Running a distributed system across Kubernetes clusters

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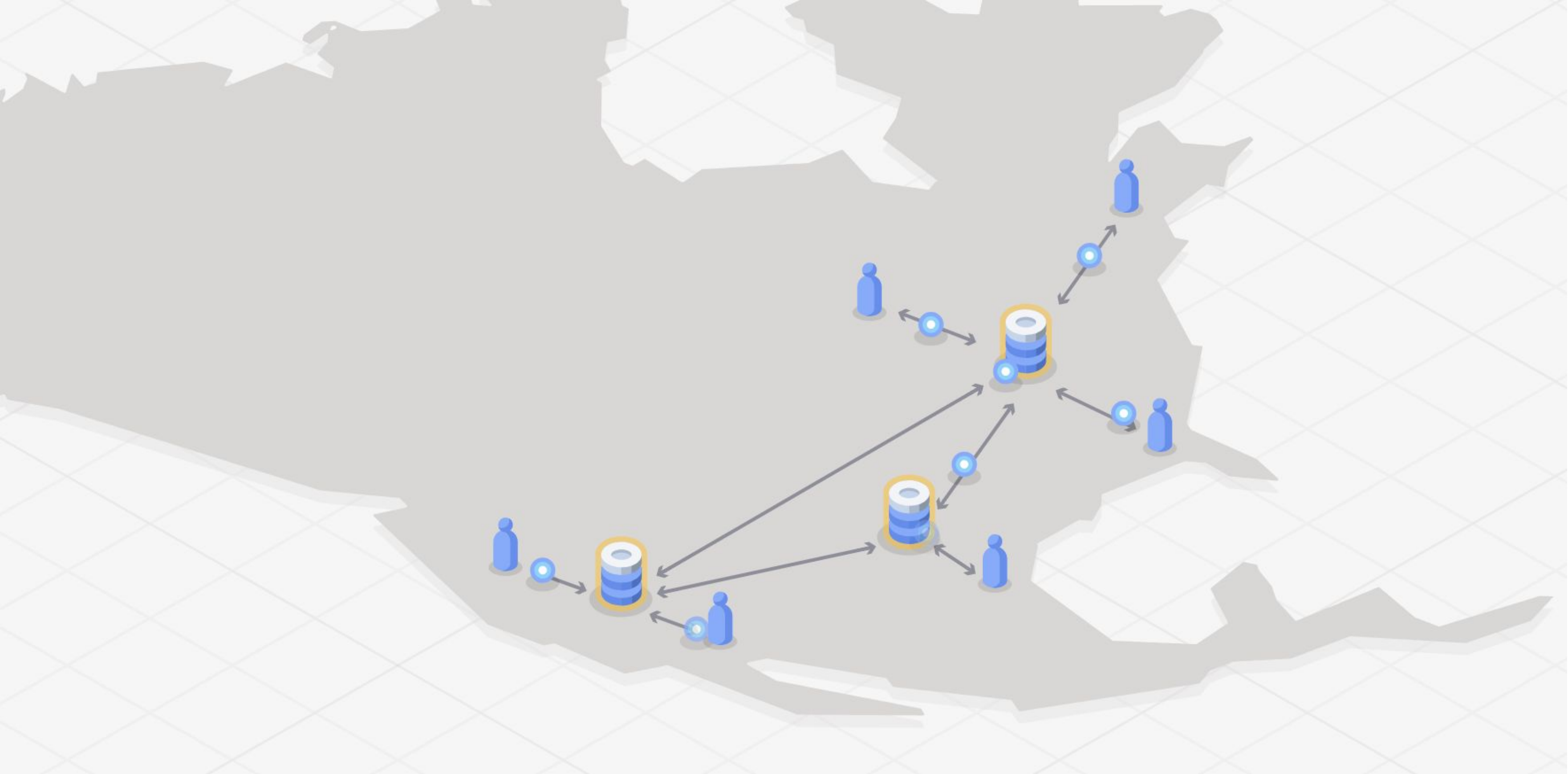
Cockroach LABS

Running on Kubernetes has gotten much easier

- Dynamic volume provisioning
- Statefulsets
- Multi-zone clusters
- Managed Kubernetes services
- Helm Charts
- Operators

…Unless you want your service to span regions



Why run a system across multiple regions?

