beam Documentation

Release 0.7.0

The BEAM Team

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Contents

BEAM extends the [Multi-Agent Transportation Simulation Framework (MATSim)](http://www.matsim.org/) to enable powerful and scalable analysis of urban transportation systems.

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CHAPTER 1

About BEAM

1.1 Overview

BEAM stands for Behavior, Energy, Autonomy, and Mobility. The model is being developed as a framework for a series of research studies in sustainable transportation at Lawrence Berkeley National Laboratory and the UC Berkeley Institute for Transportation Studies.

BEAM is an extension to the MATSim (Multi-Agent Transportation Simulation) model, where agents employ reinforcement learning across successive simulated days to maximize their personal utility through plan mutation (exploration) and selecting between previously executed plans (exploitation). The BEAM model shifts some of the behavioral emphasis in MATSim from across-day planning to within-day planning, where agents dynamically respond to the state of the system during the mobility simulation. In BEAM, agents can plan across all major modes of travel including driving, walking, biking, transit, and transportation network companies (TNCs).

These key features are summarized here and described in further detail below:

- **MATSim Integration** BEAM leverages the MATSim modeling framework[1], an open source simulation tool with a vibrant community of global developers. MATSim is extensible (BEAM is one of those extensions) which allows modelers to utilize a large suite of tools and plug-ins to serve their research and analytical interests.
- **Resource Markets** While BEAM can be used as a tool for modeling and analyzing the detailed operations of a transportation system, it is designed primarily as an approach to modeling resource markets in the transportation sector. The transportation system is composed of several sets of mobility resources that are in limited supply (e.g. road capacities, vehicle seating, ride hail fleet availability, refueling infrastructure). By adopting the MATSim utility maximization approach to achieving user equilibrium for traffic modeling, BEAM is able to find the corresponding equilibrium point across all resource markets of interest.
- **Dynamic Within-Day Planning** Because BEAM places a heavy emphasis on within-day planning, it is possible to simulate modern mobility services in a manner that reflects the emerging transportation system. For example, a virtual TNC in BEAM responds to customer inquiries by reporting the wait time for a ride, which the BEAM agents consider in their decision on what service or mode to use.
- **Rich Modal Choice** BEAM's mode choice model is structured so that agents select modal strategies (e.g. "car" versus "walk to transit" versus "ride hail") for each tour prior to the simulation day, but resolve the outcome of these strategies within the day (e.g. route selection, standard ride hail versus pooled, etc.).

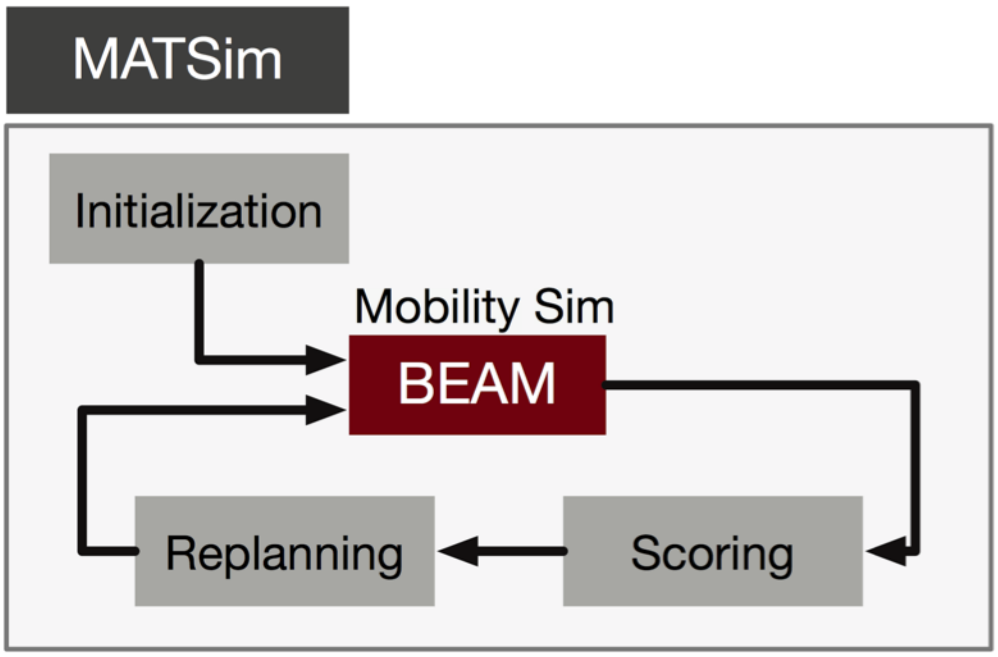
- **Transportation Network Companies** TNCs are already changing the mobility landscape and as driverless vehicles come online, the economics of these services will improve substantially. In BEAM, TNCs are modeled as a fleet of ride hail vehicles controlled by a centralized manager that responds to requests from customers and dispatches vehicles accordingly. The fleet can be composed of human drivers, autonomous vehicles, or a hybrid of both human and driverless. The management of the fleet has been developed as an API that can be implemented using mutliple algorithms, allowing users of BEAM to test their own fleet control strategies. Finally, we have implemented a scalable pooling algorithm that efficiency matches customers and pools them into vehicles. Pooled ride hail is treated as a distinct mode and therefore only customers who request such a ride are considered for pooling.
- **Parallel Within Day Dynamics** BEAM is written primarily in Scala and leverages the Akka library for currency which implements the [Actor Model of Computation](https://en.wikipedia.org/wiki/Actor_model). These tools enable the model to run as a parallel discrete event simulation. This capability is critical to simulate a transportation system that is more dynamic (primarily via on-demand forms of mobility) in a manner than can still achieve non-trivial scales. In addition, this approach allows BEAM to continue to use parallel processing while also simulating resource competition, e.g. agents are accessing finite resources like parking spaces, charging infrastructure, or micromobility vehicles in a manner that is still parallelized but nevertheless disallows one resource to be used by two agents simultaneously.
- **Open Source Code and Data** BEAM is released under a permissive open source license. The code can be copied, modified, and/or used for any purpose. In addition, we publish all of the data necessary to do production runs of BEAM. In other words, anyone can run the same BEAM scenarios that we use for our own projects and research activities. At the moment this consists of a San Francisco Bay Area application that has been calibrated and validated for use by the U.S. DOE's SMART Mobility Consortium.
- **Cloud Deployable** BEAM has been designed to integrate with Amazon Web Services including a framework to automatically deploy simulation runs to the cloud, to monitor those runs in real-time, and then upload results to S3 for permanent storage. An amazon EC2 snapshot capable of running BEAM can be made available to interested users upon request.

1.2 MATSim Integration

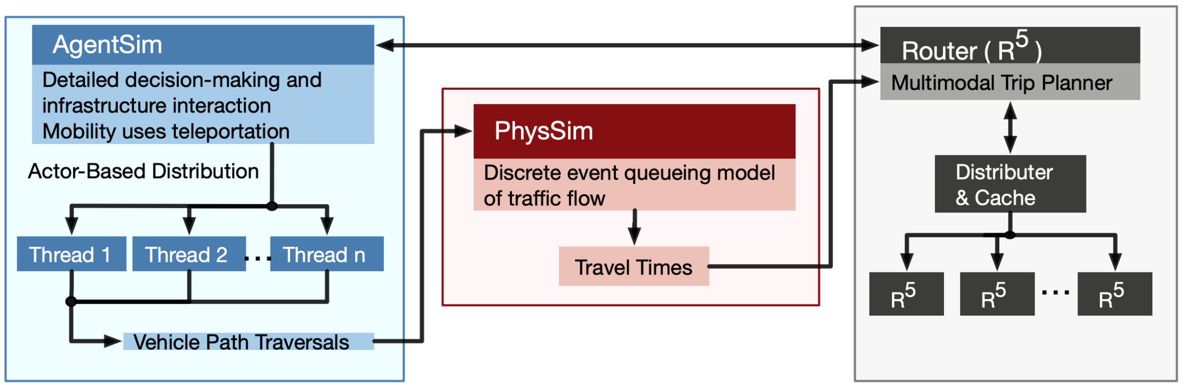
MATSim is a well established agent-based transportation simulation framework with hundreds of users and developers worldwide. BEAM leverages much of the overall structure and conventions of MATSim, but replaces several facilities with new software. The most important of these are the Mobility Simulation and Router.

1.2.1 BeamMobSim

When BEAM is executed, the MATSim engine manages loading of most data (population, households, vehicles, and the network used by PhysSim) as well as executing the MobSim -> Scoring -> Replanning iterative loop. BEAM takes over the MobSim, replacing the legacy MobSim engines (i.e. QSim) with the BeamMobSim.



The BeamMobSim is composed of two simulators, the **AgentSim** and the **PhysSim**. These simulators are related to each other and to the router as illustrated in the following diagram:



1.2.2 AgentSim

The AgentSim is designed to execute the daily plans of the population, allowing the agents to dynamically resolve how limited transportation resources are allocated (see *Resource Markets*).

All movements in the AgentSim occur via “teleportation” as discrete events. In other words, given a route and a travel time, an agent simply schedules herself to “arrive” at the destination accordingly. When this occurs, a PathTraversal Event is thrown – one for each vehicle movement, not necessarily each passenger movement – which is used by the PhysSim to simulate traffic flow, resolve congestion, and update travel times in the router so that in future iterations, agents will teleport according to travel times that are consistent with network congestion.

1.2.3 PhysSim

The PhysSim simulates traffic on the road network. The underlying simulation engine is based on the Java Discrete Event Queue Simulator (JDEQSim) from the MATSim framework. The JDEQSim then simulates traffic flow through the system and updated the Router with new network travel times for use in subsequent iterations.

JDEQSim was designed as a MobSim engine for MATSim, so it is capable of simulating activities and movements through the network. In BEAM, we use JDEQSim within PhysSim as purely a **vehicle** movement simulator. As PathTraversalEvents are received by the PhysSim, a set of MATSim Plans are created, with one plan for each vehicle in the AgentSim. These plans include "Activities" but they are just dummy activities that bracket the movement of each vehicle.

Currently, PhysSim and AgentSim run serially, one after another. This is due to the fact that the PhysSim is substantially faster to run than the AgentSim, because the PhysSim does not need to do any routing calculations. As improvements to AgentSim reduce run times, future versions of BEAM will likely allow AgentSim and PhysSim to run concurrently, or even be run in a tightly coupled manner where each teleportation in AgentSim is replaced with a direct simulation of the propagation of vehicles through the network by the PhysSim.

1.2.4 R5 Router

BEAM uses the R5 routing engine to accomplish multi-modal routing. Agents from BEAM make request of the router, and the results of the routing calculation are then transformed into objects that are directly usable by the BEAM agents to choose between alternative routes and move throughout the system.

1.2.5 MATSim Events

BEAM adopts the MATSim convention of throwing events that correspond to key moments in the agent's day. But in BEAM, there are two separate event managers, one for the ActorSim and another for the PhysSim.

The standard events output file (e.g. *0.events.csv*) comes from the AgentSim, but in the outputs directory, you will also find an events file from the PhysSim (e.g. *0.physSimEvents.xml.gz*). The events from AgentSim pertain to agents while the events in PhysSim pertain to vehicles. This is an important distinction.

The following MATSim events are thrown within the AgentSim:

- ActivityEndEvent
- PersonDepartureEvent
- PersonEntersVehicleEvent
- PersonLeavesVehicleEvent
- PersonArrivalEvent
- ActivityStartEvent

The following MATSim events are thrown within the PhysSim:

- ActivityEndEvent - these are dummy activities that bracket every vehicle movement
- PersonDepartureEvent - should be interpreted as **vehicle** departure
- LinkEnterEvent
- Wait2LinkEvent / VehicleEntersTraffic
- LinkLeaveEvent
- PersonArrivalEvent - should be interpreted as **vehicle** arrival

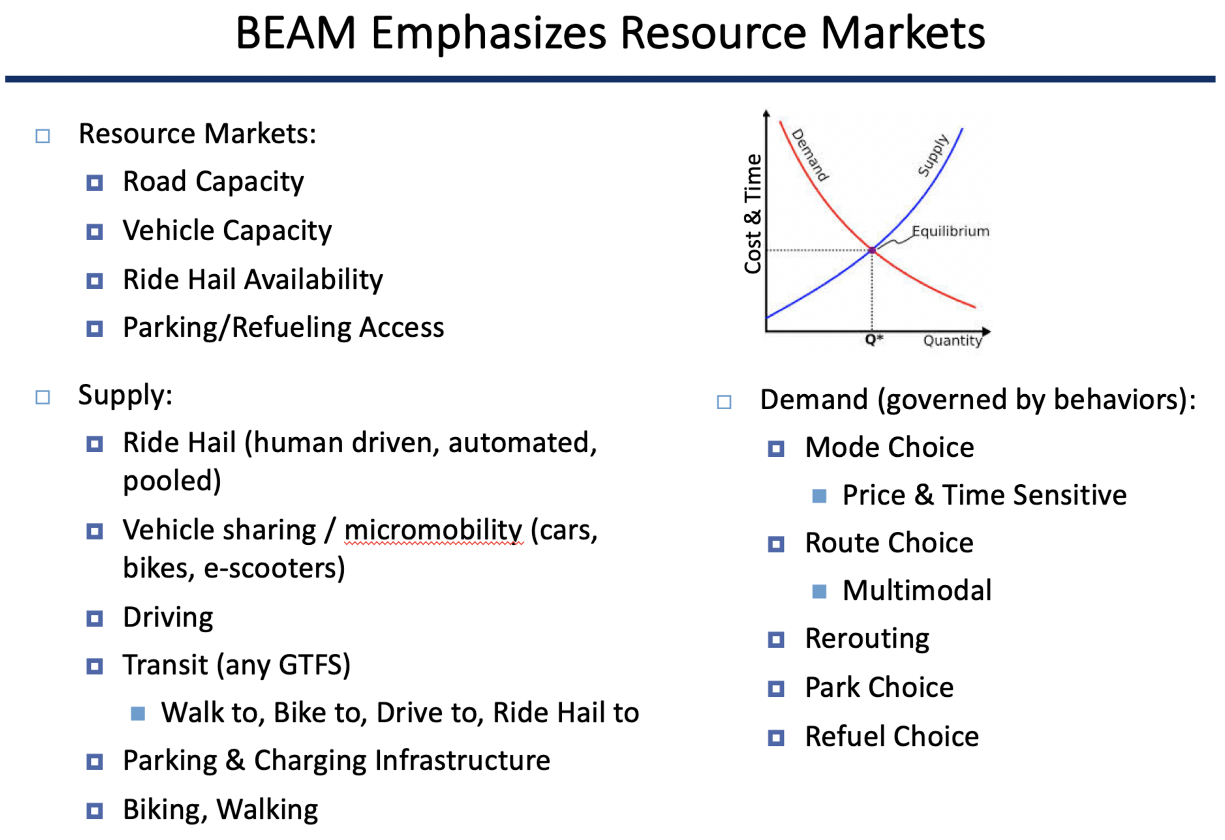
- ActivityStartEvent - these are dummy activities that bracket every vehicle movement

Extensions and modules written to observe the above MATSim events can be seamlessly integrated with BEAM in a read-only manner (i.e. for analysis, summary, visualization purposes). However, extensions that are designed to accomplish "within-day" replanning in MATSim will not be directly compatible with BEAM. This is because BEAM already does extensive "within-day" replanning in a manner that is substantially different from QSim.

In addition to the standard MATSim events described above, BEAM throws additional events that correspond to the act of choosing a Mode (*ModeChoiceEvent*) and of vehicle movements through the network (*PathTraversalEvent*).

All events (both MATSim and BEAM-specific) and their field descriptions are described in further detail in *Event Specifications*.

1.3 Resource Markets



BEAM Emphasizes Resource Markets

- Resource Markets:
  - Road Capacity
  - Vehicle Capacity
  - Ride Hail Availability
  - Parking/Refueling Access
- Supply:
  - Ride Hail (human driven, automated, pooled)
  - Vehicle sharing / micromobility (cars, bikes, e-scooters)
  - Driving
  - Transit (any GTFS)
    - Walk to, Bike to, Drive to, Ride Hail to
  - Parking & Charging Infrastructure
  - Biking, Walking
- Demand (governed by behaviors):
  - Mode Choice
    - Price & Time Sensitive
  - Route Choice
    - Multimodal
  - Rerouting
  - Park Choice
  - Refuel Choice

While BEAM can be used as a tool for modeling and analyzing the detailed operations of a transportation system, it is designed primarily as an approach to modeling resource markets in the transportation sector.

The transportation system is composed of several sets of mobility resources that are in limited supply (e.g. road capacities, vehicle seating, ride hail fleet availability, refueling infrastructure). With the exception of road capacities, all resources in BEAM are explicitly modeled. For example, there are a finite number of seats available on transit vehicles and there are a finite number of ride hail drivers.

As resources are utilized by travelers, they become unavailable to other travelers. This resource competition is resolved dynamically within the AgentSim, making it impossible for multiple agents to simultaneously utilize the same resource.

The degree to which agents use resources is determined both by resource availability and traveler behavior. As the supply of ride hail drivers becomes limited, the wait times for hailing a ride increase, which leads to lower utility scores in the mode choice process and therefore reduced consumption of that resource.

By adopting the MATSim utility maximization approach to achieving user equilibrium for traffic modeling, BEAM is able to find the corresponding equilibrium point across all resource markets of interest. Each agent maximizes her utility through the replanning process (which occurs outside the simulation day) as well as within the day through dynamic choice processes (e.g. choosing mode based on with-in day evaluation of modal alternatives).

Ultimately, the combined outcome of running BEAM over successive iterations is a system equilibrium that balances the trade-offs between all resources in the system.

In the figure above, the resource markets that are functioning in BEAM v0.8.0 are listed.

1.4 Dynamic Within-Day Planning

Because BEAM places a heavy emphasis on within-day planning, it is possible to simulate modern mobility services in a manner that reflects the emerging transportation system.

For example, a virtual TNC in BEAM responds to customer inquiries by reporting the wait time for a ride, which the BEAM agents consider in their decision on what service or mode to use.

1.5 Rich Modal Choice

BEAM's mode choice model is structured so that agents select modal strategies (e.g. "car" versus "walk to transit" versus "ride hail") for each tour prior to the simulation day, but resolve the outcome of these strategies within the day (e.g. route selection, standard ride hail versus pooled, etc.). BEAM currently supports a simple multinomial logit choice model and a more advanced model is under development and will be fully supported by Spring 2018.

1.6 Plug-in Electric Vehicle Modeling with BEAM

In 2016, BEAM was originally developed to simulate personally-owned plug-in electric vehicles (PEVs), with an emphasis on detailed representation of charging infrastructure and driver behavior around charging.

In 2017, BEAM underwent a major revision, designed to simulate all modes of travel and to prepare the software for scalability and extensibility. We therefore no longer support the "PEV Only" version of BEAM, though the codebase is still available on the BEAM Github repository under the branch pev-only. In 2018, PEVs were re-implemented in BEAM following the new framework. In addition, BEAM supports modeling the refueling of fleets of electrified ride hail vehicles.

The key features of the "PEV Only" version of BEAM are summarized here and described in further detail in reports linked below.

- **Detailed Representation of Charging Infrastructure** In BEAM, individual chargers are explicitly represented in the region of interest. Chargers are organized as sites that can have multiple charging points which can have multiple plugs of any plug type. The plug types are defined by their technical characteristics (i.e. power capacity, price, etc.) and their compatibility with vehicles types (e.g. Tesla chargers vs. CHAdeMO vs. SAE). Physical access to chargers is also represented explicitly, i.e., charging points can only be accessed by a limited number of parking spaces. Chargers are modeled as queues, which can be served in an automated fashion (vehicle B begins charging as soon as vehicle A ends) or manually by sending notifications to agents that it is their turn to begin a charging session.

- **Robust Behavioral Modeling** The operational decisions made by PEV drivers are modeled using discrete choice models, which can be parameterized based on the outcomes of stated preference surveys or reveled preference analyses. For example, the decision of whether and where to charge is currently modeled in BEAM as a nested logit choice that considers a variety of factors including the location, capacity, and price of all chargers within a search radius in addition to the state of charge of the PEV and features of the agent's future mobility needs for the day. The utility functions for the model are in part based on empirical work by Wen et al.[2] who surveyed PEV drivers and analyzed the factors that influence their charging decisions.

1.7 Contact Information

Primary Technical Contacts:

Colin Sheppard colin.sheppard@lbl.gov

Rashid Waraich rwaraich@lbl.gov

1.8 References

1. Horni, A., Nagel, K. and Axhausen, K.W. (eds.) 2016 The Multi-Agent Transport Simulation MATSim. London: Ubiquity Press. DOI: http://dx.doi.org/10.5334/baw. License: CC-BY 4.0.
2. Wen, Y., MacKenzie, D. & Keith, D. Modeling the Charging Choices of Battery Electric Vehicle Drivers Using Stated Preference Data. TRB Proc. Pap. No 16-5618

CHAPTER 2

User's Guide

2.1 Getting Started

The following guide is designed as a demonstration of using BEAM and involves running the model on a scaled population and transportation system. This is the ideal place to familiarize yourself with the basics of configuring and running BEAM as well as doing small scale tests and analysis.

For more advanced utilization or to contribute to the BEAM project, see the *Developer's Guide*.

2.1.1 System Requirements

- At least 8GB RAM
- Windows, Mac OSX, Linux
- Java Development Kit 1.8. Oracle JDK 1.8: https://www.oracle.com/java/technologies/javase-jdk8-downloads.html. You can also use OpenJDK 8 JDK. For Ubuntu you can get it installed by running *sudo apt-get install openjdk-8-jdk*
- Verify that you have both java runtime and java compiler:

```
ubuntu@ip-172-31-14-187:~/git/beam$ java -version
openjdk version "1.8.0_252"
OpenJDK Runtime Environment (build 1.8.0_252-8u252-b09-1~18.04-b09)
OpenJDK 64-Bit Server VM (build 25.252-b09, mixed mode)
ubuntu@ip-172-31-14-187:~/git/beam$ javac -version
javac 1.8.0_252
ubuntu@ip-172-31-14-187:~/git/beam$
```

- We also recommend downloading the VIA vizualization app and obtaining a free or paid license: https://simunto.com/via/
- Git and Git-LFS

2.1.2 Prerequisites :

Install Java

BEAM requires Java 1.8 JDK. If a different version of java is already installed on your system, please upgrade the version to 1.8. See this link for steps to check the current version of your JDK.

If java is not already installed on your system , please follow this download manual to install java on your system.

Please note that BEAM is currently compatible only with Java 1.8 and is not compatible with any of the older or recent versions.

Install Gradle

BEAM uses gradle as its build tool. If gradle is not already installed, check this gradle installation guide for steps on how to download and install gradle. Once gradle is successfully installed , verify the installation by running the command

```
gradle
```

2.1.3 GIT-LFS Configuration

The installation process for git-lfs client(v2.3.4, latest installer has some issue with node-git-lfs) is very simple. For detailed documentation please consult github guide for Mac, windows and Linux.

To verify successful installation, run following command:

```
$ git lfs install
Git LFS initialized.
```

To confirm that you have installed the correct version of client run the following command:

```
$ git lfs env
```

It will print out the installed version, and please make sure it is *git-lfs/2.3.4*.

To update the text pointers with the actual contents of files, run the following command (if it requests credentials, use any username and leave the password empty):

```
$ git lfs pull
Git LFS: (98 of 123 files) 343.22 MB / 542.18 MB
```

Installing git lfs on windows :

With Git LFS windows installation, it is common to have the wrong version of git-lfs installed, because in these latest git client version on windows, git lfs comes packaged with the git client.

When installing the git client one needs to uncheck git lfs installation. If mistakenly you installed git lfs with the git client, the following steps are needed to correct it (uninstalling git lfs and installing the required version does not work. . .):

- Uninstall git
- Install the git client (uncheck lfs installation)
- Install git lfs version 2.3.4 separately

Another alternative to above is to get the old git-lfs.exe from the release archives and replace the executable found in

[INSTALL PATH]\mingw6\bin and *[INSTALL PATH]\cmd*, where the default installation path usually is *C:\Program Files\Git*

2.1.4 Installing BEAM

Clone the beam repository:

```
git clone git@github.com:LBNL-UCB-STI/beam.git
```

Change directories into that repository:

```
cd beam
```

Fetch the remote branches and tags:

```
git fetch
```

Now checkout the latest stable version of BEAM, v0.7.0:

```
git checkout v0.7.0
```

Run the gradle command to compile BEAM, this will also downloaded all required dependencies automatically:

```
./gradlew classes
```

Now you're ready to run BEAM!

2.1.5 Running BEAM

Inside of the respository is a folder 'test/input' containing several scenarios and configurations you can experiment with.

The simplest, smallest, and fastest is the beamville scenario (described below). Try to run beamville with this command:

```
./gradlew :run -PappArgs="['--config', 'test/input/beamville/beam.conf']"
```

The BEAM application by default sets max RAM allocation to 140g (see **maxRAM** setting in gradle.properties). This needs to be adjusted based on the available memory on your system.

The max allocatable RAM value can be overriden by setting the environment variable **MAXRAM** to the required value.

On Ubuntu , the environment variable can be set using the below command :

```
export MAXRAM=10g
```

where 10g = 10GB

Similarly on windows it can be set using the below command :

```
setx MAXRAM="10g"
```

The outputs are written to the 'output' directory, should see results appear in a sub-folder called "beamville_%DATE_TIME%".

Optionally you can also run BEAM from your favourite IDE . Check the below section on how to configure and run BEAM using Intellij IDEA.

There is a way to watch real-time graphs from a BEAM run, see *Real time graphs*.

2.1.6 Running BEAM with Intellij IDE

IntelliJ IDEA community edition is an open source IDE available for free. It can be downloaded from here

After successful download , run the executable and follow the installation wizard to install Intellij IDEA.

When running the IDE for the first time , it asks to import previous settings (if any) from a local path, if no previous settings to choose , select "Do not import settings" and click Ok.

Importing BEAM project into IDE

Once the IDE is successfully installed , proceed with the below steps to import BEAM into the IDE.

1. **Open the IDE and agree to the privacy policy and continue**

    (Optional) IDEA walks you through some default configurations set up here . In case you want to skip these steps , cl

    - Select a UI theme of choice and go to Next: Default Plugins
    - Select only the required plugins (gradle , java are mandatory) and disable the others and go to Next:Feature plugins
    - Install scala and click "Start using Intellij IDEA"

2. In the welcome menu , select "Import Project" and provide the location of the locally cloned BEAM project
3. Inside the import project screen, select "Import project from external model" and choose "Gradle" from the available and click Next
4. Click Finish.

The project should now be successfully imported into the IDE and a build should be initiated automatically. If no build is triggered automatically , you can manually trigger one by going to Build > Build Project.

Installing scala plugin

If optional configuration in step 1 of above section was skipped , scala plugin will not be added automatically . To manually enable scala plugin go to File > Settings > Plugins. Search for scala plugin and click Install.

Setting up scala SDK

Since BEAM is built with java/scala . A scala sdk module needs to be configured to run BEAM. Check the below steps on how to add a scala module to IDEA * Go to File > Project Settings > Global Libraries * Click + and select Scala SDK * Select the required scala SDK from the list , if no SDK found click Create. * Click "Browse" and select the scala home path or click "Download" (choose 2.12.x version)

Running BEAM from IDE

BEAM requires some arguments to be specified during run-time like the scenario configuration. These configuration settings can be added as a run configuration inside the IDE.

Steps to add a new configuration :

- Go to Run > Edit Configurations
- Click + and from the templates list and select "Application"
- Fill in the following values
  - Main Class : beam.sim.RunBeam
  - VM options : -Xmx8g
  - Program Arguments : –config test/input/beamville/beam.conf (this runs beamville scenario, changes the folder path to run a different scenario)

  - Working Directory : /home/beam/BEAM
  - Environment Variables : PWD=/home/beam/BEAM
  - use submodule of path : beam.main
- Click Ok to save the configuration.

To add a configuration for a different scenario , follow the above steps and change the folder path to point to the required scenario in program arguments

2.1.7 BEAM in Docker image

Building new BEAM image from any branch

There is a gradle commands to build new BEAM Docker image. This command will build a docker image and tag it with the *version* taken from build.gradle file.:

```
./gradlew buildImage
```

Running the docker image with BEAM

To run the docker image with BEAM one needs to provide input folder with all input information (config, map, plans, etc.) and point to the output folder.

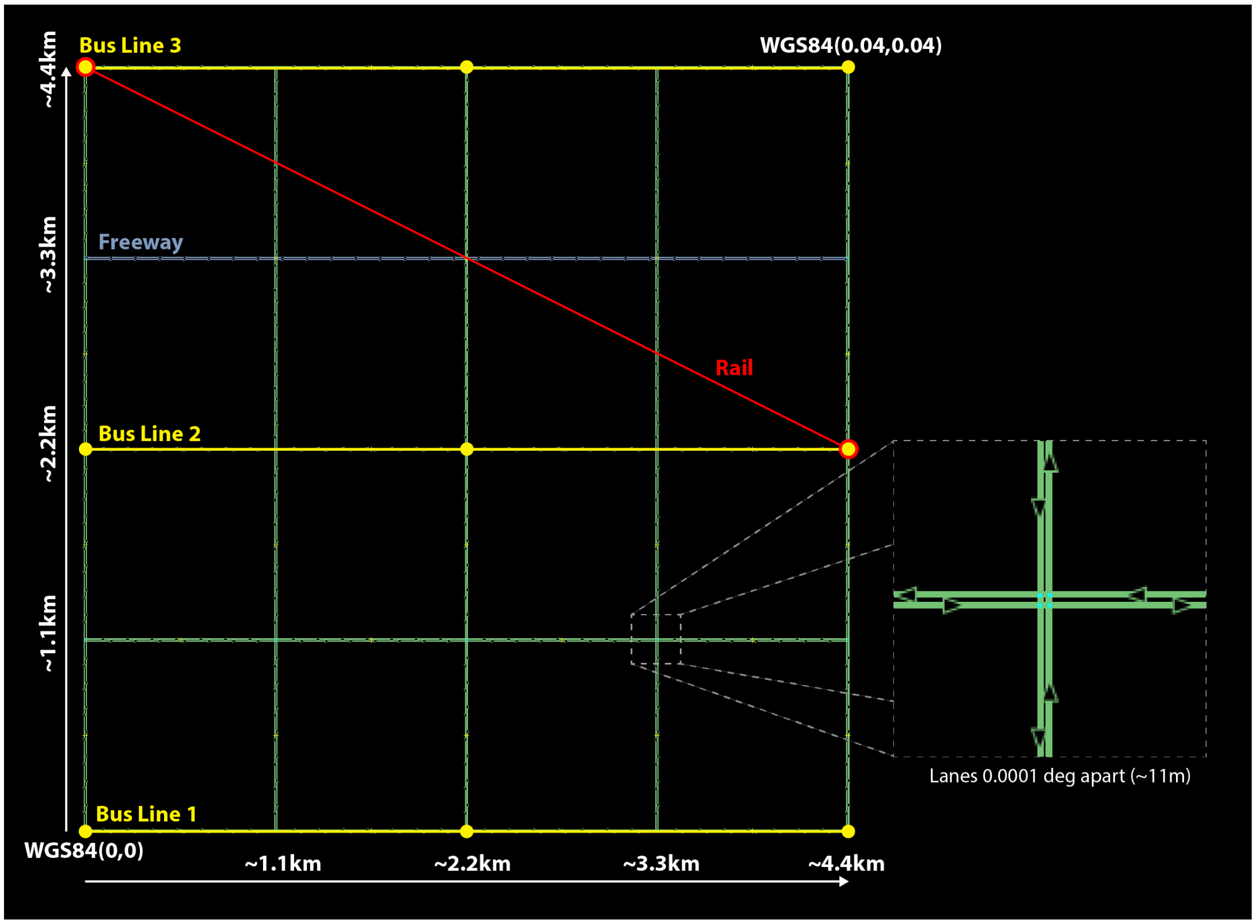
For example here is a shell script which might be used to run the docker image. One needs to replace 'tag', input and output folder name:

```
#!/bin/bash

config=$1
beam_image="beammodel/beam:0.8.6"
input_folder_name="test"
output_folder_name="beam_output"
mkdir -m 777 $output_folder_name 2>/dev/null

max_ram='10g'
java_opts="-Xmx$max_ram -XX:+UnlockExperimentalVMOptions -
↪XX:+UseCGroupMemoryLimitForHeap"

docker run \
  --network host \
  --env JAVA_OPTS="$java_opts" \
  --mount source="$(pwd)/$input_folder_name",destination=/app/$input_folder_name,
↪type=bind \
  --mount source="$(pwd)/$output_folder_name",destination=/app/output,type=bind \
  $beam_image --config=$config
```

2.1.8 Scenarios

We have provided two scenarios for you to explore under the *test/input* directory.

The *beamville* test scenario is a toy network consisting of a 4 x 4 block gridded road network, a light rail transit agency, a bus transit agency, and a population of ~50 agents.



The *sf-light* scenario is based on the City of San Francisco, including the SF Muni public transit service and a range of sample populations from 1000 to 25,000 agents.

2.1.9 Inputs

For more detailed inputs documentation, see *Model Inputs*.

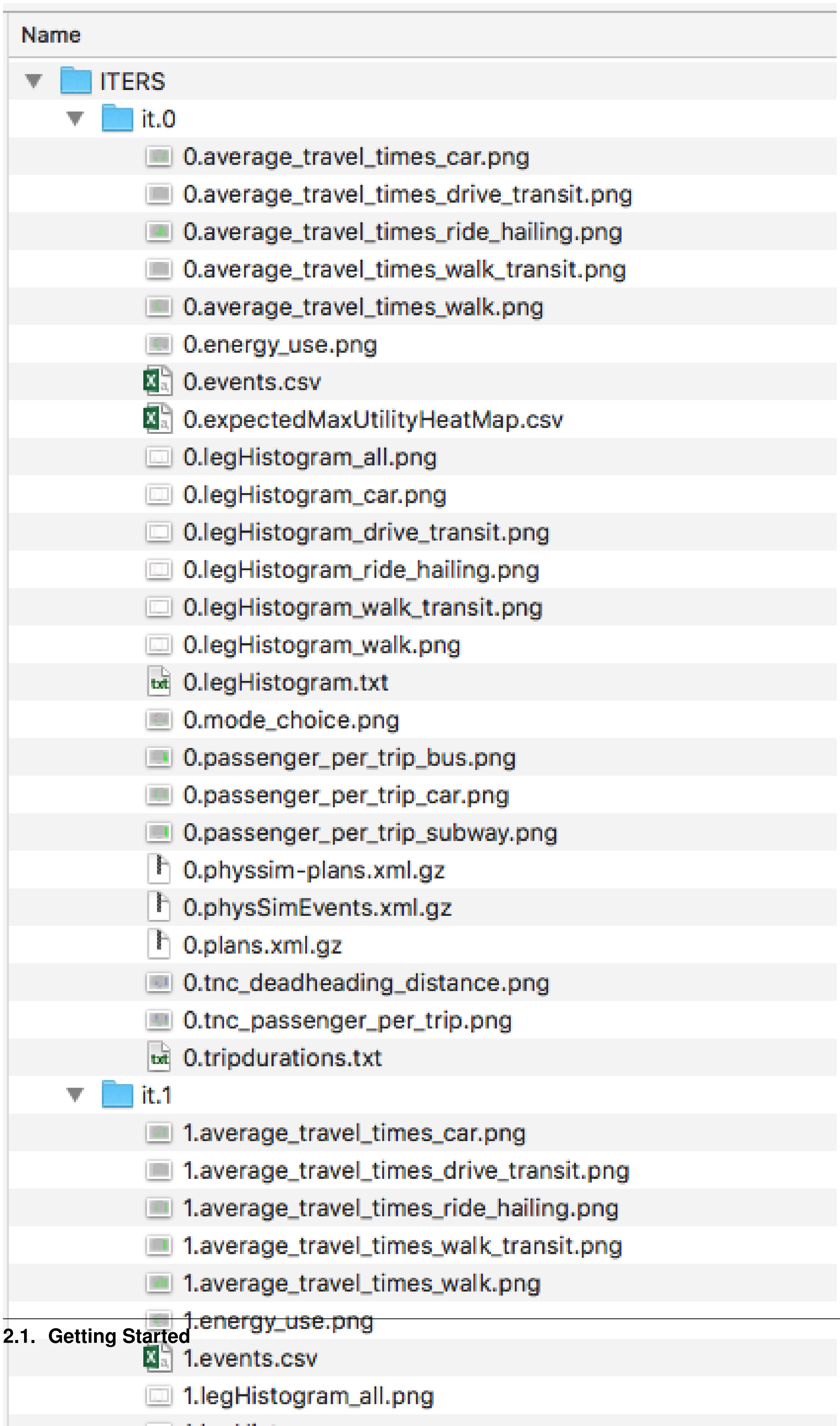
BEAM follows the MATSim convention for most of the inputs required to run a simulation, though some inputs files can alternatively be provided in CSV instead of XML format. Also, the road network and transit system inputs are based on the R5 requirements. The following is a brief overview of the minimum requirements needed to conduct a BEAM run.

- A configuration file (e.g. *beam.conf*)
- The person population and corresponding attributes files (e.g. *population.xml* and *populationAttributes.xml*)
- The household population and corresponding attributes files (e.g. *households.xml* and *householdAttributes.xml*)
- The personal vehicle fleet (e.g. *vehicles.csv*)
- The definition of vehicle types including for personal vehicles and the public transit fleet (e.g. *vehicleTypes.csv*)

- A directory containing network and transit data used by R5 (e.g. *r5/*)
- The open street map network (e.g. *r5/beamville.osm*)
- GTFS archives, one for each transit agency (e.g. *r5/bus.zip*)

2.1.10 Outputs

At the conclusion of a BEAM run using the default *beamville* scenario, the output files in the should look like this when the run is complete:



```
Name
▼ ITERS
    ▼ it.0
        0.average_travel_times_car.png
        0.average_travel_times_drive_transit.png
        0.average_travel_times_ride_hailing.png
        0.average_travel_times_walk_transit.png
        0.average_travel_times_walk.png
        0.energy_use.png
        0.events.csv
        0.expectedMaxUtilityHeatMap.csv
        0.legHistogram_all.png
        0.legHistogram_car.png
        0.legHistogram_drive_transit.png
        0.legHistogram_ride_hailing.png
        0.legHistogram_walk_transit.png
        0.legHistogram_walk.png
        0.legHistogram.txt
        0.mode_choice.png
        0.passenger_per_trip_bus.png
        0.passenger_per_trip_car.png
        0.passenger_per_trip_subway.png
        0.physsim-plans.xml.gz
        0.physSimEvents.xml.gz
        0.plans.xml.gz
        0.tnc_deadheading_distance.png
        0.tnc_passenger_per_trip.png
        0.tripdurations.txt
    ▼ it.1
        1.average_travel_times_car.png
        1.average_travel_times_drive_transit.png
        1.average_travel_times_ride_hailing.png
        1.average_travel_times_walk_transit.png
        1.average_travel_times_walk.png
        1.energy_use.png
        1.events.csv
        1.legHistogram_all.png
```

Each iteration of the run produces a sub-folder under the *ITERS* directory. Within these, several automatically generated outputs are written including plots of modal usage, TNC dead heading, and energy consumption by mode.

In addition, raw outputs are available in the two events file (one from the AgentSim and one from the PhysSim, see *MATSim Events* for more details), titled *%ITER%.events.csv* and *%ITER%.physSimEvents.xml.gz* respectively.

