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API Evolution with CRDs: best practices for authoring & fuzz testing APIs

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Designing CRDs

- Designing a “Kubernetes-like” API is easier said than done
- There’s a number of resources available to help
  - A lot still requires intuition and carefully studying conventions

Designing CRDs

- One CRD or many?
  - `objectRef` fields help break up CRDs
  - Can increase complexity of controllers and cognitive overhead for users
  - One concept to one CRD
- Generic example:
  - One CRD modelling the ‘source’ of something (e.g. a CA, a secret store)
  - One CRD modelling a single item within that store (e.g. a Certificate, an ExternalSecret)

Writing a great schema

Writing a great schema

- Once you work out what CRDs you need, writing the schema is next…
- API conventions doc is your reference manual:

  https://github.com/kubernetes/community/blob/master/contributors/devel/sig-architecture/api-conventions.md
- Join #sig-api-machinery and ask your questions!

Writing a great schema

- Write a complete schema (controller-gen can help!)
  - Required for all v1 CRDs
  - Enables `kubectl explain` output
  - Ensures you have an exhaustive schema
  - Check the `NonStructural` condition on your CRD
  - Better validation: reject fields that are unknown (aka pruning)
    - This avoids typos, and makes it clear to users up front about their errors
    - Matches behaviour of other core built-in resources

Writing a great schema

- Utilise OpenAPI validation within your schemas
  - Allows apiserver to evaluate resource without network roundtrips
  - ***MaxLength***, ***MaxItems***, ***Minimum***, ***Maximum***
    - Helps ensure a bounded size/agreement between from platform on what's persisted
  - Regex for strings
    - Surfaces errors to users earlier on, reduces error handling code in clients
  - Enum values for fields
    - Clear to users what options are valid
  - CEL (**C**ommon-**E**xpression-**L**anguage) for more advanced/expressive validations
    - Can be used for conditional validation logic
    - https://kubernetes.io/blog/2022/09/23/crd-validation-rules-beta/

Writing a great schema

Validation Rule	Purpose
`self.minReplicas <= self.replicas`	Validate an integer field is less than or equal to another integer field
`'Available' in self.stateCounts`	Validate an entry with the 'Available' key exists in a map
`self.set1.all(e, !(e in self.set2))`	Validate that the elements of two sets are disjoint
`self == oldSelf`	Validate that a required field is immutable once it is set
`self.created + self.ttl < self.expired`	Validate that 'expired' date is after a 'create' date plus a 'ttl' duration

Source: https://kubernetes.io/blog/2022/09/23/crd-validation-rules-beta/

Writing a great schema

- Consider default values
  - Embedded in schema and simple is best
    - Allows for the apiserver to apply defaulting on read operations (backward and forward compatibility way easier)
  - Avoid defaults that are co-dependent on other fields
    - These can be confusing and lead to subtle unexpected behaviours