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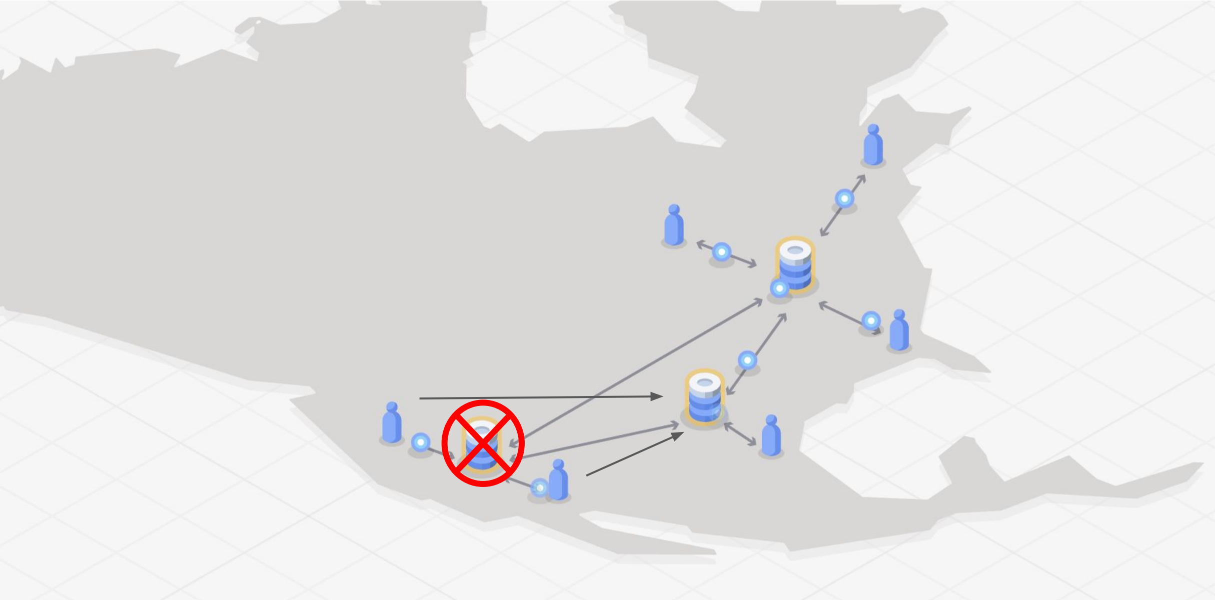
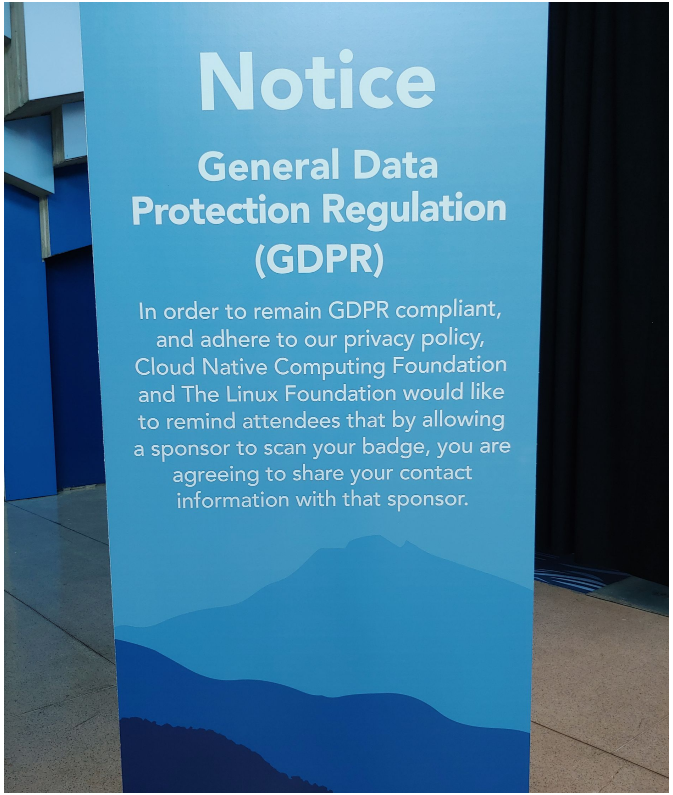
- Fault tolerance



Why run a system across multiple regions?

- Latency
- Fault tolerance
- ...Bureaucracy?



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Let’s talk about running across Kubernetes clusters

- Why is it hard?
- What do you need to know to get started?
- Solutions

My experience with Kubernetes

- Worked directly on Kubernetes and GKE from 2014-2016
  - Part of the original team that launched GKE
- Lead all container-related efforts for CockroachDB
  - Configurations for Kubernetes, DC/OS, Docker Swarm, even Cloud Foundry
  - AWS, GCP, Azure, On-Prem
  - From single availability zone deployments to multi-region
  - Help users deploy and troubleshoot their custom setups

kubernetes

Cockroach DB

The problem

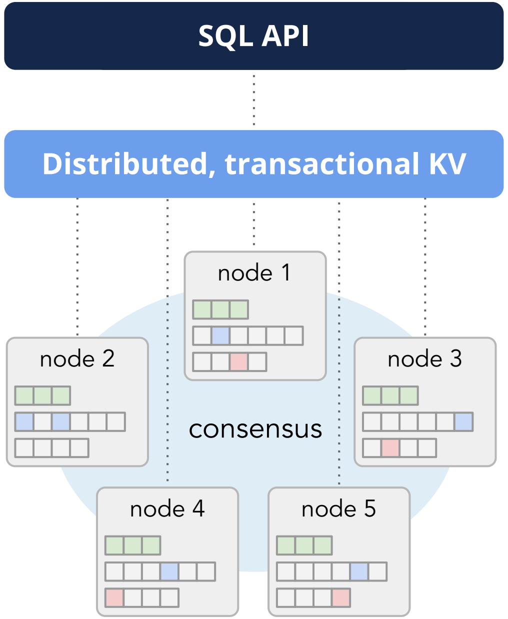
What’s so hard about spanning across clusters?

