-20180910000450-7ca32eb868bf
go: downloading github.com/googleapis/gax-go v1.0.0
go: downloading google.golang.org/genproto v0.0.0-20180831171423-11092d34479b
go: downloading google.golang.org/grpc v1.14.0
go: downloading go.opencensus.io v0.18.0
go: downloading google.golang.org/appengine v1.6.7
go: downloading google.golang.org/protobuf v1.26.0
go: downloading golang.org/x/sys v0.0.0-20210514084401-e8d321eab015
go: downloading golang.org/x/sys v0.0.0-20210521203332-0cec03c779c1
go: downloading golang.org/x/text v0.3.6
go: downloading contrib.go.opencensus.io/exporter/stackdriver v0.13.6
go: downloading contrib.go.opencensus.io/exporter/stackdriver v0.6.0
cloud.google.com/go tested by
cloud.google.com/go.test imports
golang.org/x/oauth2/google: cannot find module providing package golang.org/x/oauth2/googl
cloud.google.com/go tested by
cloud.google.com/go.test imports
google.golang.org/api/option imports
golang.org/x/oauth2: cannot find module providing package golang.org/x/oauth2
cloud.google.com/go tested by
cloud.google.com/go.test imports
cloud.google.com/go/datastore imports
google.golang.org/api/transport/grpc imports
google.golang.org/grpc/credentials/oauth imports
golang.org/x/oauth2/jwt: cannot find module providing package golang.org/x/oauth2/jwt
```

6.1 code.gitea.io/sdk@v0.14.0

This simply fails with a 404 error. Looking at the versions listed on pkg.go.dev, v0.14.0 is not displayed. The package is not module-enabled, but the documentation has a longer import path (`import "code.gitea.io/sdk/gitea"`) listed.

This MAY be a case of a shortened URL, as there are also entries for the longer path.

6.2 contrib.go.opencensus.io/exporter/ocagent@v0.4.6

This is failing due to a non-existing dependency, but in a fashion that the existing toolchain doesn't recognise as such.

```
go: contrib.go.opencensus.io/exporter/ocagent@v0.4.6 requires
github.com/census-instrumentation/opencensus-proto@v0.1.0-0.20181214143942-ba49f56771b8: r
```

7 Investigation of (some) build errors

There are some packages that do not work to download with “go mod download”, this seems to be down to structural problems with the repositories, like “at higher than v1, but not under a v2 (or later) path prefix”. Observing that this is a possible source of “fewer transitive dependencies” as well as “possibly false failed download” numbers, the build environment has been changed to first try a “go mod download”, and if that fails, a “go get” at the same version.

Some packages fail because the path declared in their go.mod does not correspond to the path their dependencies have declared[9].

In some cases, an erroneous version number has snuck in, causing problems downloading the package[10]. One possibility may be that the go.mod file using local rewrites for dependencies. These work for the “root” package, but do not work during a transitive build. Another possibility is an automatic attempt to convert a godeps dependency file to a go.mod.

7.1 cloud.google.com/go/bigquery@v1.7.0

This is a simple build error, but interesting in that it shoudl be catchable with checks during code review. It could be that it is for “this is how the code WILL look”, or other code having changed since merge.

```
# cloud.google.com/go/bigquery/reservation/apiv1beta1
/go/pkg/mod/cloud.google.com/go/bigquery@v1.7.0/reservation/apiv1beta1/reservation_client.
    Build of cloud.google.com/go/bigquery/reservation/apiv1beta1 failed
```

7.2 cloud.google.com/go/pubsub@v1.0.0

This error is because the go.sum file for this specific version of the module genuinely does not contain any data for golang.org/x/time/rate. On the flip side, there is no go.mod file for golang.org/x/time/rate, but there is one for golang.org/x/time, so there’s something a bit weird happening here.

Not surprising, we are seeing two build targets failing on the same thing, both included for completeness sake.

