Lecture Notes
Introduction to Cloud Computing
Chameleon Cloud

Theory and Practice

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Chameleon

This section is entirely copied from the Chameleon Web page. However we have included where appropriate some updates. We like to mention that we do not want to plagiarize, but are asking chameleon for permission to redistribute this.

Chameleon is an experimental testbed for Computer Science funded by the NSF FutureCloud program. Chameleon is built over two sites, University of Chicago and TACC, offering a total of over 550 nodes and 5 PB of space in twelve Standard Cloud Unit (SCU) racks. To effectively support Computer Science experiments Chameleon offers bare metal reconfigurability on most of the hardware. To provide easy access to educational users, three SCUs at TACC (a quarter of the testbed) are configured with OpenStack KVM. You can read more about Chameleon here.

Chameleon is broadly available to members of the US Computer Science research community and its international collaborators working in the open community on cloud research. The expectation is that any research performed on Chameleon will result in publication in a broadly available journal or conference.

In order to promote fairness to all users, we have the following set of Best Practices for using Chameleon bare metal partitions:

Think Small for Development and class use: If you are just developing or prototyping a system, and not yet running experiments at scale, use only as many nodes as you actually need (e.g., many projects can be developed and tested on 3-4 nodes), and try to take short reservations. Start with hours first and do not let your VMs unnecessarily run for long unused periods.

Automate deployments: You can always snapshot your work/images between sessions using the snapshotting instructions to simplify the redeployment of your environment during the next work session. You can also use scripting and environment customization to make it easier to redeploy images. An additional benefit of automation is that it makes it easier for you to reproduce your work and eventually share it with colleagues within your lab and other collaborators.

Think Big for Experimentation: Once you are ready to experiment you will want to test your experimental setup on increasingly larger scales. This is possible by taking an advance reservation for many resources for a relatively short time. The more resources you need, the more likely it is that you will need to run experiments at a less attractive time (e.g., during the weekend) — here's where automation will also help. In justified cases, we will support reserving even the whole bare metal testbed.

0.1 More Information

In any case please visit the Chameleon Web page as there is also more information about other topics that we may not care about. Furthermore we do not use Advanced Appliences, but use ansible instead as it is independent from OpenStack and can be used with other frameworks.

If you prefer you can also go to the Chameleon Web site using the following links. However we have improved some of the documentation found in this document. We would like to get your feedback in case you find errors or like to contribute tho this documentation.

The links to Chameleons Documentation

F section/cloud/chameleon/resources.tex

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section/cloud/chameleon/hardware.tex

1. Hardware

The Chameleon architecture consists of a set of standard cloud units (SCUs), each of which is a single rack with 42 compute nodes, 4 storage nodes attached to 128TB of local storage in configurable arrays, and an OpenFlow compliant network switch. In addition to the homogeneous SCUs, a variety of heterogeneous hardware types is available to experiment with alternative technologies. The testbed also includes a shared infrastructure with a persistent storage system accessible across the testbed, a top-level network gateway to allow access to public networks, and a set of management and provisioning servers to support user access, control, monitoring and configuration of the testbed. Chameleon is physically distributed between the Texas Advanced Computing Center (TACC) and the University of Chicago (UC) through 100Gbps Internet2 links, to allow users to examine the effects of a distributed cloud.

Hardware Summary

Standard Cloud Units (SCUs)	Homogeneous Hardware Types
Number of Nodes per Rack:	42 Compute Nodes
	4 Storage Nodes
Local Storage per homogeneous SCU:	128TB (configurable)
Network Switch:	OpenFlow Compliant
TACC/UC Distributed Cloud	100Gbps Internet2 links

Detailed information in our Resource Discovery Portal

Standard Cloud Units

The homogeneous standard cloud unit is a self-contained rack with all the components necessary to run a complete cloud infrastructure, and the capability to combine with other units to form a larger experiment. The rack consists of 42 Dell R630 servers; each with 24 cores delivered in dual socket Intel Xeon E5-2670 v3 “Haswell” processors (each with 12 cores @ 2.3GHz) and 128 GiB of RAM. In addition to the compute servers, each unit contains storage hosted in two FX2 chassis,

each containing two Dell FC430 servers attached to two Dell PowerEdge FD332 storage blocks containing 16 2TB hard drives, for a total of 128TB of raw disk storage per unit. These FC430 storage nodes contain dual socket Intel Xeon E5-2650 v3 "Haswell" processors (each with 10 cores @ 2.3 GHz), 64 GiB of RAM, and can be combined across SCUs to create a Big Data infrastructure with more than a PB of storage. Each node in the SCU connects to a Dell switch at 10Gbps, with 40Gbps of bandwidth to the core network from each SCU. The total system contains 12 SCUs (10 at TACC and 2 at UC) for a total of 13,056 cores, 66 TiB of RAM, and 1.5PB of configurable storage in the SCU subsystem.

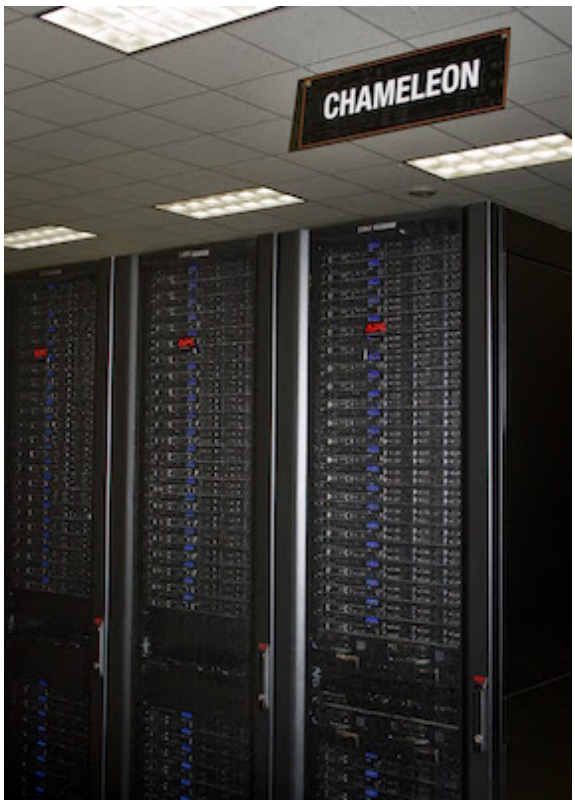


Figure 1.1: Chameleon Cloud Racks

Network

Networking is changing rapidly, and the network fabric is as much a part of the research focus of Chameleon as the compute or storage. For the Chameleon network, every switch in the research network is a fully OpenFlow compliant programmable Dell S6000-ON switch. Each node connects to this network at 10 Gbps, and each unit uplinks with 40Gbps per rack to the Chameleon core network. The core switches (Dell S6000-ON) are connected by 40 Gbps Ethernet links, which connect to the backbone 100Gbps services at both UC and TACC. A Fourteen Data Rate (FDR) Infiniband network (56Gbps) is also deployed on one SCU to allow exploration of alternate networks.

Shared Storage

While storage is dynamically provisioned to researchers to be used as an experiment needs within the SCUs, Chameleon also provides a shared storage system. The shared storage provides more than 3.6PB of raw disk in the initial configuration, which is partitioned between a file system and

an object store that is persistent between experiments. The shared storage is comprised of four Dell R630 servers with 128 GiB of RAM, four MD3260 external drive arrays, and six MD3060e drive expansion chassis, populated by 600 6TB near line SAS drives. The system also includes a dozen PowerEdge R630 servers as management nodes to provide for login access to the resource, data staging, system monitoring, and hosting various OpenStack services.

Heterogeneous Compute Hardware

The heterogeneous hardware includes various technologies: GPU and FPGA accelerators, SSD and NVMe storage, low-power ARM, Atom, and Xeon systems-on-a-chip. With the exception of the low-power systems-on-a-chip, each of the additional nodes is a Dell PowerEdge R730 server with the same CPUs as the R630 servers in our SCUs.

The two storage hierarchy nodes have been designed to enable experiments using multiple layers of caching: they are configured with 512 GiB of memory, two Intel P3700 NVMe of 2 TB each, four Intel S3610 SSDs of 1.6 TB each, and four 15K SAS HDDs of 600 GB each.

The GPU offering consists of two K80 GPU nodes, two M40 GPU nodes, sixteen P100 GPU nodes. These nodes target experiments using accelerators to improve the performance of some algorithms, experiments with new visualization systems, and deep machine learning. Each K80 GPU node is upgraded with an NVIDIA Tesla K80 accelerator, consisting of two GK210 chips with 2496 cores each (4992 cores in total) and 24 GiB of GDDR5 memory. Each M40 node is upgraded with an NVIDIA Tesla M40 accelerator, consisting of a GM200 chip with 3072 cores and 12 GiB of GDDR5 memory. The P100 nodes have two GPU cards installed each, providing 32 P100 GPUs in total. The P100 GPUs utilize GP100 chips providing 3584 cores, with 16 GiB GDDR5 RAM in each card. In order to make it easy for users to get started with the GPU nodes, we have developed a CUDA appliance that includes NVIDIA drivers as well as the CUDA framework.

GPU	Chip	Cores per GPU	RAM per GPU	GPU per node	# of nodes
Tesla K80	GK 210	2496 x 2	24 GiB GDDR5	1	2
Tesla M40	GM 200	3072	12 GiB GDDR5	1	2
Tesla P100	GP100	3584	16 GiB GDDR5	2	16

The four FPGA nodes have a Nallatech 385A board with an Altera Arria 10 1150 GX FPGA (up to 1.5 TFlops), 8 GiB DDR3 on-card memory, and dual QSFP 10/40 GbE support. The Chameleon FPGA User Guide provides details for conducting experiments on this hardware.

The low-power systems are comprised of 8 low power Xeon servers (HP ProLiant m710p with one 4-core Intel Xeon E3-1284L v4 processor), 8 Atom servers (HP ProLiant m300 with one 8-core Intel Avoton-based System on a Chip), and 24 ARM servers (HP ProLiant m400 with one 8-core AppliedMicro X-gene System on a Chip). These are all delivered in a single HP Moonshot 1500 chassis.

For more information on how you can reserve these nodes, see the heterogeneous hardware section of the bare metal user's guide.

Live updates

You can browse detailed information about the resources offered for bare metal reconfiguration in our Resource Discovery Portal.

section/cloud/chameleon/start.tex

2. Getting Started

Here we describe how you can get access to chameleon clude under the assumption that you are a student or a researcher that joins an existing project on Chameleon cloud. You will need to follow the following steps:

2.1 Step 1: Create a Chameleon account

To get started using Chameleon you will need to **create a user account.**

You will be asked to agree to the Chameleon terms and conditions which, among others, ask you to acknowledge the use of Chameleon in your publications.

As part of creating an account you may request PI status, which means that you will be able to create and lead Chameleon projects (see Step 2 below).

2.2 Step 2: Create or join a project

To use Chameleon, you will need to be associated with a project that is assigned an allocation. This means that you either need to (1) **apply for a new project** or (2) **ask the PI of an existing Chameleon project to add you.**

A project is headed by a project PI, typically a faculty member or researcher scientist at a scientific institution. If you are a student we recommend that you ask your professor to work with you on creating a project. Please note taht you must not create a project by yourself and that you indeed need to work with your proferrsor.

A project application typically consists of about one paragraph description of the intended research and takes one buisness day to process.

Enrolling you into an existing research or class project depends on the time availability of the project lead or professor of your class. It is important that you communicate your chameleon cloud

account name to the project lead so they can easily add you. Make sure you realy give them only your chameleon coount name and potentially your organizational e-mail, Firstname, and Lastname so they can check you are realy eligible to get access.

2.3 Step 3: Start using Chameleon!

Now that you have enrolled nad are added to the project by your project lead you cans tart using chameleon cloud. However be minded that you ought to shut down the resources/VMs whenever they are not in use to avoid unnecessary charging. Remember the project has imited time on chameleon and any unused time will be charged against the project.

Chameleon provides two types of resources with links to their respective users guides below:

Bare Metal User Guide will tell you how to use Chameleon bare metal resources which provide strong isolation and allow you maximum control (reboot to new operating system, reboot the kernel, etc.)

OpenStack KVM User Guide will tell you how to get started with Chamemeleon's OpenStack KVM cloud which is a multi-tenant environment providing weak performance isolation.

If you have any questions or encounter any problems, you can check out our User FAQ, or submit a ticket.

F section/cloud/chameleon/user-guide.tex

3. OpenStack Virtual Machines

OpenStack is an Infrastructure as a Service (IaaS) platform that allows you to create and manage virtual environments. Chameleon provides an installation of OpenStack version 2015.1 (Kilo) using the KVM virtualization technology.

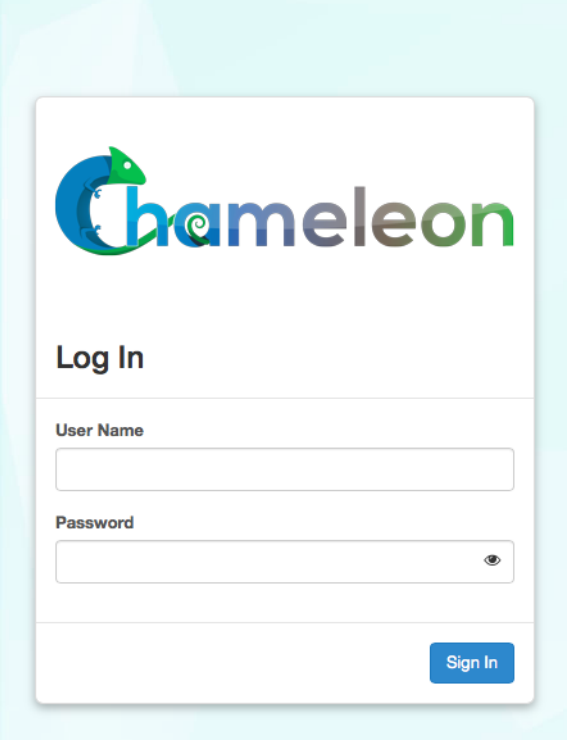
Since the KVM hypervisor is used on this cloud, any virtual machines you upload must be compatible with KVM.

This tutorial provide basic information about how to use the OpenStack web interface and provides some information specific to using OpenStack KVM on Chameleon.

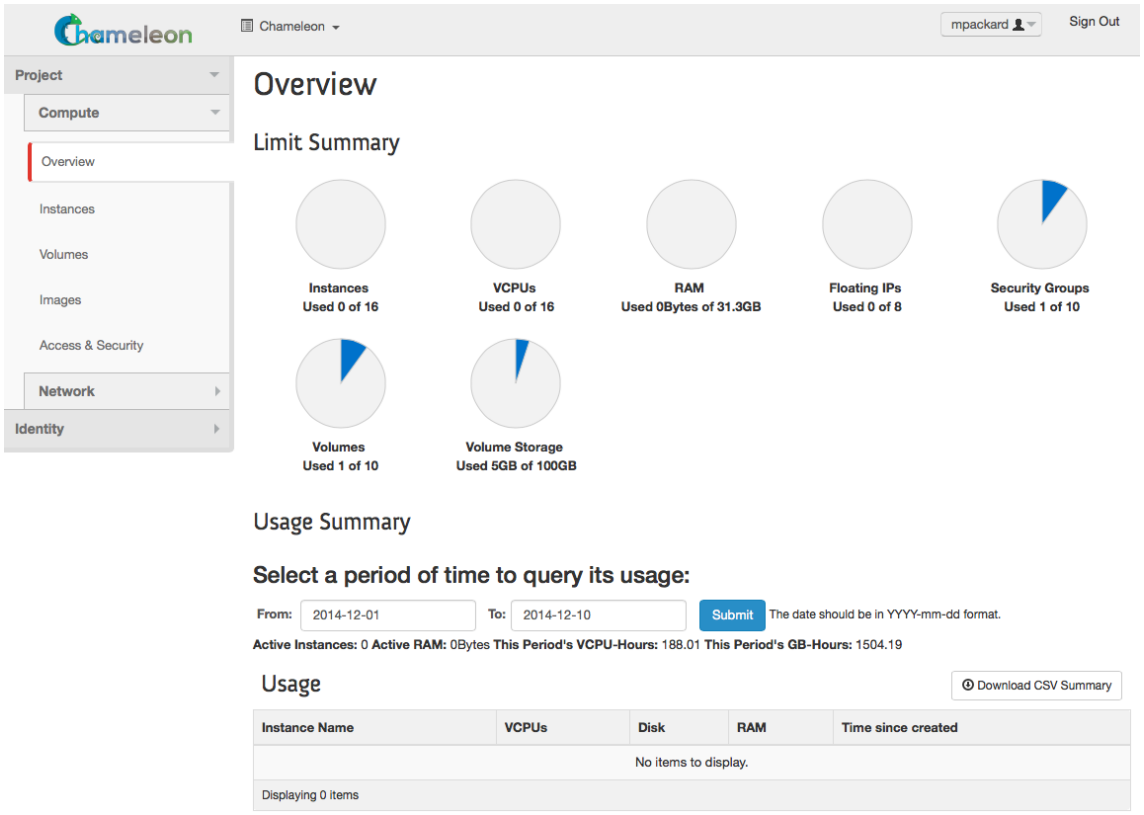
3.1 Web Interface (Horizon)

An easy way to use OpenStack KVM on Chameleon is via the OpenStack web interface. You log into the web interface using your Chameleon username and password. If you change your Chameleon password in the portal, that change will propagate to the OpenStack KVM interface in about 5 minutes.

