Minik8s Lab Final Report

Introduction

Gitee Address

https://gitee.com/xtommy/minik8s

Branch

We follow the git branch model created by [Vincent Driessen in 2010](), and it is based in the following main branches with infinite lifetime:

- `master` : This branch contains **production code**. All development code is merged into `master` sometime.
- `worker` : This branch is almost the same as `master` branch. However, `master` branch is for the master node, while `worker` branch is for worker nodes. The configuration in the two branches is slightly different.

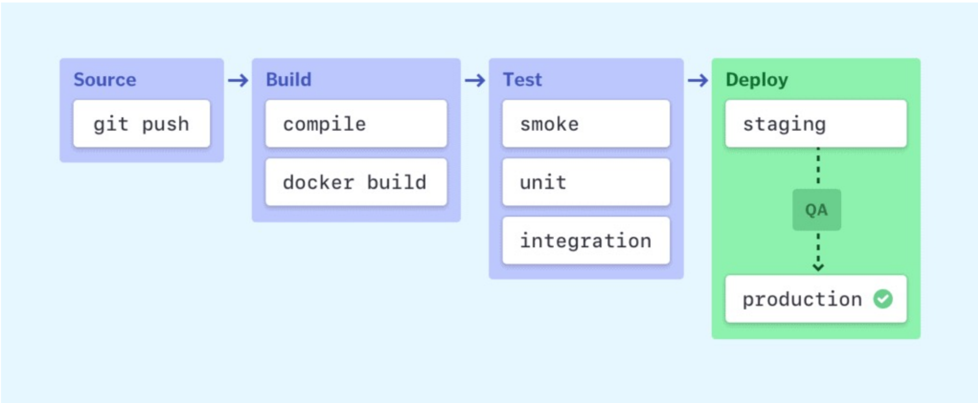
- `develop`: This branch contains pre-production code, which will finally be merged into the above two branches.

During the development cycle, a variety of supporting branches are used. The following branches are **feature branches**, which must be merged into `develop` after finished.

- `kpa` : Auto-scaling of serverless function.
- `serverless` : Serverless function, workflow, etc.
- `gpu` : Gpu-related functions which include uploading tasks to Slurm, and checking status at intervals.
- `service` : Kubernetes service abstraction.
- `dns` : DNS service in Minik8s.
- `proxy` : A network proxy runs on each node, which helps to serve load balancing for Minik8s Services.
- `iptables` : Configure all routing for Minik8s Services.
- `network` : Cluster networking model of Minik8s.
- `api-server` : Minik8s API server, validates and configures data for API objects, services REST operations and store data in etcd.
- `kubectl` : Command line tool for communicating with minik8s' control plane, using the Kubernetes API.
- `kubelet` : The primary "node agent" that registers the node and updates node status with API server.
- `controller-manager` : A control loop that watches the shared state of Minik8s cluster through API server, and attempts to move the current state towards the desired state.
- `scheduler` : A scheduler runs as part of the control plane, in charge of finding the best Node for a Pod to run on. Multiple scheduling policys are supported.
- `auto-scaling` : A Horizontal Pod Autoscaler, automatically updates a workload resource (ReplicaSet, Deployment, etc.), in order to scale the workload to match demand.

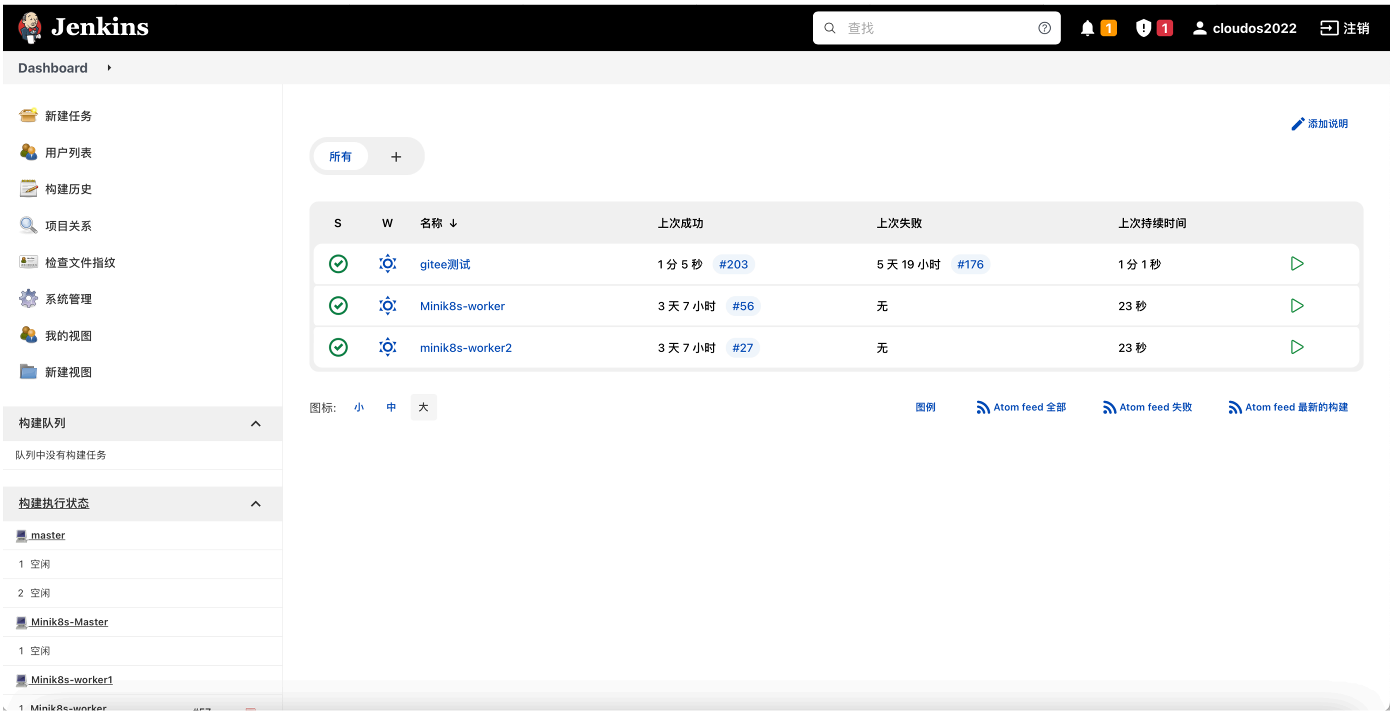
CI/CD

We use `Jenkins` as our CI/CD pipeline. `Jenkins` is an open-source server written in Java, for executing a chain of actions, to achieve continuous integration and continuous delivery in an automated fashion.



In our project, the building process of Jenkins is triggered by master branch. Every git commit on master branch is built and tested on the **master node** automatically and continuously, which ensures the changes pass all tests for the application. After that, it will trigger the same process on **worker nodes**.

After all predefined tests are passed, Jenkins will deploy the new version on all nodes, which is extremely convenient.



The script for Jenkins' building is in `minik8s/jenkins` directory. For further information, please log http://10.119.9.33:8080. The username and password are both `cloudos2022`. Note that you must access the website via the campus network.

Reference: https://zhuanlan.zhihu.com/p/90612874

Testing Methods

For testing level, we use **unit testing**, **integration testing**, and **system testing**.

For each section of the application, we use **unit testing** to ensure that it meets the design and behaves as intended. We take advantage of **Golang's built-in support for unit testing**. Take `minik8s/controller/test` as an example. We wrote several test cases for the controller manager, and `go test` command would execute all the test functions in test files.

For the combination of software modules, we use **integration testing** to verify correctness. Every time a new feature is committed, the Jenkins building process will start and initiate integration testing according to the script.

After Integration testing is done and the whole developing process is completed, we use **system testing** to test the system as a whole. Besides, **regression testing** is used after we fix a bug. We would re-running the original tests to ensure that the previously developed software still performs after a change.

For testing approach, we use **black-box testing** and **white-box testing**.

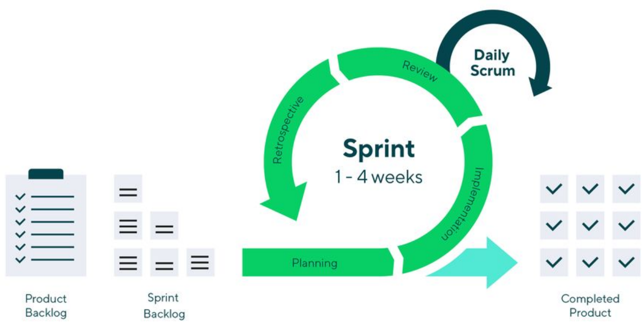
Black-box testing treats the software as a "black box", examining functionality without seeing the source code. In our project, we construct test cases and use `kubectl` for verification.

