Lesson Plan
APIs By Example

Do this immediately, if you ~~did not follow directions~~ have not already done so:
$docker pull mike909/wlpc-grpcserver:v1
$docker pull mike909/wlpc-grpcclient:v1
$docker pull mike909/wlpc-gnmiclient:v1
$docker pull mike909/wlpc-gnmitarget:v1
$docker pull mike909/influxdb:v1
$docker pull mike909/grafana:v1

Summary

1. **Subject(s):** YANG Modelling, gRPC, Protocol Buffers, gNMI, OpenConfig, Streaming Telemetry (Pub/Sub), TSDB Visualizations.
2. **Objective:** Introduction to above concepts. Go from zero to fully functioning systems, through lessons which build on each other. These are introductory, to show the reader many of the core concepts utilized in OpenConfig and gNMI APIs. The goal here is not to build production-ready systems, rather provide examples of usage and concepts so the reader can connect the dots.
3. **Prerequisite:**
   Docker.

   These lessons utilize Docker containers, therefore it must be installed on your host system. Docker is free and can be installed on OSX, Linux, Windows (See: https://docs.docker.com/install/#supported-platforms).

   Tip: Follow the very limited "Hello World" example in the Docker Getting Started to ensure it's working as intended on your host machine (eg docker run hello-world). See the appropriate section for your host OS, for example: https://docs.docker.com/docker-for-mac/.

   Limited coding experience optional.

Document Flow

Each lesson will begin with an expected end result. This is a sneak peak at the lessons final output. Following that, each lesson will have a Set Up section to prevent having to depart from the core of the lesson (Exercises) for house-keeping. There will also be an Appendix and Further Reading section, relevant to each lesson.

Lesson 1: gRPC & Protocol Buffers

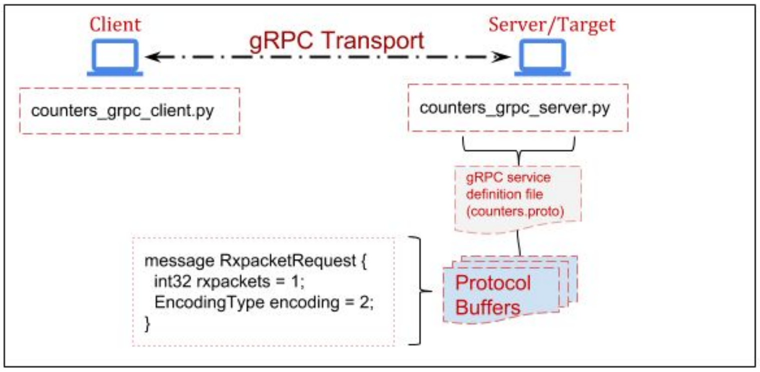
Expected End Result

```
root@grpc_client:/home/user# python counters_grpc_client.py
message: "Rx packets for eth0: 26"
```

Note, your Rx packets number will differ.

Set Up

The Topology for the following lessons is as follows:



1. Set up our virtualized network. This allows us to utilize static IPs.
   Tip: Many docker commands may need to be **prepended with sudo** if using Linux.

   On a terminal in your host machine:

```
docker network create --subnet=172.20.0.0/24 ocnet
```

   [What does this command do?]

2. Run the Client and Server containers for use in this lesson.
   In one terminal on your host machine, run:

```
docker run -it --net ocnet -h grpc_server --ip 172.20.0.2 mike909/grpc_server:v1
/bin/bash
```

   And in a **different terminal** on your host machine, run:

```
docker run -it --net ocnet -h grpc_client --ip 172.20.0.3 mike909/grpc_client:v1
/bin/bash
```

   [What do these commands do?]

Exercise

1. Write the protocol buffer.

This is a language and platform neutral definition for structured data, which in our case is a packet counter taken from the output of 'ifconfig'. There are two interfaces on the server, Loopback and eth0. Therefore, we define a message of type 'String' which we will used to determine which interface we are interested in performing 'ifconfig' on. For example:

```
message RxpacketRequest {
  string interface = 1;
```

```
}
```

Next, we need to define a message for the Rx packets taken from ifconfig. Since this is a counter, represented as a positive number, this will be of type ‘uint64’. A full description of types can be found here.

For example:

```
message RxpacketReply {
  uint64 rxpackets = 1;
  string message = 2;
}
```

Why the “string message = 2”? This will be explained later in the lesson.

The full .proto file can be found in your /home/user directory in the Client container. You should have the Client container open in a terminal window, so you can peek at the file with:

```
root@grpc_client:/home/user# cat counters.proto
```

There is more metadata in the counters.proto file. For a full understanding of all these fields, you’re encouraged to see Further Reading section at the end of this lesson.

Tip: If you accidentally closed one of your running Containers (Client or Server) you can simply restart it with the above “docker run…” commands. If desired, you can also leave a container running, and attach a second console (in a new terminal window) by doing:

```
docker exec -it <container_id> /bin/bash
```

You obtain the container_id from the ‘docker ps’ command on your host. For example:

```
$ docker ps
CONTAINER ID        IMAGE               COMMAND             CREATED
3162670c9d94        grpc_client         "bash"              3 seconds ago
```

2. Compile source code from our counters.proto.

With our .proto now defined, we will run the protocol buffer compiler. In our case we’ll be using the Python language, though remember proto’s are language (and platform) independent, so you could swap portions of these lessons with any of the supported languages. This will generate Python Classes which will be utilized by both our Client and Server applications. Ordinarily, you would need to install the protobuff compiler, however that’s been taken care of for you within the

Client and Server containers. Therefore, you generate the source code by running the 'protoc' compiler, for example:

```
root@grpc_client:/home/user# python -m grpc_tools.protoc -I./ --python_out=.
--grpc_python_out=. ./counters.proto
```

You'll notice that the current directory now contains some new files, such as 'counters_pb2.py'. These are the Python functions and classes we will use in both our Client and Server applications. You can poke around in counters_pb2.py and should recognize the names of some of them (they will resemble the 'messages' from counters.proto), but understanding all the contents of that file is out-of-scope, and unnecessary.