The initial log in page appears as:

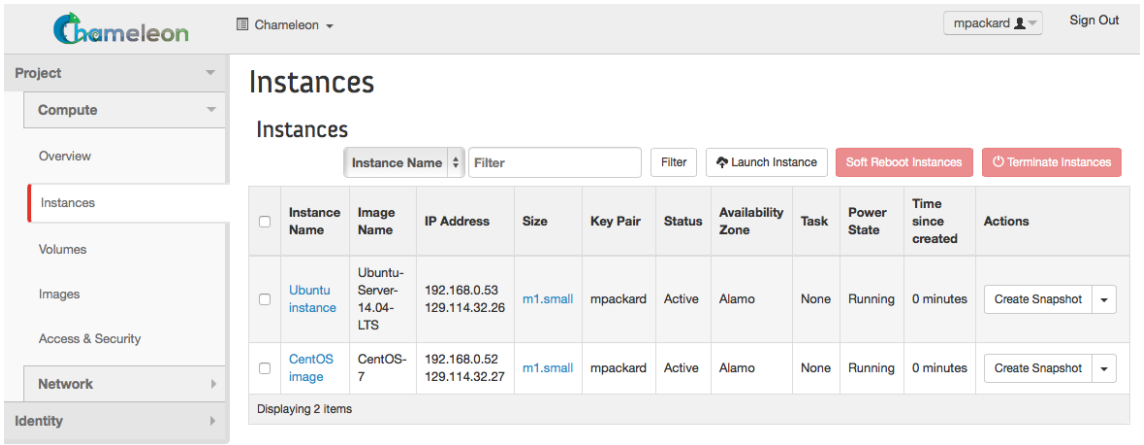


After a successful log in, you will see the Overview page as shown below. This page provides a summary of your current and recent usage and provides links to various other pages. Most of the tasks you will perform are done via the menu on the lower left and will be described below. One thing to note is that on the left, your current project is displayed. If you have multiple Chameleon projects, you can change which of them is your current project. All of the information displayed and actions that you take apply to your current project. So in the screen shot below, the quota and usage apply to the current project you have selected and no information about your other projects is shown.



3.2 Managing Virtual Machine Instances

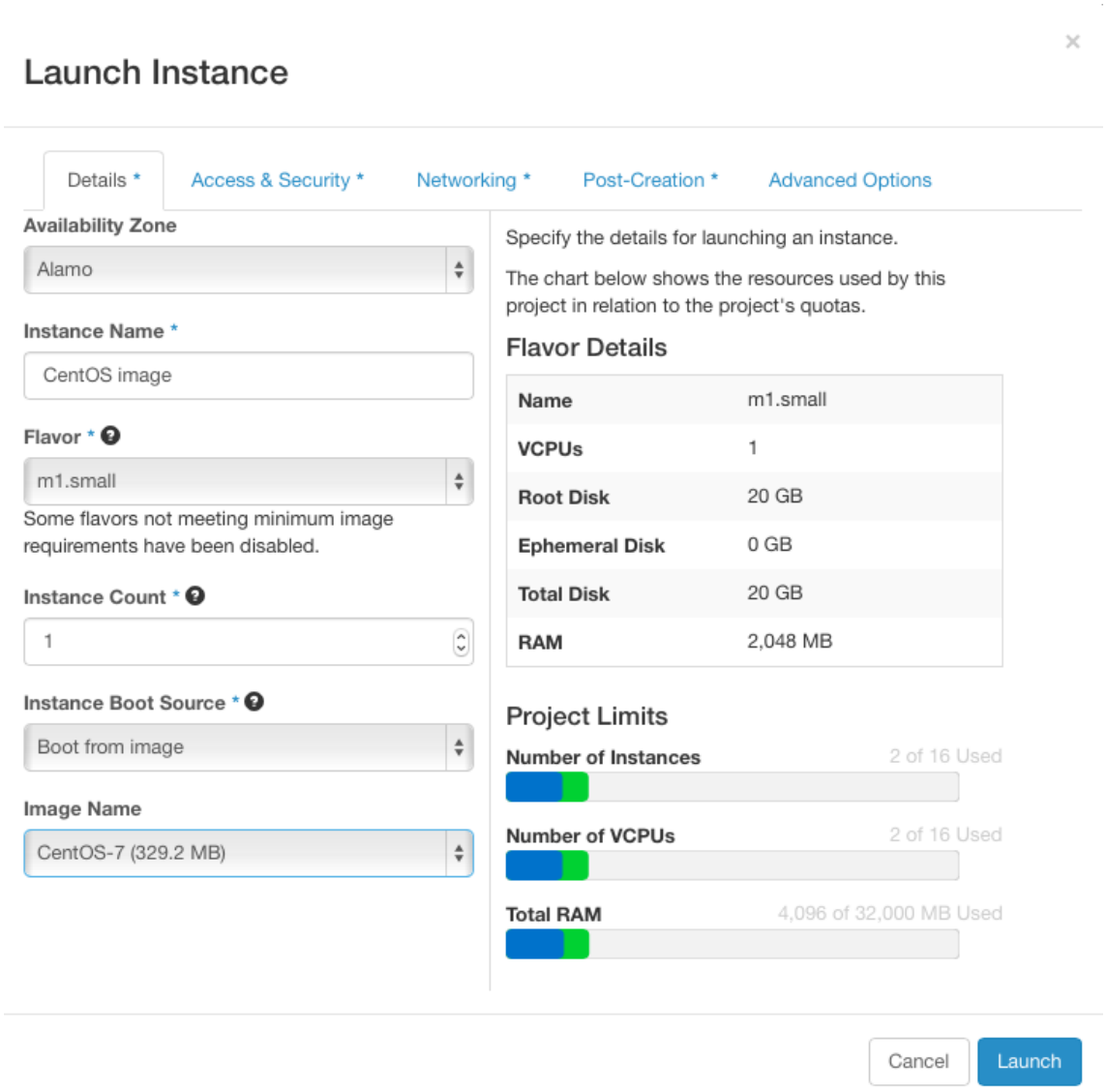
One of the main activities you'll be performing in this web interface is the management of virtual machines, or instances. You do this via the Instances page that is reachable from the menu in the lower left of the Overview page. An example Instances page is shown below. For instances that you have running, you can click on the name of the instance to get more information about it and to access the VNC interface to the console. The dropdown menu to the left of the instance lets you perform a variety of tasks such as suspending, terminating, or rebooting the instance.



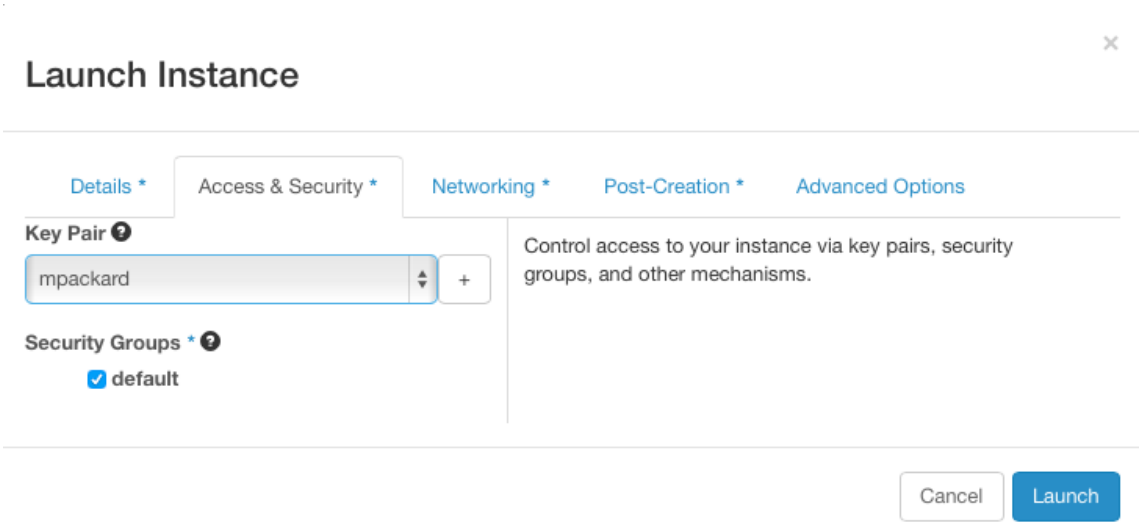
The Instances page also lets you create new virtual machines by using the 'Launch Instance' button in the upper-right. When you click this button, a dialog window pops up. In the first 'Details' tab, you select the 'Instance Boot Source' of the instance, which is either an 'Image', a 'Snapshot' (an image created from a running virtual machine), or a 'Volume' (a persistent virtual disk that can

be attached to a virtual machine). If you select 'Boot from image', the Image Name dropdown presents a list of virtual machine images that we have provided, that other Chameleon users have uploaded and made public, or images that you have uploaded for yourself. If you select 'Boot from snapshot', the Instance Snapshot dropdown presents a list of virtual machine images that you have created from your running virtual machines.

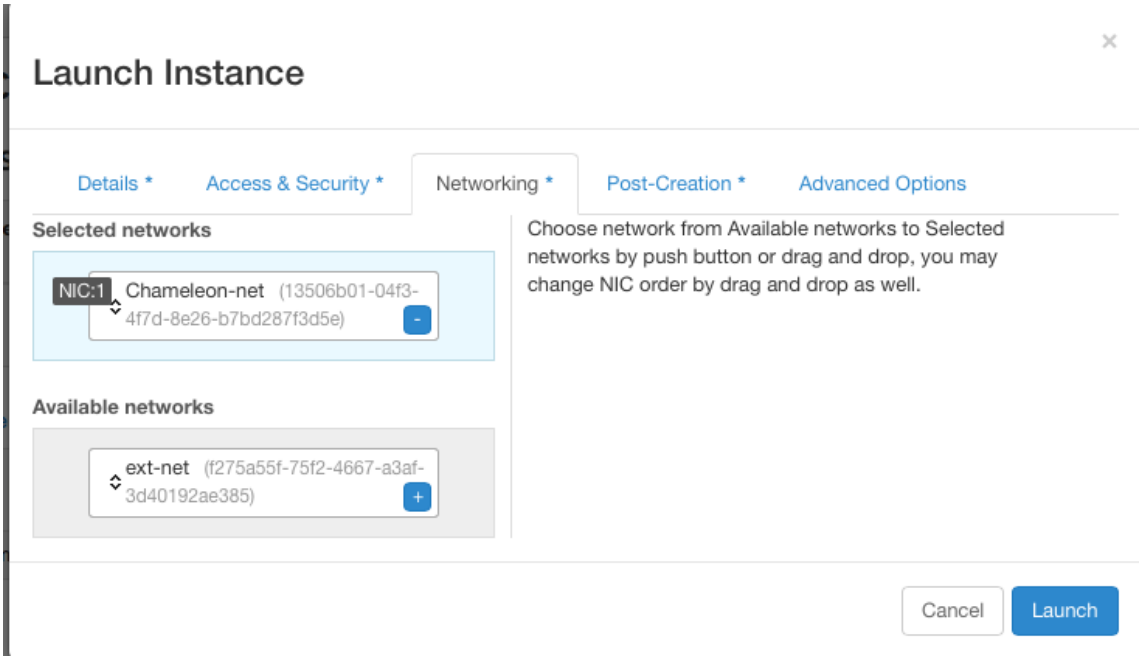
On the Details tab, you also provide a name for this instance (to help you identify instances that you are running), and select the amount of resources (Flavor) to allocate to the instance. If you select different flavors from the Flavor dropdown, their characteristics are displayed on the right.



The next tab is 'Access & Security', where you select an SSH keypair that will be inserted into your virtual machine. These keypairs can be uploaded via the main 'Access & Security' section. You will need to select a keypair here to be able to access an instance created from one of the public images Chameleon provides. These images are not configured with a default root password and you will not be able to log in to them without configuring an SSH key.

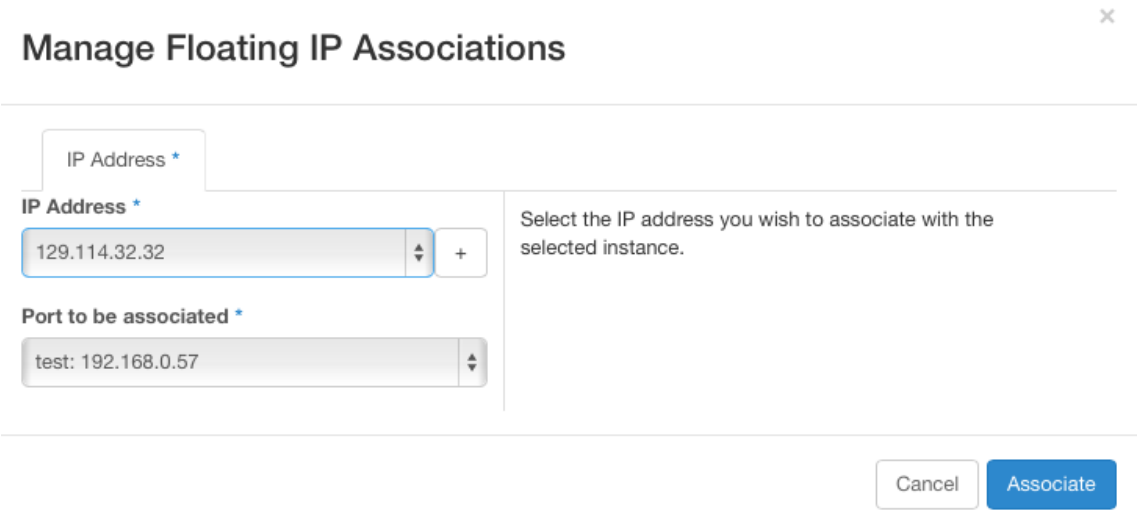


Next is 'Networking', where you select which network should be associated with the instance. Click the + next to your your project's private network (PROJECT_NAME-net), not ext-net.



Once you do this, you can Launch your instance and the Instances page will show progress as it starts.

If you would like to assign a public IP address to your VM, you can do that while it is booting up. Click on the dropdown under *Actions* and choose *Associate Floating IP*. Choose an IP from the *IP Address* menu and click *Associate*. If there are no addresses available, click the + and follow the prompts to add one.



OpenStack injects your SSH key into the VM and you can use the corresponding private SSH key to log in to the VM. You will need to use the public IP assigned to your VM to connect from outside of Chameleon, or connect through an existing instance that both a public and private IP.

Note that the images we provide do not allow SSH into the root account. For root access, SSH into the instance as user 'cc' and then use the *sudo* command to become root.

We have enabled auto-login for the cc user on the console of our supported images. This should aid in debugging if you are unable to reach the instane via ssh for some reason.

3.3 Snapshots

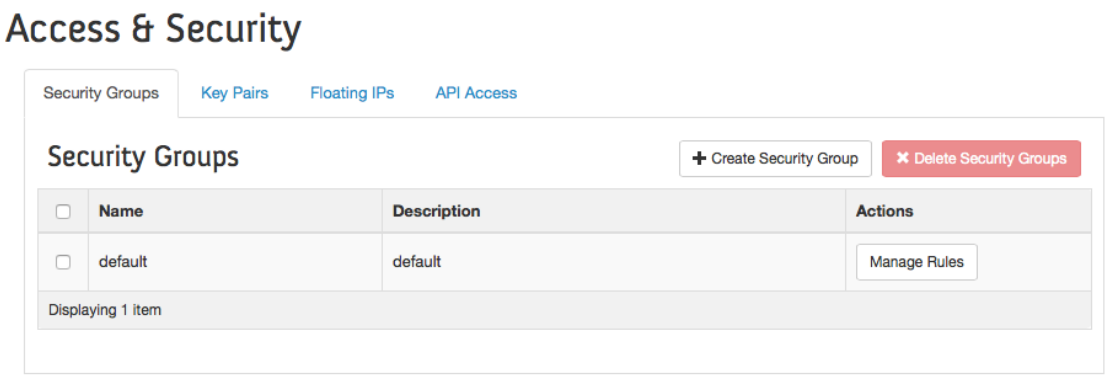
The instance list page shown above has an option 'Create Snapshot' that allows you to save a copy of the disk contents of a running virtual machine. This allows you to start new virtual machines in the future that are identical to this one and is an easy way to save any changes you make to a

running virtual machine.