2.1.11 Model Config

To get started, we will focus your attention on a few of the most commonly used and useful configuration parameters that control beam:

```
# Ride Hailing Params
beam.agentsim.agents.rideHail.initialization.procedural.
↪numDriversAsFractionOfPopulation=0.05
beam.agentsim.agents.rideHail.defaultCostPerMile=1.25
beam.agentsim.agents.rideHail.defaultCostPerMinute=0.75
# Scaling and Tuning Params; 1.0 results in no scaling
beam.agentsim.tuning.transitCapacity = 0.2
beam.agentsim.tuning.transitPrice = 1.0
beam.agentsim.tuning.tollPrice = 1.0
beam.agentsim.tuning.rideHailPrice = 1.0
```

- numDriversAsFractionOfPopulation - Defines the # of ride hailing drivers to create. Drivers begin the simulation located at or near the homes of existing agents, uniformly distributed.
- defaultCostPerMile - One component of the 2 part price of ride hail calculation.
- defaultCostPerMinute - One component of the 2 part price of ride hail calculation.
- transitCapacity - Scale the number of seats per transit vehicle… actual seats are rounded to nearest whole number. Applies uniformly to all transit vehilces.
- transitPrice - Scale the price of riding on transit. Applies uniformly to all transit trips.
- tollPrice - Scale the price to cross tolls.
- rideHailPrice - Scale the price of ride hailing. Applies uniformly to all trips and is independent of defaultCostPerMile and defaultCostPerMinute described above. I.e. price = (costPerMile + costPerMinute)*rideHailPrice

2.2 Experiment Manager

BEAM features a flexible experiment manager which allows users to conduct multi-factorial experiments with minimal configuration. The tool is powered by Jinja templates (see more http://jinja.pocoo.org/docs/2.10/).

We have created two example experiments to demonstrate how to use the experiment manager. The first is a simple 2-factorial experiment that varies some parameters of scientific interest. The second involves varying parameters of the mode choice model as one might do in a calibration exercise.

In any experiment, we seek to vary the parameters of BEAM systematically and producing results in an organized, predicable location to facilitate post-processing. For the two factor experiment example, we only need to vary the contents of the BEAM config file (beam.conf) in order to achieve the desired anlaysis.

Lets start from building your experiment definitions in experiment.yml (see example in *test/input/beamville/example-experiment/experiment.yml*). *experiment.yml* is a YAML config file which consists of 3 sections: header, defaultParams, and factors.

The Header defines the basic properties of the experiment, the title, author, and a path to the configuration file (paths should be relative to the project root):

```
title: Example-Experiment
author: MyName
beamTemplateConfPath: test/input/beamville/beam.conf
```

The Default Params are used to override any parameters from the BEAM config file for the whole experiment. These values can, in turn, be overridden by factor levels if specified. This section is mostly a convenient way to ensure certain parameters take on specific values without modifying the BEAM config file in use.

Experiments consist of ‘factors’, which are a dimension along which you want to vary parameters. Each instance of the factor is a level. In our example, one factor is “transitCapacity” consisting of two levels, “Low” and “High”. You can think about factors as of main influencers (or features) of simulation model while levels are discrete values of each factor.

Factors can be designed however you choose, including adding as many factors or levels within those factors as you want. E.g. to create a 3 x 3 experimental design, you would set three levels per factor as in the example below:

```
factors:
  - title: transitCapacity
    levels:
    - name: Low
      params:
        beam.agentsim.tuning.transitCapacity: 0.01
    - name: Base
      params:
        beam.agentsim.tuning.transitCapacity: 0.05
    - name: High
      params:
        beam.agentsim.tuning.transitCapacity: 0.1

  - title: ridehailNumber
    levels:
    - name: Low
      params:
        beam.agentsim.agents.rideHail.numDriversAsFractionOfPopulation: 0.001
    - name: Base
      params:
        beam.agentsim.agents.rideHail.numDriversAsFractionOfPopulation: 0.01
    - name: High
      params:
        beam.agentsim.agents.rideHail.numDriversAsFractionOfPopulation: 0.1
```

Each level and the baseScenario defines *params*, or a set of key,value pairs. Those keys are either property names from beam.conf or placeholders from any template config files (see below for an example of this). Param names across factors and template files must be unique, otherwise they will overwrite each other.

In our second example (see directory *test/input/beamville/example-calibration/*), we have added a template file *modeChoiceParameters.xml.tpl* that allows us to change the values of parameters in BEAM input file *modeChoiceParameters.xml*. In the *experiment.yml* file, we have defined 3 factors with two levels each. One level contains the property *mnl_ride_hail_intercept*, which appears in modeChoiceParameters.xml.tpl as *{{ mnl_ride_hail_intercept }}*. This placeholder will be replaced during template processing. The same is true for all properties in the defaultParams and under the facts. Placeholders for template files must NOT contain the dot symbol due to special behaviour of Jinja. However it is possible to use the full names of properties from *beam.conf* (which *do* include dots) if they need to be overridden within this experiment run.

Also note that *mnl_ride_hail_intercept* appears both in the level specification and in the baseScenario. When using a template file (versus a BEAM Config file), each level can only override properties from Default Params section of *experiment.yml*.

Experiment generation can be run using following command:

```
./gradlew -PmainClass=beam.experiment.ExperimentGenerator -PappArgs="['--experiments',
↪ 'test/input/beamville/example-experiment/experiment.yml']" execute
```

It's better to create a new sub-folder folder (e.g. 'calibration' or 'experiment-1') in your data input directory and put both templates and the experiment.yml there. The ExperimentGenerator will create a sub-folder next to experiment.yml named *runs* which will include all of the data needed to run the experiment along with a shell script to execute a local run. The generator also creates an *experiments.csv* file next to experiment.yml with a mapping between experimental group name, the level name and the value of the params associated with each level.

Within each run sub-folder you will find the generated BEAM config file (based on beamTemplateConfPath), any files from the template engine (e.g. *modeChoiceParameters.xml*) with all placeholders properly substituted, and a *runBeam.sh* executable which can be used to execute an individual simulation. The outputs of each simulation will appear in the *output* subfolder next to runBeam.sh

2.3 Calibration

This section describes calibrating BEAM simulation outputs to achieve real-world targets (e.g., volumetric traffic counts, mode splits, transit boarding/alighting, etc.). A large number of parameters affect simulation behavior in complex ways such that grid-search tuning methods would be extremely time-consuming. Instead, BEAM uses SigOpt, which uses Bayesian optimization to rapidly tune scenarios as well as analyze the sensitivity of target metrics to parameters.

2.3.1 Optimization-based Calibration Principles

At a high level, the SigOpt service seeks to find the *optimal value*, p^* of an *objective*, $f_0 : \mathbb{R}^n \rightarrow \mathbb{R}$, which is a function of a vector of *decision variables* $x \in \mathbb{R}^n$ subject to *constraints*, $f_i : \mathbb{R}^n \rightarrow \mathbb{R}, i = 1, \ldots, m.$

In our calibration problem, p^* represents the value of a *metric* representing an aggregate measure of some deviation of simulated values from real-world values. Decision variables are hyperparameters defined in the *.conf* file used to configure a BEAM simulation. The constraints in this problem are the bounds within which it is believed that the SigOpt optimization algorithm should search. The calibration problem is solved by selecting values of the hyperparameters that minimize the output of the objective function.

Operationally, for each calibration attempt, BEAM creates an *Experiment* using specified *Parameter* variables, their *Bounds's, and the number of workers (applicable only when using parallel calibration execution) using the SigOpt API. The experiment is assigned a unique ID and then receives a 'Suggestion* (parameter values to simulate) from the SigOpt API, which assigns a value for each *Parameter*. Once the simulation has completed, the metric (an implementation of the *beam.calibration.api.ObjectiveFunction* interface) is evaluated, providing an *Observation* to the SigOpt API. This completes one iteration of the calibration cycle. At the start of the next iteration new *Suggestion* is returned by SigOpt and the simulation is re-run with the new parameter values. This process continues for the number of iterations specified in a command-line argument.

> Note: that this is a different type of iteration from the number of iterations of a run of BEAM itself. Users may wish to run BEAM for several iterations of the co-evolutionary plan modification loop prior to evaluating the metric.

2.3.2 SigOpt Setup

Complete the following steps in order to prepare your simulation scenarios for calibration with SigOpt:

1. Sign up for a SigOpt account (note that students and academic researchers may be able to take advantage of educational pricing options).

2. Log-in to the SigOpt web interface.

3. Under the API Tokens menu, retrieve the **API Token** and **Development Token** add the tokens as environmental variables in your execution environment with the keys *SIGOPT_API_TOKEN* and *SIGOPT_DEV_API_TOKEN*.

2.3.3 Configuration

Prepare YML File

Configuring a BEAM scenario for calibration proceeds in much the same way as it does for an experiment using the *Experiment Manager*. In fact, with some minor adjustments, the *YAML* text file used to define experiments has the same general structure as the one used to specify tuning hyperparameters and ranges for calibration (see example file beam/test/input/beamville/example-calibration/experiment.yml):

```
title: this is the name of the SigOpt experiment
beamTemplateConfPath: the config file to be used for the experiments
modeChoiceTemplate: mode choice template file
numWorkers: this defines for a remote run, how many parallel runs should be executed␣
↪(number of machines to be started)
params:
 ### ---- run template env variables ---####
 EXPERIMENT_MAX_RAM: 16g (might be removed in future)
 S3_OUTPUT_PATH_SUFFIX: "sf-light" (might be removed in future)
 DROP_OUTPUT_ONCOMPLETE: "true" (might be removed in future)
 IS_PARALLEL: "false" (might be removed in future)

runName: instance name for remote run
beamBranch: branch name
beamCommit: commit hash
deployMode: "execute"
executeClass: "beam.calibration.RunCalibration"
beamBatch: "false"
shutdownWait: "15"
shutdownBehavior: "terminate"
s3Backup: "true"
maxRAM: "140g"
region: "us-west-2"
instanceType: "m4.16xlarge"
```

The major exceptions are the following:

- Factors may have only a single numeric parameter, which may (at the moment) only take two levels (High and Low). These act as bounds on the values that SigOpt will try for a particular decision variable.
- The level of parallelism is controlled by a new parameter in the header called *numberOfWorkers*. Setting its value above 1 permits running calibrations in parallel in response to multiple concurrent open *Suggestions*.

Create Experiment

Use *beam.calibration.utils.CreateExperiment* to create a new SigOpt experiment. Two inputs are needed for this: a *YAML* file and a *benchmark.csv* file (this second parameter might be removed in the near future, as not needed).

After running the script you should be able to see the newly created experiment in the SigOpt web interface and the experiment id is also printed out in the console.

Set in Config

One must also select the appropriate implementation of the *ObjectiveFunction* interface in the *.conf* file pointed to in the *YAML*, which implicitly defines the metric and input files. Several example implementations are provided such as *ModeChoiceObjectiveFunction*. This implementation compares modes used at the output of the simulation with benchmark values. To optimize this objective, it is necessary to have a set of comparison benchmark values, which are placed in the same directory as other calibration files:

```
beam.calibration.objectiveFunction = "ModeChoiceObjectiveFunction_
↪AbsolutErrorWithPreferrenceForModeDiversity"
beam.calibration.mode.benchmarkFileLoc=${beam.inputDirectory}"/calibration/benchmark.
↪csv"
```

(Needed for scoring funtions which try to match mode share).

2.3.4 Execution

Execution of a calibration experiment requires running the *beam.calibration.RunCalibration* class using the following arguments:

--experiments	production/application-sfbay/calibration/experiment_counts_calibration.yml
--benchmark	Location of the benchmark file (production/applicaion-sfbay/calibration/benchmark.csv)
--num_iters	Number of SigOpt iterations to be conducted (in series).
--experiment_id	If an *experimentID* has already been defined, add it here to continue an experiment or put "None" to start a new experiment.
--run_type	Can be local or remote

2.3.5 Manage Experiment

As the number of open suggestions for an experiment is limited (10 in our case), we sometimes might need to cleanup suggestions maually using *beam.calibration.utils.DeleteSuggestion* script to both delete specific and all open suggestions (e.g. if there was an exception during all runs and need to restart).

2.4 Timezones and GTFS

There is a subtle requirement in BEAM related to timezones that is easy to miss and cause problems.

BEAM uses the R5 router, which was designed as a stand-alone service either for doing accessibility analysis or as a point to point trip planner. R5 was designed with public transit at the top of the developers' minds, so they infer the time zone of the region being modeled from the "timezone" field in the "agency.txt" file in the first GTFS data archive that is parsed during the network building process.

Therefore, if no GTFS data is provided to R5, it cannot infer the locate timezone and it then assumes UTC.

Meanwhile, there is a parameter in beam, "beam.routing.baseDate" that is used to ensure that routing requests to R5 are send with the appropriate timestamp. This allows you to run BEAM using any sub-schedule in your GTFS archive. I.e. if your base date is a weekday, R5 will use the weekday schedules for transit, if it's a weekend day, then the weekend schedules will be used.

The time zone in the baseDate parameter (e.g. for PST one might use "2016-10-17T00:00:00-07:00") must match the time zone in the GTFS archive(s) provided to R5.

As a default, we provide a "dummy" GTFS data archive that is literally empty of any transit schedules, but is still a valid GTFS archive. This archive happens to have a time zone of Los Angeles. You can download a copy of this archive here:

https://www.dropbox.com/s/2tfbhxuvmep7wf7/dummy.zip?dl=1

But in general, if you use your own GTFS data for your region, then you may need to change this baseDate parameter to reflect the local time zone there. Look for the "timezone" field in the "agency.txt" data file in the GTFS archive.

The date specified by the baseDate parameter must fall within the schedule of all GTFS archives included in the R5 sub-directory. See the "calendar.txt" data file in the GTFS archive and make sure your baseDate is within the "start_date" and "end_date" fields folder across all GTFS inputs. If this is not the case, you can either change baseDate or you can change the GTFS data, expanding the date ranges… the particular dates chosen are arbitrary and will have no other impact on the simulation results.

One more word of caution. If you make changes to GTFS data, then make sure your properly zip the data back into an archive. You do this by selecting all of the individual text files and then right-click-compress. Do not compress the folder containing the GTFS files, if you do this, R5 will fail to read your data and will do so without any warning or errors.

Finally, any time you make a changes to either the GTFS inputs or the OSM network inputs, then you need to delete the file "network.dat" under the "r5" sub-directory. This will signal to the R5 library to re-build the network.

2.5 Converting a MATSim Scenario to Run with BEAM

The following MATSim input data are required to complete the conversion process:

- Matsim network file: (e.g. network.xml)
- Matsim plans (or population) file: (e.g. population.xml)
- A download of OpenStreetMap data for a region that includes your region of interest. Should be in pbf format. For North American downloads: http://download.geofabrik.de/north-america.html

The following inputs are optional and only recommended if your MATSim scenario has a constrained vehicle stock (i.e. not every person owns a vehicle):

- Matsim vehicle definition (e.g. vehicles.xml)
- Travel Analysis Zone shapefile for the region, (e.g. as can be downloaded from https://www.census.gov/geo/maps-data/data/cbf/cbf_taz.html)

Finally, this conversion can only be done with a clone of the full BEAM repository. Gradle commands will **not** work with releases: https://github.com/LBNL-UCB-STI/beam/releases

2.5.1 Conversion Instructions

Note that we use the MATSim Sioux Falls scenario as an example. The data for this scenario are already in the BEAM repository under "test/input/siouxfalls". We recommend that you follow the steps in this guide with that data to produce a working BEAM Sioux Falls scenario and then attempt to do the process with your own data.

1. Create a folder for your scenario in project directory under test/input (e.g: test/input/siouxfalls)
2. Create a sub-directory to your scenario directory and name it "conversion-input" (exact name required)
3. Create a another sub-directory and name it "r5".
4. Copy the MATSim input data to the conversion-input directory.

5. Copy the BEAM config file from test/input/beamville/beam.conf into the scenario directory and rename to your scenario (e.g. test/input/siouxfalls/siouxfalls.conf)

6. Make the following edits to siouxfalls.conf (or your scenario name, replace Sioux Falls names below with appropriate names from your case):

- Do a global search/replace and search for "beamville" and replace with your scenario name (e.g. "siouxfalls").
- matsim.conversion.scenarioDirectory = "test/input/siouxfalls"
- matsim.conversion.populationFile = "Siouxfalls_population.xml" (just the file name, assumed to be under conversion-input)
- matsim.conversion.matsimNetworkFile = "Siouxfalls_network_PT.xml" (just the file name, assumed to be under conversion-input)
- matsim.conversion.generateVehicles = true (If true – common – the conversion will use the population data to generate default vehicles, one per agent)
- matsim.conversion.vehiclesFile = "Siouxfalls_vehicles.xml" (optional, if generateVehicles is false, specify the matsim vehicles file name, assumed to be under conversion-input)
- matsim.conversion.defaultHouseholdIncome (an integer to be used for default household incomes of all agents)
- matsim.conversion.osmFile = "south-dakota-latest.osm.pbf" (the Open Street Map source data file that should be clipped to the scenario network, assumed to be under conversion-input)
- matsim.conversion.shapeConfig.shapeFile (file name shape file package, e.g: for shape file name tz46_d00, there should be following files: tz46_d00.shp, tz46_d00.dbf, tz46_d00.shx)
- matsim.conversion.shapeConfig.tazIdFieldName (e.g. "TZ46_D00_I", the field name of the TAZ ID in the shape file)
- beam.spatial.localCRS = "epsg:26914" (the local EPSG CRS used for distance calculations, should be in units of meters and should be the CRS used in the network, population and shape files)
- beam.routing.r5.mNetBuilder.toCRS = "epsg:26914" (same as above)
- beam.spatial.boundingBoxBuffer = 10000 (meters to pad bounding box around the MATSim network when clipping the OSM network)
- The BEAM parameter beam.routing.baseDate has a time zone (e.g. for PST one might use "2016-10-17T00:00:00-07:00"). This time zone must match the time zone in the GTFS data provided to the R5 router. As a default, we provide the latest GTFS data from the City of Sioux Falls ("siouxareametro-sd-us.zip". downloaded from transitland.org) with a timezone of America/Central. But in general, if you use your own GTFS data for your region, then you may need to change this baseDate parameter to reflect the local time zone there. Look for the "timezone" field in the "agency.txt" data file in the GTFS archive. Finally, the date specified by the baseDate parameter must fall within the schedule of all GTFS archives included in the R5 sub-directory. See the "calendar.txt" data file in the GTFS archive and make sure your baseDate is within the "start_date" and "end_date" fields folder across all GTFS inputs. If this is not the case, you can either change baseDate or you can change the GTFS data, expanding the date ranges… the particular dates chosen are arbitrary and will have no other impact on the simulation results.

8. Run the conversion tool

- Open command line in beam root directory and run the following command, replace [/path/to/conf/file] with the path to your config file: gradlew matsimConversion -PconfPath=[/path/to/conf/file]

The tool should produce the following outputs:

- householdAttributes.xml
- households.xml

- population.xml
- populationAttributes.xml
- taz-centers.csv
- transitVehicles.xml
- vehicles.xml

9. Run OSMOSIS

The console output should contain a command for the osmosis tool, a command line utility that allows you manipulate OSM data. If you don't have osmosis installed, download and install from: https://wiki.openstreetmap.org/wiki/Osmosis

Copy the osmosis command generated by conversion tool and run from the command line from within the BEAM project directory:

```
osmosis --read-pbf file=/path/to/osm/file/south-dakota-latest.osm.pbf --bounding-box␣
↪top=43.61080226522504 left=-96.78138443934351 bottom=43.51447260628691 right=-96.
↪6915507011093 completeWays=yes completeRelations=yes clipIncompleteEntities=true --
↪write-pbf file=/path/to/dest-osm.pbf
```

10. Run BEAM

- Main class to execute: beam.sim.RunBeam
- VM Options: -Xmx2g (or more if a large scenario)
- Program arguments, path to beam config file from above, (e.g. –config “test/input/siouxfalls/siouxfalls.conf”)
- Environment variables: PWD=/path/to/beam/folder

2.6 Converting BEAM events file into MATSim events file

There is a script to convert BEAM events into MATSim events so, one can use Via to visualize BEAM simulation results.

The script will convert all PathTraversalEvents into sequence of various MATSim events.

There are, at least, two ways to run conversion:

- directly run script from *beam/src/main/scala/beam/utils/beam_to_matsim/EventsByVehicleMode.scala*
- run script by gradle task:

```
./gradlew execute -PmainClass=beam.utils.beam_to_matsim.
↪EventsByVehicleMode -PappArgs="[<parameters>]"
```

Both ways require four parameters:

- BEAM events file path
- MATSim output file path
- Comma separated list of chosen vehicle modes
- Vehicle population fraction for sampling

Example: *./gradlew execute -PmainClass=beam.utils.beam_to_matsim.EventsByVehicleMode -PappArgs=”[‘BEAM events file path’, ‘output file path’, ‘car,bus’, ‘1’]” -PmaxRAM=16g*

If it is required to sample not by just population but also select only vehicles that passes through specific circle with center in X,Y and radius R then there are 4 optional arguments. They should be provided together.

Parameters for circle sampling:

- PhysSim network file path
- X circle coordinate
- Y circle coordinate
- radius R of circle

Example: *./gradlew execute -PmainClass=beam.utils.beam_to_matsim.EventsByVehicleMode -PappArgs="['BEAM events file path', 'output file path', 'car,bus', '0.2', 'path to physSimNetwork.xml', '548966', '4179000', '5000']" -PmaxRAM=16g*

Worth noting the fact that running the script require sufficient amount of computing resources corresponding to source events file size. For example: processing a BEAM file of 1.5Gb while selecting all vehicles (with fraction of 1) require about 16Gb memory for Java and takes about 12 minutes on modern laptop. During transformation the script will provide additional information about computation progress.

CHAPTER 3

Developer's Guide

3.1 Repositories

The beam repository on github is here.

The convention for merging into the develop branch is that develop needs to be pass all tests and at least one other active BEAM developer needs to review your changes before merging. Please do this by creating a pull request from any new feature branches into develop. We also encourage you to create pull requests early in your development cycle which gives other's an opportunity to observe and/or provide feedback in real time. When you are ready for a review, invite one or more through the pull request.

Please use the following naming convention for feature branches, "<initials-or-username>/<descriptive-feature-branch-name>". Adding the issue number is also helpful, e.g.:

cjrs/#112-update-docs

An example workflow for contributing a new feature beam might look like this:

- create a new branch off of develop (e.g. cjrs/#112-update-docs)
- push and create a pull request right away
- work in cjrs/#112-update-docs
- get it to compile, pass tests
- request reviews from pull request
- after reviews and any subsequent iterations, merge into develop and close pull request
- delete feature branch unless continued work to happy imminently on same feature branch

The pev-only and related feature branches hold a previous version of BEAM (v0.1.X) which is incompatible with develop but is still used for modeling and analysis work.

3.2 Configuration

We use typesafe config for our configuration parser and we use the tscfg utility for generating typesafe container class for our config that we can browse with auto-complete while developing.

Then you can make a copy of the config template under:

```
src/main/resources/config-template.conf
```

and start customizing the configurations to your use case.

To add new parameters or change the structure of the configuration class itself, simply edit the *config-template.conf* file and run the gradle task:

```
./gradlew generateConfig
```

This will generate a new class *src/main/scala/beam/sim/config/BeamConfig.scala* which will reflect the new structure and parameters.

3.3 Environment Variables

BEAM supports using an environment variable to optionally specify a directory to write outputs. This is not required.

Depending on your operating system, the manner in which you want to run the BEAM application or gradle tasks, the specific place where you set these variables will differ. To run from the command line, add these statements to your .bash_profile file:

```
export BEAM_OUTPUT=/path/to/your/preferred/output/destination/`
```

To run from IntelliJ as an "Application", edit the "Environment Variables" field in your Run Configuration to look like this:

```
BEAM_OUTPUT="/path/to/your/preferred/output/destination/"
```

Finally, if you want to run the gradle tasks from IntelliJ in OS X, you need to configure your variables as launch tasks by creating a plist file for each. The files should be located under `~/Library/LaunchAgents/` and look like the following. Note that after creating the files you need to log out / log in to OS X and you can't Launch IntelliJ automatically on log-in because the LaunchAgents might not complete in time.

File: `~/Library/LaunchAgents/setenv.BEAM_OUTPUT.plist`:

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN" "http://www.apple.com/DTDs/
↪PropertyList-1.0.dtd">
<plist version="1.0">
  <dict>
    <key>Label</key>
    <string>setenv.BEAM_OUTPUT</string>
    <key>ProgramArguments</key>
    <array>
      <string>/bin/launchctl</string>
      <string>setenv</string>
      <string>BEAM_OUTPUT</string>
      <string>/path/to/your/preferred/output/destination/</string>
    </array>
```

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```
    <key>RunAtLoad</key>
    <true/>
    <key>ServiceIPC</key>
    <false/>
  </dict>
</plist>
```

3.4 GIT-LFS - known issues

** IntelliJ IDEA credentials issue **

Sometimes it might be possible that IntelliJ IDEA integration struggles with the credentials of git-lfs if they are different from your regular git credentials (which is most probably the case for beam). Hence if you changed files in beam that are tracked by git-lfs (e.g. vehicles.csv.gz) you should use command line git for pushing them to the server.

** timeout **

Sometimes it is possible to face a timeout issue when trying to push huge files. The steps below can be followed:

1. Connect to some EC2 server inside the same Amazon S3 region: us-east-2
2. Copy the file to the server using scp:

   ```
   $ scp -i mykey.pem somefile.txt remote_username@machine.us-east-2.compute.
   ↪amazonaws.com:/tmp
   ```

3. Clone the repository as usual (make sure git and git-lfs are properly installed)
4. Just push the files as usual

3.5 Keeping Production Data out of Master Branch

Production versus test data. Any branch beginning with "production" or "application" will contain data in the "production/" subfolder. This data should stay in that branch and not be merged into master. To keep the data out, the easiest practice is to simply keep merges one-way from master into the production branch and not vice versa.

However, sometimes troubleshooting / debugging / development happens on a production branch. The cleanest way to get changes to source code or other non-production files back into master is the following.

Checkout your production branch:

```
git checkout production-branch
```

Bring branch even with master:

```
git merge master
```

Resolve conflicts if needed

Capture the files that are different now between production and master:

```
git diff --name-only HEAD master > diff-with-master.txt
```

You have created a file "diff-with-master.txt" containing a listing of every file that is different.

IMPORTANT!!!! – Edit the file diff-with-master.txt and remove all production-related data (this typically will be all files underneath "production" sub-directory.

Checkout master:

```
git checkout master
```

Create a new branch off of master, this is where you will stage the files to then merge back into master:

```
git checkout -b new-branch-with-changes-4ci
```

Do a file by file checkout of all differing files from production branch onto master:

```
cat diff-with-master.txt | xargs git checkout production-branch --
```

Note, if any of our diffs include the deletion of a file on your production branch, then you will need to remove (i.e. with "git remove" these before you do the above "checkout" step and you should also remove them from the diff-with-master.txt"). If you don't do this, you will see an error message ("did not match any file(s) known to git.") and the checkout command will not be completed.

Finally, commit the files that were checked out of the production branch, push, and go create your pull request!

3.6 Automated Cloud Deployment

This functionality is available for core BEAM development team with Amazon Web Services access privileges. Please contact Colin for access to capability.

3.6.1 BEAM run on EC2

To run a BEAM simulation or experiment on amazon ec2, use following command with some optional parameters:

```
./gradlew deploy -P[beamConfigs | beamExperiments]=config-or-experiment-file
```

The command will start an ec2 instance based on the provided configurations and run all simulations in serial. At the end of each simulation/experiment, outputs are uploaded to a public Amazon S3 bucket. To run each each simulation/experiment parallel on separate instances, set *beamBatch* to false. For customized runs, you can also use following parameters that can be specified from command line:

- **propsFile**: to specify file with default values
- **runName**: to specify instance name.
- **beamBranch**: To specify the branch for simulation, current source branch will be used as default branch.
- **beamCommit**: The commit SHA to run simulation. use *HEAD* if you want to run with latest commit, default is *HEAD*.
- **deployMode**: to specify what type of deploy it will be: config | experiment | execute
- **beamConfigs**: A comma , separated list of *beam.conf* files. It should be relative path under the project home. You can create branch level defaults by specifying the branch name with *.configs* suffix like *master.configs*. Branch level default will be used if *beamConfigs* is not present.

- **beamExperiments**: A comma , separated list of *experiment.yml* files. It should be relative path under the project home.You can create branch level defaults same as configs by specifying the branch name with *.experiments* suffix like *master.experiments*. Branch level default will be used if *beamExperiments* is not present. *beamConfigs* has priority over this, in other words, if both are provided then *beamConfigs* will be used.
- **executeClass** and **executeArgs**: to specify class and args to execute if *execute* was chosen as deploy mode
- **maxRAM**: to specify MAXRAM environment variable for simulation.
- **storageSize**: to specfy storage size of instance. May be from *64* to *256*.
- **beamBatch**: Set to *false* in case you want to run as many instances as number of config/experiment files. Default is *true*.
- **s3Backup**: to specify if copying results to s3 bucket is needed, default is *true*.
- **instanceType**: to specify s2 instance type.
- **region**: Use this parameter to select the AWS region for the run, all instances would be created in specified region. Default *region* is *us-east-2*.
- **shutdownWait**: As simulation ends, ec2 instance would automatically terminate. In case you want to use the instance, please specify the wait in minutes, default wait is 30 min.
- **shutdownBehaviour**: to specify shutdown behaviour after and of simulation. May be *stop* or *terminate*, default is *terminate*.

There is a default file to specify parameters for task: gradle.deploy.properties and it is advised to use it (or custom) file to specify all default values for *deploy* task and not use gradle.properties file because latter used as a source of default values for all gradle tasks.

The order which will be used to look for parameter values is follow:

1. command line arguments
2. gradle.properties file
3. gradle.deploy.properties file or custom file specified in *propsFile*

To run a batch simulation, you can specify multiple configuration files separated by commas:

```
./gradlew deploy -PbeamConfigs=test/input/beamville/beam.conf,test/input/sf-light/sf-
↪light.conf
```

Similarly for experiment batch, you can specify comma-separated experiment files:

```
./gradlew deploy -PbeamExperiments=test/input/beamville/calibration/transport-cost/
↪experiments.yml,test/input/sf-light/calibration/transport-cost/experiments.yml
```

For demo and presentation material, please follow the link on google drive.

3.6.2 BEAM run on NERSC

In order to run BEAM on NERSC one needs to get an ssh key that allows you to ssh to NERSC systems without further authentication until the key expires (24 hours). You also need to specify your user name on NERSC in the following property: **nerscUser**, i.e:

```
./gradlew deployToNersc -PnerscUser=dmitriio
```

You need to define the deploy properties that are similar to the ones for AWS deploy. These are the properties that is used on NERSC:

- **runName**: to specify instance name.
- **beamBranch**: To specify the branch for simulation, current source branch will be used as default branch.
- **beamCommit**: The commit SHA to run simulation. use *HEAD* if you want to run with latest commit, default is *HEAD*.
- **beamConfigs**: The *beam.conf* file. It should be relative path under the project home.
- **s3Backup**: to specify if copying results to s3 bucket is needed, default is *true*.
- **region**: Use this parameter to select the AWS region for the run, all instances would be created in specified region. Default *region* is *us-east-2*.

Your task is going to be added to the queue and when it starts/finishes you receive a notification on your git user email. It may take 1-24 hours (or even more) for the task to get started. It depends on the NERSC workload. In your user home directory on NERSC you can find the output file of your task that looks like *slurm-<job id>.out*. The BEAM output directory is resides at *$SCRATCH/beam_runs/*. Also the output is uploaded to s3 if *s3Backup* is set to true.

3.6.3 PILATES run on EC2

It is possible to start PILATES simulation on AWS instance from gradle task

```
./gradlew deployPilates [-Pparam1name=param1value [... -PparamNname=paramNvalue]]
```

This command will start PILATES simulation on ec2 instance with specified parameters.

- **propsFile**: to specify file with default values
- **runName**: to specify instance name.
- **startYear**: to specify start year of simulation.
- **countOfYears**: to specify count of years.
- **beamItLen**: to specify simulations year step.
- **urbansimItLen**: to specify urbansim simulation length.
- **inYearOutput**: to allow urbansim to write in year output, default is 'off'.
- **beamConfig**: to specify BEAM config file for all runs during simulation.
- **initialS3UrbansimInput**: to specify initial data for first urbansim run.
- **initialS3UrbansimOutput**: to specify initial urbansim data for first BEAM run if it is not skipped.
- **initialSkimPath**: to specify initial skim file for first urbansim run if first BEAM run is skipped. Setting this parameter to any value will lead to skipping first BEAM run.
- **s3OutputBucket**: to specify s3 output bucket name, default is *//pilates-outputs*.
- **s3OutputBasePath**: to specify s3 output path from bucket to output folder. Setting this parameter empty will lead to putting output folder in root of s3 output bucket. By default is empty.
- **pilatesScenarioName**: name of output folder. Full name will contain this parameter value and datetime of start of run. By default is *pilates*.
- **beamBranch**: to specify the branch for simulation, current source branch will be used as default branch.
- **beamCommit**: the commit SHA to run simulation. use *HEAD* if you want to run with latest commit, default is *HEAD*.
- **maxRAM**: to specify MAXRAM environment variable for simulation.

- **shutdownWait**: to specify shutdown wait after end of simulation, default is *15*.
- **shutdownBehaviour**: to specify shutdown behaviour after and of simulation. May be *stop* or *terminate*, default is *terminate*.
- **storageSize**: to specfy storage size of instance. May be from *64* to *256*.
- **region**: to specify region to deploy ec2 instance. May be different from s3 bucket instance.
- **dataRegion**: to specify region of s3 buckets. All operations with s3 buckets will be use this region. By default equal to *region*.
- **instanceType**: to specify s2 instance type.
- **pilatesImageVersion**: to specify pilates image version, default is *latest*.
- **pilatesImageName**: to specify full pilates image name, default is *beammodel/pilates*.

There is a default file to specify parameters for task: gradle.deployPILATES.properties and it is advised to use it (or custom) file to specify all default values for *deployPilates* task and not use gradle.properties file because latter used as a source of default values for all gradle tasks.

The order which will be used to look for parameter values is follow:

1. command line arguments
2. gradle.properties file
3. gradle.deployPILATES.properties file or custom file specified in *propsFile*

If none of sources contains parameter, then parameter will be omitted. This will ends with output message: "*parameters wasn't specified: <omitted parameters list>*"

Running this function will leads to:

1. creating new ec2 instance
2. pulling from github selected branch/commit
3. pulling from docker hub PILATES image
4. running PILATES image with specified parameters
5. writing output from every iteration to s3 bucket

All run parameters will be stored in *run-params* file in root of PILATES output.

Also during simulation for every BEAM run will be created a new config file with specified paths to output folder and to urbansim data. Those config files will be created near original config file (from *beamConfig* variable) with year added to the name. So it will be possible to rerun BEAM for selected year.

3.6.4 AWS EC2 start stop and terminate

To maintain ec2 instances, there are some utility tasks that reduce operation cost tremendously. You can start already available instances using a simple *startEC2* gradle task under aws module. You can specify one or more instance ids by a comma saturated list as *instanceIds* argument. Below is syntax to use the command:

```
./gradlew startEC2 -PinstanceIds=<InstanceID1>[,<InstanceID2>]
```

As a result of task, instance DNS would be printed on the console.

Just like starting instance, you can also stop already running instances using a simple *stopEC2* gradle task. You can specify one or more instance ids by a comma saturated list as *instanceIds* argument. Below is syntax to use the command:

```
./gradlew stopEC2 -PinstanceIds=<InstanceID1>[,<InstanceID2>]
```

It is possible not just stop instance but terminate it using *terminateEC2* gradle task. Terminated instances are not available to start and will be completely removed along with all data they contain. You can specify one or more instance ids by a comma saturated list as *instanceIds* argument. Below is syntax to use the command:

```
./gradlew terminateEC2 -PinstanceIds=<InstanceID1>[,<InstanceID2>]
```

3.7 Performance Monitoring

Beam uses Kamon as a performance monitoring framework. It comes with a nice API to instrument your application code for metric recoding. Kamon also provide many different pingable recorders like Log Reporter, StatsD, InfluxDB etc. You can configure your desired recorder with project configurations under Kamon/metrics section. When you start the application it will measure the instrumented components and recorder would publish either to console or specified backend where you can monitor/analyse the metrics.

If you would like to review basic JVM metrics then it is already configured so that you can use jconsole.

3.7.1 Beam Metrics Utility (*MetricsSupport*)

Beam provides metric utility as part of performance monitoring framework using Kamon API. It makes developers life very easy, all you need is to extend your component from *beam.sim.metrics.MetricsSupport* trait and call your desired utility. As you extend the trait, it will add some handy entity recorder methods in your component, to measure the application behaviour. By using *MetricSupport* you measure following different metricises.

- Count occurrences or number of invocation:

```
countOccurrence("number-of-routing-requests", Metrics.VerboseLevel)
```

In this example first argument of *countOccurrence* is the name of entity you want to record and second is the metric level. It is the simplest utility and just counts and resets to zero upon each flush. you can use it for counting errors or occurrences of specifics events.

- Execution time of some expression, function call or component:

```
latency("time-to-calculate-route", Metrics.RegularLevel) {
    calcRoute(request)
}
```

In this snippet, first two arguments are same as of *countOccurrence*. Next, it takes the actual piece of code/expression for which you want to measure the execution time/latency. In the example above we are measuring the execution time to calculate a router in *RoutingWorker*, we named the entity as *"request-router-time"* and set metric level to *Metrics.RegularLevel*. When this method executes your entity recorder record the metrics and log with provided name.

3.7.2 Beam Metrics Configuration

After instrumenting your code you need configure your desired metric level, recorder backends and other Kamon configurations in your project configuration file (usually beam.conf). Update your metrics configurations as below:

```
beam.metrics.level = "verbose"

kamon {
    trace {
      level = simple-trace
    }

    metric {
        #tick-interval = 5 seconds
        filters {
            trace.includes = [ "**" ]

            akka-actor {
                includes = [ "beam-actor-system/user/router/**", "beam-actor-system/
↪user/worker-*" ]
                excludes = [ "beam-actor-system/system/**", "beam-actor-system/user/
↪worker-helper" ]
            }

            akka-dispatcher {
                includes = [ "beam-actor-system/akka.actor.default-dispatcher" ]
            }
        }
    }

    statsd {
        hostname = 127.0.0.1  # replace with your container in case local loop didn't␣
↪work
        port = 8125
    }

    influxdb {
        hostname = 18.216.21.254   # specify InfluxDB server IP
        port = 8089
        protocol = "udp"
    }

    modules {
        #kamon-log-reporter.auto-start = yes
        #kamon-statsd.auto-start = yes
        #kamon-influxdb.auto-start = yes
    }
}
```

Make sure to update the **host** and **port** for StatsD or InfluxDB (either one(or both) of them you are using) with its relevant the server IP address in the abode config.

Other then IP address you also need to confirm few thing in your environment like.

- beam.metrics.level would not be pointing to the value *off*.
- kamon-statsd.auto-start = yes, under kamon.modules.
- build.gradle(Gradle build script) has kamon-statsd, kamon-influxdb or kamon-log-reporter available as dependencies, based on your kamon.modules settings and desired backend/logger.

3.7.3 Setup Docker as Metric Backend

Kamon's StatsD reporter enables beam to publish matrices to a verity of backends. Graphite as the StatsD backend and Grafana to create beautiful dashboards build a very good monitoring ecosystem. To make environment up and running in a few minutes, use Kamon's provided docker image (beam dashboard need to import) from docker hub or build using Dockerfile and supporting configuration files available in metrics directory under beam root. All you need is to install few prerequisite like docker, docker-compose, and make. To start a container you just need to run the following command in metrics directory (available at root of beam project):

```
$ make up
```

With the docker container following services start and exposes the listed ports:

- 80: the Grafana web interface.
- 81: the Graphite web port
- 2003: the Graphite data port
- 8125: the StatsD port.
- 8126: the StatsD administrative port.

Now your docker container is up and required components are configured, all you need to start beam simulation. As simulation starts, kamon would load its modules and start publishing metrics to the StatsD server (running inside the docker container).

In your browser open http://localhost:80 (or with IP you located in previous steps). Login with the default username (admin) and password (admin), open existing beam dashboard (or create a new one).

If you get the docker image from docker hub, you need to import the beam dashboard from metrics/grafana/dashboards directory.

- To import a dashboard open dashboard search and then hit the import button.
- From here you can upload a dashboard json file, as upload complete the import process will let you change the name of the dashboard, pick graphite as data source.
- A new dashboard will appear in dashboard list.

Open beam dashboard (or what ever the name you specified while importing) and start monitoring different beam module level matrices in a nice graphical interface.