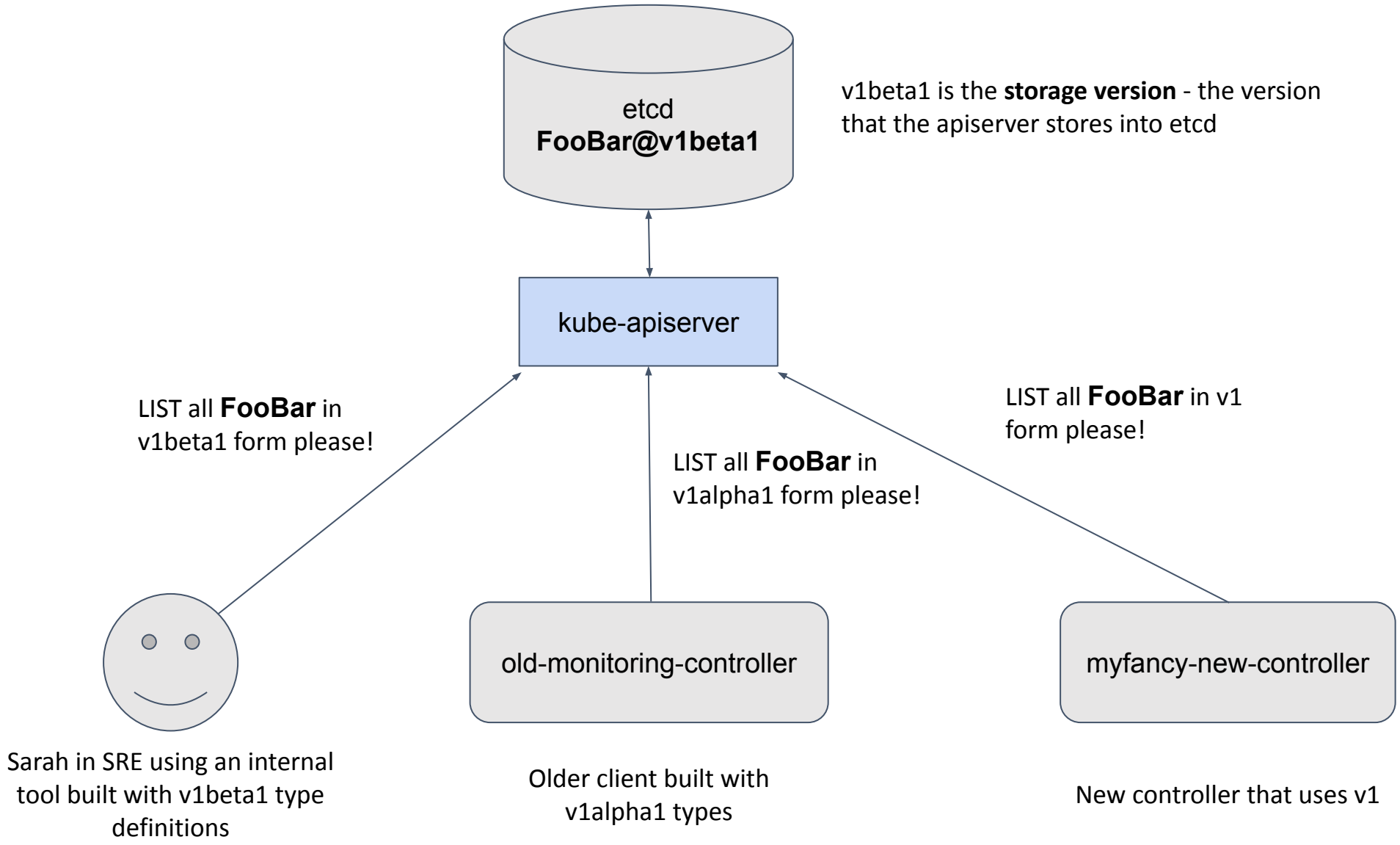
Versioning & conversion

Versioning & conversion

Versioning of Kubernetes APIs is a fundamental principle of how Kubernetes evolves

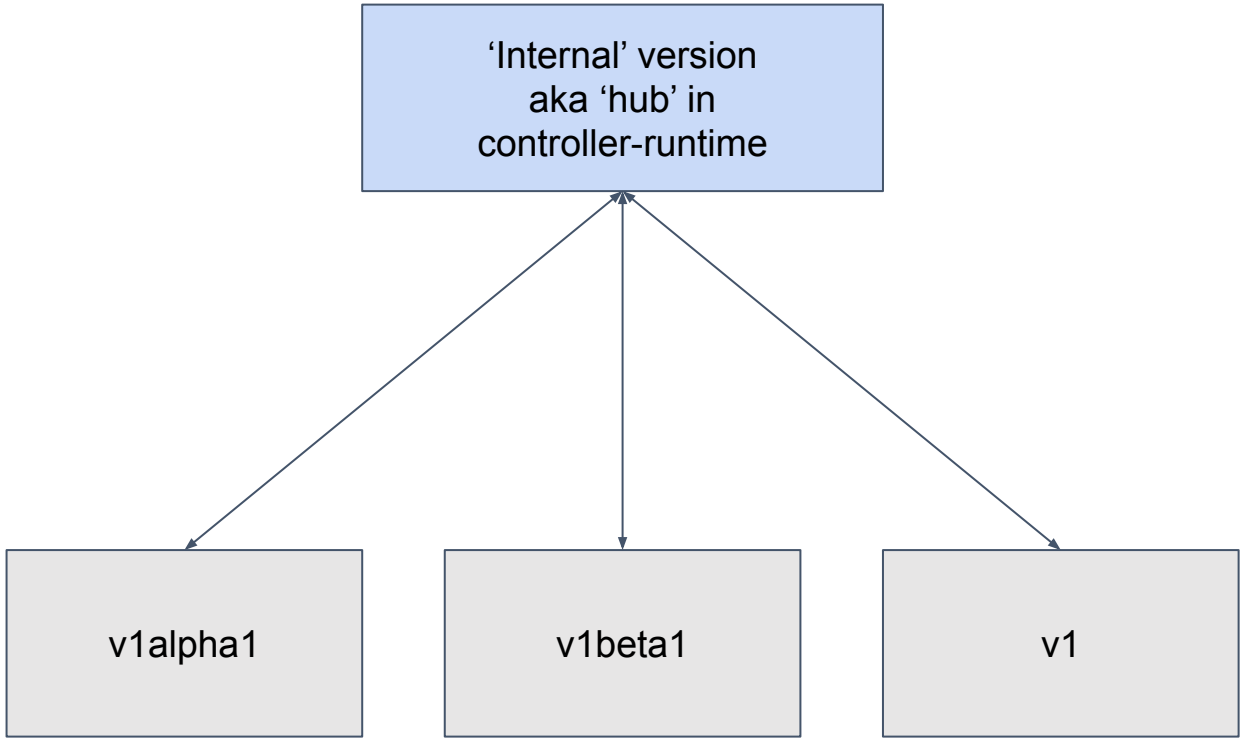
- A version is:
  - An API endpoint that offers backward compatibility
  - A specific view of a resource type stored in etcd
- Conversion enables the apiserver to return any object, regardless of its stored version, in a particular API version.
  - This allows clients built against **older** versions of the API to continue to function when new versions are released
  - Eventually, **non-GA** versions will be removed
  - Full details: https://kubernetes.io/docs/reference/using-api/deprecation-policy/