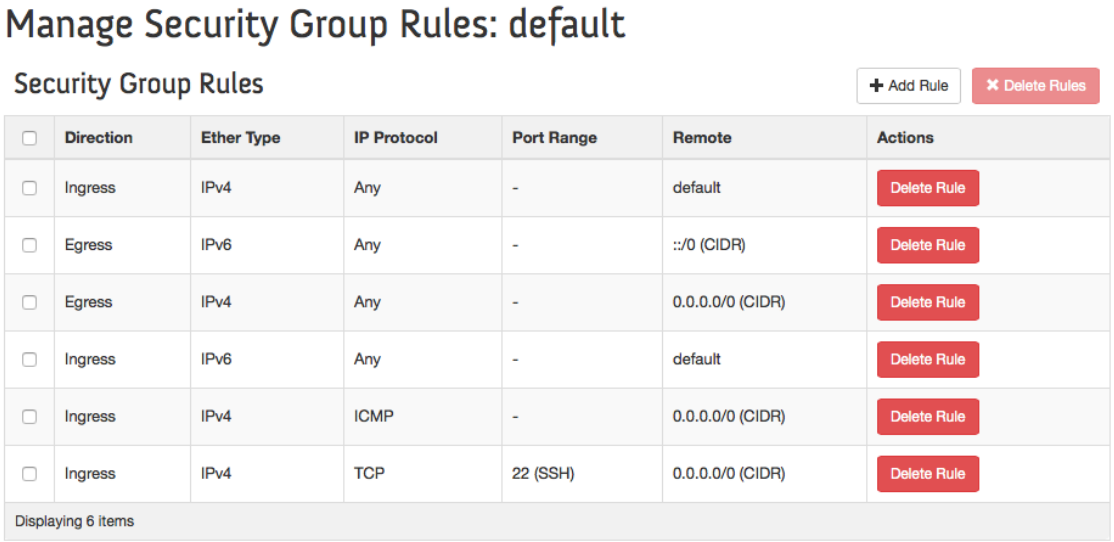
3.4 Firewall (Access Security)

Each project has control over their own firewall settings for their instances. At minimum you'll probably want to allow SSH access so you can reach your instances.

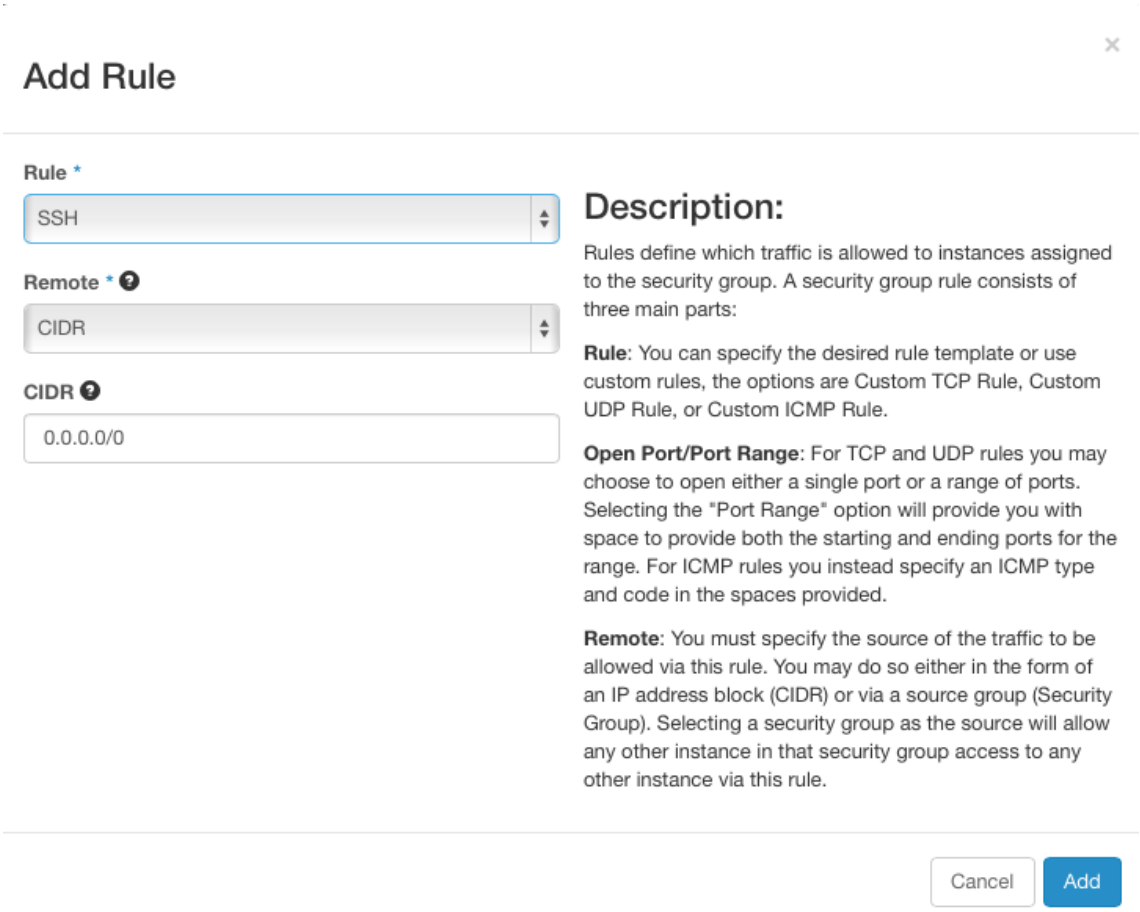
To enable this traffic, you need to configure the security group used by your virtual machine. You can see a list of your security groups using the "Access & Security" link on the left.



To edit a security group, click on "Edit Rules". This opens a page showing the existing rules in the security group.



Click on "Add Rule" and choose the *SSH* rule from the list, and click *Add*. Modifications are automatically propagated to the OpenStack cloud. Feel free to add other rules as necessary.



3.5 OpenStack REST Interfaces

The OpenStack REST Interfaces are supported on Chameleon over secure HTTP connections. You can download your OpenStack credentials file from the web interface via the “Access & Security” link in the left of any page and then click on the “API Access” link on the top.

You can then install the OpenStack command line clients following these instructions. If using pip, we recommend setting up a virtualenv.

The SSL certificate used by Chameleon is trusted by most operating systems, so you shouldn’t have to provide any extra options to OpenStack commands, i.e. “nova list” should work. If your command-line tool complains about the certificate, download the Mozilla CA bundle from the cURL website and run the OpenStack client tools with the –os-cacert cacert.pem arguments.

3.6 EC2 Interface

OpenStack KVM on Chameleon supports the EC2 interface for programmatic access. You can download your EC2 credentials from the web interface via the “Access & Security” link in the left of any page and then click on the “API Access” link on the top. You should see a ‘Download EC2 Credentials’ button on the top-right. Note that you have different EC2 credentials for each Chameleon project you participate in. If you are a member of multiple Chameleon projects, we request that you use the corresponding EC2 credentials when starting virtual machines for a project.

3.7 Downloading and uploading data

You can use the OpenStack command line clients to download data from and upload data to Chameleon clouds. Configure your environment by following the "OpenStack REST Interfaces" section above, then use the following commands:

- `glance image-download` to download images and snapshots from Glance
- `glance image-create` to upload images and snapshots to Glance
- `cinder upload-to-image` to convert a Cinder volume to a Glance image
- `cinder create [--image-id <image-id>] [--image <image>]` to create a Cinder volume from a Glance image

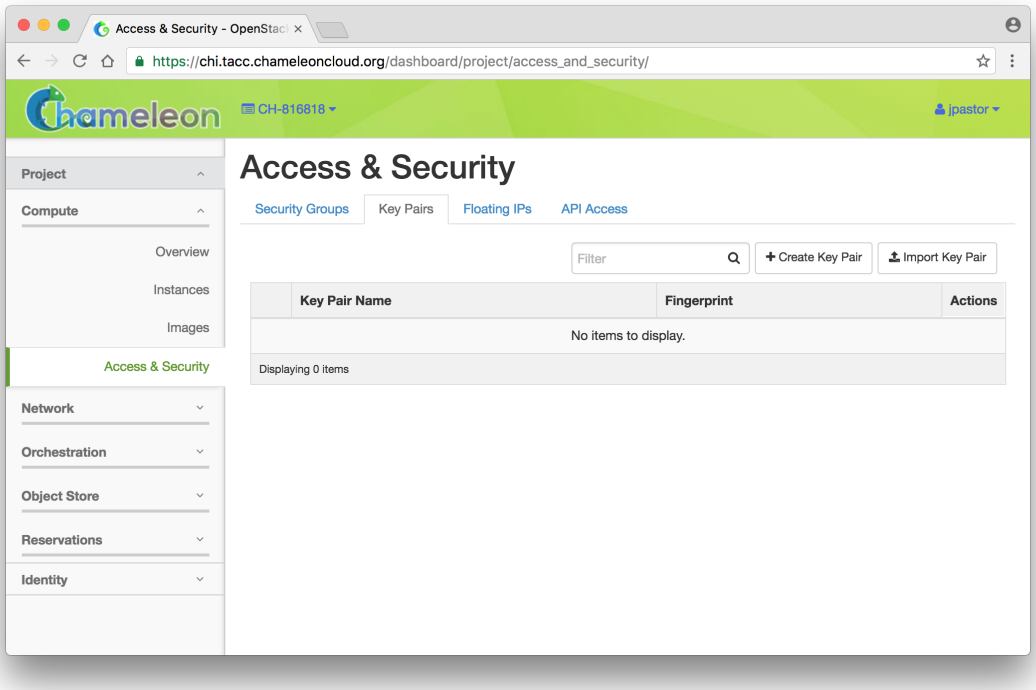
section/cloud/chameleon/horizon.tex

4. Horizon Graphical User Interface

4.1 Configure resources

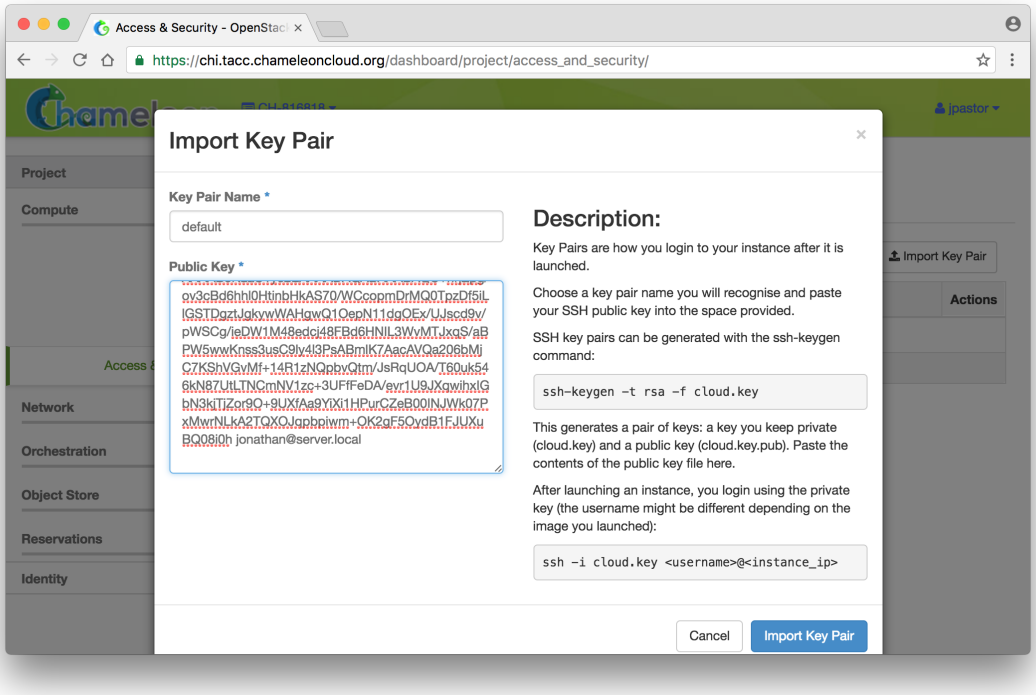
Once your lease is started, you are almost ready to start an instance. But first, you need to make sure that you will be able to connect to it by setting up a key pair. This only has to be done once per user per project.

Go to Project > Compute > Access & Security, then select the Key Pairs tab.

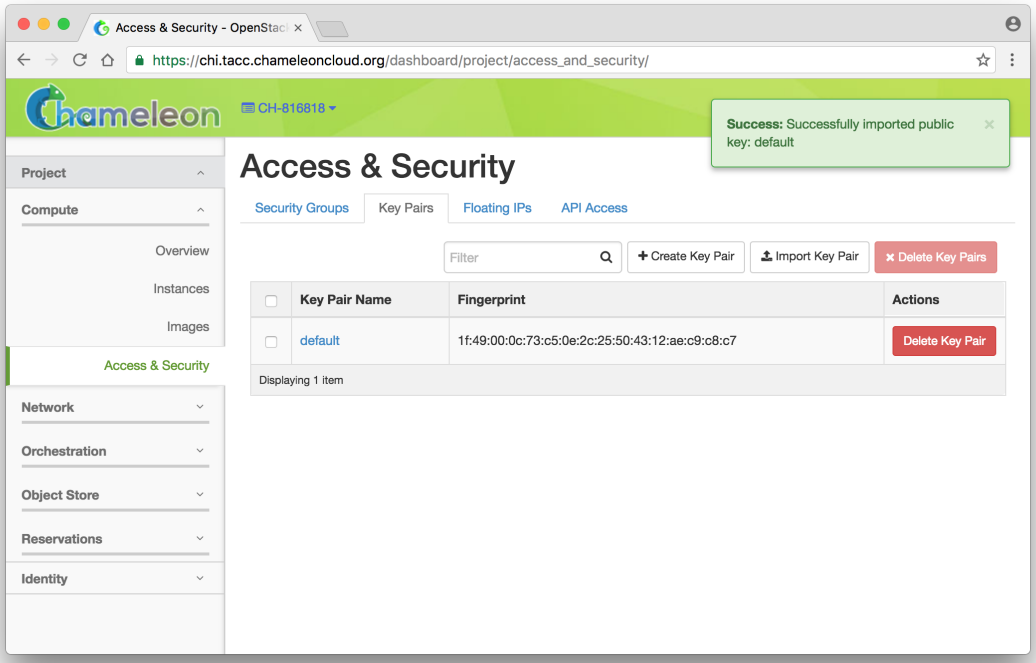


Here you can either ask OpenStack to create an SSH key pair for you (via the "Create Key" Pair button), or, if you already have an SSH key pair on your machine and are happy to use it, click on "Import Key Pair".

If you chose to import a key pair, you will be asked to enter a name for the key pair, for example laptop. In the "Public Key" box, copy the content of your SSH public key. Typically it will be at ~/.ssh/id_rsa.pub. On Mac OS X, you can run in a terminal: `cat ~/.ssh/id_rsa.pub | pbcopy`
It copies the content of the public key to your copy/paste buffer. Then you can simply paste in the "Public Key" box.

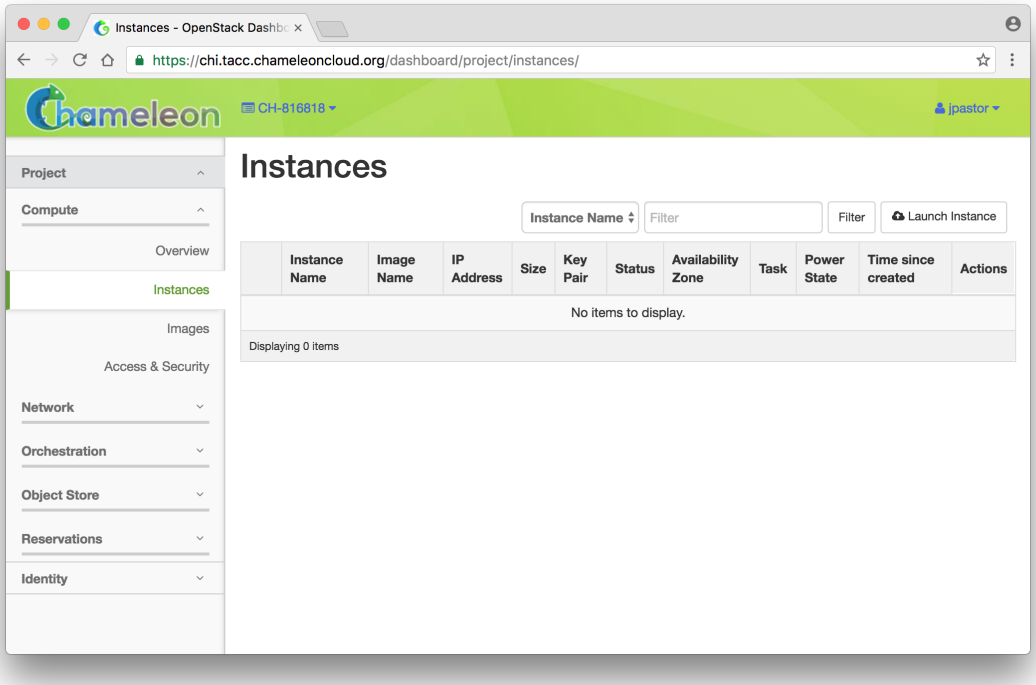


Then, click on the blue "Import Key Pair" button. This should show you the list of key pairs, with the one you just added.

