Pod Lifecycle

This page describes the lifecycle of a Pod. Pods follow a defined lifecycle, starting in the `Pending` phase, moving through `Running` if at least one of its primary containers starts OK, and then through either the `Succeeded` or `Failed` phases depending on whether any container in the Pod terminated in failure.

Whilst a Pod is running, the kubelet is able to restart containers to handle some kind of faults. Within a Pod, Kubernetes tracks different container states and determines what action to take to make the Pod healthy again.

In the Kubernetes API, Pods have both a specification and an actual status. The status for a Pod object consists of a set of Pod conditions. You can also inject custom readiness information into the condition data for a Pod, if that is useful to your application.

Pods are only scheduled once in their lifetime. Once a Pod is scheduled (assigned) to a Node, the Pod runs on that Node until it stops or is terminated.

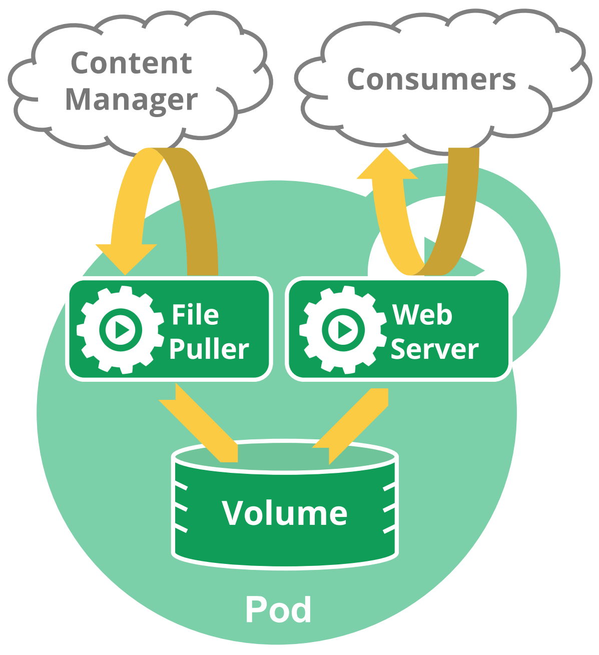
Pod lifetime

Like individual application containers, Pods are considered to be relatively ephemeral (rather than durable) entities. Pods are created, assigned a unique ID (UID), and scheduled to nodes where they remain until termination (according to restart policy) or deletion. If a Node dies, the Pods scheduled to that node are scheduled for deletion after a timeout period.

Pods do not, by themselves, self-heal. If a Pod is scheduled to a node that then fails, the Pod is deleted; likewise, a Pod won't survive an eviction due to a lack of resources or Node maintenance. Kubernetes uses a higher-level abstraction, called a controller, that handles the work of managing the relatively disposable Pod instances.

A given Pod (as defined by a UID) is never "rescheduled" to a different node; instead, that Pod can be replaced by a new, near-identical Pod, with even the same name if desired, but with a different UID.

When something is said to have the same lifetime as a Pod, such as a volume, that means that the thing exists as long as that specific Pod (with that exact UID) exists. If that Pod is deleted for any reason, and even if an identical replacement is created, the related thing (a volume, in this example) is also destroyed and created anew.



Pod diagram

A multi-container Pod that contains a file puller and a web server that uses a persistent volume for shared storage between the containers.

Pod phase

A Pod's `status` field is a PodStatus object, which has a `phase` field.

The phase of a Pod is a simple, high-level summary of where the Pod is in its lifecycle. The phase is not intended to be a comprehensive rollup of observations of container or Pod state, nor is it intended to be a comprehensive state machine.

The number and meanings of Pod phase values are tightly guarded. Other than what is documented here, nothing should be assumed about Pods that have a given `phase` value.

