University of Bologna

Dipartimento di Informatica –
Scienza e Ingegneria (DISI)

Engineering Bologna Campus

Class of

Computer Networks M

Openstack & more…

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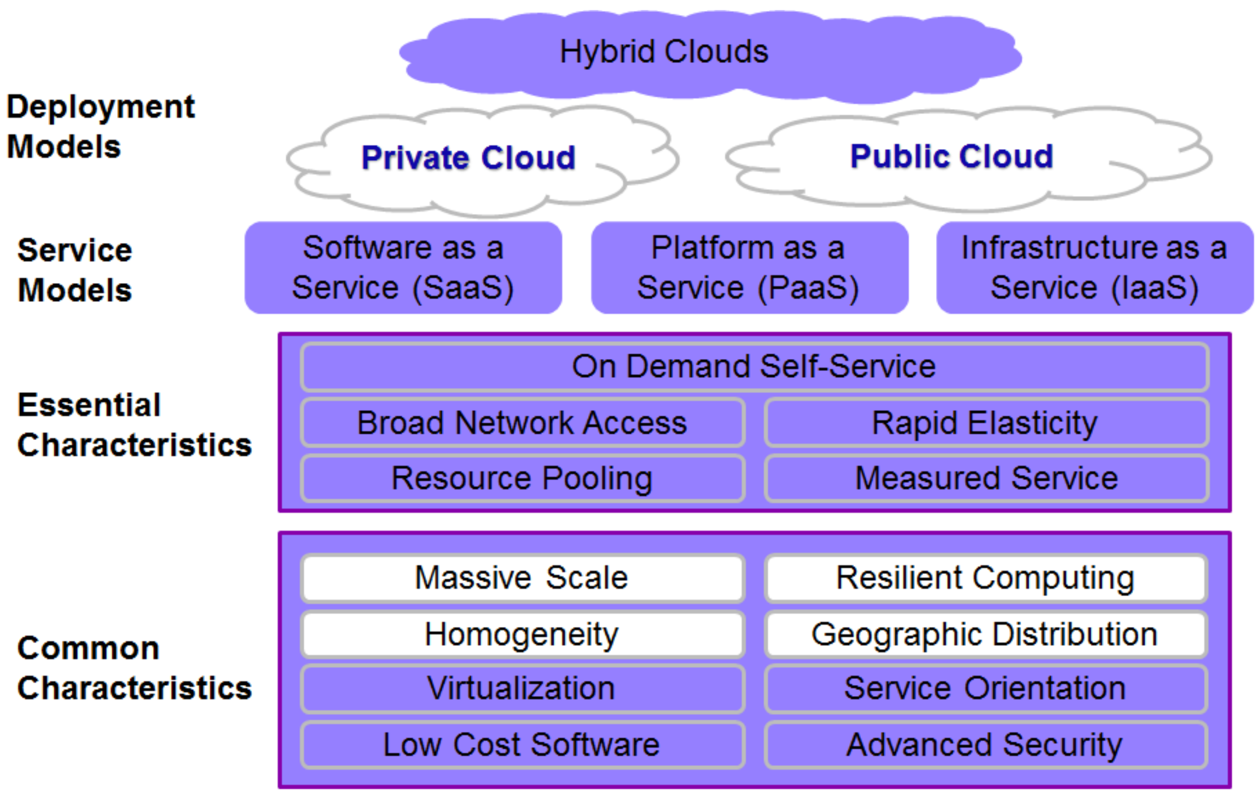
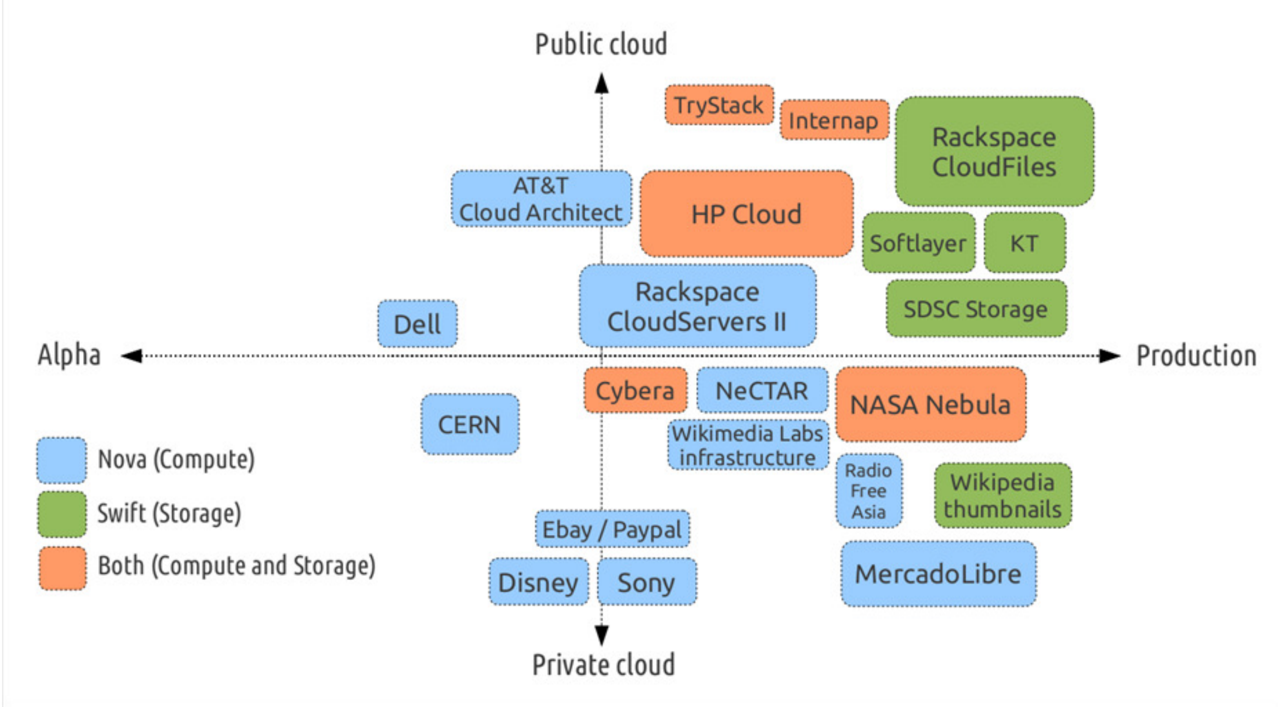
Academic year 2017/2018

NIST STANDARD CLOUD



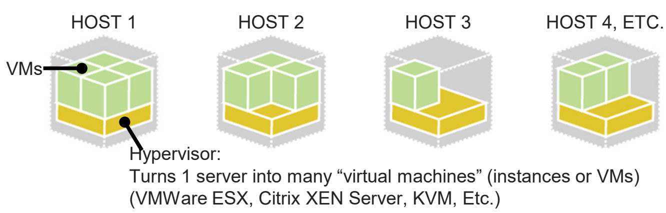
National Institute of Standards and Technology www.nist.gov/

Known Deployment Models



Cloud: resource virtualization

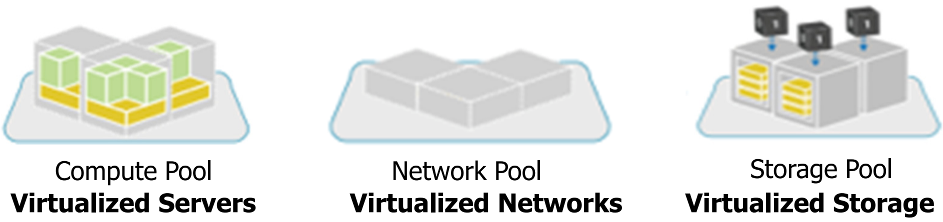
- First step: *Server virtualization*



- Hypervisors provide an abstraction layer between hardware and software
- Hardware abstraction
- Better resource utilization for every single server

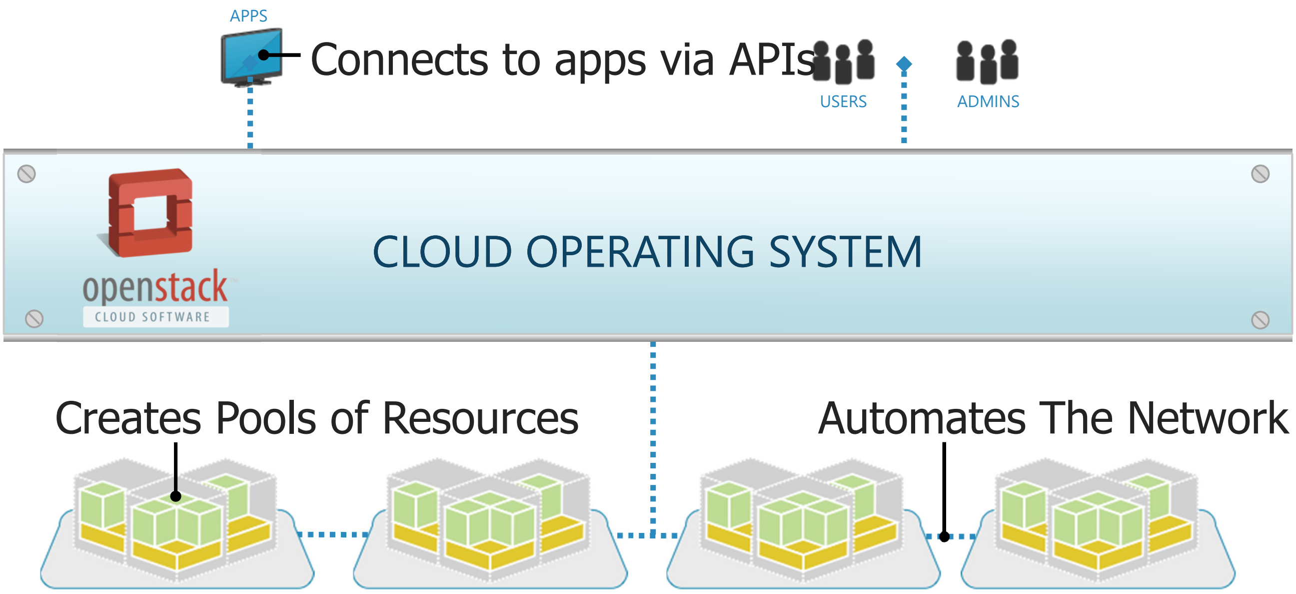
Cloud: resource virtualization

- Second step: *network and storage virtualization*



- Resource pool available for several applications
- Flexibility and efficiency

High-level Architecture of the OpenStack Cloud IaaS



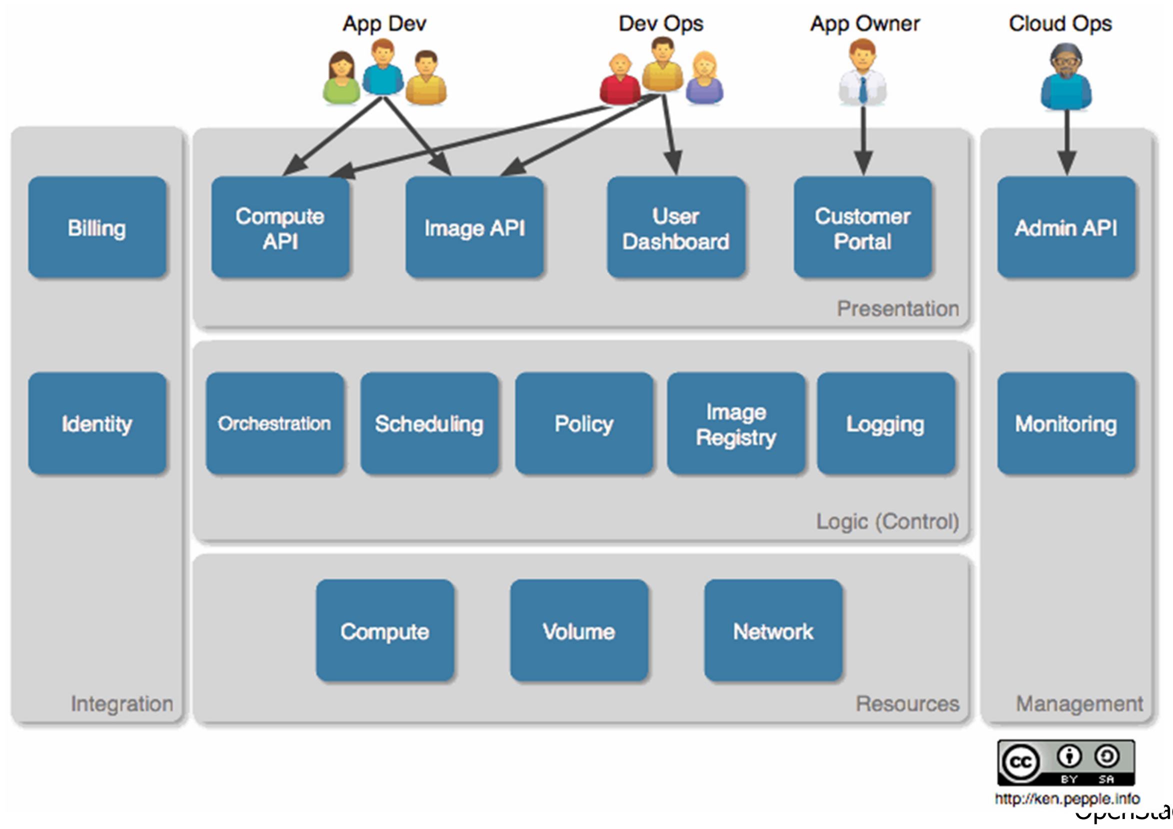
OpenStack history in a nutshell

OpenStack

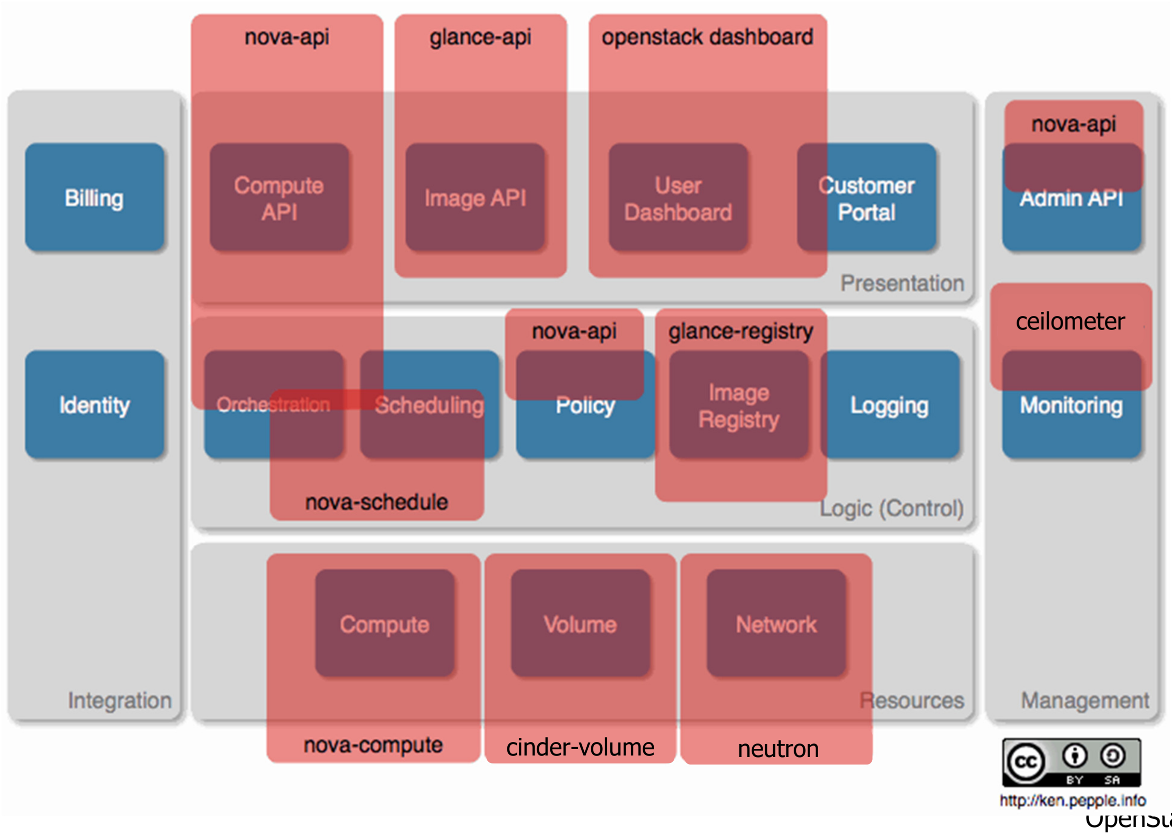
- – Founded by **NASA** and **Rackspace** in 2010
- – Currently supported by more than **300 companies** and **13866 people**
- – Latest release: **Juno**, October 2014