Multi-region == Multi-Kubernetes-cluster

- Kubernetes is not designed to span WANs
  - Originally didn’t even want to have to span datacenters/AZs within a region, but the community fought for that and made it happen
- Try to run a single k8s cluster across regions at your own risk

What does a distributed stateful system need?

Our example: CockroachDB



CockroachDB is an open source distributed SQL database

1. **SQL:** Your applications use standard PostgreSQL
2. **Ranges:** Tables are sorted by key, split into 64MB chunks and each range is then replicated across the cluster
3. **Nodes:** If a node is added, remove or fails, the cluster automates redistribution and replication of ranges
4. **Consensus:** Consensus protocol ensures consistency and highest level of isolation for transactions
5. **Locality:** In a distributed environment you can tie data to a location (physical, logical, real)

Running CockroachDB in Kubernetes

- Cockroach requires (roughly) three things:
  1. Each node has persistent storage that survives restarts
  2. Each node can communicate directly with every other node
  3. Each node has a network address that survives restarts

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Running CockroachDB in Kubernetes

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- Kubernetes provides these very well within a single cluster
- Across multiple Kubernetes clusters, we lose #3 and often #2

The core problems: what's missing?

- It all comes down to networking:
    - Pod-to-pod communication across clusters
        - Including across private networks (e.g. cloud VPCs) when applicable
    - Persistent address that works both within and between clusters

Kubernetes networking

What’s the deal with multi-cluster networking?

Kubernetes networking

- Kubernetes doesn't care *how* it's done, but it requires that:
  1. Each pod has its own IP address
  2. The IP that a pod sees itself as is the same IP that others see it as
  3. All pods can communicate with all other pods without NAT

Kubernetes networking

- Kubernetes doesn’t care *how* it’s done, but it requires that:
  1. Each pod has its own IP address
  2. The IP that a pod sees itself as is the same IP that others see it as
  3. All pods can communicate with all other pods without NAT
- The problem: we want to run tens of pods on each machine, but traditional networks only allocate one or two IP addresses to each host

Kubernetes networking

- From the very beginning, Kubernetes made these specific demands about what the network in a cluster must enable
    - Since then, dozens of solutions have been built to satisfy those requirements
- But the multi-cluster scenario is left completely unspecified

Google Cloud
Azure
weaveworks
cilium
CISCO
PROJECT CALICO
amazon web services
flannel

Kubernetes networking

- Some enable pod-to-pod communication across clusters out of the box
    - e.g. GKE, EKS
- Some make it fairly easy to enable
    - e.g. AKS (“advanced” networking mode), Cilium (“cluster mesh”)
- It can be quite difficult in others

Solutions

So what can we do?

Multi-cluster solutions

- The options all have one problem or another
    - Don’t work in subsets of environments
    - Break easily if operator doesn’t know exactly what they’re doing
    - Use a slow, less reliable datapath
    - Don’t work with TLS certificates
    - Rely on a relatively immature, complex system

Solution #1: Static pod placement + HostNetwork

- `HostNetwork` option lets a pod use the host machine's network directly
- Use each host's routable IP address for all communication
- Statically assign pods to machines so that all nodes' IPs stay the same

