Competitive Clustering of Stochastic Communication Patterns on the Ring

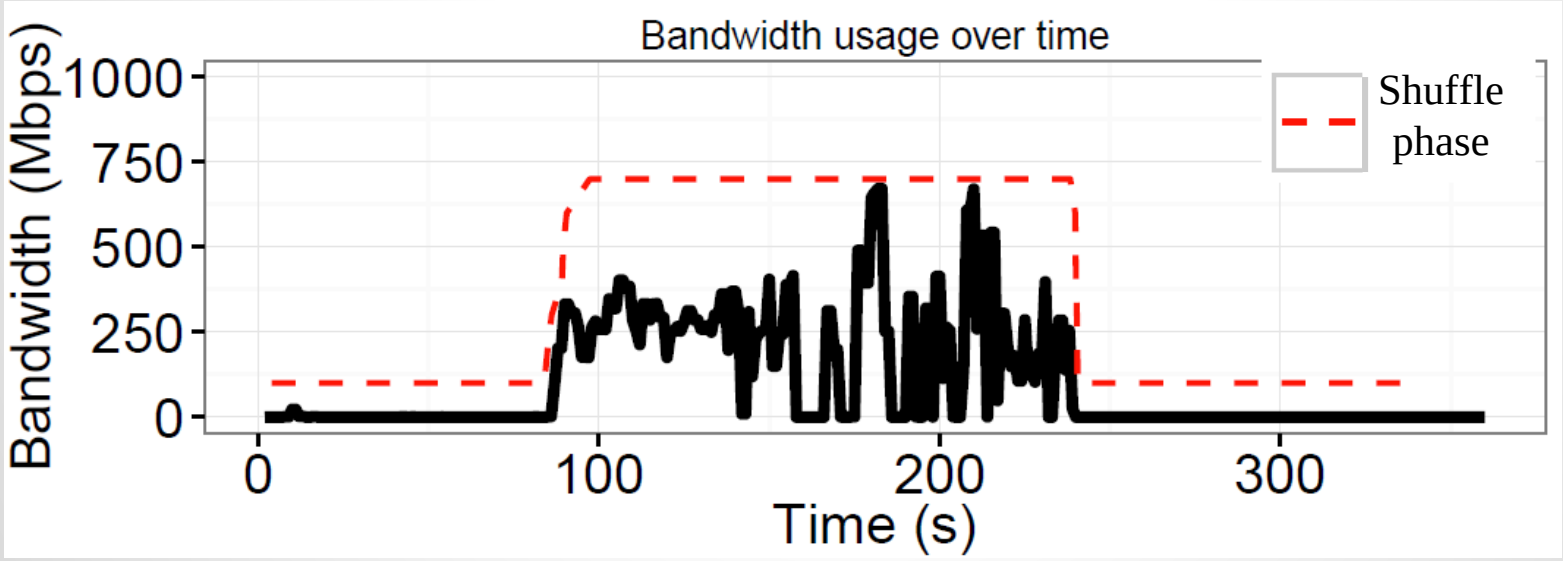
Chen Avin Louis Cohen Stefan Schmid

Nice to meet you!

The Network Matters

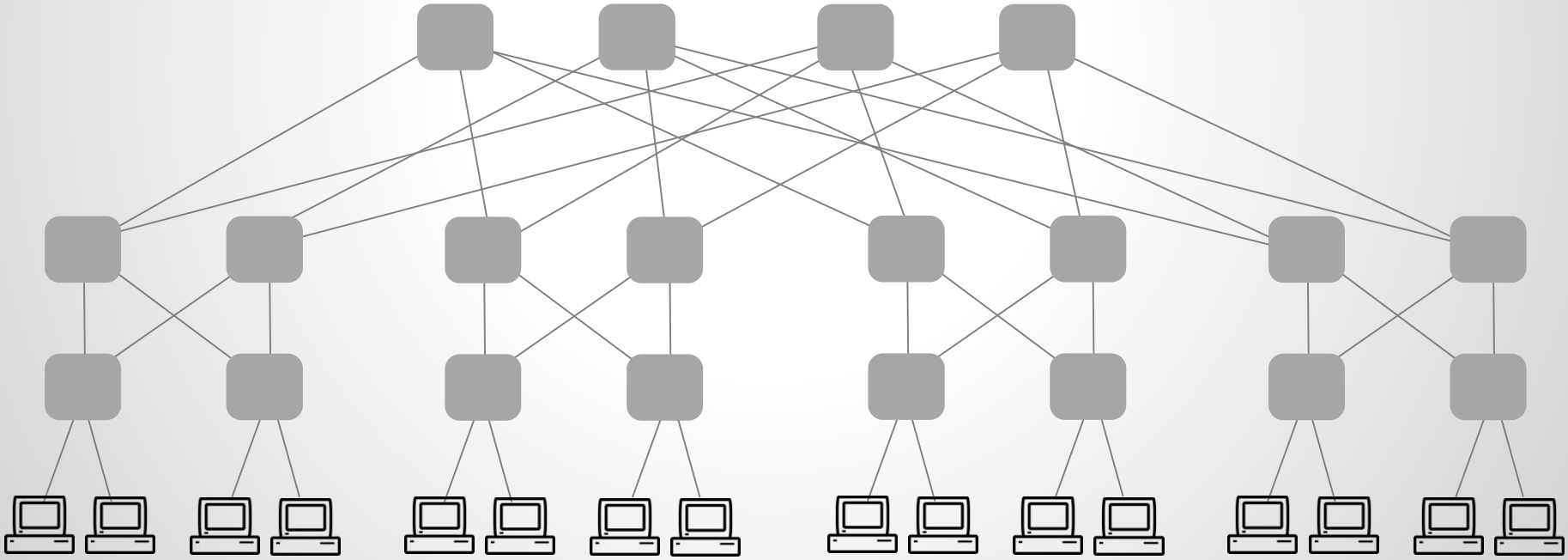
- Cloud-based applications generate significant network traffic
  - E.g., scale-out databases, streaming, batch processing applications

- E.g., Hadoop Terrasort job:



Example: VM Placememt

- Virtual machine placement affects bandwidth costs
- Example: map reduce in Clos datacenter



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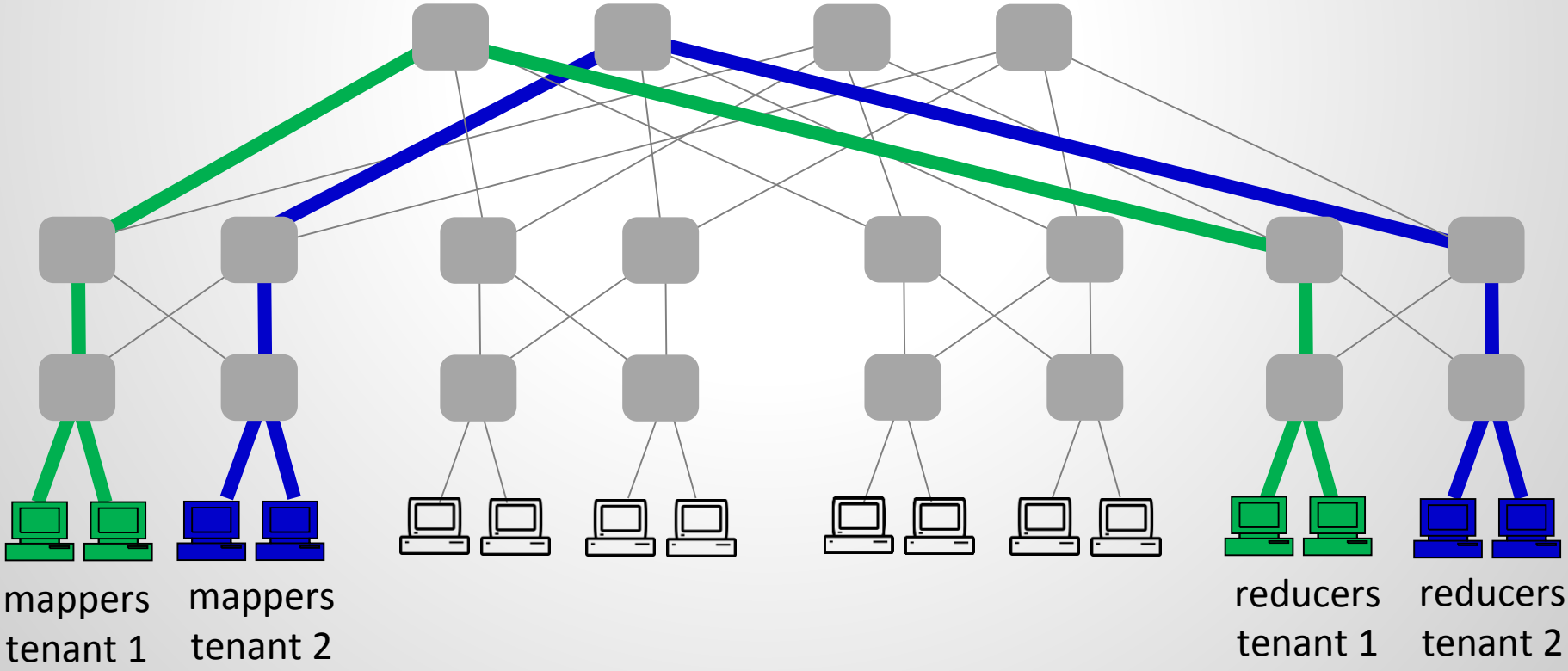

