

Self-Healing Microservices with Kubernetes

Self-Adaptation in Micro-Service Architectures with Kubernetes Seminar – Summer Term 2019

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Abstract: Abstract goes here.

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1 Introduction

1. cloud
 - cloud computing de-facto standard in industry
 - reasons: more flexibility, higher and dynamically available performance, and competitive prices [To15]
 - more hardware means more hardware can fail → plan for failure [Ne15]
 - need for resilient systems [Bo14]
 - achieve it via replication, containment, isolation, and monitoring paired with responsive actions to failures
2. microservices
 - way to allow scaling of applications combined with a way to realize containment and isolation on business boundaries
 - decompose software application into small, lightweight, autonomous services (= scaling units)
 - embrace failure: services relying on other services should deal with them failing [Ne15]
3. deployment and orchestration → Kubernetes
4. self-adaptive systems
 - self-* properties
 - MAPE-K loop
5. self-healing

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- currently widely-used definition for self-healing systems is from Ghosh et al. [Gh07]:

The key focus [...] is that a self-healing system should recover from the abnormal (or “unhealthy”) state and return to the normative (“healthy”) state, and function as it was prior to disruption.

- Neither fault-tolerant systems, nor survivable systems include recovery oriented functionalities that bring the system back to the healthy state, which is the key aspect of self-healing systems [Gh07].
- Combination of [PD11]
 - Fault-tolerant (handle transient failures and mask permanent ones)
 - self-stabilizing (non-fault masking; system converges to legal state in finite time and tries to remain in the same (closure))
 - survivable (maintain essential service and recover non-essential after intrusions have been dealt with)

6. self-healing of microservices in cloud environments

- Psailer; Dustdar compare self-healing in cloud environments to the techniques that achieve continuous availability of the application [PD11]:

In cloud environments, self-healing can be considered as the techniques to achieve continuous availability, which involves detecting disruptions, diagnosing failures and recovering with a sound strategy.

- In a cloud environment and a VM or container deployment, all failures are reduced to a single one: service unavailable after a while

2 Related Work

- Reactive Manifesto [Bo14] asks for more resilient and responsive systems. The resilience is achieved by replication, containment, isolation, and delegation. Recovery should be handled by an external component. This could be a self healing component.
- [To15]
- [St17]
- [FN16]
- [DHT02]
- Kubernetes and alternatives

3 Self-Healing

1. sub control loop of MAPE-K loop (Detect – Analyze – Recover) [PD11]
2. different levels of self-healing (architecture-based, model-based, hierarchical, etc.)
3. self-healing management logic external and internal to the managed application
external to application

- self-healing and management logic is run in isolation from the application code
- Examples: using services from the infrastructure provider, using third party services, or building an ad-hoc solution (e. g. using Kubernetes) [To15]
- current state of the art for monitoring, health management, and scaling logic
- could lead to vendor lock-in
- external management logic has to be themselves resilient, fault-tolerant, and scalable

within application

- approach by Toffetti et al. for microservices; leverages standard methods from distributed systems (such as consensus algorithms) to assign self-management functionality to nodes of the application; hierarchical approach [To15]

4 Kubernetes

1. what is Kubernetes? → <https://kubernetes.io/docs/concepts/overview/what-is-kubernetes/>
2. architecture and how it works
 - master-slave architecture
 - master runs kube controller manager, API server, etcd, kube scheduler, cloud controller manager
 - slave (nodes) run kubelet (pod management and health monitoring) and kube proxy (cluster networking), and container runtime (e.g. Docker)
 - only slaves run application code
3. Kubernetes objects² and labels³
4. pods and containers⁴

5 Using Kubernetes to implement a self-healing application

1. How would a setup of a self-healing microservice architecture look like?
2. comparable to architecture-based approach
 - a) Kubernetes object configuration corresponds to the desired runtime architecture of the managed application. ([To15] call it *instance graph*)
 - b) Kubernetes internally holds the current architecture of the running components (in *etcd*)

² <https://kubernetes.io/docs/concepts/overview/working-with-objects/kubernetes-objects/>