3. Write our client application

First, we write a small script which imports the previously generated protobuff code, along with some other mandatory libraries. The focus here is on simplicity, not the Python code, however it may help to walk through the more important bits. If you prefer to skip ahead, simply peak at /home/user/counters_grpc_client.py.

```
channel = grpc.insecure_channel(172.20.0.2:50051')
```

As the variable name implies, this establishes an insecure gRPC channel to our Server (172.20.0.2) on port 50051.

```
stub = counters_pb2.int_counterStub(channel)
```

Here we utilize the imported protobuf code, counters_pb2, which references the service int_counter (line 5 of counters.proto) and creates a 'Stub'. This stub is just a local object in Python. Refer back to the counters.proto file for reference.

```
response = stub.GetCounter(counters_pb2.RxpacketRequest(interface=server_int))
```

Here we utilize the 'GetCounter' RPC, from the counters.proto, and specify the interface we're interested in getting Rx packets for. Note, this interface is passed into the 'GetRxPackets' function. For example, if you wanted to get Rx packets for the Loopback interface, you would simply change line 24 to "lo". For example:

```
response = GetRxPackets('eth0') →  response = GetRxPackets('lo')
```

You could alternatively utilize the Python interactive interpreter to achieve the same results. For example:

```
grpc_client$ python
>>> import grpc
```

```
>>> import counters_pb2
>>> import counters_pb2_grpc
>>> channel = grpc.insecure_channel('172.20.0.2:50051')
>>> stub = counters_pb2_grpc.int_counterStub(channel)
>>> response = stub.GetCounter(counters_pb2.RxpacketRequest(interface='eth0'))
>>> print(response)
```

If you run this, either through the interpreter or with "$ python counters_grpc_client.py", **it will fail**. That's expected, since we have not set up the Server yet. Let's do that!

4. Set up the grpc server.

Over in your other terminal window (where you started the grpc_server container), the counters_pb2.py & counters_pb2_grpc.py files already exist. What we'll be doing is essentially the reverse of the Client app, which means we'll import the protobuffer code here as well. We'll also need to write a small function to run 'ifconfig' and parse the output to get what we're interested in, which in this case is Rx packets on an interface.

Again, if you'd prefer to skip the explanation of the code, feel free to peek at counters_grpc_server.py. I'll highlight the important bits here.

```
input = os.popen('ifconfig ' + request.interface)
```

Here we're assigning the output of the entire ifconfig command to a variable named 'input'. The request message from the client written in Step 3 includes the interface we're interested in. Remember the "string interface" in the proto? In other words, this enumerates to "ifconfig eth0".

Next, we utilize simple list comprehension to loop over the ifconfig output and assign the integer to our variable, rxcounter.

```
rxcounter = int(''.join([x.split()[2] for x in input if 'RX packets' in x]))
```

For example, 'rxcounter' would equal "31" in the following output:

```
root@grpc_server:/home/user# ifconfig
eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet 172.20.0.2  netmask 255.255.255.0  broadcast 172.20.0.255
        ether 02:42:ac:14:00:02  txqueuelen 0  (Ethernet)
        RX packets 31  bytes 3099 (3.0 KiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 14  bytes 1554 (1.5 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

Now we'll see why we assigned that string in the counters.proto file earlier. Refer back to counters.proto (string message = 2;):

```
    return counters_pb2.RxpacketReply(
            message='Rx packets for %s: %i' % (request.interface, rxcounter))
```

When we respond to the Client app over the RPC, we do so by returning two fields (See 'RxpacketReply' in counters.proto). One is simply a string of our choosing ("Rx packets for…"), the other an integer (the rxcounter). Responding with this concatenation of a string and an integer here is more for example, and won't show up in later lessons when we get into YANG models and dealing with real Network Elements.

5. Put it together.

With some understanding of what the Client and Server are doing, let's run the Server by executing "python counters_grpc_server.py" on the "grpc_server" container. For example:

```
root@grpc_server:/home/user# python counters_grpc_server.py
gRPC server listening on port 50051
```

Let's run the Client by executing "python counters_grpc_client.py" on the "grpc_client" container. For example:

```
root@grpc_client:/home/user# python counters_grpc_client.py
```

You should see the following output on the client:

```
message: "Rx packets for eth0: 32"
```

That's it! You are now getting "Telemetry" over a gRPC connection between a Client and a Server. In further lessons you'll learn about data modelling and the gNMI specification. For now all you need to understand is that gRPC connections such as this here are what's occurring at the lower level.

Extra credit; change the Rx packet value to a string, and see what happens. **Why does it fai?**

Leave these containers running for Lesson 2.

Answer

It *should* fail, as the proto strictly specifies the type as a 'uint64'. Therefore, if you change the server app (counters_grpc_server.py) to assign the Rx packets as a string, you'd see [something like this]() on the Client.

Later, you'll see similar Schematic errors when we utilize YANG models and gNMI.

Lesson 1 Appendix

Docker Network Create...

By default Docker picks the next unused IP and MAC address for a container. This can get confusing as we work through the client/server model in the lab, so we assign IPs manually at instantiation of the containers.

Docker Run...

This instantiates a Docker Container from a local Image. If the local Image is not found, it will be downloaded from Docker Hub. We are also specifying the use of the previously created subnet and the static IP for this container to utilize. Finally, we attach to a local shell within this container. In this case, you should see output similar to the following:

```
Something not found downloading now
```

Why does it fail...

Client output:

```
grpc._channel._Rendezvous: <_Rendezvous of RPC that terminated with:
        status = StatusCode.UNKNOWN
        details = "Exception calling application: %d format: a number is required, not str"
        debug_error_string =
"{"created":"@1537377279.885271400","description":"Error received from peer","file":"src/core/lib/surface/call.cc","file_line":1099,"grpc_message":"Exception calling application: %d format: a number is required, not str","grpc_status":2}"
```

Further Reading

If you find yourself copy/pasting from these examples, without grasping the core concepts, you are encouraged to read through the following:

- Protocol Buffer language guide.
- gRPC FAQ
- gRPC Hello World

Lesson 2: Streaming RPC's

Expected End Result

```
root@grpc_client:/home/user# python counters_grpc_client.py
message: "Rx packets for eth0: 26"
message: "Rx packets for eth0: 27"
message: "Rx packets for eth0: 28"
...
```

Note, your Rx packets number will differ.

Set Up

This is a short lesson, simply to show how a Streaming RPC works. Same topology and containers in use as Lesson 1.

Exercise

Streaming Telemetry, where a Publisher/Subscriber mechanism is used, is a big part of OpenConfig. It changes the construct from a constant 'Polling' of Network Elements to one where a collection system (eg NMS) simply Subscribes to messages, reducing system overhead while increasing the granularity of Telemetry. Below we'll show a very basic example of this.

1. Change the proto

A slight modification to the proto file is all that's needed. We simply add the word "stream" to the rpc definition. For example:

```
rpc GetCounter(RxpacketRequest) returns (stream RxpacketReply) {}
```

Note, the "streaming" proto is already present in the Client container; "/home/user/counters-stream.proto". Don't forget to generate new source code from this proto file with:

```
root@grpc_client$ python -m grpc_tools.protoc -I./ --python_out=.
--grpc_python_out=. ./counters-stream.proto
```

Again, this has already been done for you on the Server, so no need to generate source code there.

2. Change the Client

Here we'll be slightly modifying the Client app, to utilize the new proto source code, and introducing a loop to repeatedly print the Server response. The Python code is not the focus here, so you can simply look at "/home/user/counters_grpc_streamclient.py". The below lines are what's changed.