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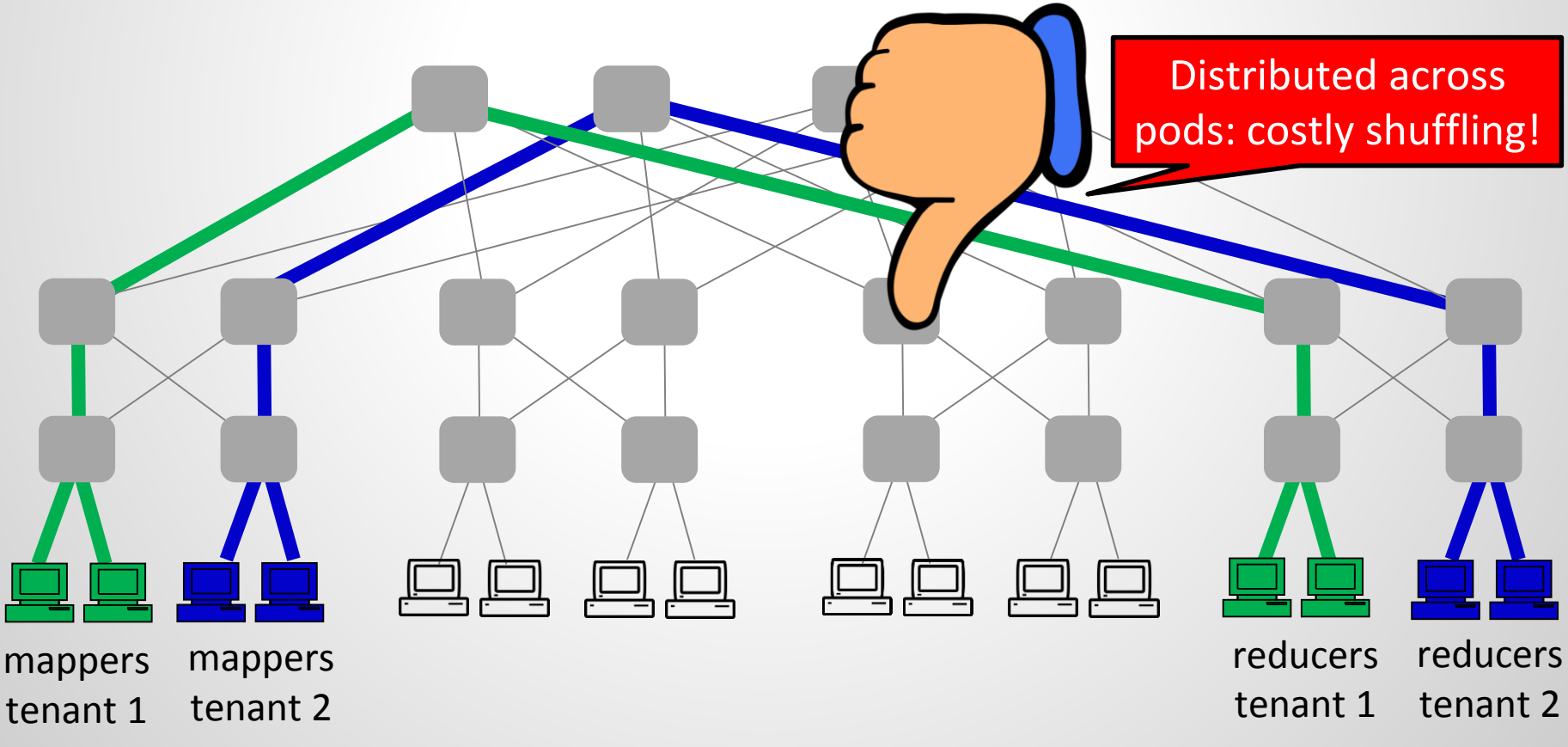

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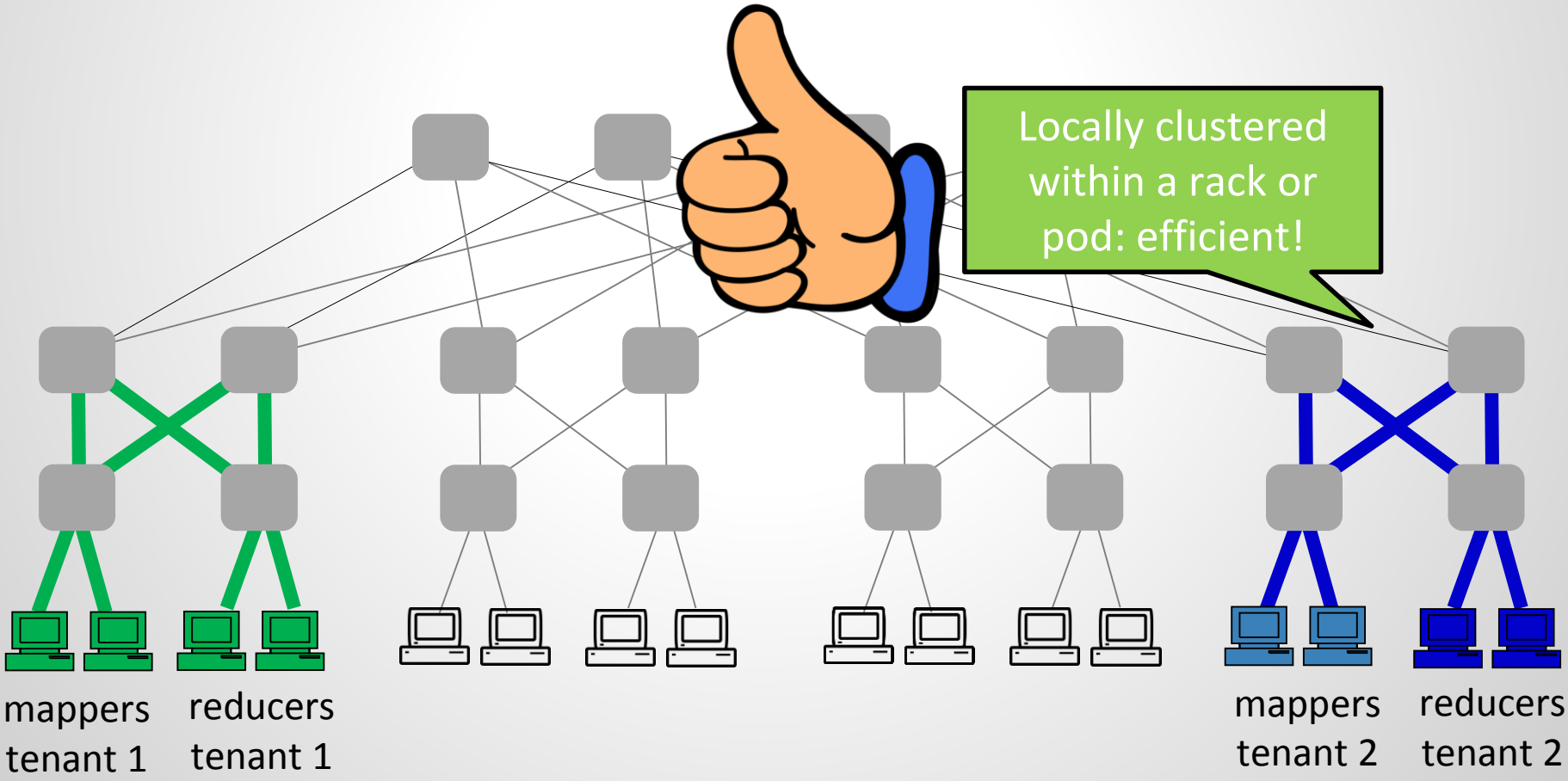

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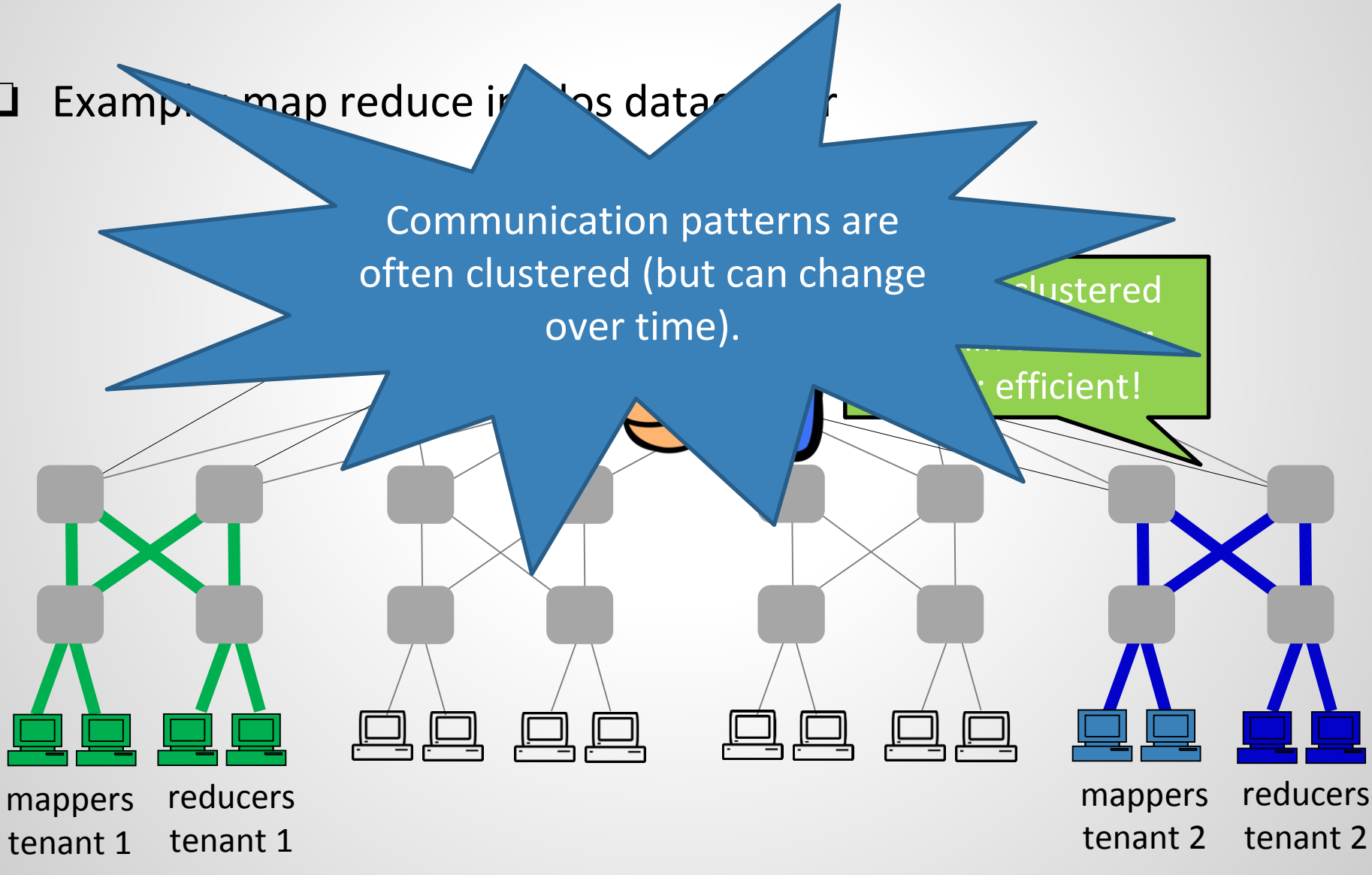

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- ❑ Protot[illegible]ctToR
- ❑ Base[illegible]

We are working on it! E.g., „SplayNets @ TON 2016“.
But not today!