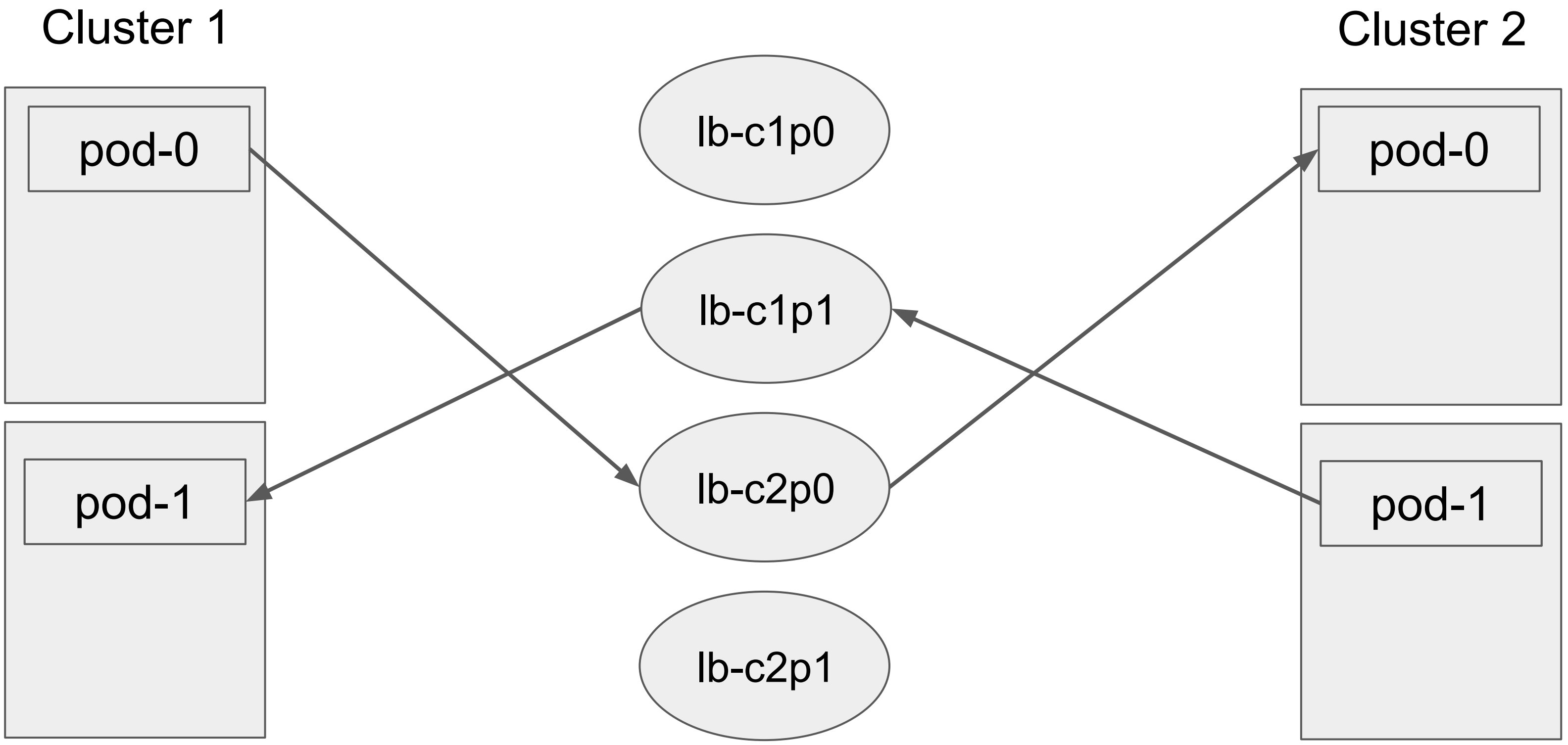
Solution #1: HostNetwork + Public IPs

- Pros:
  - Works even when pod-to-pod communication between clusters doesn’t
  - No moving parts
  - Using `HostNetwork` can actually give a nice performance boost
- Cons:
  - Depends on host IPs not changing
    - Some cloud providers delete and recreate VMs during node upgrades
  - Requires a lot of manual config-file editing and certificate creating
  - Uses up valuable ports on the host machines, can hit port conflicts

Solution #2: External load balancer for each pod

- Create a public load balancer for each Cockroach pod
    - It’s really easy to expose a service with a load balancer in all the major cloud providers
- Have all pods connect to each other with the load balancer IPs/DNS names

Solution #2: External load balancer for each pod



Solution #2: External load balancer for each pod

- Pros:
  - Works even when pod-to-pod communication between clusters doesn’t
  - Continues working even as Kubernetes hosts churn in/out of the cluster
  - No need to configure a cross-cluster naming service
    - Because the load balancer addresses never change once they’re created