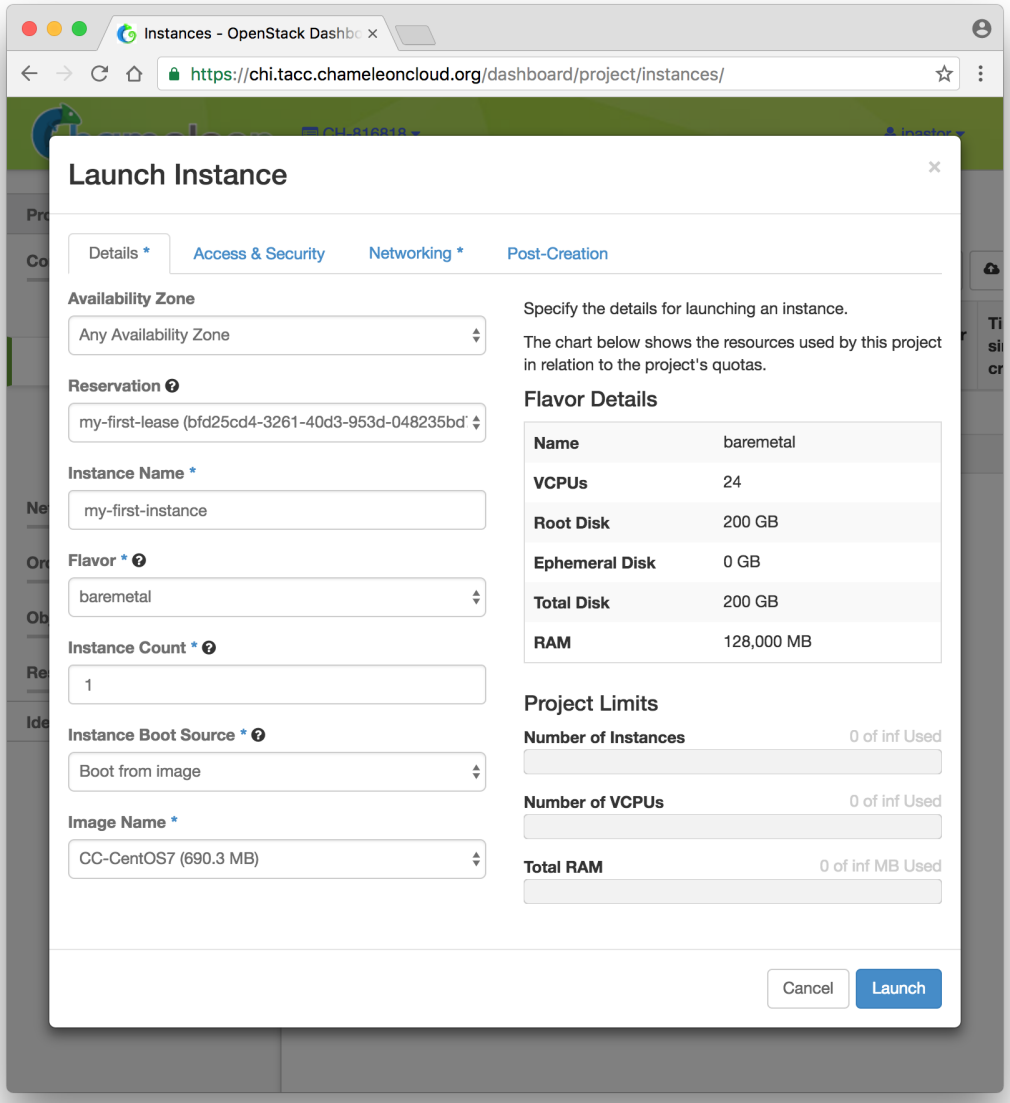


For those already familiar with OpenStack, note that Security Groups are not functional on bare-metal. All instances ports are open to the Internet and any security group rule you add will not be respected.

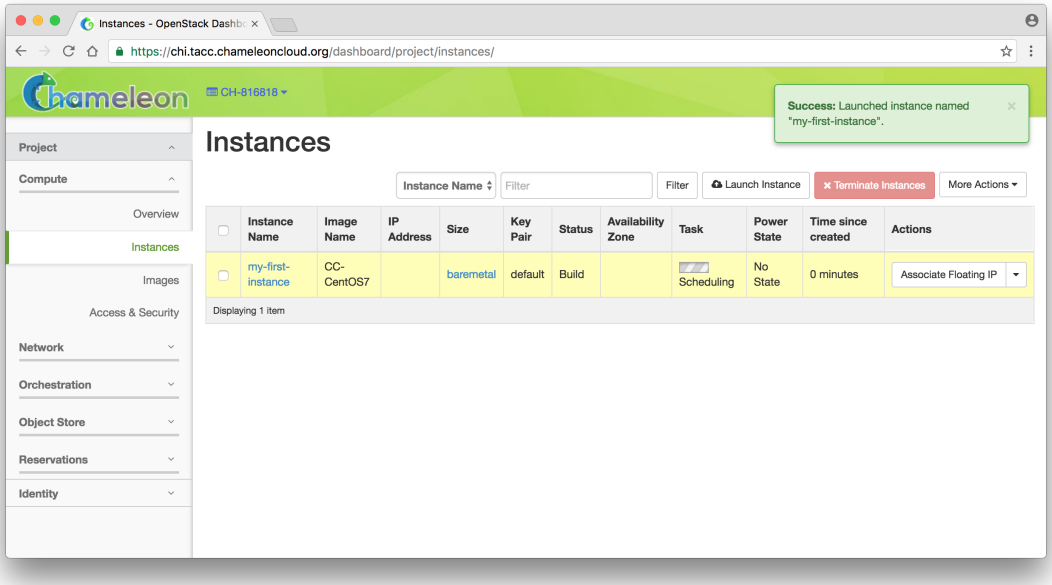
Now, go to the "Instances" panel.



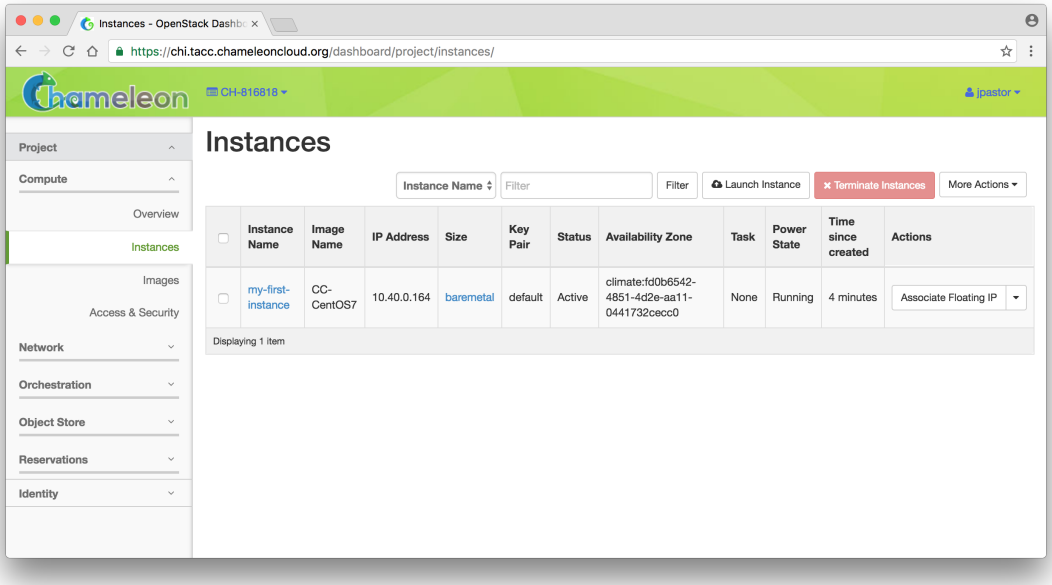
Click on the “Launch Instance” button in the top right corner. Select a reservation in the Reservation box, pick an instance name (in this example my-first-instance) and in the Image Name list select our default environment named CC-CentOS7. If you have multiple key pairs registered, you need to select one in the “Access & Security” tab. Finally, click on the blue “Launch” button.



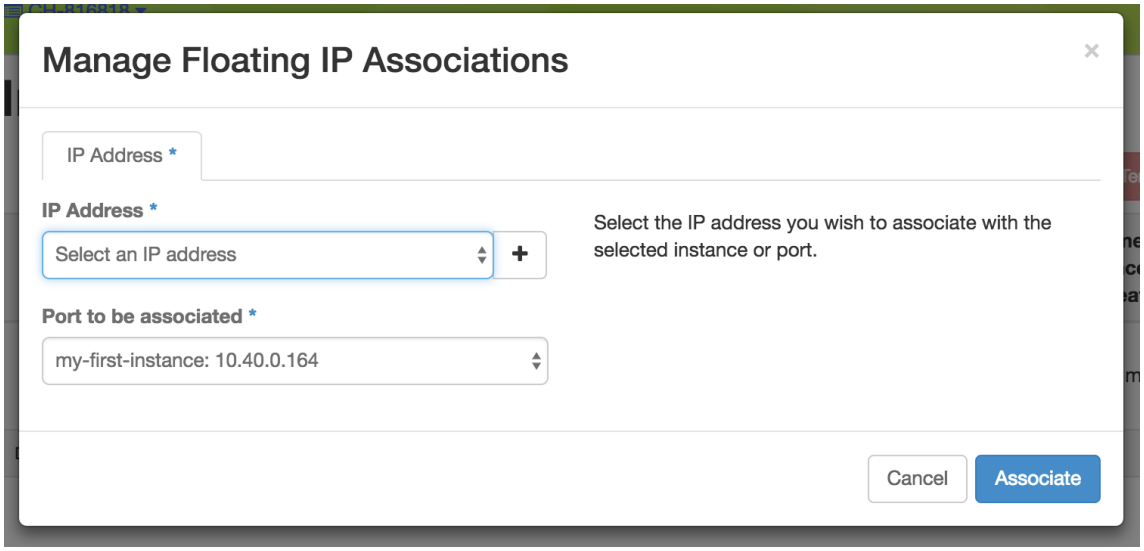
The instance will show up in the instance list, at first in Build status. It takes a few minutes to deploy the instance on bare-metal hardware and reboot the machine.



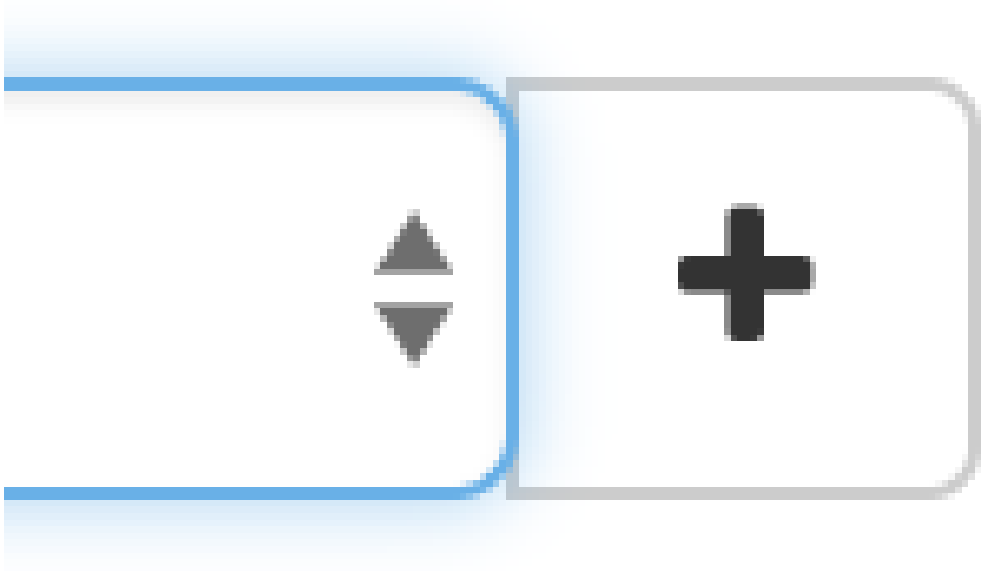
After a few minutes the instance should become in Active status and the Power State should be Running.



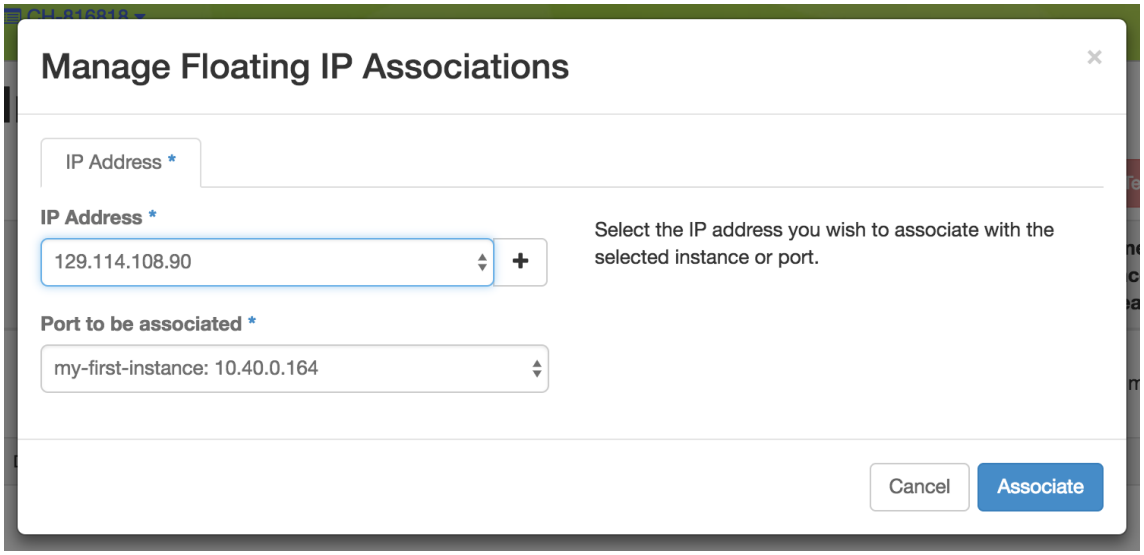
At this point the instance might still be booting: it might take a minute or two to actually be accessible on the network and accept SSH connections. In the meantime, you can attach a floating IP to the instance. Click on the "Associate Floating IP" button. You should get a screen like the one below:



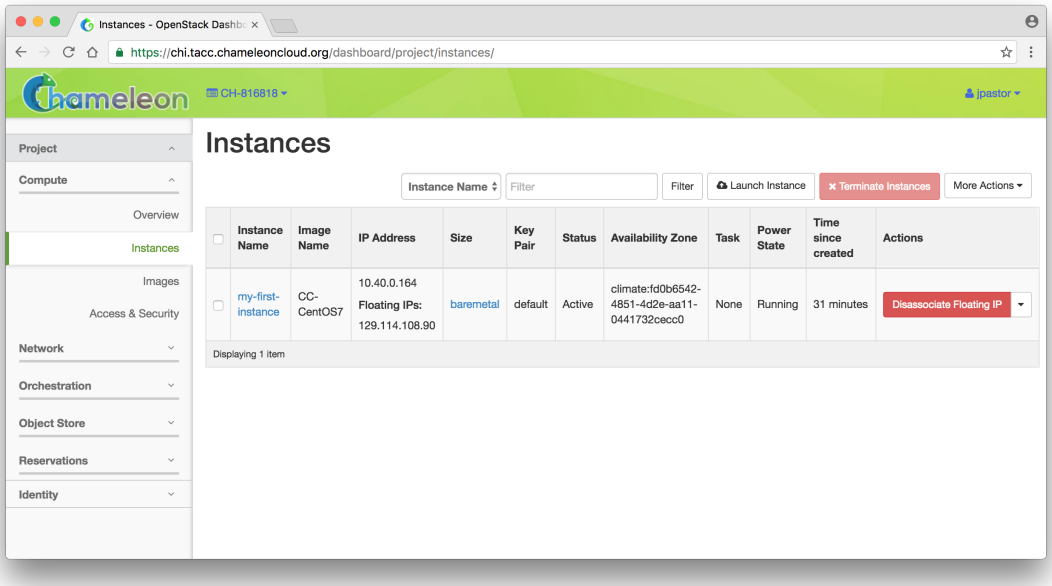
If there are no unused floating IP already allocated to your project, click on the + button. In the window that opens, select the ext-net pool if not already selected by default and click on the blue Allocate IP button.



You will be returned to the previous window. The correct value for “Port to be associated” should already be selected, so you only have to click on “Associate”.



This should send you back to the instance list, where you can see the floating IP attached to the instance (you may need to refresh your browser to see the floating IP).



4.2 Interact with resources

Now you should be able to connect to the instance via SSH using the cc account. In a terminal, type ssh cc@<floating_ip>, in our example this would be `ssh cc@130.202.88.241`

SSH will probably tell you:

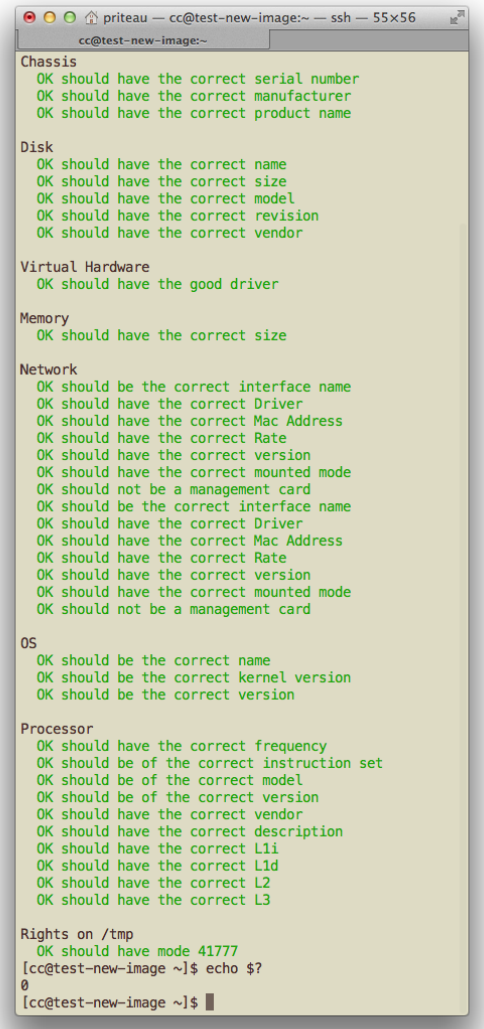
```
The authenticity of host \textquotesingle{}130.202.88.241
(130.202.88.241) can't be established. RSA key fingerprint
is 5b:ca:f0:63:6f:22:c6:96:9f:c0:4a:d8:5e:dd:fd:eb.
Are you sure you want to continue connecting (yes/no)?
```

Type yes and press Enter. You should arrive to a prompt like this one:

```
[cc@my-first-instance ~]$
```

If you notice SSH errors such as connection refused, password requests, or failures to accept your key, it is likely that the physical node is still going through the boot process. In that case, please wait before retrying. Also make sure that you use the **cc** account. If after 10 minutes you still cannot connect to the machine, please open a ticket with our help desk.