Here are the possible values for `phase`:

Value	Description
`Pending`	The Pod has been accepted by the Kubernetes cluster, but one or more of the containers has not been set up and made ready to run. This includes time a Pod spends waiting to be scheduled as well as the time spent downloading container images over the network.
`Running`	The Pod has been bound to a node, and all of the containers have been created. At least one container is still running, or is in the process of starting or restarting.
`Succeeded`	All containers in the Pod have terminated in success, and will not be restarted.
`Failed`	All containers in the Pod have terminated, and at least one container has terminated in failure. That is, the container either exited with non-zero status or was terminated by the system.
`Unknown`	For some reason the state of the Pod could not be obtained. This phase typically occurs due to an error in communicating with the node where the Pod should be running.

> **Note:** When a Pod is being deleted, it is shown as `Terminating` by some kubectl commands. This `Terminating` status is not one of the Pod phases. A Pod is granted a term to terminate gracefully, which defaults to 30 seconds. You can use the flag `--force` to terminate a Pod by force.

Since Kubernetes 1.27, the kubelet transitions deleted Pods, except for static Pods and force-deleted Pods without a finalizer, to a terminal phase (`Failed` or `Succeeded` depending on the exit statuses of the pod containers) before their deletion from the API server.

If a node dies or is disconnected from the rest of the cluster, Kubernetes applies a policy for setting the `phase` of all Pods on the lost node to Failed.

Container states

As well as the phase of the Pod overall, Kubernetes tracks the state of each container inside a Pod. You can use container lifecycle hooks to trigger events to run at certain points in a container's lifecycle.

Once the scheduler assigns a Pod to a Node, the kubelet starts creating containers for that Pod using a container runtime. There are three possible container states: `Waiting`, `Running`, and `Terminated`.

To check the state of a Pod's containers, you can use `kubectl describe pod <name-of-pod>`. The output shows the state for each container within that Pod.

Each state has a specific meaning:

`Waiting`

If a container is not in either the `Running` or `Terminated` state, it is `Waiting`. A container in the `Waiting` state is still running the operations it requires in order to complete start up: for example, pulling the container image from a container image registry, or applying Secret data. When you use `kubectl` to query a Pod with a container that is `Waiting`, you also see a Reason field to summarize why the container is in that state.

`Running`

The `Running` status indicates that a container is executing without issues. If there was a `postStart` hook configured, it has already executed and finished. When you use `kubectl` to query a Pod with a container that is `Running`, you also see information about when the container entered the `Running` state.

`Terminated`

A container in the `Terminated` state began execution and then either ran to completion or failed for some reason. When you use `kubectl` to query a Pod with a container that is `Terminated`, you see a reason, an exit code, and the start and finish time for that container's period of execution.

If a container has a `preStop` hook configured, this hook runs before the container enters the `Terminated` state.

Container restart policy

The `spec` of a Pod has a `restartPolicy` field with possible values Always, OnFailure, and Never. The default value is Always.

The `restartPolicy` for a Pod applies to app containers in the Pod and to regular init containers. Sidecar containers ignore the Pod-level `restartPolicy` field: in Kubernetes, a sidecar is defined as an entry inside `initContainers` that has its container-level `restartPolicy` set to `Always`. For init containers that exit with an error, the kubelet restarts the init container if the Pod level `restartPolicy` is either `OnFailure` or `Always`.

When the kubelet is handling container restarts according to the configured restart policy, that only applies to restarts that make replacement containers inside the same Pod and running on the same node. After containers in a Pod exit, the kubelet restarts them with an exponential back-off delay (10s, 20s, 40s, …), that is capped at five minutes. Once a container has executed for 10 minutes without any problems, the kubelet resets the restart backoff timer for that container. Sidecar containers and Pod lifecycle explains the behaviour of `init containers` when specify `restartpolicy` field on it.

Pod conditions

A Pod has a PodStatus, which has an array of PodConditions through which the Pod has or has not passed. Kubelet manages the following PodConditions:

- `PodScheduled`: the Pod has been scheduled to a node.
- `PodReadyToStartContainers`: (beta feature; enabled by default) the Pod sandbox has been successfully created and networking configured.
- `ContainersReady`: all containers in the Pod are ready.
- `Initialized`: all init containers have completed successfully.
- `Ready`: the Pod is able to serve requests and should be added to the load balancing pools of all matching Services.