To view the container log:

```
$ make tail
```

To stop the container:

```
$ make down
```

Cloud visualization services become more popular nowadays and save much effort and energy to prepare an environment. In future we are planing to use Datadog (a cloud base monitoring and analytic platform) with beam. Kamon Datadog integration is the easiest way to have something (nearly) production ready.

How to get Docker IP?

Docker with VirtualBox on macOS/Windows: use docker-machine IP instead of localhost. To find the docker container IP address, first you need to list the containers to get container id using:

```
$ docker ps
```

Then use the container id to find IP address of your container. Run the following command by providing container id in following command by replacing YOUR_CONTAINER_ID:

```
$ docker inspect YOUR_CONTAINER_ID
```

Now at the bottom, under NetworkSettings, locate IP Address of your docker container.

3.8 Tagging Tests for Periodic CI

ScalaTest allows you to define different test categories by tagging your tests. These tags categorise tests in different sets. And later you can filter these set of tests by specifying these tags with your build tasks. Beam also provide a custom tag *Periodic* to mark your tests for periodic CI runs. As you mark the test with this tag, your test would be included automatically into execution set and become the part of next scheduled run. It also be excluded immediately for regular gradle test task and CI. Follow the example below to tag your test with *Periodic* tag:

```
behavior of "Trajectory"
   it should "interpolate coordinates" taggedAs Periodic in {
      ...
   }
```

This code marks the test with *com.beam.tags.Periodic* tag. You can also specify multiple tags as a comma separated parameter list in *taggedAs* method. Following code demonstrate the use of multiple tags:

```
"The agentsim" must {
   ...

   "let everybody walk when their plan says so" taggedAs (Periodic, Slow) in {
      ...
   }

   ...
}
```

You can find details about scheduling a continuous integration build under DevOps section Configure Periodic Jobs.

3.9 Instructions for forking BEAM

These instructions are based on this page

1. Clone BEAM repo

```
git clone https://github.com/LBNL-UCB-STI/beam

cd beam
```

When asked for user name and password for LFS server (http://52.15.173.229:8080) enter anything but do not leave them blank.

2. Fetch Git LFS files

```
git lfs fetch origin
```

Many tutorials on cloning Git LFS repos say one should use

```
git lfs fetch --all origin
```

However, in BEAM this represents over 15 GB data and often fails.

3. Add new origin

```
git remote add new-origin <URL to new repo>
```

4. Create internal master branch, master branch will used to track public repo

```
git branch master-internal
git checkout master-internal
```

5. Update .lfsconfig to have only the new LFS repo

```
[lfs] url = <URL to new LFS repo>
```

Note: for Bitbucket, the <URL to new LFS repo> is <URL to new repo>/info/lfs

6. Commit changes

```
git commit --all
```

7. Push to new repo

```
git push new-origin --all
```

There will be errors saying that many files are missing (LFS upload missing objects). That is OK.

Note: As of this writing, the repo has around 250 MB LFS data. However, the push fails if the LFS server sets a low limit on LFS data. For example, it fails for Bitbucket free which sets a limit of 1 GB LFS data

8. Set master-internal as default branch in the repository's website.
9. Clone the new repo

```
git clone <URL to new repo>
cd <folder of new repo>
```

Note: Cloning might take a few minutes since the repo is quite large.

If everything turned out well, the cloning process should not ask for the credentials for BEAM's LFS server (http://52.15.173.229:8080).

10. Add public repo as upstream remote

```
git remote add upstream https://github.com/LBNL-UCB-STI/beam
```

11. Set master branch to track public remote and pull latest changes

```
git fetch upstream
git checkout -b master upstream/master
git pull
```

3.10 Build BEAM docker image

To build Beam docker image run:

```
$ ./gradlew buildImage
```

in the root of Beam project. If you want to tag the built image run:

```
$ ./gradlew tagImage
```

Once you have the image you can run Beam in Docker. Here is an example how to run test/input/beamville/beam.conf scenario on Windows OS:

```
$ docker run -v c:/repos/beam/output:/app/output -e JAVA_OPTS='-Xmx12g' \
   beammodel/beam:0.8.6 --config test/input/beamville/beam.conf
```

Docker run command mounts host folder c:/repos/beam/output to be /app/output which allows to see the output of the Beam run. It also passes environment variable e JAVA_OPTS to the container in order to set maximum heap size for Java application.

3.11 Scala tips

3.11.1 Scala Collection

Use `mutable` buffer instead of `immutable var`:

```
// Before
var buffer = scala.collection.immutable.Vector.empty[Int]
buffer = buffer :+ 1
buffer = buffer :+ 2

// After
val buffer = scala.collection.mutable.ArrayBuffer.empty[Int]
buffer += 1
buffer += 2
```

Additionally note that, for the best performance, use mutable inside of methods, but return an immutable

```
val mutableList = scala.collection.mutable.MutableList(1,2)
mutableList += 3
mutableList.toList // returns scala.collection.immutable.List
                   // or return mutableList but explicitly set the method return type␣
↪to
                   // a common, assumed immutable one from scala.collection (more␣
↪dangerous)
```

Don’t create temporary collections, use view:

```
val seq: Seq[Int] = Seq(1, 2, 3, 4, 5)

// Before
seq.map(x => x + 2).filter(x => x % 2 == 0).sum

// After
seq.view.map(x => x + 2).filter(x => x % 2 == 0).sum
```

Don’t emulate `collectFirst` and `collect`:

```
// collectFirst
// Get first number >= 4
val seq: Seq[Int] = Seq(1, 2, 10, 20)
val predicate: Int => Boolean = (x: Int)  => { x >= 4 }

// Before
seq.filter(predicate).headOption

// After
seq.collectFirst { case num if predicate(num) => num }

// collect
// Get first char of string, if it's longer than 3
val s: Seq[String] = Seq("C#", "C++", "C", "Scala", "Haskel")
val predicate: String => Boolean = (s: String)  => { s.size > 3 }

// Before
s.filter(predicate).map { s => s.head }

// After
s.collect { case curr if predicate(curr) => curr.head }
```

Prefer `nonEmpty` over `size > 0`:

```
// Before
(1 to x).size > 0

// After
(1 to x).nonEmpty

// nonEmpty shortcircuits as soon as the first element is encountered
```

Prefer not to use `_1, _2,...` for `Tuple` to improve readability:

```
// Get odd elements of sequence s
val predicate: Int => Boolean = (idx: Int)  => { idx % 2 == 1 }
val s: Seq[String] = Seq("C#", "C++", "C", "Scala", "Haskel")

// Before
s.zipWithIndex.collect {
```

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```scala
    case x if predicate(x._2) => x._1   // what is _1 or _2 ??
}

// After
s.zipWithIndex.collect {
    case (s, idx) if predicate(idx) => s
}

// Use destructuring bindings to extract values from tuple
val tuple = ("Hello", 5)

// Before
val str = tuple._1
val len = tuple._2

// After
val (str, len) = tuple
```

Great article about Scala Collection tips and tricks, must read

3.11.2 Use lazy logging

When you log, prefer to use API which are lazy. If you use `scala logging`, you have it for free. When use `ActorLogging` in Akka, you should not use string interpolation, but use method with replacement arguments:

```scala
// Before
log.debug(s"Hello: $name")

// After
log.debug("Hello: {}", name)
```

CHAPTER 4

Auto Capturing Beam Messages

4.1 Capturing most messages that BEAM Actors generate

BEAM uses triggerId to trace down all the actor interactions starting from TriggerWithId Event that is sent by the Scheduler. When developing a new message type, extend it from HasTriggerId trait in order to trace these messages. In order to enable saving messages to csv files one needs to add the following property to beam.conf file:

```
beam.debug.messageLogging=true
```

The files are saved in the iteration directories, ie $RUN_OUTPUT_DIR$/ITERS/it.0/0.actor_messages_0.csv.gz. There may be multiple of these files per iteration. For the scenario sf-light-1k about 400Mb of gzipped data generated.

4.2 Generated csv files

The files contains the following columns

- type: one of the following types (transition, event, message)
- sender_parent
- sender_name
- receiver_parent
- receiver_name
- payload: message content or previous state in case of type = transition
- state: FSM data or next state in case of type = transition
- tick: current tick
- triggerId: the triggerId which started the message sequence (if available)

4.3 How to visualize them

VisualizingApp can convert these files to different diagrams. It creates PlantUML files that can be easily converted to pictures. You can run it with gradle with the following command:

```
$ ./gradlew :execute -PmainClass=beam.utils.protocolvis.VisualizingApp -PappArgs=["'--
↪input', 'output/sf-light/sf-light_2021-05-03_10-50-55_cxc/ITERS/it.0', '--output',
↪'docs/uml/sequence1.puml', '--diagram-type', 'Sequence', '--force', '--person-id',
↪'010900-2012001379980-0-560057'"]
```

4.3.1 Parameters

parameter	values
input	directory or file where to read message files
output	the output file
diagram-type	Sequence | ActorAsState | AgentState | SingleActorAsState
force	allows to overwrite the output without prompt
person-id	the person id which the message sequence should be generated for

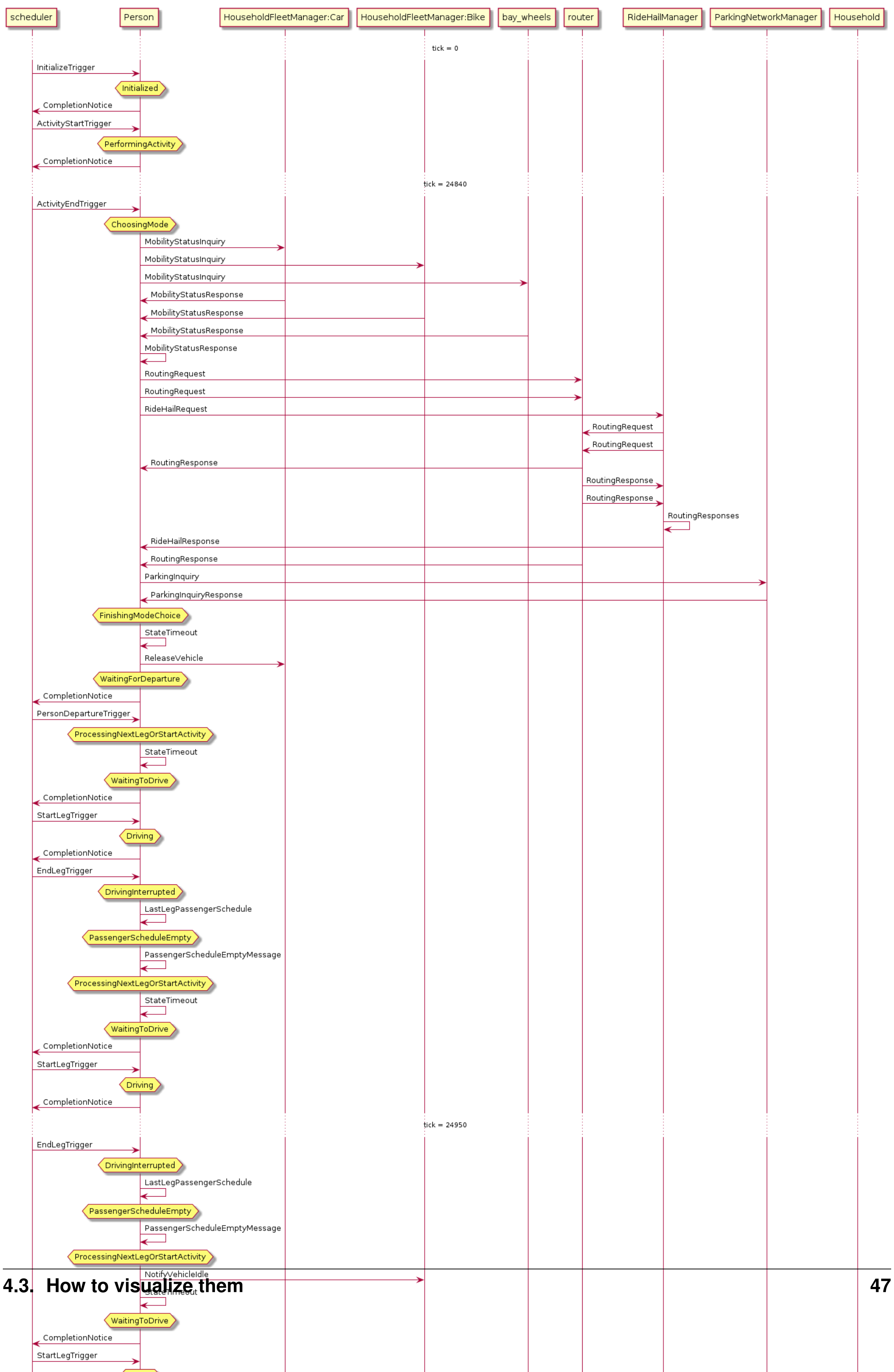
Note: For Sequence diagram it's always better to provide either a single limited size file as an *input* or a *person-id* for limiting the number of interactions in order to avoid creating a huge file.

4.3.2 Diagram types

Sequence

Sequence diagrams display every line from the beam message csv files. Because of that one always needs to limit the number of messages processed. It can be done by providing a small file that is filtered down to interesting messages. And also it can be done via providing person-id as a parameter to VisualizingApp.

This is an example of a sequence diagram for a person.


scheduler
Person
HouseholdFleetManager:Car
HouseholdFleetManager:Bike
bay_wheels
router
RideHailManager
ParkingNetworkManager
Household
tick = 0
InitializeTrigger
Initialized
CompletionNotice
ActivityStartTrigger
PerformingActivity
CompletionNotice
tick = 24840
ActivityEndTrigger
ChoosingMode
MobilityStatusInquiry
MobilityStatusInquiry
MobilityStatusInquiry
MobilityStatusResponse
MobilityStatusResponse
MobilityStatusResponse
MobilityStatusResponse
RoutingRequest
RoutingRequest
RideHailRequest
RoutingRequest
RoutingRequest
RoutingResponse
RoutingResponse
RoutingResponse
RoutingResponses
RideHailResponse
RoutingResponse
ParkingInquiry
ParkingInquiryResponse
FinishingModeChoice
StateTimeout
ReleaseVehicle
WaitingForDeparture
CompletionNotice
PersonDepartureTrigger
ProcessingNextLegOrStartActivity
StateTimeout
WaitingToDrive
CompletionNotice
StartLegTrigger
Driving
CompletionNotice
EndLegTrigger
DrivingInterrupted
LastLegPassengerSchedule
PassengerScheduleEmpty
PassengerScheduleEmptyMessage
ProcessingNextLegOrStartActivity
StateTimeout
WaitingToDrive
CompletionNotice
StartLegTrigger
Driving
CompletionNotice
tick = 24950
EndLegTrigger
DrivingInterrupted
LastLegPassengerSchedule
PassengerScheduleEmpty
PassengerScheduleEmptyMessage
ProcessingNextLegOrStartActivity
NotifyVehicleIdle
StateTimeout
WaitingToDrive
CompletionNotice
StartLegTrigger

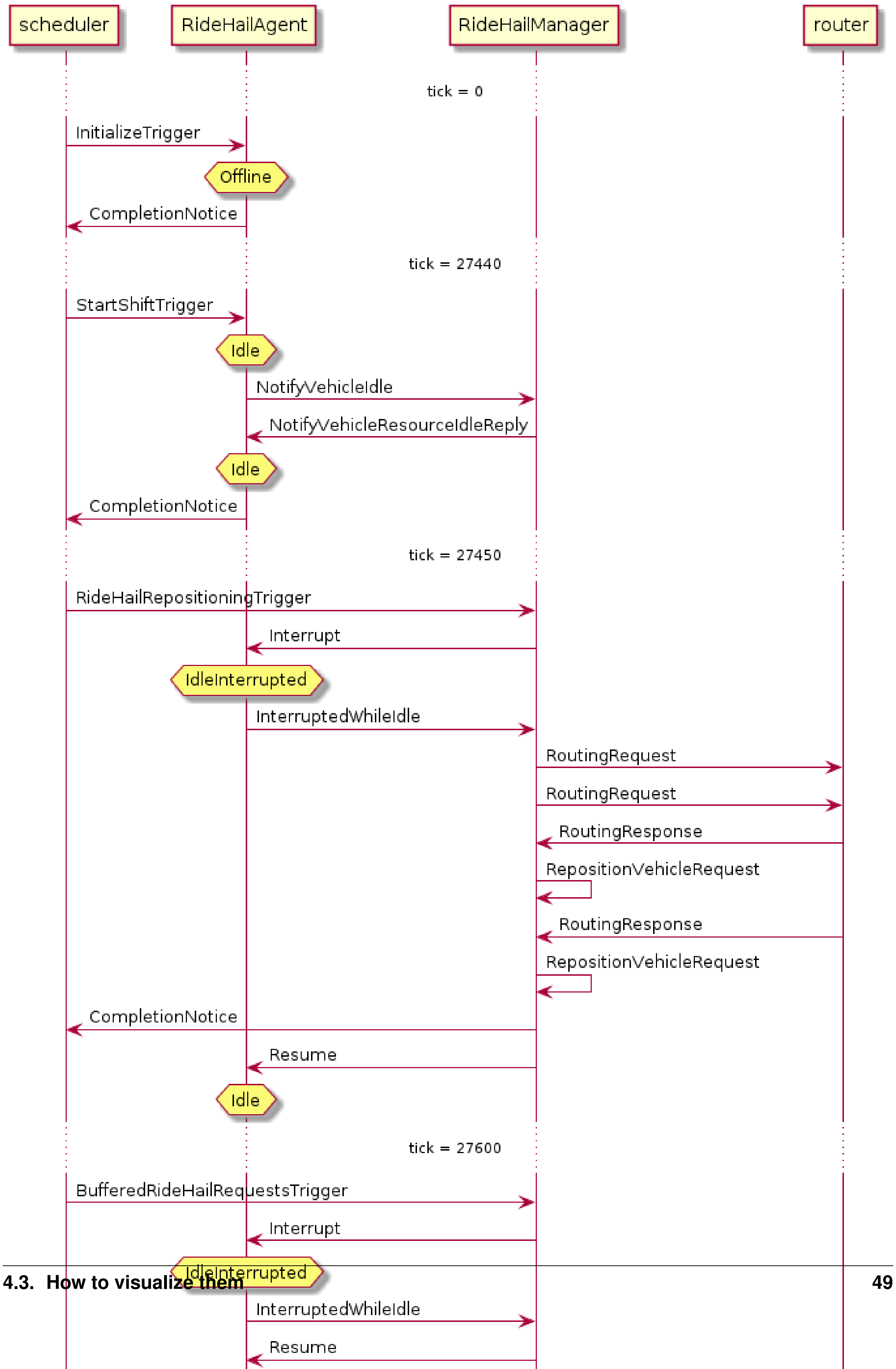
This is an example of a sequence diagram for a ridehail agent. It is produced by filtering the ridehail agent messages with pandas and saving them ot a csv with the following script.

```
msg = pd.read_csv(f"../output/sf-light/{dir}/ITERS/it.0/0.actor_messages_0.csv.gz")

agent_id = 'rideHailAgent-020700-2013000080675-0-5008509'

trigger_ids = msg[(msg['sender_name'] == agent_id) | (msg['receiver_name'] == agent_
↪id)]['triggerId'].unique()
trigger_ids = [id for id in trigger_ids if id >= 0]

allAgents = msg[
    (
            (msg['sender_name'] == agent_id)
            | (msg['receiver_name'] == agent_id)
            | (msg['triggerId'].isin(trigger_ids))
    )
]
allAgents[(
    ~((allAgents['sender_name'].str.startswith('rideHailAgent-') & (allAgents['sender_
↪name'] != agent_id))
      | (allAgents['receiver_name'].str.startswith('rideHailAgent-') & (allAgents[
↪'receiver_name'] != agent_id))
      )
)
].to_csv("../docs/uml/ride-hail-agent.csv")
```


scheduler
RideHailAgent
RideHailManager
router
tick = 0
InitializeTrigger
Offline
CompletionNotice
tick = 27440
StartShiftTrigger
Idle
NotifyVehicleIdle
NotifyVehicleResourceIdleReply
Idle
CompletionNotice
tick = 27450
RideHailRepositioningTrigger
Interrupt
IdleInterrupted
InterruptedWhileIdle
RoutingRequest
RoutingRequest
RoutingResponse
RepositionVehicleRequest
RoutingResponse
RepositionVehicleRequest
CompletionNotice
Resume
Idle
tick = 27600
BufferedRideHailRequestsTrigger
Interrupt
IdleInterrupted
InterruptedWhileIdle
Resume

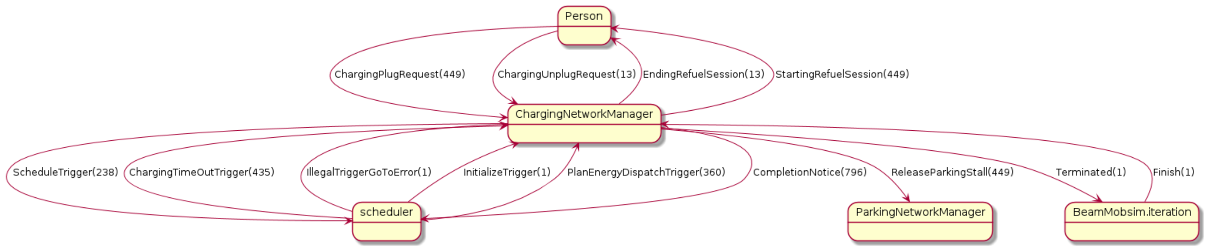
Actor Message State Diagram

It’s not a real state diagram. It has actors as nodes and messages as edges between nodes. This diagram is generated with setting parameter *–diagram-type=ActorAsState*. The picture of this diagram is pretty big and messy. It makes sense to filter the messages by providing –person-id parameter.

Single Actor Message State Diagram

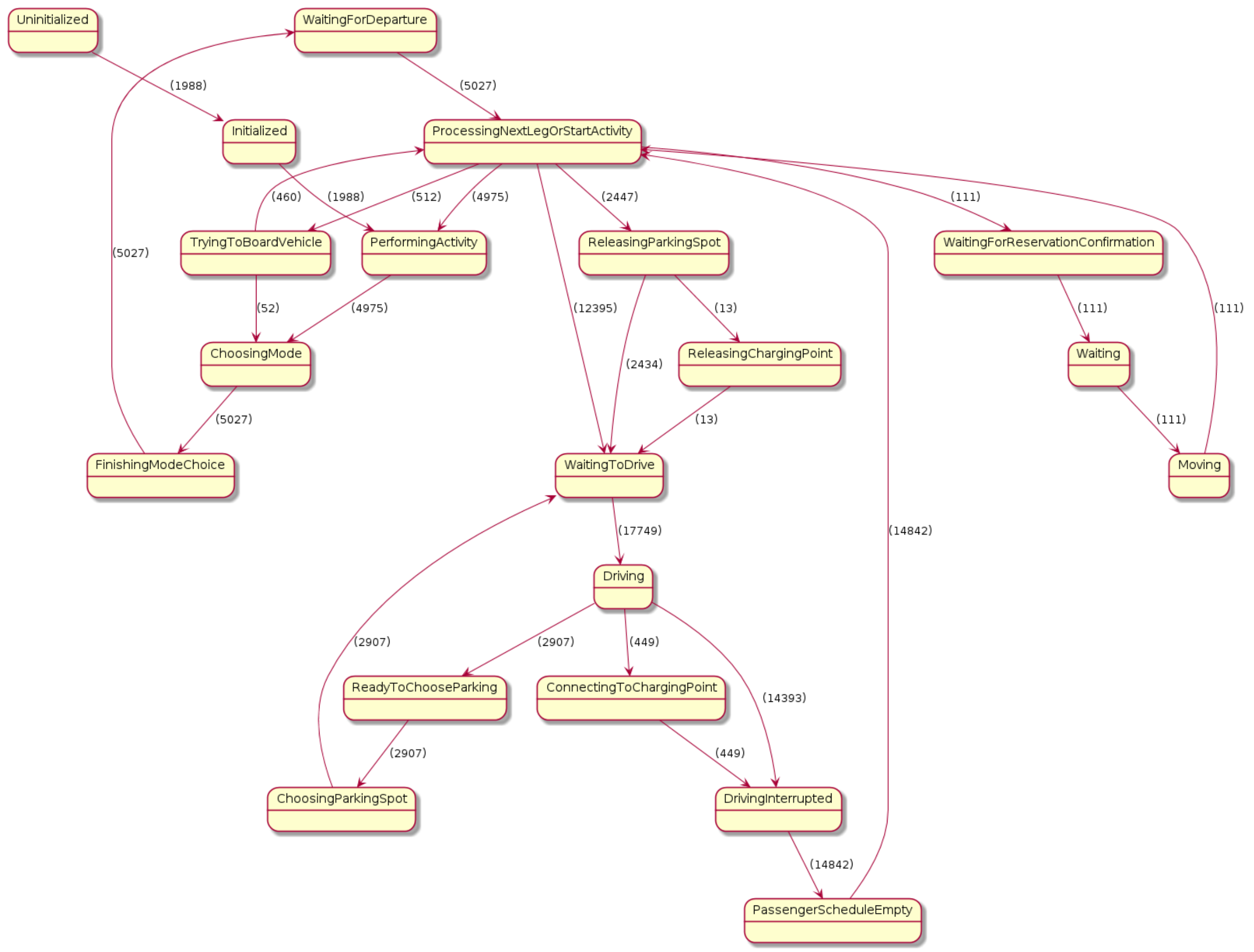
It’s diagram is similar to the previous one. But it uses only messages that go to/from a single actor (i.e. RideHailManager). This diagram is generated with setting parameter *–diagram-type=SingleActorAsState*. The *–output* parameter must point to a folder because the VisualizingApp generates multiple puml files (one for each actor).

This is an example of Actor Message state diagram for ChargingNetworkManager actor.



Agent State Diagram

This diagram is generated with setting parameter *–diagram-type=AgentState*. It’s a real state diagram which shows agent states and transitions between them. The *–output* parameter must point to a folder because the VisualizingApp generates multiple puml files (one for each agent). This is an example state diagram



4.3.3 Converting puml files to pictures

Converting puml files to pictures can be done in a number of ways. The easiest way would be running the following command for multiple files:

```
$  java -jar docs/uml/plantuml.1.2017.18.jar -DPLANTUML_LIMIT_SIZE=16000 -o <PICTURE_
↪OUTPUT_DIR> ./*
```

For a single file:

```
$ java -jar docs/uml/plantuml.1.2017.18.jar -DPLANTUML_LIMIT_SIZE=16000 single_file.
↪puml
```

CHAPTER 5

Real time graphs

5.1 Grafana

Grafana is an open source analytics and monitoring solution and may be used to view various BEAM metrics in real time during BEAM execution. It is a tool to display data from data source. In our case the data source is InfluxDB .

5.2 Docker installation and configuration

There is a docker image with Grafana and InfluxDB preconfigured to work with BEAM, thus docker needs installed in order to use Grafana.

5.2.1 Ubuntu Linux users

Requirements

- 64-bit version of one of these Ubuntu versions: Disco 19.04, Cosmic 18.10, Bionic 18.04 (LTS), Xenial 16.04 (LTS)

Installation

There is an official installation guide for Ubuntu Linux users and a Post-installation guide for Linux with optional procedures for configuring Linux hosts to work better with Docker for non-root users.

Otherwise use these commands:

```
sudo apt-get update
sudo apt-get install docker-ce docker-ce-cli containerd.io docker-compose
```

5.2.2 Mac users

Requirements

- Mac hardware must be a 2010 or newer model
- macOS must be version 10.13 or newer
- VirtualBox prior to version 4.3.30 must not be installed as it is not compatible with Docker Desktop.

Installation

There is an official installation guide for Mac users.

Otherwise download and install Docker CE for Mac (Stable).

5.2.3 Windows users

Requirements

- Windows 10 64-bit (Pro, Enterprise, or Education (Build 15063 or later)) - these are pre-req for Docker Desktop.
- Enable Hyper-V & Containers Windows features (usually done by docker installer).
- BIOS-level hardware virtualization support must be enabled in the BIOS settings (here's a *guide* on how to do it)

Installation

There is an official installation guide for Windows users.

Otherwise download and install Docker CE for Windows (Stable).

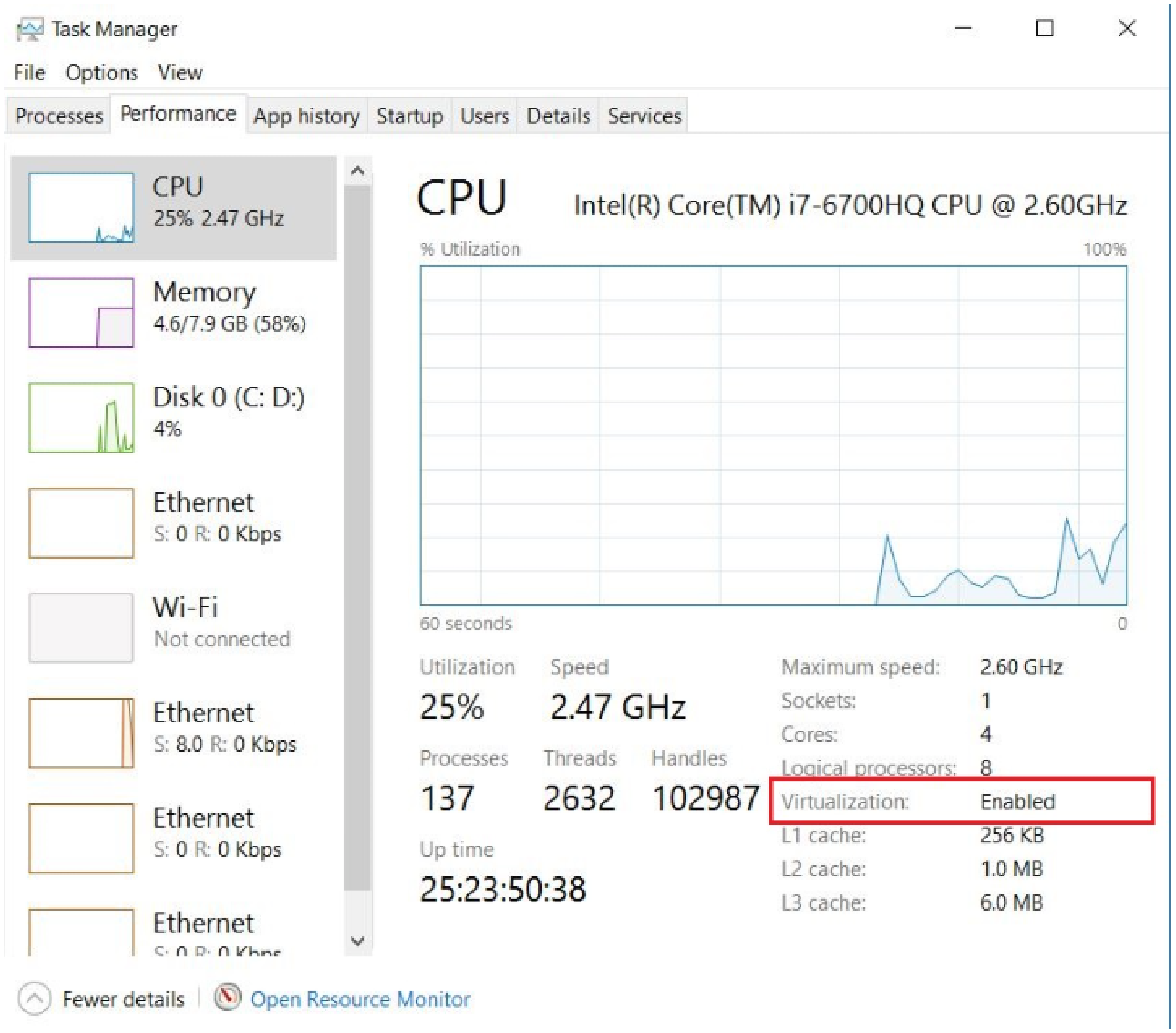
Virtualization

Windows users should also check if virtualization is enabled in firmware. To do so, check the Performance tab on the Task Manager:

If not, virtualization should be enabled in BIOS:

- Reboot your computer
- Right when the computer is coming up from the black screen, press Delete, Esc, F1, F2, or F4. Each computer manufacturer uses a different key but it may show a brief message at boot telling you which one to press. If you miss it the first time, reboot and try again. It helps to tap the key about twice a second when the computer is coming up.
- In the BIOS settings, find the configuration items related to the CPU. These can be found under the headings Processor, Chipset, or Northbridge.
- Enable virtualization; the setting may be called VT-x, AMD-V, SVM, or Vanderpool. Enable Intel VT-d or AMD IOMMU if options are available.
- Save your changes and reboot.

Another instruction with examples for different computer manufacturers can be found here.



CPU Intel(R) Core(TM) i7-6700HQ CPU @ 2.60GHz

Utilization	Speed		Maximum speed:	2.60 GHz
25%	2.47 GHz		Sockets:	1
			Cores:	4
Processes	Threads	Handles	Logical processors:	8
137	2632	102987	Virtualization:	Enabled
Up time			L1 cache:	256 KB
25:23:50:38			L2 cache:	1.0 MB
			L3 cache:	6.0 MB

Fig. 1: check if virtualization is enabled

5.2.4 Verify docker installation

Verify that docker is installed correctly by typing in a terminal or in a command window:

```
docker run hello-world
```

Output should contain:

```
Hello from Docker!
This message shows that your installation appears to be working correctly.
```

5.3 Control Grafana using gradle commands

5.3.1 Start Grafana

To run Grafana one should use gradle command `grafanaStart`. The command will start the Grafana and InfluxDB docker container, configure them and print URLs to Grafana *dashboards* after the docker image is running.

```
./gradlew grafanaStart
```

After that command execution one may run BEAM multiple times, all data will be stored in the InfluxDB database.

5.3.2 Stop Grafana

When Grafana is stopped, all collected InfluxDB data will be stored in snapshots on the file system. The snapshot will be used next time Grafana starts, thus data won't be lost.

To stop Grafana one should use the gradle command `grafanaStop`.

```
./gradlew grafanaStop
```

5.3.3 Clear collected data

To clear all the BEAM run data collected by InfluxDB one should use the gradle command `grafanaClearData`. This command should only be used after Grafana has stopped.