- **Six-month** time-based **release cycle** (aligned with Ubuntu release cycle)
- **Open-source** vs Amazon, Microsoft, Vmware…
- **Constantly growing** project

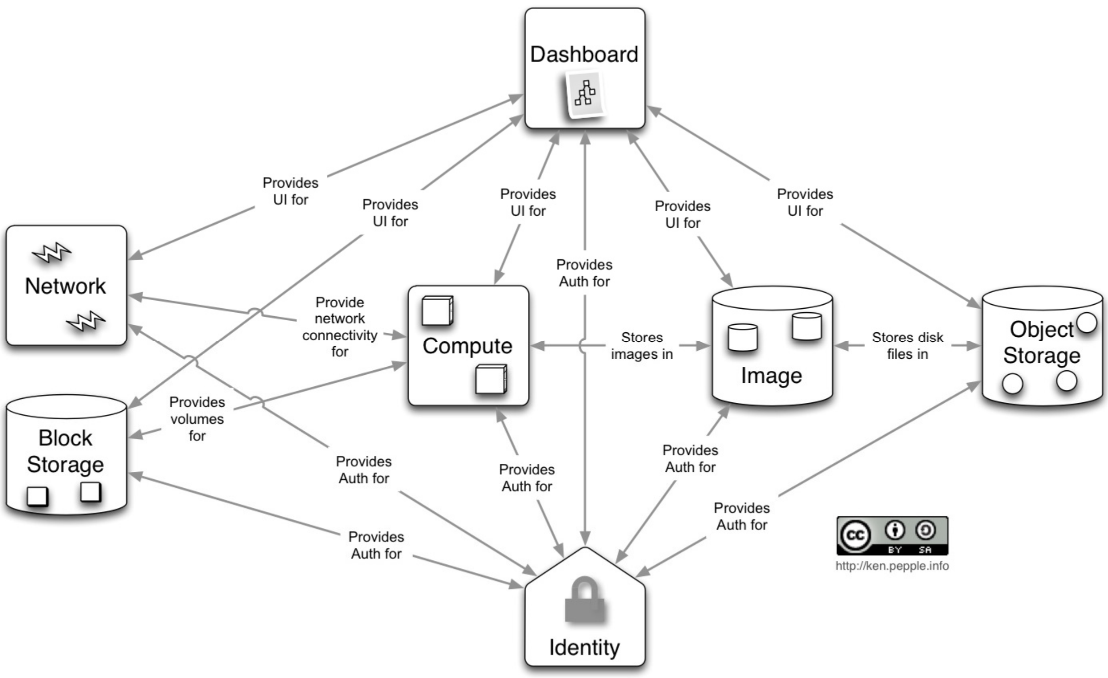
Main Function in a Cloud



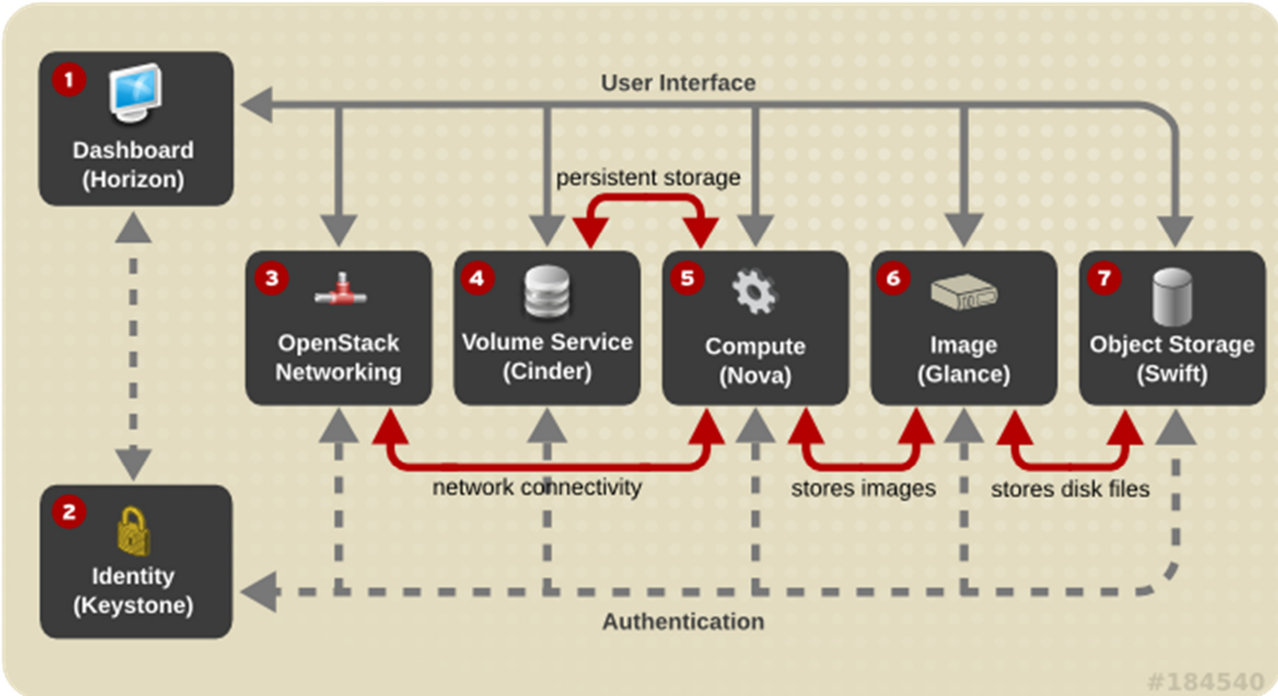
Main Function in a Cloud



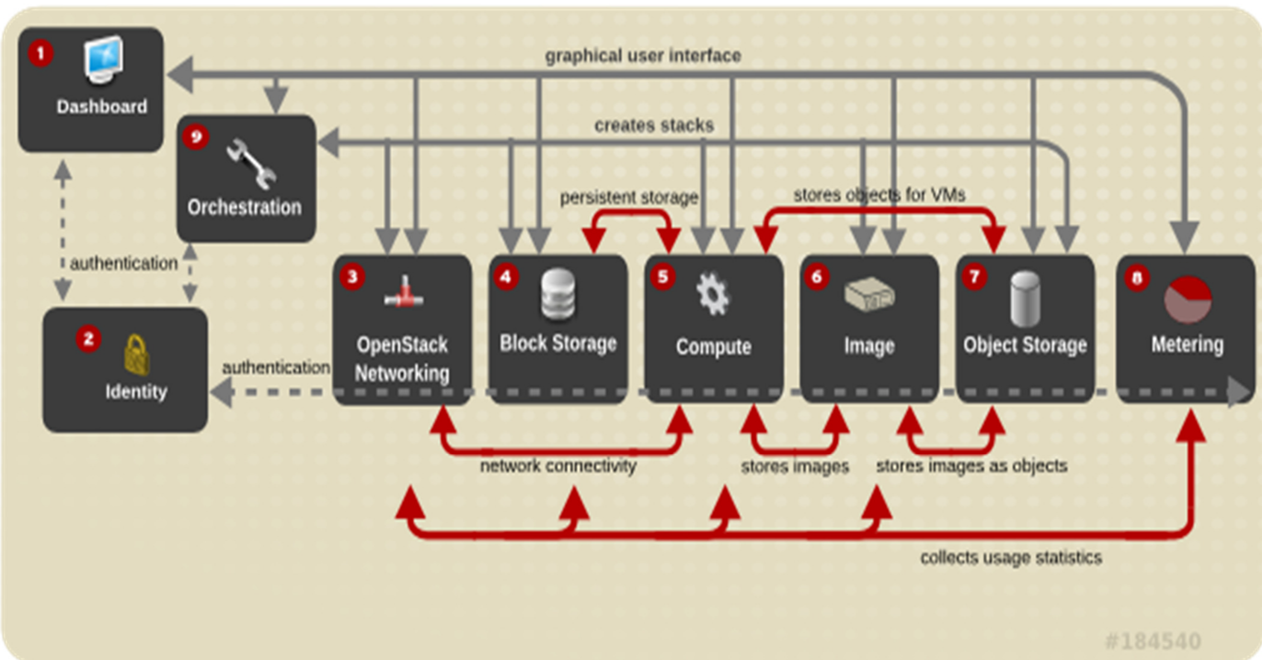
OpenStack main services



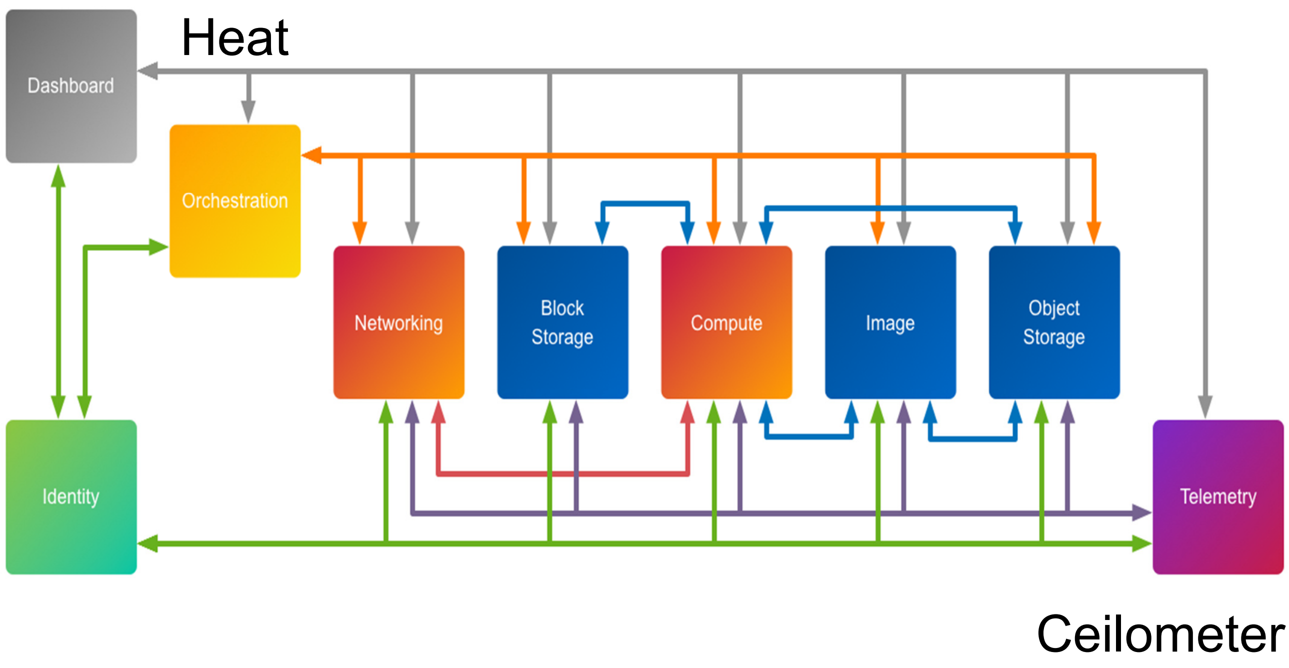
OpenStack main services



OpenStack main services



OpenStack services



OpenStack main components

Dashboard =Horizon

Compute Systems =Nova

Identity =Keystone

Network Switch =Quantum / Neutron

Image =Glance

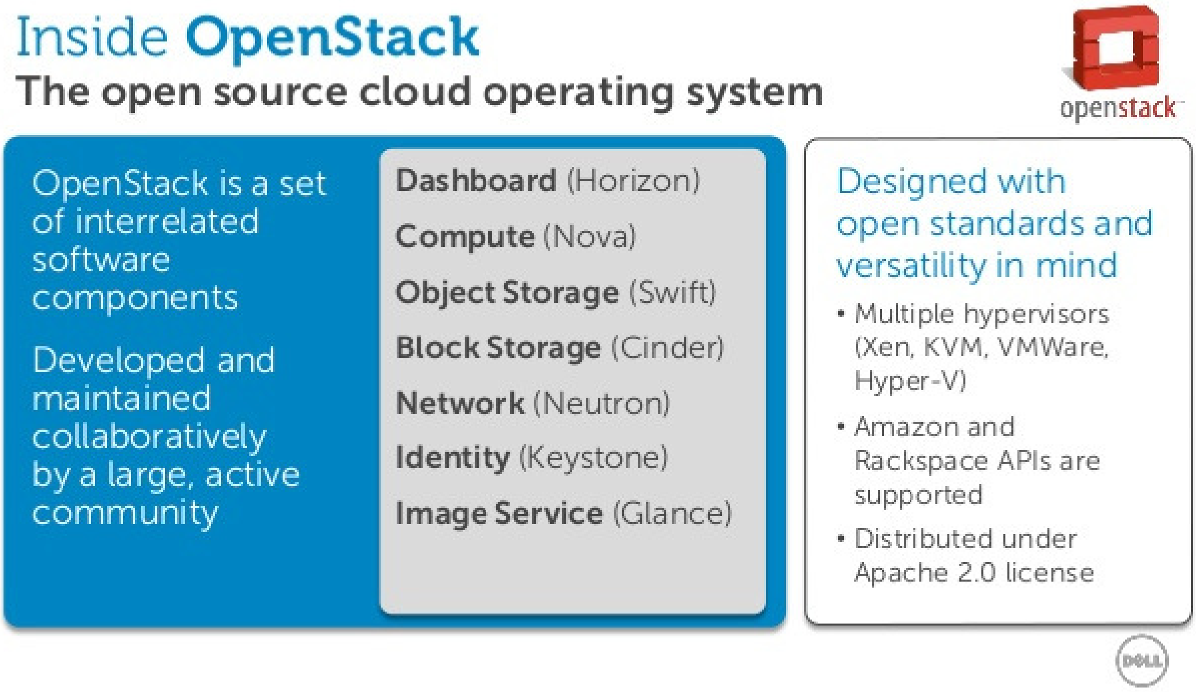
Object Store =Swift

Block Storage =Cinder

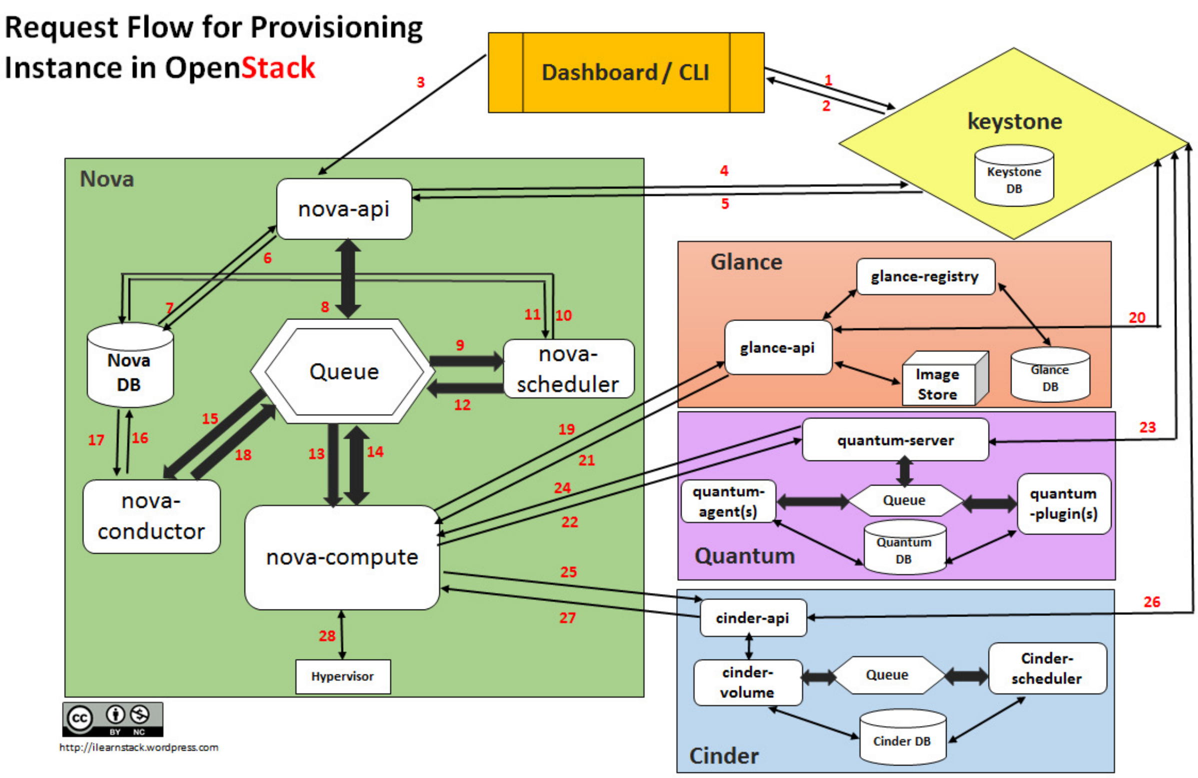
Ceilometer

Heat

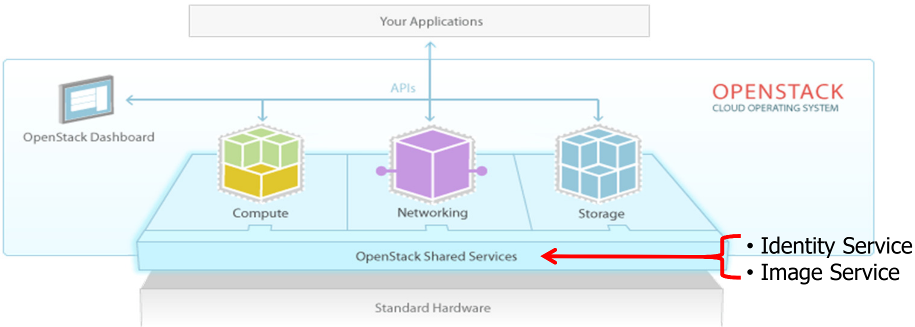
OpenStack main components



OpenStack main worflow



OpenStack services (detailed)



- **Dashboard**: Web application used by administrators and users to manage cloud resources
- **Identity**: provides unified authentication across the whole system
- **Object Storage**: redundant and highly scalable object storage platform
- **Image Service**: component to save, recover, discover, register and deliver VM images
- **Compute**: component to provision and manage large sets of VMs
- **Networking**: component to manage networks in a pluggable, scalable, and API-driven fashion

OpenStack Services: Design Guidelines

All OpenStack services share the same internal architecture organization that follow a few clear design and implementation guidelines:

- **Scalability and elasticity:** gained mainly through ***horizontal scalability***
- **Reliability:** ***minimal dependencies*** between different services and ***replication*** of core components
- **Shared nothing between different services:** each service ***stores all needed information internally***
- **Loosely coupled asynchronous interactions:** internally, ***completely decoupled pub/sub communications*** between core components/services are preferred, even to realize high-level synch RPC-like operations

OpenStack Services: Main Components

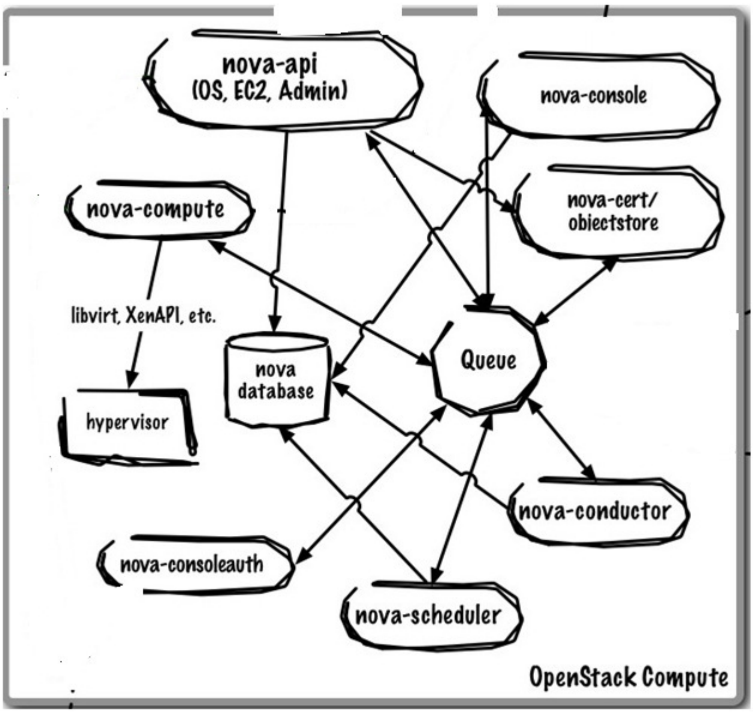
Deriving from the guidelines, every service consists of the following core components:

- **pub/sub messaging service:** Advanced Message Queuing Protocol (***AMQP***) standard and RabbitMQ default implementation
- **one/more internal core components:** realizing the service application logic
- **an API component:** acting as a service front-end to export service functionalities via interoperable ***RESTful APIs***
- **a local database component:** ***storing internal service state*** adopting existing solutions, and making different technological choices depending on service requirements (ranging from MySQL to highly scalable MongoDB, SQLAlchemy, and HBase)

Nova - Compute

- Provides **on-demand virtual servers**
- Provides and manages **large networks** of virtual machines (functionality moving to Neutron)
- Modular architecture designed to horizontally scale on standard hardware
- Supports several hypervisor (i.e. KVM, XenServer, etc.)
- Developers can access computational resources through **APIs**
- Administrators and users can access computational resources through **Web interfaces** or **CLI**

Nova – Components
(a good OpenStack service example)



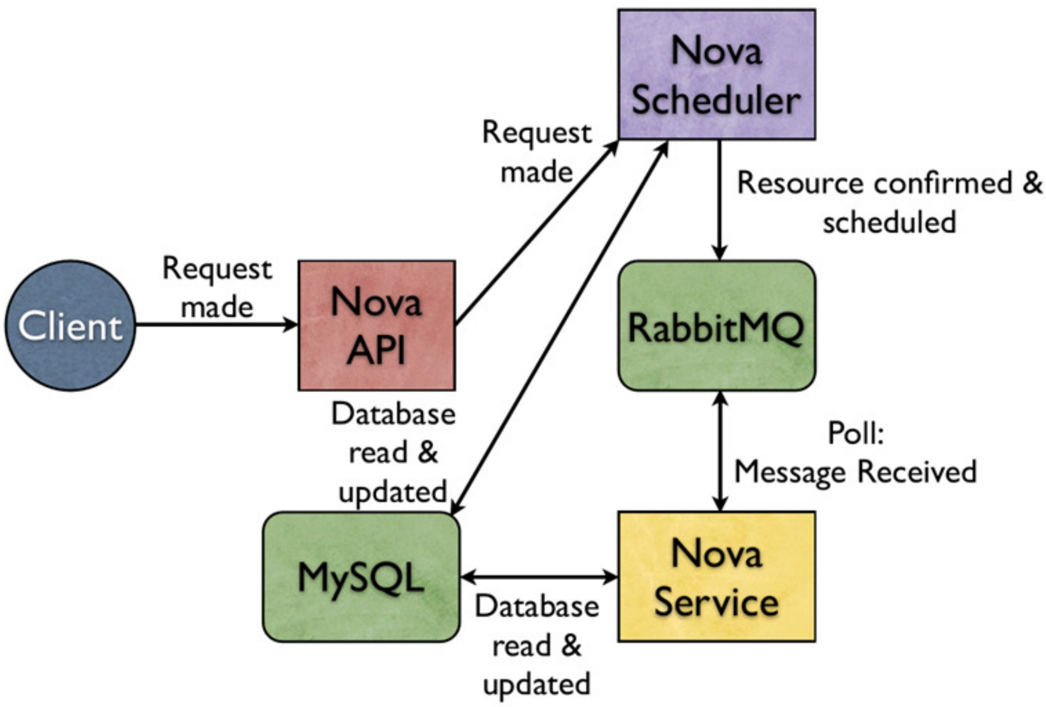
Nova – Components (1)