Meanwhile, white-box testing verifies the internal structures of a program, and code coverage is important. For example, according to the process of `etcd`, we wrote programs to verify the correctness of communicating with the database under different situations.

Development Process

We use **Scrum** as our software development process. Scrum is based on Agile Software Development. According to our plans, we divided the whole project into 3 short stretches of time called sprints. A sprint lasts two weeks. With each sprint, we add and improve features to perfect the project. Through `Jenkins`, we continuously test and deploy our project.

Daily scrums, or daily meetings, are short meetings held at the same time each morning. In our project, we held these meetings about every four days, and we mainly discuss the implementation detail of the project and unify APIs of different parts to prevent inconsistency.



Contribution

- Lin Zihong: 36%
- Huang Zhemin: 32%
- Wang Xunjie: 32%

Work Distribution

- Lin Zihong: Pod, Replicaset, Auto-scaling, Scheduler, Kubectl, GPU
- Huang Zhemin: Api-server, Serverless, GPU, CI/CD
- Wang Xunjie: Service, DNS, Container network

Video

For videoes used in presentation, please refer to https://jbox.sjtu.edu.cn/l/o1XU6X.

Structure

Project overview

license Apache | go 1.16

Dependencies

- gin: https://github.com/gin-gonic/gin
- cobra: https://github.com/spf13/cobra
- cast: https://github.com/spf13/cast
- gjson: https://github.com/tidwall/gjson
- go.uuid: https://github.com/satori/go.uuid
- etcd: https://github.com/etcd-io/etcd
- table: https://github.com/rodaine/table
- goph: https://github.com/melbahja/goph
- redis: https://github.com/go-redis/redis
- goquery: https://github.com/PuerkitoBio/goquery
- yaml: https://github.com/go-yaml/yaml
- testify: https://github.com/stretchr/testify
- go-iptables: https://github.com/coreos/go-iptables

Architecture

The main language of our project is `golang`. The reason we chose `golang` is that the whole ecosystem of `docker` and `k8s` is based on it. Also, `golang` is now a very mature language and has a good ecosystem, which means that we can use the libraries developed by others easily. What's more, it is also efficient in development, thanks to its language features.

For the implementation of some functions, using `golang` is too heavy, so we choose to use `shell`. For example, we use many shell scripts in the development of `Service`. And for some tiny jobs like starting a specified container, `shell` is more suitable.

In the whole system, `listwatch` is a very important function, it's based on message publishing and message watching. So, we need a message-oriented middleware, and we finally chose `Redis` because it's simple enough (message middleware is not the key point of the system) and we are all familiar with it.

The overall architecture is similar to `Kubernetes`. We implement `api-server`, `scheduler`, `controller-manager` in the control plane, `kubelet` and `kube-proxy` that are running in a node, and a command-line tool `kubectl`, which provides commands for controlling the system and acquiring its status.

All the components will be compiled as independent parts. The components of the control plane will be running in the master node, while the other components like `kubelet` will be running on a certain node.

We have applied for 3 cloud hosts for our project, one as both master and worker node, and the other two as worker nodes.

Node

`Node` here refers to `worker node`. `Pods` will be scheduled to any suitable node.

Node registration

We provide two ways to register a node to the control plane. One is using `kubectl apply -f` command that will parse a given YAML file specifying the attributes of a node, another is registering automatically by `kubelet`.

For the first method, here is an example:

```yaml
kind: Node
metadata:
  name: node
  namespace: default
ip: 0.0.0.0
```

Node monitor

`Node controller` is responsible for monitoring node statuses. The status of a node contains a field standing for the last time the node was synchronized with the system. And the controller will calculate the difference between the current time and the last synchronization time. The node will be marked as `Ready`, `unhealthy`, and `Unknown` according to the difference.

If a node keeps `unhealthy` for a certain time, it will be considered `unknown`. All the pods on such node will be removed, and all the metadata of it will be removed from `etcd`. Therefore, the scheduler will no longer schedule pods to such node, because it won't be able to get the information of this node.

Heartbeat

To stay connected with the control plane, the `kubelet` in a node will periodically publish the status of the node, as a kind of heartbeat. The `controller-manager` will watch the messages and store the statuses of nodes in its own cache. The `node controller` can then fetch the statuses and do its job.

Once there is a network partition and the heartbeats can not be sent to the control plane timely, the node will be considered unconnected and the pods scheduled to this node will be removed in order to recycle resources and immediately schedule the pods to the other available nodes to keep the service working.

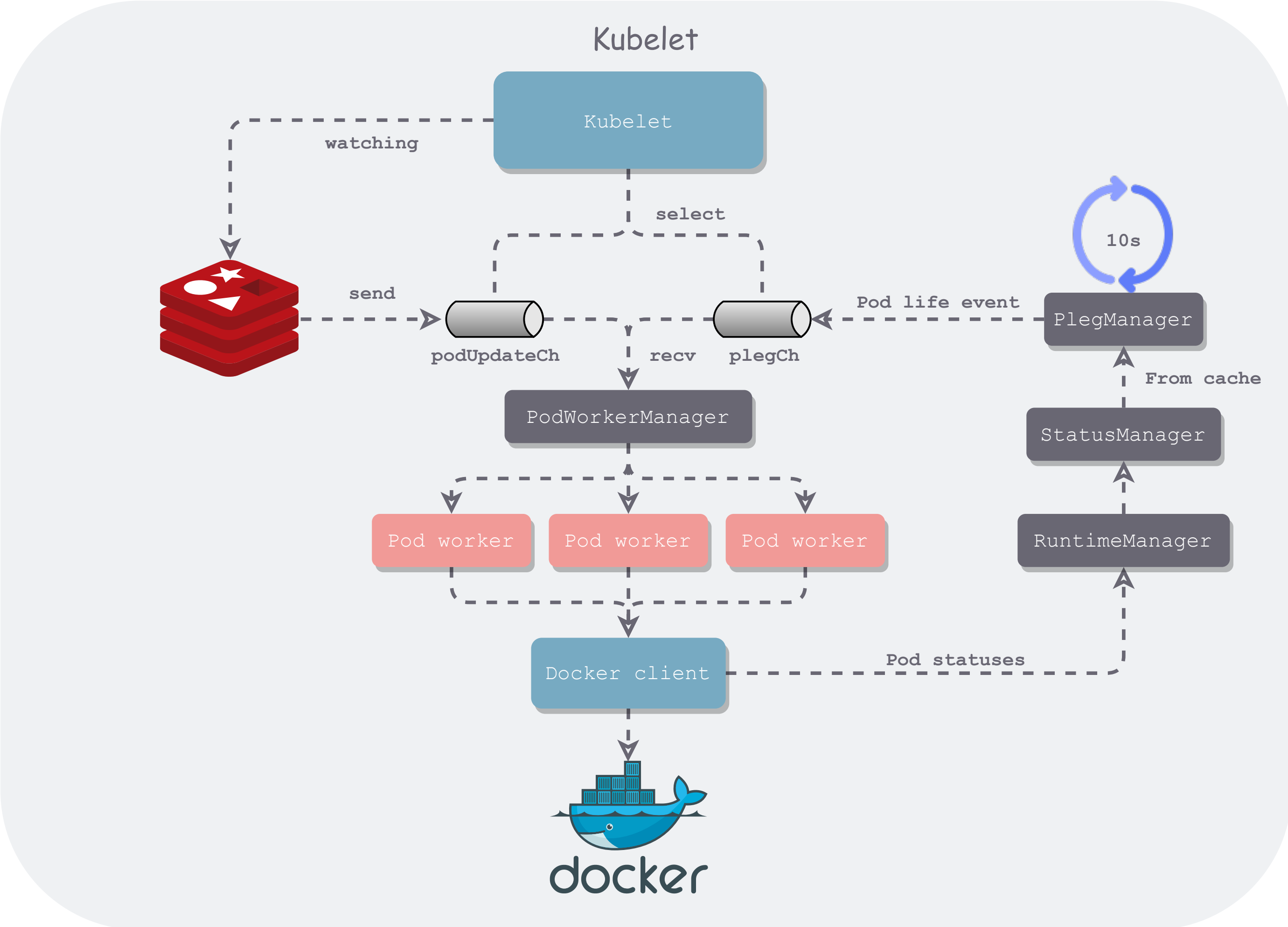
Kubectl

`kubectl` is a command-line tool that helps user controller `minik8s`. It's similar to `kubectl` in `Kubernetes`, but it's simplified and different in some commands. It is also based on `cobra`.