Field name	Description
`type`	Name of this Pod condition.
`status`	Indicates whether that condition is applicable, with possible values "`True`", "`False`", or "`Unknown`".
`lastProbeTime`	Timestamp of when the Pod condition was last probed.
`lastTransitionTime`	Timestamp for when the Pod last transitioned from one status to another.
`reason`	Machine-readable, UpperCamelCase text indicating the reason for the condition's last transition.
`message`	Human-readable message indicating details about the last status transition.

Pod readiness

FEATURE STATE: `Kubernetes v1.14 [stable]`

Your application can inject extra feedback or signals into PodStatus: *Pod readiness*. To use this, set `readinessGates` in the Pod's `spec` to specify a list of additional conditions that the kubelet evaluates for Pod readiness.

Readiness gates are determined by the current state of `status.condition` fields for the Pod. If Kubernetes cannot find such a condition in the `status.conditions` field of a Pod, the status of the condition is defaulted to "`False`".

Here is an example:

```yaml
kind: Pod
...
spec:
  readinessGates:
    - conditionType: "www.example.com/feature-1"
status:
  conditions:
    - type: Ready                              # a built in PodCondition
      status: "False"
      lastProbeTime: null
      lastTransitionTime: 2018-01-01T00:00:00Z
    - type: "www.example.com/feature-1"        # an extra PodCondition
      status: "False"
      lastProbeTime: null
      lastTransitionTime: 2018-01-01T00:00:00Z
  containerStatuses:
    - containerID: docker://abcd...
      ready: true
...
```

The Pod conditions you add must have names that meet the Kubernetes label key format.

Status for Pod readiness

The `kubectl patch` command does not support patching object status. To set these `status.conditions` for the Pod, applications and operators should use the `PATCH` action. You can use a Kubernetes client library to write code that sets custom Pod conditions for Pod readiness.

For a Pod that uses custom conditions, that Pod is evaluated to be ready **only** when both the following statements apply:

- All containers in the Pod are ready.
- All conditions specified in `readinessGates` are `True`.

When a Pod's containers are Ready but at least one custom condition is missing or `False`, the kubelet sets the Pod's condition to `ContainersReady`.

Pod network readiness

FEATURE STATE: `Kubernetes v1.29 [beta]`

Note: During its early development, this condition was named `PodHasNetwork`.

After a Pod gets scheduled on a node, it needs to be admitted by the kubelet and to have any required storage volumes mounted. Once these phases are complete, the kubelet works with a container runtime (using Container runtime interface (CRI)) to set up a runtime sandbox and configure networking for the Pod. If the `PodReadyToStartContainersCondition` feature gate is enabled (it is enabled by default for Kubernetes 1.29), the `PodReadyToStartContainers` condition will be added to the `status.conditions` field of a Pod.

The `PodReadyToStartContainers` condition is set to `False` by the Kubelet when it detects a Pod does not have a runtime sandbox with networking configured. This occurs in the following scenarios:

- Early in the lifecycle of the Pod, when the kubelet has not yet begun to set up a sandbox for the Pod using the container runtime.
- Later in the lifecycle of the Pod, when the Pod sandbox has been destroyed due to either:
    - the node rebooting, without the Pod getting evicted
    - for container runtimes that use virtual machines for isolation, the Pod sandbox virtual machine rebooting, which then requires creating a new sandbox and fresh container network configuration.

The `PodReadyToStartContainers` condition is set to `True` by the kubelet after the successful completion of sandbox creation and network configuration for the Pod by the runtime plugin. The kubelet can start pulling container images and create containers after `PodReadyToStartContainers` condition has been set to `True`.

For a Pod with init containers, the kubelet sets the `Initialized` condition to `True` after the init containers have successfully completed (which happens after successful sandbox creation and network configuration by the runtime plugin). For a Pod without init containers, the kubelet sets the `Initialized` condition to `True` before sandbox creation and network configuration starts.

Pod scheduling readiness

FEATURE STATE: `Kubernetes v1.26 [alpha]`

See Pod Scheduling Readiness for more information.