You can now check whether the resource matches its known description in the resource registry. For this, simply run: `sudo cc-checks -v`



The cc-checks program prints the result of each check in green if it is successful and red if it failed.

You can now run your experiment directly on the machine via SSH. You can run commands with root privileges by prefixing them with `sudo`. To completely switch user and become root, use the `sudo su - root` command.

4.2.1 Snapshot an instance

All instances in Chameleon, whether KVM or bare-metal, are running off disk images. The content of these disk images can be snapshotted at any point in time, which allows you to save your work and launch new instances from updated images later.

While OpenStack KVM has built-in support for snapshotting in the Horizon web interface and via the command line, bare-metal instances require a more complex process. To make this process easier, we developed the cc-snapshot tool, which implements snapshotting a bare-metal instance from command line and uploads it to Glance, so that it can be immediately used to boot a new bare-metal instance. The snapshot images created with this tool are whole disk images.

For ease of use, *cc-snapshot* has been installed in all the appliances supported by the Chameleon project. If you would like to use it in a different setting, it can be downloaded and installed from the github repository.

Once cc-snapshot is installed, to make a snapshot of a bare-metal instance, run the following command from inside the instance:

```
sudo cc-snapshot <snapshot_name>
```

You can verify that it has been uploaded to Glance by running the following command:

```
glance image-list
```

If you prefer to use a series of standard Unix commands, or are generally interested in more detail about image management, please refer to our image management guide.

4.3 Use FPGAs

Consult the dedicated page if you would like to use the FPGAs available on Chameleon.

4.4 Next Step

Now that you have created some resources, it is time to interact with them! You will find instructions to the next step by visiting the following link:

- Monitor resources and collect results

F section/cloud/chameleon/faq.tex

5. Frequently Asked Questions

5.1 General

5.1.1 What are the best practices for Chameleon usage?

5.1.2 Are there any limitations on Chameleon usage?

We have two types of limitations, introduced to promote fair resource usage to all:

- Allocation: Chameleon projects are limited to a per-project allocation currently set to 20,000 service units for 6 months. Allocations can be renewed or extended—see the Project and Allocation Management section for more details on Chameleon allocations.
- Lease: To ensure fairness to all users, resource reservations (leases) are limited to a duration of 7 days. However, an active lease within 48 hours of its end time can be prolonged by up to 7 days from the moment of request if resources are available. To prolong a lease, click on the "Update Lease" button in the Reservations panel of the CHI OpenStack dashboard, and enter the additional duration requested in the "Prolong for" box including the unit suffix, e.g. "5d" for 5 days or "30m" for 30 minutes. If there is an advance reservation blocking your lease prolongation that could potentially be moved, you can interact through the users mailing list to coordinate with others users. Additionally, if you know from the start that your lease will require longer than a week and can justify it, you can contact Chameleon staff via the ticketing system to request a one-time exception to create a longer lease.

5.1.3 How should I acknowledge Chameleon in my publications?

An acknowledgement of support from the Chameleon project and the National Science Foundation should appear in any publication of material, whether copyrighted or not, that describes work which benefited from access to Chameleon cyberinfrastructure resources. The suggested acknowledgement is as follows: "Results presented in this paper were obtained using the Chameleon testbed supported by the National Science Foundation".

5.1.4 What infrastructures is Chameleon federated with?

Chameleon supports identity federation with GENI designed to give GENI users immediate access to Chameleon without having to create a Chameleon account or project. GENI users can log in with their GENI credentials and charge their usage the GENI Federation Project created to provide startup cycles to researchers evaluating Chameleon. To obtain a larger allocation focused on their research needs, GENI users can then go on to create individual Chameleon projects. Chameleon users can also log in to the GENI Experimenter Portal using their Chameleon credentials. When selecting the organization with whom to log in to GENI, search for "Chameleon Cloud" in the list of Identity Providers. You will be redirected to the Chameleon Auth Service to log in and then back to the GENI Experimenter Portal upon successful login.

5.2 Project and Allocation Management

5.2.1 My PI/Professor/Colleague already has a Chameleon Project. How do I get added as a user on the project?

You will need to contact the project PI and request that they add you as a user. Provide the PI with your Chameleon username. The project PI should visit the Chameleon Project Management page. From the list of projects, locate the project to which the user is to be added and click

View Project

. Near the bottom of the page, under the heading *Project Users*, is a form where the PI can enter the Chameleon username of the user to add. Clicking

Add user

will add the user to the project.

5.2.2 What are the units of an allocation, and how am I charged?

Chameleon allocations can consist of several components of the system. Users can request allocation of individual compute nodes, storage servers, or complete Scalable Compute Units (SCUs) which contain compute servers, storage nodes, and an open flow switch.

Compute servers are allocated in Service Units (SUs), which equates to one hour of wall clock time on a single server (for virtual machines, an SU is 24 cores with up to 128GB of RAM). Note this unit differs from traditional HPC or cloud service units that are charged in core-hours; a Chameleon SU is a full server, as the type of experiments and performance measurements users may wish to do may be contaminated by sharing nodes.

Storage servers are also charged in SUs, at 2x the rate of compute servers (i.e., 1 hour allocation of 1 storage server == 2 SUs). SCUs are charged at the rate of 50 SUs per wall clock hour (42 compute servers, 4 storage nodes, plus one OpenFlow switch).

An allocation may make use of multiple SCUs, up to the size of the full testbed.

For example, a user wishing to provision a 10 node cluster +1 storage server for a 1 week experiment should budget `[(10 + 2) SUs per hour] * [7 days * 24 hours/day] = 2,016 SUs` for that experiment.

SUs are charged the same regardless of use case. Hence, whether asking for bare metal access, virtual machine access, or use of default images, the charge is the same — you are charged for the

fraction of the resource your experiment occupies, regardless of the type of the experiment.

The basic principle for charging service units for Chameleon resources is to evaluate the amount of time a fraction of the resource is unavailable to other users. If a reservation is made through the portal for a particular date/time in the future, the user will be charged for this time regardless of whether the reservation is actually used, as the Chameleon scheduling system will have to drain the appropriate part of the system to satisfy the reservation, even if the nodes requested are not actually used. A reservation request may be cancelled in which case no charges will apply.

5.2.3 What are the project allocation sizes and limits?

In the initial phase Chameleon is operating on a "soft allocation model" where each project, if approved, will receive a startup allocation of 20,000 SUs for six months that can be both recharged (i.e., more SUs can be added) and renewed (i.e., the duration can be extended) via submitting a renew/recharge request. This startup allocation value has been designed to respond to both PI needs (i.e., cover an amount of experimentation needed to obtain a significant result) and balance fairness to other users (it represents roughly 1% of testbed six months' capacity). Requests for these startup projects will receive a fast track internal review (i.e., users can expect them to be approved within a few days).

A PI can apply for multiple projects/allocations; however, the number of held allocations will be taken into account during review.

As our understanding of user need grows we expect the Chameleon allocation model to evolve towards closer reflection of those needs in the form of more differentiated allocations that will allow us to give larger allocations to users for longer time.

5.3 Account Management Troubleshooting

5.3.1 When I attempt to create an account it says my email is already registered; why does it happen?

Chameleon relies on TACC's Identity Service for account management. If you already have a TACC account, possibly through XSEDE or directly through TACC, then you should use that account to log in to Chameleon. If you don't know your TACC password, you can reset your password. After resetting your password you should be able to log in to Chameleon.

5.3.2 I cannot log into the portal after creating an account, what should I do?

Please make sure that you have successfully confirmed your email address. Check your junk folder as the confirmation email might have been marked as spam. Double- check that you are using the password that you provided during the registration. If you are unsure of the password you used, you can reset it. If you still cannot log in, please open a ticket.

5.3.3 I have an account, but when I try to log in to OpenStack/Experiment it says my username/password is unknown, why?

You must be a member of an active project to access the OpenStack/Experiment interface. If you are PI Eligible, you can request a new project on the Chameleon Project Management page. If you are not PI Eligible, you will need to be added to an existing project by the project PI. You can check that a project has an active Chameleon allocation by clicking on the **View Project** button. If you

are part of a project but the allocation is *Pending*, it means your project is under review. If you still cannot log in, please open a ticket with our help desk.

5.4 Appliances

5.4.1 What is an appliance?

An appliance is an application packaged together with the environment that this application requires. For example, an appliance can consists of the operating system, libraries and tools used by the application, configuration features such as environment variable settings, and the installation of the application itself. Examples of appliances might include a KVM virtual machine image, a Docker image, or a bare metal image. Chameleon appliance refers to bare metal images that can be deployed on the Chameleon testbed. Since an appliance captures the experimental environment exactly, it is a key element of reproducibility; publishing an appliance used to obtain experimental results will go a long way to allowing others to reproduce and build on your research easily.

To deploy distributed applications on several Chameleon instances, complex appliances combine an image and a template describing how the cluster should be configured and contextualized. You can read more about them in the Complex Appliances documentation.

5.4.2 What is the Chameleon Appliance Catalog?

The Chameleon Appliance Catalog is a repository that allows users to discover, publish, and share appliances. The appliance catalog contains useful images of both bare metal and virtual machine appliances supported by the Chameleon team as well appliances contributed by users.

5.4.3 How do I publish an appliance in the Chameleon Appliance Catalog?

The new Appliance Catalog allows you to easily publish and share your own appliances so that others can discover them and use them either to reproduce the research of others or as a basis for their own research. Before creating your own appliance it is advisable to review other appliances on the Chameleon Appliance Catalog in order to get an idea of the categories you will want to contribute and what others have done.

Once you are ready to proceed, an appliance can be contributed to Chameleon in the following steps:

1. Create the appliance itself. You may want to test it as well as give some thought to what support you are willing to provide for the appliance (e.g., if your group developed and supports a software package, the appliance may be just a new way of packaging the software and making it available, in which case your standard support channels may be appropriate for the appliance as well).
2. Upload the appliance to the Chameleon Image Repository (Glance) and make the image public. In order to enter the appliance into the Catalog you will be asked to provide the Glance ID for the image. These IDs are per-cloud, so that there are three options right now: bare metal/CHI at University of Chicago, bare metal/CHI at TACC, and OpenStack/KVM at TACC. You will need to provide at least one appliance, but may want to provide all three.
3. Go to the Appliance Catalog Create Appliance web form, fill out, and submit the form. Be prepared to provide the following information: a descriptive name (this sometimes requires some thought!), author and support contact, version, and an informative description. The description is a very important part of the appliance record; others will use it to evaluate if the

appliance contains tools they need for their research so it makes sense to prepare it carefully. To make your description effective you may want to think of the following questions: what does the appliance contain? what are the specific packages and their versions? what is it useful for? where can it be deployed and/or what restrictions/limitations does it have? how should users connect to it / what accounts are enabled?

If you are adding a complex appliance, skip the image ID fields and enter your template instead in the dedicated text box.

As always, if you encounter any problems or want to share with us additional improvements we should do to the process, please don't hesitate to submit a ticket.

5.4.4 How can I manage an appliance on Chameleon Appliance Catalog?

If you are the owner of the appliance, you can edit the appliance data, such as the description or the support information. Browse to the appliance that you want to edit and view its Details page. At the top right of the page is an Edit button. You will be presented with the same web form as when creating the appliance, pre-filled with the appliances current information. Make changes as necessary and click Save at the bottom of the page.

And finally, you can delete appliances you had made available. Browse to the appliance that you want to delete and click Edit on the Appliance Details page. At the bottom of the page is a Delete button. You will be asked to confirm once more that you do want to delete this appliance. After confirming, the appliance will be removed and no longer listed on the Appliance Catalog.

5.4.5 Why are there different image IDs for KVM@TACC, CHI@TACC, and CHI@UC for the same appliance?

The three clouds forming the Chameleon testbed are fully separated, each having its own Glance image repository. The same appliance image uploaded to the three clouds will produce three different image IDs.

In addition, it is sometimes needed to customize an appliance image for each site, resulting in slightly different image files.

5.4.6 Can I use Ubuntu, Debian, or another operating system rather than CentOS on bare-metal?

The recommended appliance for Chameleon is CentOS 7 (supported by Chameleon staff), or appliances built on top of it.
These appliances provide Chameleon-specific customizations, such as login using the cc account, the cc-checks utility to verify hardware against our resource registry, gathering of metrics, etc.

Since 2016, we also provide and support Ubuntu 14.04 and 16.04 appliances with the same functionality.

5.5 Bare Metal Troubleshooting

5.5.1 Why are my Bare Metal instances failing to launch?

The Chameleon Bare Metal clouds require users to reserve resources before allowing them to launch instances. Please follow the documentation and make sure that:

1. You have created a lease and it has started (the associated reservation is shown as **Active**)
2. You have selected your reservation in the **Launch Instance** panel

If you still cannot start instances, please open a ticket with our help desk.

5.6 OpenStack KVM Troubleshooting

5.6.1 Why are my OpenStack KVM instances failing to launch?

If you get an error stating that **No valid host was found**, it might be caused by a lack of resources in the cloud. The Chameleon staff continuously monitors the utilization of the testbed, but there might be times when no more resources are available. If the error persists, please open a ticket with our help desk.

5.6.2 Why can't I ping or SSH to my instance?

While the possibility that the system is being taking over by nanites should not be discounted too easily, it is always prudent to first check for the following issues:

- Do you have a floating IP associated with your instance? By default, instances do not have publicly-accessible IP addresses assigned. See the **Managing Virtual Machine Instances** section in the User Guide.
- Does your security group allow incoming ICMP (e.g. ping) traffic? By default, firewall rules do not allow ping to your instances. If you wish to enable it, see the **Firewall (Access Security)** section in the User Guide.
- Does your security group allow incoming SSH (TCP port 22) traffic? By default, firewall rules do not allow SSH to your instances. If you wish to enable it, see the **Firewall (Access Security)** section in the User Guide.

If none of these solve your problem, please open a ticket with our help desk, and send us the results of the above (and any evidence of nanites you find as well).

5.7 Create your own SSH key pairs

The following document describes the procedure on how you can create an SSH key pair on your Unix, Linux or Windows operating system.

5.7.1 For Linux / Mac OS X

Open a terminal window:

- In a Mac OS X system, click on your launchpad and search for terminal
- In an Ubuntu system you can use the keys Ctrl+Alt+T (for desktop version)

Access the SSH key pairs directory; in your terminal type the command:

```
$ cd ~/.ssh
```

Create your ssh key pair (public and private keys); in the `.ssh` directory, type the command:

```
$ ssh-keygen
```

Press the enter key, then enter a name for your key.

After completing the previous step, a message stating “Enter file in which to save the Key” will be displayed. Enter the name of your preference. I will use in this example the name “sample-key”. Then press the enter key.

Then, you will be requested to enter a passphrase for your key. Entering a passphrase is not necessary, so you can proceed to leave it blank and press enter. You will receive a message “Enter same passphrase again:” so just leave it blank and press enter.

Since we are still in the `.ssh` directory, now you can see your newly created key by typing:

```
$ ls
```

You will see two files:

- sample-key (containing the private key)
- sample-key.pub (containing the public key)

Then, provide the public key to your cloud system or individual instance. To add a key pair in Chameleon, access one of the resource dashboards and go the following tabs:

Compute > Access and Security > Key Pairs > Import Key Pair

In this window, you only need to provide a name for your key pair and paste your public key pair in the “Public Key” window. To obtain the contents of your public key, access your local `.ssh` directory through your terminal and use the command:

```
$ cat sample-key.pub
```

Select and copy the contents displayed starting ssh-rsa all the way to the end. Paste these contents into the “Public Key” window mentioned earlier.

Whenever you are creating an instance in Chameleon, you will have an option to select the Public Key you just imported. Once selected, this public key will be inserted into the instance’s ~/.ssh/known_hosts file. When a user attempts to connect to the instance, the private key provided by the user will be validated against this public key in the known_hosts file.