- **nova-API**: RESTful API web service used to send commands to interact with OpenStack. It is also possible to use CLI clients to make OpenStack API calls
- **nova-compute**: hosts and manages VM instances by communicating with the underlying hypervisor
- **nova-scheduler**: coordinates all services and determines placement of new requested resources
- **nova database**: stores build-time and run-time states of Cloud infrastructure
- **queue**: handles interactions between other Nova services By default, it is implemented by RabbitMQ, but also Qpid can be used

Nova – Components (2)

- **nova-console**, **nova-novncproxy** e **nova-consoleauth**: provides, through a proxy, user access to the consoles of virtual instances
- **nova-network**: accepts requests coming from the queue and executes tasks to configure networks (i.e., changing IPtables rules, creating bridging interfaces, … These functionalities are now moved to Neutron service.
- **nova-volume**: handles persistent volumes creation and their de/attachment from/to virtual instances
These functionalities are now moved to Cinder services

Nova General interaction scheme



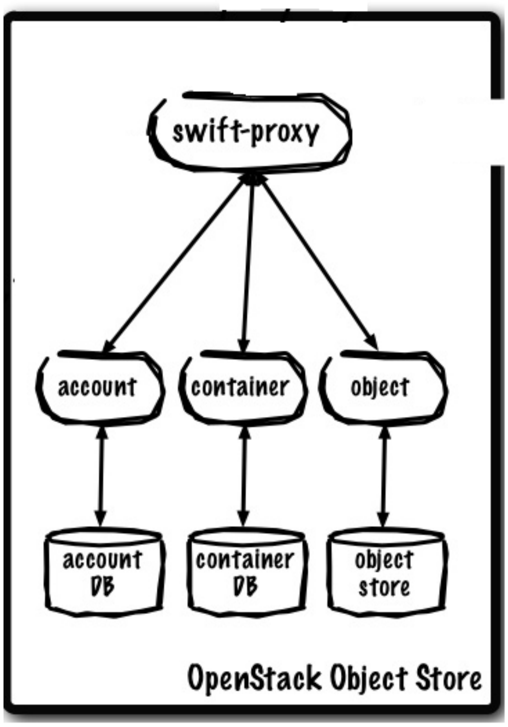
Swift - Storage

Swift allows to store and recover files

- Provides a **completely distributed storage** platform that can be accessed by APIs and integrated inside applications or used to store and backup data
- **It is not** a **traditional filesystem**, but rather a distributed storage system for static data such as virtual machine images, photo storage, email storage, backups and archives
- It doesn't have a central point of control, thus providing properties like **scalability**, **redundancy**, and **durability**

Swift - Components

- **Proxy Server**: handles incoming requests such as files to upload, modifications to metadata or container creation
- **Accounts server**: manages accounts defined through the object storage service
- **Container server**: maps containers inside the object storage service
- **Object server**: manages files that are stored on various storage nodes



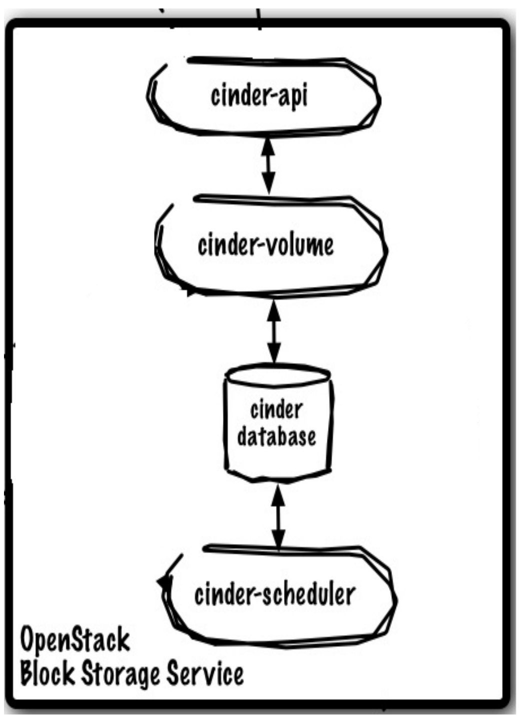
Cinder – Block Storage

Cinder handles **storage devices** that can be attached to **VM instances**

- Handles the **creation**, **attachment** and **detachment** of volumes to/from instances
- Supports iSCSI, NFS, FC, RBD, GlusterFS protocols
- Supports several storage platforms like Ceph, NetApp, Nexenta, SolidFire, and Zadara
- Allows to **create snapshots** to backup data stored in volumes. Snapshots can be restored or used to create a new volume

Cinder – Block Storage

- **cinder-API**: accepts user requests and redirects them to cinder-volume in order to be processed
- **cinder-volume**: handles requests by reading/writing from/to cinder database, in order to maintain the system in a consistent state
  Interacts with the other components through a message queue
- **cinder-scheduler**: selects the best storage device where to create the volume
- **cinder database**: maintains volumes' state



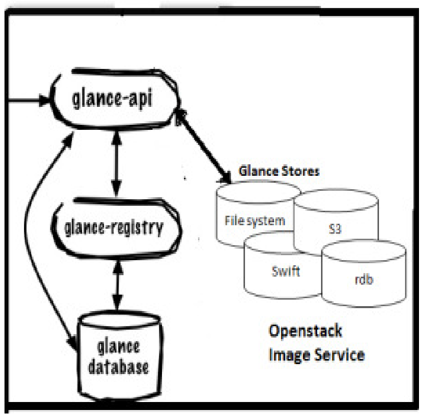
Glance – Image Service

Glance handles the **discovery**, **registration**, and **delivery** of disk and virtual server **images**

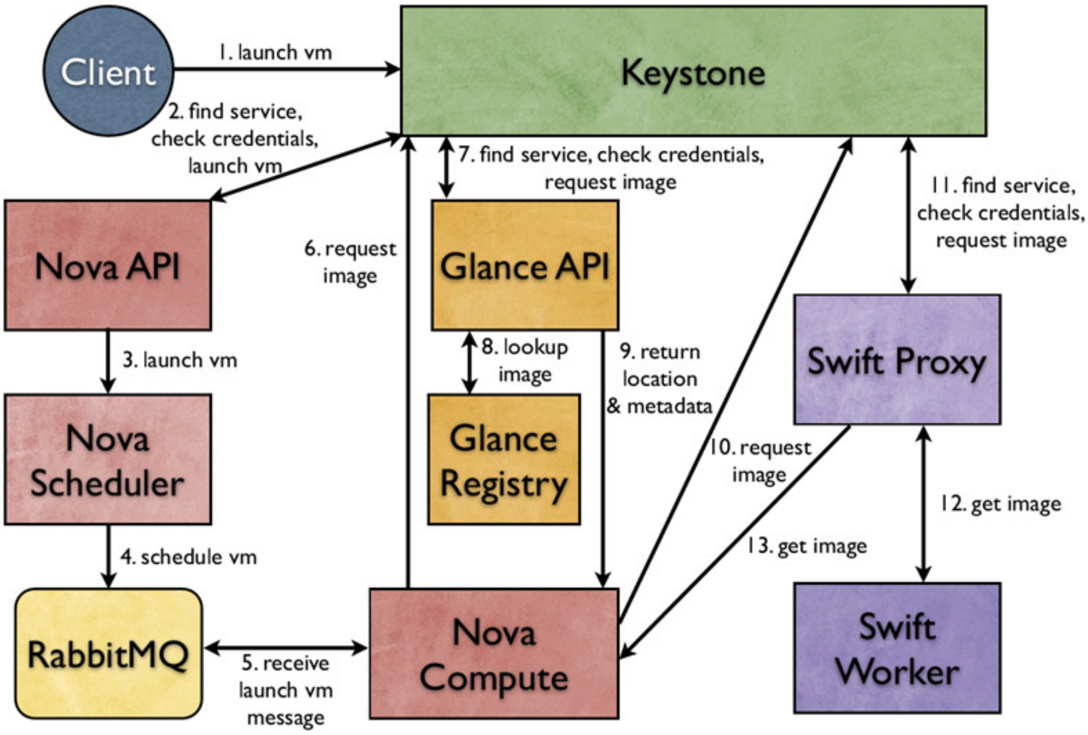
- Allows to store images on **different storage systems**, i.e., Swift
- Supports **several disk formats** (i.e. Raw, qcow2, VMDK, etc.)