```
./gradlew grafanaClearData
```

5.4 Working with Grafana graphs

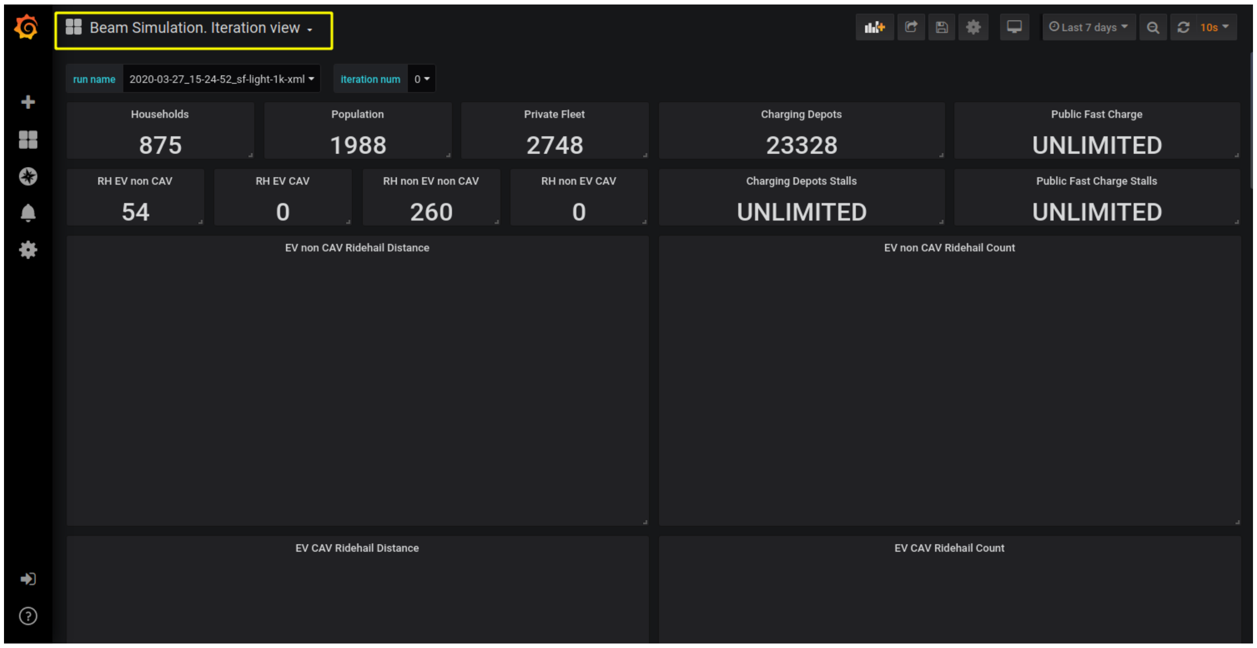
There are different *views* which are called dashboards that allow you to see BEAM results in different ways:

- The Global view plots output metrics from the simulation in an iteration-by-iteration format. I.e. this view is good for seeing how the system evolves over the iterations as user equilibrium is established.
- The Iteration view shows the output of a single iteration within BEAM and plots metrics on an hourly time scale, this is useful for seeing granular dynamics like the use of charging infrastructure over time.
- In both of the previous views, only one BEAM run may be viewed at a time but there are also Global view comparison and Iteration view comparison which allow you to view two BEAM runs at the same time or one BEAM run but with different iterations.

- The Iteration MAP view allows you to see various BEAM metrics displayed on a map with the ability to choose any combination of available metrics, hour and iteration to display.

5.4.1 Select dashboard

To choose a dashboard to view one can click on a dashboard name:


Beam Simulation. Iteration view
Last 7 days
10s
EV non CAV Ridehail Distance
EV non CAV Ridehail Count
EV CAV Ridehail Distance
EV CAV Ridehail Count

run name 2020-03-27_15-24-52_sf-light-1k-xml
iteration num 0

Households 875
Population 1988
Private Fleet 2748
Charging Depots 23328
Public Fast Charge UNLIMITED
RH EV non CAV 54
RH EV CAV 0
RH non EV non CAV 260
RH non EV CAV 0
Charging Depots Stalls UNLIMITED
Public Fast Charge Stalls UNLIMITED

Fig. 2: choose dashboard

5.4.2 Select BEAM run

To select which BEAM run graphs should be displayed one can use the switch `run name`. A BEAM run name has the format: *date_time_simulation-name* where *date* and *time* are local date and time for the pc where BEAM is running, and the simulation name is taken from the `beam.agentsim.simulationName` config value. The BEAM run list containing the `run name` switch is updated after a page refresh. So make sure to refresh your browser after a new BEAM run is started and output from the simulation have begun to accumulate. If there are no active BEAM runs in the local history then one will see no choice for 'run_name':

5.4.3 Disable and enable data traces

It is possible to disable and enable some of the value traces on a graph by clicking on the name of a trace.

5.4.4 Select BEAM iteration

On Iteration View it is possible to select the iteration to see through the 'iteration_num' switch. Iteration number switch will update after a page refresh.

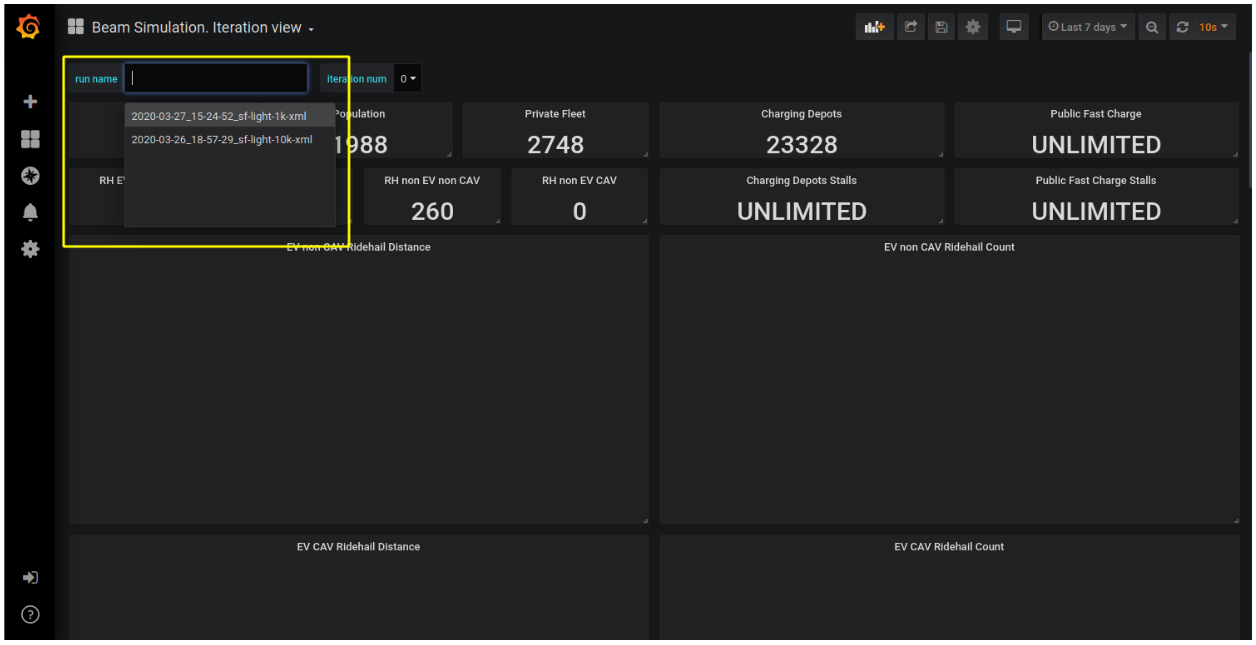


Fig. 3: BEAM run name switch

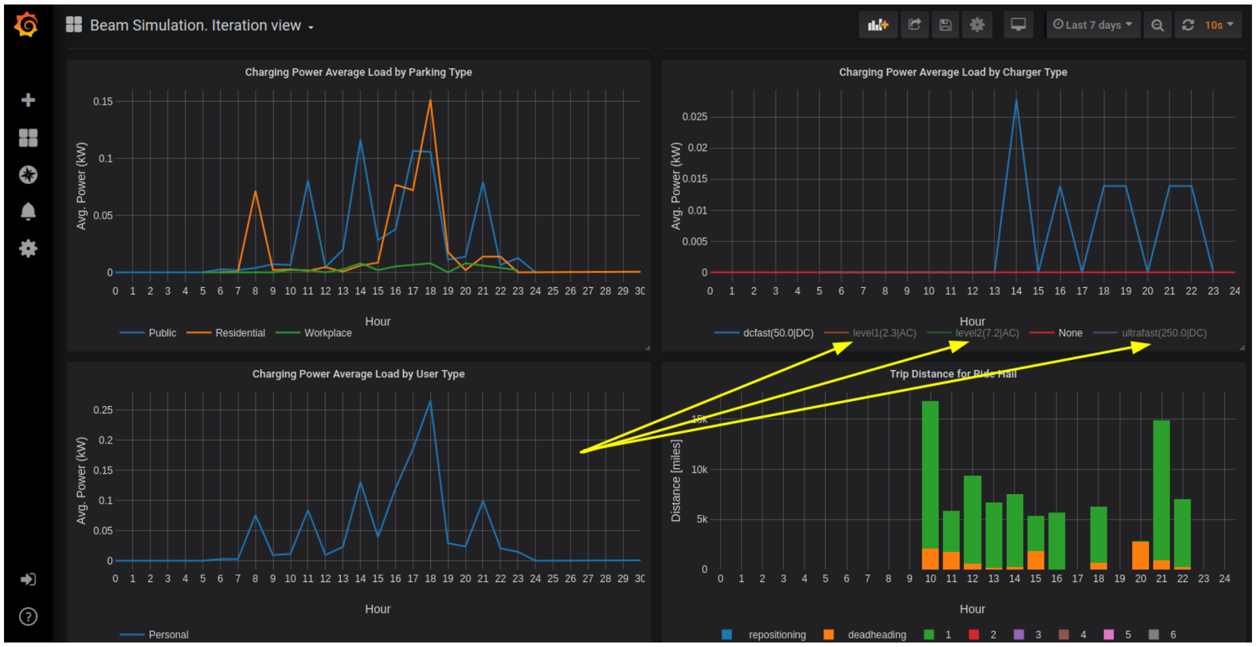

Beam Simulation. Iteration view
Last 7 days
10s
Charging Power Average Load by Parking Type
Avg. Power (kW)
Hour
Public
Residential
Workplace
Charging Power Average Load by Charger Type
dcfast(50.0|DC)
level1(2.3|AC)
level2(7.2|AC)
None
ultrafast(250.0|DC)
Charging Power Average Load by User Type
Personal
Trip Distance for Ride Hail
Distance [miles]
repositioning
deadheading

Fig. 4: enable | disable traces

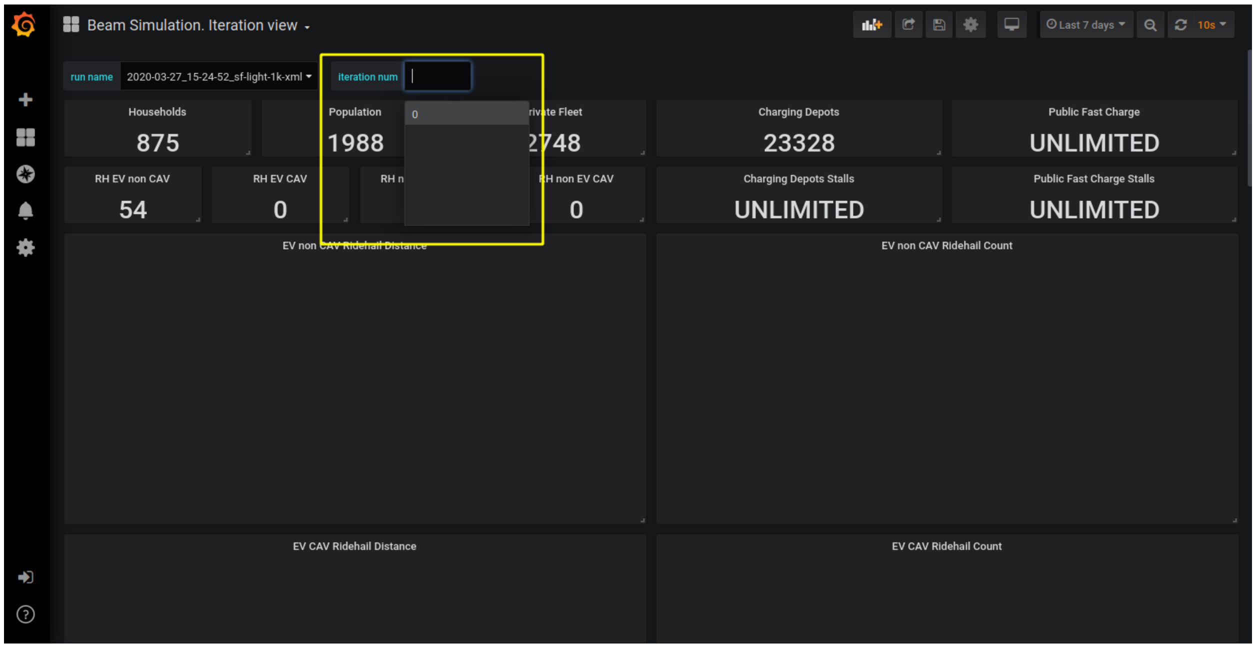


Fig. 5: BEAM iteration switch

5.4.5 Select data update frequency

There is a switch to choose how frequently grafana should gather data from the output DB. The switch is in the top right corner of all dashboards. In the example below the switch is set to update every 10 seconds. Also, there is a refresh button near the switch, this button does not refresh the entire page, run name or iteration num switch, *only the graphs*.

5.4.6 Iteration Map View

On the **Iteration Map View** oone may choose which data trace are displayed as bar graphs **(1)**, which data traces are displayed on a map **(2)** and for what hour data traces are displayed on a map **(3)**. Map is functional too, so, one may zoom in and out and move around with mouse controls.

5.5 Configure BEAM metrics in Grafana

5.5.1 Existing metrics

To configure which metrics will be written one should use BEAM configuration files.

There is a configuration entry `beam.sim.metric.collector.metrics` which contains the names of enabled metrics and thus controls which metrics will be written during BEAM execution.

By default metrics which do not affect performance are enabled globally in "test/input/common/metrics.conf" file.

To configure metrics for a specific BEAM configuration one may add the configuration entry in that specific configuration file.

Metrics description:

Metrics which contain a run name and an iteration number and are **necessary for displaying any metric**:

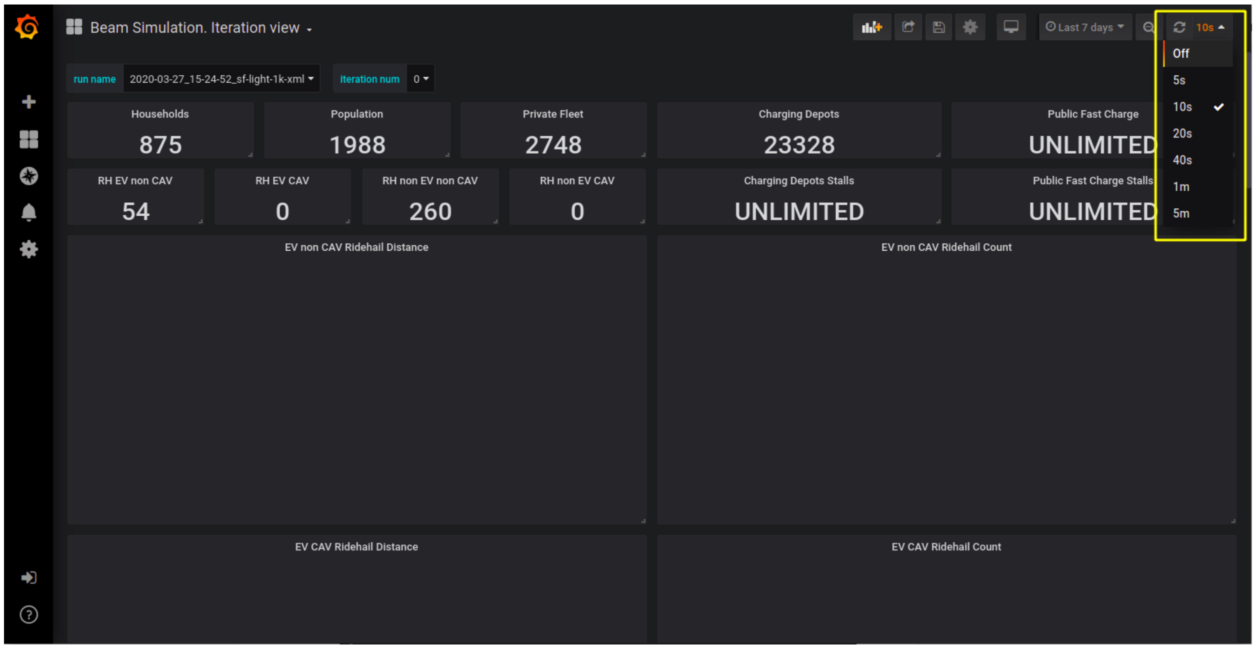


Fig. 6: shoose graphs update frequency

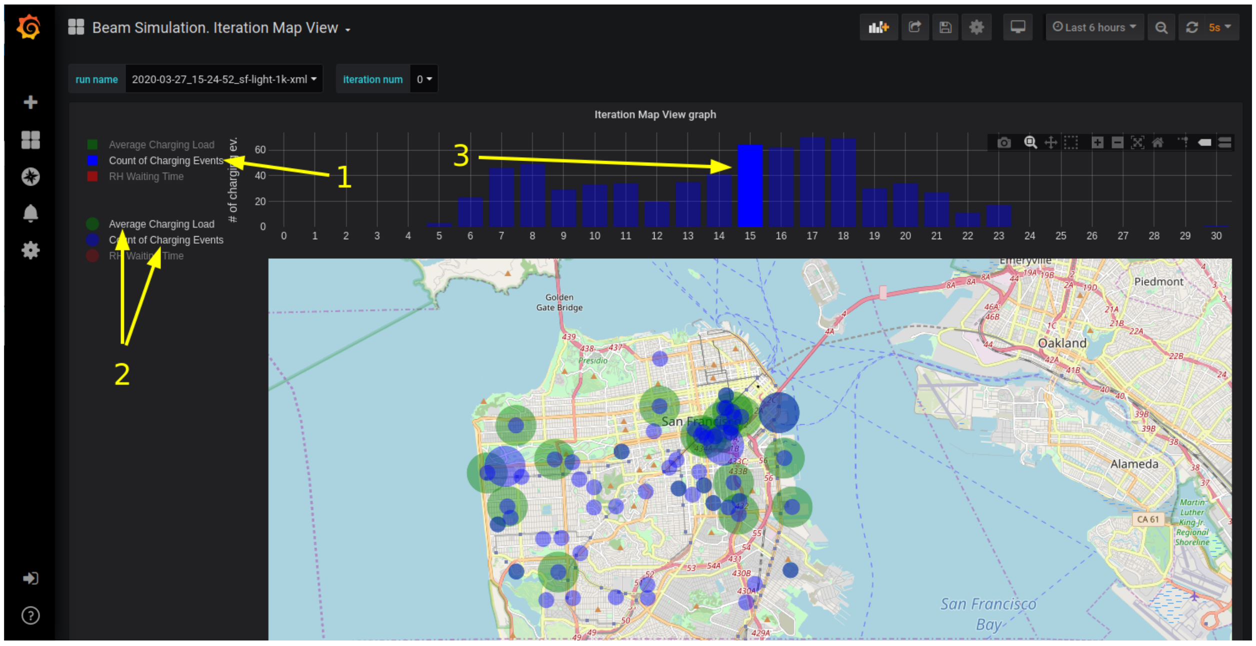


Fig. 7: example of map view

```
beam-run,
beam-iteration
```

Metrics which contain a single number with a count of households, population size, charging stalls count e.t.c:

```
beam-run-households,
beam-run-population-size,
beam-run-private-fleet-size,
beam-run-charging-depots-cnt,
beam-run-charging-depots-stalls-cnt,
beam-run-public-fast-charge-cnt,
beam-run-public-fast-charge-stalls-cnt
```

Metrics which contain a single number with a count of different types of ride hail vehicles:

```
beam-run-RH-ev-cav,
beam-run-RH-non-ev-cav,
beam-run-RH-ev-non-cav,
beam-run-RH-non-ev-non-cav
```

Various metrics for all vehicles/persons:

```
parking,
chargingPower,
mode-choices,
average-travel-time
```

Various metrics for ride hail

```
ride-hail-waiting-time,
ride-hail-waiting-time-map,
ride-hail-trip-distance,
ride-hail-inquiry-served (graph is not added to a grafana dashboard),
ride-hail-allocation-reserved (graph is not added to a grafana dashboard)
```

Metrics which impact performance

Ride hail EV (electric vehicle), CAV (connected and automated vehicle) metrics:

```
rh-ev-cav-count,
rh-ev-cav-distance,
rh-ev-nocav-count,
rh-ev-nocav-distance,
rh-noev-cav-count,
rh-noev-cav-distance,
rh-noev-nocav-count,
rh-noev-nocav-distance
```

5.5.2 New metrics

In order to write and display a new metric one should do two things:

- write metric into metric storage
- display metric on a grafana dashboard.

How to write a new metric into storage

To write a new metric into storage during a BEAM execution one needs to use an appropriate method from trait `SimulationMetricCollector`. There are methods to write iteration-level metrics with hours on X axis or to be displayed on a map and methods to write global-level metrics with iteration on X axis. There is also a method to check if a metric is enabled.

5.6 Troubleshooting

Error: for docker-influxdb-grafana Cannot create container for service docker-influxdb-grafana: Conflict. The container name "/docker-influxdb-grafana" is already in use by container "<CONTAINER ID>". You have to remove (or rename) that container to be able to reuse that name.

This error means that one already has a container with the name 'docker-influxdb-grafana' in docker. To handle that one may remove that container:

```
docker container stop docker-influxdb-grafana
docker rm docker-influxdb-grafana
```

CHAPTER 6

BeamAgents

BEAM is composed of Actors. Some of these Actors are BeamAgents. BeamAgents inherit the Akka FSM trait which provides a domain-specific language for programming agent actions as a finite state machine.

How are BeamAgents different from Actors?

In general, we reserve "BeamAgent" (also referred to as "Agent") for entities in the simulation that exhibit agency. I.e. they don't just change state but they have some degree of control or autonomy over themselves or other Agents.

A Person or a Manager is an Agent, but a Vehicle is only a tool used by Agents, so it is not a BeamAgent in BEAM.

Also, only BeamAgents can schedule callbacks with the BeamAgentScheduler. So any entity that needs to schedule itself (or be scheduled by other entities) to execute some process at a defined time within the simulation should be designed as a BeamAgent.

Programming a BeamAgent involves constructing a finite state machine and the corresponding logic that responds to Akka messages from different states and then optionally transitions between states.

6.1 Person Agents

6.2 Ride Hail Agents

6.3 Transit Driver Agents

CHAPTER 7

Behaviors

Person Agents in BEAM exhibit several within-day behaviors that govern their use of the transportation system.

7.1 Mode Choice

The most prominent behavior is mode choice. Mode choice can be specified either exogensously as a field in the persons plans, or it can be selected during replanning, or it can remain unset and be selected within the day.

Within day mode choice is selected based on the attributes of the first trip of each tour. Once a mode is selected for the tour, the person attempts to stick with that mode for the duration of the tour.

In all cases (whether mode is specified before the day or chosen within the day) person agents use WALK as a fallback option throughout if constraints otherwise prevent their previously determined mode from being possible for any given trip. E.g. if a person is in the middle of a RIDE_HAIL tour, but the Ride Hail Manager is unable to match a driver to the person, then the person will walk.

In BEAM the following modes are considers:

- Walk
- Bike
- Drive (alone)
- Walk to Transit
- Drive to Transit (Park and Ride)
- Ride Hail
- Ride Hail to/from Transit

There are two mode choice models that are possible within BEAM.

7.1.1 Multinomial Logit Mode Choice

The first is a simple multinomial logit choice model that has the following form for modal alternative j:

V_j = ASC_j + Beta_cost * cost + Beta_time * time + Beta_xfer * num_transfers

The ASC (alternative specific constant) parameters as well as the Beta parameters can be configured in the BEAM configuration file and default to the following values:

beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.cost = -1.0 beam.agentsim.agents.modalBehaviors.mulitnomialLogit.p
= -0.0047 beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.transfer = -
1.4 beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.car_intercept = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.walk_transit_intercept = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.drive_transit_intercept = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.ride_hail_transit_intercept
= 0.0 beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.ride_hail_intercept
= 0.0 beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.walk_intercept =
0.0 beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.bike_intercept = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.transit_crowding = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.transit_crowding_percentile = 90

7.1.2 Latent Class Mode Choice

7.2 Parking

In BEAM, parking is issued at the granularity of a Traffic Analysis Zone (TAZ). Upon initialization, parking alternatives are read in from the CSV file listed in the BEAM config parameter *beam.agentsim.taz.parking*. Each row identifies the attributes of a parking alternative for a given TAZ, of which a given combination of attributes should be unique. Parking attributes include the following:

BEAM agents seek parking mid-tour, from within a leg of their trip. A search is run which starts at the trip destination and expands outward, seeking to find the closest TAZ centers with increasing search radii. Agents will pick the closest and cheapest parking alternative with attributes which match their use case. The location can be overridden for ride hail agents using the config parameter *beam.agentsim.agents.rideHail.refuelLocationType*, which may be set to "AtRequestLocation" or "AtTAZCenter".

The following should be considered when configuring a set of parking alternatives. The default behavior is to provide a nearly unbounded number of parking stalls for each combination of attributes, per TAZ, for the public, and provide no parking alternatives for ride hail agents. This behavior can be overridden manually by providing replacement values in the parking configuration file. Parking which is *reservedFor* a RideHailManager should only appear as *Workplace* parking. Free parking can be instantiated by setting *feeInCents* to zero. *numStalls* should be non-negative. Charging behavior is currently implemented for ride hail agents only.

the *chargingPointType* attribute will result in the following charger power in kW:

7.3 Refueling

CHAPTER 8

Event Specifications

For an overview of events, including compatibility with MATSim, see *MATSim Events*.

The following lists each field in each event with some brief descriptions and contextual information where necessary.

8.1 MATSim Events

The following MATSim events are thrown within the AgentSim:

8.1.1 ActivityStartEvent

- Time - Time of the start of the activity.
- Activity Type - String denoting the type of activity (e.g. "Home" or "Work")
- Person - Person ID of the person agent engaged in the activity.
- Link - Link ID of the nearest link to the activity location
- Facility - Facility ID (unused in BEAM)

8.1.2 ActivityEndEvent

- Time - Time of the end of the activity.
- Activity Type - String denoting the type of activity (e.g. "Home" or "Work")
- Person - Person ID of the person agent engaged in the activity.
- Link - Link ID of the nearest link to the activity location
- Facility - Facility ID (unused in BEAM)

8.1.3 PersonDepartureEvent

- Time - Time of the person departure.
- Person - Person ID of the person departing.
- Leg Mode - String denoting the trip mode of the trip to be attempted (trip mode is the overall mode of the trip, which is different than the mode of individual sub-legs of the trip, e.g. a trip with leg mode TRANSIT might have sub-legs of mode WALK, BUS, SUBWAY, WALK).
- Link - Link ID of the nearest link to the departure location.

8.1.4 PersonArrivalEvent

- Time - Time of the person arrival.
- Person - Person ID of the person arriving.
- Leg Mode - String denoting the trip mode of the trip completed (trip mode is the overall mode of the trip, which is different than the mode of individual sub-legs of the trip, e.g. a trip with leg mode TRANSIT might have sub-legs of mode WALK, BUS, SUBWAY, WALK).
- Link - Link ID of the nearest link to the arrival location.

8.1.5 PersonEntersVehicleEvent

- Time - Time of the vehicle entry.
- Person - Person ID of the person entering the vehicle.
- Vehicle - Vehicle ID of the vehicle being entered.

8.1.6 PersonLeavesVehicleEvent

- Time - Time of the vehicle exit.
- Person - Person ID of the person exiting the vehicle.
- Vehicle - Vehicle ID of the vehicle being exited.

8.2 BEAM Events

These events are specific to BEAM and are thrown within the AgentSim:

8.2.1 ModeChoiceEvent

Note that this event corresponds to the moment of choosing a mode, if mode choice is occurring dynamically within the day. If mode choice occurs outside of the simulation day, then this event is not thrown. Also, the time of choosing mode is not always the same as the departure time.

- Time - Time of the mode choice.
- Person - Person ID of the person making the mode choice.
- Mode - The chosen trip mode (e.g. WALK_TRANSIT or CAR)

- Expected Maximum Utility - The logsum from the utility function used to evalute modal alternatives. If the mode choice model is not a random utility based model, then this will be left blank.
- Location - Link ID of the nearest location.
- Available Alternatives - Comma-separated list of the alternatives considered by the agent during the mode choice process.
- Persona Vehicle Available - Boolean denoting whether this agent had a personal vehicle availalbe to them during the mode choice process.
- Length - the length of the chosen trip in meters.
- Tour index - the index of the chosen trip within the current tour of the agent (e.g. 0 means the first trip of the tour, 1 is the second trip, etc.)

8.2.2 PathTraversalEvent

A Path Traversal is any time a vehicle moves within the BEAM AgentSim.

- Length - Length of the movement in meters.
- Fuel - fuel consumed during the movement in Joules.
- Num Passengers - the number of passengers on board during the vehicle movement (the driver does not count as a passenger).
- Links - Comma-separated list of link IDs indicating the path taken.
- Mode - the sub-leg mode of the traversal (e.g. BUS or CAR or SUBWAY).
- Departure Time - the time of departure.
- Arrival Time - the time of arrival.
- Vehicle - the ID of the vehilce making the movement.
- Vehicle Type - String indicating the type of vehicle.
- Start X - X coordinate of the starting location of the movement. Coordinates are output in WGS (lat/lon).
- Start Y - Y coordinate of the starting location of the movement. Coordinates are output in WGS (lat/lon).
- End X - X coordinate of the ending location of the movement. Coordinates are output in WGS (lat/lon).
- End Y - Y coordinate of the ending location of the movement. Coordinates are output in WGS (lat/lon).
- End Leg Fuel Level - Amount of fuel (in Joules) remaining in the vehicle at the end of the movement.

CHAPTER 9

Model Inputs

9.1 Configuration file

The BEAM configuration file controls where BEAM will source input data and the value of parameters. To see an example of the latest version of this file:

https://github.com/LBNL-UCB-STI/beam/blob/master/test/input/beamville/beam.conf

As of Fall 2018, BEAM is still under rapid development. So the configuration file will continue to evolve. Particularly, it should be expected that new parameters will be created to contol new model features and old configuration options may be modified, simplied, or eliminated.

Furthermore, the BEAM configuration file contains a hybrid between parameters from MATSim (see namespace *matsim* in the config file). Not all of the matsim parameters are used by BEAM. Only the specific MATSim parameters described in this document are relevant. Modifying the other parameters will have no impact. In future releases of BEAM, the irrelevant parameters will be removed.

In order to see example configuration options for a particular release of BEAM replace *master* in the above URL with the version number, e.g. for Version v0.6.2 go to this link:

https://github.com/LBNL-UCB-STI/beam/blob/v0.6.2/test/input/beamville/beam.conf

BEAM follows the MATSim convention for most of the inputs required to run a simulation, though specifying the road network and transit system is based on the R5 requirements. Refer to these external documntation for details on the following inputs.

- The person population and corresponding attributes files (e.g. *population.xml* and *populationAttributes.xml*)
- The household population and corresponding attributes files (e.g. *households.xml* and *householdAttributes.xml*)
- A directory containing network and transit data used by R5 (e.g. *r5/*)
- The open street map network (e.g. *r5/beamville.osm*)
- GTFS archives, one for each transit agency (e.g. *r5/bus.zip*)

Config Options

The following is a list of the most commonly used configuration options in approximate order of apearance in the beamville example config file (order need not be preserved so it is ok to rearrange options). A complete listing will be added to this documentation soon

9.1.1 General parameters

```
beam.agentsim.simulationName = "beamville"
beam.agentsim.numAgents = 100
beam.agentsim.thresholdForWalkingInMeters = 1000
beam.agentsim.thresholdForMakingParkingChoiceInMeters = 100
beam.agentsim.schedulerParallelismWindow = 30
beam.agentsim.timeBinSize = 3600
```

- simulationName: Used as a prefix when creating an output directory to store simulation results.
- numAgents: This will limit the number of PersonAgents created in the simulation agents will be . Note that the number of agents is also limited by the total number of "person" elements in the population file specified by *matsim.modules.plans.inputPlansFile*. In other words, if there are 100 people in the plans and numAgents is set to 50, then 50 PersonAgents will be created. If numAgents is >=100, then 100 PersonAgents will be created. Sampling to a smaller number of agents is accomplished by sampling full households until the desired number of PersonAgents is reached. This keeps the household structure intact.
- thresholdForWalkingInMeters: Used to determine whether a PersonAgent needs to route a walking path through the network to get to a parked vehicle. If the vehicle is closer than thresholdForWalkingInMeters in Euclidean distance, then the walking trip is assumed to be instantaneous. Note, for performance reasons, we do not recommend values for this threshold less than 100m.
- thresholdForMakingParkingChoiceInMeters: Similar to thresholdForWalkingInMeters, this threshold determines the point in a driving leg when the PersonAgent initiates the parking choice processes. So for 1000m, the agent will drive until she is <=1km from the destination and then seek a parking space.
- schedulerParallelismWindow: This controls the discrete event scheduling window used by BEAM to achieve within-day parallelism. The units of this parameter are in seconds and the larger the window, the better the performance of the simulation, but the less chronologically accurate the results will be.
- timeBinSize: For most auto-generated output graphs and tables, this parameter will control the resolution of time-varying outputs.

9.1.2 Mode choice parameters

```
beam.agentsim.agents.modalBehaviors.modeChoiceClass = "ModeChoiceMultinomialLogit"
beam.agentsim.agents.modalBehaviors.defaultValueOfTime = 8.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.transfer = -1.4
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.car_intercept = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.walk_transit_intercept =␣
↪0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.drive_transit_intercept =␣
↪2.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.ride_hail_transit_
↪intercept = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.ride_hail_intercept = -1.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.walk_intercept = -3.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.bike_intercept = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.transit_crowding = 0.0
beam.agentsim.agents.modalBehaviors.mulitnomialLogit.params.transit_crowding_
↪percentile = 90
```

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```
beam.agentsim.agents.modalBehaviors.lccm.paramFile = ${beam.inputDirectory}"/lccm-
↪long.csv"
#Toll params
beam.agentsim.toll.file=${beam.inputDirectory}"/toll-prices.csv"
```

- modeChoiceClass: Selects the choice algorithm to be used by agents to select mode when faced with a choice. Default of ModeChoiceMultinomialLogit is recommended but other algorithms include ModeChoiceMultinomialLogit ModeChoiceTransitIfAvailable ModeChoiceDriveIfAvailable ModeChoiceRideHailIfAvailable ModeChoiceUniformRandom ModeChoiceLCCM.
- defaultValueOfTime: This value of time is used by the ModeChoiceMultinomialLogit choice algorithm unless the value of time is specified in the populationAttributes file.
- params.transfer: Constant utility (where 1 util = 1 dollar) of making transfers during a transit trip.
- params.car_intercept: Constant utility (where 1 util = 1 dollar) of driving.
- params.walk_transit_intercept: Constant utility (where 1 util = 1 dollar) of walking to transit.
- params.drive_transit_intercept: Constant utility (where 1 util = 1 dollar) of driving to transit.
- params.ride_hail_transit_intercept: Constant utility (where 1 util = 1 dollar) of taking ride hail to/from transit.
- params.ride_hail_intercept: Constant utility (where 1 util = 1 dollar) of taking ride hail.
- params.walk_intercept: Constant utility (where 1 util = 1 dollar) of walking.
- params.bike_intercept: Constant utility (where 1 util = 1 dollar) of biking.
- params.transit_crowding: Multiplier utility of avoiding “crowded” transit vehicle. Should be negative.
- params.transit_crowding_percentile: Which percentile to use to get the occupancyLevel (number of passengers / vehicle capacity). The route may have different occupancy levels during the legs/vehicle stops.
- lccm.paramFile: if modeChoiceClass is set to *ModeChoiceLCCM* this must point to a valid file with LCCM parameters. Otherwise, this parameter is ignored.
- toll.file: File path to a file with static road tolls. Note, this input will change in future BEAM release where time-varying tolls will possible.

9.1.3 Vehicles and Population

```
#BeamVehicles Params
beam.agentsim.agents.vehicles.beamFuelTypesFile = ${beam.inputDirectory}"/
↪beamFuelTypes.csv"
beam.agentsim.agents.vehicles.beamVehicleTypesFile = ${beam.inputDirectory}"/
↪vehicleTypes.csv"
beam.agentsim.agents.vehicles.beamVehiclesFile = ${beam.inputDirectory}"/vehicles.csv"
```

- useBikes: simple way to disable biking, set to true if vehicles file does not contain any data on biking.
- beamFuelTypesFile: configure fuel fuel pricing.
- beamVehicleTypesFile: configure vehicle properties including seating capacity, length, fuel type, fuel economy, and refueling parameters.
- beamVehiclesFile: replacement to legacy MATSim vehicles.xml file. This must contain an Id and vehicle type for every vehicle id contained in households.xml.

9.1.4 TAZs, Scaling, and Physsim Tuning

```
#TAZ params
beam.agentsim.taz.file=${beam.inputDirectory}"/taz-centers.csv"
beam.agentsim.taz.parking = ${beam.inputDirectory}"/parking/taz-parking-default.csv"
# Parking Manager name (DEFAULT | PARALLEL)
beam.agentsim.taz.parkingManager.name = "DEFAULT"
beam.agentsim.taz.parkingManager.parallel.numberOfClusters = 8
# Scaling and Tuning Params
beam.agentsim.tuning.transitCapacity = 0.1
beam.agentsim.tuning.transitPrice = 1.0
beam.agentsim.tuning.tollPrice = 1.0
beam.agentsim.tuning.rideHailPrice = 1.0
# PhysSim name (JDEQSim | BPRSim | PARBPRSim | CCHRoutingAssignment)
beam.physsim.name = "JDEQSim
# PhysSim Scaling Params
beam.physsim.flowCapacityFactor = 0.0001
beam.physsim.storageCapacityFactor = 0.0001
beam.physsim.writeMATSimNetwork = false
beam.physsim.ptSampleSize = 1.0
beam.physsim.jdeqsim.agentSimPhysSimInterfaceDebugger.enabled = false
beam.physsim.skipPhysSim = false
# Travel time function for (PAR)PBR sim (BPR | FREE_FLOW)
beam.physsim.bprsim.travelTimeFunction = "BPR"
beam.physsim.bprsim.minFlowToUseBPRFunction = 10
beam.physsim.bprsim.inFlowAggregationTimeWindowInSeconds = 900
beam.physsim.parbprsim.numberOfClusters = 8
beam.physsim.parbprsim.syncInterval = 60
```

- agentsim.taz.file: path to a file specifying the centroid of each TAZ. For performance BEAM approximates TAZ boundaries based on a nearest-centroid approach. The area of each centroid (in m^2) is also necessary to approximate average travel distances within each TAZ (used in parking choice process).
- taz.parking: path to a file specifying the parking and charging infrastructure. If any TAZ contained in the taz file is not specified in the parking file, then ulimited free parking is assumed.
- beam.agentsim.taz.parkingManager.name: the name of the parking manager. PARALLEL parking manager splits the TAZes into a number of clusters. This allows the users to speed up the searching for parking stalls. But as a tradeoff, it has degraded quality. Usually, 8-16 clusters can provide satisfactory quality on big numbers of TAZes.
- beam.agentsim.taz.parkingManager.parallel.numberOfClusters: the number of clusters for PARALLEL parking manager.
- tuning.transitCapacity: Scale the number of seats per transit vehicle… actual seats are rounded to nearest whole number. Applies uniformly to all transit vehilces.
- tuning.transitPrice: Scale the price of riding on transit. Applies uniformly to all transit trips.
- tuning.tollPrice: Scale the price to cross tolls.
- tuning.rideHailPrice: Scale the price of ride hailing. Applies uniformly to all trips and is independent of defaultCostPerMile and defaultCostPerMinute described above. I.e. price = (costPerMile + costPerMinute)*rideHailPrice
- physsim.name: Name of the physsim. BPR physsim calculates the travel time of a vehicle for a particular link basing on the inFlow value for that link (number of vehicle entered that link within last n minutes. This value is upscaled to one hour value.). PARBPR splits the network into clusters and simulates vehicle movement for each cluster in parallel.

- physsim.flowCapacityFactor: Flow capacity parameter used by JDEQSim for traffic flow simulation.
- physsim.storageCapacityFactor: Storage capacity parameter used by JDEQSim for traffic flow simulation.
- physsim.writeMATSimNetwork: A copy of the network used by JDEQSim will be written to outputs folder (typically only needed for debugging).
- physsim.ptSampleSize: A scaling factor used to reduce the seating capacity of all transit vehicles. This is typically used in the context of running a partial sample of the population, it is advisable to reduce the capacity of the transit vehicles, but not necessarily proportionately. This should be calibrated.
- agentSimPhysSimInterfaceDebugger.enabled: Enables special debugging output.
- skipPhysSim: Turns off the JDEQSim traffic flow simulation. If set to true, then network congestion will not change from one iteration to the next. Typically this is only used for debugging issues that are unrelated to the physsim.
- physsim.bprsim.travelTimeFunction: Travel time function (BPR of free flow). For BPR function see https://en.wikipedia.org/wiki/Route_assignment. Free flow implies that the vehicles go on the free speed on that link.
- physsim.bprsim.minFlowToUseBPRFunction: If the inFlow is below this value then BPR function is not used. Free flow is used in this case.
- physsim.bprsim.inFlowAggregationTimeWindowInSeconds: The length of inFlow aggregation in seconds.
- physsim.parbprsim.numberOfClusters: the number of clusters for PARBPR physsim.
- physsim.parbprsim.syncInterval: The sync interval in seconds for PARBPRsim. When the sim time reaches this interval in a particular cluster then it waits for the other clusters at that time point.

9.1.5 Warm Mode

```
##################################################################
# Warm Mode
##################################################################
# valid options: disabled, full, linkStatsOnly (only link stats is loaded (all the␣
↪other data is got from the input directory))
beam.warmStart.type = "disabled"
#PATH TYPE OPTIONS: PARENT_RUN, ABSOLUTE_PATH
#PARENT_RUN: can be a director or zip archive of the output directory (e.g. like what␣
↪get's stored on S3). We should also be able to specify a URL to an S3 output.
#ABSOLUTE_PATH: a directory that contains required warm stats files (e.g. linkstats␣
↪and eventually a plans).
beam.warmStart.pathType = "PARENT_RUN"
beam.warmStart.path = "https://s3.us-east-2.amazonaws.com/beam-outputs/run149-base__
↪2018-06-27_20-28-26_2a2e2bd3.zip"
```

- warmStart.enabled: Allows you to point to the output of a previous BEAM run and the network travel times and final plan set from that run will be loaded and used to start a new BEAM run.
- beam.warmStart.pathType: See above for descriptions.
- beam.warmStart.path: path to the outputs to load. Can we a path on the local computer or a URL in which case outputs will be downloaded.

