Kubernetes Operator Pattern 實作

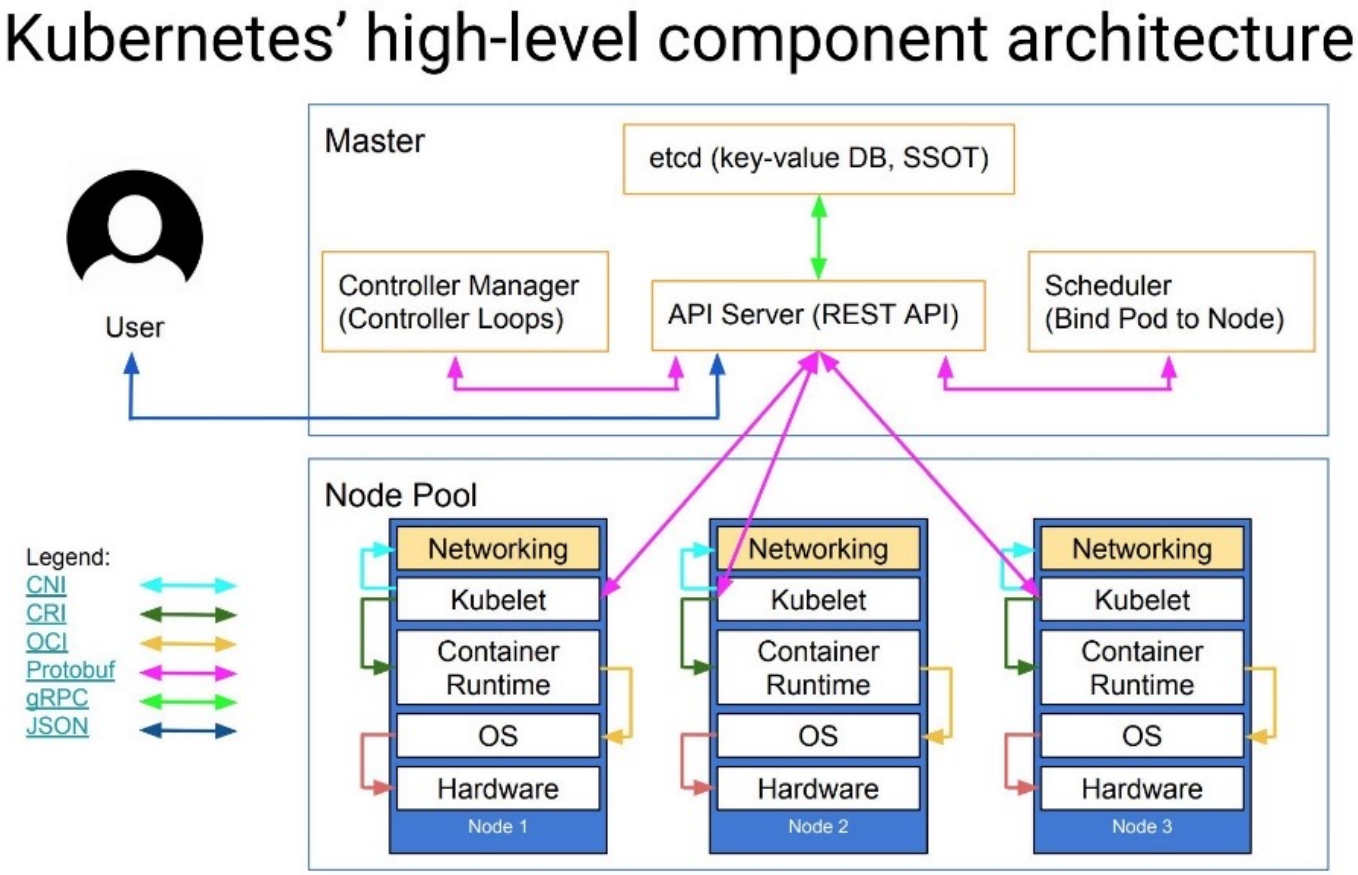
莊家儁

什麼是Kubernetes

- Kubernetes 是 Google 開源的Container分散式管理系統
- 管理OCI標準映像檔的容器叢集排程服務，簡稱為k8s(‘k’ + 8 letters + 's’)

Kubernetes 基本架構

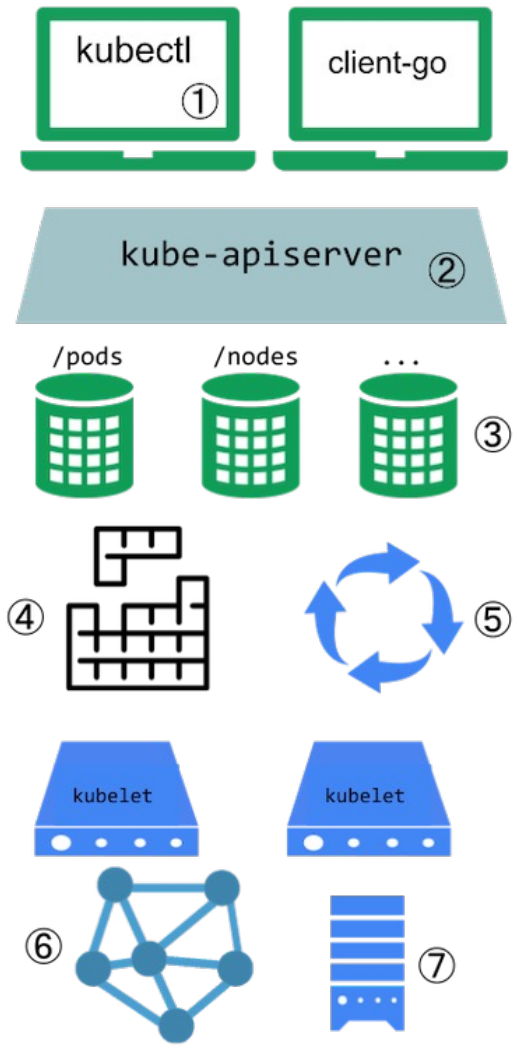
- Kubernetes 屬於分散式架構系統，主要由master與多個node組成



Kubernetes基本機制

- configuration convergence:
  - 不斷的比較期望的配置和實際的配置，修訂實際配置以收斂到期望配置
- 寫入期望配置:
  - Kubernetes 裡的所有資源對象， Service、Deployment、等等，都是通過 api-server 檢查格式後，序列化並存入 etcd
- 收斂到期望配置:
  - controller 使用api-server 的 watch API 收取 etcd 裡資源的期望配置，和通過 kubelet 收集到的實際配置做對比並修正差異

Kubernetes Extension Point



- 1. Kubectl Plugin
- 2. Admission Controll hook
- 3. Custom Resource
- 4. Scheduler
- 5. Custom Resource Controller
- 6. CNI
- 7. Device Plugin

Operator Pattern

Operator pattern

Operators are software extensions to Kubernetes that make use of custom resources to manage applications and their components. Operators follow Kubernetes principles, notably the control loop.

Motivation

The Operator pattern aims to capture the key aim of a human operator who is managing a service or set of services. Human operators who look after specific applications and services have deep knowledge of how the system ought to behave, how to deploy it, and how to react if there are problems.