We support basic commands like `kubectl get pods`, `kubectl apply -f xxx.yaml`. For more info, see kubectl README. (Appendix 1)

Kubelet

The structure of `kubelet` in `minik8s` is similar to k8s, but it's greatly simplified.



Control flow

A pod will be created in many cases, manually using `kubectl` command, `replicaSet` maintaining `replicas`, creating `function` instance, etc. All of them will call apis provided by `api-server`. `Api-server` will handle created pods by publishing a `update message` (of type `entity.PodUpdate`) to a topic.

On the other side, `kubelet` will be watching on the topic and receive the message from `api-server`. The message will then be passed to `pod worker manager`. It will create corresponding `pod work` and dispatch it to a worker.

The worker can interact with docker through methods provided by `runtime manager`. `Runtime manager` is responsible for interacting with docker through docker client. It exposes apis for creating/deleting a pod, creating/deleting a container, pulling images, etc.

`Status manager` is responsible for fetching the statuses of pods through apis provided by `runtime manager`, and storing them in a cache. It will periodically do full synchronization with `api-server` to keep the cache consistent with the whole system.

`Pleg manager` is responsible for monitoring the statuses of pods and creating corresponding `ple` (namely **Pod Life Event**). The statuses come from the cache maintained by `status manager`. And a `ple` will be pushed into a channel called `plegCh`. Then the `ple` will be received by `pod worker manager` and it will create corresponding pod work and dispatch it to a worker.

Core: How to create a pod

Start an infra container first(default image is `registry.aliyuncs.com/google_containers/pause:3.6`). The infra container provides network namespace and volumes for all the other containers. So they can communicate with each other through `localhost` and share the same volumes. The infra container is responsible for creating the `port bindings` and `volume mounting`.

Here is an example of pod:

```yaml
apiVersion: v1
kind: Pod
metadata:
  name: pod
  namespace: default
  labels:
    app: myApp
spec:
  restartPolicy: Always
  containers:
    - name: viewer
      image: dplsming/nginx-fileserver:1.0
      ports:
        - containerPort: 80
      volumeMounts:
        - name: volume
          mountPath: /usr/share/nginx/html/files
    - name: downloader
      image: dplsming/aria2ng-downloader:1.0
      ports:
        - containerPort: 6800
        - containerPort: 6880
      volumeMounts:
        - name: volume
          mountPath: /data
  volumes:
    - name: volume
      hostPath:
        path: /pod
```

The pod contains two containers. One for downloading, and another for browsing downloaded files. Notice that they need to expose ports `80`, `6800` and `6880`(In our design, if you only specify the `containerPort` field, the container will choose a random available port for binding). The infra container will be responsible for the port bindings(the two containers should do nothing about port bindings because it's all done by the infra container).

Both containers need a volume called `volume`, so the infra container will mount volume for them.

All these two containers need to do is to join the namespaces created by the infra container.

Here is a part of code about creating a common container. Please pay attention to the `NetworkMode`, `IpcMode` , `PidMode` and `VolumesFrom` field.

```go
return &container.ContainerCreateConfig{
  Image:       c.Image,
  Entrypoint:  c.Command,
  Cmd:         c.Args,
  Env:         rm.toFormattedEnv(c.Env),
  Volumes:     nil,
  Labels:      labels,
  Tty:         c.TTY,
  NetworkMode: container.NetworkMode(pauseContainerRef),
  IpcMode:     container.IpcMode(pauseContainerRef),
  PidMode:     container.PidMode(pauseContainerRef),
  Binds:       rm.toVolumeBinds(pod, c),
  VolumesFrom: []string{pauseContainerFullName},
}
```

Meanwhile, any container in the pod has a special label that contains the `UID` of the pod it belongs to, which will make it convenient to find the containers of a given pod.

How to allocate unique IP for pods

Weave Net can be used as a Docker plugin. A Docker network named `weave` is created by `weave launch`, which can be visible in the whole cluster. Under the Weave Net, containers can be allocated its `ClusterIP` in the cluster.

After the `pause` container has been created, `kubelet` runs the command `weave attach <ip> <pause_container_id>` to attach `ClusterIP` to the pod.

To make the Weave Net visible from host, run the command `weave expose <ip>` to join the Weave Net.

How to create a pod through control plane

We provide `kubectl apply -f` command that can create a pod in a declarative way. You can specify the attributes of a pod, like its port bindings and volumes in the YAML file. The specification of a pod is actually the same as the one of `k8s`.

We support any number of containers in a pod, and you can see the results after the pod was created in our display video.

An example of shared network namespace and volumes

Still take the pod in Core: How to create a pod as an example, if we create a file by using the command `echo 123 > test.txt` in the directory `/data` in `downloader`, then this file can be seen in the directory `/usr/share/nginx/html/files` in `viewer`. In addition, in `downloader`, we can download the file throw the command `wget localhost:80/files/test.txt`. It's all because the two containers share the same volumes and network namespace.

They can communicate with each other throw `localhost`. You can see these effects more clearly in the display video.

How is a pod scheduled

For scheduling strategy, see [scheduler](). And you can see the node a pod is scheduled to through `kubectl get pod` command.

Support & References

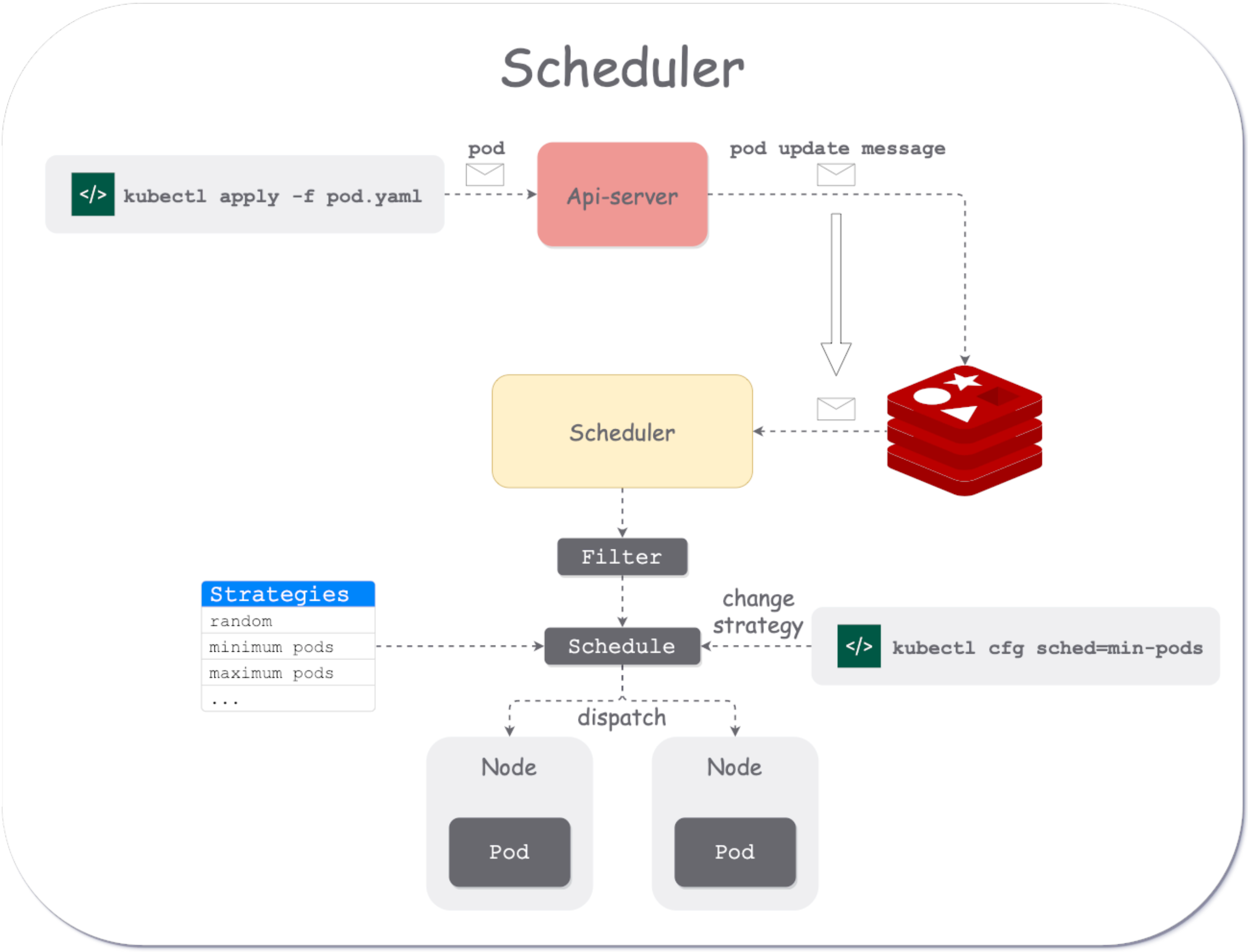
- Docker http client: [Moby]()
- Docker api document: [Docker Engine API (v1.41)]()
- A good article on pod creation: [2.2 从 Pause 容器理解 Pod 的本质]()

Scheduler

The function of `scheduler` is very clear and simple, scheduling the newly created pods.