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- Challenges of communication pattern clustering:
  - Communication patterns are not known ahead of time…
  - … and may even change over time!

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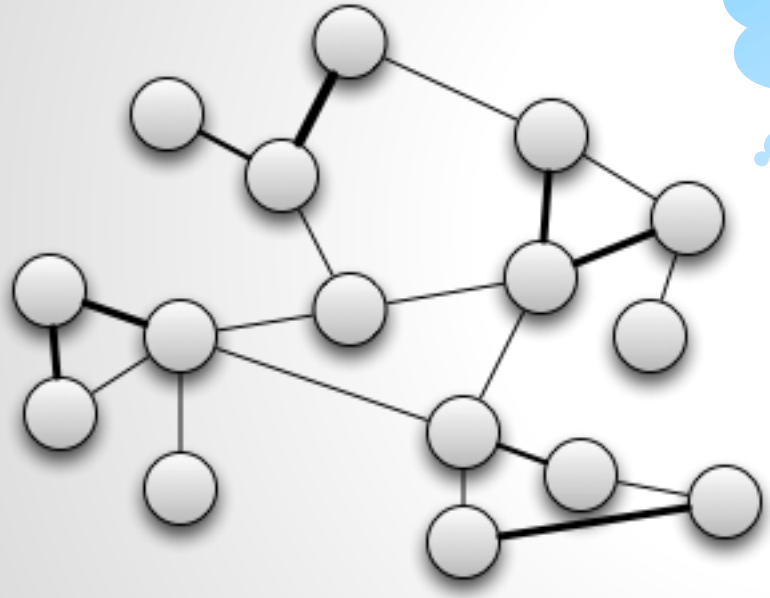
Thus: Need to repartition clusters in an online manner, depending on demand!

Example: A *Re*Partitioning Problem

- Example: 4 clusters of size 4



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Thickness of line = amount of communication

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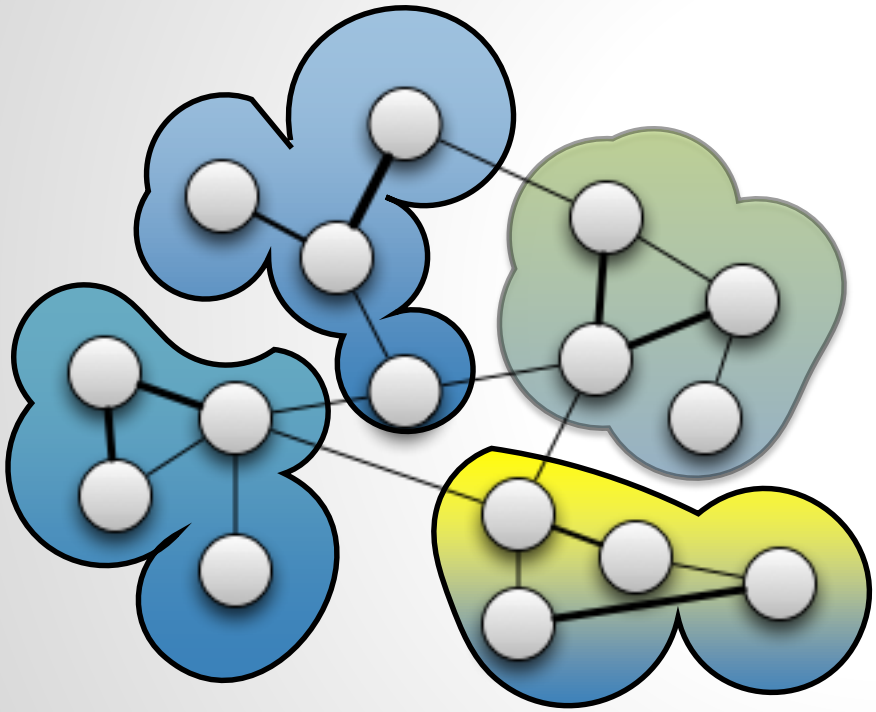

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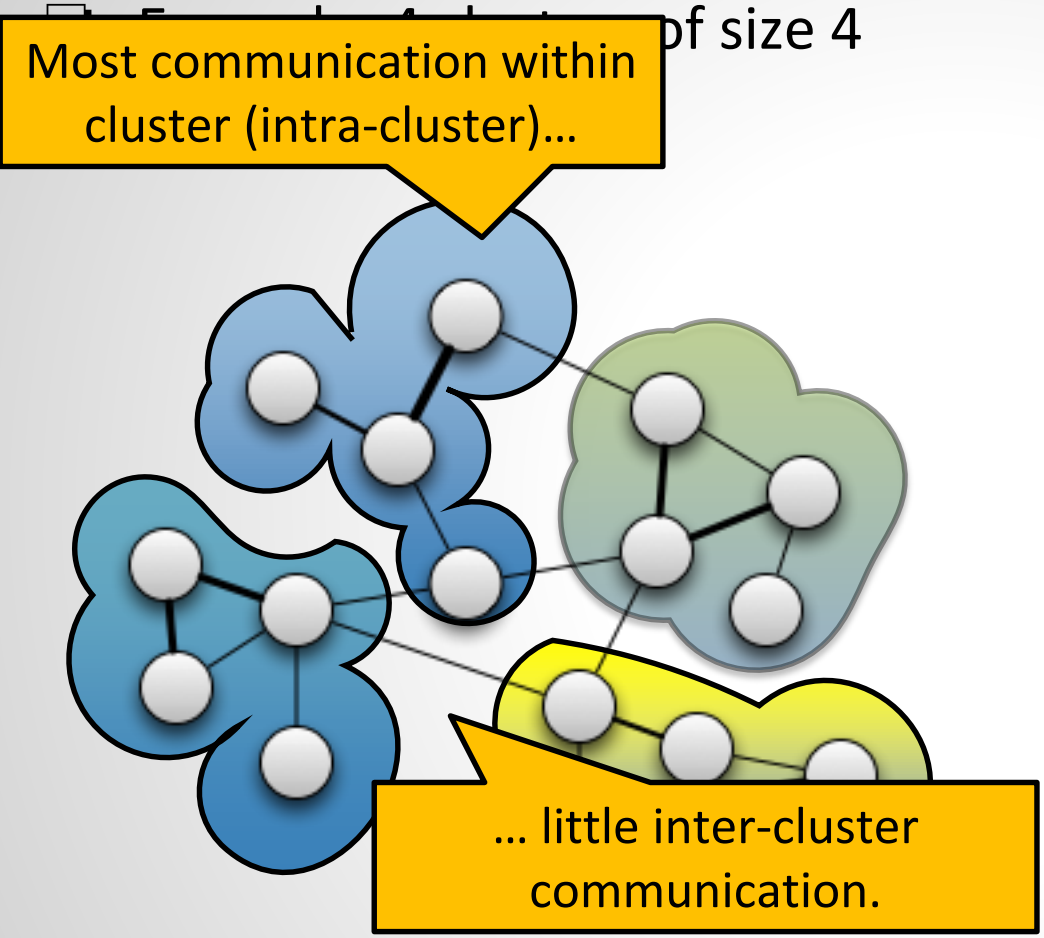

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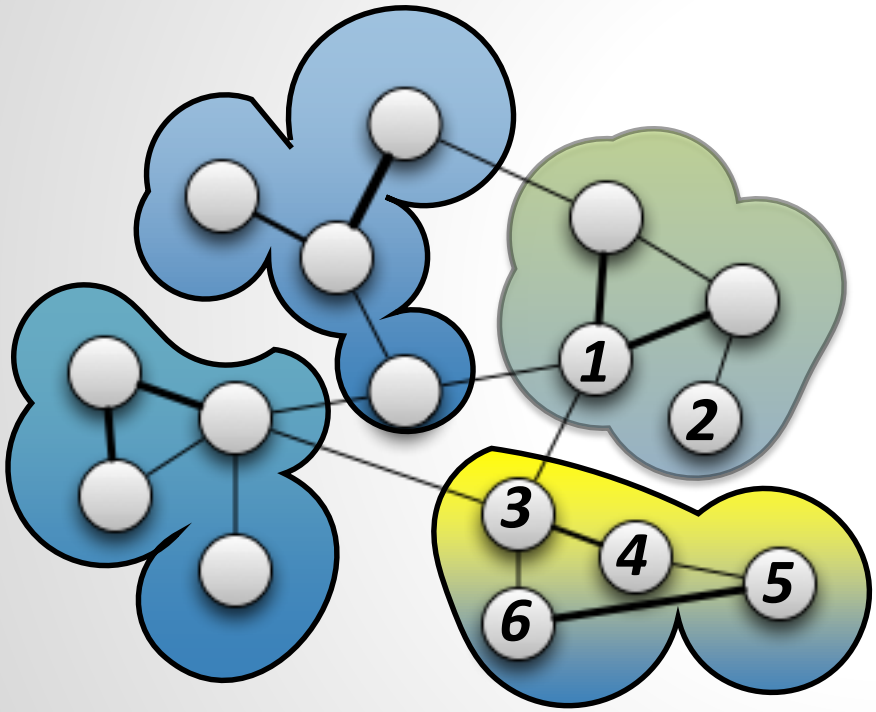