People who run workloads on Kubernetes often like to use automation to take care of repeatable tasks. The Operator pattern captures how you can write code to automate a task beyond what Kubernetes itself provides.

https://kubernetes.io/docs/concepts/extend-kubernetes/operator/

Operator Use Case

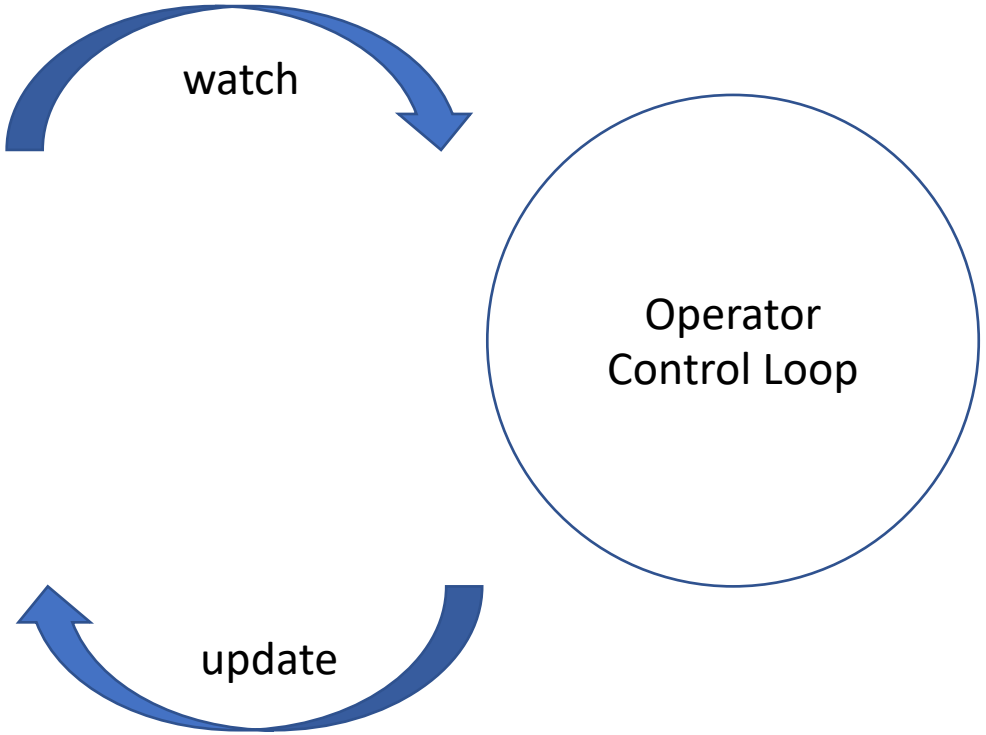
- 公司有多個部門，每個部門有對應的Namespace

- 部門成立時 (Create)
  - 建立Namespace，在其下建立:
  - ConfigMap包含共用設定檔
  - Deployment運行部門網站
- 每年稽核時 (Update)
  - 定期更新密碼
- 部門裁徹時 (Delete)
  - 要刪除這些建立的資源

使用Operator

Project CRD

```
apiVersion: xyz.com/v1
kind: Project
metadata:
   name: abc-department
spec:
   image: “abc-web-server:0.1.2”
   password: “P@ssw0rd”
status:
   Ready: True
```



Case Study: Cert manager

- Let’s Encrypt HTTP-01 Challenge

```yaml
apiVersion: cert-manager.io/v1alpha2
kind: Certificate
metadata:
  name: acme-crt
spec:
  secretName: acme-crt-secret
  dnsNames:
  - foo.example.com
  - bar.example.com
  issuerRef:
    name: letsencrypt-prod
    # We can reference ClusterIssuers by changing the kind here.
    # The default value is Issuer (i.e. a locally namespaced Issuer)
    kind: Issuer
    group: cert-manager.io
```

5. 第二個挑戰：`http-01`

這個挑戰要你在官網建立一個**特殊網址路徑**的**文字檔案**，而且必須可以讓 Let's Encrypt 網站能夠公開存取該網址，而且一定只能走 **Port 80** 進行 HTTP 連線，不能使用任何其他埠號，如此一來才能驗證你就是該網站的擁有者！

網址路徑：`/.well-known/acme-challenge/IKibDaF4-FHZoGw1U6JTyGlBDMOtE-cQCFw13e4FaUc`

檔案內容：

`IKibDaF4-FHZoGw1U6JTyGlBDMOtE-cQCFw13e4FaUc.plEmWe4UXqKWJvuRWXDnZDtkeEh2omjTeQWuZ`

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Create a file containing just this data:

IKibDaF4-FHZoGw1U6JTyGlBDMOtE-cQCFw13e4FaUc.plEmWe4UXqKWJvuRWXDnZDtkeEh2omjTeQWuZ
HEKan4

And make it available on your web server at this URL:

http://angular.tw/.well-known/acme-challenge/IKibDaF4-FHZoGw1U6JTyGlBDMOtE-cQCFw1
3e4FaUc

(This must be set up in addition to the previous challenges; do not remove,
replace, or undo the previous challenge tasks yet.)