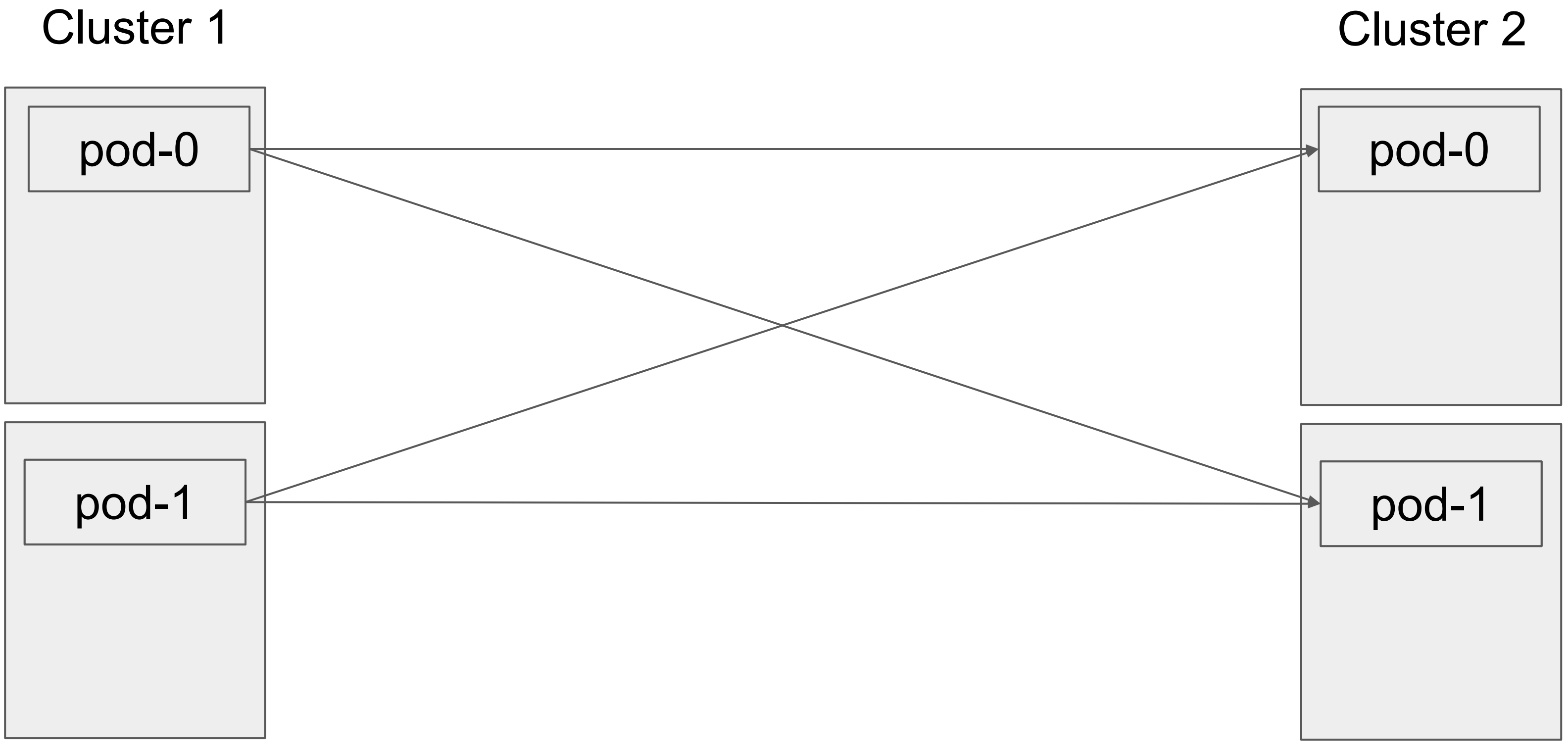
Solution #2: External load balancer for each pod

- Cons:
    - Requires provisionable load balanced addresses - not always available on-prem
    - Can be expensive to run so many load balancers
    - A lot of manual config-file editing and cert creating with LB addresses
        - Informing each pod of its public IP requires pretty complex configuration
    - Need to create new service and LB whenever you want to scale up
    - Extra hops on data path on all but the most sophisticated load balancers
        - src pod->src host->LB->random host->dst host->dst pod

Solution #3: Use pod IPs directly

- Just let pods advertise their pod IPs to each other directly
    - Assuming pod-to-pod connectivity across clusters
- Rely on Cockroach's handling of address changes to deal with the inevitable churn as pods move to different nodes and get different IPs
- Set up an internal load balancer that only gets used for the --join flag
    - Won't be used on the data path, since cockroach nodes will share their pod IP addresses internally via gossip once joining