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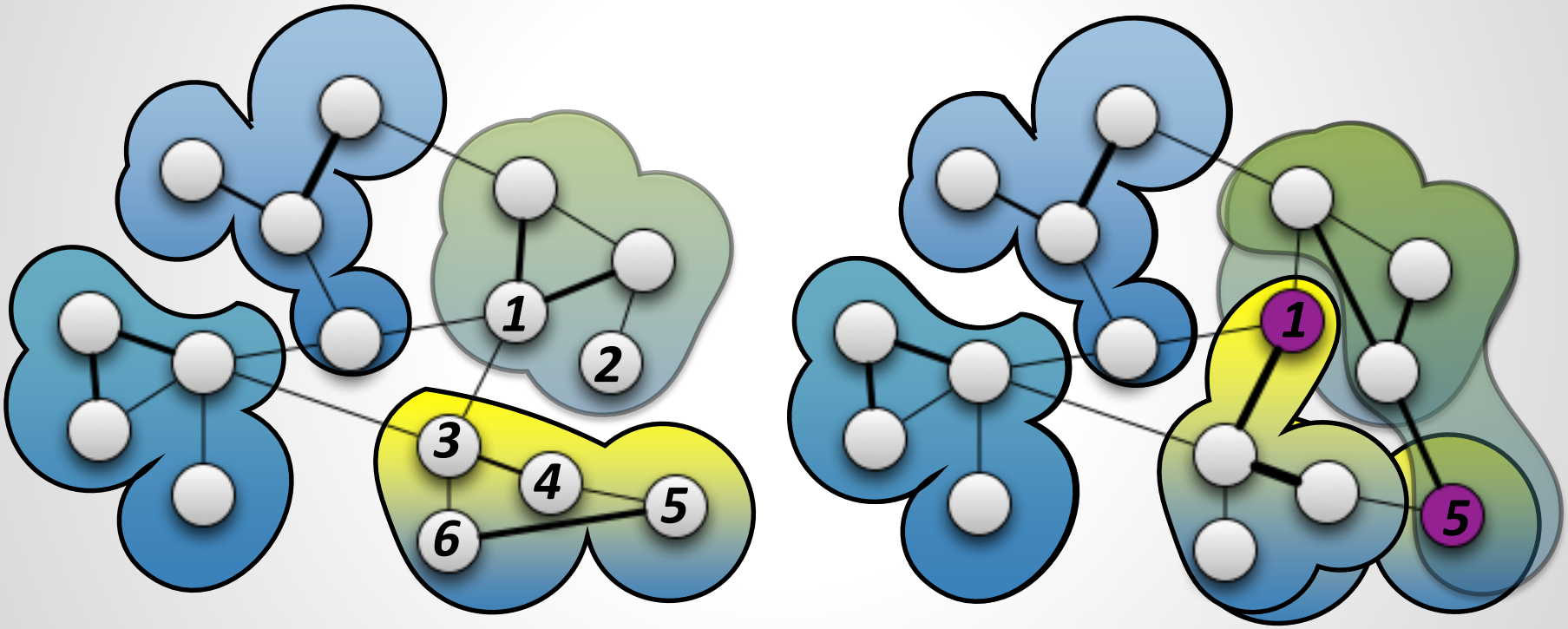

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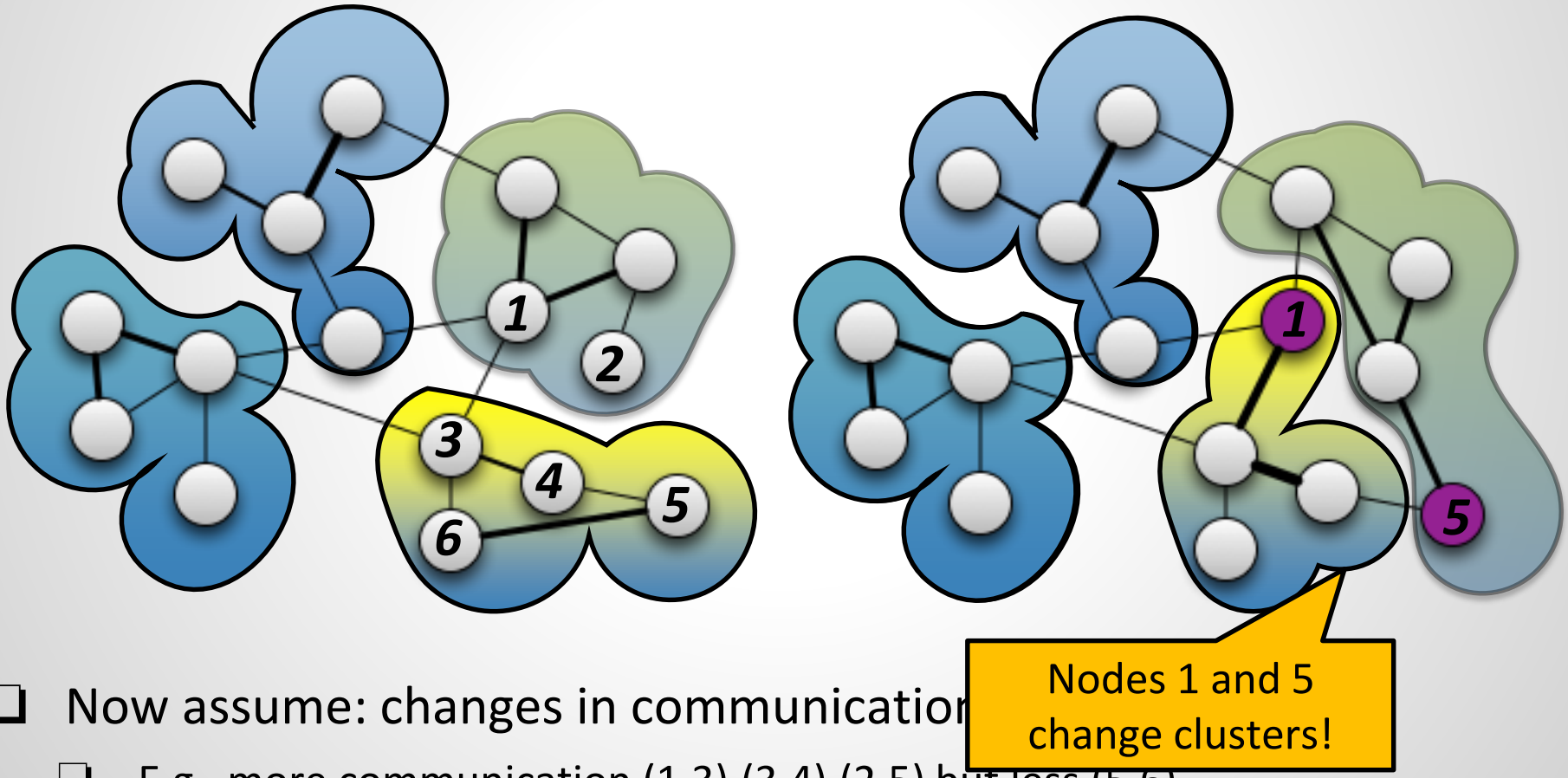

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Online *Re*Partitioning

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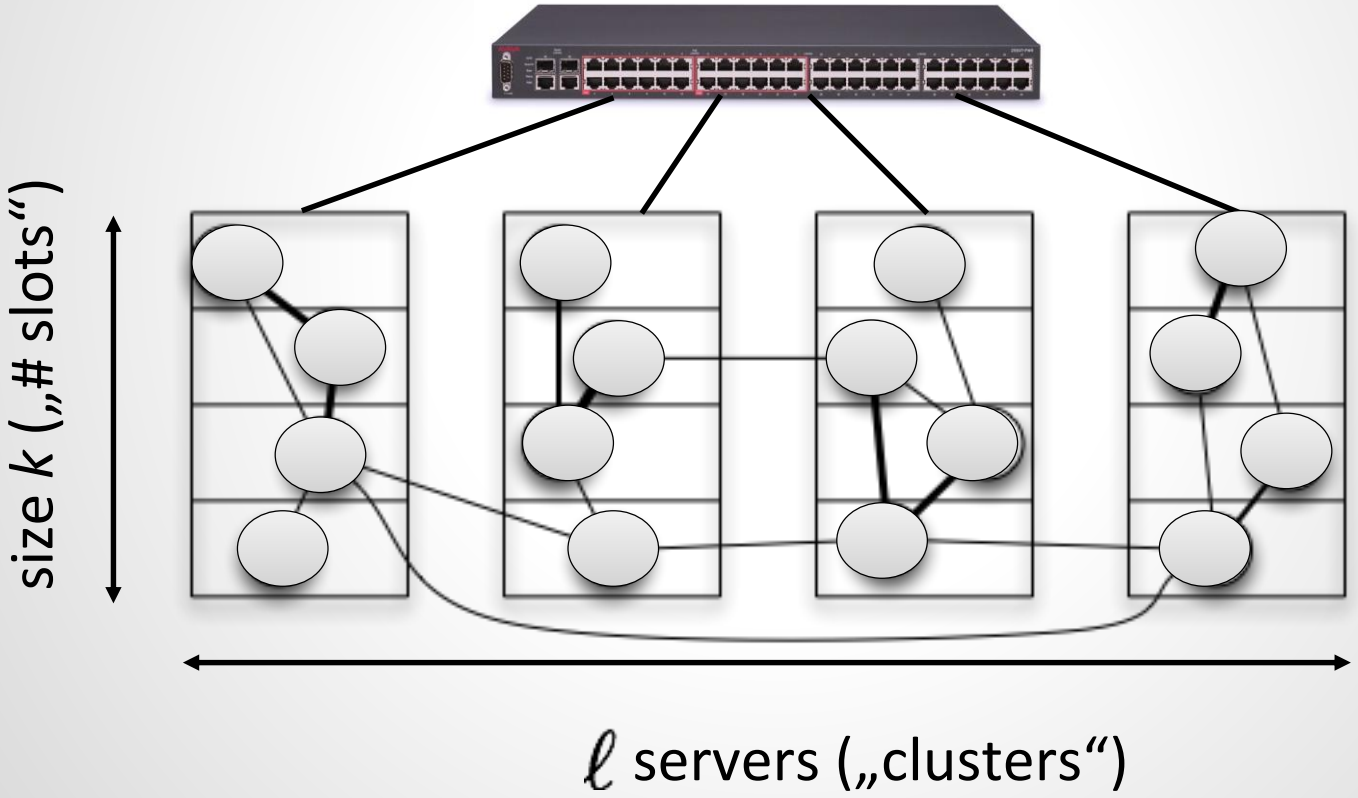