9.1.6 Ride hail management

```
##################################################################
# RideHail
##################################################################
# Ride Hailing General Params
beam.agentsim.agents.rideHail.numDriversAsFractionOfPopulation=0.1
beam.agentsim.agents.rideHail.defaultCostPerMile=1.25
beam.agentsim.agents.rideHail.defaultCostPerMinute=0.75
beam.agentsim.agents.rideHail.vehicleTypeId="BEV"
beam.agentsim.agents.rideHail.refuelThresholdInMeters=5000.0
beam.agentsim.agents.rideHail.refuelLocationType="AtRequestLocation"
# SurgePricing parameters
beam.agentsim.agents.rideHail.surgePricing.surgeLevelAdaptionStep=0.1
beam.agentsim.agents.rideHail.surgePricing.minimumSurgeLevel=0.1

# priceAdjustmentStrategy(KEEP_PRICE_LEVEL_FIXED_AT_ONE | CONTINUES_DEMAND_SUPPLY_
↪MATCHING)
beam.agentsim.agents.rideHail.surgePricing.priceAdjustmentStrategy="KEEP_PRICE_LEVEL_
↪FIXED_AT_ONE"

beam.agentsim.agents.rideHail.rideHailManager.radiusInMeters=5000

# initialLocation(HOME | UNIFORM_RANDOM | ALL_AT_CENTER | ALL_IN_CORNER)
beam.agentsim.agents.rideHail.initialLocation.name="HOME"
beam.agentsim.agents.rideHail.initialLocation.home.radiusInMeters=10000

# allocationManager(DEFAULT_MANAGER | REPOSITIONING_LOW_WAITING_TIMES | EV_MANAGER)
beam.agentsim.agents.rideHail.allocationManager.name="EV_MANAGER"
beam.agentsim.agents.rideHail.allocationManager.timeoutInSeconds=300
beam.agentsim.agents.rideHail.allocationManager.randomRepositioning.
↪repositioningShare=0.2

beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪repositionCircleRadisInMeters=3000.0
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪minimumNumberOfIdlingVehiclesThreshholdForRepositioning=1
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪percentageOfVehiclesToReposition=1.0
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪timeWindowSizeInSecForDecidingAboutRepositioning=1200
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪allowIncreasingRadiusIfDemandInRadiusLow=true
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪minDemandPercentageInRadius=0.1
# repositioningMethod(TOP_SCORES | KMEANS)
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪repositioningMethod="TOP_SCORES"
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪keepMaxTopNScores=5
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪minScoreThresholdForRepositioning=0.00001
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪distanceWeight=0.01
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪waitingTimeWeight=4.0
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪demandWeight=4.0
beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes.
↪produceDebugImages=true
```

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```

beam.agentsim.agents.rideHail.iterationStats.timeBinSizeInSec=3600
```

- numDriversAsFractionOfPopulation: Defines the # of ride hailing drivers to create, this ration is multiplied by the parameter beam.agentsim.numAgents to determine the actual number of drivers to create. Drivers begin the simulation located at or near the homes of existing agents, uniformly distributed.
- defaultCostPerMile: One component of the 2 part price of ride hail calculation.
- defaultCostPerMinute: One component of the 2 part price of ride hail calculation.
- vehicleTypeId: What vehicle type is used for ride hail vehicles. This is primarily relevant for when allocationManager is *EV_MANAGER*.
- refuelThresholdInMeters: One the fuel level (state of charge for EVs) of the vehicle falls below the level corresponding to this parameter, the *EV_MANAGER* will dispatch the vehicle to refuel. Note, do not make this value greate than 80% of the total vehicle range to avoid complications associated with EV fast charging.
- refuelLocationType: One of *AtRequestLocation* or *AtTAZCenter* which controls whether the vehicle is assumed to charge at the it's present location (*AtRequestLocation*) or whether it will drive to a nearby charging depot (*AtTAZCenter*).
- allocationManager.name: Controls whether fleet management is simple (DEFAULT_MANAGER for no repositioning, no refueling), includes repositioing (REPOSITIONING_LOW_WAITING_TIMES) or includes both repositioning and refueling (EV_MANAGER)
- allocationManager.timeoutInSeconds: How frequently does the manager make fleet repositioning decisions.
- beam.agentsim.agents.rideHail.allocationManager.repositionLowWaitingTimes: All of these parameters control the details of repositioning, more documentation will be posted for these soon.

9.1.7 Secondary activities generation

```
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.generate_secondary_activities =␣
↪true
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.intercept_file_path = ${beam.
↪inputDirectory}"/activity-intercepts.csv"
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.activity_file_path = ${beam.
↪inputDirectory}"/activity-params.csv"
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.additional_trip_utility = 0.0
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.max_destination_distance_meters =␣
↪16000
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.max_destination_choice_set_size =␣
↪6
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.destination_nest_scale_factor = 1.
↪0
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.mode_nest_scale_factor = 1.0
beam.agentsim.agents.tripBehaviors.mulitnomialLogit.trip_nest_scale_factor = 1.0
```

- generate_secondary_activities: allow/disallow generation of secondary activities.
- intercept_file_path: input file giving the relative likelihoods of starting different activities at different times of the day.
- activity_file_path: input file giving parameters for the different activity types, including mean duration (duration is drawn from an exponential distribution with that mean) and value of time multiplier. The value of time multiplier modifies how willing agents are to incur travel time and cost in order to accomplish that activity. For example, a value of 0.5 means that they get 50% more value out of participating in that activity than they would

being at home or work. So, if it's a 30 minute activity, they would on average be willing to spend 15 minutes round trip to participate in it. If the value is 2, they get 200% more value, so on average they would be willing to spend 60 minutes round trip commuting to participate in this activity. You can adjust the VOT values up or down to get more or less of a given activity.

- additional_trip_utility: this is an intercept value you can add to make all secondary activities more or less likely.
- max_destination_distance_meters: this sets a maximum distance in looking for places to participate in secondary activities. Increasing it increases the maximum and mean trip distance for secondary activities.
- max_destination_choice_set_size: this determines how many options for secondary activity locations an agent chooses between. Increasing this number decreases the mean distance traveled to secondary activities and slightly increases the number of trips that are made (because the agents are more likely to find a suitable location for a secondary activity nearby)
- destination_nest_scale_factor, mode_nest_scale_factor, trip_nest_scale_factor: these three values should all be between zero and one and determine the amount of noise in each level of the nested choice process. Increasing destination_nest_scale_factor means that people are more likely to choose a less optimal destination, mode_nest_scale_factor means people are more likely to value destinations accessible by multiple modes, and trip_nest_scale_factor means that people are more likely to take secondary trips even if the costs are greater than the benefits.

CHAPTER 10

Model Outputs

10.1 File: /modeChoice.csv

Classname: ModeChosenAnalysisObject

field	description
iterations	iteration number
car	Car chosen as travel mode
drive_transit	Drive to transit chosen as travel mode
ride_hail	Ride Hail chosen as travel mode
walk	Walk chosen as travel mode
walk_transit	Walk to transit chosen as travel mode
bike_transit	bike to transit chosen as travel mode

10.2 File: /referenceModeChoice.csv

Classname: ModeChosenAnalysisObject

field	description
iterations	Bike chosen as travel mode
bike	iteration number
car	Car chosen as travel mode
drive_transit	Drive to transit chosen as travel mode
ride_hail	Ride Hail chosen as travel mode
ride_hail_transit	Ride Hail to transit chosen as travel mode
walk	Walk chosen as travel mode
walk_transit	Walk to transit chosen as travel mode
bike_transit	bike to transit chosen as travel mode

10.3 File: /realizedMode.csv

Classname: RealizedModeAnalysisObject

field	description
car	Car chosen as travel mode
drive_transit	Drive to transit chosen as travel mode
other	Other modes of travel chosen
ride_hail	Ride Hail chosen as travel mode
walk	Walk chosen as travel mode
walk_transit	Walk to transit chosen as travel mode

10.4 File: /rideHailRevenue.csv

Classname: RideHailRevenueAnalysisObject

field	description
iteration #	iteration number
revenue	Revenue generated from ride hail

10.5 File: /ITERS/it.0/0.averageTravelTimes.csv

Classname: PersonTravelTimeAnalysisObject

field	description
Mode	Travel mode chosen
Hour,*	Average time taken to travel by the chosen mode during the given hour of the day

10.6 File: /ITERS/it.0/0.energyUse.png.csv

Classname: FuelUsageAnalysisObject

field	description
Modes	Mode of travel chosen by the passenger
Bin_*	Energy consumed by the vehicle while travelling by the chosen mode within the given time bin

10.7 File: /ITERS/it.0/0.physsimLinkAverageSpeedPercentage.csv

Classname: PhyssimCalcLinkSpeedStatsObject

field	description
Bin	A given time slot within a day
Aver-ageLinkSpeed	The average speed at which a vehicle can travel across the network during the given time bin

10.8 File: /ITERS/it.0/0.physsimFreeFlowSpeedDistribution.csv

Classname: PhyssimCalcLinkSpeedDistributionStatsObject

field	description
freeSpeedInMetersPer-Second	The possible full speed at which a vehicle can drive through the given link (in m/s)
numberOfLinks	Total number of links in the network that allow vehicles to travel with speeds up to the given free speed
linkEfficiencyInPercent-age	Average speed efficiency recorded by the the given network link in a day
numberOfLinks	Total number of links having the corresponding link efficiency

10.9 File: /ITERS/it.0/0.rideHailWaitingHistogram.csv

Classname: RideHailWaitingAnalysisObject

field	description
Waiting Time	The time spent by a passenger waiting for a ride hail
Hour	Hour of the day
Count	Frequencies of times spent waiting for a ride hail during the entire day

10.10 File: /ITERS/it.0/0.rideHailIndividualWaitingTimes.csv

Classname: RideHailWaitingAnalysisObject

field	description
timeOfDayInSeconds	Time of a day in seconds
personId	Unique id of the passenger travelling by the ride hail
rideHailVehicleId	Unique id of the ride hail vehicle
waitingTimeInSec-onds	Time spent by the given passenger waiting for the arrival of the given ride hailing vehicle

10.11 File: /ITERS/it.0/0.rideHailSurgePriceLevel.csv

Classname: GraphSurgePricingObject

field	description
PriceLevel	Travel fare charged by the ride hail in the given hour
Hour	Hour of the day

10.12 File: /ITERS/it.0/0.rideHailRevenue.csv

Classname: GraphSurgePricingObject

field	description
Revenue	Revenue earned by ride hail in the given hour
Hour	Hour of the day

10.13 File: /ITERS/it.0/0.tazRideHailSurgePriceLevel.csv.gz

Classname: GraphSurgePricingObject

field	description
TazId	TAZ id
DataType	Type of data , can be "priceLevel" or "revenue"
Value	Value of the given data type , can indicate either price Level or revenue earned by the ride hail in the given hour
Hour	Hour of the day

10.14 File: /ITERS/it.0/0.rideHailWaitingSingleStats.csv

Classname: RideHailingWaitingSingleAnalysisObject

field	description
WaitingTime(sec)	Time spent by a passenger on waiting for a ride hail
Hour*	Hour of the day

10.15 File: /stopwatch.txt

Classname: StopWatchOutput

field	description
Iteration	Iteration number
BEGIN iteration	Begin time of the iteration
BEGIN iterationStartsListeners	Time at which the iteration start event listeners started
END iterationStartsListeners	Time at which the iteration start event listeners ended
BEGIN replanning	Time at which the replanning event started
END replanning	Time at which the replanning event ended
BEGIN beforeMobsimListeners	Time at which the beforeMobsim event listeners started
BEGIN dump all plans	Begin dump all plans
END dump all plans	End dump all plans
END beforeMobsimListeners	Time at which the beforeMobsim event listeners ended
BEGIN mobsim	Time at which the mobsim run started
END mobsim	Time at which the mobsim run ended
BEGIN afterMobsimListeners	Time at which the afterMobsim event listeners started
END afterMobsimListeners	Time at which the afterMobsim event listeners ended
BEGIN scoring	Time at which the scoring event started
END scoring	Time at which the scoring event ended
BEGIN iterationEndsListeners	Time at which the iteration ends event listeners ended
BEGIN compare with counts	Time at which compare with counts started
END compare with counts	Time at which compare with counts ended
END iteration	Time at which the iteration ended

10.16 File: /scorestats.txt

Classname: ScoreStatsOutput

field	description
ITERATION	Iteration number
avg. EXECUTED	Average of the total execution time for the given iteration
avg. WORST	Average of worst case time complexities for the given iteration
avg. AVG	Average of average case time complexities for the given iteration
avg. BEST	Average of best case time complexities for the given iteration

10.17 File: /summaryStats.txt

Classname: SummaryStatsOutput

field	description
Iteration	Iteration number
agentHoursOnCrowdedTransit	Time taken by the agent to travel in a crowded transit
fuelConsumedInMJ_Diesel	Amount of diesel consumed in megajoule
fuelConsumedInMJ_Food	Amount of food consumed in megajoule
fuelConsumedInMJ_Electricity	Amount of electricity consumed in megajoule
fuelConsumedInMJ_Gasoline	Amount of gasoline consumed in megajoule
numberOfVehicles_BEV	Time at which the beforeMobsim event listeners started
numberOfVehicles_BODY-TYPE-DEFAULT	Number of vehicles of type BODY-TYPE-DEFAULT
numberOfVehicles_BUS-DEFAULT	Number of vehicles of type BUS-DEFAULT

Table 1 – continued from previous page

field	description
numberOfVehicles_Car	Time at which the beforeMobsim event listeners ended
numberOfVehicles_SUBWAY-DEFAULT	Time at which the mobsim run started
personTravelTime_car	Time taken by the passenger to travel by car
personTravelTime_drive_transit	Time taken by the passenger to drive to the transit
personTravelTime_others	Time taken by the passenger to travel by other means
personTravelTime_walk	Time taken by the passenger to travel on foot
personTravelTime_walk_transit	Time taken by the passenger to walk to the transit
totalCostIncludingIncentive_walk_transit	Total cost (including incentive) paid by the passenger to reach destination by walk
totalCostIncludingIncentive_ride_hail	Total cost (including incentive) paid by the passenger to reach destination on a rid
totalIncentive_drive_transit	Total incentive amount paid to passenger to reach destination by driving to transit
totalIncentive_ride_hail	Total incentive amount paid to passenger to reach destination by ride hail
totalIncentive_walk_transit	Total incentive amount paid to passenger to reach destination by walking to transit
totalTravelTime	Total time taken by the passenger to travel from source to destination
totalVehicleDelay	Sum of all the delay times incurred by the vehicle during the travel
vehicleHoursTraveled_BEV	Time taken (in hours) by the vehicle to travel from source to destination
vehicleHoursTraveled_BODY-TYPE-DEFAULT	Time taken (in hours) by the vehicle to travel from source to destination
vehicleHoursTraveled_BUS-DEFAULT	Time taken (in hours) by the vehicle(bus) to travel from source to destination
vehicleHoursTraveled_Car	Time taken (in hours) by the vehicle(car) to travel from source to destination
vehicleHoursTraveled_SUBWAY-DEFAULT	Time taken (in hours) by the vehicle (subway) to travel from source to destination
vehicleMilesTraveled_BEV	Miles covered by the vehicle to travel from source to destination
vehicleMilesTraveled_BODY-TYPE-DEFAULT	Miles covered by the vehicle to travel from source to destination
vehicleMilesTraveled_BUS-DEFAULT	Miles covered by the vehicle(bus) to travel from source to destination
vehicleMilesTraveled_Car	Miles covered by the vehicle(car) to travel from source to destination
vehicleMilesTraveled_SUBWAY-DEFAULT	Miles covered by the vehicle(subway) to travel from source to destination
vehicleMilesTraveled_total	Miles covered by the vehicles(all modes) to travel from source to destination

10.18 File: /ITERS/it.0/0.countsCompare.txt

Classname: CountsCompareOutput

field	description
Link Id	Iteration number
Count	Time taken by the agent to travel in a crowded transit
Station Id	Amount of diesel consumed in megajoule
Hour	Amount of food consumed in megajoule
MATSIM volumes	Amount of electricity consumed in megajoule
Relative Error	Amount of gasoline consumed in megajoule
Normalized Relative Error	Time at which the beforeMobsim event listeners started
GEH	GEH

10.19 File: /ITERS/it.0/0.events.csv

Classname: EventOutput

field	description
person	Person(Agent) Id
vehicle	vehicle id
time	Start time of the vehicle
type	Type of the event
fuel	Type of fuel used in the vehicle
duration	Duration of the travel
cost	Cost of travel
location.x	X co-ordinate of the location
location.y	Y co-ordinate of the location
parking_type	Parking type chosen by the vehicle
pricing_model	Pricing model
charging_type	Charging type of the vehicle
parking_taz	Parking TAZ
distance	Distance between source and destination
location	Location of the vehicle
mode	Mode of travel
currentTourMode	Current tour mode
expectedMaximumUtility	Expected maximum utility of the vehicle
availableAlternatives	Available alternatives for travel for the passenger
personalVehicleAvailable	Whether the passenger possesses a personal vehicle
tourIndex	Tour index
facility	Facility availed by the passenger
departTime	Time of departure of the vehicle
originX	X ordinate of the passenger origin point
originY	Y ordinate of the passenger origin point
destinationX	X ordinate of the passenger destination point
destinationY	Y ordinate of the passenger destination point
fuelType	Fuel type of the vehicle
num_passengers	Num of passengers travelling in the vehicle
links	Number of links in the network
departure_time	Departure time of the vehicle
arrival_time	Arrival time of the vehicle
vehicle_type	Type of vehicle
capacity	Total capacity of the vehicle
start.x	X ordinate of the start point
start.y	Y ordinate of the start point
end.x	X ordinate of the vehicle end point
end.y	Y ordinate of the vehicle end point
end_leg_fuel_level	Fuel level at the end of the travel
seating_capacity	Seating capacity of the vehicle
costType	Type of cost of travel incurred on the passenger

10.20 File: /ITERS/it.0/0.legHistogram.txt

Classname: LegHistogramOutput

field	description
time	Time
time	Time
departures_all	Total number of departures on all modes
arrivals_all	Total number of arrivals on all modes
duration	Duration of travel
stuck_all	Total number of travels that got stuck on all modes
en-route_all	Total number of travels by all modes
departures_car	Total number of departures by car
arrivals_car	Total number of departures by car
stuck_car	Total number of travels that got stuck while travelling by car
en-route_car	Total number of travels made by car
departures_drive_transit	Total number of departures by drive to transit
arrivals_drive_transit	Total number of arrivals by drive to transit
stuck_drive_transit	Total number of travels that got stuck while travelling by drive to transit
en-route_drive_transit	Total number of travels made by drive to transit
departures_ride_hail	Total number of departures by ride hail
arrivals_ride_hail	Total number of arrivals by ride hail
stuck_ride_hail	Total number of travels that got stuck while travelling by ride hail
en-route_ride_hail	Total number of travels made by ride hail
departures_walk	Total number of departures on foot
arrivals_walk	Total number of arrivals on foot
stuck_walk	Total number of travels that got stuck while travelling on foot
en-route_walk	Total number of travels made on foot
departures_walk_transit	Total number of departures by walk to transit
arrivals_walk_transit	Total number of arrivals by walk to transit
stuck_walk_transit	Total number of travels that got stuck while travelling by walk to transit
en-route_walk_transit	Total number of travels made by walk to transit

10.21 File: /ITERS/it.0/0.rideHailTripDistance.csv

Classname: RideHailTripDistanceOutput

field	description
hour	Hour of the day
numPassengers	Number of passengers travelling in the ride hail
vkt	Total number of kilometers travelled by the ride hail vehicle

10.22 File: /ITERS/it.0/0.tripDuration.txt

Classname: TripDurationOutput

field	description
pattern	Pattern
(5*i)+	Value

10.23 File: /ITERS/it.0/0.biasErrorGraphData.txt

Classname: BiasErrorGraphDataOutput

field	description
hour	Hour of the day
mean relative error	Mean relative error
mean bias	Mean bias value

10.24 File: /ITERS/it.0/0.biasNormalizedErrorGraphData.txt

Classname: BiasNormalizedErrorGraphDataOutput

field	description
hour	Hour of the day
mean normalized relative error	Mean normalized relative error
mean bias	Mean bias value

10.25 File: /ITERS/it.0/0.rideHailFleetFromInitializer.csv.gz

Classname: RideHailFleetInitialize

field	description
id	Id of the ride hail vehicle
rideHailManagerId	Id of the ride hail manager
vehicleType	Type of the beam vehicle
initialLocationX	X-coordinate of the initial location of the ride hail vehicle
initialLocationY	Y-coordinate of the initial location of the ride hail vehicle
shifts	Time shifts for the vehicle , usually a stringified collection of time ranges
geoFenceX	X-coordinate of the geo fence central point
geoFenceY	Y-coordinate of the geo fence central point
geoFenceRadius	Radius of the geo fence

CHAPTER 11

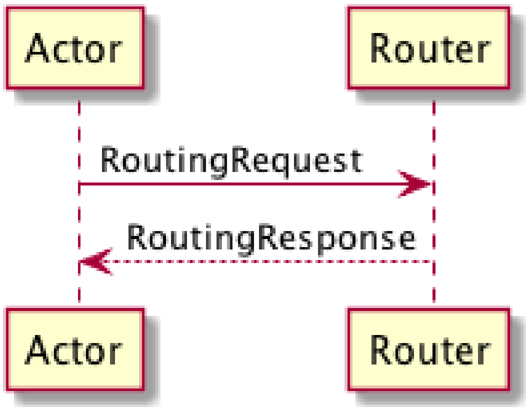
Protocols

Because BEAM is implemented using the Actor framework and simulations are executed asynchronously, there are many communications protocols between Actors and Agents that must be specified and followed. The following describes the key protocols with diagrams and narrative.

11.1 Trip Planning

11.1.1 RoutingRequests

One of the more familiar protocols, any Actor can consult the router service for routing information by sending a RoutingRequest and receiving a RoutingResponse.



The RoutingRequest message contains:

- Departure Window
- Origin / Destination
- Transit Modes to Consider

- Vehicles to Consider (their Id, Location, Mode)
- The Id of the Person for whom the request is ultimately made

The RoutingResponse message contains:

- A vector of EmbodiedBeamTrips

EmbodiedBeamTrips contain:

- A trip classifer (i.e. the overall mode for the trip which is restricted to WALK, BIKE, CAR, RIDE_HAIL, TRANSIT)
- A vector of EmbodiedBeamLegs

EmbodiedBeamLegs contain:

- A BeamLeg
- A BeamVehicle Id
- As Driver Boolean
- Optional PassengerSchedule
- Cost
- UnbecomeDriveOnCompletion Boolean

BeamLegs contain:

- Start time
- Mode (this is a more specific mode for Transit, e.g. SUBWAY or BUS)
- Duration
- BeamPath containing the path used through the network.

BeamPaths contain:

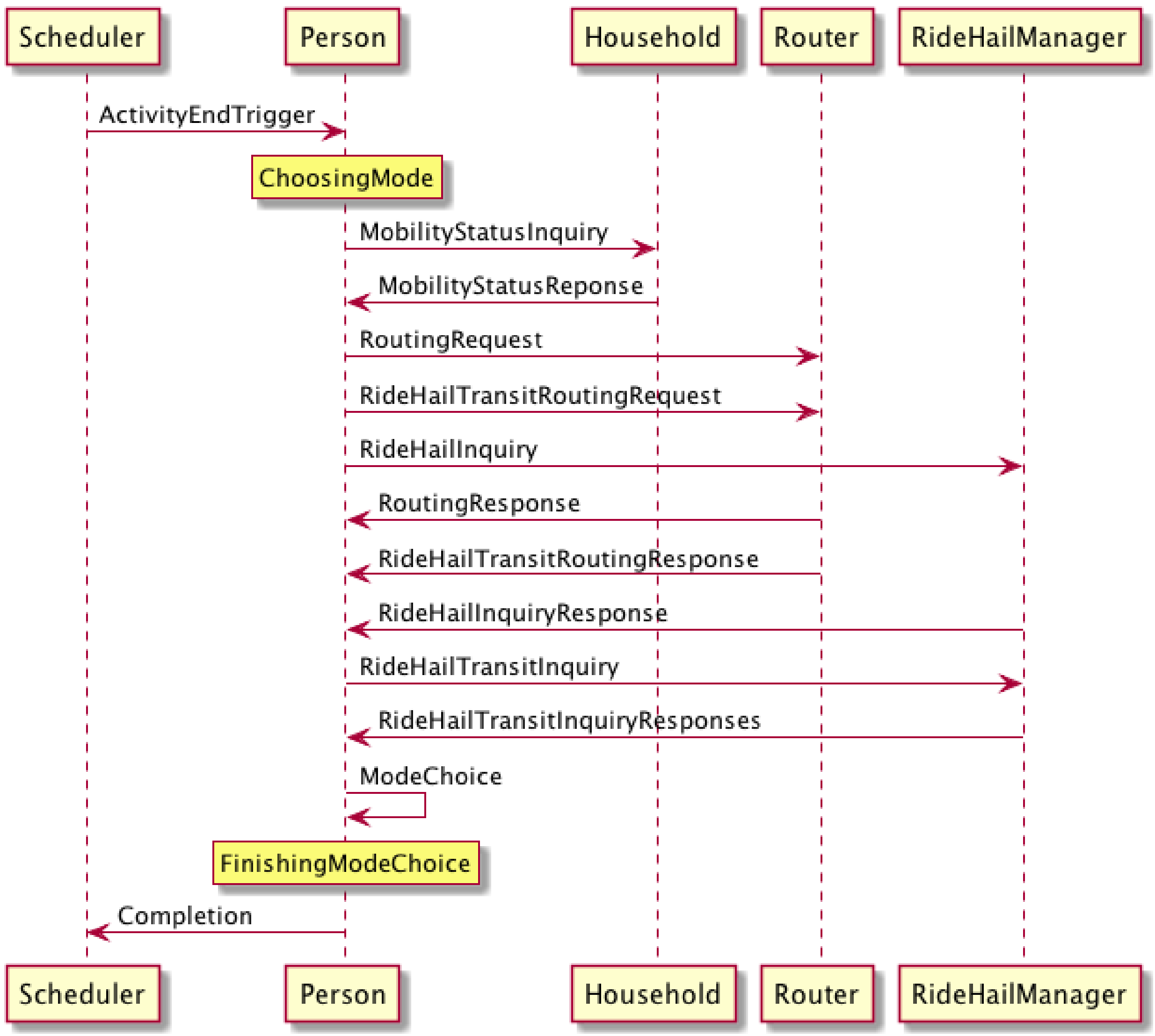
- Vector of link Ids
- Optional transit stop info (for any Transit leg, the boarding and alighting stop)
- A trajectory resolver which is resposible for translating the linkIds into coordinates

BeamTransitSegments contain:

- Origin stop
- Destination stop

11.1.2 ChoosesMode

The mode choice protocol involves gathering information, making a choice, confirming reservations if necessary, and then adapting if the chosen trip cannot be executed.



Gathering Information

1. The Person receives the BeginModeChoiceTrigger from the scheduler.
2. Person sends a MobilityStatusInquiry to their Household.
3. Household returns a MobilityStatusResponse. Based on this response, the person optionally includes vehicles in the ReservationRequest sent to the Router.
4. Person sends a ReservationRequest to the Router.
5. Person sends a RideHailInquiry to the RideHailManager.
6. Person schedules a FinalizeModeChoiceTrigger to occur in the future (representing non-zero time to make a choice).
7. Person stays in ChoosingMode state until all results are received: RoutingResponse, RideHailingInquiryResponse, FinalizeModeChoiceTrigger. With each response, the data is stored locally for use in the mode choice.

Choosing and Reserving

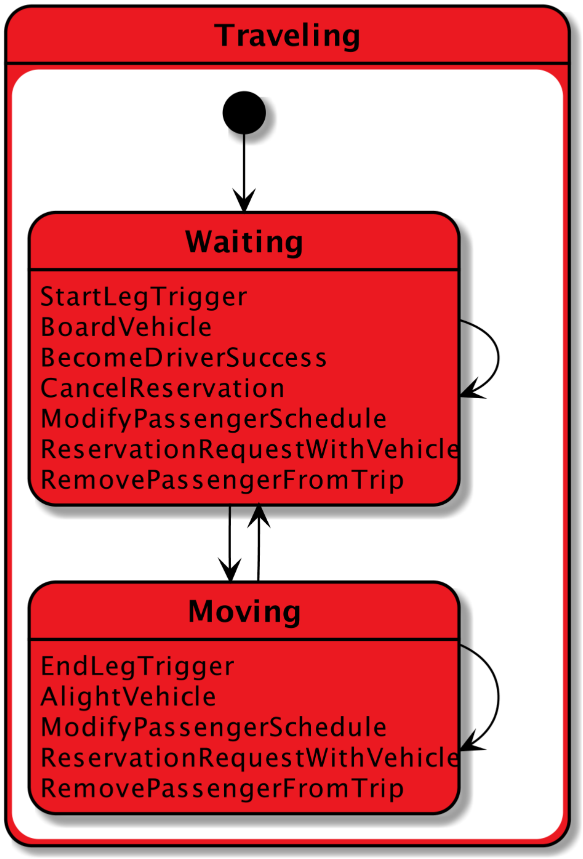
1. The Person evaluates the ModeChoiceCalculator which returns a chosen itinerary (in the form of an EmbodiedBeamTrip) from the list of possible alternatives.

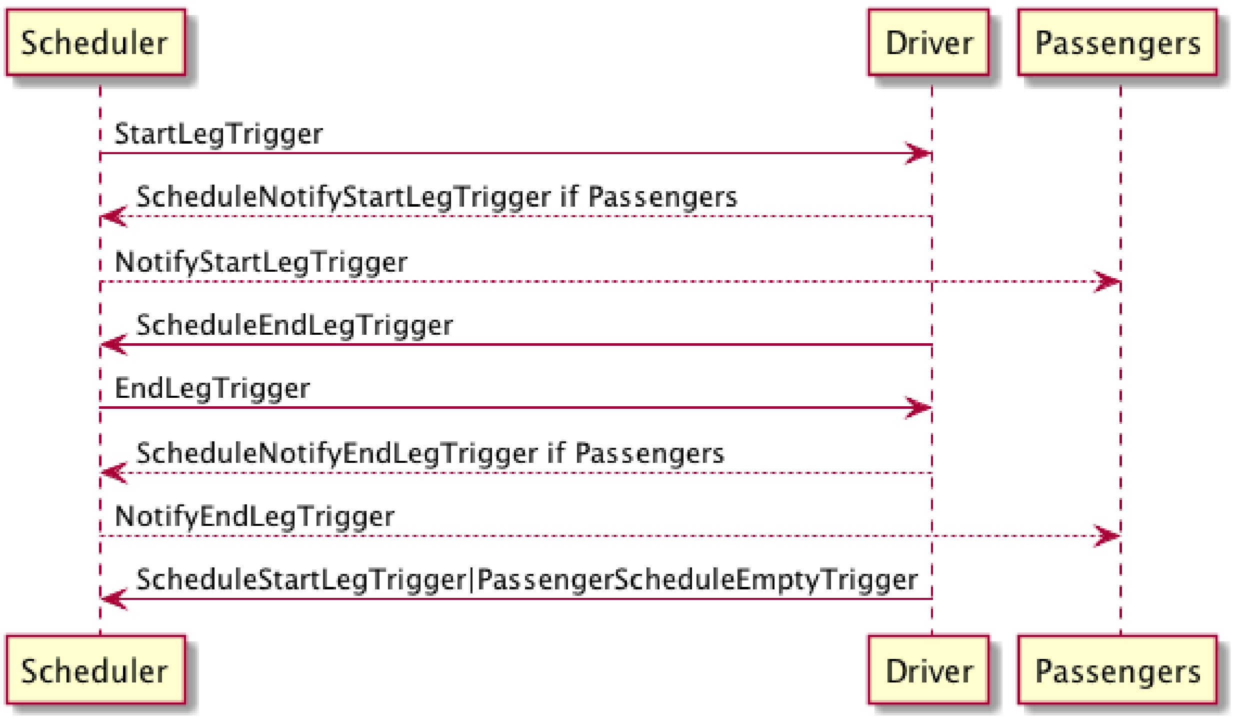
2. If a reservation is required to accomplish the chosen itinerary, the person sends ReservationRequest to all drivers in the itinerary (in the case of a transit trip) or a ReserveRide message to the RideHailManager in the case of a ride hail trip).
3. If reservation requests were sent, the Person waits (still in ChoosingMode state) for all responses to be returned. If any response is negative, the Person removes the chosen itinerary from their choice set, sends RemovePassengerFromTrip messagse to all drivers in the trip (if transit) and begins the mode choice process anew.
4. If all reservation responses are received and positive or if the trip does not require reservations at all, the person releases any reserved personal vehicles by sending ReleaseVehicleReservation messags to the Household and a ResourceIsAvailableNotification to themself, the Person throws a PersonDepartureEvent and finally schedules a PersonDepartureTrigger to occur at the departure time of the trip.

11.2 Traveling

When a PersonAgent travels, she may transition from being a driver of a vehicle to being a passenger of a vehicle. The protocol for being a driver of a vehicle is listed separately below because that logic is implemented in its own trait (DrivesVehicle) to allow BeamAgents other than PersonAgents to drive vehicles. Some agents (e.g. TransitDrivers) may not be Persons and therefore do not "travel" but they do of course operate a vehicle and move around with it.

11.2.1 Driver





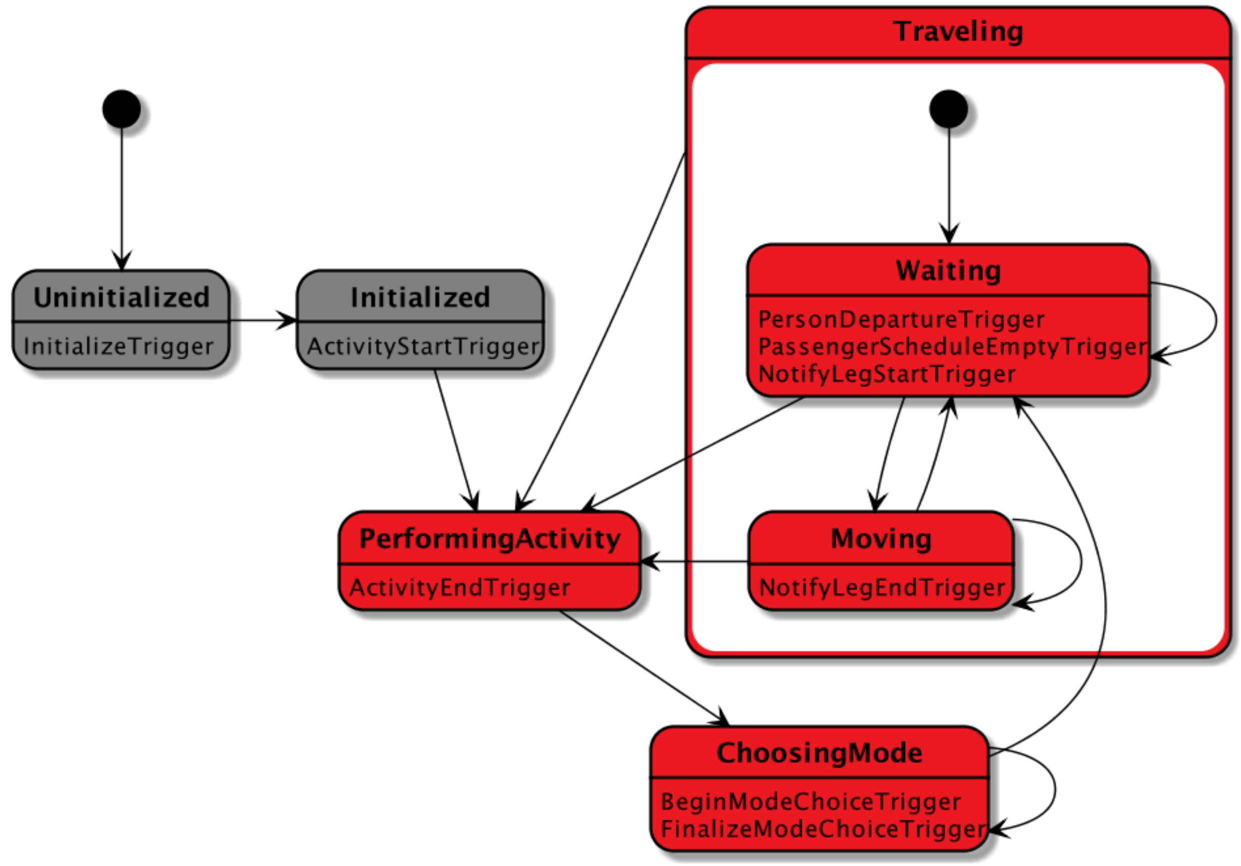
Starting Leg

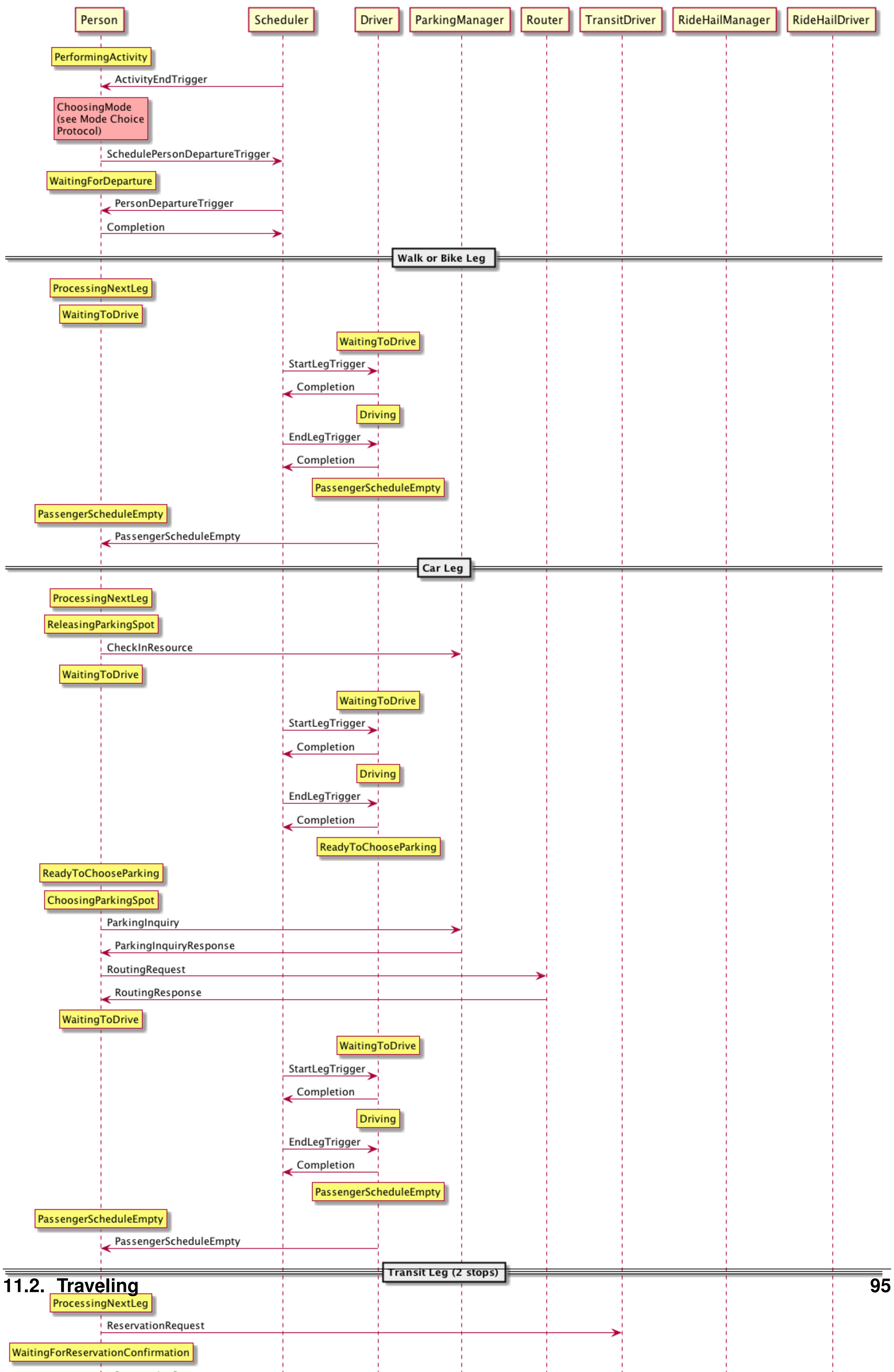
1. The Driver receives a StartLegTrigger from the Waiting state.
2. The Driver schedules NotifyLegStartTriggers for each rider in the PassengerSchedule associated with the current BeamLeg.
3. The Driver creates a list of borders from the PassengerSchedule associated with the BeamLeg to track which agents have yet to board the vehicle.
4. When all expected BoardVehicle messages are recieved by the Driver, the Driver schedules an EndLegTrigger and transitions to the Moving state.

Ending Leg

1. The Driver receives an EndLegTrigger from the Moving state.
2. The Driver schedules NotifyLegEndTriggers for all riders in the PassengerSchedule associated with the current BeamLeg.
3. The Driver creates a list of alighters from the PassengerSchedule associated with the BeamLeg to track which agents have yet to alight the vehicle.
4. When all expected AlightingConfirmation messages are recieved from the vehicle, the Driver publishes a PathTraversalEvent and proceeds with the following steps.
5. If the Driver has more legs in the PassengerSchedule, she schedules a StartLegTrigger based on the start time of that BeamLeg.
6. Else the Driver schedules a PassengerScheduleEmptyTrigger to execute in the current tick.
7. The Driver transitions to the Waiting state.

11.2.2 Traveler




Person
Scheduler
Driver
ParkingManager
Router
TransitDriver
RideHailManager
RideHailDriver
PerformingActivity
ActivityEndTrigger
ChoosingMode (see Mode Choice Protocol)
SchedulePersonDepartureTrigger
WaitingForDeparture
PersonDepartureTrigger
Completion
Walk or Bike Leg
ProcessingNextLeg
WaitingToDrive
WaitingToDrive
StartLegTrigger
Completion
Driving
EndLegTrigger
Completion
PassengerScheduleEmpty
PassengerScheduleEmpty
PassengerScheduleEmpty
Car Leg
ProcessingNextLeg
ReleasingParkingSpot
CheckInResource
WaitingToDrive
WaitingToDrive
StartLegTrigger
Completion
Driving
EndLegTrigger
Completion
ReadyToChooseParking
ReadyToChooseParking
ChoosingParkingSpot
ParkingInquiry
ParkingInquiryResponse
RoutingRequest
RoutingResponse
WaitingToDrive
WaitingToDrive
StartLegTrigger
Completion
Driving
EndLegTrigger
Completion
PassengerScheduleEmpty
PassengerScheduleEmpty
PassengerScheduleEmpty
Transit Leg (2 stops)
ProcessingNextLeg
ReservationRequest
WaitingForReservationConfirmation

Starting Trip

1. The PersonAgent receives a PersonDepartureTrigger from the scheduler while in Waiting state. She executes the ProcessNextLeg Method described below.

ProcessNextLeg Method

The following protocol is used more than once by the traveler so it is defined here as a function with no arguments.

1. The Person checks the value of _currentEmbodiedLeg to see if unbecomeDriverOnCompletion is set to TRUE, if so, then the Person sends an UnbecomeDriver message to her vehicle and updates her _currentVehicle accordingly.
2. If there are no more legs in the EbmodiedBeamTrip, the PersonAgent either schedules the ActivityEndTrigger and transitions to the PerformingActivity state or, if there are no remaining activities in the person's plan, she transitions to the Finished state and schedules no further triggers.
3. If there are more legs in the EmbodiedBeamTrip, the PersonAgent processes the next leg in the trip. If asDriver for the next leg is FALSE, then the Person transitions to Waiting state and does nothing further.
4. If asDriver is true for the next leg, the Person creates a temporary passenger schedule for the next leg and sends it along with a BecomeDriver or a ModifyPassnegerSchedule message, depending on whether this person is already the driver of the vehicle or if becoming the driver for the first time.
5. The person stays in the current state (which could be Waiting or Moving depending on the circumstances).

Driving Mission Completed

1. The PersonAgent receives a PassengerScheduleEmptyTrigger from the scheduler which indicates that as a driver, this Person has finished all legs in her PassengerSchedule.
2. The PersonAgent executes the ProcessNextLeg method.

Notify Start Leg

1. The PersonAgent receives a NotifyLegStartTrigger.
2. If the private field _currentEmbodiedLeg is non-empty or if the leg referred to in the trigger does not match the Person's next leg or if the Person's next leg has asDriver set to TRUE, this Person has received the NotifyLegStartTrigger too early, so she reschedules the NotifyLegStartTrigger to occur in the current tick, allowing other messages in her Actor mailbox to be processed first.
3. Otherwise, the PersonAgent sends an BoardVehicle message to the driver contained in the EmbodiedBeamLeg unless she is already a passenger in that vehicle.
4. The PersonAgent transitions to the Moving state.

Notify End Leg

1. The PersonAgent receives a NotifyLegEndTrigger.
2. If the private field _currentEmbodiedLeg is empty or the currentBeamLeg does not match the leg associated with the Trigger, this Person has received the NotifyLegEndTrigger too early, so she reschedules the NotifyLegEndTrigger to occur in the current tick, allowing other messages in her Actor mailbox to be processed first.
3. If another EmbodiedBeamLeg exists in her EmbodiedBeamTrip AND the BeamVehicle associated with the next EmbodiedBeamTrip is identical to the curren BeamVehicle, then she does nothing other than update her internal state to note the end of the leg and transition to Waiting.
4. Else she sends the current driver an AlightVehicle message and executes the ProcessNextLegModule method.

11.3 Household

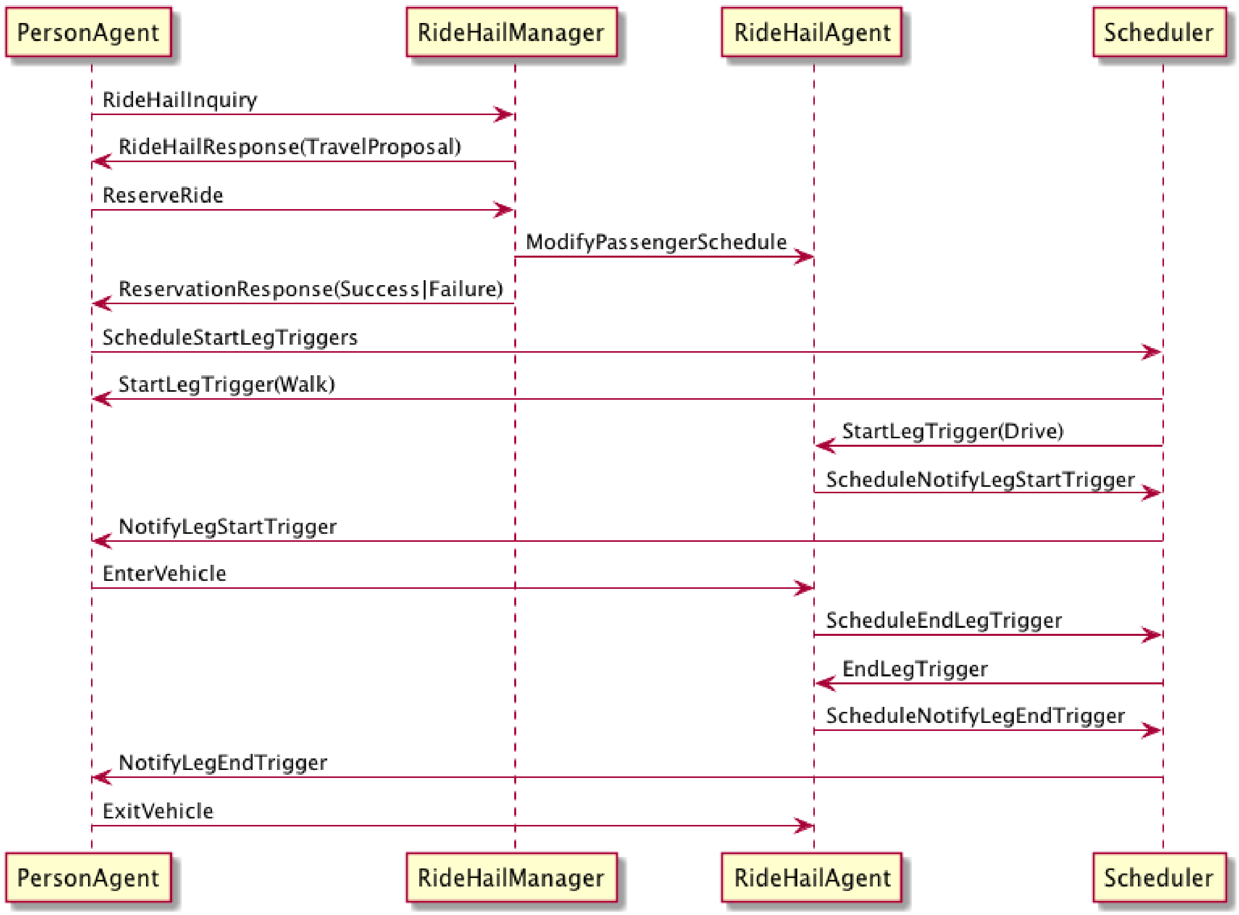
During initialization, we execute the rank and escort heuristc. Escorts and household vehicles are assigned to members.

1. The PersonAgent retrieves mobility status from her Household using a MobilityStatusInquiry message.
2. Household returns a MobilityStatusReponse message which notifies the person about two topics: a) whether she is an escortee (e.g. a child), an estorter (e.g. a parent), or traveling alone; b) the Id and location of at most one Car and at most one Bike that the person may use for their tour.
3. If the PersonAgent is an escortee, then she will enter a waiting state until she receives a AssignTrip message from her escorter which contains the BeamTrip that she will follow, at which point she schedules a PersonDepartureTrigger.
4. Else the PersonAgent goes through the mode choice process. After choosing a BeamTrip, she sends an appropriate BeamTrip to her escortees using the AssignTrip message.
5. The PersonAgent sends a VehicleConfirmationNotice to the Household, confirming whether or not she is using the Car or Bike. The Household will use this information to offer unused vehicles as options to subsequent household members.

11.3.1 Escort

11.4 RideHailing

The process of hailing a ride from a TNC is modeled after the real-world experience:



1. The PersonAgent inquires about the availability and pricing of the service using a RideHailingInquiry message.
2. The RideHailingManager responds with a RideHailingInquiryResponse.
3. The PersonAgent may choose to use the ride hailing service in the mode choice process.
4. The PersonAgent sends a ReserveRide message attempting to book the service.
5. The RideHailingManager responds with a ReservationResponse which either confirms the reservation or notifies that the resource is unavailable.

11.4.1 Inquiry

The RideHailingInquiry message contains:

- inquiryId
- customerId
- pickUpLocation
- departAt time
- destinationLocation

The RideHailingInquiryResponse message contains:

- inquiryId
- a Vector of TravelProposals

- an optional ReservationError

Each TravelProposal contains:

- RideHailingAgentLocation
- Time to Customer
- estimatedPrice
- estimatedTravelTime
- Route to customer
- Route from origin to destination

11.4.2 Reserve

The ReserveRide message contains:

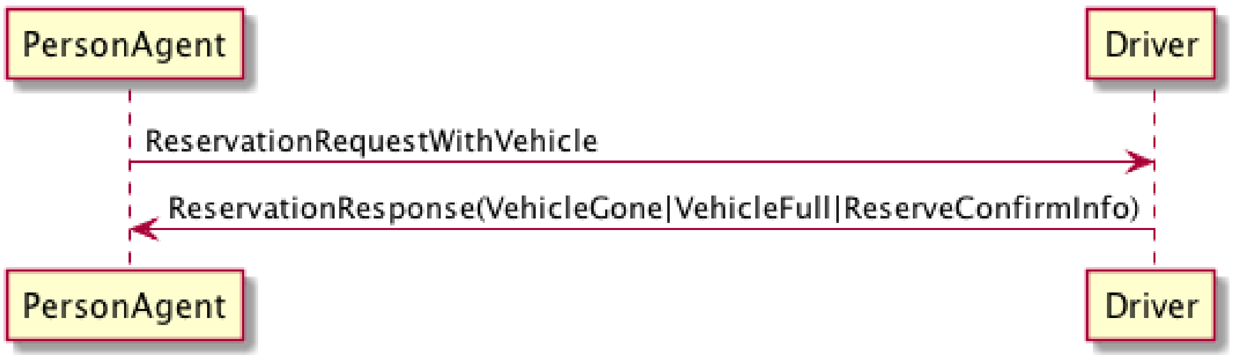
- inquiryId
- customerId in the form of a VehiclePersonId
- pickUpLocation
- departAt time
- destinationLocation)

The ReservationResponse message contains the request Id and either a ReservationError or f the reservation is successfull, a ReserveConfirmInfo object with the following:

- DepartFrom BeamLeg.
- ArriveTo BeamLeg.
- PassengerVehicleId object containin the passenger and vehicle Ids.
- Vector of triggers to schedule.

11.5 Transit

Transit itineraries are returned by the router in the Trip Planning Protocol. In order to follow one of these itineraries, the PersonAgent must reserve a spot on the transit vehicle according to the following protocol:


PersonAgent
Driver
ReservationRequestWithVehicle
ReservationResponse(VehicleGone|VehicleFull|ReserveConfirmInfo)
PersonAgent
Driver

1. PersonAgent sends ReservationRequest to the Driver.

2. The BeamVehicle forwards the reservation request to the Driver of the vehicle. The driver is responsible for managing the schedule and accepting/rejecting reservations from customers.
3. The Driver sends a ReservationConfirmation directly to the PersonAgent.
4. When the BeamVehicle makes it to the confirmed stop for boarding, the Driver sends a BoardingNotice to the PersonAgent.

5. The PersonAgent sends an BoardVehicle message to the Driver. 7. Also, concurrently, when the BeamVehicle is at the stop, the Driver sends an AlightingNotice to all passengers registered to alight at that stop. 8. Notified passengers send an AlightVehicle message to the Driver.

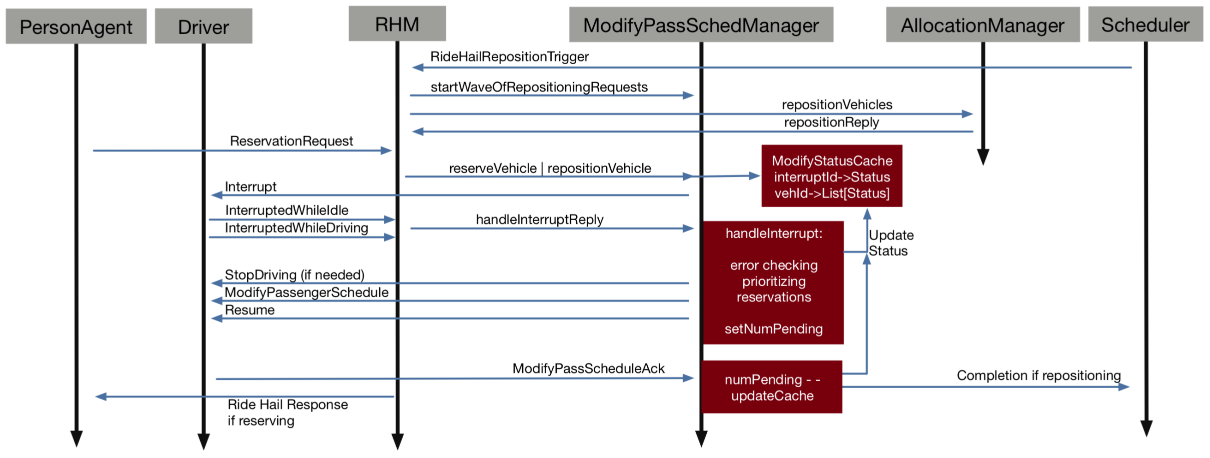
Because the reservation process ensures that vehicles will not exceed capacity, the Driver need not send an acknowledgement to the PersonAgent.

11.6 Refueling

???

11.7 Modify Passenger Schedule Manager

This protocol is deep into the weeds of the Ride Hail Manager but important for understanding how reservations and reposition requests are managed.



CHAPTER 12

DevOps Guide

12.1 Git LFS

12.1.1 Setup git-lfs Server

1. From the AWS Management Console, launch the Amazon EC2 instance from an Amazon Machine Image (AMI) that has Ubuntu 64-bit as base operating system.
2. Choose a security group that will allow SSH access as well as port 8080 to access your git lfs server. You should only enable ingress from the IP addresses you wish to allow access to your server.
3. On AWS Management Console go to Services menu from top bar and open the Amazon S3 console.
4. Click Create Bucket, it will opens a new dialog window.
6. On the Name and region tab, provide appropriate name (should be DNS compliant) and desired region, then Click Next button in the bottom.
7. Leave Set properties as is and click Next again.
8. On Set Permissions tab, set read and write access for your git-lfs user. and Click next.
9. Verify your settings on Review tab. If you want to change something, choose Edit. If your current settings are correct, choose Create bucket.
10. Connect to the ec2 instance via SSH.
11. Add NodeSource APT repository for Debian-based distributions repository AND the PGP key for verifying packages:

    $ curl -sL https://deb.nodesource.com/setup_6.x | sudo -E bash -
12. Install Node.js from the Debian-based distributions repository:

    $ sudo apt-get install -y nodejs
13. To confirm that Node.js was successfully installed on your system, you can run the following command:

    $ node -v

If Node is installed, this command should print out something like this:

v6.9.1

14. To get the most up-to-date npm, you can run the command:

    $ sudo npm install npm –global

15. Next, you can directly install git-lfs server using node package manager by executing following command:

    $ sudo npm install node-git-lfs

16. Git LFS server offers two method of configuration, via environment variable or configuration file. At this step you have to define some environment variables to configure the server:

- LFS_BASE_URL - URL of the LFS server - **required**
- LFS_PORT - HTTP portal of the LFS server, default to 3000 - **required**
- LFS_STORE_TYPE - Object store type, can be either s3 (for AWS S3) or grid (for MongoDB GridFS), default to s3 - **required**
- LFS_AUTHENTICATOR_TYPE - Authenticator type, can be basic (for basic username and password), none (for no authentication), default to none - **required**
- LFS_AUTHENTICATOR_USERNAME - Username - **required**
- LFS_AUTHENTICATOR_PASSWORD - Password - **required**
- AWS_ACCESS_KEY - AWS access key - **required**
- AWS_SECRET_KEY - AWS secret key - **required**
- LFS_STORE_S3_BUCKET - AWS S3 bucket - **required**
- LFS_STORE_S3_ENDPOINT - AWS S3 endpoint, normally this will be set by region
- LFS_STORE_S3_REGION - AWS S3 region

Set Aws access key, secret ky and s3 details based on previous steps.

17. Now start git lfs server:

    $ node-git-lfs

18. At the end, create file named .lfsconfig in you repository with following contents, update host and port based on your environment.

    [lfs] url = "http://host:port/LBNL-UCB-STI/beam.git" batch = true access = basic

This will setup everything you need to setup and install a custom gitl-lfs server on Amazon instance and github repository will start pointing to the your custom server. There is no special installation or requirement for the clint, only thing that you need is to provide lfs user name and password on you client when you pull your contents for the first time.

12.2 Jenkins

12.2.1 Setup Jenkins Server

1. From the AWS Management Console, launch the Amazon EC2 instance from an Amazon Machine Image (AMI) that has Ubuntu 64-bit as base operating system.
2. Choose a security group that will allow SSH access as well as port 8080, 80 and 443 to access your Jenkins dashboard. You should only enable ingress from the IP addresses you wish to allow access to your server.

3. Connect to the instance via SSH.
4. Add oracle java apt repository:

```
$ sudo add-apt-repository ppa:webupd8team/java
```

5. Run commands to update system package index and install Java installer script:

```
$ sudo apt update; sudo apt install oracle-java8-installer
```

6. Add the repository key to the system:

```
$ wget -q -O - https://pkg.jenkins.io/debian/jenkins-ci.org.key | sudo apt-key␣
↪add - .
```

7. Append the Debian package repository address to the server's sources:

```
$ echo deb https://pkg.jenkins.io/debian-stable binary/ | sudo tee /etc/apt/
↪sources.list.d/jenkins.list
```

8. Run update so that apt-get will use the new repository:

```
$ sudo apt-get update
```

9. Install Jenkins and its dependencies, including Java:

```
$ sudo apt-get install jenkins
```

10. Start Jenkins:

```
$ sudo service jenkins start
```

11. Verify that it started successfully:

```
$ sudo service jenkins status
```

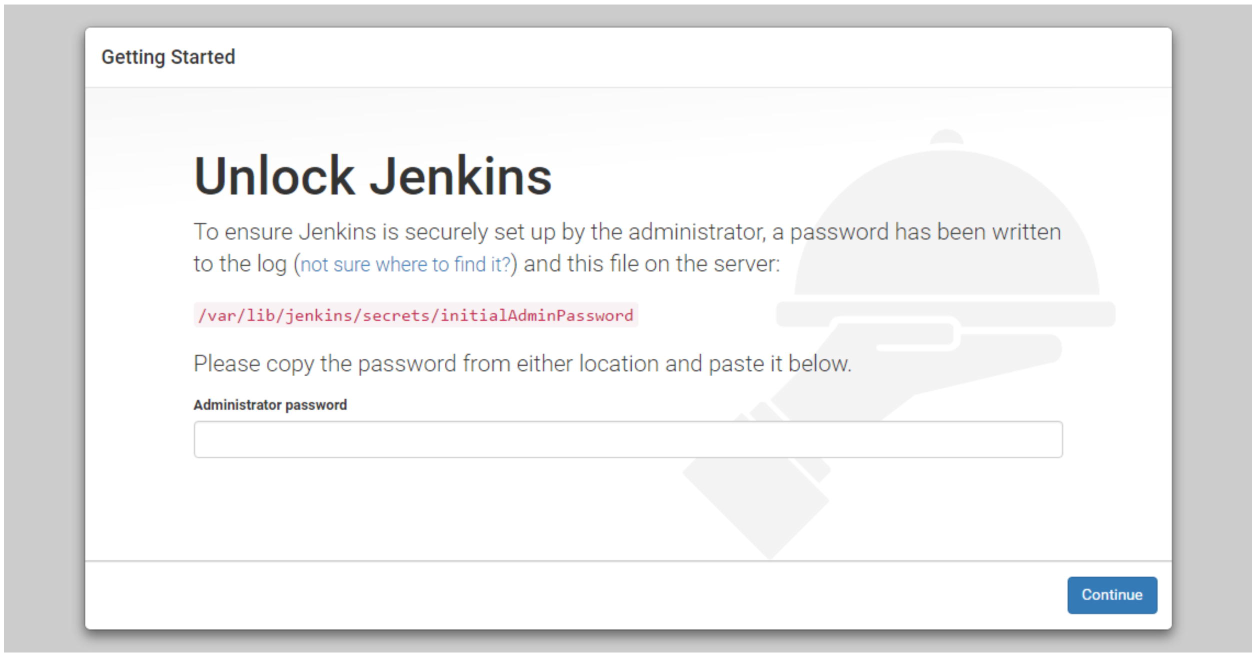
12. If everything went well, the beginning of the output should show that the service is active and configured to start at boot:

    jenkins.service - LSB: Start Jenkins at boot time Loaded: loaded (/etc/init.d/jenkins; bad; vendor preset: enabled) Active:active (exited) since Thu 2017-04-20 16:51:13 UTC; 2min 7s ago Docs: man:systemd-sysv-generator(8)

13. To set up installation, visit Jenkins on its default port, 8080, using the server domain name or IP address:

    http://ip_address_of_ec2_instance:8080

An "Unlock Jenkins" screen would appear, which displays the location of the initial password



Getting Started

Unlock Jenkins

To ensure Jenkins is securely set up by the administrator, a password has been written to the log (not sure where to find it?) and this file on the server:

`/var/lib/jenkins/secrets/initialAdminPassword`

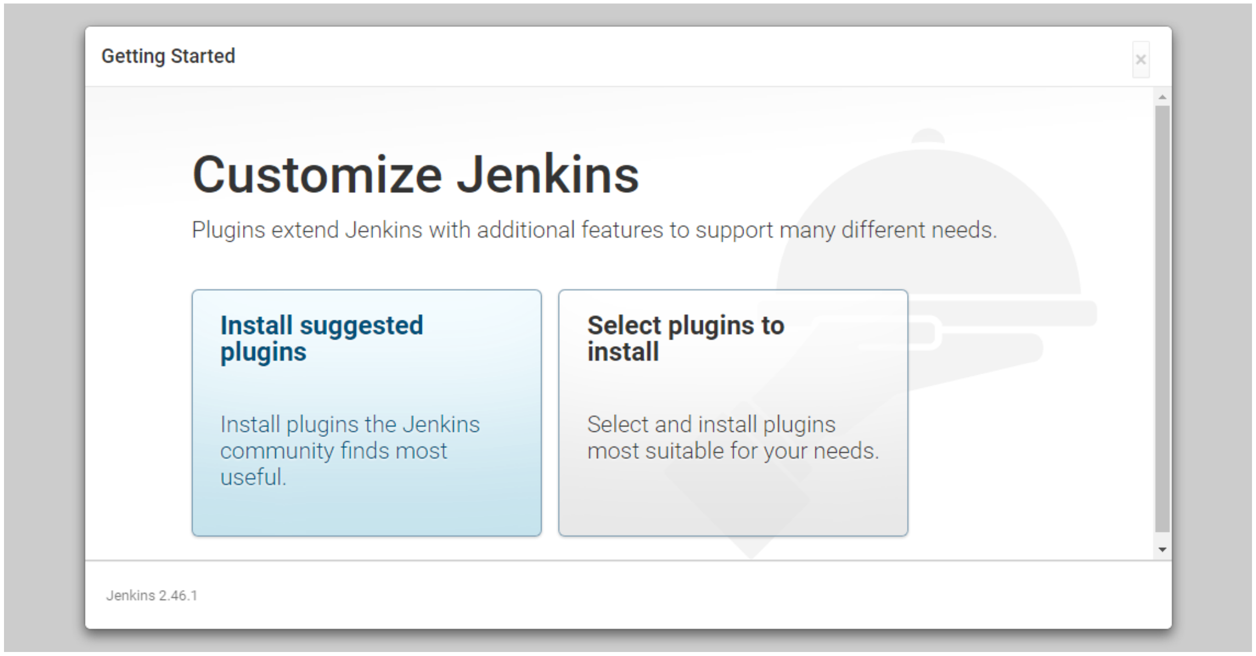
Please copy the password from either location and paste it below.

Administrator password

14. In the terminal window, use the cat command to display the password:

```
$ sudo cat /var/lib/jenkins/secrets/initialAdminPassword
```

15. Copy the 32-character alphanumeric password from the terminal and paste it into the “Administrator password” field, then click “Continue”.



Getting Started

Customize Jenkins

Plugins extend Jenkins with additional features to support many different needs.

Install suggested plugins

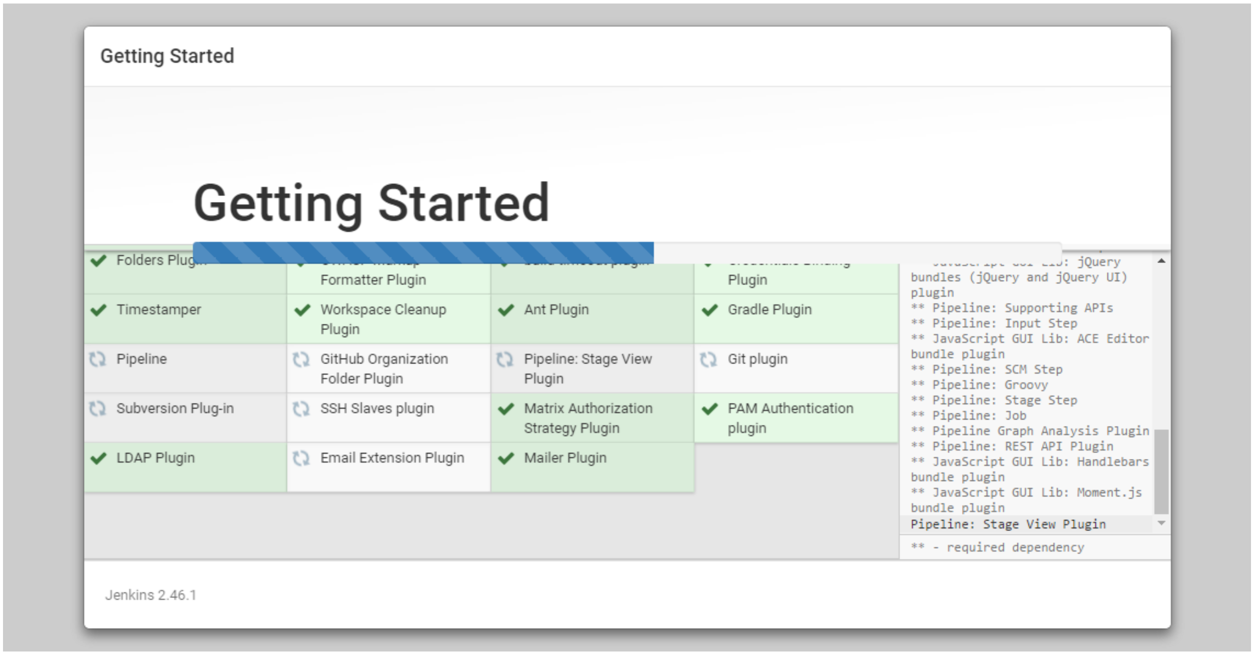
Install plugins the Jenkins community finds most useful.

Select plugins to install

Select and install plugins most suitable for your needs.

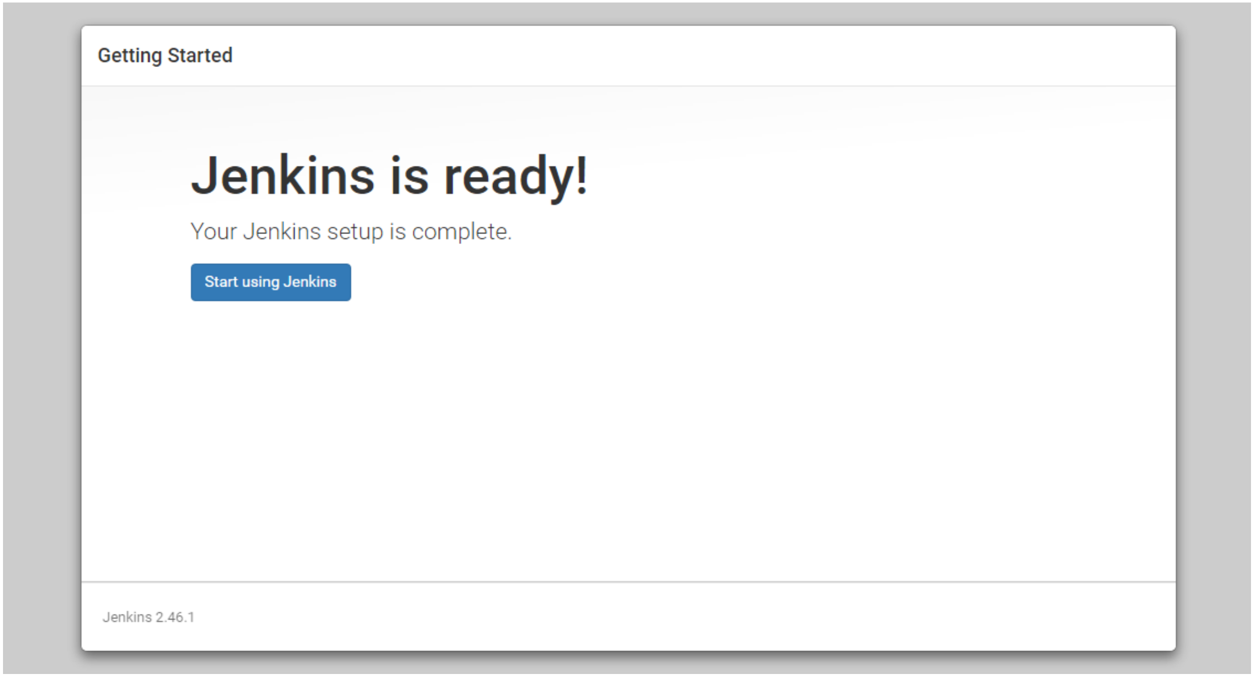
Jenkins 2.46.1

16. Click the “Install suggested plugins” option, which will immediately begin the installation process.

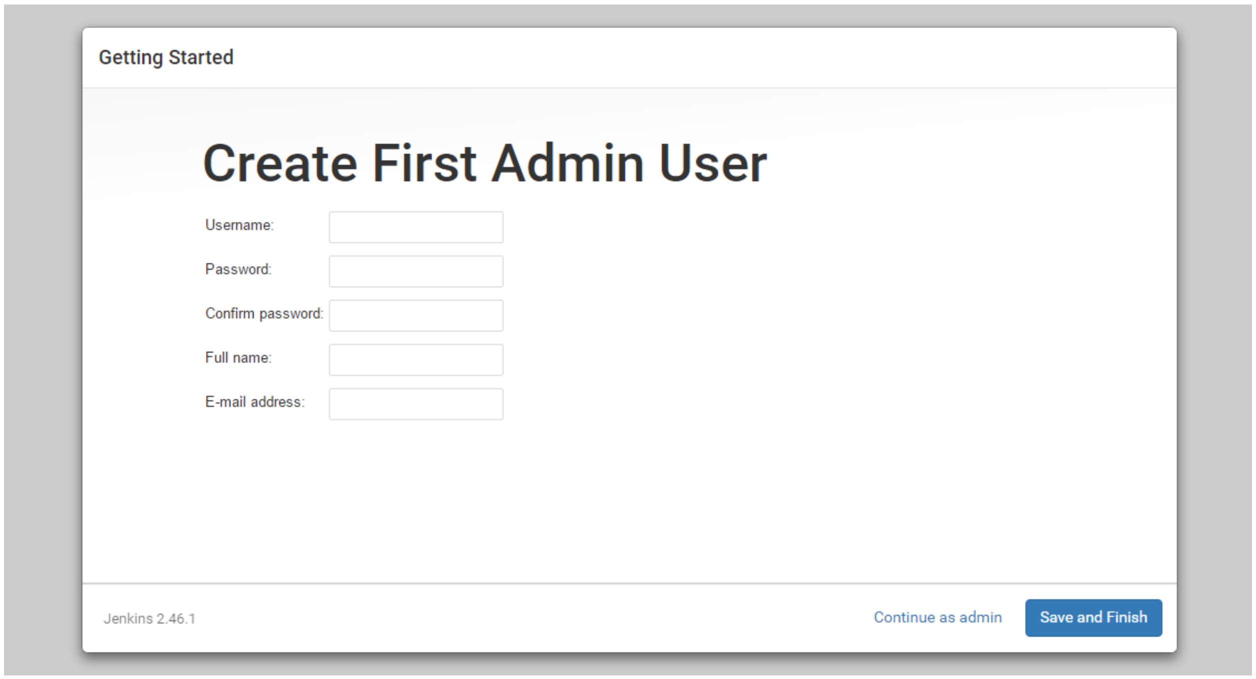


```
bundles (jQuery and jQuery UI)
plugin
** Pipeline: Supporting APIs
** Pipeline: Input Step
** JavaScript GUI Lib: ACE Editor
bundle plugin
** Pipeline: SCM Step
** Pipeline: Groovy
** Pipeline: Stage Step
** Pipeline: Job
** Pipeline Graph Analysis Plugin
** Pipeline: REST API Plugin
** JavaScript GUI Lib: Handlebars
bundle plugin
** JavaScript GUI Lib: Moment.js
bundle plugin
Pipeline: Stage View Plugin
** - required dependency
```

17. When the installation is complete, it prompt to set up the first administrative user. It's possible to skip this step and continue as admin using the initial password used above, but its batter to take a moment to create the user.



18. Once the first admin user is in place, you should see a "Jenkins is ready!" confirmation screen.



Getting Started

Create First Admin User

Username:

Password:

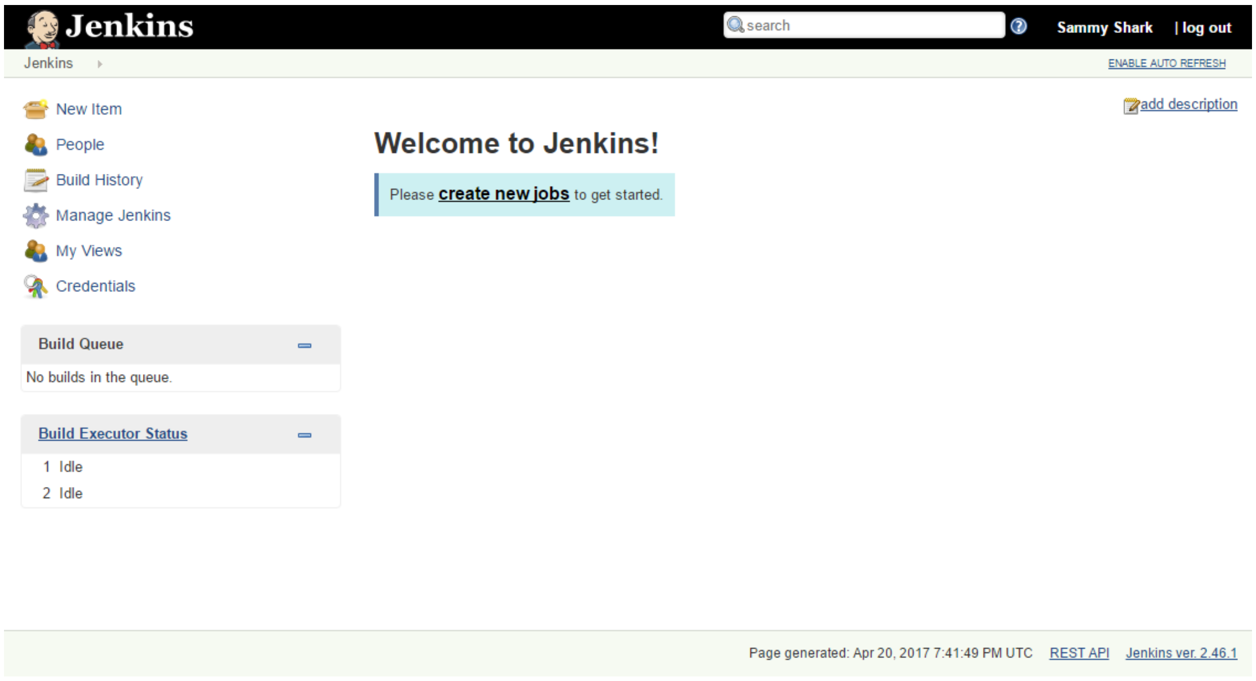
Confirm password:

Full name:

E-mail address:

Jenkins 2.46.1

19. Click "Start using Jenkins" to visit the main Jenkins dashboard.



Welcome to Jenkins!

Please **create new jobs** to get started.

Build Queue

No builds in the queue.

Build Executor Status

1 Idle

2 Idle

Page generated: Apr 20, 2017 7:41:49 PM UTC REST API Jenkins ver. 2.46.1

At this point, Jenkins has been successfully installed.

20. Update your package lists and install Nginx:

```
$ sudo apt-get install nginx
```

21. To check successful installation run:

```
$ nginx -v
```

22. Move into the proper directory where you want to put your certificates:

```
$ cd /etc/nginx
```

23. Generate a certificate:

```
$ sudo openssl req -x509 -nodes -days 365 -newkey rsa:2048 -keyout /etc/nginx/
↪cert.key -out /etc/nginx/cert.crt
```

24. Next you will need to edit the default Nginx configuration file:

```
$ sudo vi /etc/nginx/sites-enabled/default
```

25. Update the file with following contents:

    server { listen 80; return 301 https://\protect\T1\textdollarhost\protect\T1\textdollarrequest_uri;

    }

    server { listen 443; server_name beam-ci.tk;

        ssl_certificate /etc/nginx/cert.crt; ssl_certificate_key /etc/nginx/cert.key;

        ssl on; ssl_session_cache builtin:1000 shared:SSL:10m; ssl_protocols TLSv1 TLSv1.1 TLSv1.2; ssl_ciphers HIGH:!aNULL:!eNULL:!EXPORT:!CAMELLIA:!DES:!MD5:!PSK:!RC4; ssl_prefer_server_ciphers on;

        access_log /var/log/nginx/jenkins.access.log;

        location / { proxy_set_header Host $host; proxy_set_header X-Real-IP $remote_addr; proxy_set_header X-Forwarded-For $proxy_add_x_forwarded_for; proxy_set_header X-Forwarded-Proto $scheme;

            # Fix the "It appears that your reverse proxy set up is broken" error. proxy_pass http://localhost:8080; proxy_read_timeout 90;

            proxy_redirect http://localhost:8080 https://beam-ci.tk;

        }

    }

26. For Jenkins to work with Nginx, you need to update the Jenkins config to listen only on the localhost interface instead of all (0.0.0.0), to ensure traffic gets handled properly. This is an important step because if Jenkins is still listening on all interfaces, then it will still potentially be accessible via its original port (8080).

27. Modify the /etc/default/jenkins configuration file to make these adjustments:

```
$ sudo vi /etc/default/jenkins
```

28. Locate the JENKINS_ARGS line and update it to look like the following:

```
$ JENKINS_ARGS="--webroot=/var/cache/$NAME/war --httpListenAddress=127.0.0.1 --
↪httpPort=$HTTP_PORT -ajp13Port=$AJP_PORT"
```

29. Then go ahead and restart Jenkins:

```
$ sudo service jenkins restart
```

30. After that restart Nginx:

```
$ sudo service nginx restart
```

You should now be able to visit your domain using either HTTP or HTTPS, and the Jenkins site will be served securely. You will see a certificate warning because you used a self-signed certificate.

31. Next you install certbot to setup nginx with as CA certificate. Certbot team maintains a PPA. Once you add it to your list of repositories all you'll need to do is apt-get the following packages:

```
$ sudo add-apt-repository ppa:certbot/certbot
```

32. Run apt update:

```
$ sudo apt-get update
```

33. Install certbot for Nginx:

```
$ sudo apt-get install python-certbot-nginx
```

34. Get a certificate and have Certbot edit Nginx configuration automatically, run the following command:

```
$ sudo certbot -nginx
```

35. The Certbot packages on your system come with a cron job that will renew your certificates automatically before they expire. Since Let's Encrypt certificates last for 90 days, it's highly advisable to take advantage of this feature. You can test automatic renewal for your certificates by running this command:

```
$ sudo certbot renew -dry-run
```

36. Restart Nginx:

```
$ sudo service nginx restart
```

37. Go to AWS management console and update the Security Group associated with jenkins server by removing the port 8080, that you added in step 2.

12.2.2 Setup Jenkins Slave

Now configure a Jenkins slave for pipeline configuration. You need the slave AMI to spawn automatic EC2 instance on new build jobs.

1. Create Amazon EC2 instance from an Amazon Machine Image (AMI) that has Ubuntu 64-bit as base operating system.
2. Choose a security group that will allow only SSH access to your master (and temporarily for your personal system).
3. Connect to the instance via SSH.
4. Add oracle java apt repository and git-lfs:

```
$ sudo add-apt-repository ppa:webupd8team/java*
$ sudo curl -s https://packagecloud.io/install/repositories/github/git-lfs/script.
↪deb.sh | sudo bash*
```

5. Run commands to update system package index:

```
$ sudo apt update
```

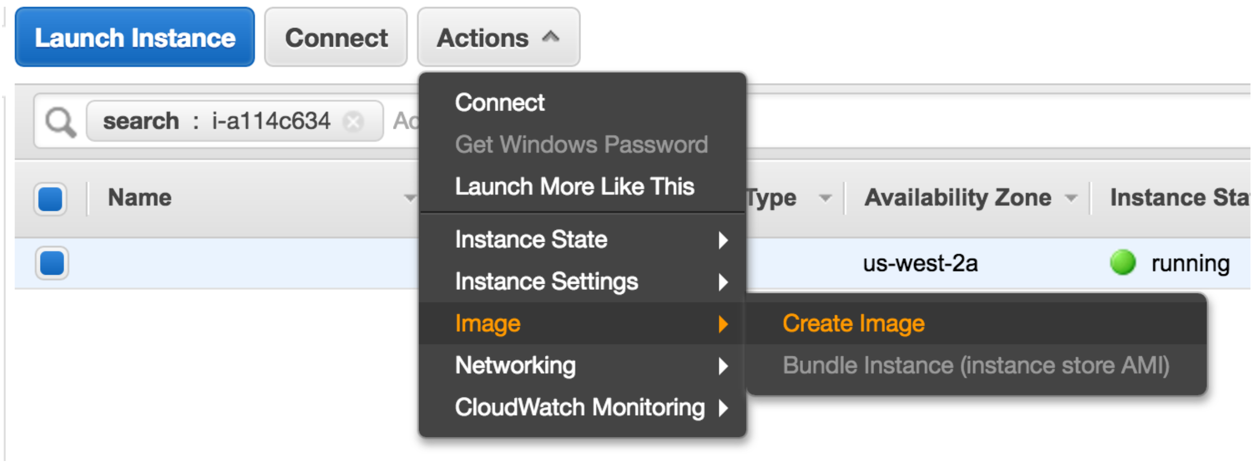
6. Install Java and other dependency components, there is no need to install any jenkins component or service. Jenkins automatically deploy an agent as it initiates the build:

```
$ sudo apt install git docker oracle-java8-installer git-lfs=2.3.4
```

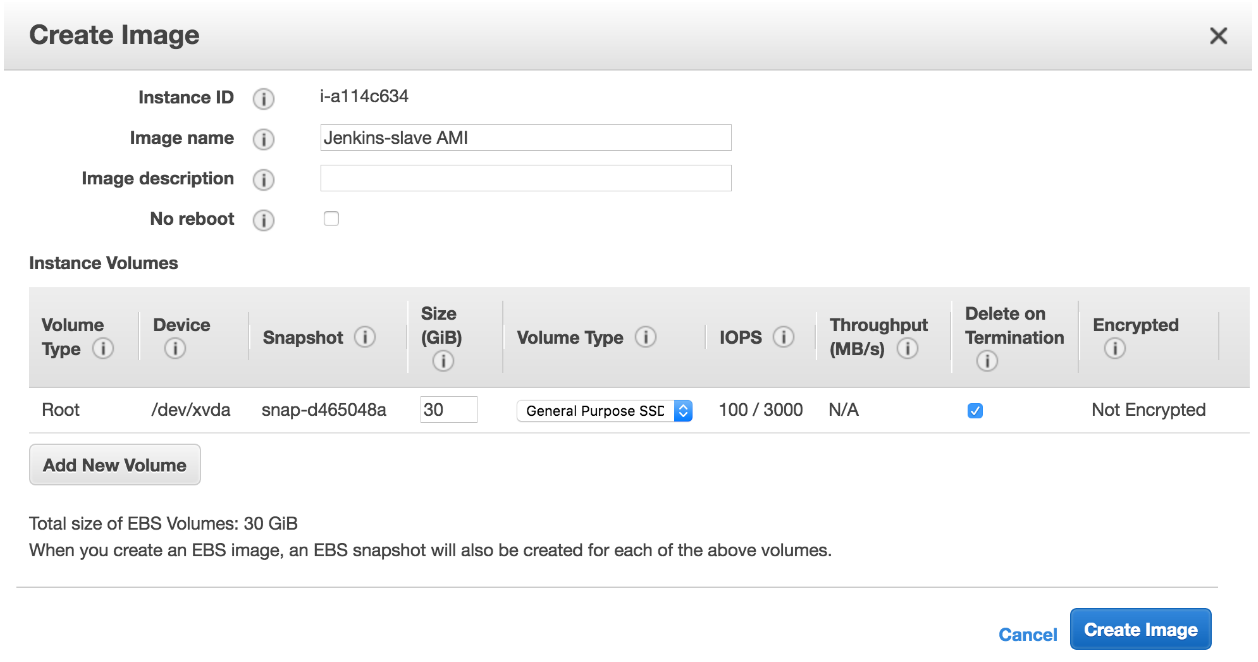
7. SSH master that you created in last topic and from inside master again ssh your newly created slave, just to test the communication:

```
$ ssh ubuntu@<slave_ip_address>
```

8. In EC2 Instances pane, click on your Jenkins slave instance you just configure, and create a new image.



9. On Create Image dialog, name the image and select “Delete on Termination”. It makes slave instance disposable, if there are any build artifacts, job should save them, that will send them to your master.



Create Image

Instance ID: i-a114c634

Image name: Jenkins-slave AMI

Image description:

No reboot: ☐

Instance Volumes

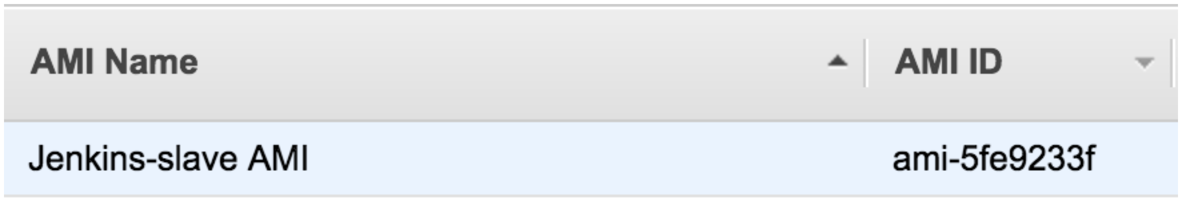
Volume Type	Device	Snapshot	Size (GiB)	Volume Type	IOPS	Throughput (MB/s)	Delete on Termination	Encrypted
Root	/dev/xvda	snap-d465048a	30	General Purpose SSD	100 / 3000	N/A	✓	Not Encrypted

Add New Volume

Total size of EBS Volumes: 30 GiB
When you create an EBS image, an EBS snapshot will also be created for each of the above volumes.

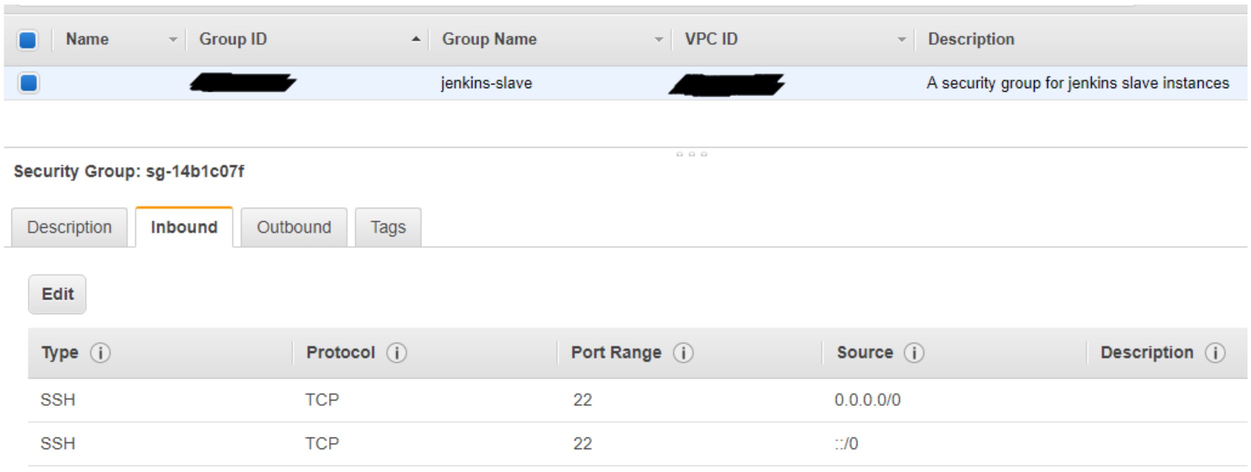
Cancel Create Image

10. Once image creation process completes, just copy the AMI ID, you need it for master configuration.



AMI Name	AMI ID
Jenkins-slave AMI	ami-5fe9233f

11. Update the Slave security group and remove all other IP addresses except master. You should only enable ingress from the IP addresses you wish to allow access to your slave.



Name	Group ID	Group Name	VPC ID	Description
	[redacted]	jenkins-slave	[redacted]	A security group for jenkins slave instances

Security Group: sg-14b1c07f

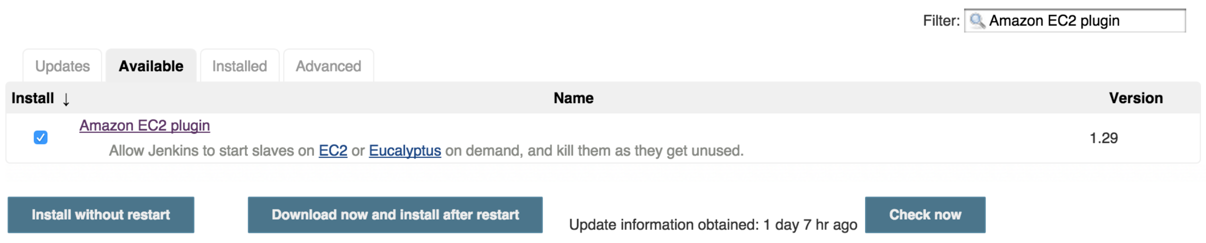
Type	Protocol	Port Range	Source	Description
SSH	TCP	22	0.0.0.0/0	
SSH	TCP	22	::/0	

12. At the end drop slave instance, its not needed anymore.

12.2.3 Configure Jenkins Master

Now start configuring Jenkins master, so it can spawn new slave instance on demand.

1. Once Master and Slave are setup, login to Jenkins server administrative console as admin.
2. On the left-hand side, click Manage Jenkins, and then click Manage Plugins.
3. Click on the Available tab, and then enter Amazon EC2 plugin at the top right.



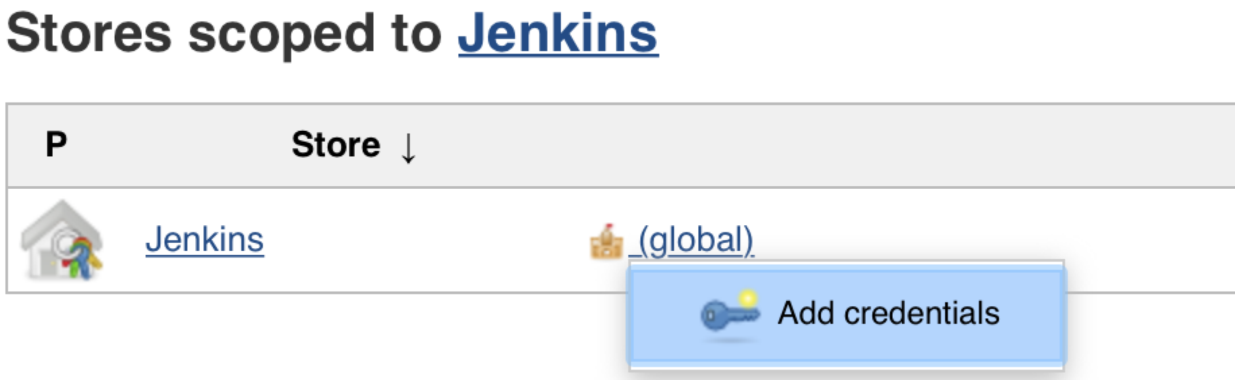
Filter: Amazon EC2 plugin

Install ↓	Name	Version
✓	Amazon EC2 plugin Allow Jenkins to start slaves on EC2 or Eucalyptus on demand, and kill them as they get unused.	1.29

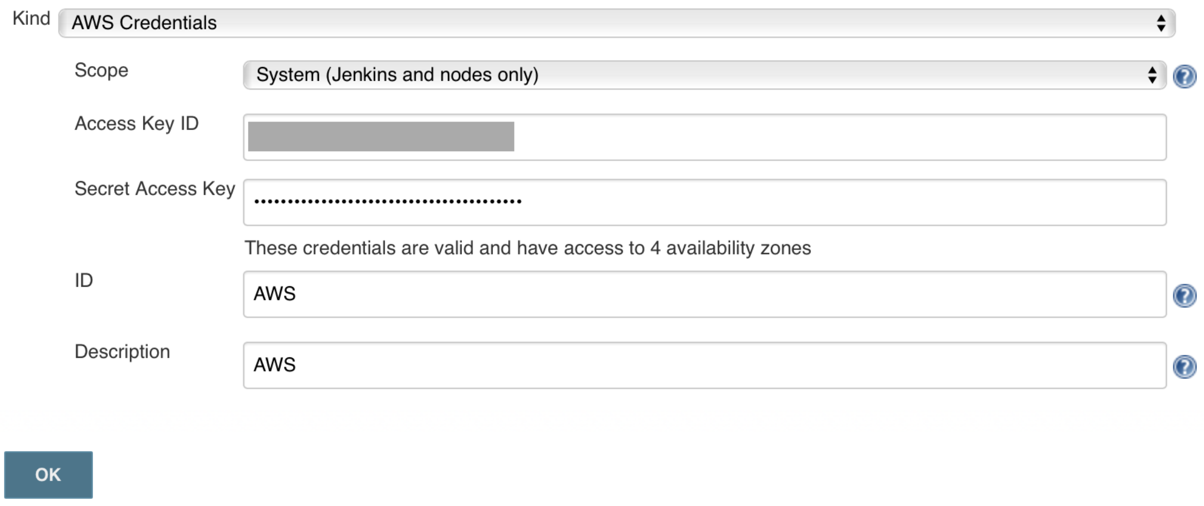
Update information obtained: 1 day 7 hr ago

3. Select the checkbox next to Amazon EC2 plugin, and then click Install without restart.

4. Once the installation is done, click Go back to the top page. 4. On the sidebar, click on Credentials, hover (global) for finding the sub menu and add a credential.

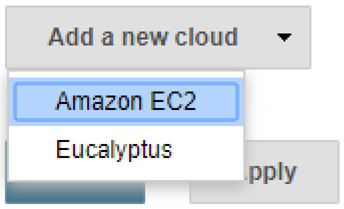


6. Choose AWS Credentials, and limit the scope to System, complete the form, if you make an error, Jenkins will add an error below the secret key. Jenkins uses access key ID and secret access key to interface with Amazon EC2.

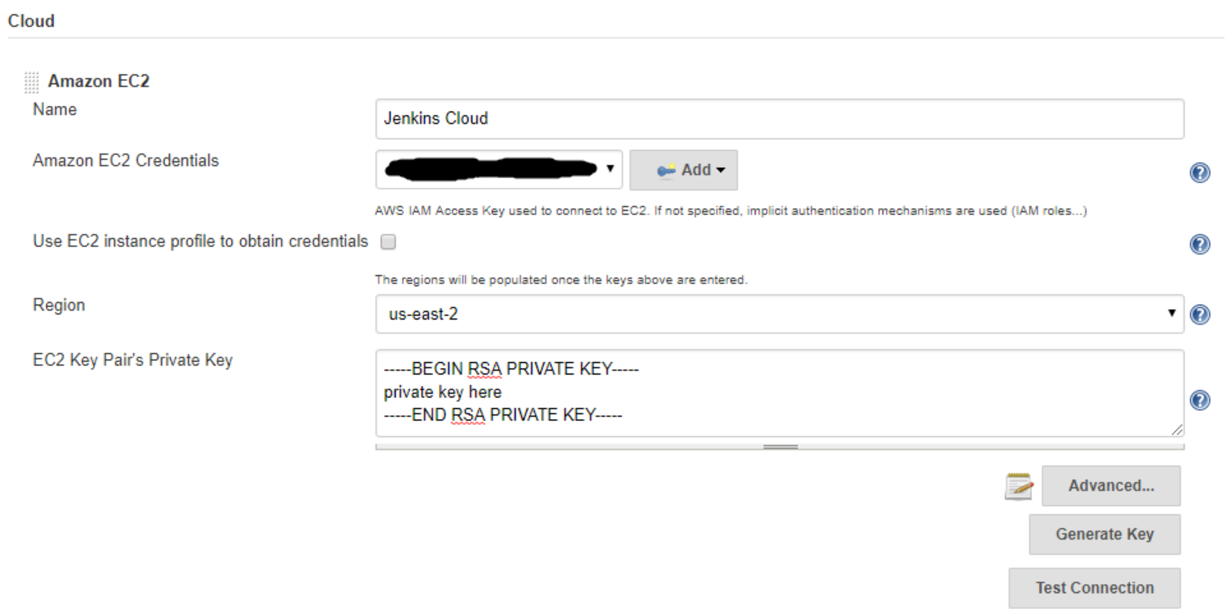


Kind	AWS Credentials
Scope	System (Jenkins and nodes only)
Access Key ID	[redacted]
Secret Access Key	••
	These credentials are valid and have access to 4 availability zones
ID	AWS
Description	AWS

7. Click on Manage Jenkins, and then Configure System.
8. Scroll all the way down to the section that says Cloud.
9. Click Add a new cloud, and select Amazon EC2. A collection of new fields appears.



10. Select Amazon EC2 Credentials that you just created. EC2 Key Pair's Private key is a key generated when creating a new EC2 image on AWS.



Cloud

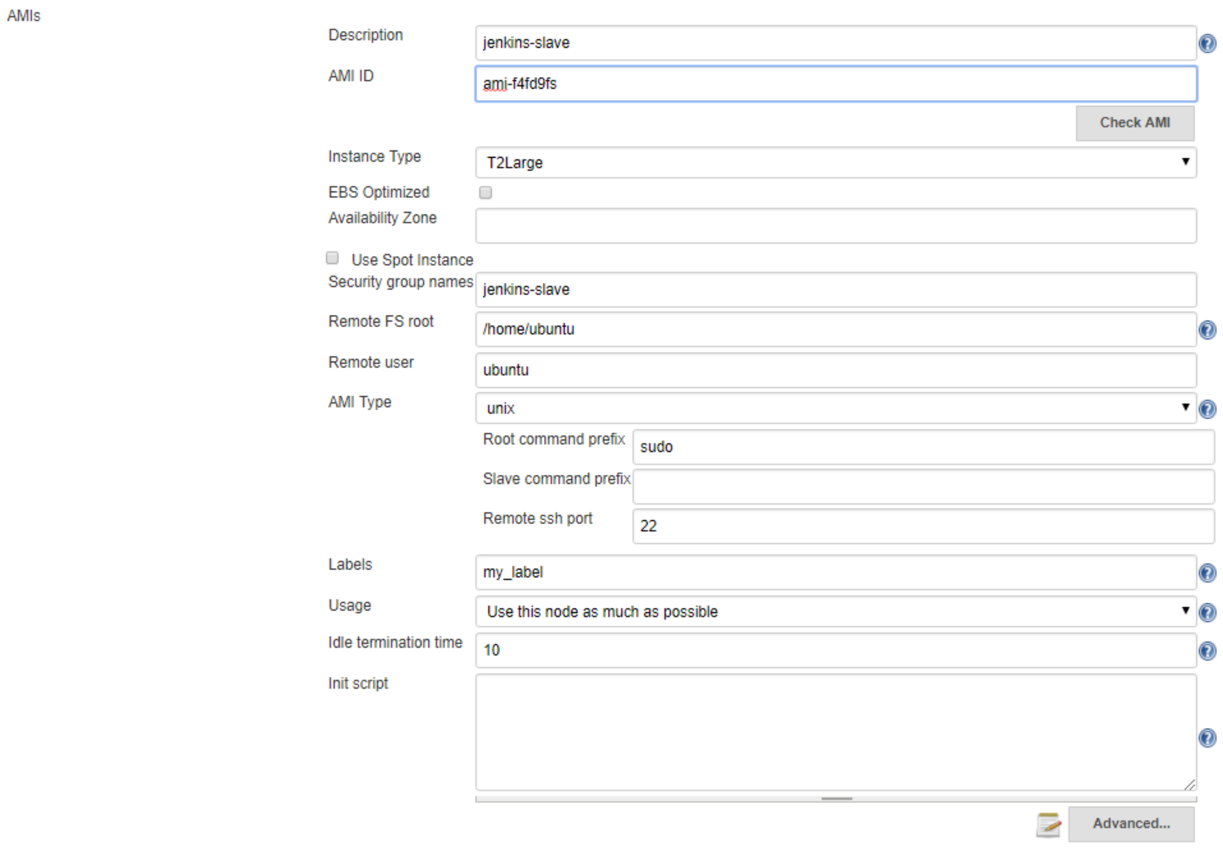
Amazon EC2

Name	Jenkins Cloud
Amazon EC2 Credentials	[redacted]
Use EC2 instance profile to obtain credentials	☐
Region	us-east-2
EC2 Key Pair's Private Key	-----BEGIN RSA PRIVATE KEY----- private key here -----END RSA PRIVATE KEY-----

AWS IAM Access Key used to connect to EC2. If not specified, implicit authentication mechanisms are used (IAM roles...)

The regions will be populated once the keys above are entered.

11. Complete the form, choose a Region, Instance Type, label and set Idle termination time. If the slave becomes idle during this time, the instance will be terminated.

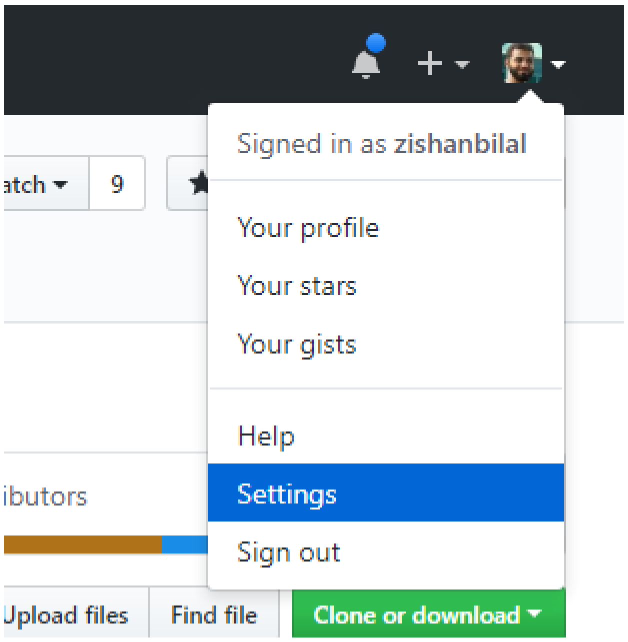


AMIs

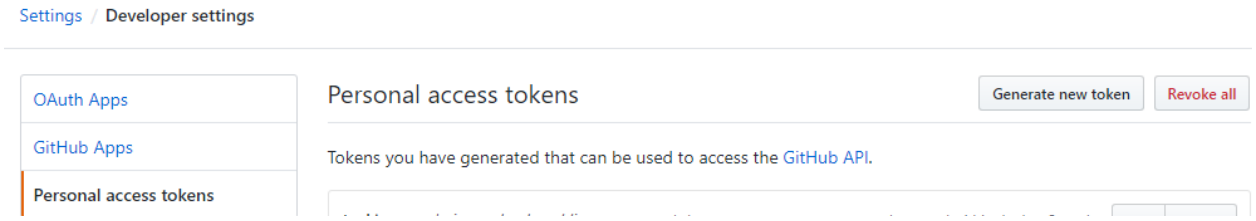
Description	jenkins-slave
AMI ID	ami-f4fd9fs
Instance Type	T2Large
EBS Optimized	☐
Availability Zone	
Use Spot Instance	☐
Security group names	jenkins-slave
Remote FS root	/home/ubuntu
Remote user	ubuntu
AMI Type	unix
Root command prefix	sudo
Slave command prefix	
Remote ssh port	22
Labels	my_label
Usage	Use this node as much as possible
Idle termination time	10
Init script	

12. In order for Jenkins to watch GitHub projects, you will need to create a Personal Access Token in your GitHub account.

Now go to GitHub and signing into your account and click on user icon in the upper-right hand corner and select Settings from the drop down menu.

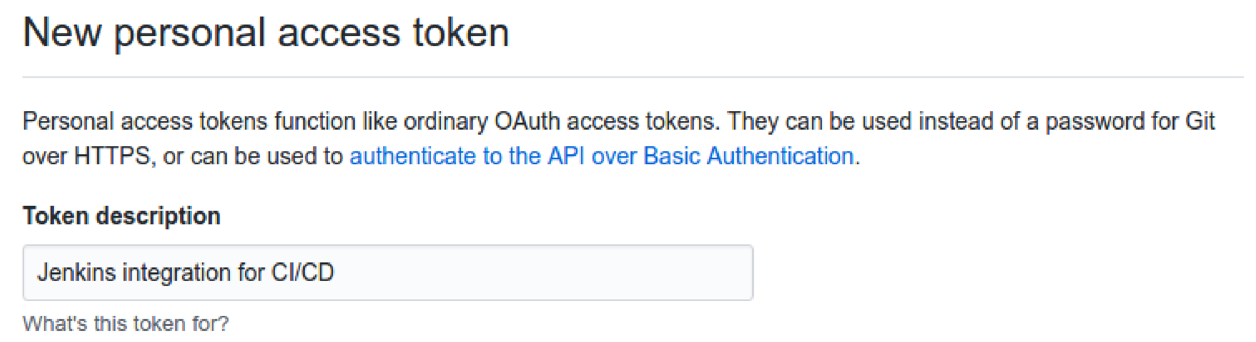


13. On Settings page, locate the Developer settings section on the left-hand menu and go to Personal access tokens and click on Generate new token button.



Tokens you have generated that can be used to access the GitHub API.

14. In the Token description box, add a description that will allow you to recognize it later.



New personal access token

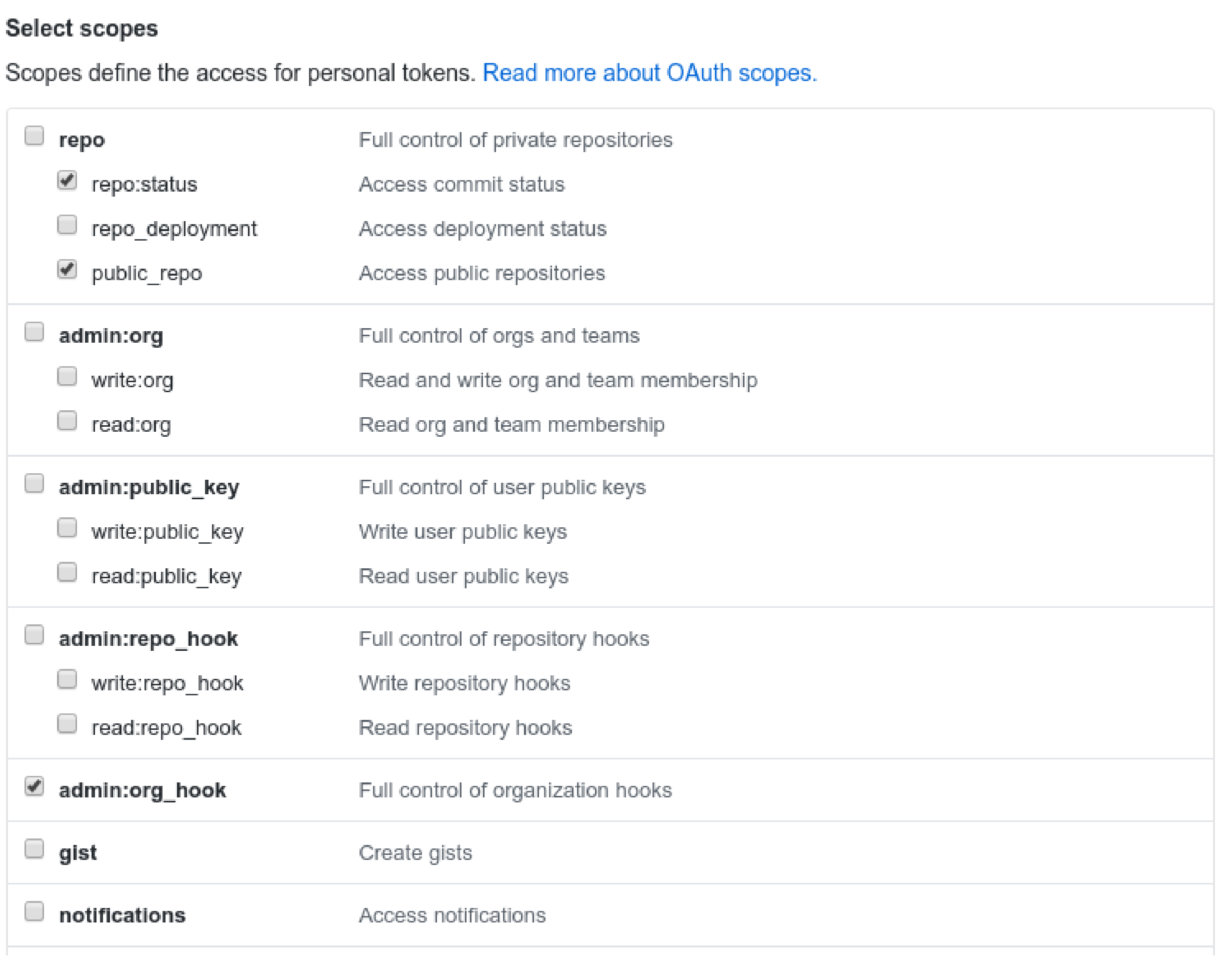
Personal access tokens function like ordinary OAuth access tokens. They can be used instead of a password for Git over HTTPS, or can be used to authenticate to the API over Basic Authentication.

Token description

Jenkins integration for CI/CD

What's this token for?

15. In the Select scopes section, check the repo:status, repo:public_repo and admin:org_hook boxes. These will allow Jenkins to update commit statuses and to create webhooks for the project. If you are using a private repository, you will need to select the general repo permission instead of the repo sub items.

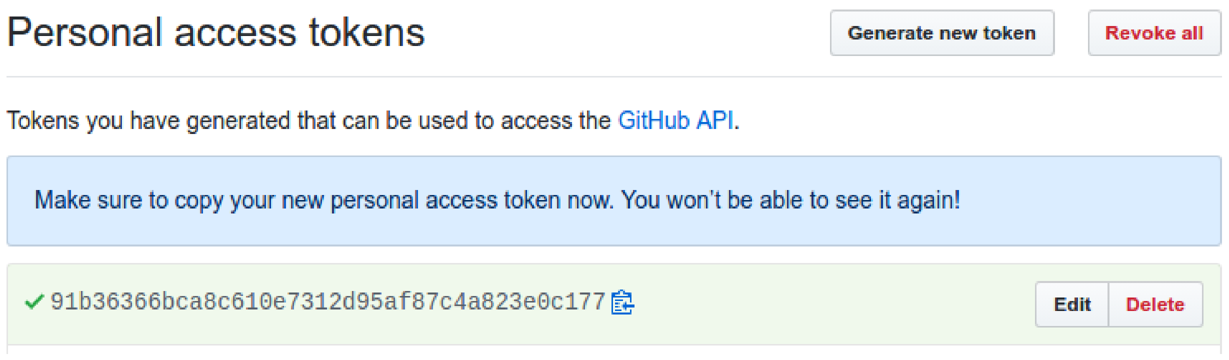


Select scopes

Scopes define the access for personal tokens. Read more about OAuth scopes.

[ ] **repo**	Full control of private repositories
[✓] repo:status	Access commit status
[ ] repo_deployment	Access deployment status
[✓] public_repo	Access public repositories
[ ] **admin:org**	Full control of orgs and teams
[ ] write:org	Read and write org and team membership
[ ] read:org	Read org and team membership
[ ] **admin:public_key**	Full control of user public keys
[ ] write:public_key	Write user public keys
[ ] read:public_key	Read user public keys
[ ] **admin:repo_hook**	Full control of repository hooks
[ ] write:repo_hook	Write repository hooks
[ ] read:repo_hook	Read repository hooks
[✓] **admin:org_hook**	Full control of organization hooks
[ ] **gist**	Create gists
[ ] **notifications**	Access notifications

16. When you are finished, click Generate token at the bottom.
17. You will be redirected back to the Personal access tokens index page and your new token will displayed.



Personal access tokens

Tokens you have generated that can be used to access the GitHub API.

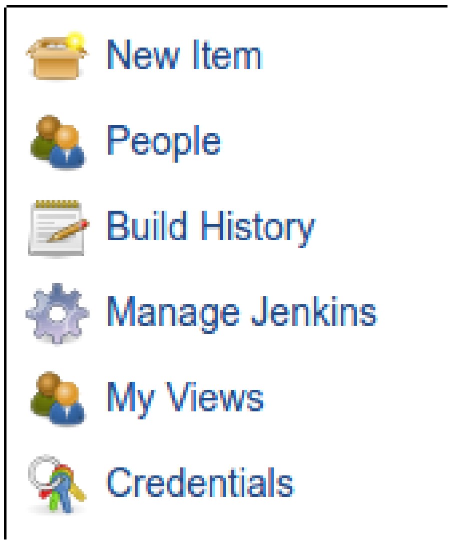
Make sure to copy your new personal access token now. You won't be able to see it again!

✓ 91b36366bca8c610e7312d95af87c4a823e0c177

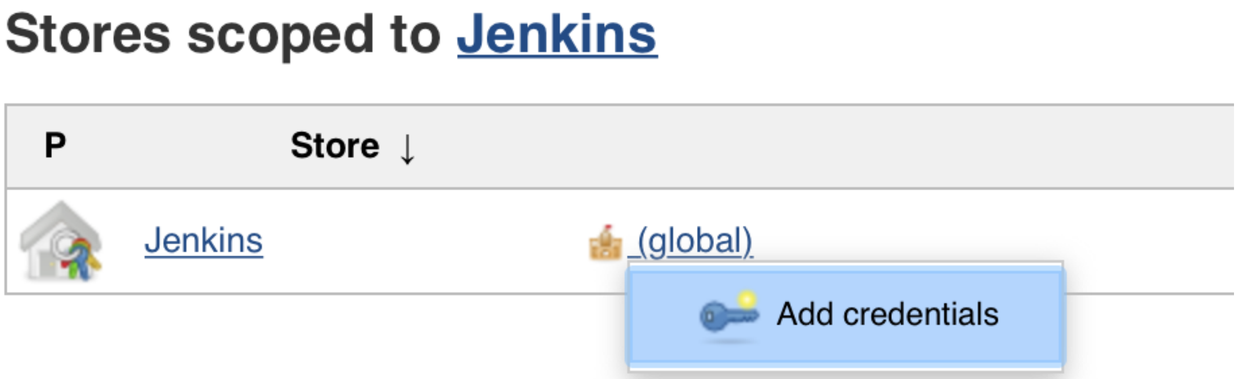
18. Copy the token now so that you can reference it later.

Now that you have a token, you need to add it to your Jenkins server so it can automatically set up webhooks. Log into your Jenkins web interface using the administrative account you configured during installation.

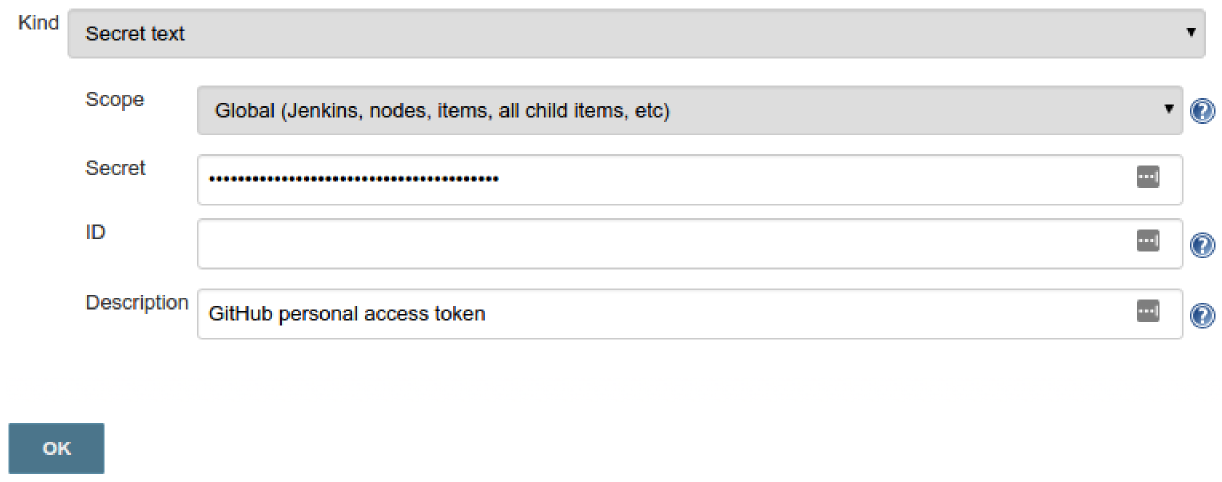
19. On Jenkins main dashboard, click Credentials in the left hand menu.



20. Click the arrow next to (global) within the Jenkins scope. In the box that appears, click Add credentials.



21. From Kind drop down menu, select Secret text. In the Secret field, paste your GitHub personal access token. Fill out the Description field so that you will be able to identify this entry at a later date and press OK button in the bottom.



Kind: Secret text

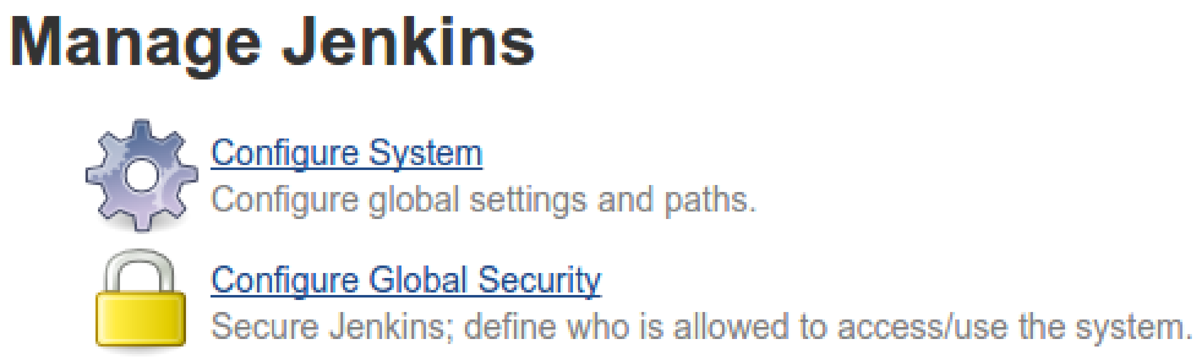
Scope: Global (Jenkins, nodes, items, all child items, etc)

Secret: ••

ID:

Description: GitHub personal access token

22. Jenkins dashboard, click Manage Jenkins in the left hand menu and then click Configure System.

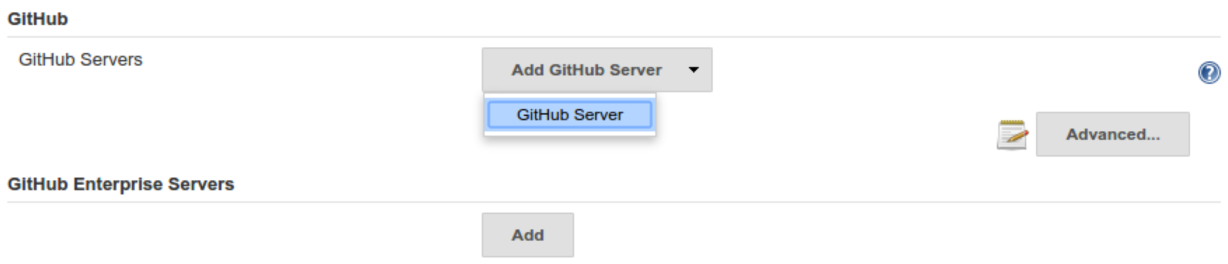


Manage Jenkins

Configure System
Configure global settings and paths.

Configure Global Security
Secure Jenkins; define who is allowed to access/use the system.

23. Find the section with title GitHub. Click the Add GitHub Server button and then select GitHub Server.

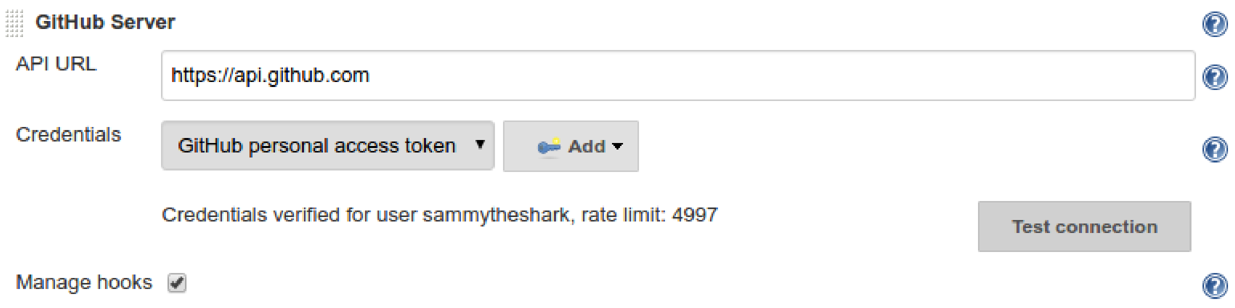


GitHub

GitHub Servers

GitHub Enterprise Servers

24. In the Credentials drop down menu, select your GitHub personal access token that you added in the last section.



GitHub Server

API URL: https://api.github.com

Credentials: GitHub personal access token

Credentials verified for user sammytheshark, rate limit: 4997

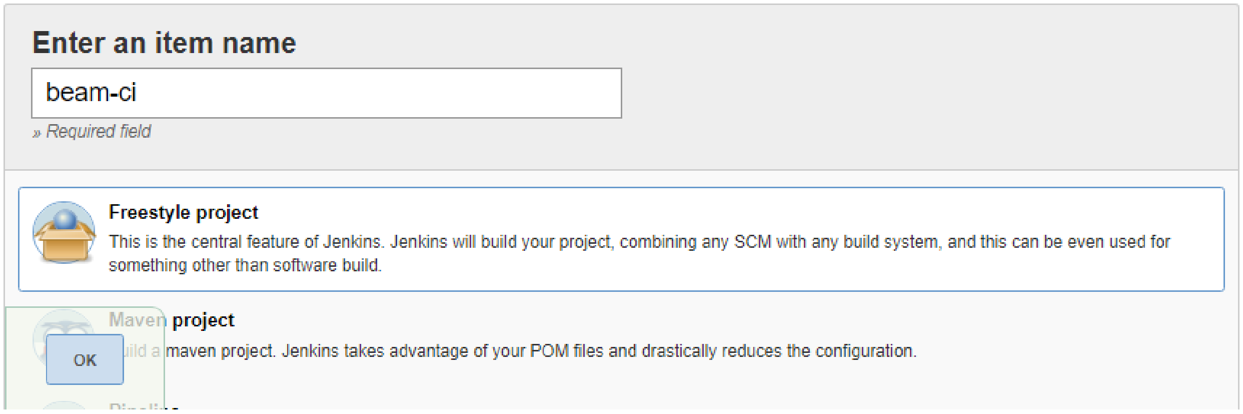
Manage hooks ✓

25. Click the Test connection button. Jenkins will make a test API call to your account and verify connectivity. On successful connectivity click Save.

12.2.4 Configure Jenkins Jobs

Once Jenkins is installed on master and its configured with slave, cloud and github. The only thing we need now, before configuring the jobs, is to install a set of plugins.

1. On the left-hand side of Jenkins dashboard, click Manage Jenkins, and then click Manage Plugins.
2. Click on the Available tab, and then enter plugin name at the top right to install following set of plugins.
   - Gradle Plugin: This plugin allows Jenkins to invoke Gradle build scripts directly.
   - Build Timeout: This plugin allows builds to be automatically terminated after the specified amount of time has elapsed.
   - HTML5 Notifier Plugin: The HTML5 Notifier Plugin provides W3C Web Notifications support for builds.
   - Notification Plugin: you can notify on deploying, on master failure/back to normal, etc.
   - HTTP Request Plugin: This plugin sends a http request to a url with some parameters.
   - embeddable-build-status: Fancy but I love to have a status badge on my README
   - Timestamper: It adds time information in our build output.
   - AnsiColor: Because some tools (lint, test) output string with bash color and Jenkins do not render the color without it.
   - Green Balls: Because green is better than blue!
3. Back in the main Jenkins dashboard, click New Item in the left hand menu:
4. Enter a name for your new pipeline in the Enter an item name field. Afterwards, select Freestyle Project as the item type and Click the OK button at the bottom to move on.



Enter an item name

beam-ci

» Required field

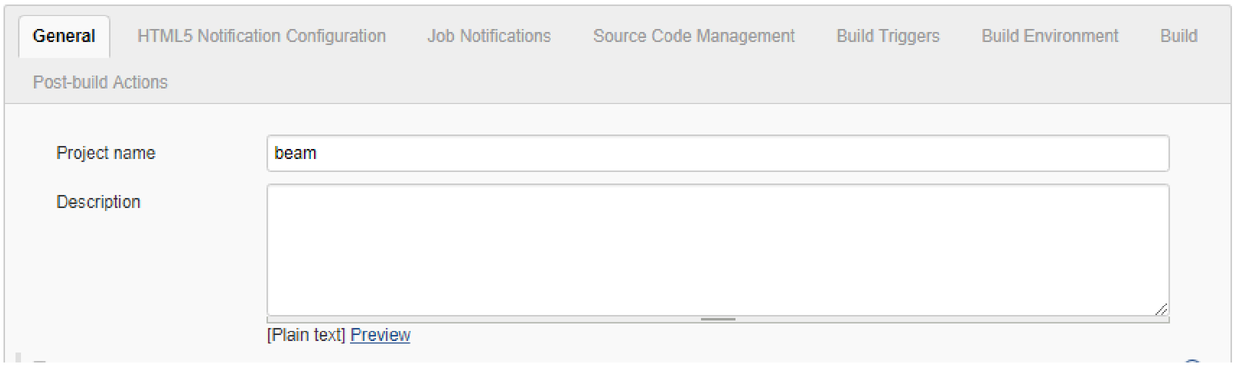
Freestyle project

This is the central feature of Jenkins. Jenkins will build your project, combining any SCM with any build system, and this can be even used for something other than software build.

Maven project

uild a maven project. Jenkins takes advantage of your POM files and drastically reduces the configuration.

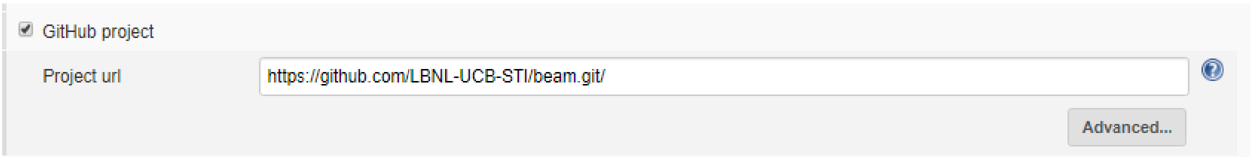
5. On the next screen, specify Project name and description.



Project name: beam

Description:

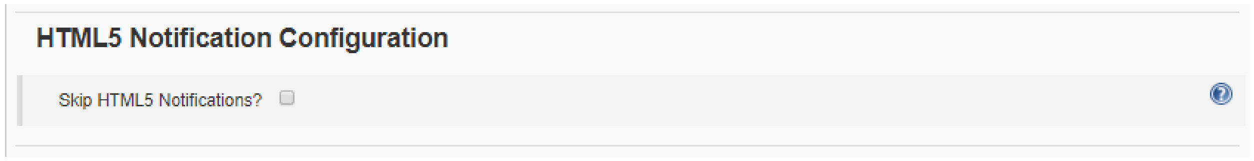
6. Then check the GitHub project box. In the Project url field that appears, enter your project's GitHub repository URL.



☑ GitHub project

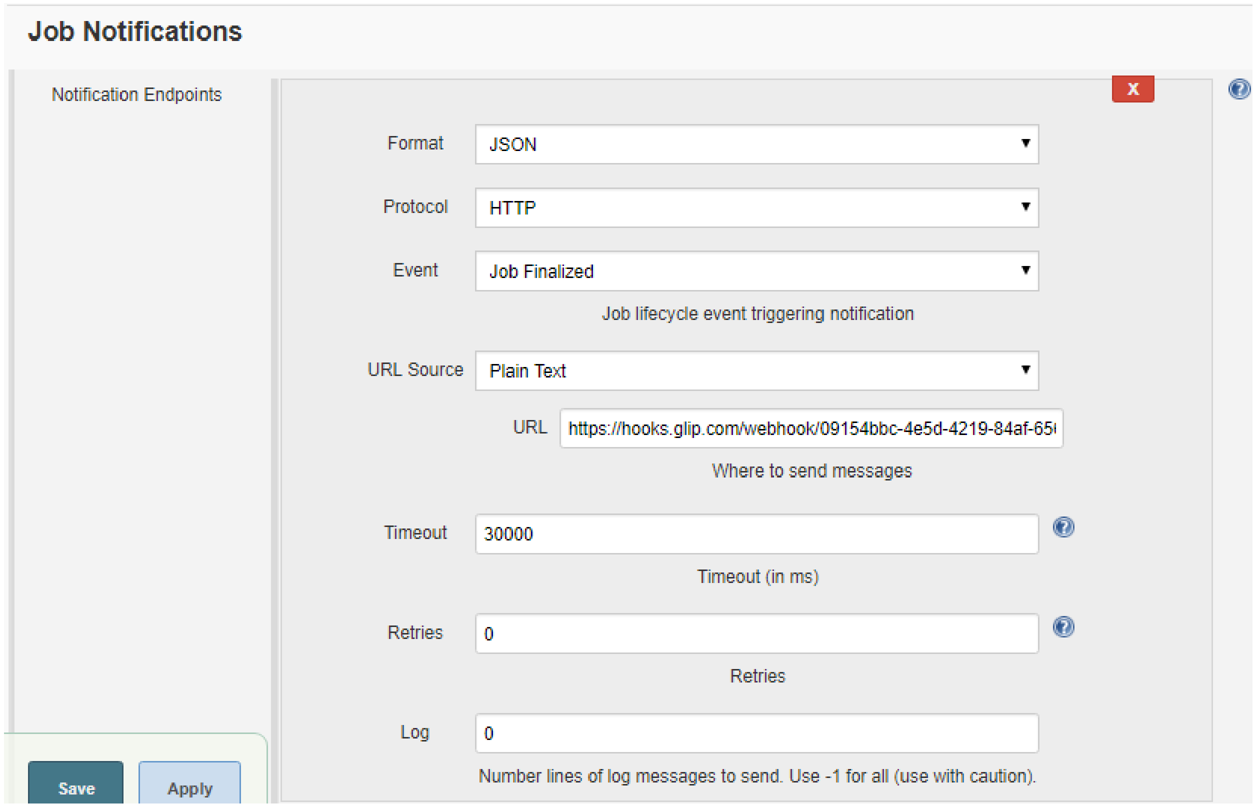
Project url: https://github.com/LBNL-UCB-STI/beam.git/

7. In the HTML5 Notification Configuration section left uncheck Skip HTML5 Notifications? Checkbox, to receive browser notifications against our builds



Skip HTML5 Notifications? ☐

8. To configure Glip Notifications with Jenkins build you need to configure notification endpoint under Job Notification section. Select JSON in Format drop-down, HTML in Protocol and to obtain end point URL follow steps 8.1 through 8.3.

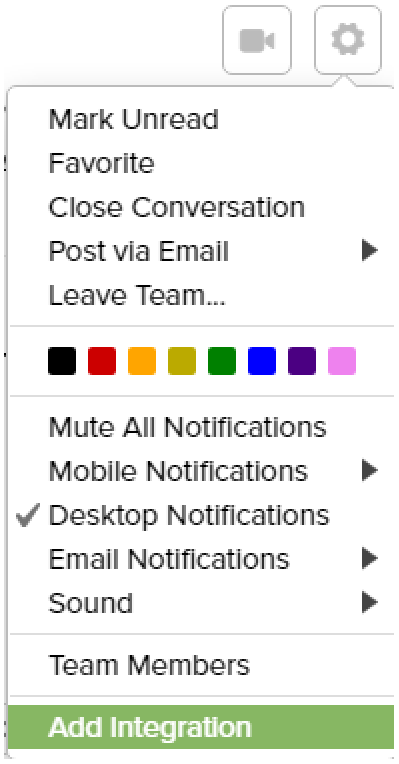


Job Notifications

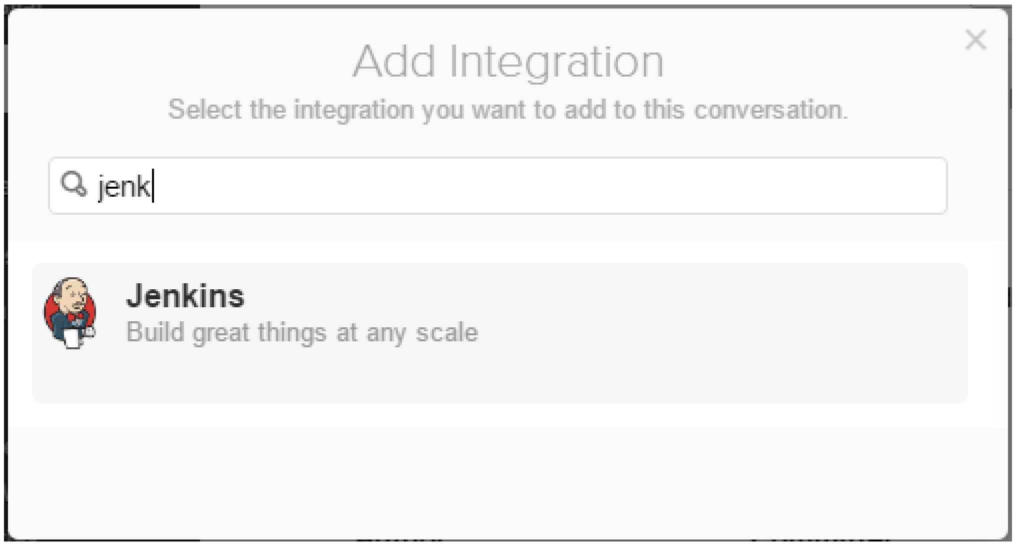
Notification Endpoints

Format	JSON
Protocol	HTTP
Event	Job Finalized
	Job lifecycle event triggering notification
URL Source	Plain Text
URL	https://hooks.glip.com/webhook/09154bbc-4e5d-4219-84af-65
	Where to send messages
Timeout	30000
	Timeout (in ms)
Retries	0
	Retries
Log	0
	Number lines of log messages to send. Use -1 for all (use with caution).

8.1. Open Glip and go to your desired channel where you want to receive notifications and then click top right button for Conversation Settings. It will open a menu, click Add Integration menu item.



8.2. On Add Integration dialog search Jenkins and click on the Jenkins Integration option.



Add Integration

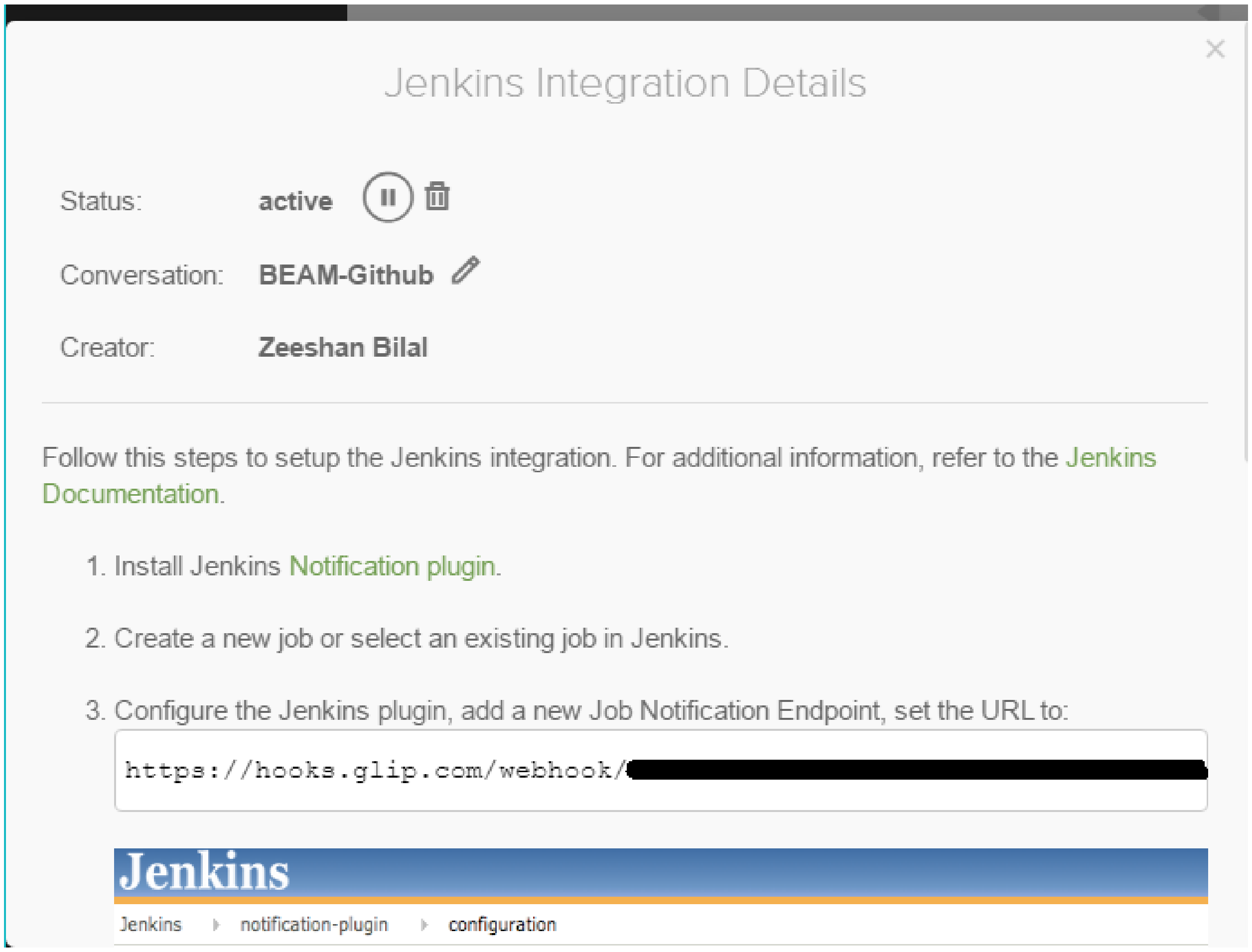
Select the integration you want to add to this conversation.

jenk

Jenkins

Build great things at any scale

8.3. A new window would appear with integration steps, copy the URL from this window and use in the above step.



Jenkins Integration Details

Status: **active**

Conversation: **BEAM-Github**

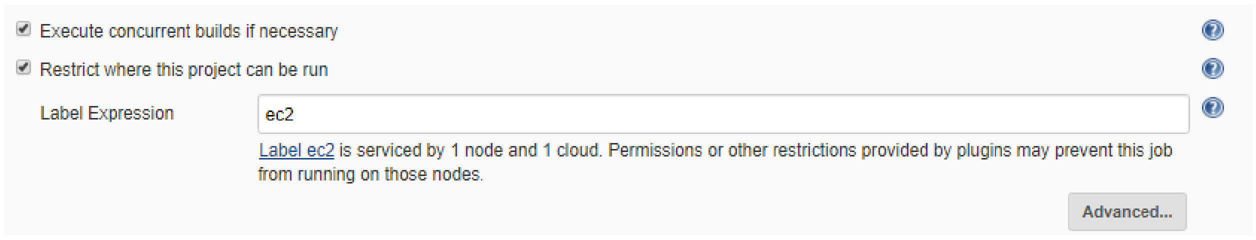
Creator: **Zeeshan Bilal**

Follow this steps to setup the Jenkins integration. For additional information, refer to the Jenkins Documentation.

1. Install Jenkins Notification plugin.
2. Create a new job or select an existing job in Jenkins.
3. Configure the Jenkins plugin, add a new Job Notification Endpoint, set the URL to:

```
https://hooks.glip.com/webhook/[redacted]
```

9. At the end of notification section check Execute concurrent build if necessary and Restrict where this project can run and specify the label that we mentioned in last section while configuring master.



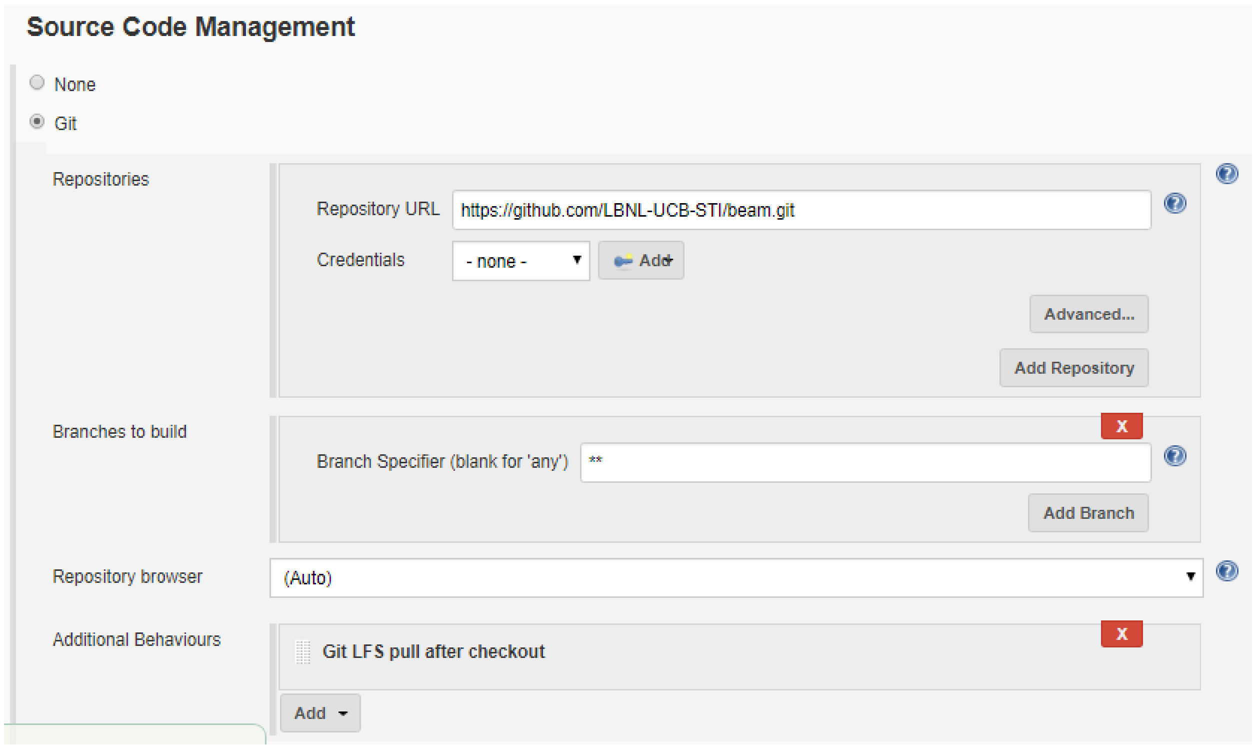
☑ Execute concurrent builds if necessary

☑ Restrict where this project can be run

Label Expression: ec2

Label ec2 is serviced by 1 node and 1 cloud. Permissions or other restrictions provided by plugins may prevent this job from running on those nodes.

10. In Source Code Management specify the beam github url against Repository URL and select appropriate credentials. Put ** for all branches, to activate build for all available bit hub branches.



Source Code Management

○ None

● Git

Repositories

Repository URL: https://github.com/LBNL-UCB-STI/beam.git

Credentials: - none -

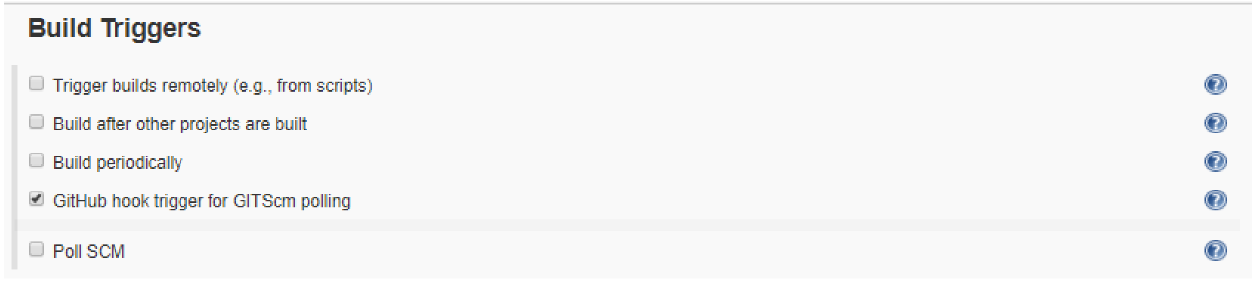
Branches to build

Branch Specifier (blank for 'any'): **

Repository browser: (Auto)

Additional Behaviours: Git LFS pull after checkout

11. Next, in the Build Triggers section, check the GitHub hook trigger for GITScm polling box.



Build Triggers

☐ Trigger builds remotely (e.g., from scripts)

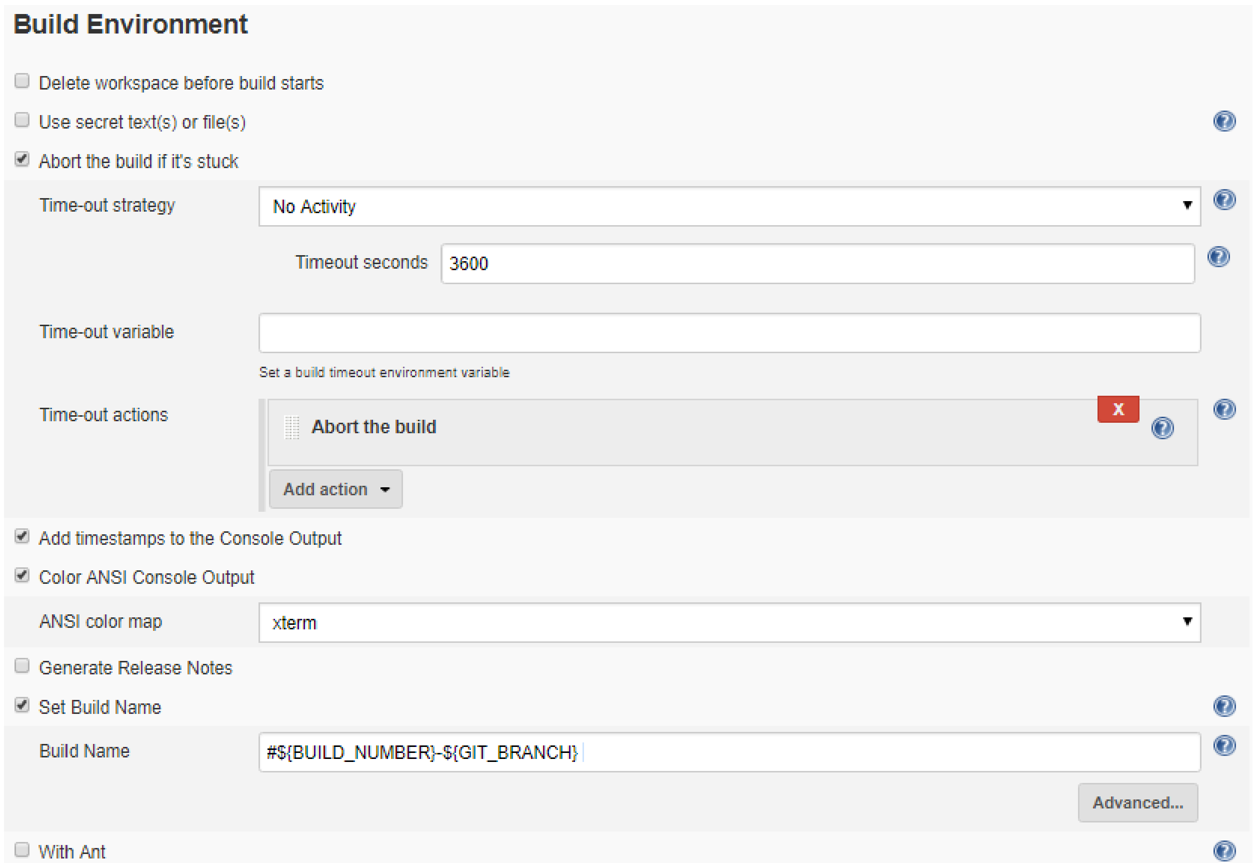
☐ Build after other projects are built

☐ Build periodically

☑ GitHub hook trigger for GITScm polling

☐ Poll SCM

12. Under Build Environment section, click Abort build if it's stuck and specify the timeout. Enable timestamps to Console output and select xterm in ANSI color option and in the end specify the build name pattern for more readable build names.


Build Environment

- [ ] Delete workspace before build starts
- [ ] Use secret text(s) or file(s)
- [x] Abort the build if it's stuck

Time-out strategy: No Activity

Timeout seconds: 3600

Time-out variable:

Set a build timeout environment variable

Time-out actions: Abort the build

- [x] Add timestamps to the Console Output
- [x] Color ANSI Console Output

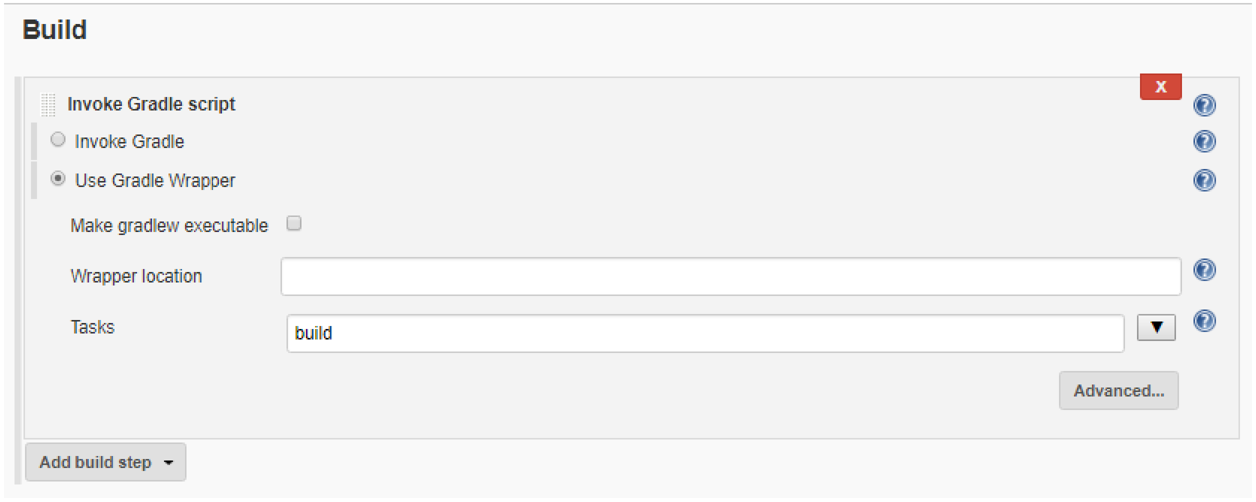
ANSI color map: xterm

- [ ] Generate Release Notes
- [x] Set Build Name

Build Name: #${BUILD_NUMBER}-${GIT_BRANCH}

- [ ] With Ant

13. Last but not least, in Build section add a gradle build step, check Use Gradle Wrapper and specify the gralde task for build.


Build

Invoke Gradle script

- ( ) Invoke Gradle
- (●) Use Gradle Wrapper

Make gradlew executable: [ ]

Wrapper location:

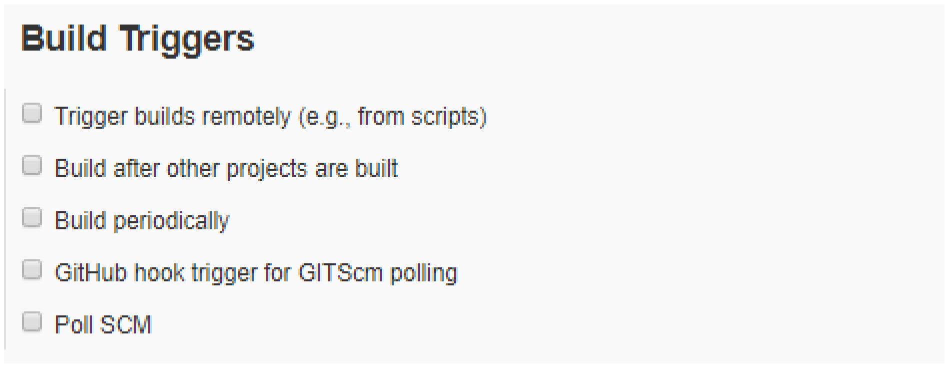
Tasks: build

12.2.5 Configure Periodic Jobs

You can schedule any Jenkins job to run periodically based on provided schedule. To configure periodic build follow the steps below:

1. First click on Configure menu item from menu on left hand side of Job/Project home page.

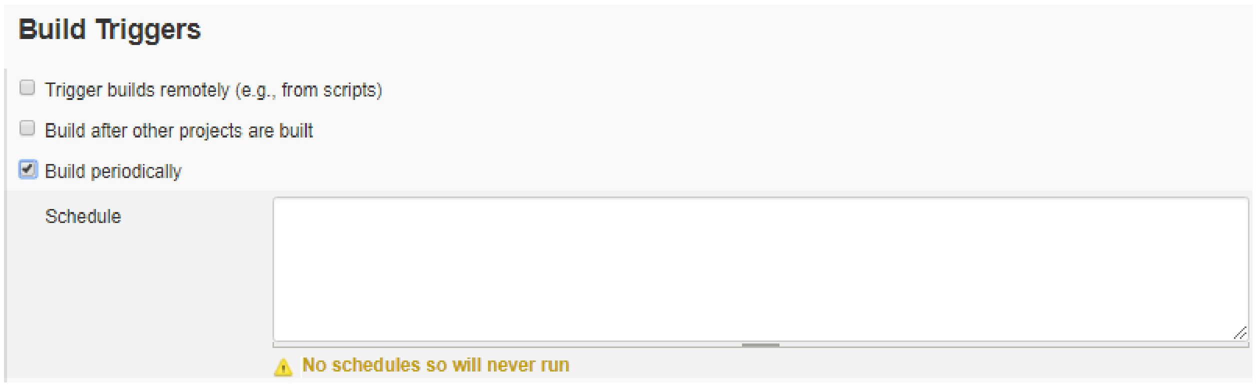
2. On the next (configuration) page, go to *Build Triggers* section.



Build Triggers

- [ ] Trigger builds remotely (e.g., from scripts)
- [ ] Build after other projects are built
- [ ] Build periodically
- [ ] GitHub hook trigger for GITScm polling
- [ ] Poll SCM

3. Click on check box labeled *Build periodically* to enable the option. It will expand and ask for Schedule with a warning message some thing like, No schedules so will never run.



Build Triggers

- [ ] Trigger builds remotely (e.g., from scripts)
- [ ] Build after other projects are built
- [x] Build periodically

Schedule

No schedules so will never run

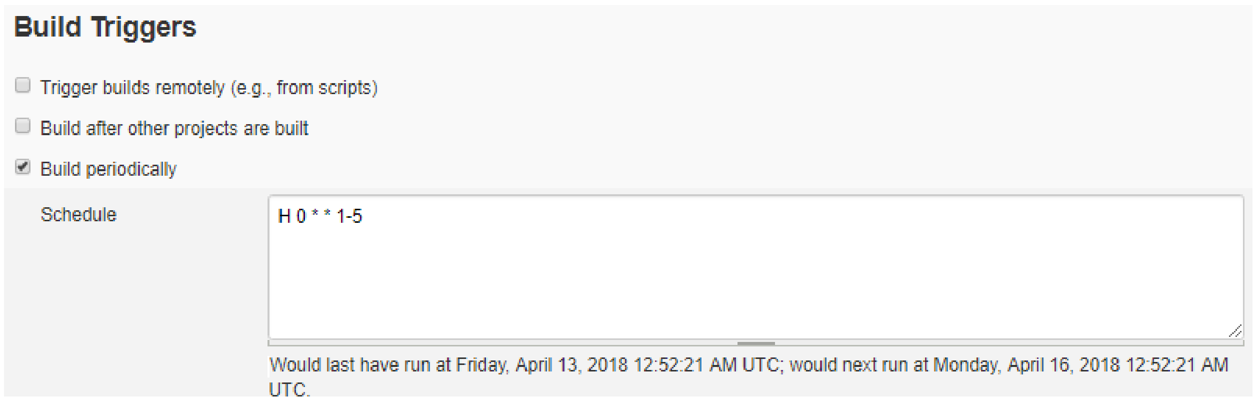
4. You have to specify a schedule by following the similar syntax of cron job as a line consists of 5 fields separated by TAB or whitespace:

   MINUTE HOUR DOM MONTH DOW

   - MINUTE Minutes within the hour (0–59)
   - HOUR The hour of the day (0–23)
   - DOM The day of the month (1–31)
   - MONTH The month (1–12)
   - DOW The day of the week (0–7) where 0 and 7 are Sunday.

To schedule once daily every 24 hours for only 5 working days, we need to specify some thing like:

```
H 0 * * 1-5
```


Build Triggers

- [ ] Trigger builds remotely (e.g., from scripts)
- [ ] Build after other projects are built
- [✓] Build periodically

Schedule
```
H 0 * * 1-5
```
Would last have run at Friday, April 13, 2018 12:52:21 AM UTC; would next run at Monday, April 16, 2018 12:52:21 AM UTC.

As you specify the schedule, warning would be replaced with a descriptive schedule.

5. Save the configurations and now you have setup job to run periodically.

12.2.6 References

https://d0.awsstatic.com/whitepapers/DevOps/Jenkins_on_AWS.pdf

https://www.digitalocean.com/community/tutorials/how-to-configure-nginx-with-ssl-as-a-reverse-proxy-for-jenkins

https://www.digitalocean.com/community/tutorials/how-to-set-up-continuous-integration-pipelines-in-jenkins-on-ubuntu-16-04

https://jmaitrehenry.ca/2016/08/04/how-to-install-a-jenkins-master-that-spawn-slaves-on-demand-with-aws-ec2

12.3 Automated Cloud Deployment

12.3.1 Automatic Image (AMI) Update

In Automated Cloud Deployment capability, there is a baseline image (AMI) that used to instantiate new EC2 instance. It contains copy of git repository and gradle dependency libraries. All of these are outdated in few days due to active development of BEAM. And when we start instance from an outdated image it take additional time to update them before starting the simulation/run. This process help Cloud Automatic Deployment to keep up to date image for fast execution. To trigger this update process a Cloud Watch Event is setup with one week frequency. This event triggers an AWS Lambda (named *updateDependencies*) and lambda then starts an instance from the outdated image with instructions to update the image with latest LFS files for pre configured branches (these branches are mentioned in its environment variables that we can configure easily without any change in lambda code). One LFS files and gradle dependencies are updated in the new instance, the instance invoke a new lambda (named *updateBeamAMI*) to take its new image. This new lambda creates an image of the instance, terminate the instance and update this new image id to Automated Cloud Deployment process for future use.

This process is designed to get latest LFS files from different branches. To add a new branch or update existing one, an environment variable named *BRANCHES* need to update with space as branch name delimiter.

CHAPTER 13

Indices and tables

- genindex
- modindex
- search