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Press Enter to Continue
```

> 注意：網站一定要能夠接聽 Port 80 的 HTTP 連接喔！

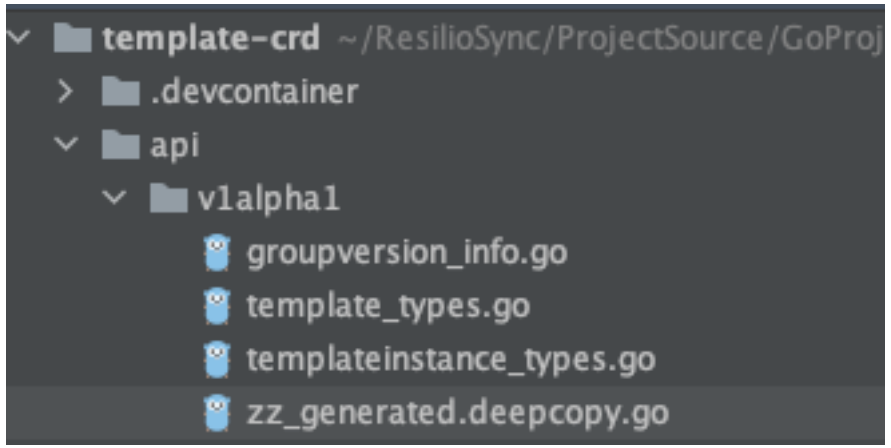
最後用瀏覽器確定 `http-01` 挑戰的網址可以順利打開，才能按下 `Enter` 繼續！

> 照理說，這個步驟其實很容易完成，就建立幾個資料夾與一個文字檔案而已。但我的網站不小心在 IIS 設定了一個**虛擬目錄**(Virtual Directory)，導致這個 `.well-known` 目錄無法存取該檔案。如果你真的遇到這個問題，可以在**網站根目錄**的 `web.config` 檔案 (如果沒有這個檔案可以自己建立同名檔案) 加入一條 Rewrite 規則，讓 `.well-known/acme-challenge/IKibDaF4-FHZoGw1U6JTyGlBDMOtE-cQCFw13e4FaUc` 網址會直接**重寫**(Rewrite)到 `/acme-challenge.txt` 路徑，最後到網站根目錄建立一個 `acme-challenge.txt` 文字檔案，放入應該放入的內容即可：

Operator Pattern

- CRD
  - 定義客制化的CR (HW-11)
  - 產生CR所要使用的Client Code (HW-12)
- Controller (HW-13)
  - Reconcile邏輯 (HW-14)
    - CR建立後，依照業務邏輯進行處理
    - CR變動後，依照業務邏輯進行處理
    - CR刪除後，依照業務邏輯進行處理
- 部署至K8S (HW-15)

流程



- 設計CRD
- 產生api code (類似k8s.io/api)
  - xxx_type.go
  - zz_generated.deepcopy.go
- 開發相對應的Controller
  - Controller透過Reconcile處理CR
- Controller打包成Image，運行在Cluster內
- 建立CR

Custom Resource (CR)
and
Custom Resource Definition (CRD)

Outline

- Custom Resource (CR)
- Custom Resource Definition (CRD)
- Define your own CRD
- CR的go-client

Custom Resource

- Resource
  - K8S預設安裝後即有的Resource, eg: Pod、Node、…
- Custom Resource
  - 擴充K8S的一種機制，讓K8S得以支援預設之外的Resoruce
  - 可以動態註冊新的Custom Resource讓K8S使用，而不需動新安裝或啟動
- Controller
  - Custom Resource宣告想要得到的現象
  - 需透過相對應的Controller，完成想要實現的工作

Custom Resource Definition

- K8S內建的一個Resource，和Pod、Node…相同
- 用來定義 Custom Resource的Schema
  - CR的CRD不存在時，建立CR會失敗。
- 可以用YAML寫CRD，也可以用go-client寫CRD

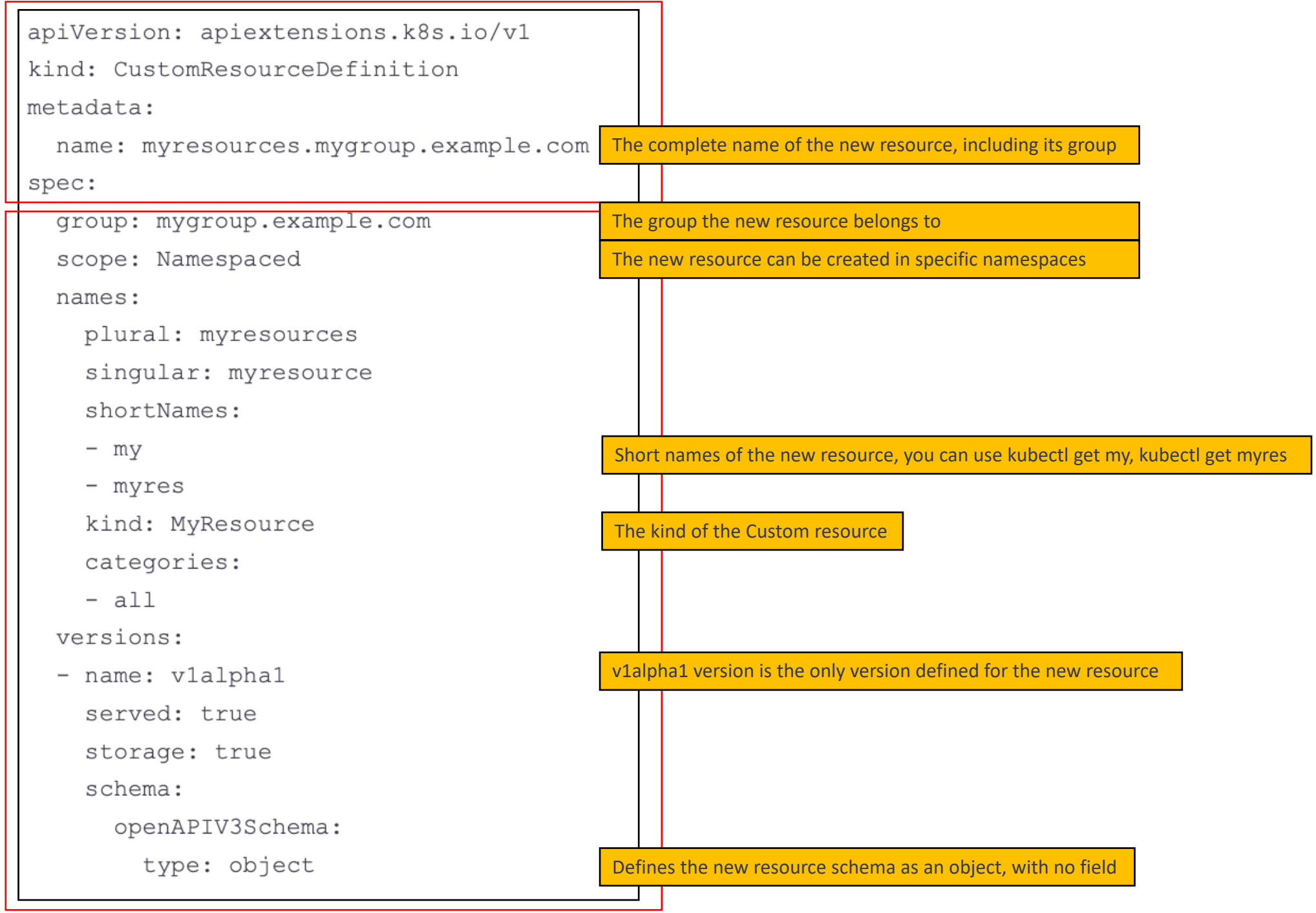
Custom Resource “**Project** ”

```
apiVersion: xyz.com/v1
kind: Project
metadata:
   name: abc-department
spec:
   image: “abc-web-server:0.1.2”
   password: “P@ssw0rd”
status:
   Ready: True
```

```
apiVersion:
apiextensions.k8s.io/v1
kind: CustomResourceDefinition
metadata:
  name: projects.xyz.com
spec:
  group: xyz.com
  version: v1
  scope: Namespaced
  names:
    plural: projects
    singular: project
    kind: Project
  versions:
  - name: v1
    served: true
    storage: true
    schema:
      openAPIV3Schema:
        type: object
        properties:
          spec:
            type: object
            properties:
              image:
                type: string
              password:
                type: string
          status:
            type: object
            properties:
              Ready:
                type: boolean
```

Custom Resource Definition for Custom Resource “**Project** ”

CR & CRD 範例


apiVersion: apiextensions.k8s.io/v1
kind: CustomResourceDefinition
metadata:
name: myresources.mygroup.example.com
spec:
group: mygroup.example.com
scope: Namespaced
names:
plural: myresources
singular: myresource
shortNames:
- my
- myres
kind: MyResource
categories:
- all
versions:
- name: v1alpha1
served: true
storage: true
schema:
openAPIV3Schema:
type: object
The complete name of the new resource, including its group
The group the new resource belongs to
The new resource can be created in specific namespaces
Short names of the new resource, you can use kubectl get my, kubectl get myres
The kind of the Custom resource
v1alpha1 version is the only version defined for the new resource
Defines the new resource schema as an object, with no field

```
versions:
- name: v1alpha1
  served: true
  storage: true
  subresources:
    status: {}
  schema:
    openAPIV3Schema:
      type: object
      properties:
        spec:
          type: object
          properties:
            image:
              type: string
            memory:
              x-kubernetes-int-or-string: true
        status:
          type: object
          properties:
            state:
              type: string
  additionalPrinterColumns:
    - name: image
      jsonPath: .spec.image
      type: string
    - name: memory
      jsonPath: .spec.memory
      type: string
    - name: age
      jsonPath: .metadata.creationTimestamp
      type: date
```

Spec and **Status** fields will also be of type **object** and contain properties.

The accepted data types are: string, number, integer, Boolean, array, object

Spec and **Status** fields will also be of type **object** and contain properties.

The AdditionalPrinterColumns field of the CRD spec is used to indicate which columns of the resource you want to be displayed in the output of kubectl get <resource>.

```
$ kubectl apply -f myres1.yaml
myresource.mygroup.example.com/myres1
$ kubectl get myresources
NAME      IMAGE    MEMORY    AGE
myres1    nginx    1024Mi    12m
```

CR的go-client

- 內建的K8S resource，都會有相對應的ClientSet
- 自定義的CR沒有ClientSet，如何開發程式??
- Kubernetes 官方有提供code-generator，用來自動生成類似的程式碼

```
read, err := clientset.
            CoreV1().
            ConfigMaps(namespace).
            Get(
              context.Background(),
              name,
             metav1.GetOptions{},
            )
```