The process of scheduling can be broken down into several steps:

- Get the list of available nodes from `api-server` through REST apis.
- If there is a `nodeSelector` in the specification of the pod, then filter the list according to given labels.
- Select one node according to a certain strategy from the filtered nodes.



Here are some strategies we support now:

strategy	Description
random	Select a node randomly
minimum pods	Select the node with the minimum number of pods
maximum pods	Select the node with the maximum number of pods
minimum cpu utilization	Select the node with the minimum CPU utilization
minimum memory utilization	Select the node with the minimum memory utilization

The strategy is by default `random`. You can also dynamically change the strategy by using `kubectl cfg` command. For more info about this command, see the README.md of `kubectl`.

Api-server

`Api-server` is the center of `minik8s`. It should expose REST apis for other components of the control plane. For fast development, we adopted a mature framework: **gin**.

`Api-server` behaves like an agency or proxy. It provides enough apis for operating the system and is responsible for interacting with `etcd`.

Its core logic is quite simple, just interacts with all the other components, and is responsible for the transmission of data and messages. For example, if a component needs to fetch something from `etcd`, it can call the REST APIs provided by `api-server`, and `api-server` will be responsible for fetching data from `etcd`, and transmitting it to the receiver.

Proxy & Service

`Proxy` is responsible for allocating virtual service IP, which is unique and visible in the whole cluster. `Proxy` will prepare an `nginx` container for each service. The `nginx` container will attain its service IP in Weave Net and `proxy` will configure the `nginx.conf`. Users and other pods in the Weave Net can visit services just through these service IPs.

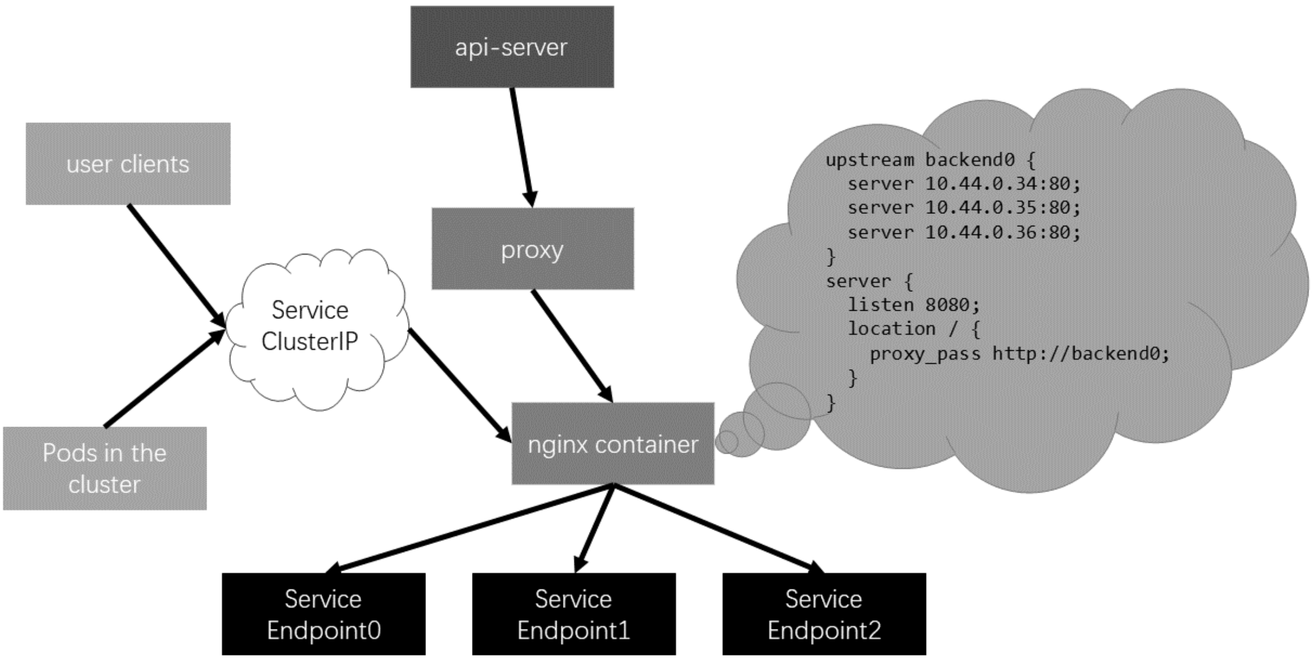
How proxy watches Service and Endpoint objects and then modifies the cluster network

- When a `Service` object is being created, `api-server` scans all `Endpoint` objects and finds all `Endpoint` objects with the corresponding key-value selector. `api-server` will publish these `Endpoint` objects and this `Service` object to the topic `serviceUpdateTopic` in `Redis` to notify `proxy` a `Service` object has been created. `Proxy` will then start an `Nginx` container, allocate `ClusterIP` of `Service` to the container and configure the `nginx.conf` file to map each `Service`

port to the corresponding `Pod` ports (`Endpoints`) and also do **load-balance** if there are **multiple** `Endpoints`, for example, a `ReplicaSet` or some `Pods` with the same key-value selector.
- When a `Service` object is being deleted, similar to `Service` creation, `api-server` will publish the `Service` objects to the topic `serviceUpdateTopic` in `Redis`. `Proxy` will then shut down the `Service`'s `nginx` container.
- When an `Endpoint` object is being created or deleted, `api-server` scans all `Service` objects and finds all `Service` objects with corresponding key-value selector. `Api-server` will publish `Endpoint` objects and `Service` objects to the topic `endpointUpdateTopic` in `Redis` to notify `proxy` an `Endpoint` object has been created or deleted. `Proxy` will update `nginx.conf` files and apply to corresponding `nginx` containers.

How Pods or users visit Services in the cluster

- All `Pods` and users in the cluster will join the Weave Net first. Then the `Service`'s `ClusterIP` (the `ClusterIP` of `nginx` container) is available to all Pods and users.



DNS

CoreDNS is a DNS server, which can be configured through its `Corefile`.
When `api-server` receives an `apply` request of `DNS`, `api-server` will first start an `nginx` container to deal with the path-service mapping issue and then add the IP-name mapping to CoreDNS.