³ <https://kubernetes.io/docs/concepts/overview/working-with-objects/labels/>

⁴ <https://kubernetes.io/docs/concepts/workloads/pods/pod-overview/>

- c) Container failures are captured by the restart policy of their pods. When set to *Always* or *OnFailure*, failing containers are restarted with an exponential back-off delay⁵.
 - d) To deal with node failures, pods have to be managed by controllers (explained later)⁶. They perform the Detect – Analyze – Recover loop by
 - monitoring the health of their managed pods with heartbeats and user-defined liveness probes⁷
 - comparing the desired and current state of their pods
 - performing actions (create or delete pod) to transition into the desired state
 - e) Kubernetes sets the phase of all pods on a died or disconnected node to *Failed*
3. self-healing properties available in Kubernetes via controllers:
- “A Controller can create and manage multiple Pods for you, handling replication and rollout, and providing self-healing capabilities at cluster scope. – <https://kubernetes.io/docs/concepts/workloads/pods/pod-overview/#pods-and-controllers>” Pods are transparently placed on the available nodes by the controller.
- recovery of stateful applications:
 - Deployment definition via StatefulSet: <https://kubernetes.io/docs/tutorials/stateful-application/basic-stateful-set/>
 - Uses PersistentVolumes (provided by the underlying cloud platform, e.g AWS, GCP, OpenStack) for storage
 - Pods have a unique identity (name, network id, K8s configuration)
 - Failed pods will be rescheduled on other nodes with their identity (re-using the assigned persistent volume and network id)
 - A headless Service takes care of service discovery using SRV records and DNS (re-routing traffic to rescheduled pods on different nodes)
 - therefore, relies on the availability and fault-tolerance of the used persistent volumes
 - recovery of stateless applications:
 - Deployment definition via Deployment and the specification of replicas > 1 or with ReplicaSet
 - Failing pods will be recreated to match the desired number of replicas (node placement is transparent)
 - daemons: applications per node
 - Defined via DaemonSets: <https://kubernetes.io/docs/concepts/workloads/controllers/daemonset>
 - Ensures (monitors, restarts) that a copy of an application is run on each node (also on added or removed nodes)

⁵ <https://kubernetes.io/docs/concepts/workloads/pods/pod-lifecycle/#restart-policy>

⁶ <https://kubernetes.io/docs/concepts/workloads/pods/pod-lifecycle/#pod-lifetime>

⁷ <https://kubernetes.io/docs/tasks/configure-pod-container/configure-liveness-readiness-probes/>

- no real recovery if a node fails. Relies on manual action to replace the failed node. Then the DaemonSet will take care of creating the daemon pod on the newly added node.
- 4. regarding the survivability aspect of self-healing systems: <https://kubernetes.io/docs/concepts/configuration/pod-priority-preemption/>
 - we can define priority classes and assign pods to those
 - pod priority will affect scheduling order (higher priority pods first)
 - under resource pressure, higher priority nodes that are created and scheduled will evict lower priority pods (with their graceful termination period after which they are killed)
 - pod disruption budgets can be specified to limit the number of replicated pods that are simultaneously down from voluntary disruption (draining, and also preemption)⁸
 - pod disruption budgets are considered only on best effort basis during preemption

6 Discussion

1. requires containerized microservice application
2. code must support scaling and dynamic communication
3. provider of PersistentVolumes must ensure their availability and fault-tolerance
4. to deal with a node failure, remaining nodes must have enough spare capacity to host the failed pods
5. with replication factor 1, there are down times during re-creation of the pod on another node
6. limitations
 - **external management logic has to be themselves resilient, fault-tolerant, and scalable**
 - Kubernetes default only one master → HA setup across availability zones
 - quite a lot of configuration work, not automation yet (WIP)
 - only one master will be active (the other two will be passive), full state replication via etcd
 - fail-over will be handled by load balancer component
 - **only external view on the system**
 - **Kubernetes does not automatically repair or restart failing nodes**
 - → automatic node repairs on GCE: <https://cloud.google.com/kubernetes-engine/docs/how-to/node-auto-repair>
 - components external to Kubernetes are not included in self-healing logic (such as external storage or load balancers of cloud provider)
7. benefits
 - healing from pod / container failures and node failures out-of-the-box

⁸ <https://kubernetes.io/docs/concepts/workloads/pods/disruptions/#how-disruption-budgets-work>

- declarative definition of system state
 - rich API to retrieve current system state
8. interesting facts and insights

7 Conclusion

- short summary (microservices, self-healing, how Kubernetes does it)
- self-healing in Kubernetes is an architectural approach
- achieves fault-tolerance through replication and redundancy
- on failure: redundant components take over
- after failure: the system converges to the desired state by rescheduling pods (pod controller)
- pod priorities and pod disruption budgets help on resource pressure and failure to keep essential services running (through terminating non-essential ones and restarting them when more resources get available)

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