Connect to an instance from your terminal

After you have created a key pair and imported it in Chameleon, you can connect to any instance configured with this key pair. To do so you can use the command:

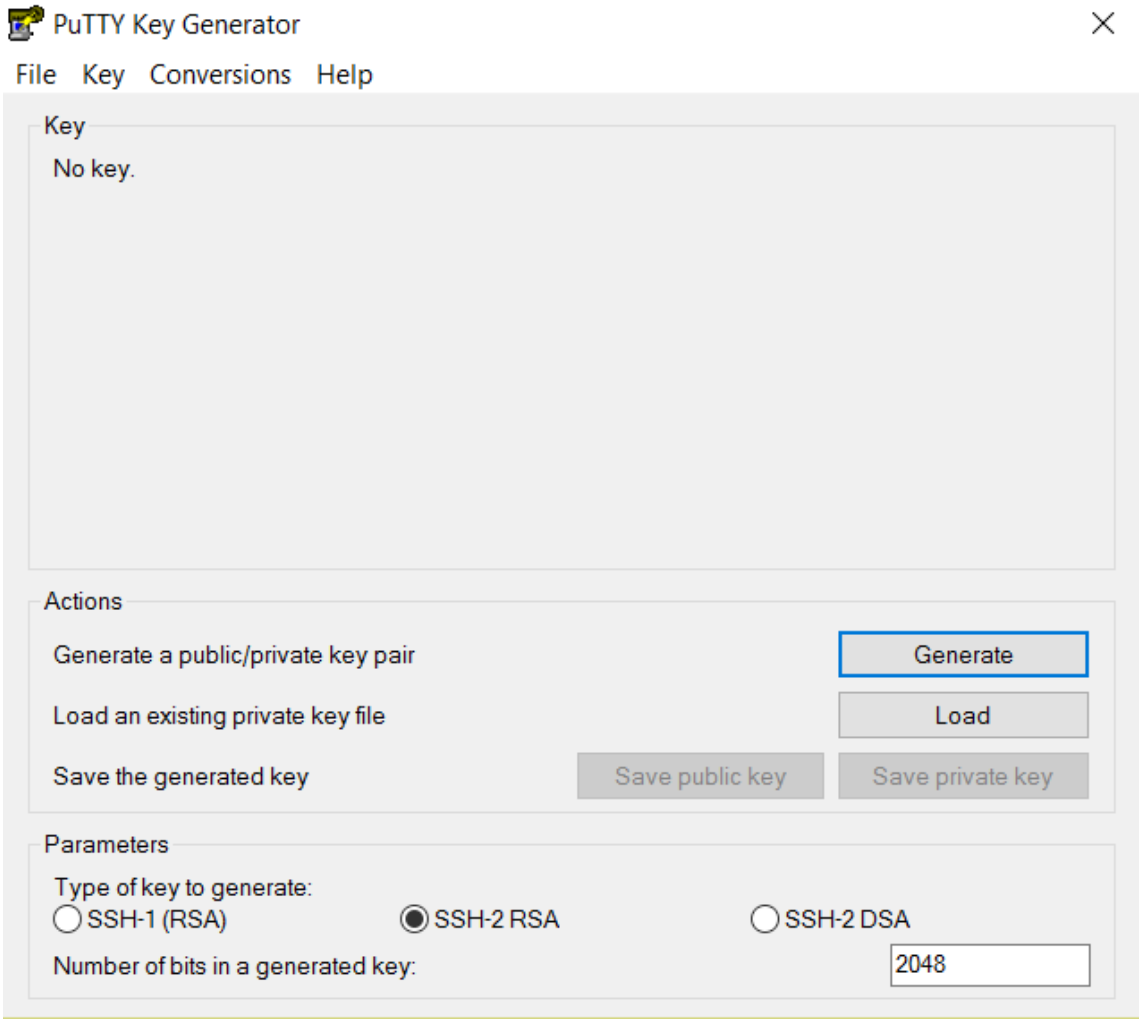
```
$ ssh -i ~/.ssh/sample-key cc@<instance ip address>
```

The full process can be viewed in the figure below:

```
Gonzalos-MBP:~ Eudora$ cd ~/.ssh
Gonzalos-MBP:.ssh Eudora$ ssh-keygen -t rsa -b 2048
Generating public/private rsa key pair.
Enter file in which to save the key (/Users/Eudora/.ssh/id_rsa): sample-key
Enter passphrase (empty for no passphrase):
Enter same passphrase again:
Your identification has been saved in sample-key.
Your public key has been saved in sample-key.pub.
The key fingerprint is:
SHA256:mqTxC5bE05xBPjzhiApj/Nuq3yVmupnqcS8xnTSQ1qY Eudora@Gonzalos-MBP
The key's randomart image is:
+---[RSA 2048]----+
|     o o         |
|.   = O .        |
|ooo = B          |
|oo.E = =         |
|.   .B B S       |
|    +oX o        |
| . oB=+.         |
|  ooX.o.         |
|.++Boo.          |
+----[SHA256]-----+
Gonzalos-MBP:.ssh Eudora$ ls
alex-key.pub            gerrit                  oci-openstack.pem
ali_key.pub             gerrit.pub              omkar_key.pub
anil_key.pub            jerod_key.pub           paul_key.pub
annie_key.pub           kalyani_key.pub         rohit_key.pub
aqsa_key.pub            known_hosts             sample-key
arun_key.pub            known_hosts.old         sample-key.pub
cano.pub                manu_key.pub            server68_key.pub
cloud.key               mitha_key.pub           server78_key.pub
cloud.key.pub           mohan_key.pub           swanand_key.pub
config                  neutron.pub             syed_key.pub
elab.pub                new.pub                 uthscsa2.pub
Gonzalos-MBP:.ssh Eudora$ vi sample-key.pub
Gonzalos-MBP:.ssh Eudora$ ssh -i ~/.ssh/sample-key cc@129.114.108.191
```

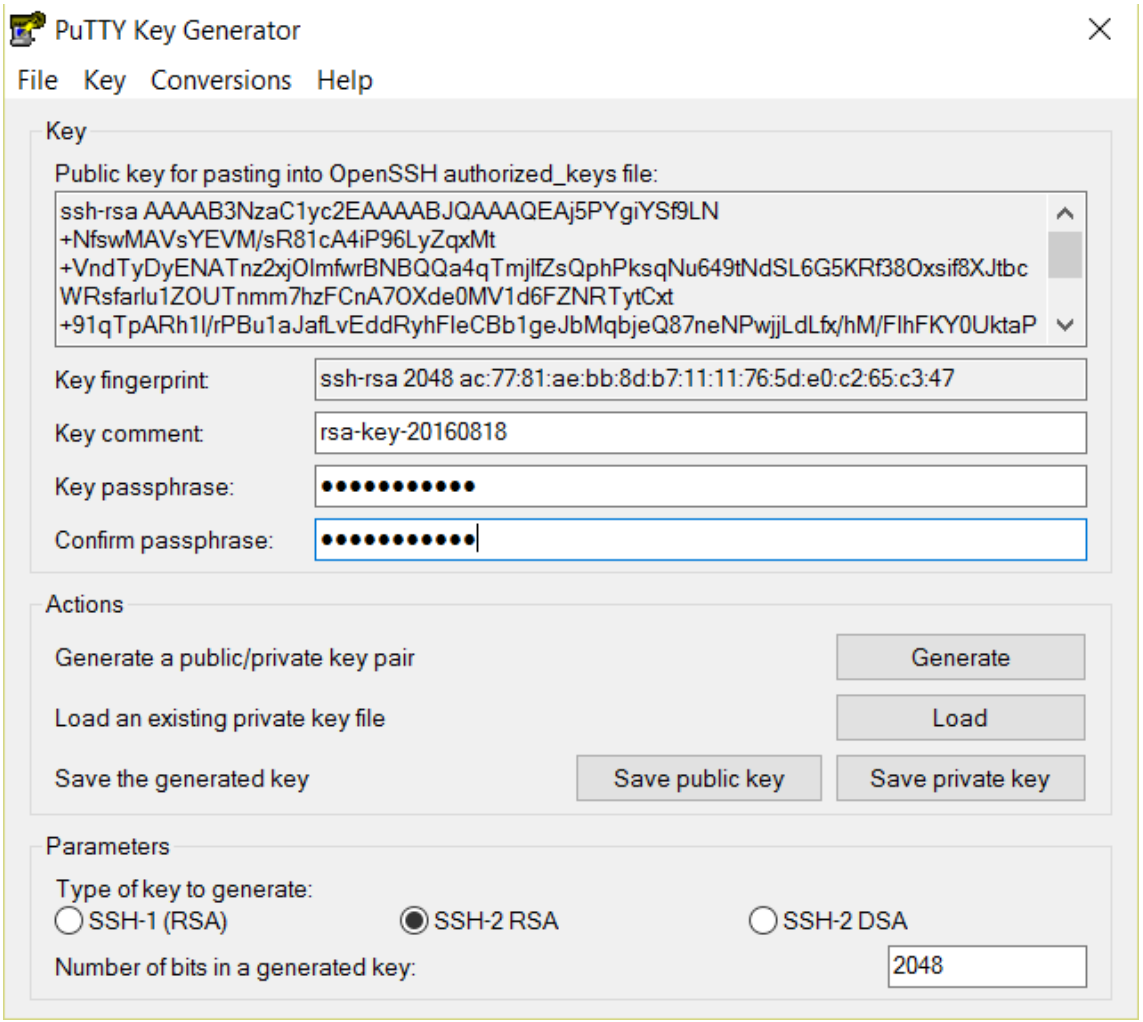
5.7.2 For Windows

First, download and install PuTTY and PuTTYgen from here. Once downloaded, opening PuTTYgen will open a key generator window, seen below.



Once the program is opened, click the Generate button, seen above in blue. PuTTY Key Generator will then ask you to move your mouse around the program's blank space to generate "randomness" for your key.?

You may enter an optional "Key passphrase" and then confirm the passphrase in the required areas but let us keep these spaces in blank just to avoid complexity. An example is shown below. Note that the passphrases are not necessary!



Save both the public and private keys into a file of your choice using the “Save public key” and “Save private key” buttons; name them something obvious like “public_key” and “private_key” so that you can distinguish between the two.

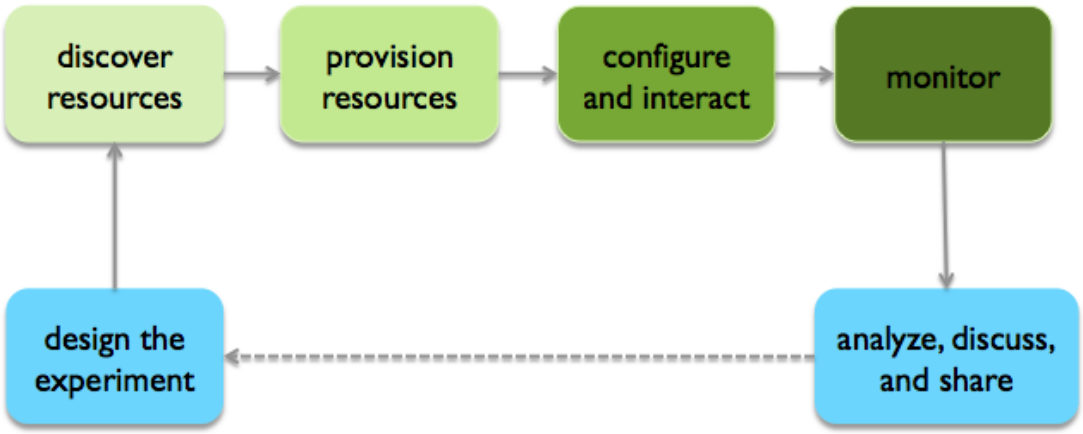
Before closing this window, select the entire public key and copy it with “Control-C”. Please note that everything should be copied, including “ssh-rsa”. This will be used when importing the key pair to Openstack.

At this time, the public key has been created and copied. Now you can now follow the steps described above (starting with the line “Provide the public key to your cloud system or individual instance”) to import the generated key pair for use with Chameleon!

F section/cloud/chameleon/baremetal.tex

6. Bare Metal

In this page you will find documentation guiding you through the bare-metal deployment features available in Chameleon. Chameleon gives users administrative access to bare-metal compute resources to run cloud computing experiments with a high degree of customization and repeatability. Typically, an experiment will go through several phases, as illustrated in the figure below:



The bare-metal user guide comes in two editions. The first is how to use Chameleon resources via the web interface, the recommended choice for new users to quickly learn how to use our testbed:

Get started with Chamelon using the web interface

1. Discover Resources
2. Provision Resources
3. Configure and Interact
4. Monitor and Collect Results

The second targets advanced users who are already familiar with Chameleon and would like to learn how to use Chameleon from the command line or with scripts.

Get started with Chameleon using the command line (advanced)

1. Discover Resources
2. Provision Resources
3. Configure and Interact
4. Monitor and Collect Results

You do not need to strictly follow the documentation sequentially. However, note that some steps assume that previous ones have been successfully performed.

You can also consult documentation describing how to use advanced features of Chameleon not covered by the guides above:

- the Chameleon Object Store,
- network isolation for bare metal.

F section/cloud/chameleon/heat.tex

7. HEAT

7.1 What are complex appliances?

Deploying an MPI cluster, an OpenStack installation, or any other type of cluster in which nodes can take on multiple roles can be complex: you have to provision potentially hundreds of nodes, configure them to take on various roles, and make them share information that is generated or assigned only at deployment time, such as hostnames, IP addresses, or security keys. When you want to run a different experiment later you have to redo all this work. When you want to reproduce the experiment, or allow somebody else to reproduce it, you have to take very precise notes and pay great attention to their execution.

To help solve this problem and facilitate reproducibility and sharing, the Chameleon team configured a tool that allows you to deploy complex clusters with "one click". This tool requires not just a simple image (i.e., appliance) but also a document, called a template, that contains the information needed to orchestrate the deployment and configuration of such clusters. We call this image + template combination complex appliance because it consists of more than just the image (i.e., appliance).

7.2 How are complex appliances supported?

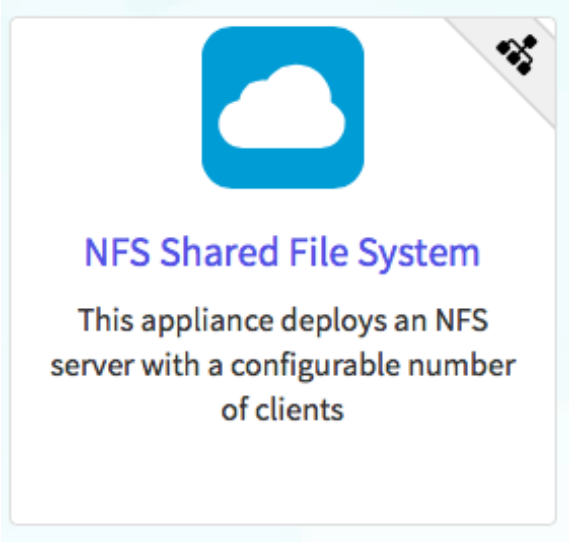
In a nutshell, complex appliances allow you to specify not only what image you want to deploy but also on how many nodes you want to deploy that image, what roles the deployed instances should boot into (such as e.g., head node and worker node in a cluster), what information from a specific instance should be passed to another instance in that complex appliance, and what scripts should be executed on boot so that this information is properly used for configuring the "one click" cluster. For example, a Network File System (NFS) appliance that we will use as an example in this guide, might specify deployment on three nodes, out of which one will be configured as head node and others as worker nodes, the information passed between the images will be hostname of the head node, and the scripts executed on the worker nodes on boot will put that hostname in the fstab file.

As you can tell from this description, images used for complex appliances are typically configured such that they can be booted into any role required on the one-click cluster we are booting; in this case the image will have both the software for NFS server node and client node.

Since complex appliances in Chameleon are currently implemented using the OpenStack Heat orchestration service, we will be using OpenStack terminology and features to work with them. The templates described above are YAML files using the Heat Orchestration Template (HOT) format (Heat also supports the AWS CloudFormation template format, but this is not covered here). A deployed complex appliance is referred to as a "stack" – just as a deployed single appliance is typically referred to as an "instance". This guide will tell you all you need to know in order to use and configure complex appliances on Chameleon; if you would like to know more about Heat, please refer to its official documentation.

7.3 Where can I find Chameleon complex appliances?

Our Appliance Catalog has several complex appliances for popular technologies that people want to deploy such as OpenStack or MPI or even more advanced deployments such as efficient SR-IOV enabled MPI in KVM virtual machines. We also provide common building blocks for cluster architectures, such as an NFS share. Complex appliances are identified by a badge in their top-right corner representing a group of machines, as shown in the screenshot:



7.4 How do I deploy a complex appliance?

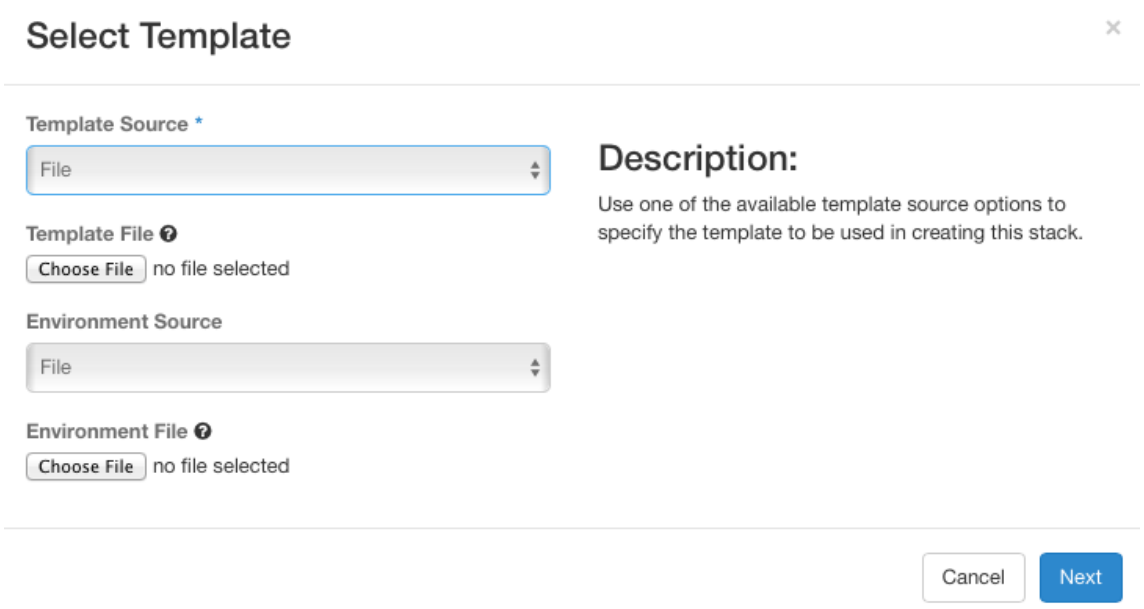
We will explain how to launch a complex appliance based on our NFS share appliance. To launch a complex appliance, you only need to follow these steps:

1. Create a lease: use the OpenStack web interface (choose between CHI@UC or CHI@TACC) to create a lease. To launch our NFS appliance, reserve at least three compute nodes (the strict minimum is two nodes but we will use three in this example and later ones).
2. Go to the Appliance Catalog and identify the appliance you want to launch. In our case you can go straight to the NFS share appliance; click on it to open its details page. You will see a "Launch" button and a "Get Template" button. Follow the "Get Template" link and copy its url to the clipboard – you will need it in the following steps.