Container probes

A *probe* is a diagnostic performed periodically by the kubelet on a container. To perform a diagnostic, the kubelet either executes code within the container, or makes a network request.

Check mechanisms

There are four different ways to check a container using a probe. Each probe must define exactly one of these four mechanisms:

`exec`

Executes a specified command inside the container. The diagnostic is considered successful if the command exits with a status code of 0.

`grpc`

Performs a remote procedure call using gRPC. The target should implement gRPC health checks. The diagnostic is considered successful if the `status` of the response is `SERVING`.

`httpGet`

Performs an HTTP `GET` request against the Pod's IP address on a specified port and path. The diagnostic is considered successful if the response has a status code greater than or equal to 200 and less than 400.

`tcpSocket`

Performs a TCP check against the Pod's IP address on a specified port. The diagnostic is considered successful if the port is open. If the remote system (the container) closes the connection immediately after it opens, this counts as healthy.

Caution: Unlike the other mechanisms, `exec` probe's implementation involves the creation/forking of multiple processes each time when executed. As a result, in case of the clusters having higher pod densities, lower intervals of `initialDelaySeconds`, `periodSeconds`, configuring any probe with exec mechanism might introduce an overhead on the cpu usage of the node. In such scenarios, consider using the alternative probe mechanisms to avoid the overhead.

Probe outcome

Each probe has one of three results:

`Success`

The container passed the diagnostic.

`Failure`

The container failed the diagnostic.

`Unknown`

The diagnostic failed (no action should be taken, and the kubelet will make further checks).

Types of probe

The kubelet can optionally perform and react to three kinds of probes on running containers:

`livenessProbe`

Indicates whether the container is running. If the liveness probe fails, the kubelet kills the container, and the container is subjected to its restart policy. If a container does not provide a liveness probe, the default state is `Success`.

`readinessProbe`

Indicates whether the container is ready to respond to requests. If the readiness probe fails, the endpoints controller removes the Pod's IP address from the endpoints of all Services that match the Pod. The default state of readiness before the initial delay is `Failure`. If a container does not provide a readiness probe, the default state is `Success`.

`startupProbe`

Indicates whether the application within the container is started. All other probes are disabled if a startup probe is provided, until it succeeds. If the startup probe fails, the kubelet kills the container, and the container is subjected to its restart policy. If a container does not provide a startup probe, the default state is `Success`.

For more information about how to set up a liveness, readiness, or startup probe, see Configure Liveness, Readiness and Startup Probes.

When should you use a liveness probe?

If the process in your container is able to crash on its own whenever it encounters an issue or becomes unhealthy, you do not necessarily need a liveness probe; the kubelet will automatically perform the correct action in accordance with the Pod's `restartPolicy`.

If you'd like your container to be killed and restarted if a probe fails, then specify a liveness probe, and specify a `restartPolicy` of Always or OnFailure.

When should you use a readiness probe?

If you'd like to start sending traffic to a Pod only when a probe succeeds, specify a readiness probe. In this case, the readiness probe might be the same as the liveness probe, but the existence of the readiness probe in the spec means that the Pod will start without receiving any traffic and only start receiving traffic after the probe starts succeeding.

If you want your container to be able to take itself down for maintenance, you can specify a readiness probe that checks an endpoint specific to readiness that is different from the liveness probe.

If your app has a strict dependency on back-end services, you can implement both a liveness and a readiness probe. The liveness probe passes when the app itself is healthy, but the readiness probe additionally checks that each required back-end service is available. This helps you avoid directing traffic to Pods that can only respond with error messages.

If your container needs to work on loading large data, configuration files, or migrations during startup, you can use a startup probe. However, if you want to detect the difference between an app that has failed and an app that is still processing its startup data, you might prefer a readiness probe.

> **Note:** If you want to be able to drain requests when the Pod is deleted, you do not necessarily need a readiness probe; on deletion, the Pod automatically puts itself into an unready state regardless of whether the readiness probe exists. The Pod remains in the unready state while it waits for the containers in the Pod to stop.

When should you use a startup probe?