Solution #3: Use pod IPs directly



Solution #3: Use pod IPs directly

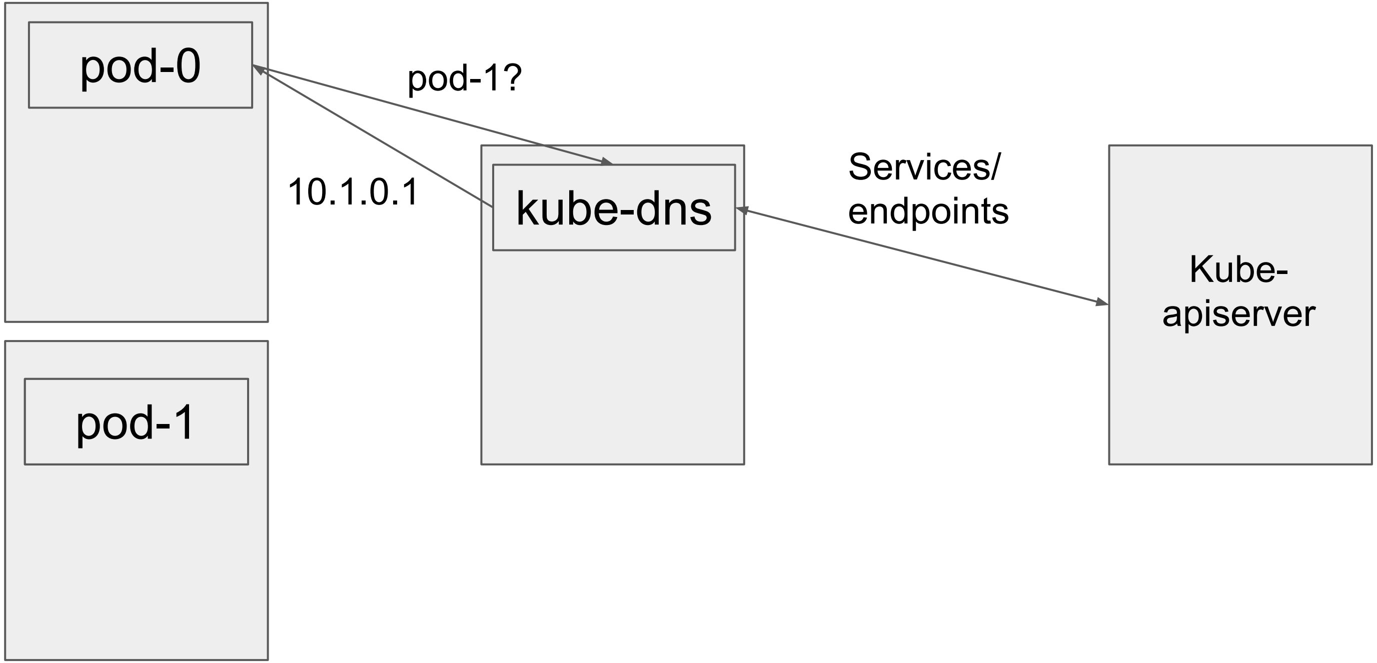
- Pros:
  - No overhead on data path (except normal Docker overhead)
  - Very resilient to changes like hosts being removed/added/restarted
  - Very little manual work needed to configure and maintain
- Cons:
  - Network must support direct pod-to-pod communication across clusters
  - Because IP addresses can change across pod deletions/recreations, creating TLS certificates that can stand up to hostname verification is very tricky

Solution #4: DNS chaining

- Basically: how can we add persistent names to the previous solution?
    - Needed for TLS certificates or for systems that can’t handle changing addresses

Solution #4: DNS chaining

Cluster 1



Solution #4: DNS chaining

- Option 1: Use CoreDNS instead of the default kube-dns service
  - CoreDNS allows for much more customization, including plugins that allow it to watch multiple Kubernetes apiservers
    - https://github.com/coredns/kubernetai was written to do just what we want
  - But swapping CoreDNS in for kube-dns on managed offerings is shockingly difficult
    - As is customizing each cluster's DNS domain from the `cluster.local.` default, which would be important for this approach
  - CoreDNS is becoming the standard as of 1.13, so this should become more feasible as more clusters switch over to it