```
read, err = clientset.
            MygroupV1alpha1().
            MyResources(namespace).
            Get(
              context.Background(),
              "myresource",
              metav1.GetOptions{}
            )
```

流程

- 手動寫types.go 與 docs.go
  - 依CRD 定義的規格，完成types.go
  - 依CRD 定義的version與group，完成docs.go
- 安裝code-generator
- 下載相依性套件
- 自動生成clientset
  - 生成 deepcopy檔
  - 生成registry檔
  - 生成clientset package

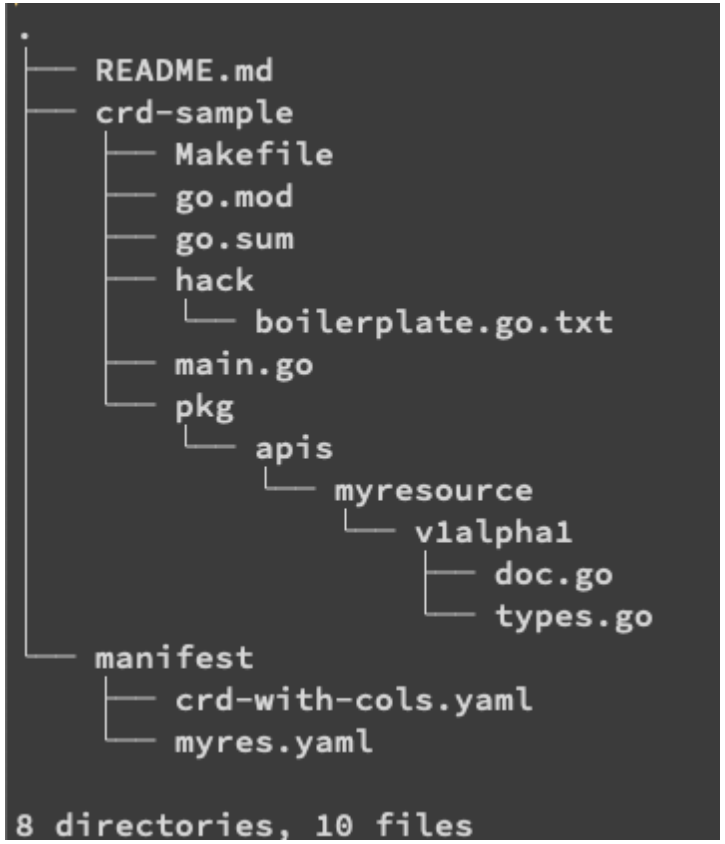
CR 與CRD

```
apiVersion: mygroup.example.com/v1alpha1
kind: MyResource
metadata:
  name: myres1
  namespace: default
spec:
  image: nginx
```

```
apiVersion: apiextensions.k8s.io/v1
kind: CustomResourceDefinition
metadata:
  name: myresources.mygroup.example.com
spec:
  group: mygroup.example.com
  scope: Namespaced
  names:
    plural: myresources
    singular: myresource
    shortNames:
    - my
    - myres
    kind: MyResource
    categories:
    - all
  versions:
  - name: v1alpha1
    served: true
    storage: true
    subresources:
      status: {}
    schema:
      openAPIV3Schema:
        type: object
        properties:
          spec:
            type: object
            properties:
              image:
                type: string
              key:
                type: string
              value:
                type: string
            required:
            - image
          status:
            type: object
            properties:
              completed:
                type: boolean
            required:
            - completed
    additionalPrinterColumns:
      - name: image
        jsonPath: .spec.image
        type: string
      - name: key
        jsonPath: .spec.key
        type: string
      - name: value
```

docs.go

```
// +k8s:deepcopy-gen=package
// +groupName=mygroup.example.com
package v1alpha1
```



types.go

```
package v1alpha1

import (
  metav1 "k8s.io/apimachinery/pkg/apis/meta/v1"
)

// +k8s:deepcopy-gen:interfaces=k8s.io/apimachinery/pkg/runtime.Object
// +genclient
type MyResource struct {
  metav1.TypeMeta `json:",inline"`
  metav1.ObjectMeta `json:"metadata,omitempty"`

  Spec MyResourceSpec `json:"spec"`
  Status MyResourceStatus `json:"status"`
}

type MyResourceSpec struct {
  Image string `json:"image"`
  Key string `json:"key"`
  Value string `json:"value"`
}

type MyResourceStatus struct {
  Completed bool `json:"completed"`
}

// +k8s:deepcopy-gen:interfaces=k8s.io/apimachinery/pkg/runtime.Object
type MyResourceList struct {
  metav1.TypeMeta `json:",inline"`
  metav1.ListMeta `json:"metadata,omitempty"`

  Items []MyResource `json:"items"`
}
```

```
.
├── README.md
├── crd-sample
│   ├── Makefile
│   ├── go.mod
│   ├── go.sum
│   ├── hack
│   │   └── boilerplate.go.txt
│   ├── main.go
│   └── pkg
│       └── apis
│           └── myresource
│               └── v1alpha1
│                   ├── doc.go
│                   └── types.go
└── manifest
    ├── crd-with-cols.yaml
    └── myres.yaml

8 directories, 10 files
```

Code generate

```
.
├── README.md
├── crd-sample
│   ├── Makefile
│   ├── go.mod
│   ├── go.sum
│   ├── hack
│   │   └── boilerplate.go.txt
│   ├── main.go
│   └── pkg
│       ├── apis
│       │   └── myresource
│       │       └── v1alpha1
│       │           ├── doc.go
│       │           ├── types.go
│       │           ├── zz_generated.deepcopy.go
│       │           └── zz_generated.register.go
│       └── clientset
│           ├── clientset.go
│           ├── doc.go
│           ├── fake
│           │   ├── clientset_generated.go
│           │   ├── doc.go
│           │   └── register.go
│           ├── scheme
│           │   ├── doc.go
│           │   └── register.go
│           └── typed
│               └── myresource
│                   └── v1alpha1
│                       ├── doc.go
│                       ├── fake
│                       │   ├── doc.go
│                       │   ├── fake_myresource.go
│                       │   └── fake_myresource_client.go
│                       ├── generated_expansion.go
│                       ├── myresource.go
│                       └── myresource_client.go
└── manifest
    ├── crd-with-cols.yaml
    └── myres.yaml