3. Click on the “Launch Complex Appliance at CHI@TACC” or “Launch Complex Appliance at CHI@UC” button depending on where your reservation was created.

This will take you to the Stacks page within the Orchestration menu. This page will show the current list of stacks, with controls to manage them and create new ones. Since we haven’t launched any yet, this list will be empty for now.

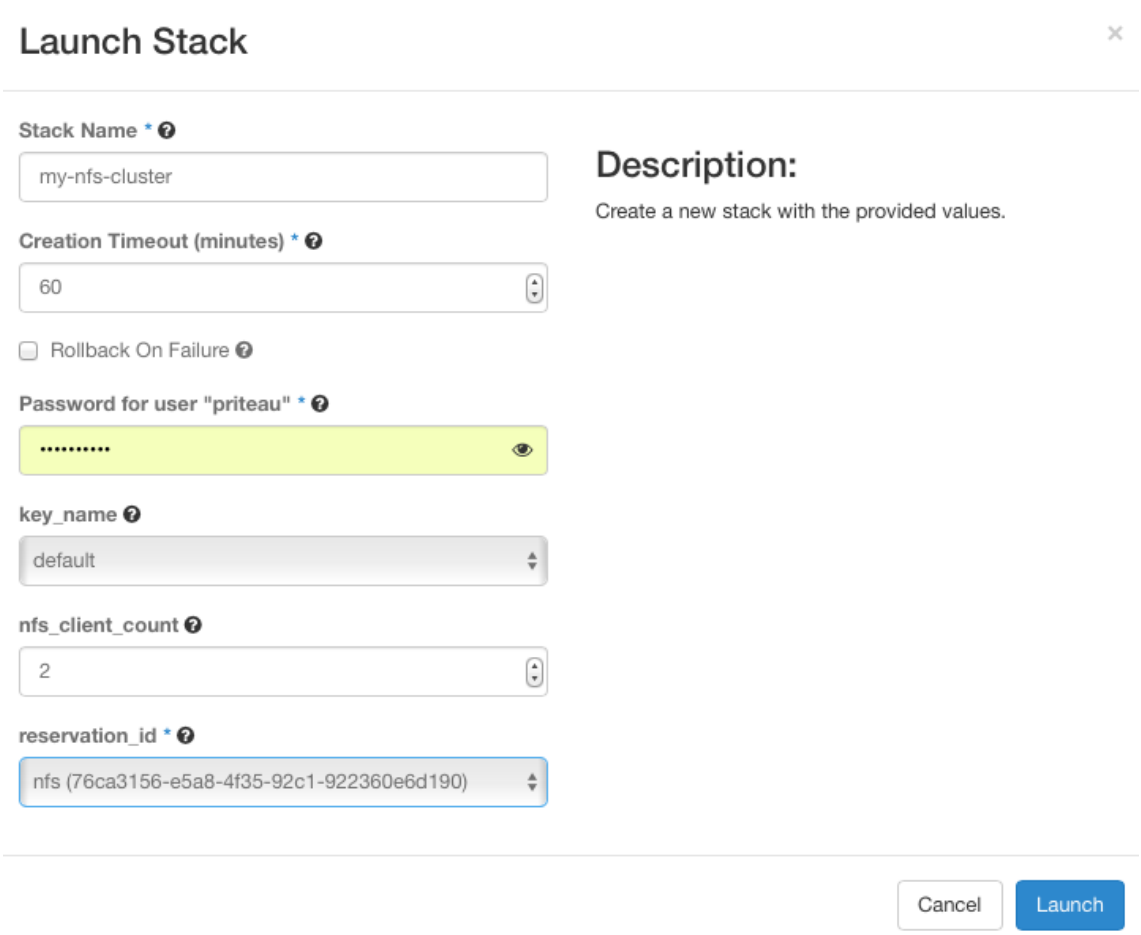
We will now create a new stack, which corresponds to the launch of a template. Click on Launch Stack on the top right. A window will pop up like below:



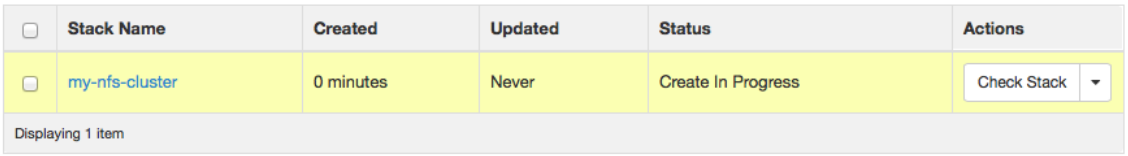
We will deploy the NFS appliance described earlier; it will consist of a server node and two client nodes. Change the template source field to URL, and paste the URL of the NFS share template (if you don’t have it in your clipboard anymore you will need to go back to the appliance and get it by clicking on “Get template” again).

Don’t change the environment source settings, and click “Next”.

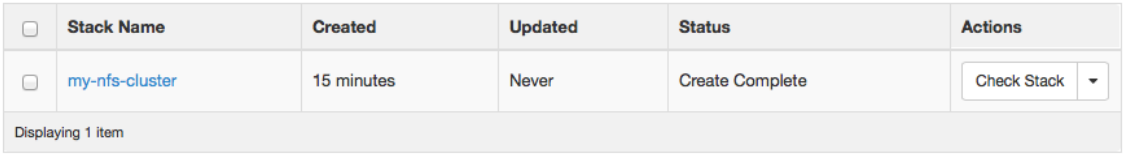
The next screen allows your to enter input values to your Heat template. Choose a name for your stack (e.g. my-nfs-cluster). Ignore the “Creation Timeout” and “Rollback On Failure” settings. You also need to enter your Chameleon password. Then, you need to select a value for the three parameters of the template: for key_name, choose your SSH key pair (this key pair will authorize access on each deployed instances, both server and client). For nfs_client_count, change the default value of 1 to 2. For reservation_id, choose your reservation created earlier. Finally, click “Launch”.



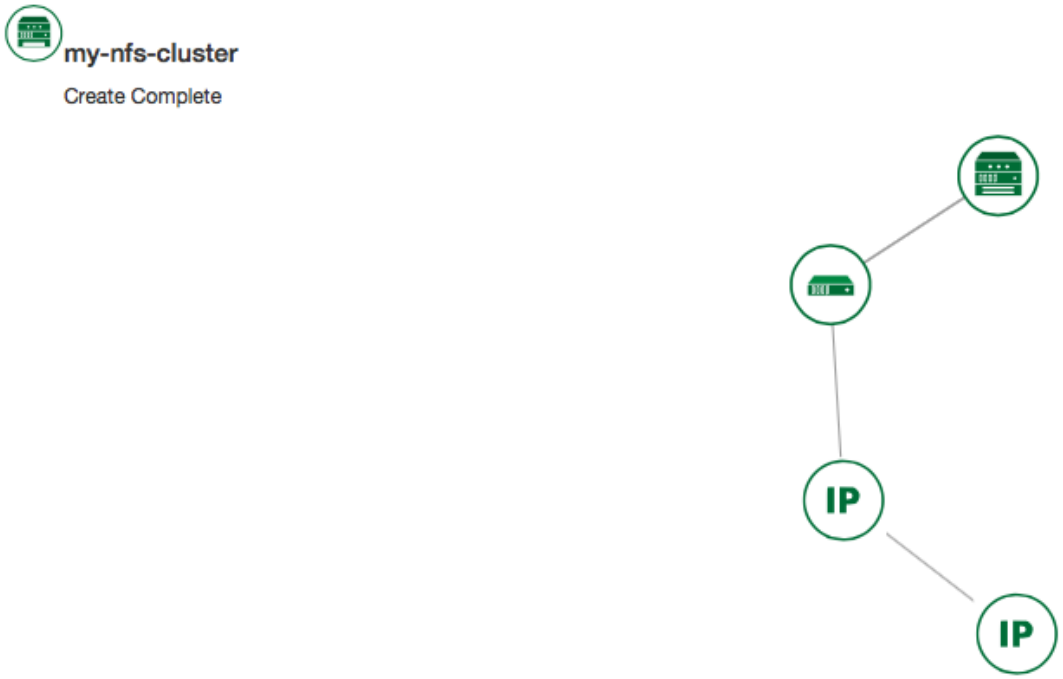
Your stack should be in status "Create In Progress" for several minutes while it first launches the NFS server instance, followed by the NFS client instances.



It will then move to the status "Create Complete".



You can click on the stack name to get more details, including a visualization of the deployed resources, as pictured below. The single machine inside a circle represents the NFS server instance. The rack of machine represents the group of NFS client instances (in this case, a group composed of two instances). The server's floating IP (the public IP assigned to a resource) is represented by an IP in a circle; an IP in a circle is also used to represent the association of the IP with the NFS server instance (not the greatest idea to use the same symbol for both the IP and the association – we agree but can't do much about it at the moment). Blow off some steam by dragging the visualization across the screen, it can be rather fun!



You can now ssh to the server using the floating IP just as you do with regular instances (use the cc account). The client does not have a floating IP attached to it (as per the visualization above) but you can connect to it via the server node with the client's private IP (connect to the server with `ssh -A` to enable the SSH agent forwarding after loading your key to your SSH agent with `ssh-add <path-to-your-key>`).

You can find out the information about the IPs and other things if you click the "Overview" tab and look in the "Outputs" section. Under the "Resources" tab you will see the resources described above (the server, clients, server's public/floating IP, and its the association) and information about them. In the "Events" tab you will see information about the history of the deployment so far. In Template you will see the template that was used to deploy this stack.

7.5 What is inside a Heat template?

The NFS share appliance deploys:

- an NFS server instance, that exports the directory /exports/example to any instance running on Chameleon bare-metal,
- one or several NFS client instances, which configure /etc/fstab to mount this NFS share to /mnt (and can subsequently read from and write to it).

This template is reproduced further below, and includes inline comments starting with the # character. There are three main sections:

- resources,
- parameters,
- outputs.

The resources section is the most important part of the template: it defines which OpenStack resources to create and configure. Inside this section you can see four resources defined:

- nfs_server_floating_ip
- nfs_server
- nfs_server_ip_association
- nfs_clients

The first resource, nfs_server_floating_ip, creates a floating IP on the ext-net public network. It is not attached to any instance yet.

The second resource, nfs_server, creates the NFS server instance (an instance is defined with the type `OS::Nova::Server` in Heat). It is a bare-metal instance (`flavor: baremetal`) using the CC-CentOS7 image and connected to the private network named sharednet1. We set the keypair to use the value of the parameter defined earlier, using the `get_param` function. Similarly, the reservation to use is passed to the scheduler. Finally, a user-data script is given to the instance, which configures it as an NFS server exporting /exports/example to Chameleon instances.

The nfs_server_ip_association resource associates the floating IP created earlier with the NFS server instance.

Finally, the nfs_clients resource defines a resource group containing instance configured to be NFS clients and mount the directory exported by the NFS server defined earlier. The IP of the NFS server is gathered using the `get_attr` function, and placed into user-data using the `str_replace` function.

Parameters all have the same data structure: each one has a name (`key_name` or `reservation_id` in this case), a data type (number or string), a comment field called description, optionally a default value, and a list of constraints (in this case only one per parameter). Constraints tell Heat to match a parameter to a specific type of OpenStack resource. Complex appliances on Chameleon require users to customize at least the key pair name and reservation ID, and will generally provide additional parameters to customize other properties of the cluster, such as its size, as in this example.

Outputs are declared similarly to parameters: they each have a name, an optional description, and a value. They allow to return information from the stack to the user.

```
# This describes what is deployed by this template.
description: NFS server and clients deployed with Heat on Chameleon

# This defines the minimum Heat version required by this template.
heat_template_version: 2015-10-15

# The resources section defines what OpenStack resources are to be deployed and
# how they should be configured.
resources:
  nfs_server_floating_ip:
    type: OS::Nova::FloatingIP
    properties:
      pool: ext-net

  nfs_server:
    type: OS::Nova::Server
    properties:
      flavor: baremetal
      image: CC-CentOS7
      key_name: { get_param: key_name }
      networks:
         - network: sharednet1
      scheduler_hints: { reservation: { get_param: reservation_id } }
      user_data: |
        #!/bin/bash
```

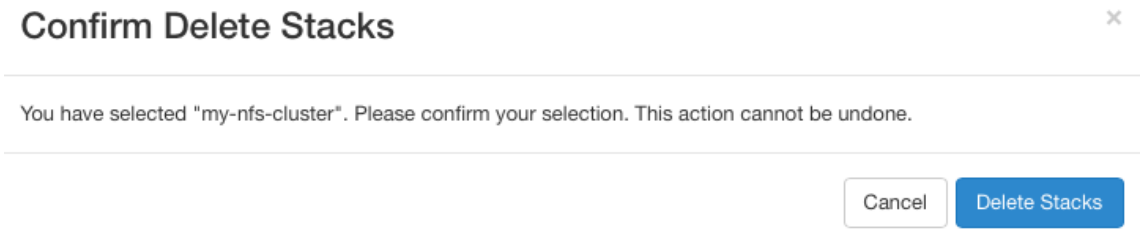
```
          yum install -y nfs-utils
          mkdir -p /exports/example
          chown -R cc:cc /exports
          echo '/exports/example 10.140.80.0/22(rw,async) 10.40.0.0/23(rw,async)' >> /etc/exports
          systemctl enable rpcbind && systemctl start rpcbind
          systemctl enable nfs-server && systemctl start nfs-server

    nfs_server_ip_association:
      type: OS::Nova::FloatingIPAssociation
      properties:
        floating_ip: { get_resource: nfs_server_floating_ip }
        server_id: { get_resource: nfs_server }

    nfs_clients:
      type: OS::Heat::ResourceGroup
      properties:
        count: { get_param: nfs_client_count }
        resource_def:
          type: OS::Nova::Server
          properties:
            flavor: baremetal
            image: CC-CentOS7
            key_name: { get_param: key_name }
            networks:
               - network: sharednet1
            scheduler_hints: { reservation: { get_param: reservation_id } }
            user_data:
              str_replace:
                template: |
                  #!/bin/bash
                  yum install -y nfs-utils
                  echo "$nfs_server_ip:/exports/example    /mnt/    nfs" > /etc/fstab
                  mount -a
                params:
                  $nfs_server_ip: { get_attr: [nfs_server, first_address] }

# The parameters section gathers configuration from the user.
parameters:
  nfs_client_count:
    type: number
    description: Number of NFS client instances
    default: 1
    constraints:
      - range: { min: 1 }
        description: There must be at least one client.
  key_name:
    type: string
    description: Name of a KeyPair to enable SSH access to the instance
    default: default
    constraints:
    - custom_constraint: nova.keypair
  reservation_id:
    type: string
    description: ID of the Blazar reservation to use for launching instances.
    constraints:
    - custom_constraint: blazar.reservation

outputs:
  server_ip:
    description: Public IP address of the NFS server
    value: { get_attr: [nfs_server_floating_ip, ip] }
```

```
  client_ips:
    description: Private IP addresses of the NFS clients
    value: { get_attr: [nfs_clients, first_address] }
```

7.6 Customizing an existing template

Customizing an existing template is a good way to start developing your own. We will use a simpler template than the previous example to start with: it is the Hello World complex appliance.

First, delete the stack you launched, because we will need all three nodes to be free. To do this, go back to the Project > Orchestration > Stacks page, select your stack, and then click on the red "Delete Stacks" button. You will be asked to confirm, so click on the blue "Delete Stacks" button.