Glance – Components

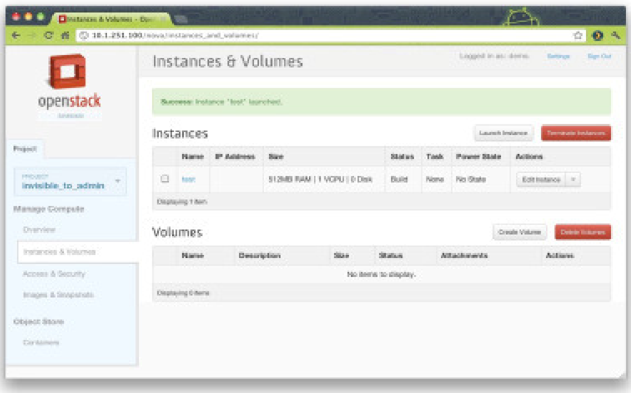
- **glance-API:** handles API requests to discover, store and deliver images
- **glance-registry:** stores, processes and retrieves image metadata (dimension, format,...).
- **glance database:** database containing image metadata
- Glance uses an external **repository** to store images Currently supported repositories include filesystems, Swift, Amazon S3, and HTTP



Nova – Launching a VM



Horizon - Dashboard



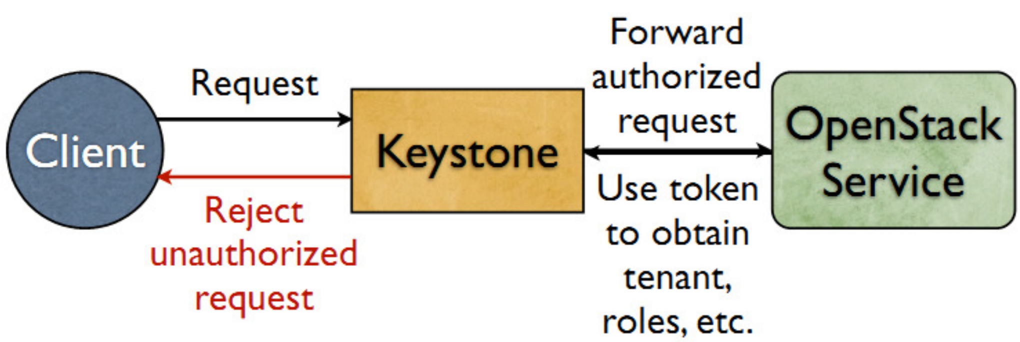
Provides a modular web-based user interface to access other OpenStack services

Through the dashboard it is possible to perform actions like launch an instance, to assign IP addresses, to upload VM images, to define access and security policies, etc.

Keystone – Authentication and Authorization

- Keystone is a framework for the authentication and authorization for all the other OpenStack services
- Creates **users** and groups (also called **tenants**), adds/removes users to/from groups, and defines **permissions** for cloud resources using role-based access control features. Permissions include the possibility to launch or terminate instances
- Provides 4 primary services:
  - **Identity**: user information authentication
  - **Token**: after logged-in, replaces password authentication
  - **Catalog**: maintains an endpoint registry used to discovery OpenStack services endpoints
  - **Policy**: provides a rule-based authorization engine

Keystone

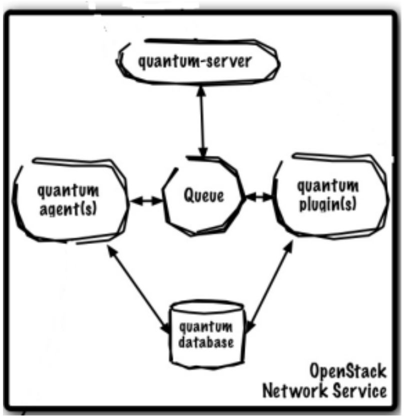


Neutron Networking

- **Pluggable**, **scalable** e **API-driven** support to manage networks and IP addresses.
- **NaaS "Network as a Service"**
  Users can create their own networks and plug virtual network interface into them
- **Multitenancy:** isolation, abstraction and full control over virtual networks
- **Technology-agnostic:** APIs specify service, while vendor provides his own implementation. Extensions for vendor-specific features
- **Loose coupling:** standalone service, not exclusive to OpenStack

Neutron – Components

- **neutron-server:** accept request sent through APIs e and forwards them to the specific plugin
- **Plugins and Agents:** executes real actions, such as dis/connecting ports, creating networks and subnets, creating routers, etc.
- **message queue:** delivers messages between quantum-server and various agents
- **neutron database:** maintains network state for some plugins



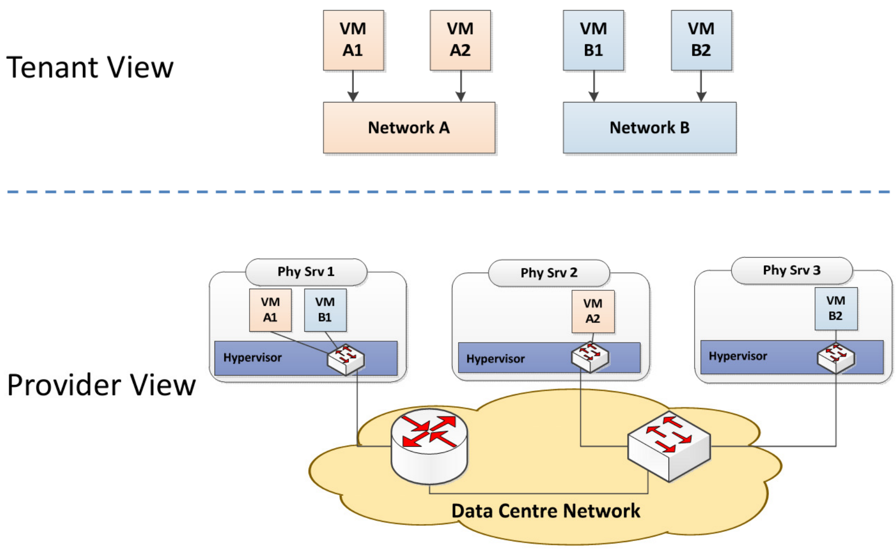
Neutron – Agents

- **dhcp agent:** provides DHCP functionalities to virtual networks
- **plugin agent:** runs on each hypervisor to perform local vSwitch configuration. The agent that runs, depends on the used plug-in (e.g. OpenVSwitch, Cisco, Brocade, etc.).
- **L3 agent:** provides L3/NAT forwarding to provide external network access for VMs

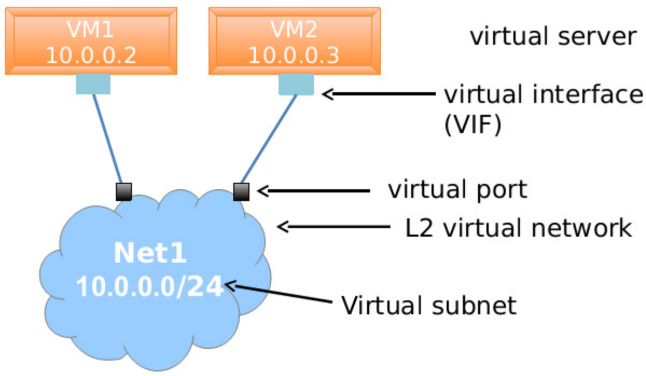
Neutron logical view vs. physical view

Neutron **decouples** the logical view of the network from the physical view

It provides APIs to define, manage and connect virtual networks



Neutron - logical view



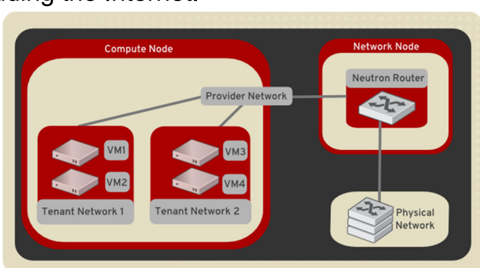
- **Network**: represents an isolated virtual Layer-2 domains; a network can also be regarded as a logical switch;
- **Subnet**: represents IPv4 or IPv6 address blocks that can be assigned to VMs or router on a given network;
- **Ports**: represent logical switch ports on a given network that can be attached to the interfaces of VMs. A logical port also defines the MAC address and the IP addresses to be assigned to the interfaces plugged into them. When IP addresses are associated to a port, this also implies the port is associated with a subnet, as the IP address was taken from the allocation pool for a specific subnet.

Neutron - tenant networks

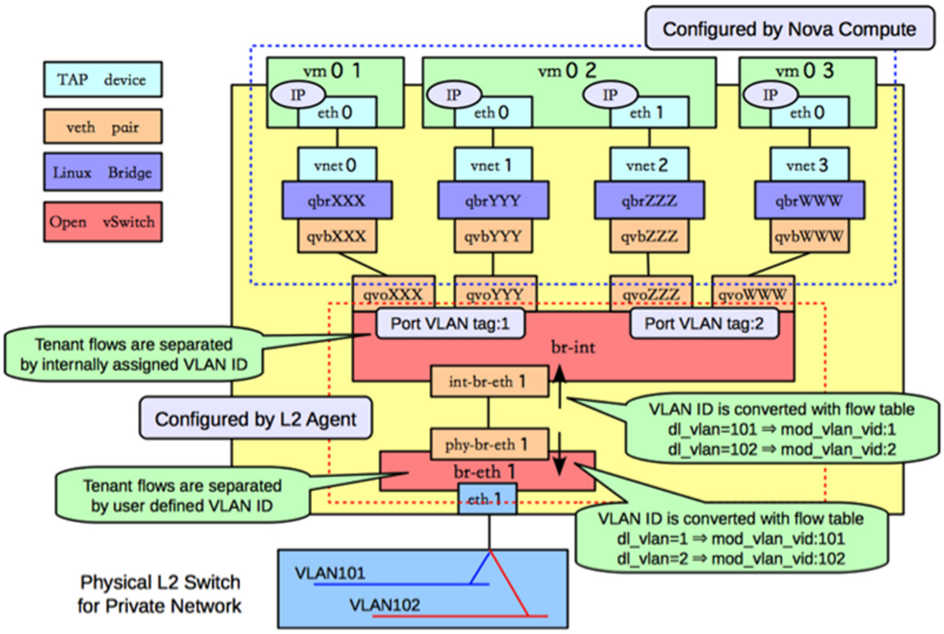
Tenant networks can be created by users to provide connectivity within tenants. Each tenant network is fully isolated and not shared with other tenants.

Neutron supports different types of tenant networks:

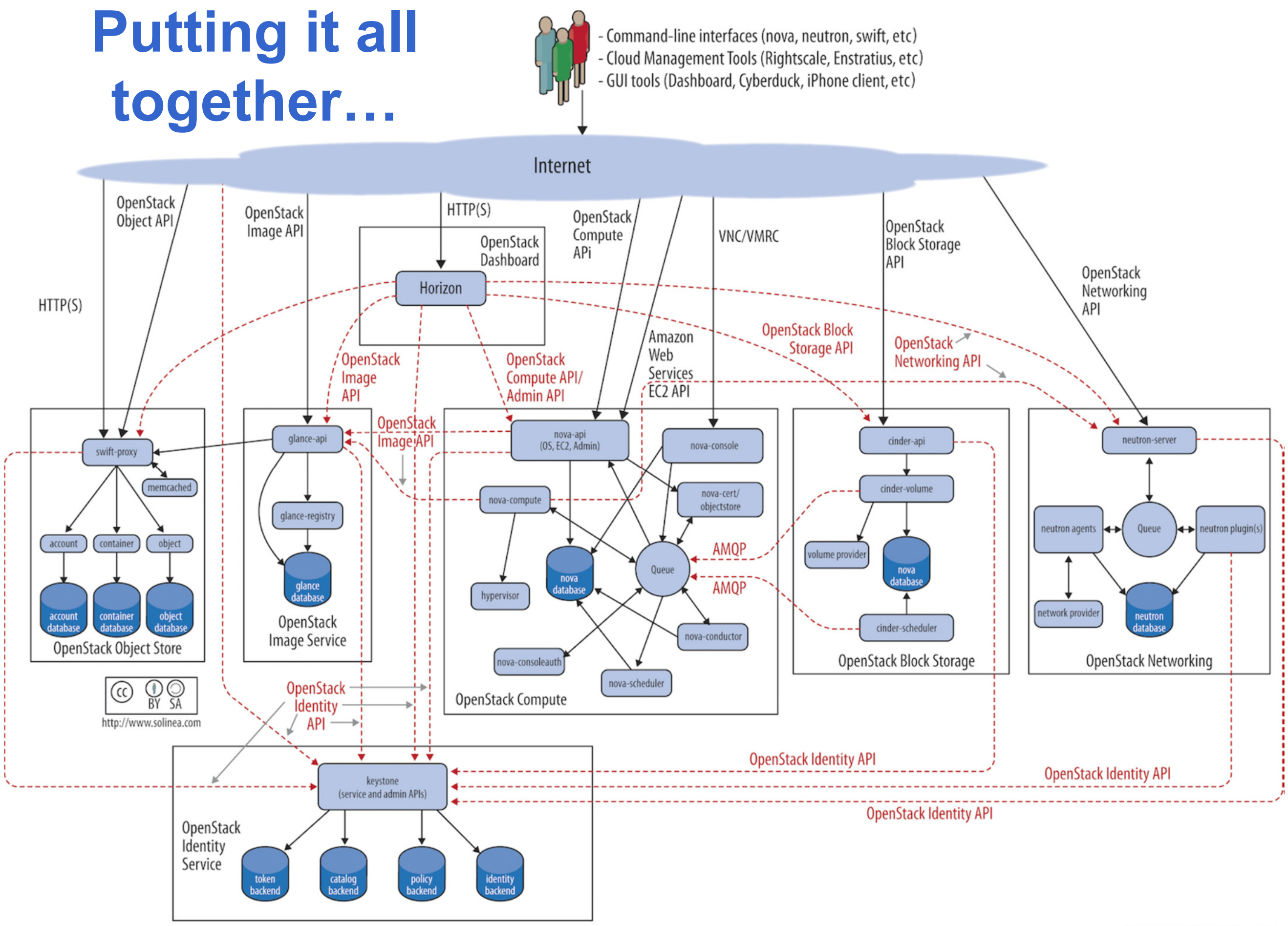
- **Flat**: no tenant support. Every instance resides on the same network, which can also be shared with the hosts. No VLAN tagging or other network segregation takes place;
- **Local**: instances reside on the local compute host and are effectively isolated from any external networks;
- **VLAN**: each tenant network uses VLAN IDs (802.1Q tagged) corresponding to VLANs present in the physical network. This allows instances to communicate with each other across the environment, other than with dedicated servers, firewalls, load balancers and other networking infrastructure on the same layer 2 VLAN. Switch must support 802.1Q standard in order to provide connectivity between two VMs on different hosts;
- **VXLAN and GRE**: tenant networks use network overlays to support private communication between instances. A Networking router is required to enable traffic to traverse outside of the tenant network. A router is also required to connect directly-connected tenant networks with external networks, including the Internet.