15 directories, 26 files
```

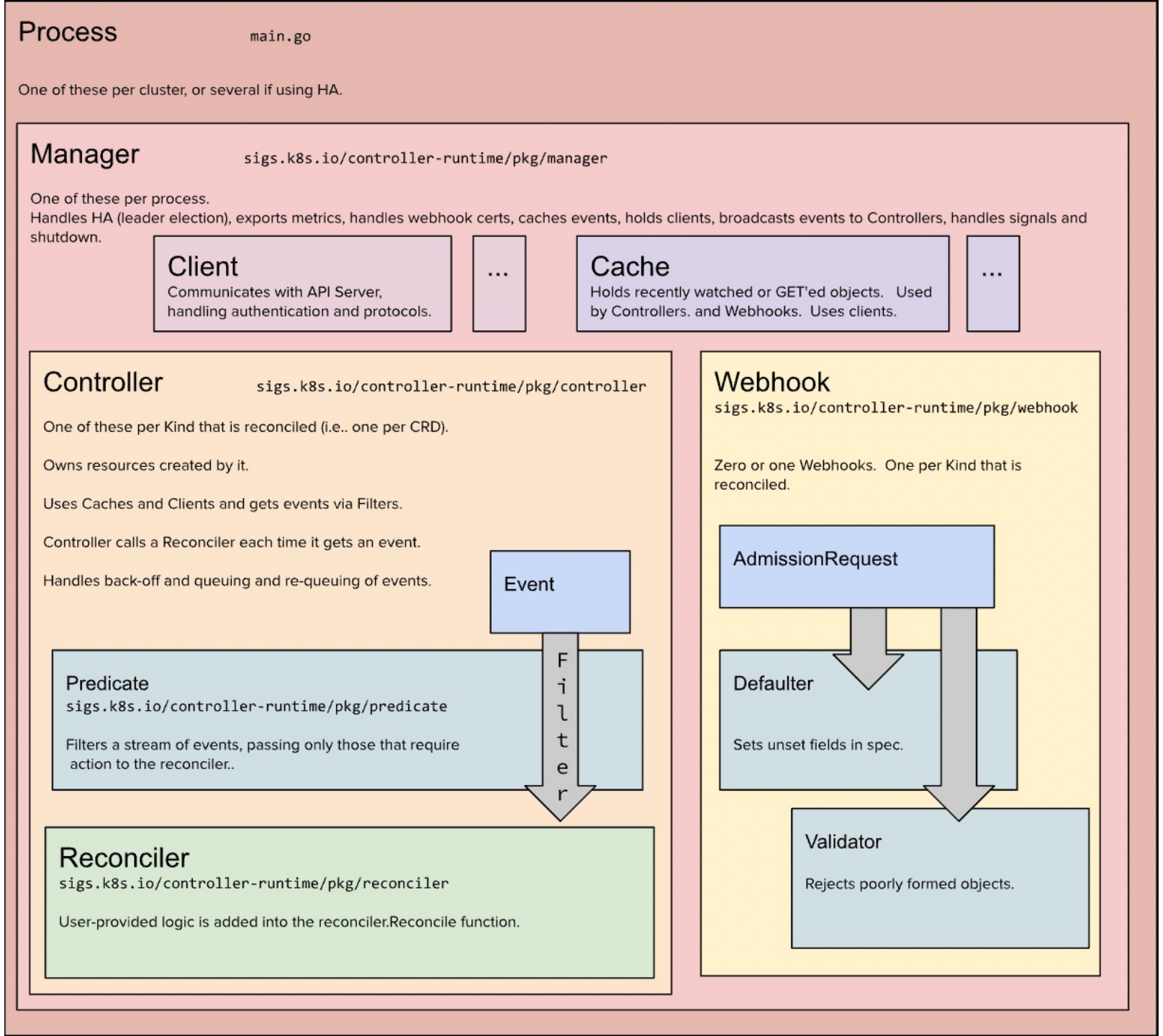
Operator程式開發

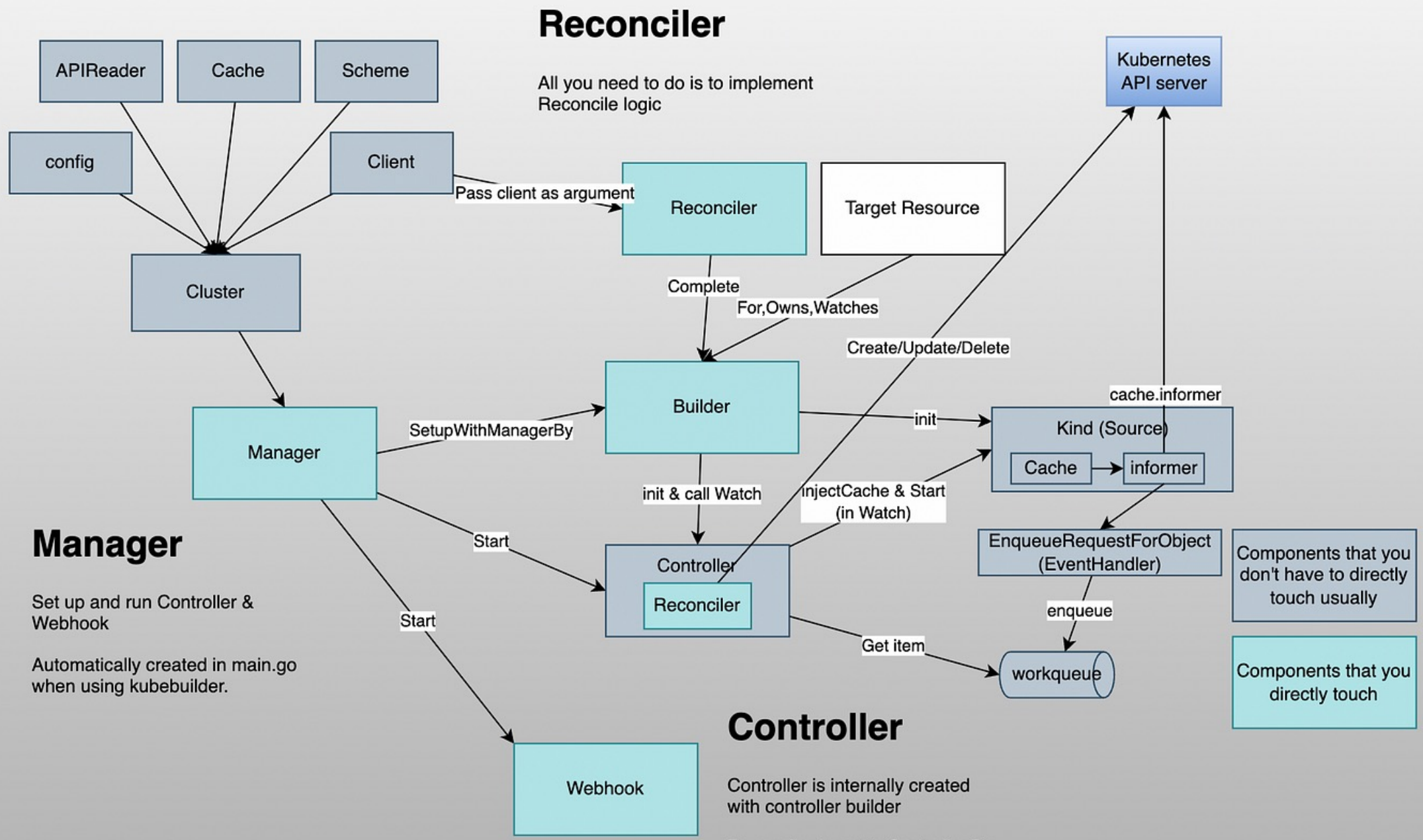
1. Kubernetes Operator series 1 — controller-runtime example controller
2. Kubernetes Operator series 2 — Overview of controller-runtime
3. Kubernetes Operator series 3 — controller-runtime component — Manager
4. Kubernetes Operator series 4 — controller-runtime component — Builder
5. Kubernetes Operator series 5 — controller-runtime component — Reconciler
6. Kubernetes Operator series 6 — controller-runtime component — Controller

Flow

- Create Manager
  - Build Controller
- Implement Reconcile()

Architecture



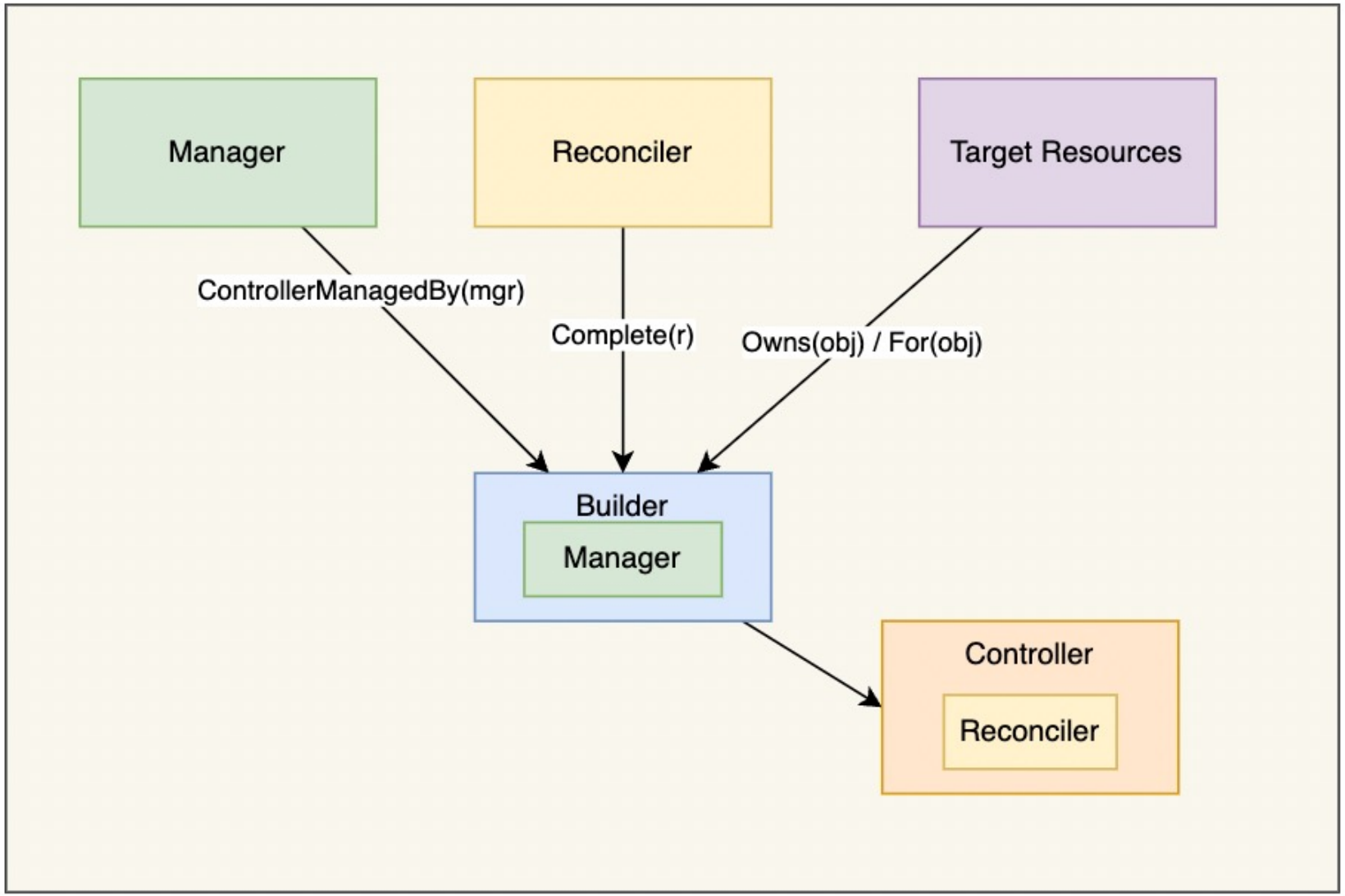

Reconciler
All you need to do is to implement Reconcile logic
APIReader
Cache
Scheme
config
Client
Cluster
Pass client as argument
Reconciler
Target Resource
Kubernetes API server
Complete
For,Owns,Watches
Create/Update/Delete
Builder
Manager
SetupWithManagerBy
init
cache.informer
Kind (Source)
Cache
informer
init & call Watch
injectCache & Start (in Watch)
Start
Controller
Reconciler
EnqueueRequestForObject (EventHandler)
enqueue
Get item
workqueue
Start
Webhook
Manager
Set up and run Controller & Webhook
Automatically created in main.go when using kubebuilder.
Controller
Controller is internally created with controller builder
Reconciler is set to Controller.Do.
Components that you don't have to directly touch usually
Components that you directly touch