```
*snip*
  for r in response:
    print(r)
*snip*
```

3. Change the Server

Similar to the Client app, we'll now use the new proto source and introduce a loop which will obtain the Rx packets in the interface every second. See the While loop in "/home/user/counters_grpc_streamserver.py" on the grpc_server container.

4. Run the Server, then the Client.

Do this in a manner similar to the previous lesson. For example, on the grpc_server container:

```
root@grpc_server:/home/user# python counters_grpc_streamserver.py
gRPC server listening on port 50051
```

And over on the grpc_client container:

```
root@grpc_client:/home/user# python counters_grpc_streamclient.py
message: "Rx packets for eth0: 54"
message: "Rx packets for eth0: 55"
message: "Rx packets for eth0: 58"
...
```

The difference should be obvious, in that the RPC is now 'streaming' the results of the ifconfig output back to the client.
You've just used a Streaming RPC!

You can stop these two containers now.

Lesson 3: YANG Models & Language Bindings

Expected End Result

```
root@gnmi_client:/home/user# python interfaces_generator.py
{
  "openconfig-interfaces:config": {
    "enabled": true
  }
}
```

Set Up

While we could re-use our previous containers, to eliminate confusion between lessons, we'll start fresh. If you have not done so already, you can exit the terminals/containers used in the previous lesson.

Run the gNMI Client for use in this lesson.
In a terminal on your host machine, run:

```
docker run -it --net ocnet -h gnmi_client --ip 172.20.0.3 --add-host
www.example.com:172.20.0.4 mike909/gnmi_client:v1 /bin/bash
```

[What do these commands do?](#)

Exercise

As you'll see in the coming lessons, an operator need not worry about writing protos or configuring gRPC when utilizing OpenConfig and gNMI. In fact, the gNMI Target (which is the Server) is going to be a Network Element, such as an Access Point, Router, Switch etc. Here we'll be writing a YANG model to define the format of the Telemetry, which again in our case is Rx packets of an interface.

OpenConfig utilizes YANG models. From [OpenConfig.net](#):
"Our initial focus in OpenConfig is on compiling a consistent set of vendor-neutral data models

(written in YANG) based on actual operational needs from use cases and requirements from multiple network operators."

You can think of YANG models as somewhat analogous to proto's, in that they define how data is supposed to look, giving it structure. YANG is a data modelling language, and like proto's, they are language-neutral. OpenConfig aims to define these YANG models in a vendor-neutral way.

1. Write our first YANG Model

Similar to the previous lesson, this won't be an all inclusive "how to write YANG models" rather an introduction through example.

With that, we start the model with some meta, such as YANG version, namespace, prefix, etc. The interesting bit is the 'packet-counter' container. In YANG a container is an interior node in the Schema; which is to say, it doesn't have a value, like a "leaf" node does. For example, in the following, "packet-counter" is the container and "rx-packets" is the leaf node.

```
container packet-counter {
   description
     "Container to hold packet counters.";
   leaf rx-packets {
     type uint32;
     description
       "Received packets on the interface.";
   }
}
```

Again, notice the 'type' here as an unsigned 32bit integer.

The full YANG model is viewable at "/home/user/interfaces.yang". This brief model is enough to generate language bindings from, and use in our code, however we're going to make this model adhere to the OpenConfig Style first…

2. Make our YANG Model adhere to [OpenConfig Style]()

This is really about structure of the YANG containers, groups, leaf nodes etc. We're also going to add a leaf node for "enabled". Specifically this is:

```
  leaf enabled {
    type boolean;
    description
      "This leaf enabled and disabled the interface.";
  }
```

This boolean type Config leaf can be used for setting an interface to enabled (True) or disabled (False).

If you reference the complete model ("/home/user/openconfig-interface.yang") there are a couple things worth mentioning here.

- Config and State are differentiated within groupings and containers, but are within the same model. There are a number of reasons for this, but for now, just know that an operator (that's you) may want to obtain both the State of a configuration on the device, and the 'actual' State of the device. These can be distinctly different (eg. just because you told a device to disable an interface does not necessarily mean it did so).
- Every Config leaf has a corresponding State leaf, however the reverse is not true. In our example, rx-counters is a State leaf only. After all, you wouldn't configure the received packets on an interface.
- The series of groupings and containers allows for maximum re-use. You'll see examples of this throughout OpenConfig models, where one Model may import another model. In fact, our interfaces model here imports openconfig-extensions (also present in your /home/user directory).

For much more verbose examples, you're encouraged to peak at the public models. For example, the real version of the OpenConfig interfaces model: openconfig-interfaces.yang.

3. Verify our YANG model does not contain errors.

This is commonly referred to as 'linting'. For this we utilize pyang (with the OpenConfig plugin). This is already on your system, so give it a shot with (all one command):

```
root@gnmi_client:/home/user# pyang --plugindir
./oc-pyang/openconfig_pyang/plugins/openconfig.py openconfig-interface.yang
--strict --lint -p ./

oc-interfaces.yang:26: error: unterminated statement definition for keyword
"description", looking at r
```

There's an error in the model at line 26.

Fix the model and run pyang again.

Model Error

Fix it by adding a trailing ";" at the end of the revision description line (25).

With the model now passing lint, there are a number of handy options in pyang. For example, you can view the Model as an ASCII tree on your terminal by adding the flag “-f tree” to the command above. The output would be:

```
module: openconfig-interface
  +--rw interfaces
     +--rw config
     |  +--rw enabled?   boolean
     +--ro state
        +--ro enabled?      boolean
        +--ro rx-packets?   uint32
```

Here it becomes more obvious what we meant before by “every config leaf has a state leaf, but not vice-versa”. ‘rx-packets’ is ONLY within the state container, while ‘enabled’ is present in both. Note, you can also use “-f jstree” or “-f docs” to generate HTML output for viewing the model in a browser. See here for example.

4. Generate language bindings

Now that we have our YANG model, let’s try to use it. YANG is language-neutral, so which tool you utilize to generate your bindings really depends on the language you’re writing your Client with. For example, we’ll be using the Open Source library PyangBind, since we’re utilizing Python in this lesson, however YGOT exists for those using Go. Functionally they do similar things, which is generate code from YANG models, which we can then use in our programs. If this sounds abstract, it should clear up by the end of this lesson. This should feel functionally similar to what we did earlier with proto’s. Except now, instead of taking a proto and generating source (using protoc compiler), we’re taking a YANG model and generating source (using PyangBind).

Since PyangBind is already installed for you, simple run the following command to generate our Python source.