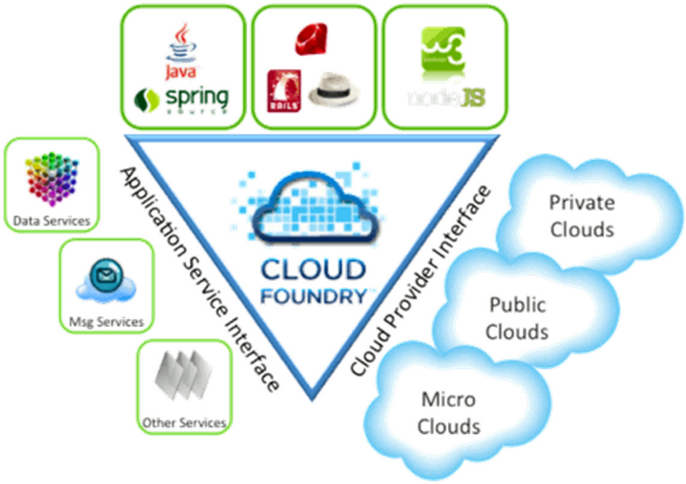
Neutron – VLAN tenant network



Putting it all together…



Cloud Foundry PaaS in a Nutshell



- Funded by VMware and EMC Corporation
- **Open Source** PaaS
- **Indipendent** from underlying **IaaS**
- Supports the development of applications written in **Ruby**, **Java** and **Javascript**, and many more…

Cloud Foundry PaaS

Cloud Foundry (CF) is an open PaaS that enables fast definition, development , and **scalable deployment** of **new applications**, offering also a wide support for different:

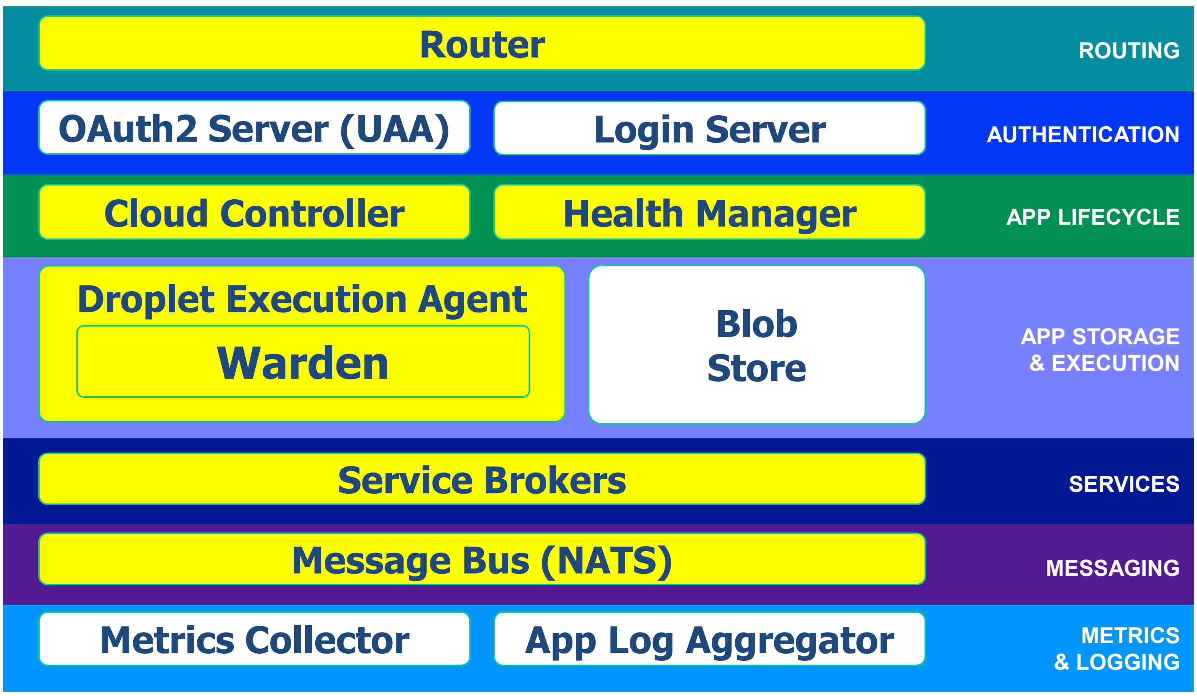
- **Languages/frameworks → to develop new applications (apps)**
  - Languages: **Ruby, Sinatra, Rack, Java, Scala, Groovy, Javascript**
  - Frameworks: **Rails, Spring, Grails, Play, Lift, Express**
- **External, bind-able and ready-to-use services**
  - **Redis, mySQL, postgreSQL, rabbitMQ, mongoDB**
- **Multiple Clouds and Infrastructure as a Service (IaaS) systems**
  - **OpenStack**, WebSphere, Amazon Elastic Cloud Computing (EC2) Web Services, … → Through the ***BOSH deployer***

Cloud Foundry – Design Guidelines

Cloud Foundry adopts an internal architecture organization that follow a few clear design and implementation guidelines:

- **Scalability and elasticity:** gained mainly through ***horizontal scalability***
- **Reliability:** ***minimal dependencies*** between different components and ***replication*** of core components
- **Shared nothing between different services:** each component is ***self-aware*** (stores all needed information internally)
- **Loosely coupled asynchronous interactions:** ***completely decoupled pub/sub communications*** between core components/services are preferred

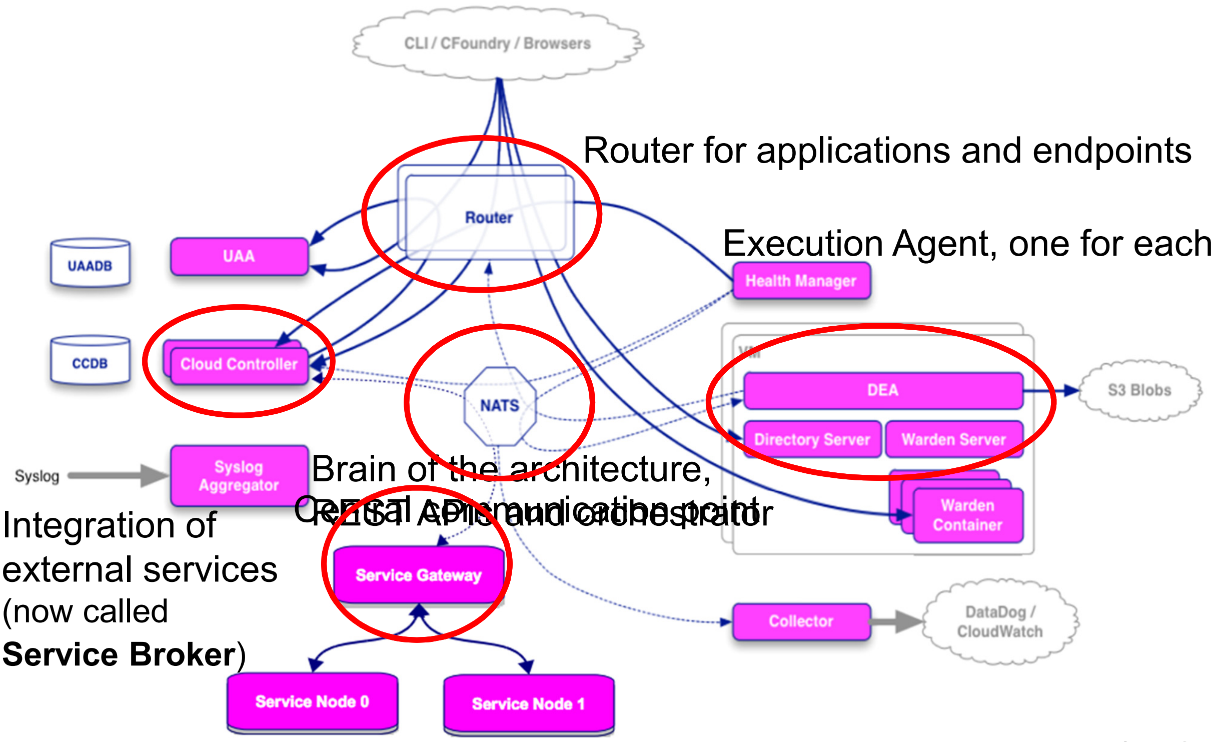
Cloud Foundry – Layered View



Main CF Components

- **Router**: forwards in-/out-bound traffic from/to the external Internet, typically toward the Cloud Controller or an application instance
- **Cloud Controller**: controls service/application lifecycle and stores all data about services applications, services, service instances, users, etc.
- **Health Manager**: monitors application status (running, stopped, crashed)
- **Droplet Execution Agent (DEA)**: controls application instances and (periodically) publishes their current application status
- **Warden**: isolated and self-contained container offering APIs to manage application execution
- **Service Broker**: services front-end API controller
- **NATS**: publish-subscribe internal messaging service

Distributed Architecture



Router for applications and endpoints

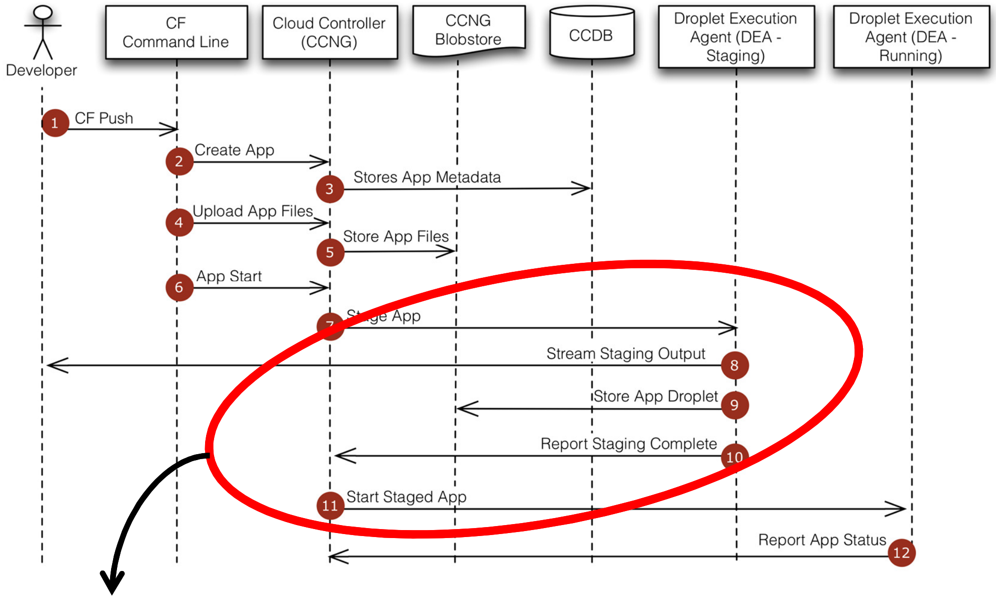
Execution Agent, one for each VM

Brain of the architecture, REST APIs and orchestrator

Central communication point

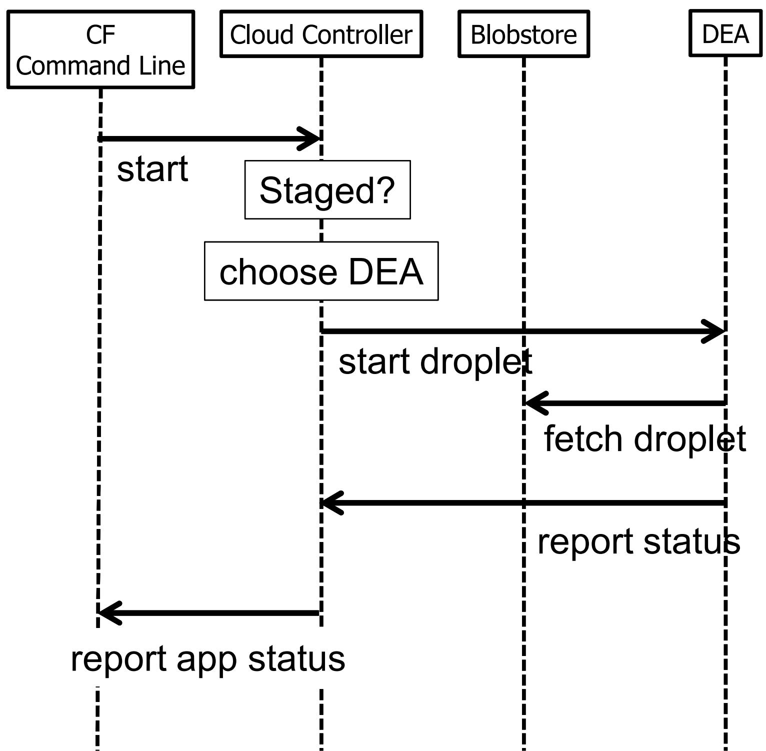
Integration of external services (now called **Service Broker**)

Management of Apps lifecycle



Digging into the code: DEA/Stager agent **starts** the app, not Cloud Controller.
Cloud Controller creates an AppStagerTask, that is in charge to find an available Stager(DEA-Agent)
The stager is found with "top_5_stagers_for(memory, stack)".
When the Stager is found, it handles the message, it starts the staging process and at the end invokes "notify_completion(message, task)" -> "bootstrap.start_app(message.data["start_message"])" -> instance = create_instance(data); instance.start

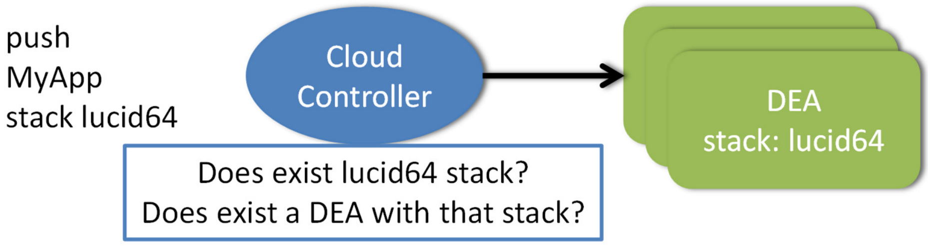
Starting an App



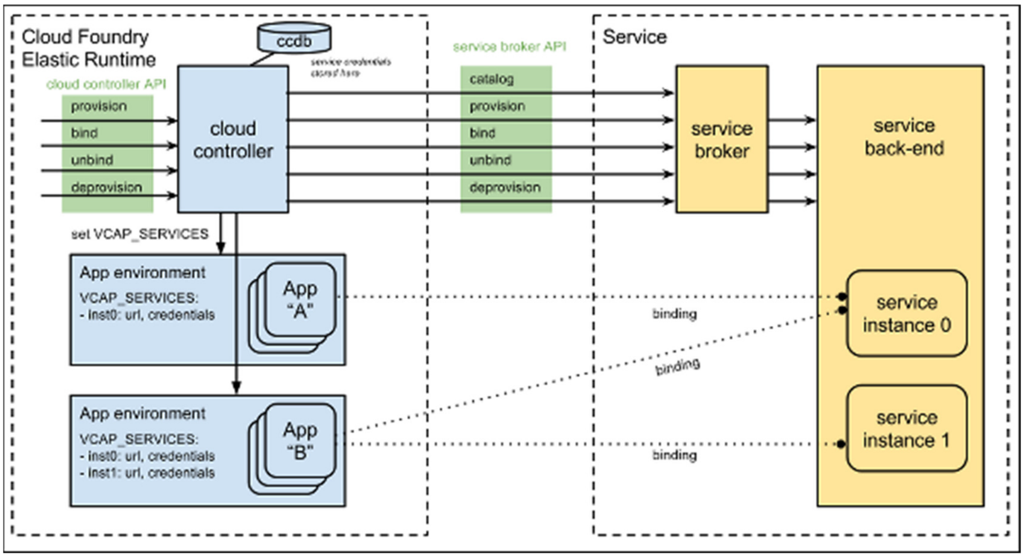
Apps and stacks

A **stack** is a prebuilt file system, including an operating system, that supports running applications with certain characteristics. Any DEA can support exactly one stack.
To stage or run an app, a DEA running the requested stack must be available (and have free memory).
For instance, the **lucid64** stack is supported out of the box as an Ubuntu 10.04 64-bit system containing a number of common programs and libraries.