Versioning & conversion



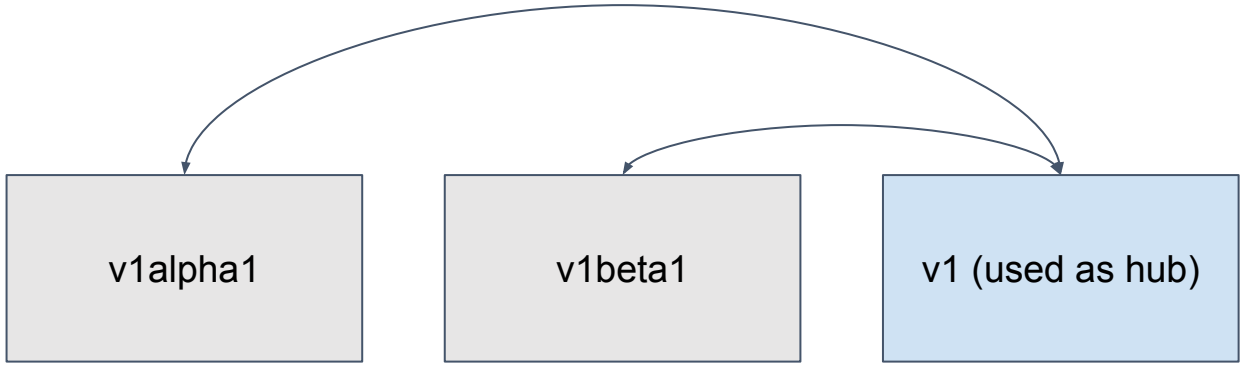
Versioning & conversion

client-go/core k8s



Versioning & conversion

controller-runtime/kubebuilder



Versioning & conversion

So what can we do with CRDs?

Versioning & conversion

- ***Nothing*** - v1alpha1 forever!
- ***No-op conversion*** - try and get it right first time…
- ***Conversion webhooks*** - powerful, full flexibility..
  - Operational risks
  - Maintenance burden
  - TLS/security is very important (what if your conversion webhook *lied*!)
  - This is an extension of your control plane

Versioning & conversion

- ***Webhooks: what did we learn?***
  - A great escape hatch, but easy to get wrong
  - Critical apiserver dependency (garbage collection stops if unavailable)
  - Most organisations don’t have much operational experience
  - Can be subtle versioning issues

Versioning & conversion

- **Key takeaways if you cannot avoid it:**
  - All conversions must be bi-directional and lossless (roundtrip testing ensures this!)
  - Minimise deprecation cycle time - removes the need for webhooks altogether
  - Consider publishing v1-only variant of your app for those that don’t want to run webhooks
  - Should have **NO** external dependencies/inputs