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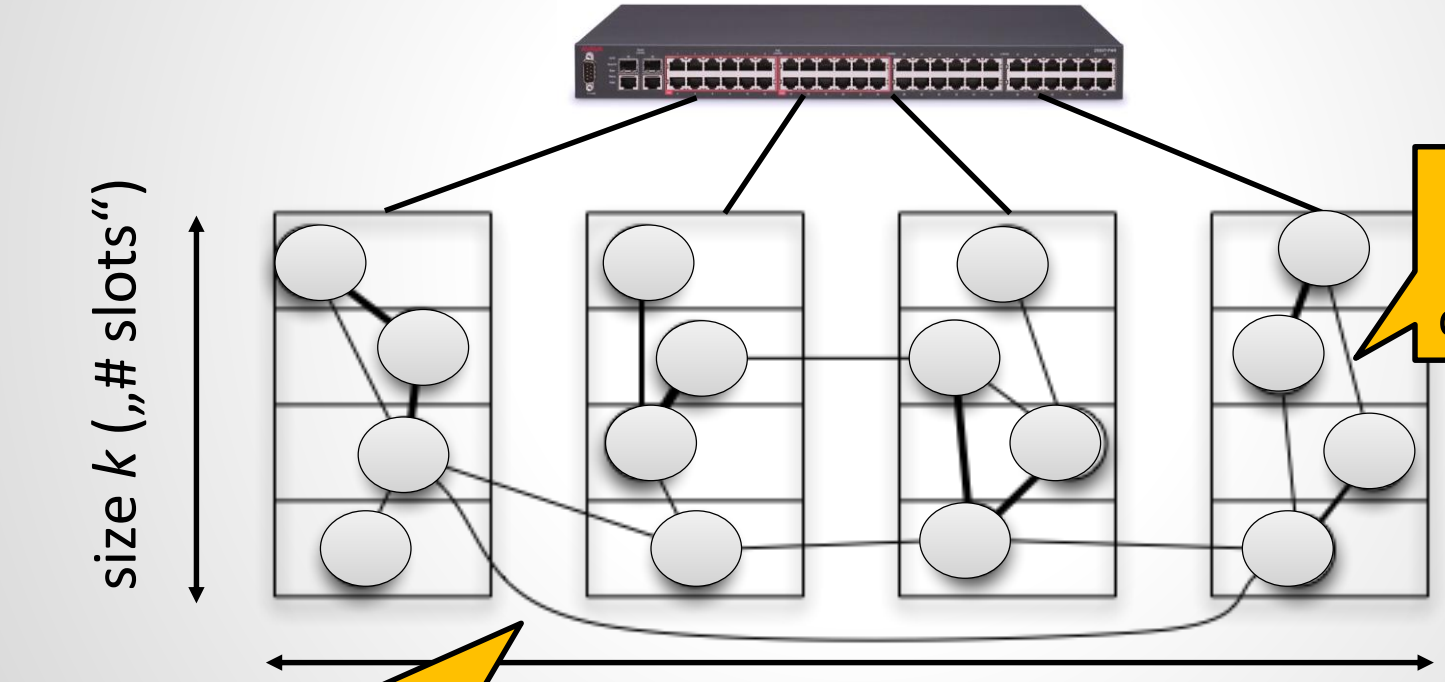

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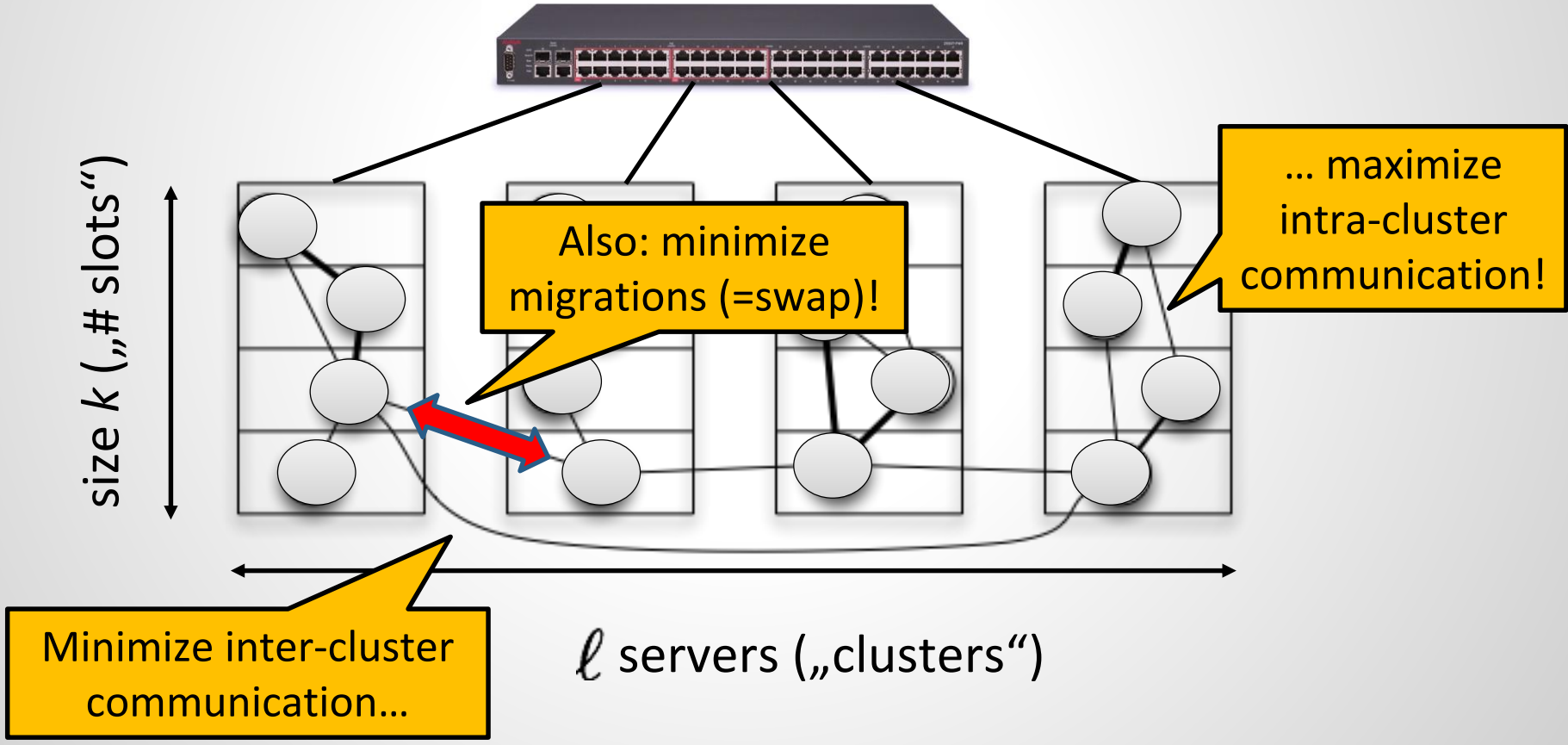

Online RePartitioning

A simple ap

In practice: $k << \ell$ (many more servers than VM slots per server)!

size k („# slots“)

Also: minimize migrations (=swap)!

… maximize intra-cluster communication!

Minimize inter-cluster communication…

ℓ servers („clusters“)

Online *Re*Partitioning

Problem inputs: k, ℓ, $\sigma = \{u_1, v_1\}, \{u_2, v_2\}, \{u_3, v_3\}, \ldots$

Communication pattern over time

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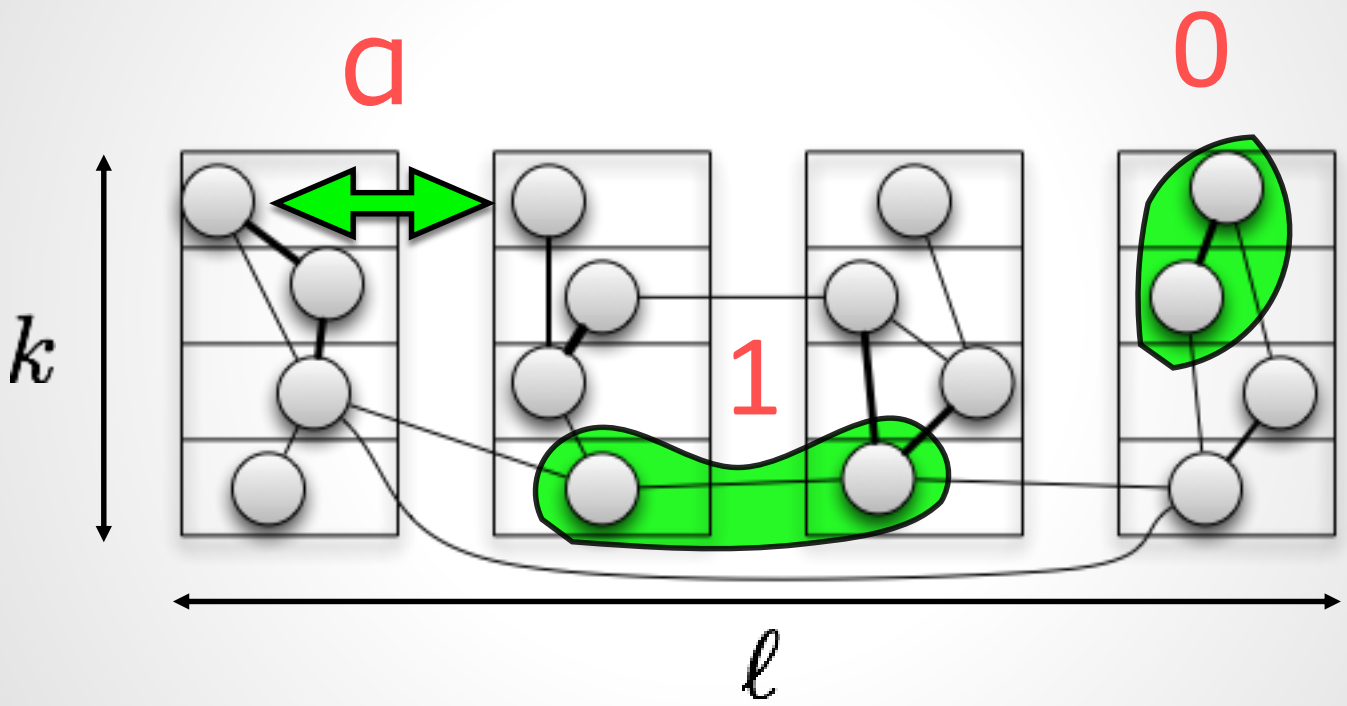

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Two flavors: (1) online (worst-case) pattern
(2) learning: from a fixed (unkown) distribution