```
DEBUG:root:  Building go target cloud.google.com/go/pubsub/loadtest
DEBUG:root:Running go build cloud.google.com/go/pubsub/loadtest
/go/pkg/mod/cloud.google.com/go/pubsub@v1.0.0/loadtest/loadtest.go:35:2: missing go.sum en
go get cloud.google.com/go/pubsub/loadtest@v1.0.0
DEBUG:root:    Build of cloud.google.com/go/pubsub/loadtest failed
DEBUG:root:Running go vet cloud.google.com/go/pubsub/loadtest
/go/pkg/mod/cloud.google.com/go/pubsub@v1.0.0/loadtest/loadtest.go:35:2: missing go.sum en
go get cloud.google.com/go/pubsub/loadtest@v1.0.0
...
DEBUG:root:  Building go target cloud.google.com/go/pubsub/loadtest/cmd
DEBUG:root:Running go build cloud.google.com/go/pubsub/loadtest/cmd
/go/pkg/mod/cloud.google.com/go/pubsub@v1.0.0/loadtest/loadtest.go:35:2: missing go.sum en
```

[9] Changing “full name” of a Go module is problematic, as that effectively changes the “unique identifier”

[10] This seems prevalent for packages listing dependencies under k8s.io, for some reason

```
go get cloud.google.com/go/pubsub/loadtest@v1.0.0
DEBUG:root:    Build of cloud.google.com/go/pubsub/loadtest/cmd failed
DEBUG:root:Running go vet cloud.google.com/go/pubsub/loadtest/cmd
/go/pkg/mod/cloud.google.com/go/pubsub@v1.0.0/loadtest/loadtest.go:35:2: missing go.sum en
go get cloud.google.com/go/pubsub/loadtest@v1.0.0
```

7.3 github.com/DATA-DOG/go-sqlmock@v1.4.1

```
Running go vet github.com/DATA-DOG/go-sqlmock/examples/orders
/go/pkg/mod/github.com/!d!a!t!a-!d!o!g/go-sqlmock@v1.4.1/examples/orders/orders.go:8:2: no
go get github.com/kisielk/sqlstruct
```

This is due to a go.mod file that does NOT contain any of the dependencies. This release also does not have a go.sum file, meaning that repeatability in build is not guaranteed (actually, pretty much the opposite).

8 Investigation of (some) test errors

As a general comment, it is a bit surprising that tagged releases have test errors at all, indicating that there's improvements to make around release processes.

In some cases, this is because the tooling has changed what constitutes a "passing" test (over time, some "go vet" warnings have become errors when they occur during a run of `go test`) and the CI pipeline is running with "not the most recent release", a situation that is totally understandable.

There's also the case of a release that was made before the most current, which for obvious reasons will not have had a CI run against a version released after itself[11]

For practical reasons, the testing has not been re-run with prior versions of the Go toolchain to find where things may have started acting up, even in the manual investigations that follow.

We will now look closer at a few packages. I have explicitly excluded packages that have build failures from closer inspection, as the test may well be because of one (or more) build failures due to missing dependencies.

The methodology for choosing packages is (approximately) looking through the emitted latest data file, in whatever order the JSON marshalling places things, investigate more closely what the test warnings are, until it is no longer fun to dig anymore.

8.1 cloud.google.com/go/bigquery@v1.0.1

```
# cloud.google.com/go/bigquery/datatransfer/apiv1 [cloud.google.com/go/bigquery/datatransf
/go/pkg/mod/cloud.google.com/go/bigquery@v1.0.1/datatransfer/apiv1/mock_test.go:428:3: unk
/go/pkg/mod/cloud.google.com/go/bigquery@v1.0.1/datatransfer/apiv1/mock_test.go:507:3: unk
/go/pkg/mod/cloud.google.com/go/bigquery@v1.0.1/datatransfer/apiv1/mock_test.go:638:3: unk
/go/pkg/mod/cloud.google.com/go/bigquery@v1.0.1/datatransfer/apiv1/mock_test.go:845:3: unk
FAIL cloud.google.com/go/bigquery/datatransfer/apiv1 [build failed]
FAIL
```

[11] But, if you can provide a CI system that will reliably test against compiler versions released in the future from the time the test is run, the author is interested in testing them...

This seems to be an outright mistake in the code. Looking at the datatransfer.TransferConfig type definition, I can't find any instance at which it has a member named that. The closest is that there's a `Destination` struct member typed as a package-internal interface, with an exported type named `TransferConfig_DestinationDatasetId` that, in turn, has a `DestinationDatasetId` struct member.

8.2 contrib.go.opencensus.io/exporter/ocagent@v0.4.12