During a Staging or Start process, the Cloud Controller checks always the stack requested by the app and chooses the DEA accordingly.



Management of Service lifecycle



1. **Provision**: to create a new Service instance
2. **Bind**: credentials and configuration information to access the Service instance saved in the App environment
3. **Unbind**: to destroy credentials/configurations from the App environment
4. **Unprovision**: to destroy the Service instance

Plus **Catalog** to advertise Service offerings and service plans.

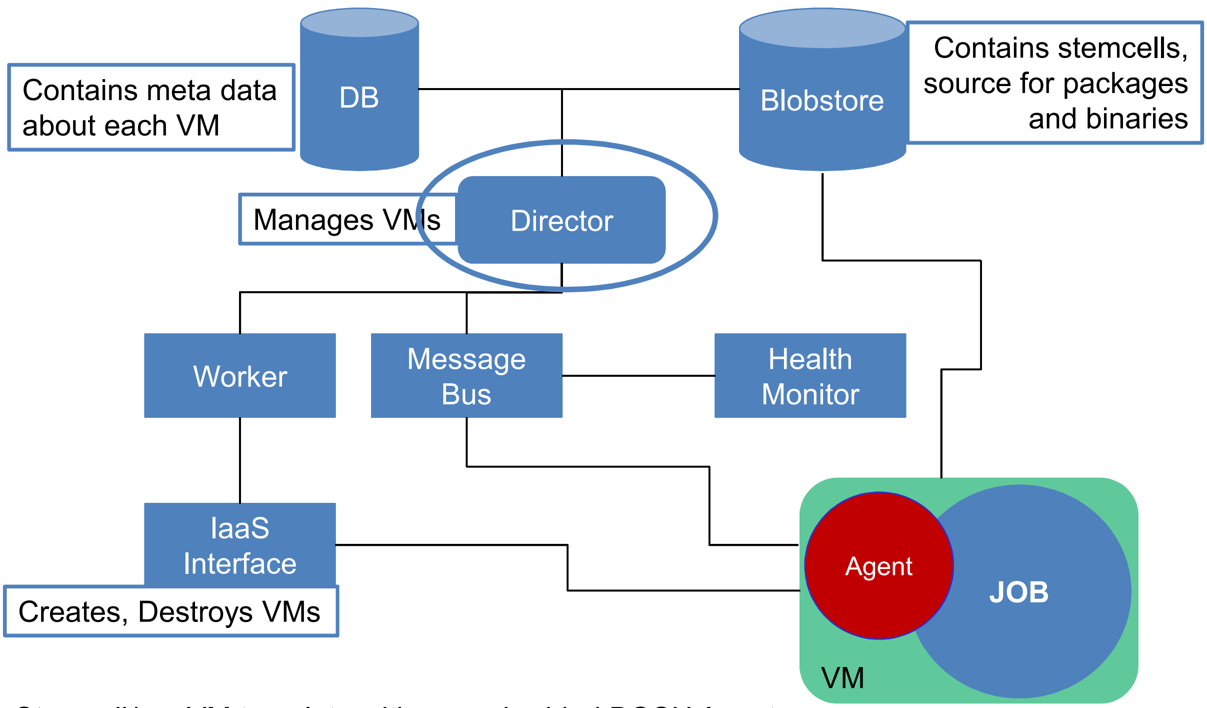
Services Implementation & Deployment

CF only requires that a Service implements the broker API in order to be available to CF end users, many deployment models are possible.

The following are examples of valid deployment models.

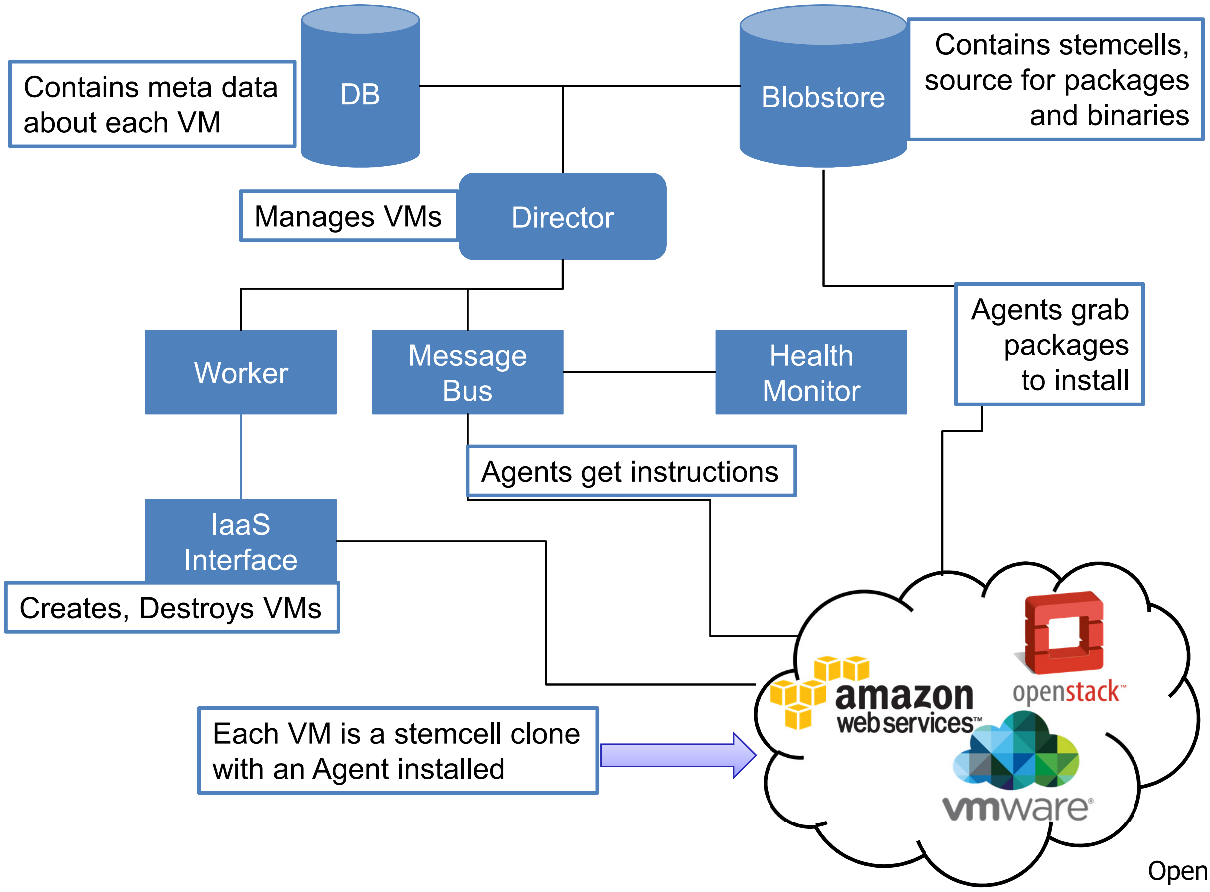
- **Entire Service** packaged and deployed **alongside CF**
- **Broker packaged and deployed alongside CF**, rest of the service deployed and maintained by other means
- **Broker (and optionally service) pushed as an application to CF user space**
- **Entire Service**, including Broker, **deployed and maintained outside of CF** by other means

Operating CF via Bosh Outer SHell (BOSH)

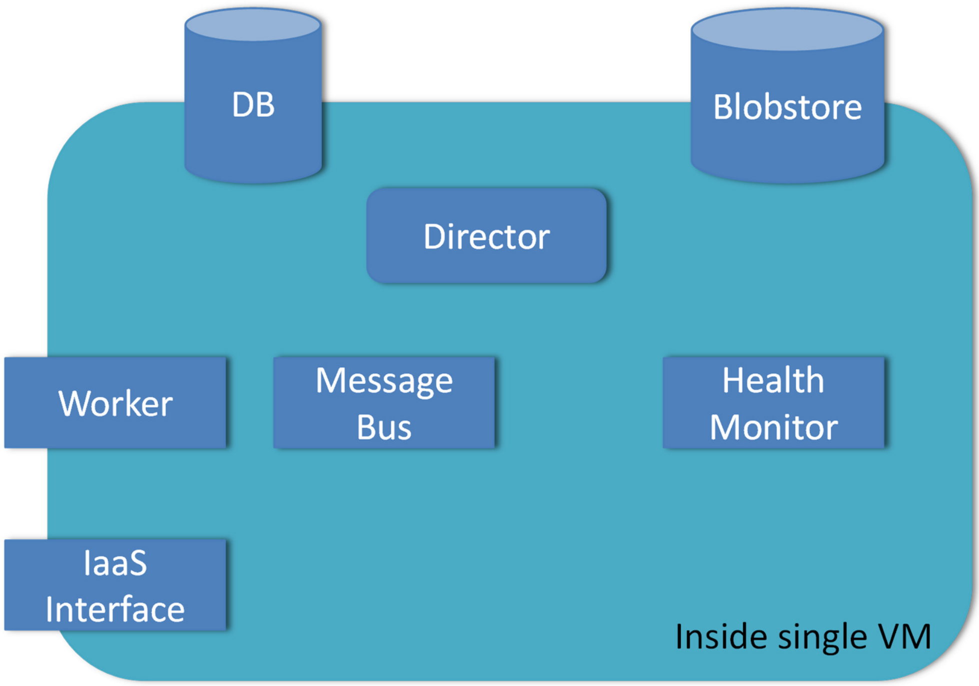


A *Stemcell* is a VM template with an embedded BOSH Agent.
Stemcells are uploaded using the BOSH CLI and used by the BOSH Director when creating VMs through the Cloud Provider Interface (CPI). When the Director creates a VM through the CPI, it will pass along configurations for networking and storage, for Message Bus and the Blobstore.

BOSH with different CPIs

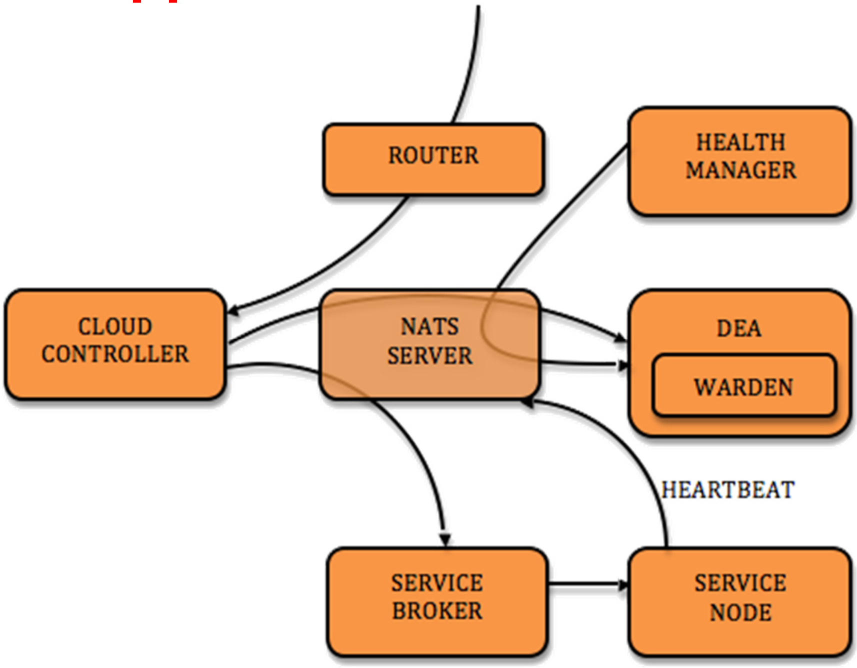


Micro BOSH

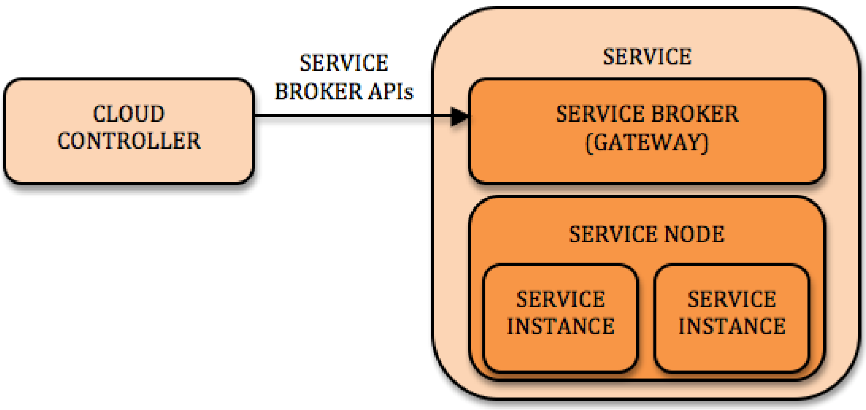


Monitoring of CF Services

Scarce support for runtime monitoring!!!

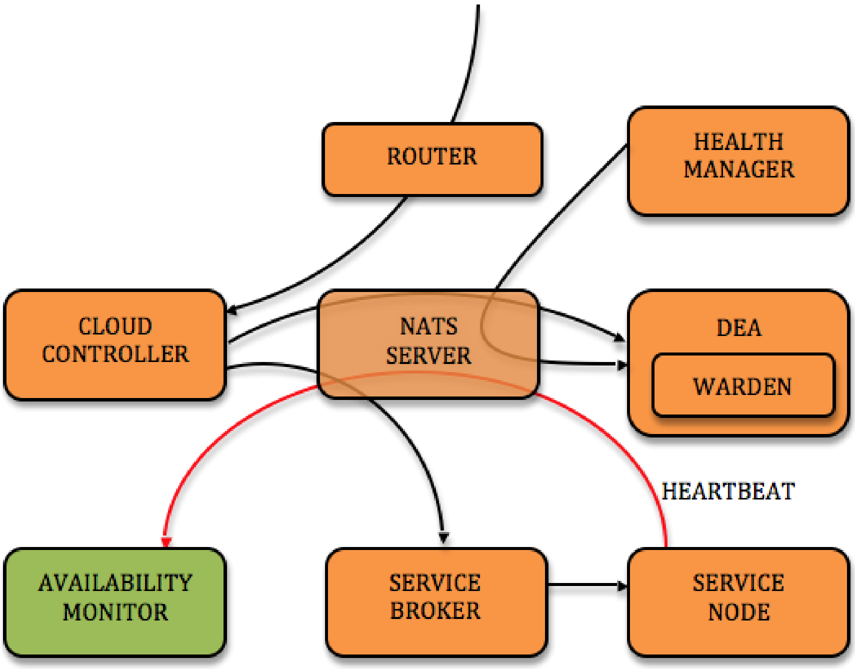


Monitoring of CF Services



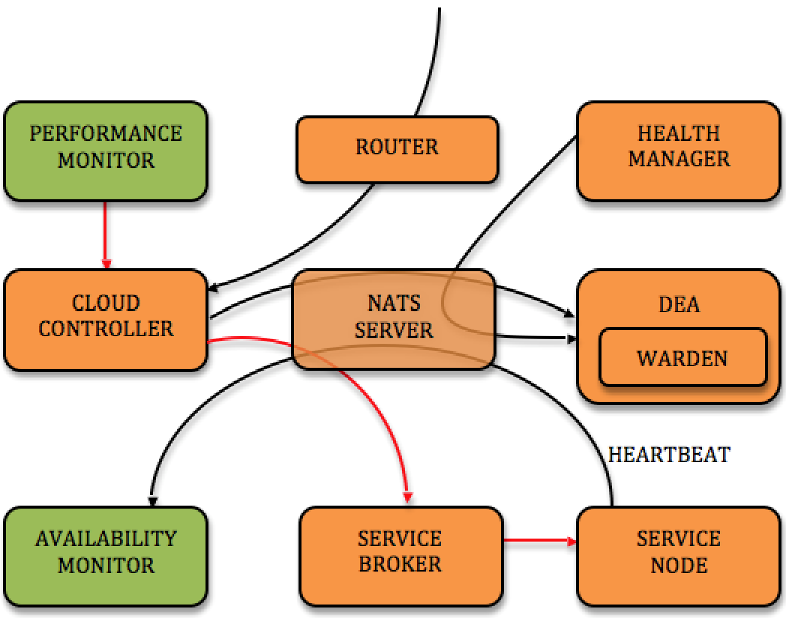
- **Service Broker (Gateway):** exposes four main dialogue APIs (***un/provisioning***, ***un/binding***) interacting with Cloud Controller, and handling commands to the Service Nodes
- **Service Node:** real business logic component (instantiates new service processes, binds them, etc.) that periodically publishes toward NATs service heartbeats