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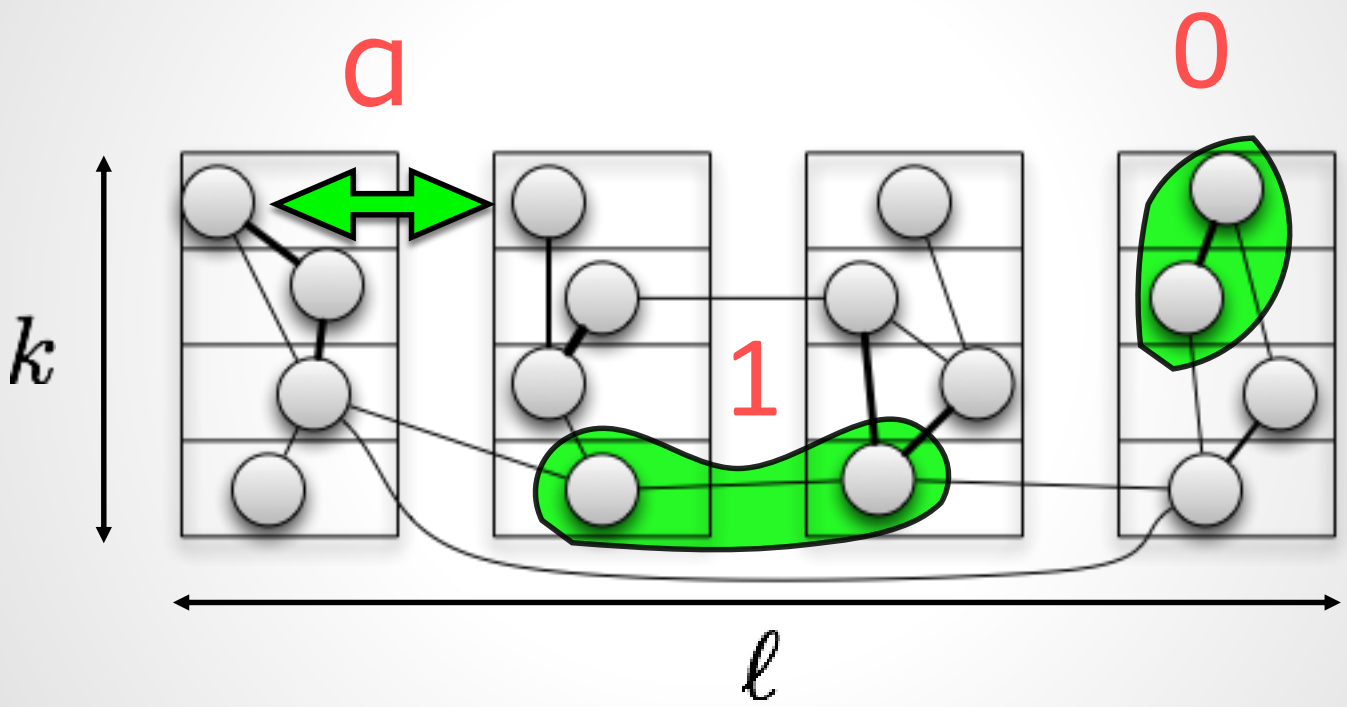

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A) **Serve remotely or migrate ("rent or buy")?** When to migrate? If a communication pattern is short-lived, it may not be worthwhile to collocate the nodes: the migration cost cannot be amortized.

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B) **Where to migrate, and what?** If nodes should be collocated, the question becomes where. Should the first node be migrated to the cluster of the second or vice versa? Or shall both be moved together to a new cluster? Moreover, an algorithm may be required to pro-actively migrate (resp. swap) additional nodes.

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C) **Which nodes to evict?** There may not exist sufficient space in the desired destination cluster. In this case, the algorithm needs to decide which nodes to evict, to free up space.

Online Variant: Competitive Ratio and Augmentation

- Goal: minimize competitive ratio

$$\rho(\mathrm{ON}) = \max_{\sigma} \frac{\mathrm{ON}(\sigma)}{\mathrm{OFF}(\sigma)}$$

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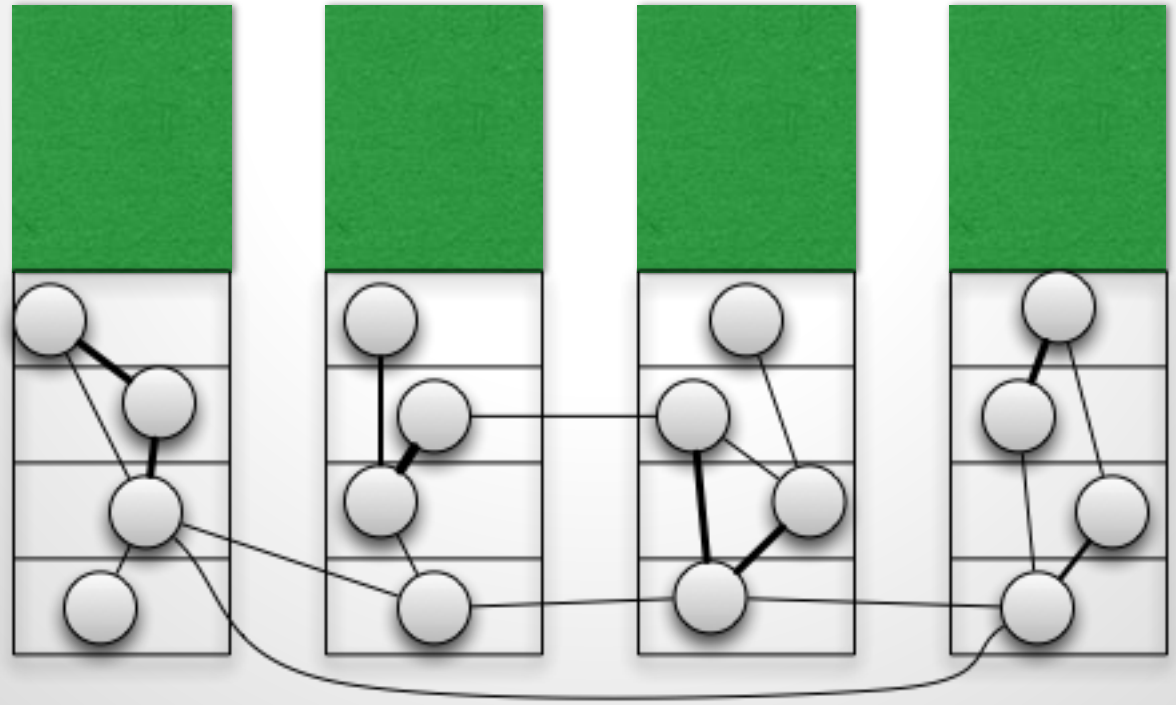
- Two flavors: without and with augmentation



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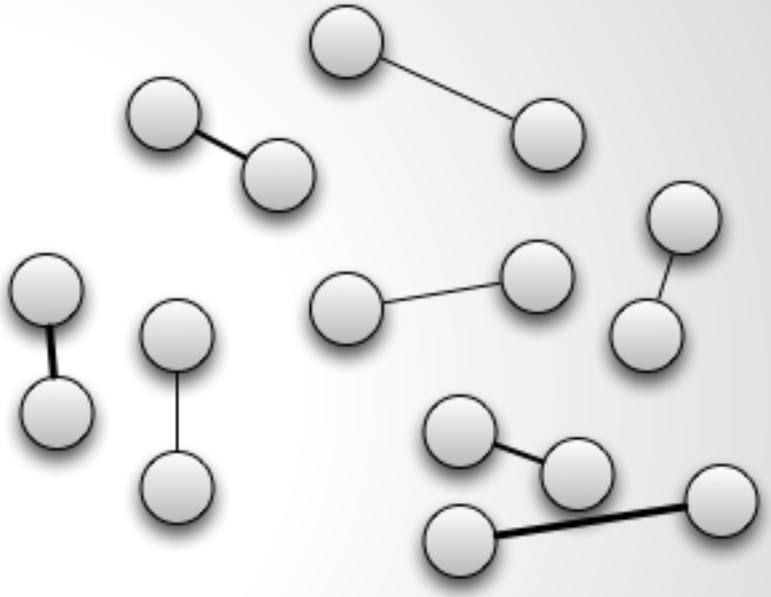

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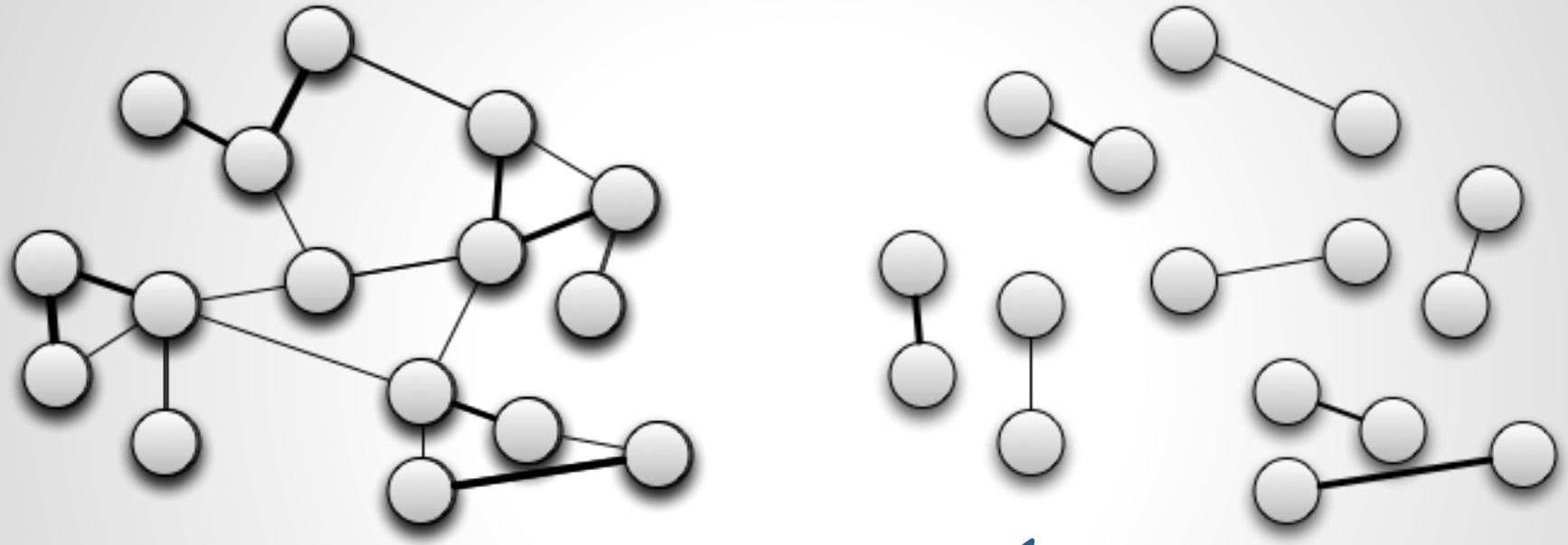
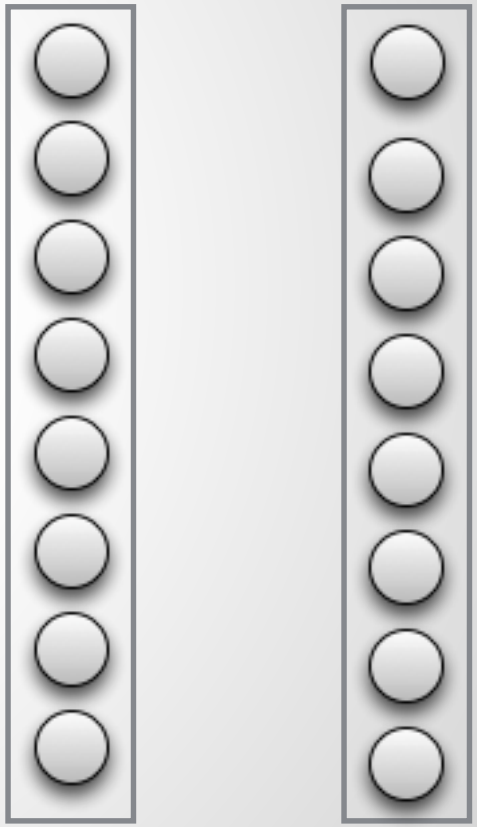