```
# contrib.go.opencensus.io/exporter/ocagent [contrib.go.opencensus.io/exporter/ocagent.tes
/go/pkg/mod/contrib.go.opencensus.io/exporter/ocagent@v0.4.12/viewdata_to_metrics_test.go:
*metricsAgent does not implement "github.com/census-instrumentation/opencensus-proto/gen-g
FAIL contrib.go.opencensus.io/exporter/ocagent [build failed]
FAIL
```

8.3 github.com/JamesClonk/vultr@v0.0.0-20210225162646-a13a15c46955

```
# github.com/JamesClonk/vultr/lib
/go/pkg/mod/github.com/!james!clonk/vultr@v0.0.0-20210225162646-a13a15c46955/lib/account_i
go get -t github.com/JamesClonk/vultr/lib@v0.0.0-20210225162646-a13a15c46955
FAIL github.com/JamesClonk/vultr/lib [setup failed]
FAIL
```

I am not at all sure why we're seeing this error message. At the 1.3.0 version, there is a go.mod for `github.com/stretchr/testify`, and there is none for the `assert` subdirectory.

8.4 github.com/Rican7/retry@v0.1.0

```
# github.com/Rican7/retry
vet: /go/pkg/mod/github.com/!rican7/retry@v0.1.0/retry_test.go:143:6: logFile declared but
FAIL github.com/Rican7/retry [build failed]
FAIL
```

This is a pretty classic Go error message. There is an unused variable, which (for good or bad) is a compile error.

In this specific case, it is in an example, but it looks like the test file has actual tests in addition to the examples.

8.5 github.com/aokoli/goutils@v1.0.1

```
# github.com/aokoli/goutils
/go/pkg/mod/github.com/aokoli/goutils@v1.0.1/randomstringutils.go:118:44: conversion from
FAIL github.com/aokoli/goutils [build failed]
FAIL
```

This is one of those Go vet checks that have been promoted to "flag as a failure during tests". There are a few more of those and as a general rule, some code from "before this was enabled" may still have it.

8.6 github.com/appc/spec@v0.8.11

```
/go/pkg/mod/github.com/appc/spec@v0.8.11/schema/types/semver.go:20:2: no required module p
go get github.com/coreos/go-semver/semver
/go/pkg/mod/github.com/appc/spec@v0.8.11/schema/types/resource/quantity.go:28:2: no requir
go get github.com/spf13/pflag
/go/pkg/mod/github.com/appc/spec@v0.8.11/schema/image.go:25:2: no required module provides
go get go4.org/errorutil
/go/pkg/mod/github.com/appc/spec@v0.8.11/schema/types/resource/amount.go:23:2: no required
go get gopkg.in/inf.v0
```

This is a pre-module package, failing to build in many ways. This seems to be the root of the test failure in this case.

9 Seed packages

This is the list of every seed package.

This time, no exhaustive manual "try each of the 718 failed packages to see why" has been done, leaving (potentially) interesting findings by the wayside.

Tab. 5: Seed modules and versions

- github.com/miekg/dns v1.1.41
- github.com/containerd/containerd v1.4.4
- github.com/hashicorp/consul v1.9.4
- helm.sh/helm/v3 v3.5.3
- github.com/influxdata/influxdb/v2 v2.0.4
- github.com/hashicorp/terraform v0.14.8
- github.com/prometheus/prometheus v1.8.2-0.20210315220929-1cba1741828b

Tab. 6: Considered seed modules intentionally excluded

- github.com/thanos-io/thanos v0.18.0