CF Services: Availability Monitoring



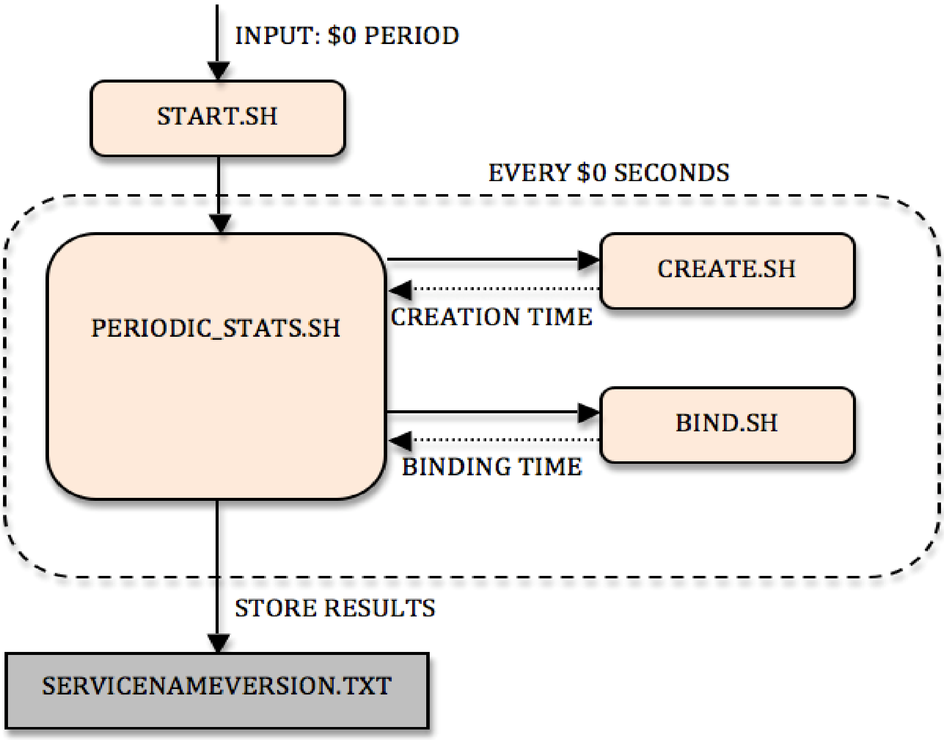
- **Monitor process:** subscribes to NATS and handles incoming heartbeats
- **Check status process:** periodically controls if the service is still functioning

CF Services: Performance Monitoring



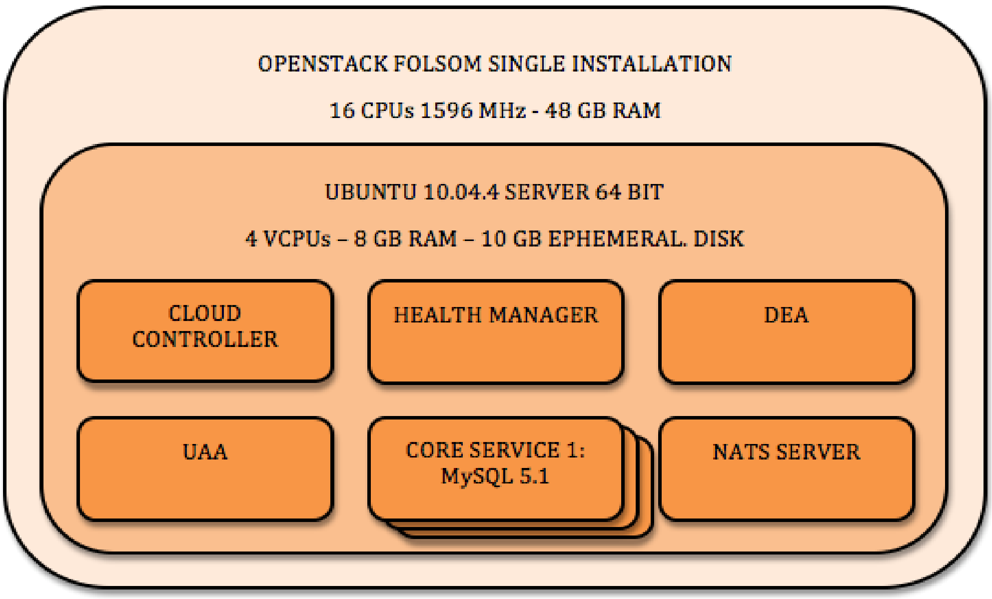
Performance monitoring exploits **CLI commands** to periodically check for activation time by using a mockup service that is dynamically created, bound, and destroyed

CF Services: Performance Monitoring



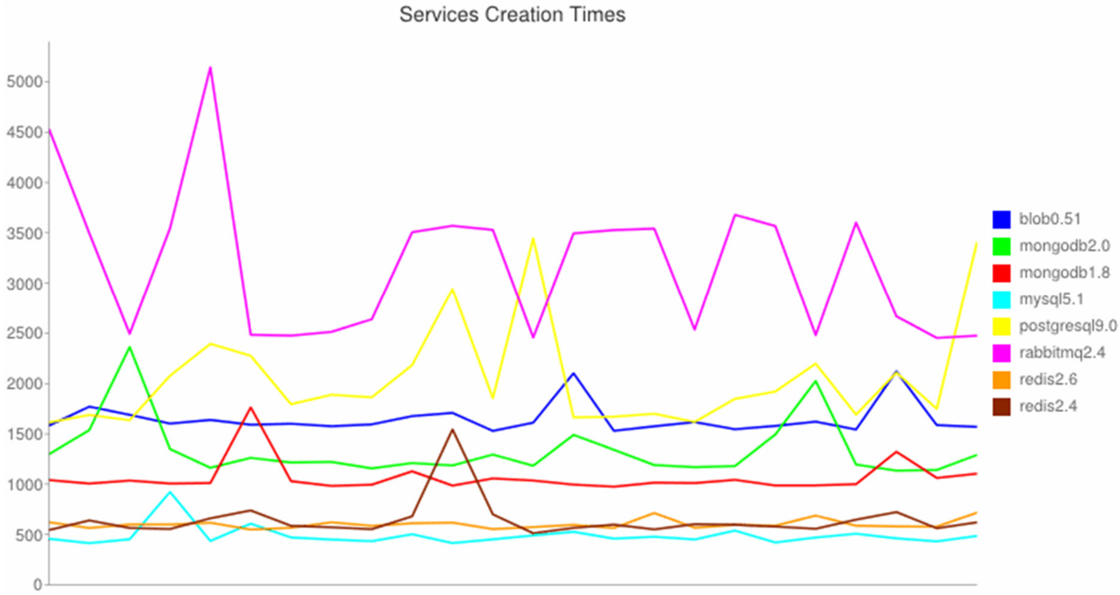
Some Experimental Results: Single Host

All-in-One single host environment: ***all*** Cloud Foundry ***components*** and ***services run*** on the ***same Virtual Machine*** (VM) managed via the OpenStack IaaS



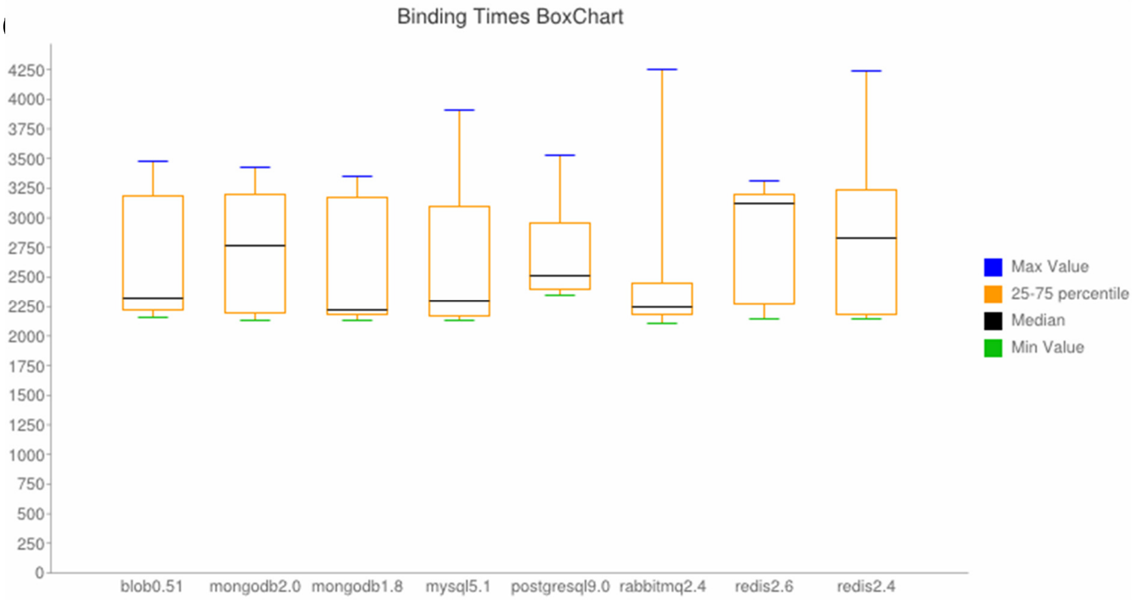
Experimental Results: Provisioning Time

Depend on the **kind** and **version of service** (different No/SQL data bases, messaging, and analytics services)



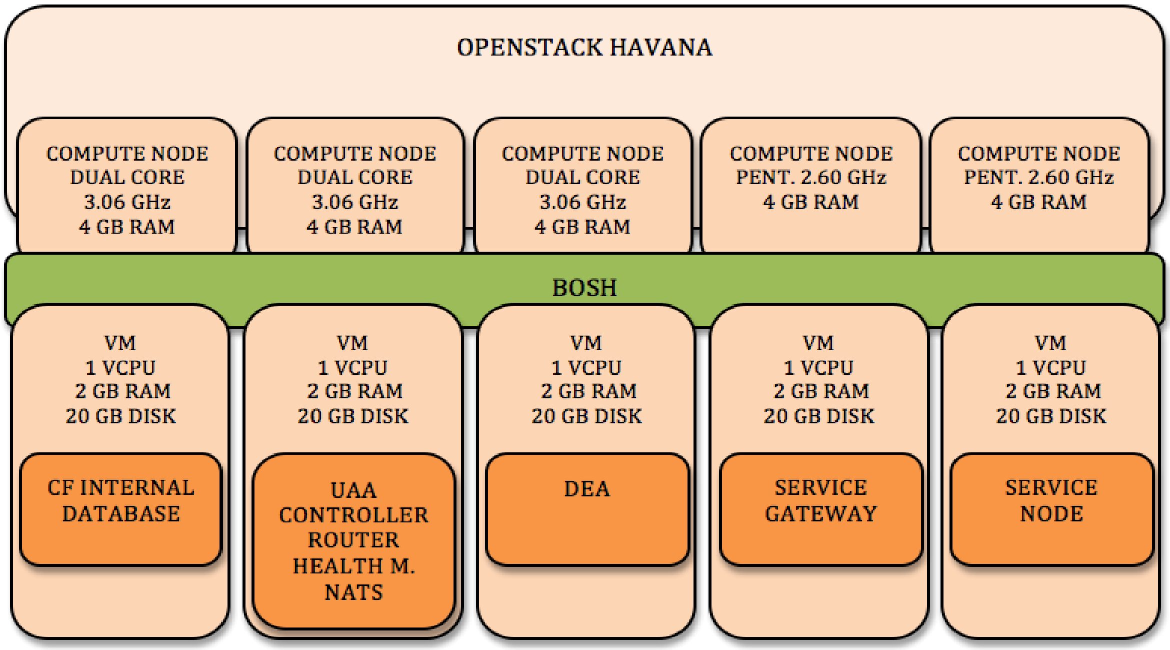
Experimental Results: Binding Time

Almost equal for all services and **versions**: the binding process consists in a credential exchange between the service an



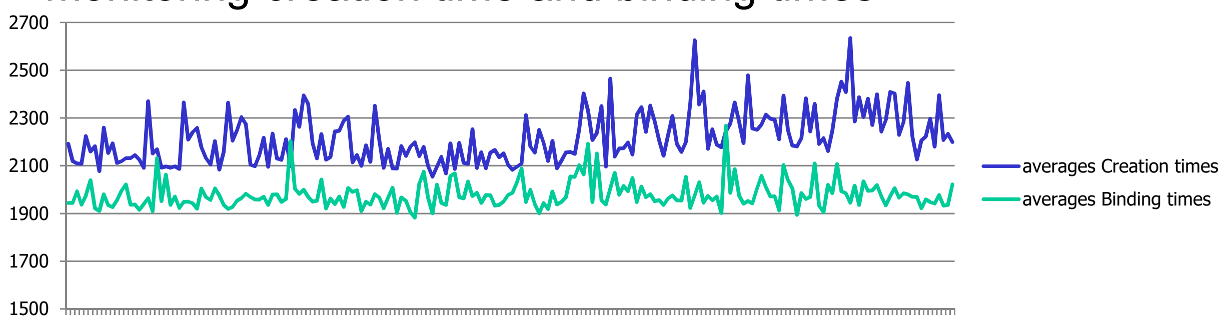
Heavy-load Experimental Results: Distributed Deployment

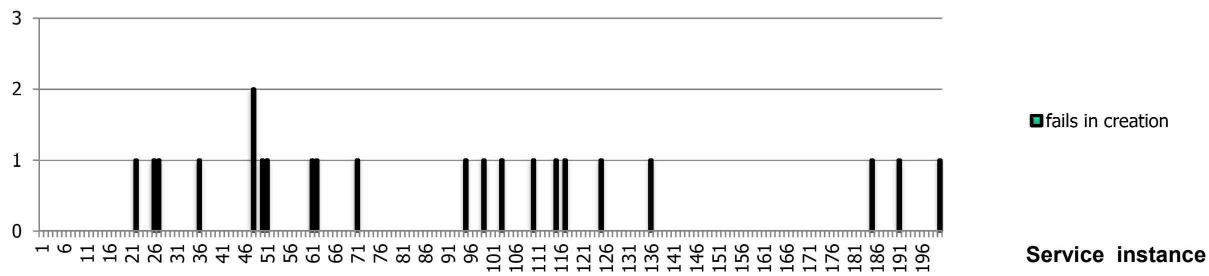
Cloud Foundry distributed deployment via **BOSH deployer** over OpenStack IaaS