Startup probes are useful for Pods that have containers that take a long time to come into service. Rather than set a long liveness interval, you can configure a separate configuration for probing the container as it starts up, allowing a time longer than the liveness interval would allow.

If your container usually starts in more than `initialDelaySeconds + failureThreshold × periodSeconds`, you should specify a startup probe that checks the same endpoint as the liveness probe. The default for `periodSeconds` is 10s. You should then set its `failureThreshold` high enough to allow the container to start, without changing the default values of the liveness probe. This helps to protect against deadlocks.

Termination of Pods

Because Pods represent processes running on nodes in the cluster, it is important to allow those processes to gracefully terminate when they are no longer needed (rather than being abruptly stopped with a `KILL` signal and having no chance to clean up).

The design aim is for you to be able to request deletion and know when processes terminate, but also be able to ensure that deletes eventually complete. When you request deletion of a Pod, the cluster records and tracks the intended grace period before the Pod is allowed to be forcefully killed. With that forceful shutdown tracking in place, the kubelet attempts graceful shutdown.

Typically, with this graceful termination of the pod, kubelet makes requests to the container runtime to attempt to stop the containers in the pod by first sending a TERM (aka. SIGTERM) signal, with a grace period timeout, to the main process in each container. The requests to stop the containers are processed by the container runtime asynchronously. There is no guarantee to the order of processing for these requests. Many container runtimes respect the `STOPSIGNAL` value defined in the container image and, if different, send the container image configured STOPSIGNAL instead of TERM. Once the grace period has expired, the KILL signal is sent to any remaining processes, and the Pod is then deleted from the API Server. If the kubelet or the container runtime's management service is restarted while waiting for processes to terminate, the cluster retries from the start including the full original grace period.

An example flow:

1. You use the `kubectl` tool to manually delete a specific Pod, with the default grace period (30 seconds).
2. The Pod in the API server is updated with the time beyond which the Pod is considered "dead" along with the grace period. If you use `kubectl describe` to check the Pod you're deleting, that Pod shows up as "Terminating". On the node where the Pod is running: as soon as the kubelet sees that a Pod has been marked as terminating (a graceful shutdown duration has been set), the kubelet begins the local Pod shutdown process.
    1. If one of the Pod's containers has defined a `preStop` hook and the `terminationGracePeriodSeconds` in the Pod spec is not set to 0, the kubelet runs that hook inside of the container. The default `terminationGracePeriodSeconds` setting is 30 seconds.

       If the `preStop` hook is still running after the grace period expires, the kubelet requests a small, one-off grace period extension of 2 seconds.

       Note: If the `preStop` hook needs longer to complete than the default grace period allows, you must modify `terminationGracePeriodSeconds` to suit this.

    2. The kubelet triggers the container runtime to send a TERM signal to process 1 inside each container.

       Note: The containers in the Pod receive the TERM signal at different times and in an arbitrary order. If the order of shutdowns matters, consider using a `preStop` hook to synchronize.

3. At the same time as the kubelet is starting graceful shutdown of the Pod, the control plane evaluates whether to remove that shutting-down Pod from EndpointSlice (and Endpoints) objects, where those objects represent a Service with a configured selector. ReplicaSets and other workload resources no longer treat the shutting-down Pod as a valid, in-service replica.

   Pods that shut down slowly should not continue to serve regular traffic and should start terminating and finish processing open connections. Some applications need to go beyond finishing open connections and need more graceful termination, for example, session draining and completion.

   Any endpoints that represent the terminating Pods are not immediately removed from EndpointSlices, and a status indicating terminating state is exposed from the EndpointSlice API (and the legacy Endpoints API). Terminating endpoints always have their `ready` status as `false` (for backward compatibility with versions before 1.26), so load balancers will not use it for regular traffic.

   If traffic draining on terminating Pod is needed, the actual readiness can be checked as a condition `serving`. You can find more details on how to implement connections draining in the tutorial Pods And Endpoints Termination Flow

Note: If you don't have the `EndpointSliceTerminatingCondition` feature gate enabled in your cluster (the gate is on by default from Kubernetes 1.22, and locked to default in 1.26), then the Kubernetes control plane removes a Pod from any relevant EndpointSlices as soon as the Pod's termination grace period *begins*. The behavior above is described when the feature gate `EndpointSliceTerminatingCondition` is enabled.