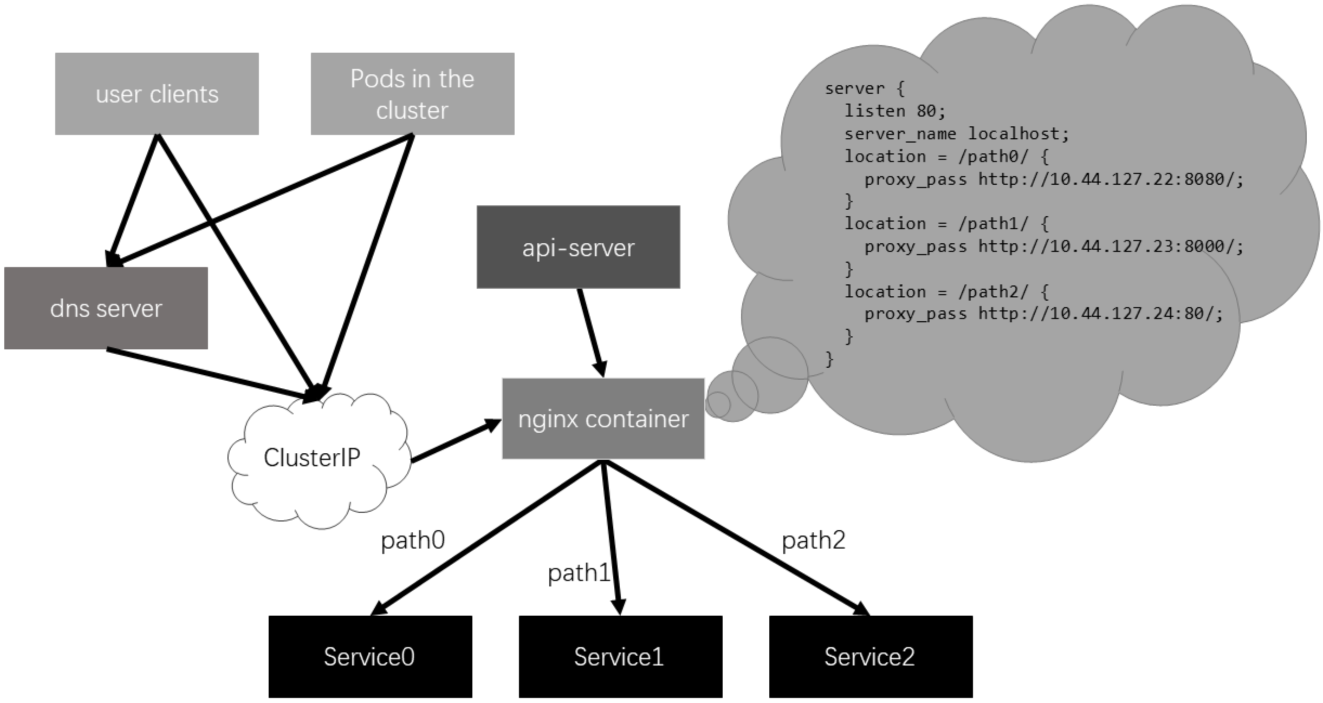
How Minik8s maps paths to Services and allocates domain name

- During initialization of Minik8s, Minik8s will redirect the nameserver of host machines and containers to CoreDNS through configuring `/etc/resolv.conf` and `/etc/docker/daemon.json`.
- Minik8s use `nginx` containers to map paths to Services. For a `DNS` object, minik8s will start an `nginx` container, allocate an IP, and then configure the `nginx.conf` file to map each path to the corresponding `Service` ports. Then Minik8s will add a name-IP(the `nginx` container IP) mapping to

CoreDNS.

How Pods or users visit Service through its domain name in the cluster

- `Pod`s and users in the cluster will ask nameserver for name-IP mapping, and then visit the corresponding `nginx` container. `nginx` container will redirect the path request to `ServiceIp:ServicePort` to visit `Service`.

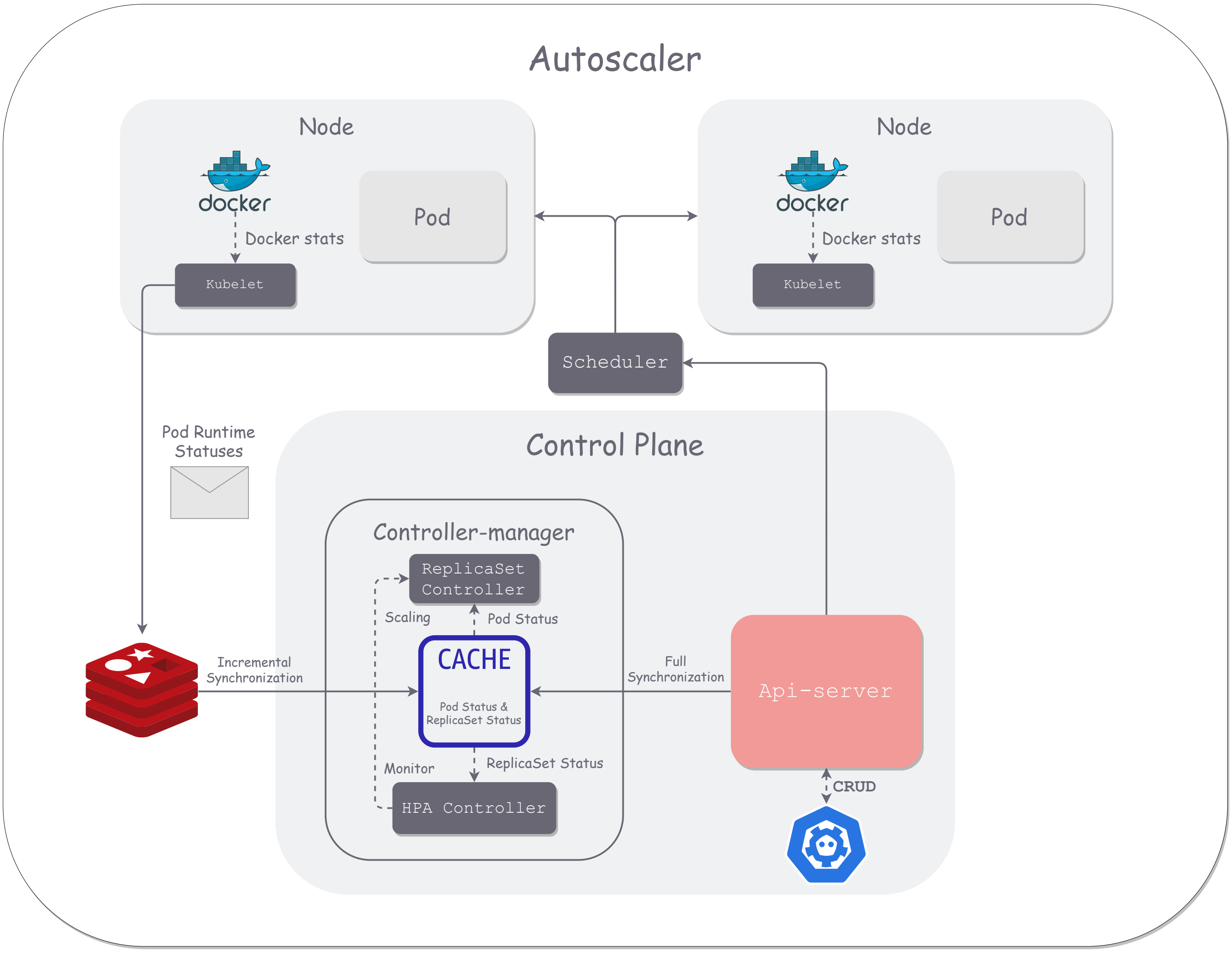


ReplicaSet & Autoscaler

Structure

`Kubelet` in each node will collect runtime status through `docker status`, including cpu and memory utilization. All these statuses will be published to a certain topic, on which both `api-server` and `controller-manager` are watching.

Here is a shared cache in the `controller-manager`. It can receive the statuses published by `kubelet` and do `incremental synchronization`. Meanwhile, `api-server` will persist these statuses into `etcd`, a distributed K-V store system.
`etcd` is the one who truly indicates the status of the whole system. So, the cache in the `controller-manager` has to
periodically do full synchronization with `api-server`, in order to stay consistent with `etcd`.



`replicaSet controller` can fetch the status of running pods, and dynamically keep the number of pods consistent with given `replicas`. Once the number of pods is inconsistent with `replicas`, the controller will create/delete pods through apis provided by `api-server`. The pods created by replicaSet have a special label that stores the `UID` of the replicaSet they belong to, which will make it convenient to find the pods of a given replicaSet.

In our display video, you can see that once we delete a pod maintained by the replicaSet, it will create a new one to keep the number of pods consistent with the specification.

Notice that all these jobs is done by a worker. Once a `replicaSet` was created, the controller will create a corresponding worker to monitor the number of pods, through a synchronization loop.

For `hpa`, there is also a controller. Once a `hpa` is created, it will also create a corresponding worker. Likewise, the worker will monitor given metrics(we support `cpu utilization` and `gpu utilization` now).

Take `cpu utilization` for example, `hpa worker` will monitor the status of a given `replicaSet`, which contains the CPU and memory utilization. The worker will compare the `cpu utilization` to the benchmark specified by user.
If `cpu utilization` of the replicaSet is higher than the benchmark, it will dynamically increase the `replicas` of the replicaSet. Therefore, the corresponding replicaSet worker can create more pods to balance the workload.