Exp. Results: Accumulation Stress Test

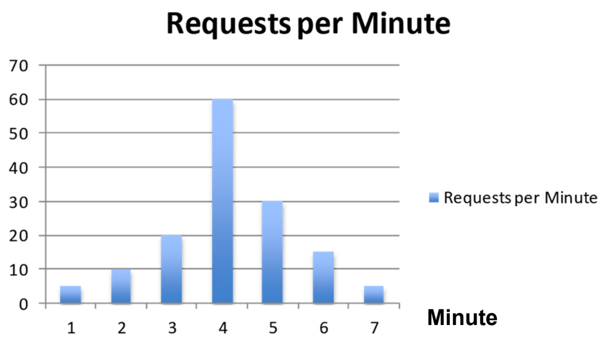
Sequential creation of ***200 service instances*** by monitoring creation time and binding times

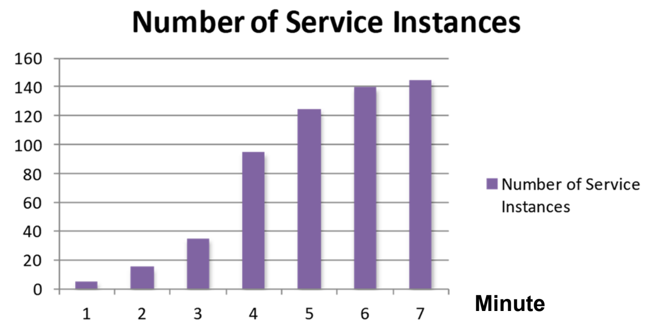


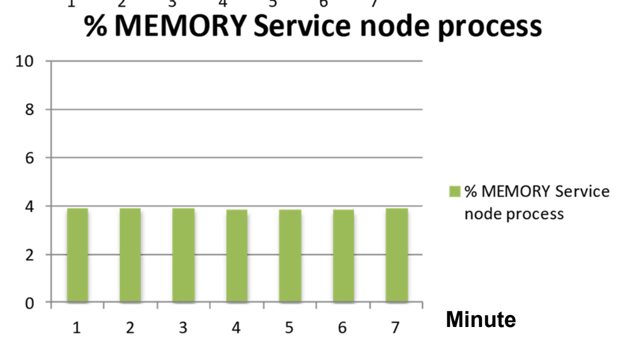


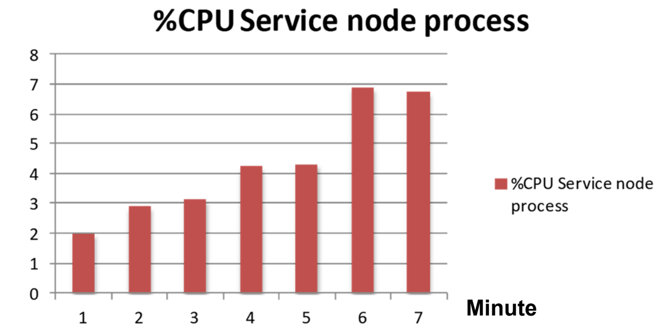
Exp. Results: High-Req-Freq Stress Test

Concurrent creation of ***service instances*** with different frequencies, up to 140 service instances



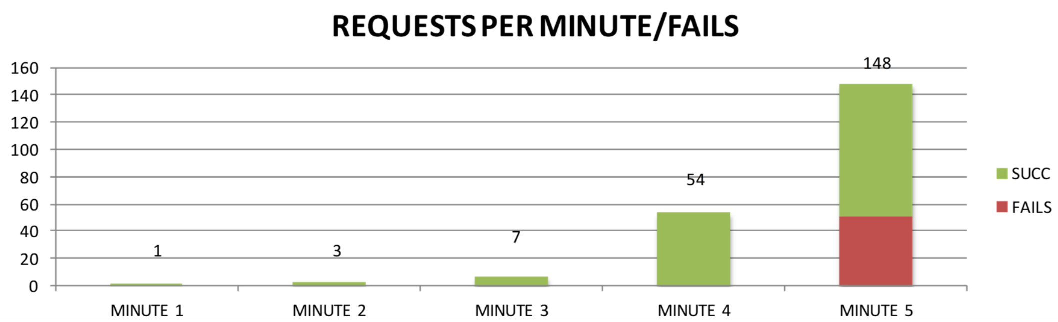


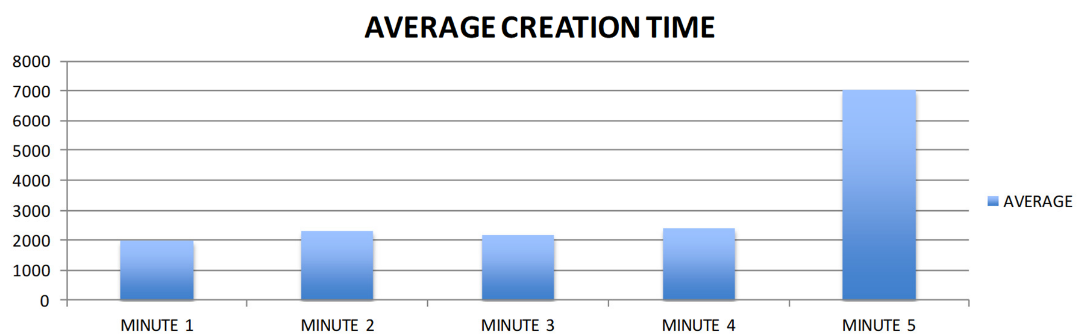




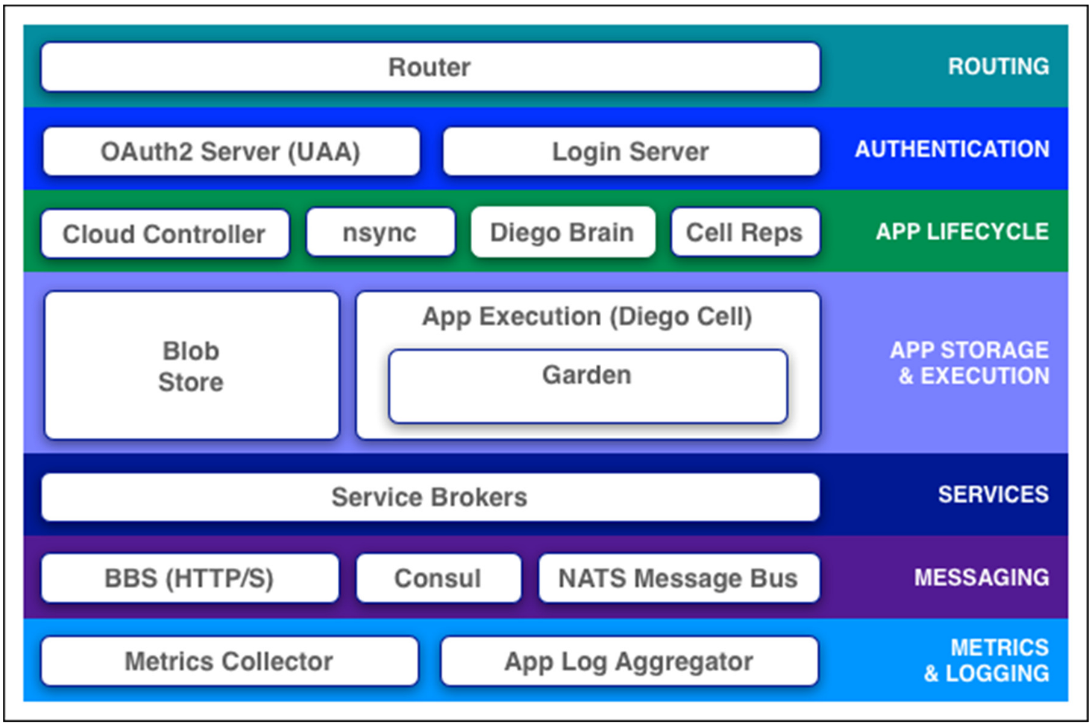
Exp. Results: Exponential Increase

Incoming requests arrival frequency follows an ***exponential increase***





Cloud Foundry v2 – Layered View



Main CF v2 Components

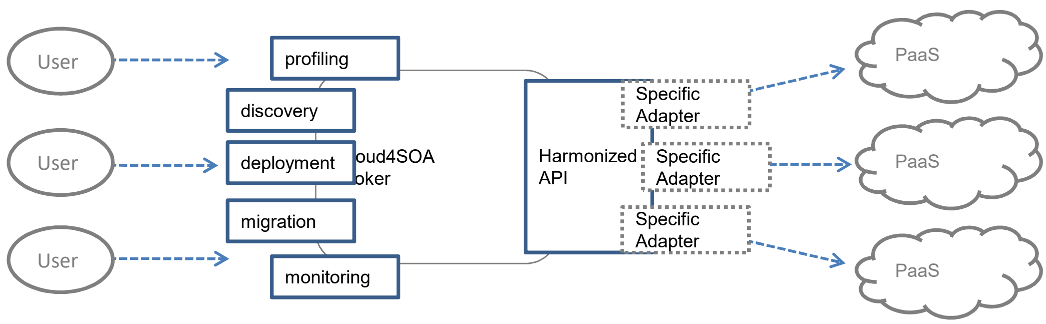
- **Router**: forwards in-/out-bound traffic from/to the external Internet, typically toward the Cloud Controller or an application instance
- **Cloud Controller and Diego Brain**: The Cloud Controller directs the deployment of applications and communicates with Diego Brain to coordinate Diego Cells that stage and run applications
- **Nsync, Bulletin Board System and Cell Reps**: work together along a chain to keep apps running and control status
- **Diego Cell**: Execute application start and stop, manages the VM's containers and reports app status/data to BBS
- **Consul**: stores longer-lived control data and distributed locks to avoid duplicating actions
- **Service Broker**: services front-end API controller

Brokering Cloud PaaS: the Cloud4SOA Project

- ***Motivations***
  - ***Lack*** of ***standards*** in ***PaaS*** domain
  - Solutions ***lock-in***
- ***Objectives***
  - ***Interoperability*** and ***portability*** across different ***PaaS***
  - ***Coordination activity***
    - ***formalization*** of use cases, concepts, guidelines, architectures, etc.
    - ***identification*** and ***analysis*** of ***semantic interoperability*** problems
  - ***Standardization activity***
    - resolution of ***semantic interoperability problems***
  - ***Supply*** a ***Reference Architecture implementation***
    - ***Semantic description*** of application ***requirements*** and PaaS ***offering***
    - ***Offerings marketplace***
    - ***Deployment***, ***Lifecycle*** management, ***Monitoring***, ***Migration***

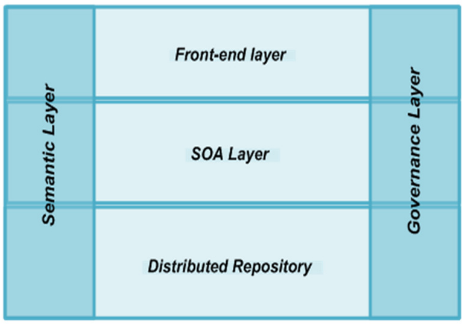
Cloud4SOA Architecture

- ***Semantic Web technologies*** used for developing simple, extendable and reusable resource and service models
- ***Service Oriented Architecture*** used to provide a unified ***Cloud broker API*** to retrieve resources in a as a Service fashion
- ***Harmonized*** and ***standard API*** used to interface with several Cloud platforms in an uniform way
- ***Specific adapters*** used to execute harmonized API calls by ***translating*** them into ***specific PaaS APIs***



Cloud4SOA Layered Architecture

- ***Front-end Layer:*** allows Cloud developers to easily ***access Cloud4SOA functionalities***
- ***SOA Layer:*** implements the ***core functionalities*** offered by the Cloud4SOA platform broker service ***discovery***, ***announcement***, ***deployment***, ***monitoring***, ***migration***, etc.
- ***Distributed Repository: stores*** both semantic and non-semantic ***information needed to perform*** the ***intermediation*** and ***harmonization*** processes
- ***Semantic Layer:*** holds lightweight ***semantic models*** and ***tools*** for ***annotating*** Cloud Computing ***resources***
- ***Governance Layer:*** offers a ***toolkit*** for ***monitoring*** the lifecycle of Cloud4SOA ***services***



Cloud4SOA: Semantic Layer

- Solution-independent **concepts**, **tools** and **mechanisms** that can be used to **model**, **understand**, **compare** and **exchange data** in a **uniform** way
- ***Interoperability*** and ***portability conflicts*** solved by
  - a ***shared knowledge base*** (KB)
  - ***tools*** and ***mechanisms*** to support the KB
- Semantic description of ***Application requirements*** and ***PaaS offerings***
- ***Application requirements*** and ***PaaS offerings matching***

Cloud4SOA Ontology Design

- ***Ontology*** development through a 5 steps modeling workflow
  - ***specification***
  - ***conceptualization***
  - ***formalization***
  - ***implementation***
  - ***maintenance***
- ***Conceptualization*** of Cloud4SOA model follows a "***meet-in-the-middle***" approach:
  - ***Top-down***: exploiting already existing ontologies (e.g. The Open Group SOA Ontology, TOGAF 9 Meta-Model, etc.)
  - ***Bottom-up***: concepts derived from PaaS domain analysis
- The ***ontology*** is formally ***expressed*** by using ***OWL2*** ontology language

Cloud4SOA Bindings

- A ***uniform interface*** is provided by Cloud4SOA APIs to ***interact*** with the ***platforms*** in a ***uniform*** and ***standardized*** way, thus ***enabling interoperability*** between the incompatible offerings
- Implemented ***bindings*** for several ***PaaS*** provide ***full*** working ***functionalities*** for ***deploying*** applications, ***managing*** their ***lifecycle*** and ***undeploying*** them
- A ***CLI*** is provided in order to ***receive***, ***interpret***, and ***execute*** user ***commands***
- The ***CLI*** language was designed to provide the ***same expressivity*** of ***OWL2*** language, but ***closer*** to the ***user world***

→ Recall the CF Service Broker concept!!!

AWS Beanstalk Amazon PaaS

- ***PaaS*** solution provided by ***Amazon***
- ***Based*** on the ***concept*** of ***application*** and ***application version***, representing a ***specific set*** of ***application functionalities*** at a specific time
- ***Environment*** as a ***collection*** of ***AWS resources*** instantiated to ***run*** a specific version of an ***application***
- ***Container type*** to describe the ***application stack***, default ***configuration***, and the ***AWS resources needed*** to create an environment
- ***APIs*** to ***manage*** the ***application lifecycle***
  - ***create***, ***delete***, and ***update*** an ***application*** with ***no version*** information
  - ***assign***, ***remove*** or ***update*** a specific ***application version***

Cloudbees PaaS

- ***PaaS*** solution focusing on ***developers needs***
- Cloud environment natively bound with tools and systems used by developers for building and testing their applications
- ***Continuous Integration***
- ***Ecosystem***
  - set of ***third-party*** Cloud-based ***tools*** that can be ***used*** in the ***CloudBees environment***
- ***DEV@Cloud*** framework
  - ***deploy*** applications to the ***Cloud***
  - ***continuous integration*** of a project into the ***Cloud***
- ***RUN@Cloud*** framework
  - ***deployment*** and ***management*** services to ***run applications*** in the ***Cloud***

Some Experimental Results

- A first set of tests reports on the ***overhead*** introduced by ***each module*** when ***performing*** the ***broker functionalities***
  - ***performance evaluations*** about the ***deployment*** of an application, by ***measuring*** the ***elapsed time*** of the operation
  - use of ***implemented adapters*** for ***AWS Beanstalk*** and ***Cloudbees***
  - Test performed by using a ***single account per provider***
- A second set of tests analyzes ***system performance*** by varying the ***workload***
  - use of ***mockup modules*** that ***simulate real adapters***
- Application ***size 4KB***
- Results are ***average values*** over ***10 runs***

Overhead for different PaaS Bindings

- ***CloudBees adapter*** does ***not introduce overhead*** because the ***mapping*** is almost ***one-to-one***
- ***Beanstalk adapter*** has to manage several interactions by ***calling various specific APIs***
- ***Specific API*** execution time is the ***longest*** one also because it is affected by ***network latency*** and ***provider performance***