```
root@gnmi_client:/home/user# pyang --plugindir $PYBINDPLUGIN -f pybind -o
interface_bindings.py openconfig-interface.yang
```

Paraphrasing from the README:

- $PYBINDPLUGIN is the location of the PyangBind plugin.
- interface_bindings.py is the desired output file.
- openconfig-interface.yang is the path to the YANG module that bindings are to be generated for.

You'll now notice a new file in your /home/user directory, "interface_bindings.py". If you poke around in there, you'll recognize some of the classes and function names, but just like before, it's not important to understand this file. We'll just be importing it into our Client, like before.

5. Use the language bindings

Here we'll be writing a small script which simply imports our language bindings (interface_bindings.py) and prints some JSON to our terminal. The full script is in /home/user/interface_generator.py. Here are the interesting bits:

```
configs = openconfig_interface()
def CreateConfigs():
  int_conf = configs.interfaces
  int_conf.config.enabled = True
```

Here we are assigning the imported bindings to a variable named 'configs'.
We use that inside the CreateConfigs function by assigning the 'interfaces' Class to the variable "int_conf" (recall the "container interfaces" in the YANG model we wrote earlier). We can now manipulate this configs object, by setting config leaf's. In this example we're setting the interface enabled boolean to "True". This would result in the Target (Network Element) enabling the interface.

```
  print(pybindJSON.dumps(all_configs, indent=2))
```

Here we are simply using PyangBinds function to 'serialize' the configs object as JSON, and print that to stdout.

Note, this is an oversimplified contrived example, as in the reality the YANG model would be much more verbose, containing lists [of interfaces], types, etc., as would the Client software and resulting JSON payload, but the core concepts are the same.

Run the script. You should see the following:

```
root@gnmi_client:/home/user# python interface_generator.py
{
  "config": {
    "enabled": true
  }
}
```

So we've now gone from a YANG model [to an OpenConfig YANG model] to generating language bindings from that YANG model, to using those bindings in a small script, which prints our OpenConfig conforming JSON. The JSON is exactly what would end up getting sent to the gNMI Target (eg the AP, Router, Switch) to enable an interface.

Similar to before, you can purposefully break this by utilizing the incorrect 'type' in the script. For example, "enabled" is of type 'boolean'. What happens if you change that to a string? It should (and does) break, as that violates the Schema we've defined in the YANG model.

In the next lesson, we will do the reverse of this. We will deserialize, or rather, take JSON and load it into a class object (called 'configs' in our example) while ensuring it adheres to the language bindings (again, generated from the YANG model). See here. Note, this is precisely what occurs when we collect or Get Telemetry from network elements. This ensures the vendor is strictly adhering to the defined Schema in the YANG model.

You should leave the gnmi_client container running for the next lesson.

Further Reading

- RFC7590 - The YANG 1.1 Data Modeling Language
- www.openconfig.net
- https://github.com/openconfig/public
- PyangBind
- OpenConfig YANG Style Guide

Lesson 3 Appendix

Dump as IETF

If you'd like to dump the JSON as IETF, simply add a 'mode=ietf' to dumps. For example:

```
print(pybindJSON.dumps(all_configs, indent=2, mode='ietf'))
```

Why The --add-host?

In this lesson, we run the client with the --add-host parameter so that it can resolve "www.example.com" to our sample gNMI Target (172.20.0.4). You can see this in the /etc/hosts file of the container.

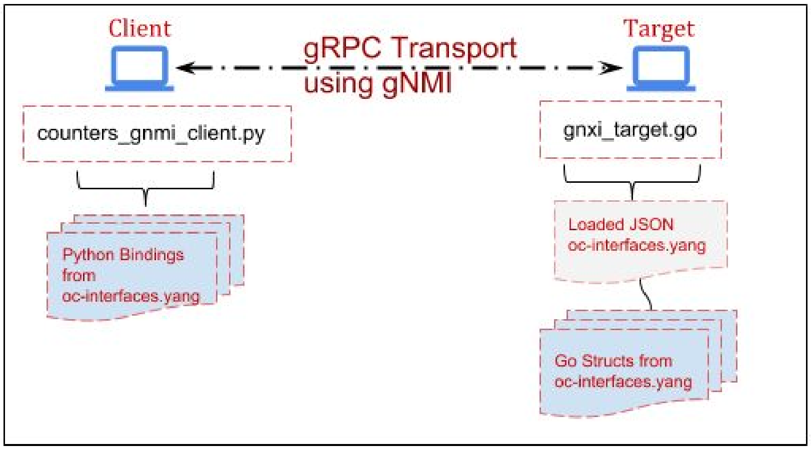
Lesson 4: gNMI. Get and SetRequests

Expected End Result

```
root@gnmi_client:/home/user# python simple_client.py
notification {
  timestamp: 1537939439031070110
  update {
    path {
      elem {
        name: "interfaces"
      }
      elem {
        name: "state"
      }
      elem {
        name: "rx-packets"
      }
    }
    val {
      uint_val: 73
    }
  }
}
```

Set Up

The Topology for the following lessons is as follows:



Grab the gnxi_target container for use in this lesson.

In your host machine, run:

```
docker run -it --net ocnet -h gnxi_target --ip 172.20.0.4 mike909/gnxi_target:v1
```

Note, we left off the '/bin/bash' so you should see something similar to the following in your terminal:

```
1 gnmi_target.go:119] starting to listen on :10161
1 gnmi_target.go:125] starting to serve
```

Our emulated Target has loaded a JSON payload in memory, which includes a key/value for the state leaf for "rx-packets". Leave it running for the duration of this lesson.

You already have the gnmi_client container from the last lesson, and we'll be expanding on that in this lesson. If you closed it, you can restart the container with:

```
docker run -it --net ocnet -h gnmi_client --ip 172.20.0.3 --add-host
www.example.com:172.20.0.4 mike909/gnmi_client:v1 /bin/bash
```

The files used within this gnmi_client container are also hosted on github:
https://github.com/mike-albano/wlpc-ocapi

Exercise

We'll be continuing to utilize the gnmi_client container from the previous lesson. You also set up a new container to act as a gNMI Target. The Target in this case will be a container running gnxi_target; a reference implementation written in Go. Ordinarily, this would be a network element (AP/Router/Switch etc.), however this reference implementation helps us emulate that. This also highlights the **language and platform neutrality** of YANG, gNMI, gRPC and OpenConfig.

Note, the gnxi_target has been pre-loaded with proper bindings, referred to as Structs in the Go language (these are loosely analogous to Classes in Python, generated with PyangBind), so let's jump in to setting up the gNMI Client app.

1. Create the gNMI Source Files

Just like we did back in Lesson 1, we're going to generate the source code by running the 'protoc' compiler. This time however, we'll point to the gNMI proto, instead of the proto we created in Lesson 1. The gNMI repo, with necessary proto files is already in your /home/user directory, so you can simply run the following from /home/user on your gnmi_client container:

```
root@gnmi_client:/home/user# python -m grpc.tools.protoc
--proto_path=/home/user/gnmi/proto/gnmi_ext/
--proto_path=/home/user/gnmi/proto/gnmi/ --python_out=./client_app
--grpc_python_out=./client_app /home/user/gnmi/proto/gnmi/gnmi.proto
```

You should now see additional files in /home/user/client_app (gnmi_pb2.py & gnmi_pb2_grpc.py). Just like in Lesson 1, these are the source-code files which we've generated from the .proto. These files will be imported into our Client app in the following exercise.

2. Set up the Client & Issue GetRequests

As before, you can peek at the final code for this portion of the lesson in/home/user/simple_client.py. We will go over the interesting bits here:

```
import gnmi_pb2
import gnmi_pb2_grpc
import gprc
```

Firstly, we are importing our protoc-generated code from the previous step. With our gNMI source imported, we set up the gNMI channel (which semantically is actually a gRPC channel):

```
channel = grpc.secure_channel('www.example.com:10161', creds)
```

This should look very familiar to Lesson 1 - Step 3. The added creds variable in use here is due to our sample gNMI Target's usage of a 'secure' channel. We specify the certificate files to use in the line directly previous to this one.

We then define the gRPC stub and move on to formulate the gNMI GetRequest (in a function called ... GetRequest):

```
stub = gnmi_pb2_grpc.gNMIStub(channel)
```

Again, this should look very familiar as we did the same thing in Lesson 1.

Now we'll begin to formulate some gNMI calls.

```
gnmi_response = GetRequest(stub, 'interfaces')
```

Here we're assigning a variable to what we will ultimately 'Get' from the gNMI Target (our other container running gnxi_target). "interfaces" in this context represents the xpath, which should look familiar, as it's the first YANG container -- Line 55 of openconfig-interface.yang. Since we want our gNMI Target in this lesson to be more representative of a real Network Element, we also added some State leaf's from the YANG model into the JSON. Here is the full JSON loaded into the gNMI Target:

```
{
  "interfaces": {
    "config": {
      "enabled": true
    },
    "state": {
      "enabled": true,
      "rx-packets": 73
    }
  }
}
```

This JSON is in “/home/user/interface.json” on the gNMI Target container.

In the GetRequest function we see the following gNMI specific helpers:

```
path_list = [gnmi_pb2.PathElem(name=path, key={})]
paths = gnmi_pb2.Path(elem=path_list)
response = stub.Get(gnmi_pb2.GetRequest(path=[paths]), metadata=[
    ('username', 'foo'), ('password', 'bar')])
```

The first line utilizes the imported proto-generated code to formulate an array (Python List) of gNMI Path’s we will supply in our gNMI GetRequest. In this case, the ‘path’ in ‘name=path’ is passed in to this function; which is literally ‘interfaces’.

The second line is constructing our paths into Path Elements. See gnmi path conventions for more info here. Path encoding is critical to gNMI; and exactly what is occurring here will become more clear in the exercises following this one. Something we won’t be utilizing in our simple example, is the “key={}”, or rather we’ll be leaving that empty. This is used when we have a leaf-list in our YANG model, in order to reference an instance within the list. For example, if we had a ‘list’ of interfaces, key’d by the interface name, you would utilize something like “key={eth1}”. See here for more info.

The third line is actually initiating the GetRequest. This includes some required metadata, like username/password which our gNMI Target is expecting for authentication.

Give it a shot. Run the simple_client.py.

```
root@gnmi_client:/home/user# python simple_client.py
notification {
  timestamp: 1537927476628149440
  update {
    path {
      elem {
        name: "interfaces"
      }
```

```
    }
    val {
      json_val:
"{\"config\":{\"enabled\":true},\"state\":{\"enabled\":true,\"rx-packets\":73}}"
    }
  }
}
```

You just initiated a gNMI GetRequest, received a GetRespone, and printed that response to the terminal (stdout). The above is the protobuffer response. You can probably recognize the 'json_val' content. Later, we'll turn this into JSON and Serialize it according to the same YANG model we used to generate the JSON.

3. Convert the protobuf response to JSON

To make the GetResponse a bit easier to read, let's turn it into JSON (and print it). We're also going to index into the protobuf response, since we're only after what's contained in the 'json_val' in the above protobuf response.

Add the following lines to the bottom of simple_client.py:

```
js_response = json.loads(gnmi_response.notification[0].update[0].val.json_val)
print(json.dumps(js_response, indent=2))
```

Note, you should also comment out the previous print statement; "print(gnmi_response)". This will make the output contain only JSON, using the built-in Python JSON library. For example, your output should now resemble this:

```
{
  "state": {
    "rx-packets": 73,
    "enabled": true
  },
  "config": {
    "enabled": true
  }
}
```

You should experiment with changing the 'print(gnmi_response)' line of code. For example, how would you print out only the timestamp of the GetResponse message?

4. Utilize gNMI Paths

Here we'll be modifying simple_client.py to provide a gNMI Path in our GetRequest. As mentioned previously, gNMI Paths are a big part of the protocol and an operator would often want to limit the GetRequest to something more granular than '/' (eg everything from the root of the OpenConfig Tree).

The appropriate way to do this would be through a helper function, accepting paths as an argument to the script, but we'll do it the easy way here just to show an example. We're going to create a list of paths, and pass that to the GetRequest function.

For example, replace the current 'path_list' variable with the following:

```
path_list = [gnmi_pb2.PathElem(name='interfaces', key={}),
        gnmi_pb2.PathElem(name='state', key={}),
        gnmi_pb2.PathElem(name='rx-packets', key={})]
```

Now, instead of using a single path of "interfaces", we're supplying a list of gNMI PathElements. If you look at the response you'll now see the value of our GetResponse is limited to simply 'rx-packets'...or 73. If you've done it correctly, your output should resemble:

```
root@gnmi_client:/home/user# python simple_client.py
notification {
  timestamp: 1537939439031070110
  update {
    path {
      elem {
        name: "interfaces"
      }
      elem {
        name: "state"
      }
      elem {
        name: "rx-packets"
      }
    }
    val {
      uint_val: 73
    }
  }
}
```

Note, if you did not comment out/delete the previous lines where you loaded the Response as JSON (js_response) the script will fail, as the current GetResponse is now returning a uint_val (not a json_val). How could you change this, if you did want to print **only** the current GetResponse value of 73? (answer)

5. Deserialize the Response

We already have our Python language bindings from the previous lesson, but now we're going to utilize them to ensure the response we get from the gNMI Target is adhering to our YANG model. A real-world example of this might be for an operator to ensure what they have configured previously on a network element, is actually still configured.
This process of taking the response JSON and placing it back 'in to' our language bindings from Lesson 3 is referred to as 'deserializing' (See [here](#)). To do this, we can basically combine our two sample scripts (simple_client.py & interface_generator.py). You can peak at the final version of this in /home/user/notso_simple_client.py.

Basically, the interesting bits are in these lines:

```
path_list = [gnmi_pb2.PathElem(name='interfaces', key={}),
             gnmi_pb2.PathElem(name='config', key={})]

js_response = json.loads(gnmi_response.notification[0].update[0].val.json_val)
pybindJSONDecoder.load_json(js_response, None, None, obj=configs.interfaces.config)
```

The first two lines show we're doing a gNMI GetRequest while specifying the path of "/interfaces/config". Accordingly the gNMI GetResponse contains only the JSON value of that portion of the tree. Specifically, this is:

```
{
  "enabled": true
}
```

"js_response" is loading the gNMI response as JSON. Finally, we use PyangBinds pybindJSONDecoder to load the above JSON into our configs object. Again, this enforces strict adherence to the YANG model we created back in Lesson 3.

Similar to what we did in Lesson 3, you can print the contents of this configs object (which now contains the response from the gNMI Target) as JSON with:

```
  print(pybindJSON.dumps(configs, indent=2))
```

This would yield:

```
{
  "interfaces": {
    "config": {
      "enabled": true
```

```
    }
  }
}
```

So to recap what we've done here:

We've created source-code from the gNMI Protocol Buffer file (available on GitHub). We've used that source-code in our Python script to issue some gNMI GetRequest messages against our sample gNMI Target. We then used gNMI Paths to issue another GetRequest, and converted the GetResponse to JSON, loading it into our generated language bindings from Lesson 3.

Worth noting, many of these steps would fail/throw an error if any of the attributes (either Key or Value) did not strictly adhere to the YANG model we created back in Lesson 1. This is important, as that YANG model defines the Schema, and it MUST be adhered to by any Network Element (gNMI Target) we deal with. In OpenConfig the YANG models are the source-of-truth so to speak. This allows us to write tooling without fear of vendor APIs returning differing structured data (or no structure at all).

Leave both containers running for the next lesson.

Further Reading

- gNMI Specification
- gNMI Path Conventions

Lesson 4 Appendix

- You can generate your own GoStructs, using the YGOT library. An example usage, as was done for our gnmi_target Container above would be:

```
go run ./ygot/generator/generator.go -path=./ -output_file=./generated.go
-package_name=gostruct -generate_fakeroot -fakeroot_name=device
-compress_paths=false openconfig-interface.yang
```

- You can also utilize the gnmi_client, written in Go. It's present in the gnmi_target container. An example usage would be:

```
go run /go/src/github.com/google/gnxi/gnmi_get/gnmi_get.go -xpath "/" -target_addr
172.20.0.4:10161 -target_name www.example.com -key ./client.key -cert ./client.crt
-ca ./ca.crt -username foo -password bar -alsologtostderr
```

- Tooling & versions used in this lesson:

- python -m pip install --no-binary=protobuf -I grpcio-tools==1.15.0
- Modification of gnmi.proto import of gnmi_ext.proto required:

```
import "gnmi_ext.proto";
```

Print only the value of rx-packets, when supplying gNMI paths:

```
print(gnmi_response.notification[0].update[0].val.uint_val)
```

Lesson 5: Storing & Visualizing Telemetry

Expected End Result

Set Up

The Topology for the following lessons is the same as the previous one.

Open a terminal and run InfluxDB in it's own container.

```
docker run -it --net ocnet --ip 172.20.0.5 mike909/influxdb:v1
```

Note, this container was built using [InfluxDB container.](#)

Leave that container open for informational messages and open another terminal to run Grafana in it's own container:

```
docker run -dp 3000:3000 --net ocnet --ip 172.20.0.6 mike909/grafana:v1
```

Note, this container was built using [grafana container.](#) This container will run in daemon mode, so you won't see any messages on the terminal after running. You can view the running containers with "docker ps".

Exercise

This is a bonus lesson. This is out-of-scope from gNMI, OpenConfig, YANG, gRPC etc. however may help to serve as an example of "how does all this stuff tie together?". Let's try to show that with a simple Time Series Database (TSDB) and some visualizations.

We're going to utilize an Open Source TSDB, [InfluxDB](#) and [Grafana](#), in this lesson though obviously each operator will utilize whichever systems they want.

1. Populate The Database

Here we're going to add our 'rx-packets' as a metric. We'll be using the containers and scripts we set up in earlier lessons. Over on your gnmi_client container, we're going to use the InfluxDB [Python client library](#). So let's add a couple lines to our "notso_simple_client.py" script, within the main function. For example:

```
if __name__ == '__main__':
  client = InfluxDBClient('172.20.0.5', 8086, 'root', 'root', 'oc_by_example')
  client.create_database('oc_by_example')
```

Now we're ready to start populating data, which is done using "client.write_points(<data_points>)". So let's add that into our script, and put it in a loop so we continually add the rx-packets value, every 5 seconds.
Replace our 'path_list' variable, and add the following:

```
  path_list = [gnmi_pb2.PathElem(name='interfaces', key={}),
               gnmi_pb2.PathElem(name='state', key={}),
               gnmi_pb2.PathElem(name='rx-packets', key={})]
  while True:
    gnmi_response = GetRequest(stub, path_list)
    rx_packets = gnmi_response.notification[0].update[0].val.uint_val
    print('Adding rx-packets %s to TSDB' % rx_packets)
    client.write_points([{"measurement": "rx_packets", "fields": { "value":
        rx_packets}}])
```