```go
func main() {

    mgr, err := manager.New(
        config.GetConfigOrDie(),
        manager.Options{
            Scheme: scheme,
        },
    )

    if err != nil {
        panic(err)
    }

    err = builder.
        ControllerManagedBy(mgr).
        For(&myresourcev1alpha1.MyResource{}).
        Owns(&corev1.ConfigMap{}).
        Owns(&batchv1.Job{}).
        Complete(&MyReconciler{})

    if err != nil {
        panic(err)
    }

    err = mgr.Start(context.Background())

    if err != nil {
        panic(err)
    }
}
```

```go
type MyReconciler struct {
    client client.Client
    scheme *runtime.Scheme
}

func (r *MyReconciler) Reconcile(ctx context.Context, req reconcile.Request) (reconcile.Result, error) {

    log := log.FromContext(ctx)

    sample := &myresourcev1alpha1.MyResource{}
    err := r.client.Get(ctx, req.NamespacedName, sample)
    if err != nil {…
    }

    foundJob := &batchv1.Job{}
    err = r.client.Get(ctx, types.NamespacedName{Name: sample.Name, Namespace: sample.Namespace}, foundJob)
    if err != nil && errors.IsNotFound(err) {…
    } else if err != nil {…
    }

    foundCM := &corev1.ConfigMap{}
    err = r.client.Get(ctx, types.NamespacedName{Name: sample.Name, Namespace: sample.Namespace}, foundCM)
    if err != nil && errors.IsNotFound(err) {…
    } else if err != nil {…
    }

    return reconcile.Result{}, nil

}

func (r *MyReconciler) newConfigMap(s *myresourcev1alpha1.MyResource) *corev1.ConfigMap {…
}

func (r *MyReconciler) newJob(s *myresourcev1alpha1.MyResource) *batchv1.Job {…
}
```

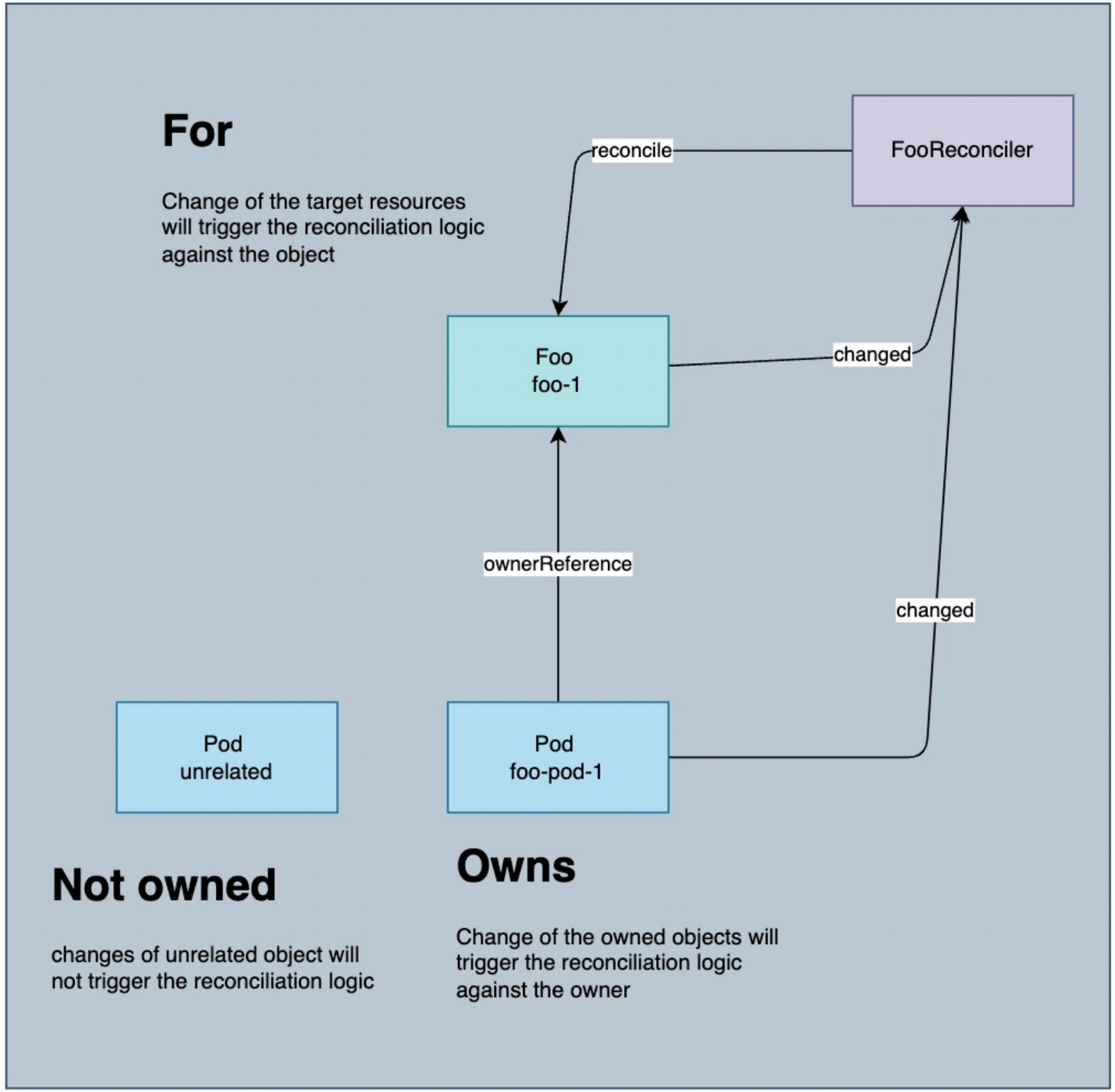
Core Components

- Manager
- Controller
- Reconciler
- Builder



For & Owns