Clusters of size 2: A new type of online matching problem!

Special Cases: ℓ =2



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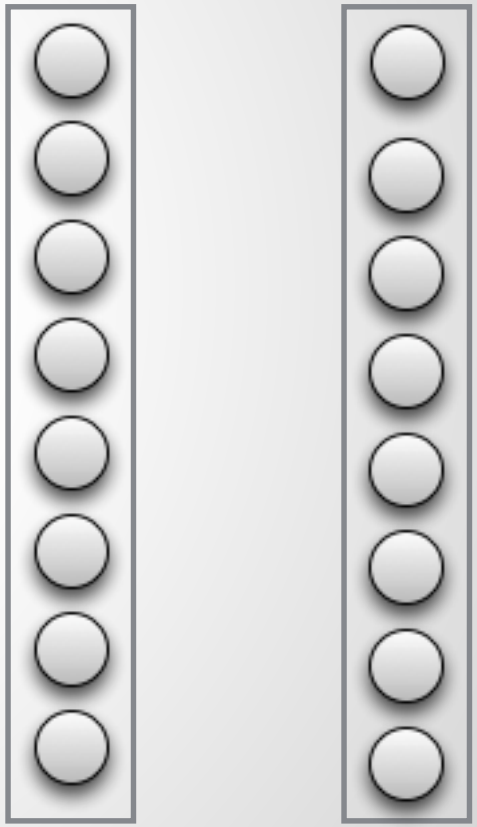
2 Clusters: A generalization of online caching!



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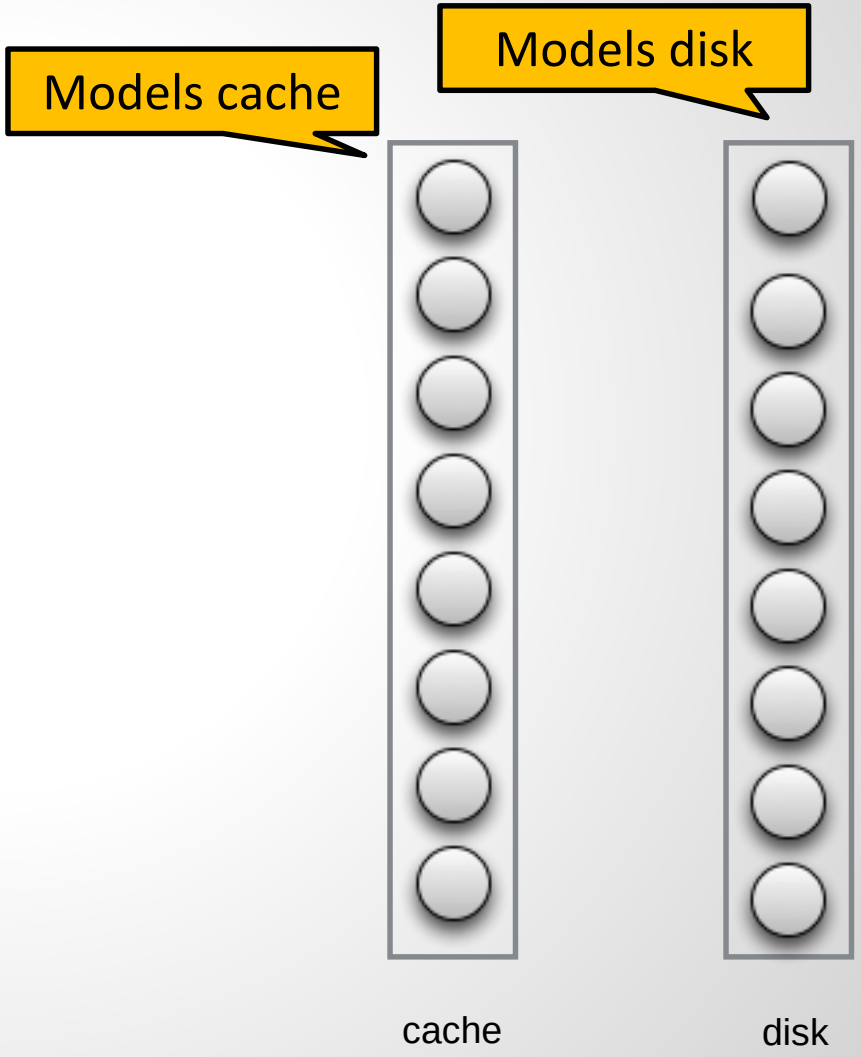

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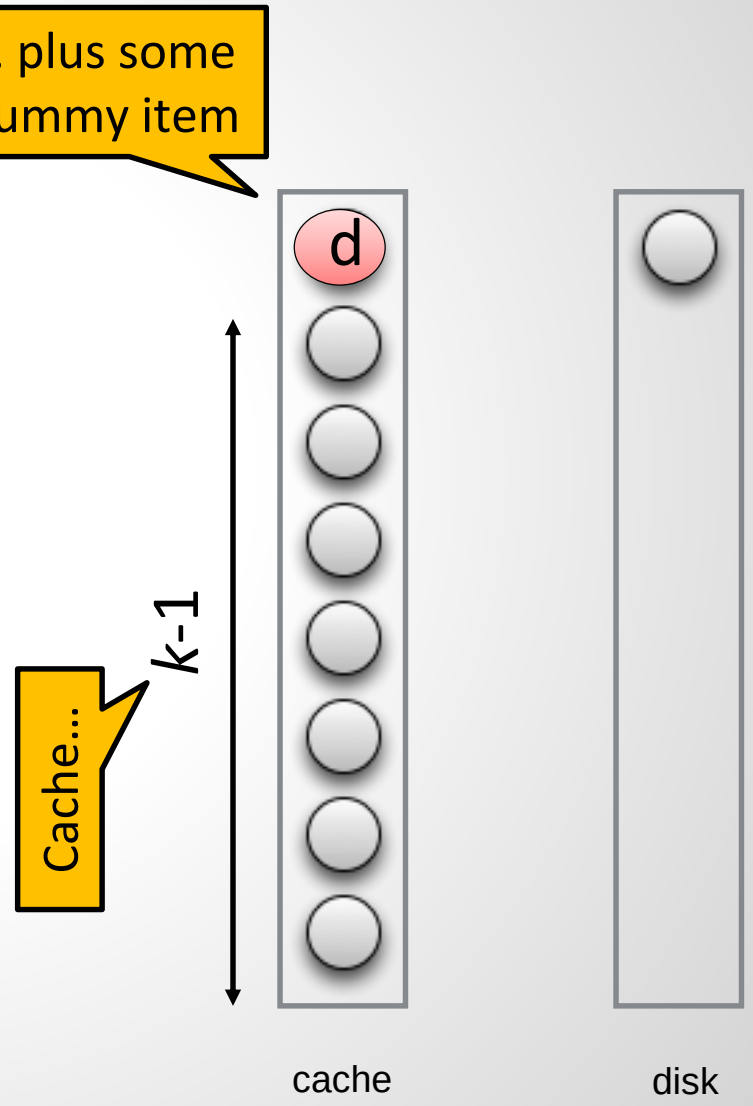

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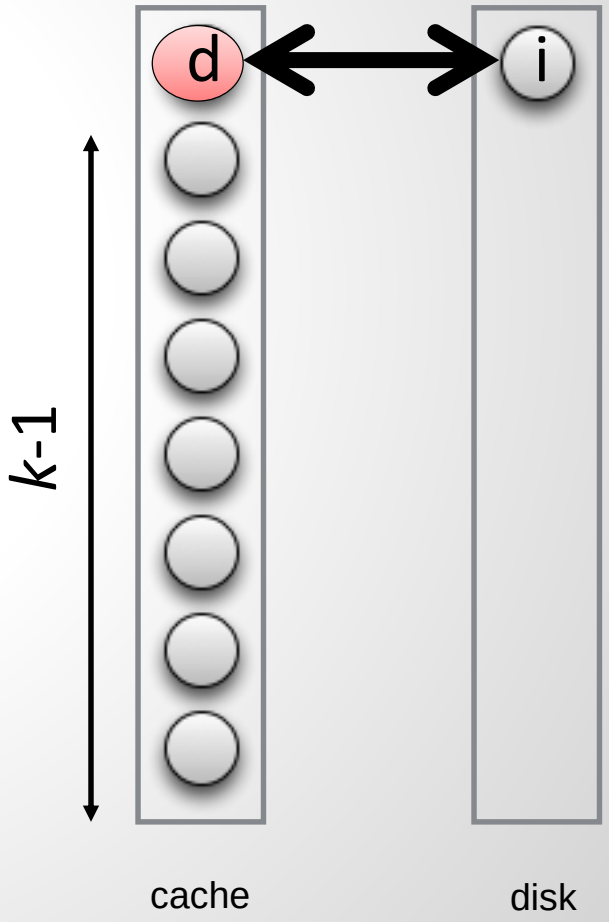