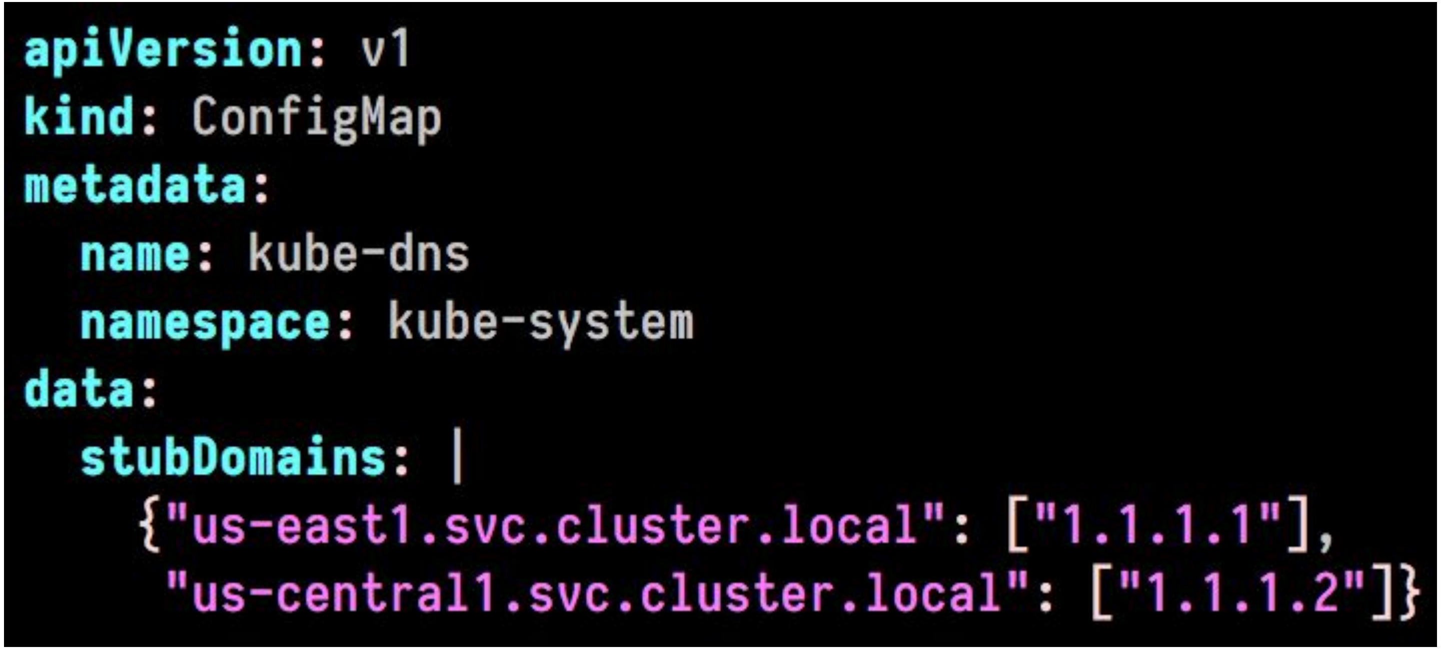
Solution #4: DNS chaining

- Option 1.5: Use CoreDNS alongside the default kube-dns service
  - Configure kube-dns to defer certain lookups to CoreDNS
  - Configure CoreDNS to watch the other k8s clusters’ apiservers
  - Add in some CoreDNS rewrite rules to make cross-cluster lookups work out
  - Haven’t properly tried this out so I’m being a little fuzzy on the details

Solution #4: DNS chaining

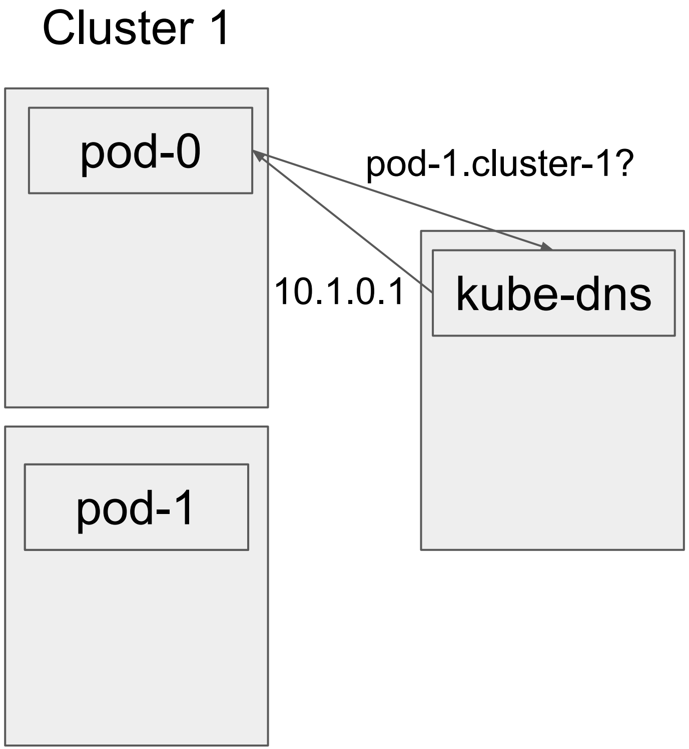
- Option 2: Chain DNS servers together using “stub domains”
    - Use KubeDNS config feature to defer DNS lookups for certain domains to the nameserver of your choice
    - e.g., configure KubeDNS in us-west1 to redirect lookups for `*.us-east1.svc.cluster.local` to the us-east1 cluster’s DNS service
    - This is what I’ve put together scripts for people to try out on GKE

Solution #4: DNS chaining



```
apiVersion: v1
kind: ConfigMap
metadata:
  name: kube-dns
  namespace: kube-system
data:
  stubDomains: |
    {"us-east1.svc.cluster.local": ["1.1.1.1"],
     "us-central1.svc.cluster.local": ["1.1.1.2"]}
```