```go
mgr, err := manager.New(
    config.GetConfigOrDie(),
    manager.Options{
        Scheme: scheme,
    },
)

if err != nil {
    panic(err)
}

err = builder.
    ControllerManagedBy(mgr).
    For(&myresourcev1alpha1.MyResource{}).
    Owns(&corev1.ConfigMap{}).
    Owns(&batchv1.Job{}).
    Complete(&MyReconciler{})
```



OwnerReference

- 指定Owner 和 Dependent的關係
- 刪除Owner時， Dependent同時被刪除

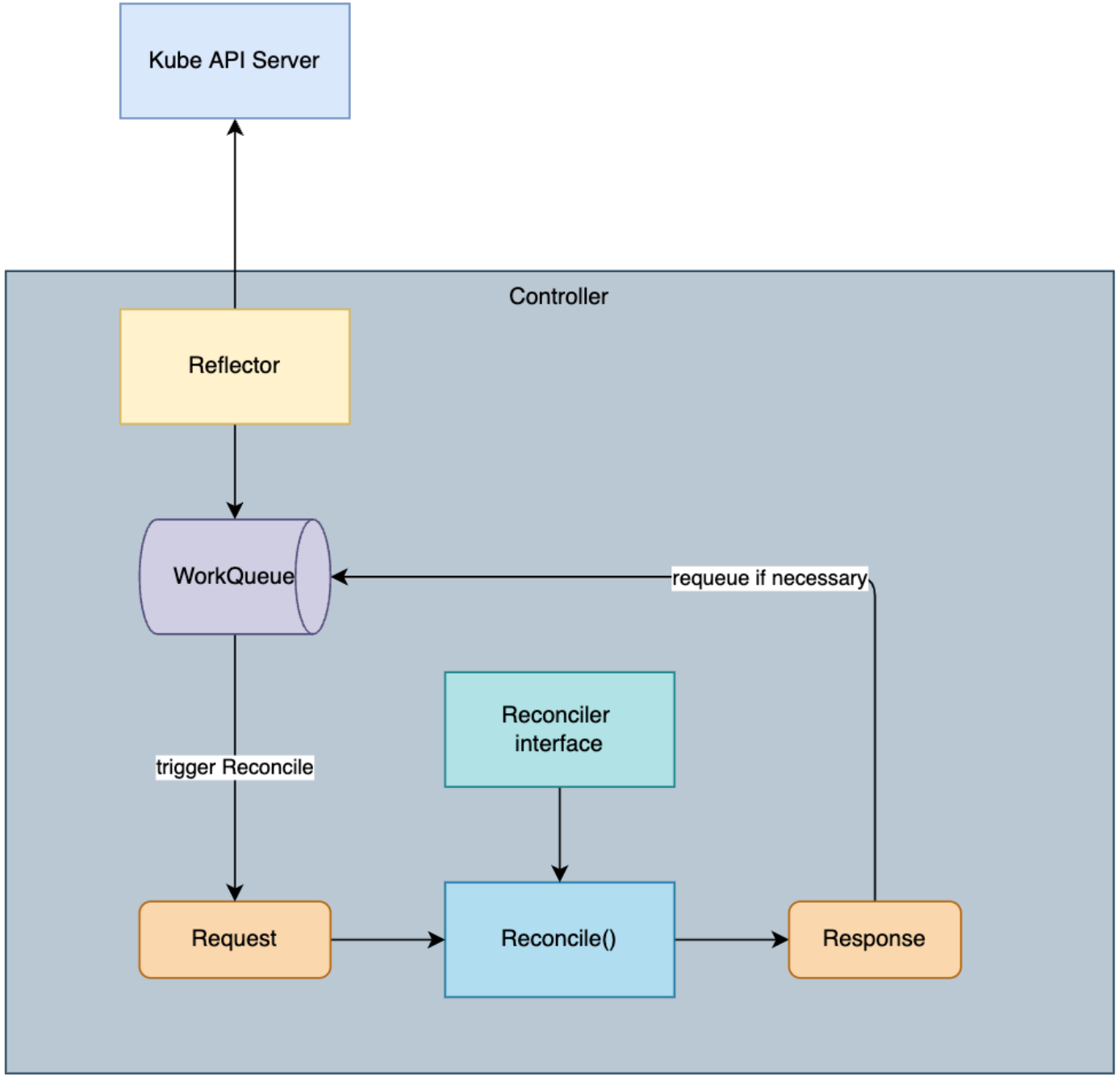
```
ctrl.SetControllerReference(s, cm, r.Scheme)
```

```
oc get pod coredns-6d4b75cb6d-m9jjr -o yaml | yq e 'del(.metadata.managedFields)' -
apiVersion: v1
kind: Pod
metadata:
  creationTimestamp: "2022-05-12T05:14:38Z"
  generateName: coredns-6d4b75cb6d-
  labels:
    k8s-app: kube-dns
    pod-template-hash: 6d4b75cb6d
  name: coredns-6d4b75cb6d-m9jjr
  namespace: kube-system
  ownerReferences:
    - apiVersion: apps/v1
      blockOwnerDeletion: true
      controller: true
      kind: ReplicaSet
      name: coredns-6d4b75cb6d
      uid: 0061f051-b359-43d7-91c5-046535aa329d
  resourceVersion: "971877"
  uid: f29b8cb5-7baf-48cc-bd24-6805fb6df72f
```

```
oc get rs coredns-6d4b75cb6d -o yaml | yq e 'del(.metadata.managedFields)' -
apiVersion: apps/v1
kind: ReplicaSet
metadata:
  annotations:
    deployment.kubernetes.io/desired-replicas: "2"
    deployment.kubernetes.io/max-replicas: "3"
    deployment.kubernetes.io/revision: "1"
  creationTimestamp: "2022-05-12T05:14:38Z"
  generation: 1
  labels:
    k8s-app: kube-dns
    pod-template-hash: 6d4b75cb6d
  name: coredns-6d4b75cb6d
  namespace: kube-system
  ownerReferences:
    - apiVersion: apps/v1
      blockOwnerDeletion: true
      controller: true
      kind: Deployment
      name: coredns
      uid: 161f6a46-0992-4b99-b3b2-d8be75d7ea52
  resourceVersion: "971881"
  uid: 0061f051-b359-43d7-91c5-046535aa329d
```