```
    time.sleep(5)
```

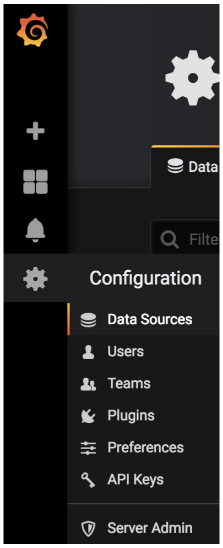
You should recognize most of this. We've experimented in previous lessons with dealing with the gNMI GetResponse, changing paths etc.. The only new line here is the 'client.write_points...', which as the name implies sends the result of our Gets to our TSDB. When you run this, it should show the following in your terminal:

```
root@gnmi_client:/home/user# python notso_simple_client.py
Adding rx-packets 73 to TSDB
Adding rx-packets 73 to TSDB
...
```

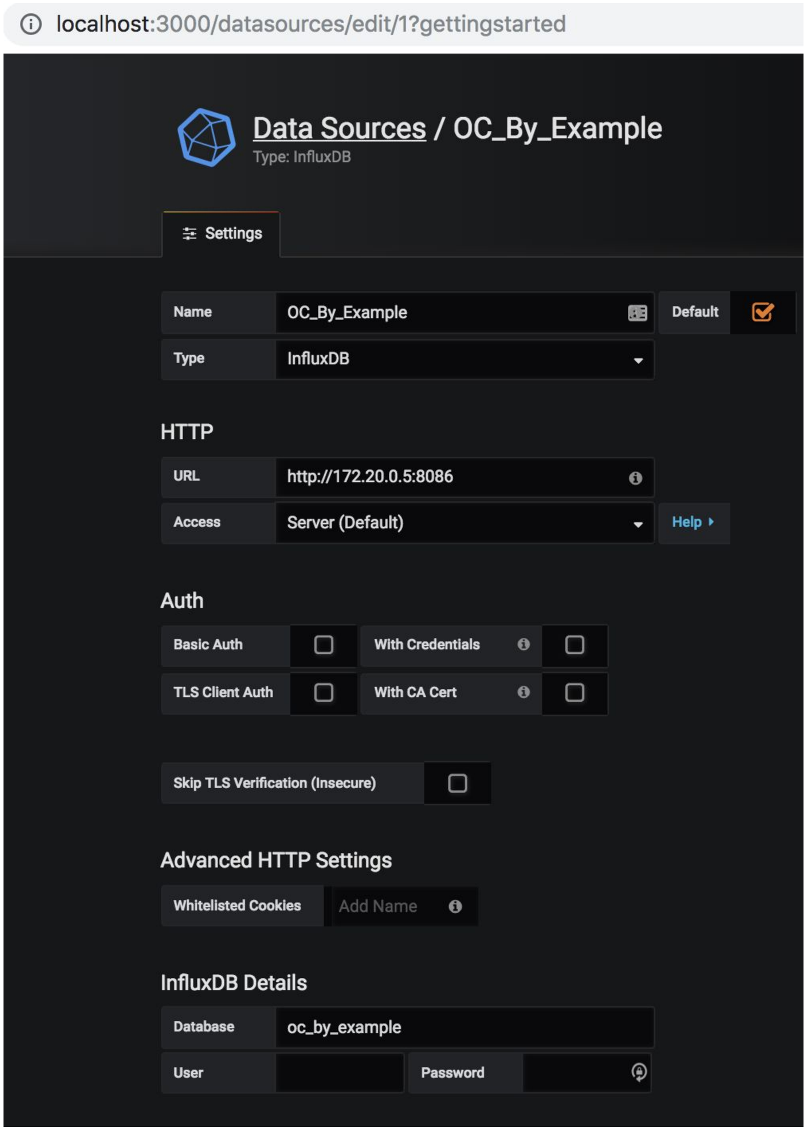
Leave that script running, as it will continually add data points to the TSDB using the InfluxDB HTTP API.

2. InfluxDB & Grafana

First, lets set up Grafana, and point it to our TSDB data source. Browse to http://localhost:3000. Default user/pass is admin/admin. Click Configure-->Data Sources, Add New Data Source:

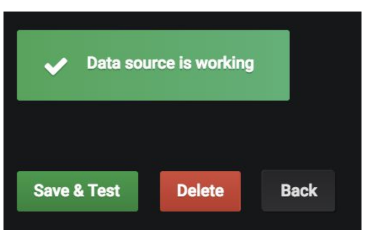


The options are mostly self explanatory, but here are the highlights:



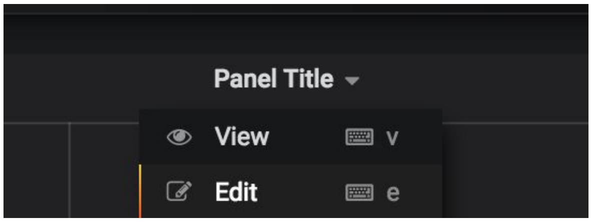
Type: InfluxDB
Name: OC_By_Example
URL: http://172.20.0.5:8086 (this is our Container running InfluxDB)
Database: oc_by_example

Click Save & Test, and you should see “Data source is working”:

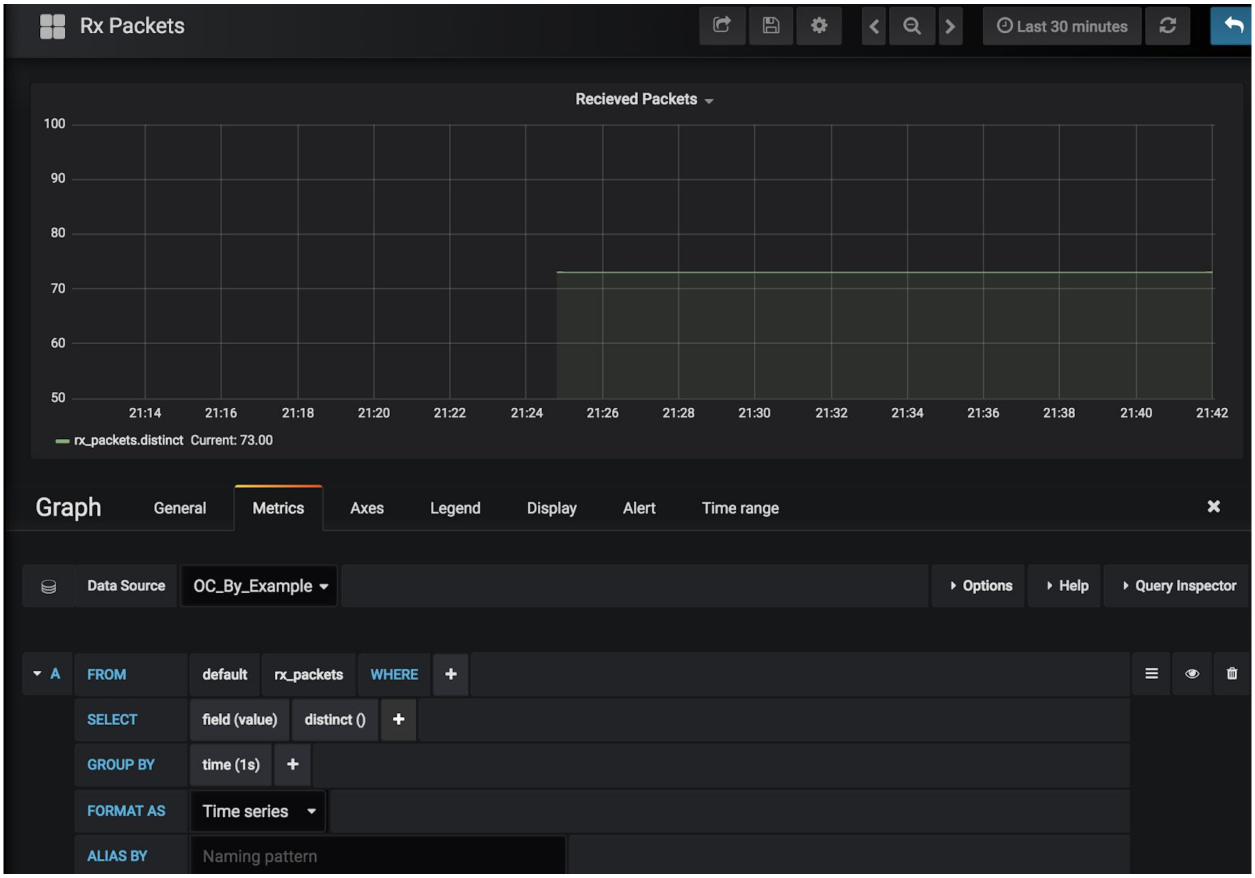


3. Graph It!

Lets graph the Telemetry we are consuming, eg the rx-packets. Click Dashboards→ Add New Dashboard. Again, the selections here are self explanatory, but for this lesson we'll be using a dashboard type of 'Graph'. Click 'Panel Title'-->Edit:



Change your Data Source to what you named it in Step 1 (OC_By_Example), and click in the 'Select Measurement' field. It should pre-populate with our metrics that are being inserted by our script, eg 'rx_packets':



You should see the graph beginning to populate itself with the results. That's it!

[Why don’t the rx-packets change over time?]

Lesson 5 Appendix

Why rx-packets don’t change

Recall that we’re emulating a gNMI Target. This emulated target has an ‘in-memory’ version of the our openconfig-interface.yang model. It’s not actually parsing the output of ifconfig, as we were doing in Lesson 1 & 2. Our in-person Deep Dive session utilized real Access Points.

Useful links

- [InfluxDB Python Client]

Conclusion

Obviously almost all the tools, concepts and descriptions here are introductory. Hopefully this was enough to draw some conclusions about the advantage of vendor/language/tool-chain neutrality and freedom of choice in all aspects. You are encouraged to learn more by checking each lessons Further Reading section, and breaking things.

Docker Cheat Sheet

Start a container and attach to local shell