We reuse the implementation of `replicaSet`, making its `replicas` **mutable**. We can dynamically change it through
apis provided by `api-server`. You can see that we also reuse this feature in [function].

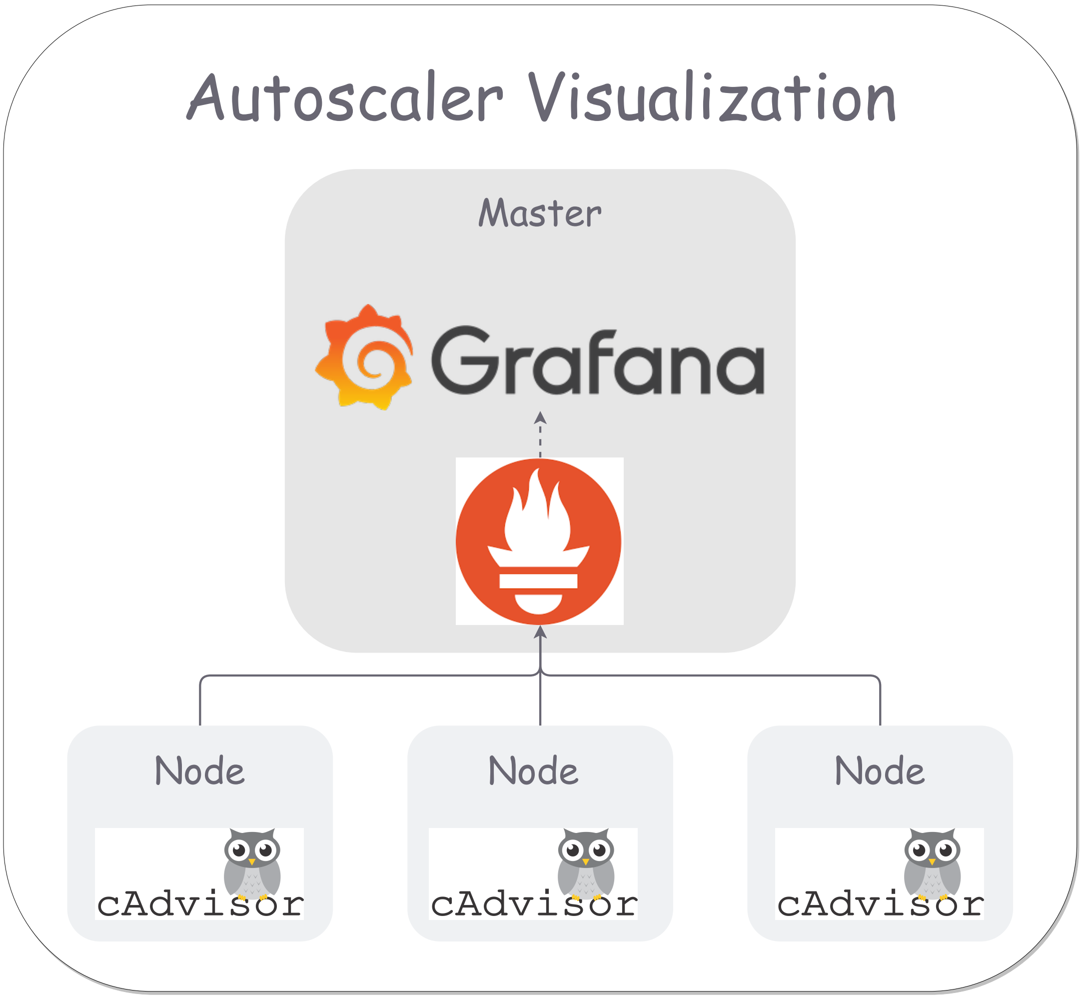
Notice that user can flexibly specify the interval of scaling by using `kubectl autoscale` command(`-i` flag). For example, if the specified interval is `15s`. Then the `hpa controller` will check every 15 seconds whether scaling is needed. For example, if the target replicaSet should be scaled to 5, while the current replicas is 3, then the `hpa controller` will dynamically change the replicas of the replicaSet to 4. In this way, it can guarantee that there will be at most 1 new pod to create every 15s.

How do we collect metrics

Take `cpu utilization` for example. The `kubelet` in a node will collect status of containers through `docker stats` command. The status contains `cpu utilization`, `memory utilization` and many other useful metrics. Once we get the metrics of containers, then we can get the metrics of the pod they belong to. Likewise, we can also get the metrics of a replicaSet in this way.

Visualization

The pod resources monitor is based on `cAdvisor`, `Prometheus` and `Grafana`.



All the worker nodes will start a `cAdvisor` container, which will continuously collect the status of docker containers. `cAdvisor` is based on `docker stats`, and can expose metrics which can be used by `Prometheus`.

`Prometheus` can collect all metrics produced by `cAdvisor` and exposed them to `Grafana`.

`Grafana` can visualize the metrics in customized dashboard.

We recommend you to use grafana dashboard with UID `11277` and `893`.

Here is a good reference: [Build up Prometheus + Grafana + cAdvisor]

Hint

Because all these components are running in containers, so you can't access other running components by simply using `localhost`(Even if they are running in `host` network mode). Please use the IP instead.

How to create a replicaSet

You can create a `replicaSet` in the same way as creating a `pod`. The specification is the same as `k8s`, consisting of metadata, the number of replicas and the template of pod. You can see the status of the newly created replicaSet and the pods created by it, through `kubectl get` command.

How to create a hpa

We provide two ways to create a `hpa`, one is the same as creating a replicaSet, another is using command `kubectl autoscale`. You can specify the minimum and maximum replicas, the target replicaSet, the metrics(`cpu utilization` or `memory utilization`) and the scaling interval in the yaml file or command line.

Here is an example(suppose we have created a replicaSet called `rs`, and if the target replicaSet does not exist, it will raise an error):

- command line: `kubectl autoscale hpa --target=rs --min=1 --max=4 -c 25 -i 10`
- yaml file:

  ```yaml
  apiVersion: autoscaling/v1
  kind: HorizontalPodAutoscaler
  metadata:
    name: hpa
    namespace: default
  spec:
    minReplicas: 1
    maxReplicas: 4
    scaleTargetRef:
      apiVersion: v1
      kind: ReplicaSet # we only support replicaSet now
      metadata:
        name: rs
        namespace: default
    scaleInterval: 10
    metrics:
      CPUUtilizationPercentage: 25
  ```

  You can see the status of a hpa through `kubectl get` command.

Display

For display, we prepare a docker image, here is its dockerfile:

```
FROM alpine

COPY autoscaler-testcase ./autoscaler-testcase

RUN chmod +x ./autoscaler-testcase

ENTRYPOINT ["./autoscaler-testcase"]
```

`autoscaler-testcase` is an executable file. It is written in `golang`. It runs a http server and provides apis for immediately increasing/decreasing cpu utilization. So, we can increase/decrease a container's cpu utilization flexibly in this way, to display the feasibility of the implementation of `hpa controller`.

In our display video, you can see that once the cpu utilization of a container/pod/replicaSet increases(dramatically), the replicas will be dynamically increased by `hpa controller` to balance such workload. So the job can then be passed from `hpa controller` to `replicaSet controller`. It is `replicaSet controller` that controls the number of pods.

You can see that whether increasing or decreasing the cpu utilization, the `hpa controller` all behaves as expected.