Solution #4: DNS chaining



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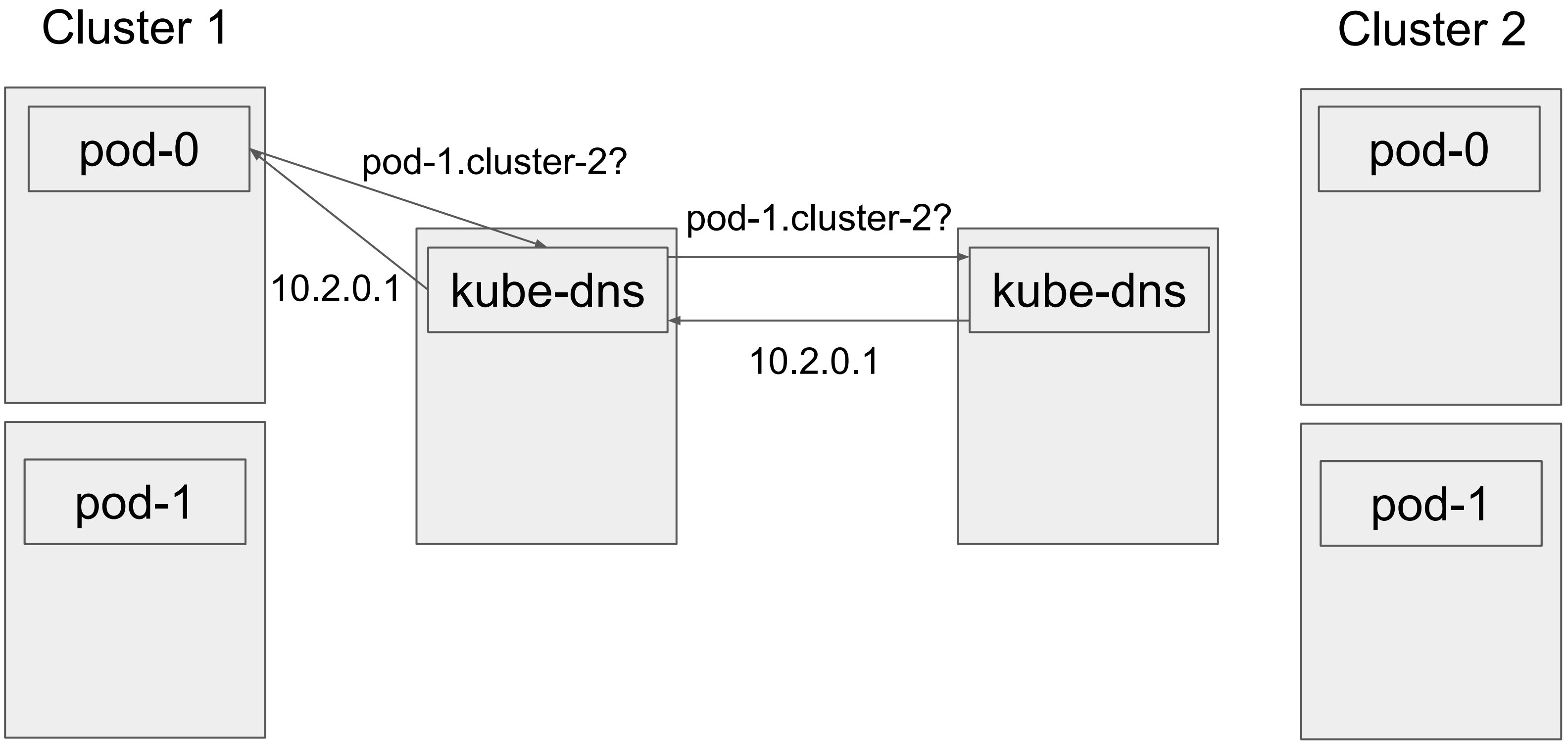

Solution #4: DNS chaining

- Pros of using stub domains:
  - No overhead on data path (except normal Docker overhead)
  - Very resilient to changes like hosts being removed/added/restarted
  - No need to add any extra controllers to the clusters
  - Very little manual work needed to get running (totally scriptable)
- Cons of using stub domains:
  - Network must support pod-to-pod communication across clusters
  - Need to set up load balanced endpoints for each DNS server
    - Cloud support for this isn't great…

Solution #5: Istio

- Istio has been working on a “multi-cluster” mode to handle the problem of addressing services across clusters
  - It’s explicitly not addressing the problem of pod-to-pod connectivity, though -- just naming
- Install Istio control plane in one primary k8s cluster, then install special “istio-remote” components in others

Solution #5: Istio

- Pros:
  - Under very active development, looks likely to improve over time
  - Small overhead on data path (packets go through Envoy proxy)
  - Very resilient to changes like hosts being removed/added/restarted (at least in theory)
- Cons:
  - Still immature - entire control plane runs in a single k8s cluster (single point of failure)
  - Very involved setup process
  - Docs say “production environment might require additional steps”, at least one of which essentially boils down to solving this problem for the Istio components themselves
  - Requires copying k8s cluster credentials into each other (potential security concern)

Solution #6: Roll your own

- Can always do your own thing, e.g.:
  - Set up your own custom DNS servers outside Kubernetes
  - Set up your own auto-certificate approver for pod IPs then use them directly
  - Manage your own clusters, use CoreDNS, and modify it as you please
  - Set up your own proxy server(s) to manage stable, routable addresses
  - Etc.
- Tough for us to widely recommend due to environmental differences, but actually quite reasonable if you have a single stable environment

Summary

Conclusions

- Multi-cluster networking is a bit of a minefield
  - Left completely unspecified, so different installations can vary wildly
  - Very little has been done about it for years
- Even after you nail pod-to-pod connectivity, you still have to solve naming
- People are finally starting to care, though! (e.g. Cilium, Istio, Upbound)
- It’s hard to recommend a single answer for everyone, but there are very reliable options if you’re willing to spend some time up-front on setup

Thank You!

For more info:

cockroachlabs.com

github.com/cockroachdb/cockroach

@alexwritescode

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Questions?

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