The template for the Hello World complex appliance is reproduced below. It is similar to the NFS share appliance, except that it deploys only a single client. You can see that it has four resources defined:

- nfs_server_floating_ip
- nfs_server
- nfs_server_ip_association
- nfs_client

The nfs_client instance mounts the NFS directory shared by the nfs_server instance, just like in our earlier example.

```
# This describes what is deployed by this template.
description: NFS server and client deployed with Heat on Chameleon

# This defines the minimum Heat version required by this template.
heat_template_version: 2015-10-15

# The resources section defines what OpenStack resources are to be deployed and
# how they should be configured.
resources:
  nfs_server_floating_ip:
    type: OS::Nova::FloatingIP
    properties:
      pool: ext-net

  nfs_server:
    type: OS::Nova::Server
    properties:
      flavor: baremetal
      image: CC-CentOS7
      key_name: { get_param: key_name }
      networks:
         - network: sharednet1
      scheduler_hints: { reservation: { get_param: reservation_id } }
      user_data: |
```

```
            #!/bin/bash
            yum install -y nfs-utils
            mkdir -p /exports/example
            chown -R cc:cc /exports
            echo '/exports/example 10.140.80.0/22(rw,async) 10.40.0.0/23(rw,async)' >> /etc/exports
            systemctl enable rpcbind && systemctl start rpcbind
            systemctl enable nfs-server && systemctl start nfs-server

      nfs_server_ip_association:
        type: OS::Nova::FloatingIPAssociation
        properties:
          floating_ip: { get_resource: nfs_server_floating_ip }
          server_id: { get_resource: nfs_server }

      nfs_client:
        type: OS::Nova::Server
        properties:
          flavor: baremetal
          image: CC-CentOS7
          key_name: { get_param: key_name }
          networks:
             - network: sharednet1
          scheduler_hints: { reservation: { get_param: reservation_id } }
          user_data:
            str_replace:
              template: |
                #!/bin/bash
                yum install -y nfs-utils
                echo "$nfs_server_ip:/exports/example    /mnt/    nfs" > /etc/fstab
                mount -a
              params:
                $nfs_server_ip: { get_attr: [nfs_server, first_address] }

# The parameters section gathers configuration from the user.
parameters:
  key_name:
    type: string
    description: Name of a KeyPair to enable SSH access to the instance
    default: default
    constraints:
    - custom_constraint: nova.keypair
  reservation_id:
    type: string
    description: ID of the Blazar reservation to use for launching instances.
    constraints:
    - custom_constraint: blazar.reservation
```

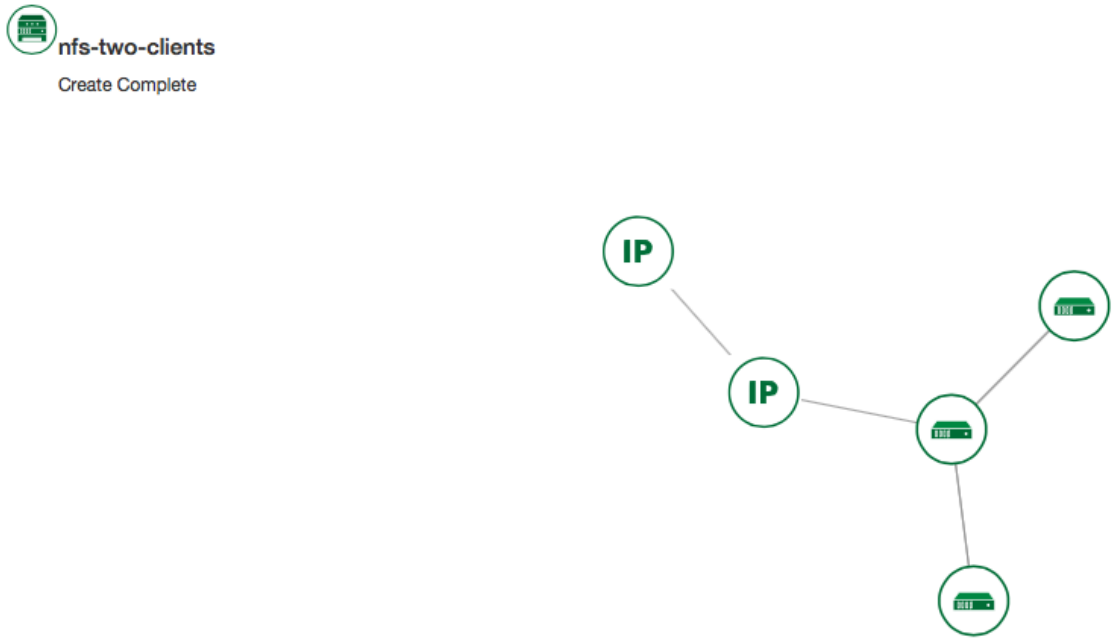
Download this template from the Hello World complex appliance details page to your local machine, and open it in your favorite text editor.

We will customize the template to add a second NFS client by creating a new resource called another_nfs_client. Add the following text to your template inside the resources section. Make sure to respect the level of indentation, which is important in YAML.

```
      another_nfs_client:
        type: OS::Nova::Server
        properties:
          flavor: baremetal
          image: CC-CentOS7
          key_name: { get_param: key_name }
          networks:
```

```
      - network: sharednet1
    scheduler_hints: { reservation: { get_param: reservation_id } }
    user_data:
      str_replace:
        template: |
          #!/bin/bash
          yum install -y nfs-utils
          echo "$nfs_server_ip:/exports/example    /mnt/    nfs" > /etc/fstab
          mount -a
        params:
          $nfs_server_ip: { get_attr: [nfs_server, first_address] }
```

Now, launch a new stack with this template. Since the customized template is only on your computer and cannot be addressed by a URL, use the "Direct Input" method instead and copy/paste the content of the customized template. The resulting topology view is shown below: as you can see, the two client instances are shown separately since each one is defined as a separate resource in the template.



You may have realized already that while adding just one additional client instance was easy, launching more of them would require to copy / paste blocks of YAML many times while ensuring that the total count is correct. This would be easy to get wrong, especially when dealing with tens or hundreds of instances.

So instead, we leverage another construct from Heat: resource groups. Resource groups allow to define one kind of resource and request it to be created any number of times.

Remove the nfs_client and another_client resources from your customized template, and replace them with the following:

```
nfs_clients:
  type: OS::Heat::ResourceGroup
  properties:
    count: 2
    resource_def:
      type: OS::Nova::Server
```

```
    properties:
      flavor: baremetal
      image: CC-CentOS7
      key_name: { get_param: key_name }
      networks:
         - network: sharednet1
      scheduler_hints: { reservation: { get_param: reservation_id } }
      user_data:
        str_replace:
          template: |
            #!/bin/bash
            yum install -y nfs-utils
            echo "$nfs_server_ip:/exports/example    /mnt/    nfs" > /etc/fstab
            mount -a
          params:
            $nfs_server_ip: { get_attr: [nfs_server, first_address] }
```

A resource group is configured with a properties field, containing the definition of the resource to launch (`resource_def`) and the number of resources to launch (`count`). Once launched, you will notice that the topology view groups all client instances under a single Resource Group icon. We use the same `resource_def` than when defining separate instances earlier.

Another way we can customize this template is by adding outputs to the template. Outputs allow a Heat template to return data to the user. This can be useful to return values like IP addresses or credentials that the user must know to use the system.

We will create an output returning the floating IP address used by the NFS server. We define an outputs section, and one output with the name `server_ip` and a description. The value of the output is gathered using the `get_attr` function which obtains the IP address of the server instance.

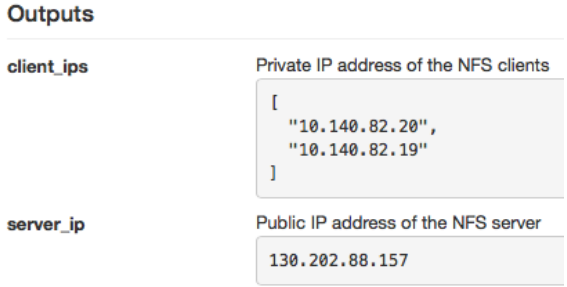
```
outputs:
  server_ip:
    description: Public IP address of the NFS server
    value: { get_attr: [nfs_server_floating_ip, ip] }
```

You can get outputs in the "Overview" tab of the Stack Details page. If you want to use the command line, install `python-heatclient` and use the `heat output-list` and `heat output-show` commands, or get a full list in the information returned by `heat stack-show`.

Multiple outputs can be defined in the outputs section. Each of them needs to have a unique name. For example, we can add another output to list the private IPs assigned to client instances:

```
  client_ips:
    description: Private IP addresses of the NFS clients
    value: { get_attr: [nfs_clients, first_address] }
```

The image below shows the resulting outputs as viewed from the web interface. Of course IP addresses will be specific to each deployment.



Finally, we can add a new parameter to replace the hardcoded number of client instances by a value passed to the template. Add the following text to the parameters section:

```
nfs_client_count:
  type: number
  description: Number of NFS client instances
  default: 1
  constraints:
    - range: { min: 1 }
      description: There must be at least one client.
```

Inside the resource group definition, change `count: 2` to `count: { get_param: nfs_client_count }` to retrieve and use the parameter we just defined. When you launch this template, you will see that an additional parameter allows you to define the number of client instances, like in the NFS share appliance.

At this stage, we have fully recreated the NFS share appliance starting from the Hello World one! The next section will explain how to write a new template from scratch.

7.7 Writing a new template

You may want to write a whole new template, rather than customizing an existing one. Each template should follow the same layout and be composed of the following sections:

- Heat template version
- Description
- Resources
- Parameters
- Outputs

7.7.1 Heat template version

Each Heat template has to include the heat_template_version key with a valid version of HOT (Heat Orchestration Template). Chameleon bare-metal supports any HOT version up to 2015-10-15, which corresponds to OpenStack Liberty. The Heat documentation lists all available versions and their features. We recommended that you always use the latest supported version to have access to all supported features:

```
heat_template_version: 2015-10-15
```

7.7.2 Description

While not mandatory, it is good practice to describe what is deployed and configured by your template. It can be on a single line:

```
description: This describes what this Heat template deploys on Chameleon.
```

If a longer description is needed, you can provide multi-line text in YAML, for example:

```
description: >
  This describes what this Heat
  template deploys on Chameleon.
```

7.7.3 Resources

The resources section is required and must contain at least one resource definition. A complete list of resources types known to Heat is available.

However, only a subset of them are supported by Chameleon, and some are limited to administrative use. We recommend that you only use:

- OS::Glance::Image
- OS::Heat::ResourceGroup
- OS::Heat::SoftwareConfig
- OS::Heat::SoftwareDeployment
- OS::Heat::SoftwareDeploymentGroup
- OS::Neutron::FloatingIP
- OS::Neutron::FloatingIPAssociation
- OS::Neutron::Port (advanced users only)
- OS::Nova::Keypair
- OS::Nova::Server

If you know of another resource that you would like to use and think it should be supported by the OpenStack services on Chameleon bare-metal, please let us know via our help desk.

7.7.4 Parameters

Parameters allow users to customize the template with necessary or optional values. For example, they can customize which Chameleon appliance they want to deploy, or which key pair to install. Default values can be provided with the `default` key, as well as constraints to ensure that only valid OpenStack resources can be selected. For example, `custom_constraint: glance.image` restricts the image selection to an available OpenStack image, while providing a pre-filled selection box in the web interface. More details about constraints are available in the Heat documentation.

7.7.5 Outputs

Outputs allow template to give information from the deployment to users. This can include usernames, passwords, IP addresses, hostnames, paths, etc. The outputs declaration is using the following format:

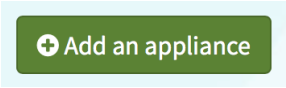
```
outputs:
  first_output_name:
    description: Description of the first output
    value: first_output_value
  second_output_name:
    description: Description of the second output
    value: second_output_value
```

Generally values will be calls to get_attr, get_param, or some other function to get information from parameters or resources deployed by the template and return them in the proper format to the user.

7.8 Sharing new complex appliances

If you have written your own complex appliances or substantially customized an existing one, we would love if you shared them with our user community!

The process is very similar to regular appliances: log into the Chameleon portal, go to the appliance catalog, and click on the button in the top-right corner: "Add an appliance" (you need to be logged in to see it).



You will be prompted to enter a name, description, and documentation. Instead of providing appliance IDs, copy your template to the dedicated field. Finally, share your contact information and assign a version string to your appliance. Once submitted, your appliance will be reviewed. We will get in touch if a change is needed, but if it's all good we will publish it right away!

7.9 Advanced topics

7.9.1 All-to-all information exchange

The previous examples have all used user-data scripts to provide instances with contextualization information. While it is easy to use, this contextualization method has a major drawback: because it is given to the instance as part of its launch request, it cannot use any context information that is not yet known at this time.

In practice, this means that in a client-server deployment, only one of these pattern will be possible:

- The server has to be deployed first, and once it is deployed, the clients can be launched and contextualized with information from the server. The server won't know about the clients unless there is a mechanism (not managed by Heat) for the client to contact the server.
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This limitation was already apparent in our NFS share appliance: this is why the server instance exports the file system to all bare-metal instances on Chameleon, because it doesn't know which specific IP addresses are allocated to the clients.

This limitation is even more important if the deployment is not hierarchical, i.e. all instances need to know about all others. For example, a cluster with IP and hostnames populated in /etc/hosts required each instance to be known by every other instance.

This section presents a more advanced form of contextualization that can perform this kind of information exchange. This is implemented by Heat agents running inside instances and communicating with the Heat service to send and receive information. This means you will need to use an image bundling these agents. Currently, our CC-CentOS7 appliance and its CUDA version are the only ones supporting this mode of contextualization. If you build your own images using the CC-CentOS7 appliance builder, you will automatically have these agents installed.

This contextualization is performed with several Heat resources:

- `OS::Heat::SoftwareConfig`. This resource describes code to run on an instance. It can be configured with inputs and provide outputs.
- `OS::Heat::SoftwareDeployment`. This resource applies a SoftwareConfig to a specific instance.
- `OS::Heat::SoftwareDeploymentGroup`. This resource applies a SoftwareConfig to a specific group of instances.

The template below illustrates how it works. It launches a group of instances that will automatically populates their /etc/hosts file with IP and hostnames from other instances in the deployment.

```
heat_template_version: 2015-10-15

description: >
  This template demonstrates how to exchange hostnames and IP addresses to populate /etc/hosts.

parameters:
  flavor:
    type: string
    default: baremetal
    constraints:
    - custom_constraint: nova.flavor
  image:
    type: string
    default: CC-CentOS7
    constraints:
    - custom_constraint: glance.image
  key_name:
    type: string
    default: default
    constraints:
    - custom_constraint: nova.keypair
  instance_count:
    type: number
    default: 2
  reservation_id:
    type: string
    description: ID of the Blazar reservation to use for launching instances.
    constraints:
    - custom_constraint: blazar.reservation

resources:
  export_hosts:
    type: OS::Heat::SoftwareConfig
    properties:
      outputs:
        - name: hosts
      group: script
      config: |
        #!/bin/sh
        (echo -n $(facter ipaddress); echo -n ' '; echo $(facter hostname)) > ${heat_outputs_path}.ho

  export_hosts_sdg:
    type: OS::Heat::SoftwareDeploymentGroup
    properties:
      config: { get_resource: export_hosts }
      servers: { get_attr: [server_group, refs_map] }
      signal_transport: HEAT_SIGNAL

  populate_hosts:
    type: OS::Heat::SoftwareConfig
    properties:
      inputs:
        - name: hosts
      group: script
      config: |
        #!/usr/bin/env python
        import ast
        import os
```

```
            import string
            import subprocess
            hosts = os.getenv('hosts')
            if hosts is not None:
                hosts = ast.literal_eval(string.replace(hosts, '\n', '\\n'))
            with open('/etc/hosts', 'a') as hosts_file:
              for ip_host in hosts.values():
                  hosts_file.write(ip_host.rstrip() + '\n')

      populate_hosts_sdg:
        type: OS::Heat::SoftwareDeploymentGroup
        depends_on: export_hosts_sdg
        properties:
          config: { get_resource: populate_hosts }
          servers: { get_attr: [server_group, refs_map] }
          signal_transport: HEAT_SIGNAL
          input_values:
            hosts: { get_attr: [ export_hosts_sdg, hosts ] }

      server_group:
        type: OS::Heat::ResourceGroup
        properties:
          count: { get_param: instance_count }
          resource_def:
            type: OS::Nova::Server
            properties:
              flavor: { get_param: flavor }
              image: { get_param: image }
              key_name: { get_param: key_name }
              networks:
                 - network: sharednet1
              scheduler_hints: { reservation: { get_param: reservation_id } }
              user_data_format: SOFTWARE_CONFIG
              software_config_transport: POLL_SERVER_HEAT

  outputs:
    deployment_results:
      value: { get_attr: [export_hosts_sdg, hosts] }
```

There are two SoftwareConfig resources.

The first SoftwareConfig, export_hosts, uses the facter tool to extract IP address and hostname into a single line (in the format expected for /etc/hosts) and writes it to a special path (${heat_outputs_path}.hosts). This prompts Heat to assign the content of this file to the output with the name hosts.

The second SoftwareConfig, populate_hosts, takes as input a variable named hosts, and applies a script that reads the variable from the environment, parses it with ast.literal_eval (as it is formatted as a Python dict), and writes each value of the dictionary to /etc/hosts.

The SoftwareDeploymentGroup resources export_hosts_sdg and populate_hosts_sdg apply each SoftwareConfig to the instance ResourceGroup with the correct configuration.

Finally, the instance ResourceGroup is configured so that each instance uses the following contextualization method instead of a user-data script:

```
            user_data_format: SOFTWARE_CONFIG
            software_config_transport: POLL_SERVER_HEAT
```

You can follow the same template pattern to configure your own deployment requiring all-to-all information exchange.