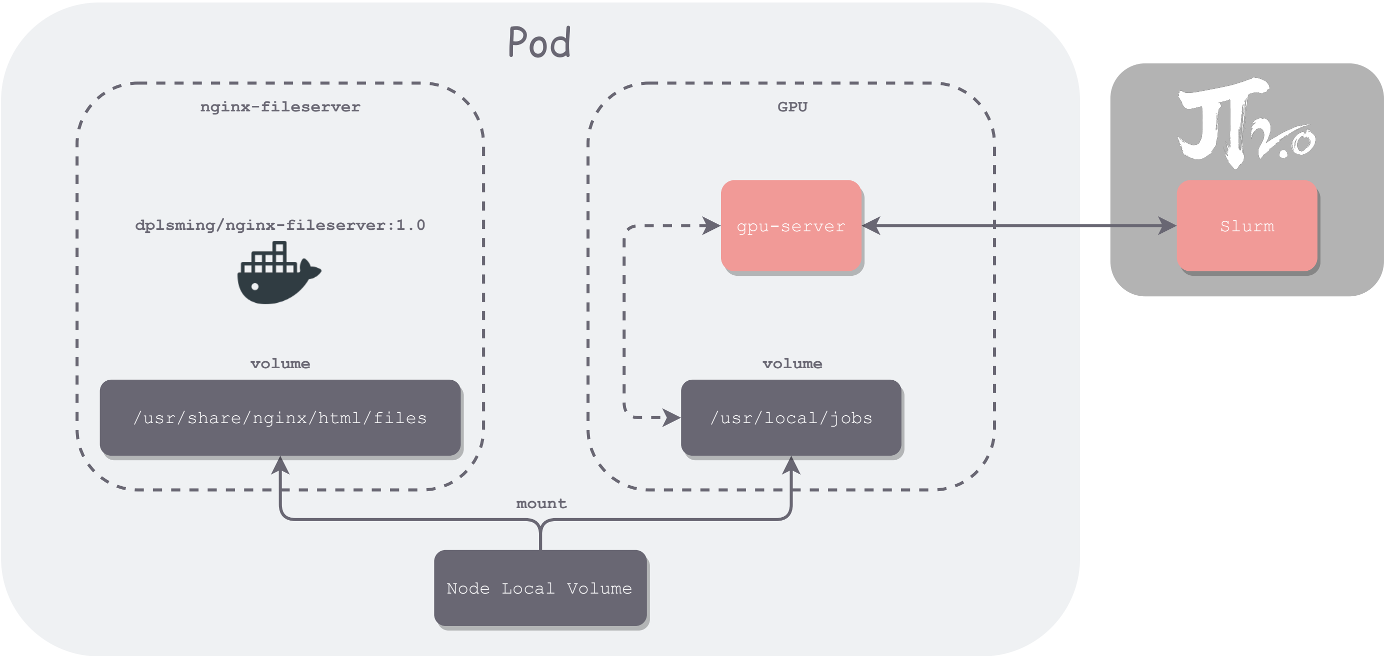
GPU

Users only need to specify the scripts needed to compile cuda files and run them, and also the working directory.

The cuda files(ended with `.cu`) will be recognized and uploaded to the π2.0 platform. The slurm script will be created automatically according to given parameters.

The jobs should be independent of each other, so we adopt a sidecar structure. The `gpu-server` will upload cuda files, compile them, create slurm script and finally submit the job by using the command `sbatch`.

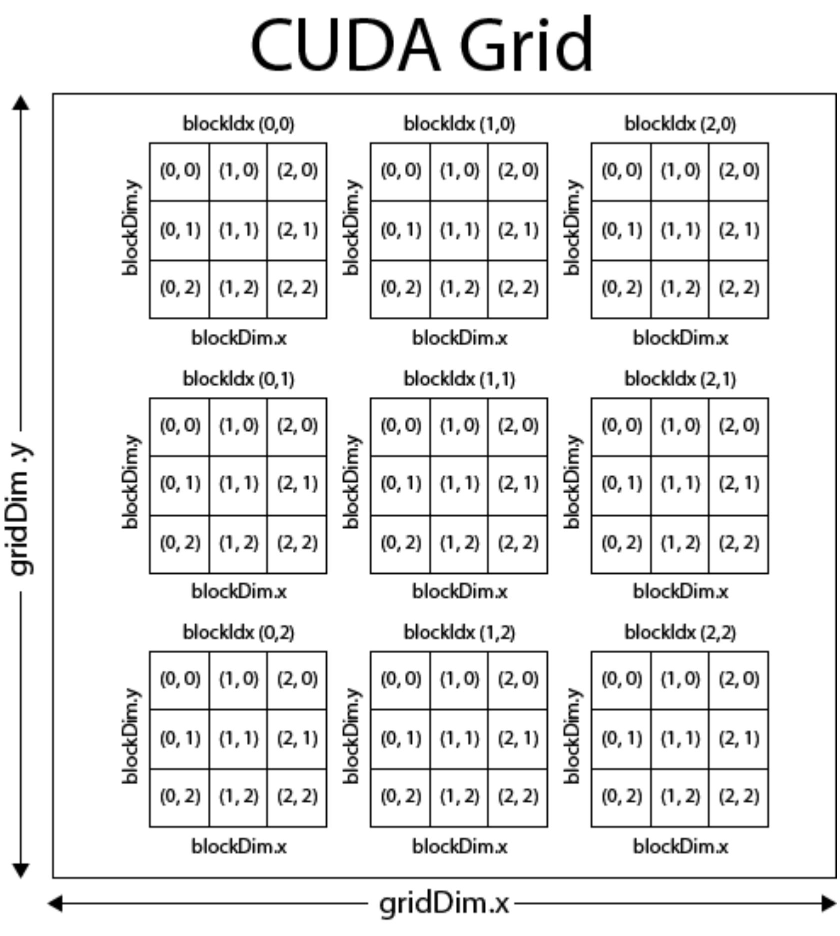
Since we don't have a good idea to be aware of the completion of submitted jobs(π2.0 supports email alert, but it's not suitable for this situation). So we temporarily adopt the strategy of polling(every 5 minutes). Once the job has been completed(can be known by using command `sacct`. If the job returned is `COMPLETED` in its `State` field, then it is completed), the `gpu-server` will download the output file and error file(`xxx.out`, `xxx.err`, specified by users).
Users can then browse and download the results of jobs using `nginx-fileserver`.



Cuda

Each block in `cuda grid` is corresponding to an area in a matrix. We can map a cell in the block to an element in a
matrix.

```
int i = blockIdx.x * blockDim.x + threadIdx.x;
int j = blockIdx.y * blockDim.y + threadIdx.y;
```



`blockIdx` stands for the coordinate of a block. For example, the block in the upper left corner has `blockIdx(0,0)`

`blockDim` stands for the dimension of a block. A block is two-dimensional, so `blockDim.x` stands for the width while `blockDim.y` stands for the height.

`threadIdx` stands for the coordinate of a thread inside a block. Similar to `blockIdx`.

Because `gpu` is a `device` and it does not share memory with `cpu`. Special functions should be used to do memory operations in `gpu`.

Keyword `__global__` can be used to define a function that will be called in `gpu`. If you have defined a function f:

```
__global__ void f() {}
```

Then you can call it by:

```
f <<<blockDim, threadDim>>>();
```

The types of both `blockDim` and `threadDim` are `Dim3`. You can define a variable of type `Dim3` by:

```
Dim3 var(x, y)
```

You only need specify the first two dimension, for the third dimension is always 1.

For matrix addition:

```
__global__ void matrix_add(int **A, int **B, int **C) {
    int i = blockIdx.x * blockDim.x + threadIdx.x;
    int j = blockIdx.y * blockDim.y + threadIdx.y;
    C[i][j] = A[i][j] + B[i][j];
}
```

For matrix multiplication:

```
__global__ void matrix_multiply(int **A, int **B, int **C) {
    int i = blockIdx.x * blockDim.x + threadIdx.x;
    int j = blockIdx.y * blockDim.y + threadIdx.y;
    int value = 0;
    for (int k = 0; k < N; k++) {
        value += A[i][k] * B[k][j];
    }
    C[i][j] = value;
}
```

π2.0 GPU Support

Reference:

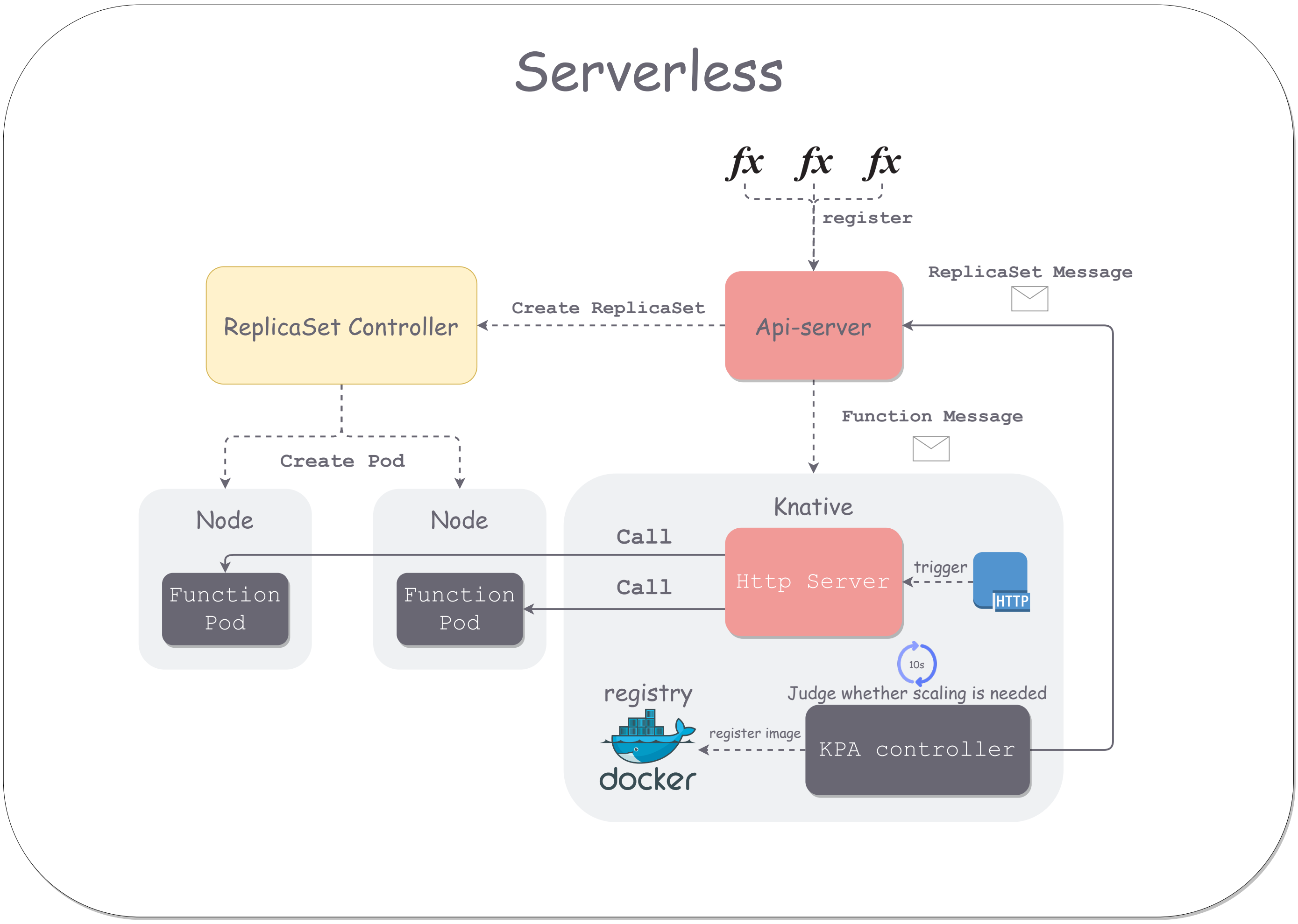
- https://github.com/SJTU-HPC/docs.hpc.sjtu.edu.cn
- https://docs.hpc.sjtu.edu.cn/index.html
- https://docs.hpc.sjtu.edu.cn/job/slurm.html
- https://studio.hpc.sjtu.edu.cn/

Serverless

Structure

The structure of our serverless system draws lessons from `Knative` but is quite simplified. Users can register functions to `api-server`. `KPA controller` will create corresponding function image and push it into docker registry.
It will also create a replicaSet through `api-server` apis.

The `ReplicaSet Controller` can then create pods on nodes. Notice that there is a http server running on master node
(port `8081`), and you can call a function by http trigger.



Function Registration

User can register a function (we only support `python` now) to the `api-server`. Here is an example of function:

```
def main(params):
    x = params["x"]
    x = x + 5
    result = {
        "x": x
    }
    return result
```

This function needs a parameter `x` and `x` is passed in the form of `json`, and will add 5 to `x` and return a dictionary/json.

In our system, all parameters and results can be transferred in the form of `json` , and there is no need to pass the parameter type in `json`, since interpreter itself can infer variable type automatically.

Once a function is registered, a corresponding image will be pushed to the registry and a replicaSet will be created, which will create pods(function instances) on worker nodes.

Http Trigger

We support a convenient way to call a function by http trigger. You can type `kubectl trigger [funcname] -d [data]` to
send http trigger to the specified function instances.

Because the function instances are maintained by a `replicaSet`, so the http server in `Knative` will randomly choose one pod in the replicaSet and call it.

Take `addFive` for example, you can type `kubectl trigger addFive -d '{"x": 100}'`, and you will get a response: `'{"x": 105}'`

All pods have their own unique ip, so they can be called by `POST` http request to `${pod_ip}:8080`.

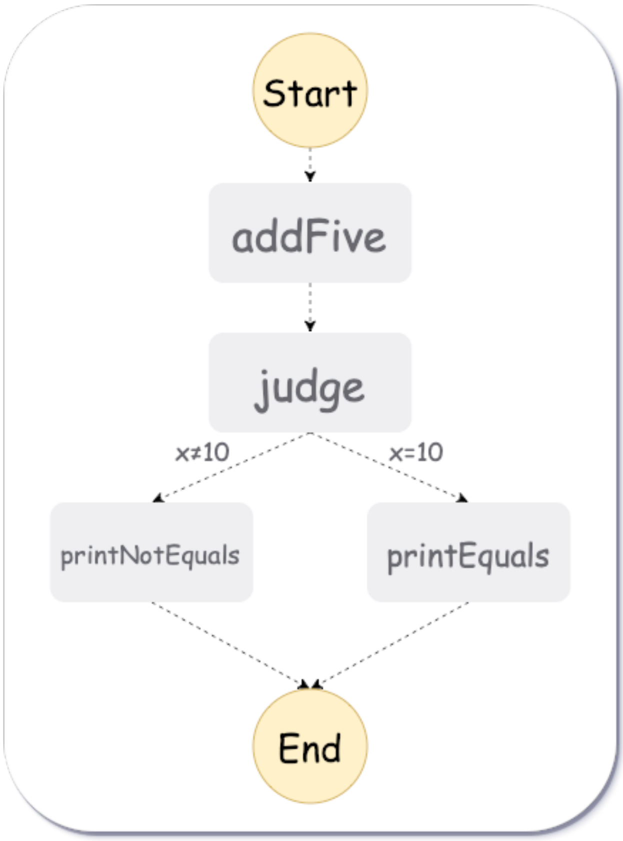
Workflow

A workflow is equivalent to a DAG of functions. It can be defined in the form of `json`, see [workflow]() for examples.

Our implementation draws lessons from AWS. We also support `Choice` and `Task`.

For parameters' types, we support String, Boolean, and Numeric types. Each of these types supports Equal, NotEqual, GreaterThan, and LessThan. Besides, since the result is passed by `json`, the interpreter will automatically defer types, and users do not need to declare types of variables.

Workflow example(Graph):



Workflow example(Json):

```
{
  "apiVersion": "/api/v1",
  "kind": "Workflow",
  "metadata": {
    "namespace": "default",
    "name": "print"
  },
  "startAt": "addFive",
  "params": {
    "x": 5
  },
  "nodes": {
    "addFive": {
      "type": "Task",
      "next": "judge"
    },
    "judge": {
      "type": "Choice",
      "choices": [
        {
          "variable": "x",
          "numericEquals": 10,
          "next": "printEquals"
        },
        {
```

```
          "variable": "x",
          "numericNotEquals": 10,
          "next": "printNotEquals"
        }
      ]
    },
    "printEquals": {
      "type": "Task"
    },
    "printNotEquals": {
      "type": "Task"
    }
  }
}
```

Reference

- [创建无服务器工作流]

NOTE: If you want to delete function image from the docker registry, you should set the environment variable `REGISTRY_STORAGE_DELETE_ENABLED=true`.

Consistency

All the states are persisted in `etcd`. If a component is crashed, when it restarts, it will recover its state to stay consistent with `etcd`.

For example, if a pod is scheduled to a node, and the node crashed. When it has restarted, it will do full synchronization with the states stored in `etcd`. So it will know that a pod has been scheduled to it before. It can then recreate the pod according to the state of the pod.

In addition, we use cache in many components. The cache will do incremental synchronization by watching on certain messages, and periodically do full synchronization with `etcd`.

It is `etcd` that stores the state of the whole system. As long as all components synchronize with it, the consistency of the whole system can be guaranteed.

Tools

Container Management

For `windows`, we have `Docker Desktop` to monitor the stats of all containers. But in linux, we don't have such convenience.

Fortunately, `portainer` performs even better than `Docker Desktop`. It can be deployed easily by using docker. You can type `./portainer-run.sh` to start the portainer. Then you can access it at http://localhost:9000.