Note:

Beginning with Kubernetes 1.29, if your Pod includes one or more sidecar containers (init containers with an Always restart policy), the kubelet will delay sending the TERM signal to these sidecar containers until the last main container has fully terminated. The sidecar containers will be terminated in the reverse order they are defined in the Pod spec. This ensures that sidecar containers continue serving the other containers in the Pod until they are no longer needed.

Note that slow termination of a main container will also delay the termination of the sidecar containers. If the grace period expires before the termination process is complete, the Pod may enter emergency termination. In this case, all remaining containers in the Pod will be terminated simultaneously with a short grace period.

Similarly, if the Pod has a preStop hook that exceeds the termination grace period, emergency termination may occur. In general, if you have used preStop hooks to control the termination order without sidecar containers, you can now remove them and allow the kubelet to manage sidecar termination automatically.

1. When the grace period expires, the kubelet triggers forcible shutdown. The container runtime sends `SIGKILL` to any processes still running in any container in the Pod. The kubelet also cleans up a hidden `pause` container if that container runtime uses one.
2. The kubelet transitions the Pod into a terminal phase (`Failed` or `Succeeded` depending on the end state of its containers). This step is guaranteed since version 1.27.
3. The kubelet triggers forcible removal of Pod object from the API server, by setting grace period to 0 (immediate deletion).
4. The API server deletes the Pod's API object, which is then no longer visible from any client.

Forced Pod termination

Caution: Forced deletions can be potentially disruptive for some workloads and their Pods.

By default, all deletes are graceful within 30 seconds. The `kubectl delete` command supports the `--grace-period=<seconds>` option which allows you to override the default and specify your own value.

Setting the grace period to `0` forcibly and immediately deletes the Pod from the API server. If the Pod was still running on a node, that forcible deletion triggers the kubelet to begin immediate cleanup.

Note: You must specify an additional flag `--force` along with `--grace-period=0` in order to perform force deletions.

When a force deletion is performed, the API server does not wait for confirmation from the kubelet that the Pod has been terminated on the node it was running on. It removes the Pod in the API immediately so a new Pod can be created with the same name. On the node, Pods that are set to terminate immediately will still be given a small grace period before being force killed.

Caution: Immediate deletion does not wait for confirmation that the running resource has been terminated. The resource may continue to run on the cluster indefinitely.

If you need to force-delete Pods that are part of a StatefulSet, refer to the task documentation for deleting Pods from a StatefulSet.

Garbage collection of Pods

For failed Pods, the API objects remain in the cluster's API until a human or controller process explicitly removes them.

The Pod garbage collector (PodGC), which is a controller in the control plane, cleans up terminated Pods (with a phase of `Succeeded` or `Failed`), when the number of Pods exceeds the configured threshold (determined by `terminated-pod-gc-threshold` in the kube-controller-manager). This avoids a resource leak as Pods are created and terminated over time.

Additionally, PodGC cleans up any Pods which satisfy any of the following conditions:

1. are orphan Pods - bound to a node which no longer exists,
2. are unscheduled terminating Pods,
3. are terminating Pods, bound to a non-ready node tainted with `node.kubernetes.io/out-of-service`, when the `NodeOutOfServiceVolumeDetach` feature gate is enabled.

When the `PodDisruptionConditions` feature gate is enabled, along with cleaning up the Pods, PodGC will also mark them as failed if they are in a non-terminal phase. Also, PodGC adds a Pod disruption condition when cleaning up an orphan Pod. See Pod disruption conditions for more details.

What's next

- Get hands-on experience attaching handlers to container lifecycle events.
- Get hands-on experience configuring Liveness, Readiness and Startup Probes.
- Learn more about container lifecycle hooks.
- Learn more about sidecar containers.
- For detailed information about Pod and container status in the API, see the API reference documentation covering `status` for Pod.

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