Versioning & conversion

- **What else? What's the future look like?**
  - *kcp* has been exploring conversions through CEL (**C**ommon-**E**xpression-**L**anguage)
  - Allows for in-process conversions with a domain-specific language that hides sharp edges
  - Performant, secure and avoids network round-trips & operational burden
  - Very exciting and interesting work
  - https://github.com/kcp-dev/kcp/pull/2105

Validating & mutating

Validating & mutating

- **Validating webhooks** can be used to apply additional constraints on resources after schema validation is applied
  - Best considered as policy control rather that defining specific properties of types
- **Mutating webhooks** are used to apply additional changes to resources as they are being persisted (either CREATE or UPDATE)
  - Very flexible
  - NOT applied on read operations, unlike defaulting

Validating & mutating

Webhooks:

- Used when more expressive logic is required
- Can be used to add additional validation to any resource type beyond schema based
  - Example: validating Pod resources always set X `priorityClassName`
  - OPA, Kyverno are examples of dynamic policy webhooks
- Have access to full request context to validate & mutate
- Can be used to extract the requesting user, request URI, identify versions etc
- Can be used to prompt users with warnings: https://kubernetes.io/blog/2020/09/03/warnings/

Validating & mutating

Operationalising webhooks:

- TLS
- Scalability
- Availability (make sure platform teams are supporting webhooks)
- Ensuring upgrades are tied to the lifecycle of the CRD
    - Upgrade webhooks **before** CRDs are upgraded

Validating & mutating

What's the future?

- KEP-3488: CEL based admission control KEP

```yaml
# Policy definition
apiVersion: admissionregistration.k8s.io/v1alpha1
kind: ValidatingAdmissionPolicy
metadata:
  name: "replicalimit-policy.example.com"
spec:
  paramSource:
    group: rules.example.com
    kind: ReplicaLimit
    version: v1
  matchConstraints:
    resourceRules:
    - apiGroups:   ["apps"]
      apiVersions: ["v1"]
      operations:  ["CREATE", "UPDATE"]
      resources:   ["deployments"]
  validations:
    - name: max-replicas
      expression: "object.spec.replicas <= params.maxReplicas"
      messageExpression: "'object.spec.replicas must be no greater than ' + string(params.maxReplicas)"
      reason: Invalid
      # ...other rule related fields here...
```

Testing methodology

Testing methodology

- Separate and consider **apiserver** testing vs **controller** testing
- We need unit, integration and end-to-end tests for **both**

Testing methodology

- apiserver's/CRDs:
  - **Unit testing (in-memory, aka `go test`):**
    - Conversion roundtrip testing (`roundtrip.RoundTripTestForAPIGroup`)
      - https://github.com/kubernetes/apimachinery/blob/release-1.25/pkg/api/apitesting/roundtrip/roundtrip.go
    - Schema fuzz tests ensure a complete schema (munnerz/crd-schema-fuzz)
    - Webhooks: unit test your validation & mutation functions
    - **For schema validation**, write a corpus of valid and invalid resources and use a static analysis tool to apply your schema to them: https://github.com/yannh/kubeconform

Testing methodology

- apiserver's/CRDs:
  - **Integration testing (envtest/in-memory etcd & apiserver):**
    - Conversion functions correctly: create A@**v1alpha1**, read at **v1beta1**
    - Defaulting (create a resource and read it back - are defaults set?)
    - Validation (create a resource with an invalid value - does it fail?)

Testing methodology

- apiserver’s/CRDs:
  - **e2e testing (kind/minikube)**
    - Do your deployment manifests work?
    - Correct RBAC configuration, webhook TLS etc

Testing methodology

- controllers:
  - **Unit testing (in-memory, aka `go test`):**
    - Calling `Reconcile` once with a given input and asserting the actions taken
    - Useful for simulating errors and testing error handling behaviour

Testing methodology

- controllers:
  - **Integration testing (envtest/in-memory etcd & apiserver):**
    - Brings up a full reconciler that'll sync multiple times
    - Light-weight with no controller-manager/scheduler
    - Most of your tests will be written like this

Testing methodology

- controllers:
  - **e2e testing (kind/minikube)**
    - Testing end-to-end user facing behaviour
    - Ensures that if a collection of objects is created, the right things happen
    - Write tests that follow your own docs

Closing thoughts

Closing thoughts

- Rely on the schema as much as possible
- Be aware of the cost of webhook sprawl
- There’s lots out there to help with testing nowadays. envtest is fast and powerful.
- Test your error cases, how does your controller behave with a slow cache?

Questions?

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