```
docker run -it -<image_name> /bin/bash
```

Find a running container ID

```
docker ps
```

Attach a second terminal to that container

```
docker exec -it <container_id> /bin/bash
```

Run the container in the background

```
docker run -d <image_name>
```

Attach to a background container

```
docker attach <container_id>
```

Find details (like IP address) a container has

```
docker inspect <container_id>
```

Forward host port 4000 to Container port 80

```
docker run -p 4000:80 <image_name>
```

Delete an image

```
docker rmi <image_id> -f
```

Mount a host dir inside the container (/mnt/hostdir) & attach shell

```
docker run -it --mount type=bind,source=/Users/albanom/,target=/mnt/hostdir
friendlyhello /bin/bash
```

Run a remote image

```
docker run username/repository:tag
```

Customize the network

```
docker network create --subnet=172.18.0.0/16 mynet123
```

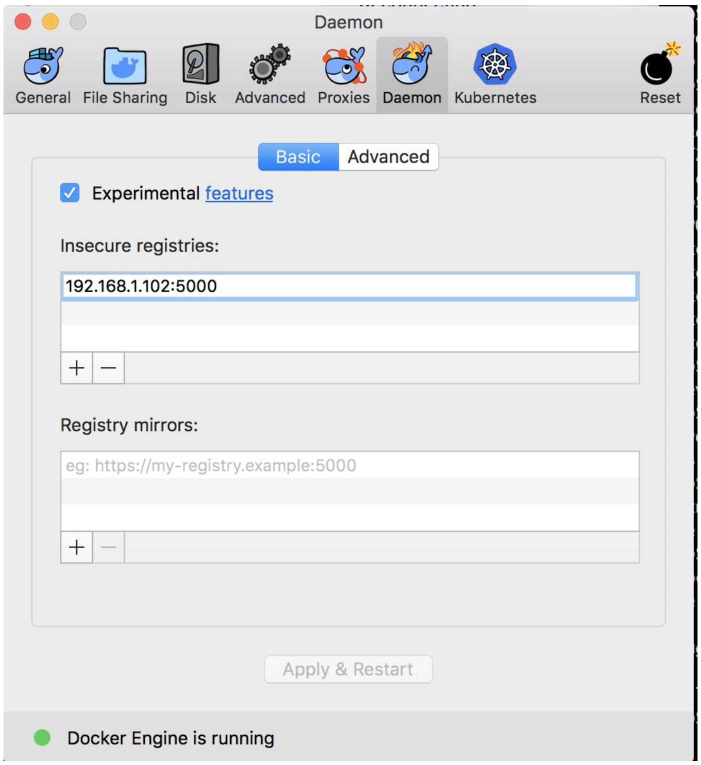
You can then use static IP with

```
docker run --net mynet123 --ip 172.18.0.22 -it ubuntu bash
```

Delete all stopped containers and unused images

```
docker system prune -a
```

Adding a local registry



And then:

```
docker pull 192.168.1.102:5000/influxdb:v1
```

InfluxDB Cheat Sheet

Initiate Influx CLI and connect to DB

```
$ Influx
> use ap_telemetry
```

List measurements

```
> show measurements
```

Show measurements for metric ‘radio0_state’

```
select * from radio0_state
```

Clear all entries for metric ‘radio0_state’

```
drop measurement radio0_state
```

Show field keys for a metric

```
show field keys from "radio0_state"
```