```
oc get deployments.apps coredns -o yaml | yq e 'del(.metadata.managedFields)' -
apiVersion: apps/v1
kind: Deployment
metadata:
  annotations:
    deployment.kubernetes.io/revision: "1"
  creationTimestamp: "2022-05-12T05:14:23Z"
  generation: 1
  labels:
    k8s-app: kube-dns
  name: coredns
  namespace: kube-system
  resourceVersion: "971882"
  uid: 161f6a46-0992-4b99-b3b2-d8be75d7ea52
```

Reconcile loop

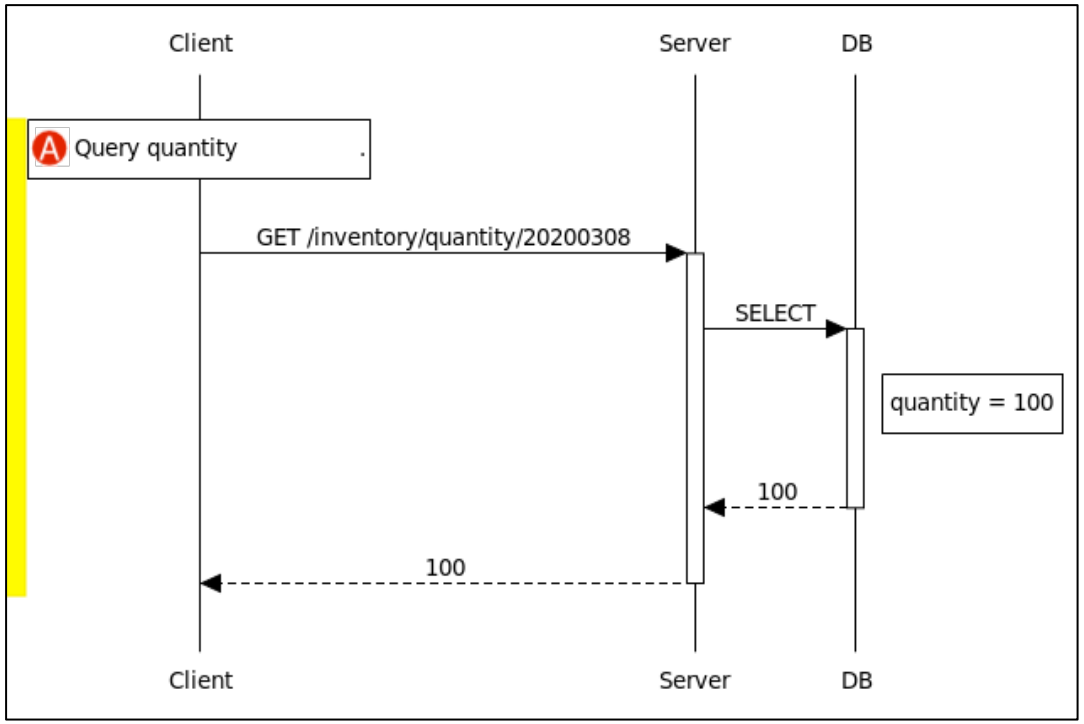


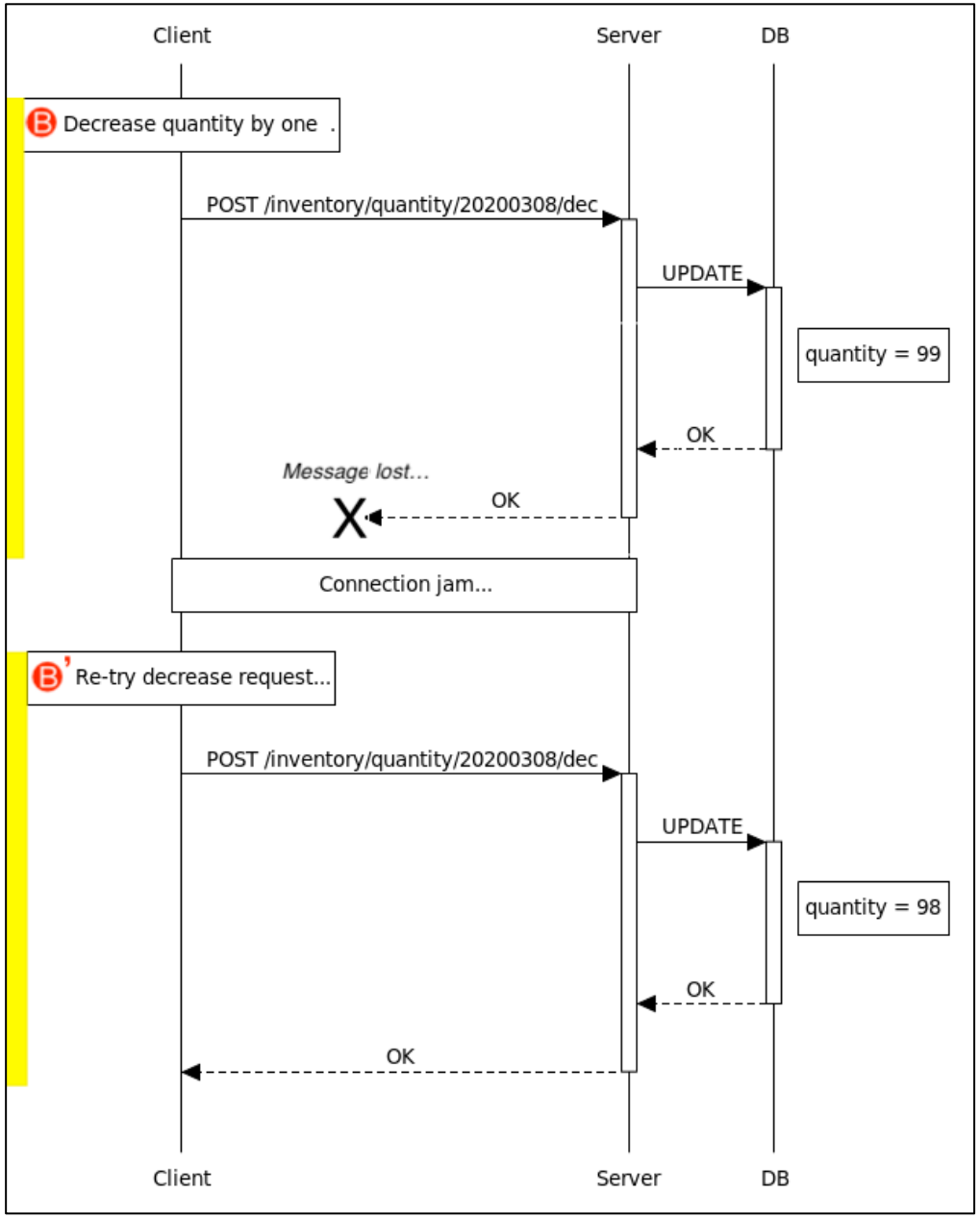

```go
type MyReconciler struct{}

func (a *MyReconciler) Reconcile(
    ctx context.Context,
    req reconcile.Request,
) (reconcile.Result, error) {
    fmt.Printf("reconcile %v\n", req)
    return reconcile.Result{}, nil

}
```

Idempotent

Develop idempotent reconciliation solutions

When developing operators, it is essential for the controller's reconciliation loop to be idempotent. By following the Operator pattern you will create Controllers which provide a reconcile function responsible for synchronizing resources until the desired state is reached on the cluster. Breaking this recommendation goes against the design principles of controller–runtime and may lead to unforeseen consequences such as resources becoming stuck and requiring manual intervention.





https://william-yeh.net/post/2020/03/idempotency-key-test/

https://sdk.operatorframework.io/docs/best-practices/common-recommendation/

部署Operator

Operator 需要那些權限

- Resource
  - MyResource、ConfigMap、Job
- Verbs
  - Create、delete、get、list、patch、update、watch
- Scope
  - 整個Cluster

```
mgr, err := manager.New(
    config.GetConfigOrDie(),
    manager.Options{
        Scheme: scheme,
    },
)

if err != nil {
    panic(err)
}

err = builder.
    ControllerManagedBy(mgr).
    For(&myresourcev1alpha1.MyResource{}).
    Owns(&corev1.ConfigMap{}).
    Owns(&batchv1.Job{}).
    Complete(&MyReconciler{})
```

```yaml
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRole
metadata:
  name: operator-role
rules:
  - apiGroups:
      - batch
    resources:
     - jobs
    verbs: ⋯
  - apiGroups:
      - ""
    resources:
      - configmaps
    verbs: ⋯
  - apiGroups:
      - mygroup.example.com
    resources:
      - myresources
    verbs:
      - create
      - delete
      - get
      - list
      - patch
      - update
      - watch
```

```yaml
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRoleBinding
metadata:
  name: operator-rolebinding
roleRef:
  apiGroup: rbac.authorization.k8s.io
  kind: ClusterRole
  name: operator-role
subjects:
  - kind: ServiceAccount
    name: operator
    namespace: default
```