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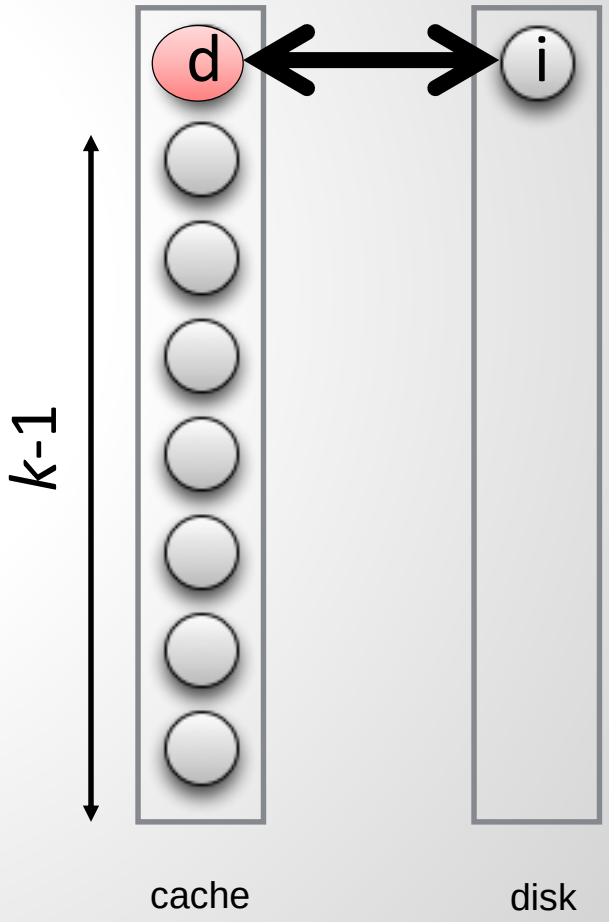

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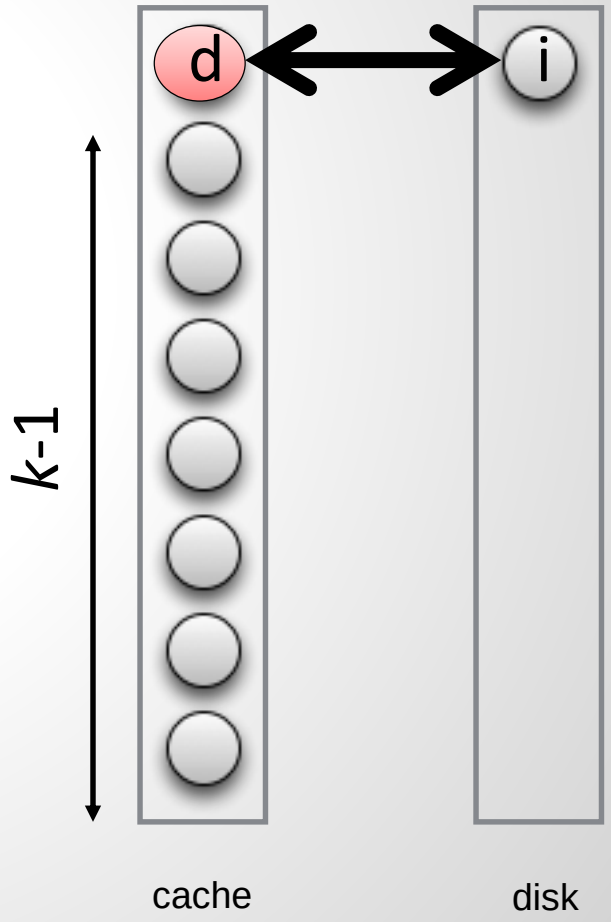

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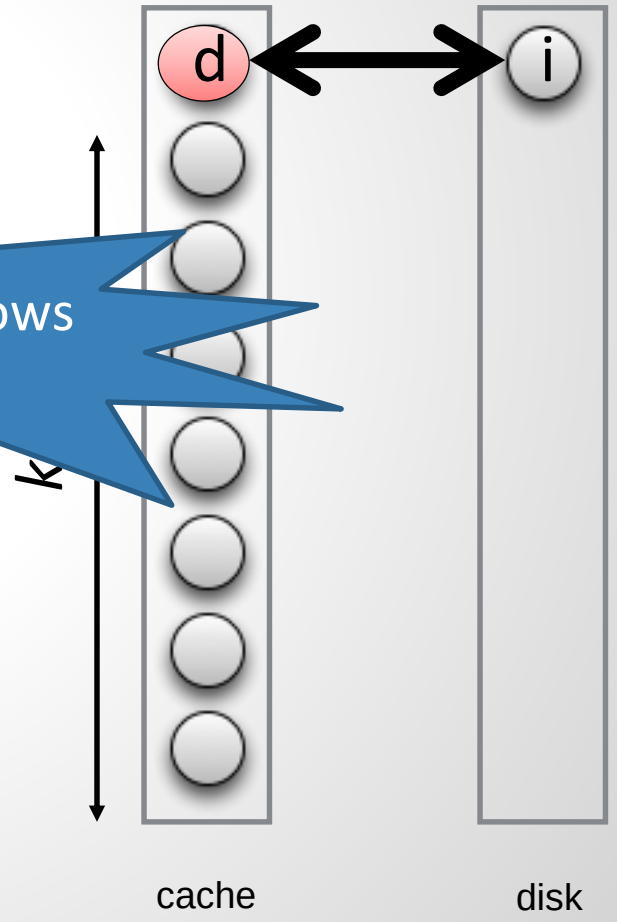
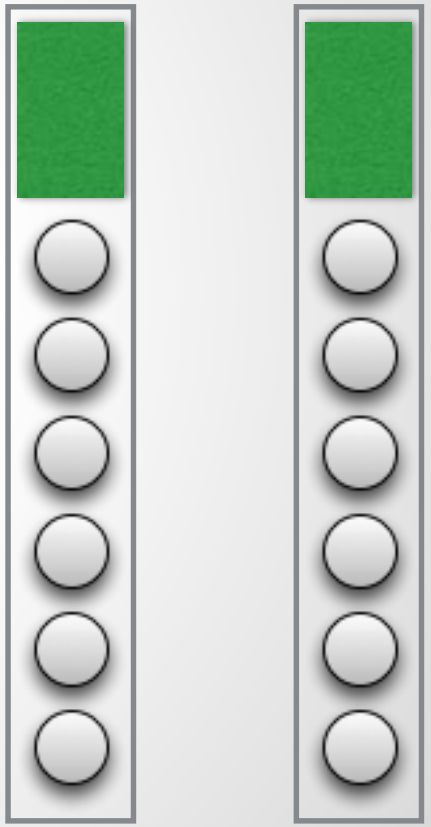
Lower bound *k* follows from caching!



Intriguing: Lower bound even with augmentation!



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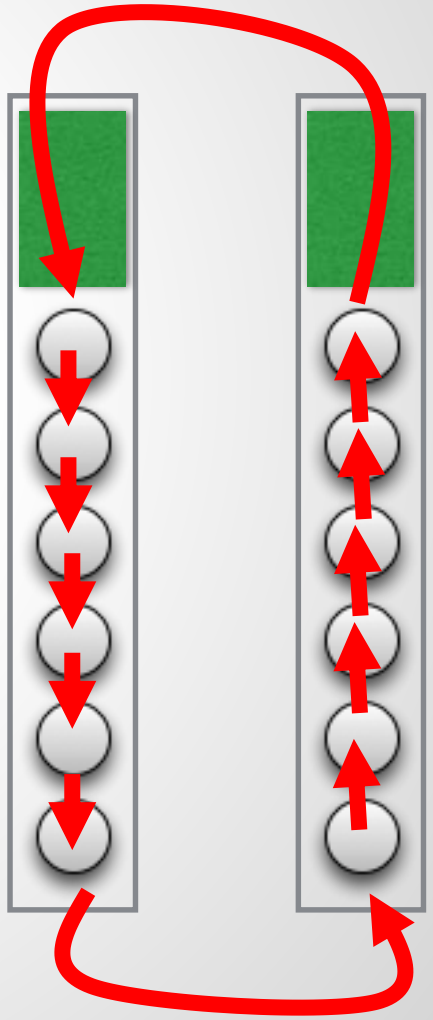

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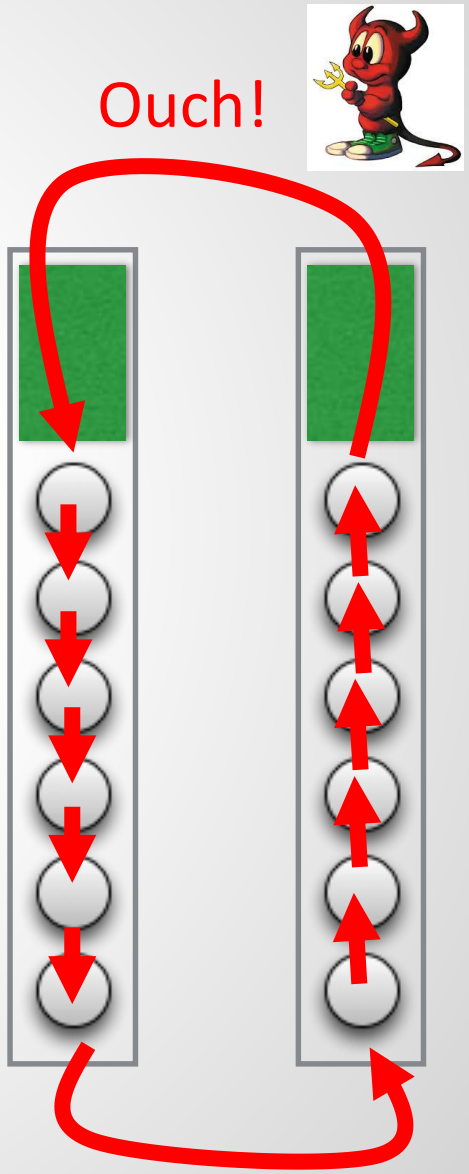

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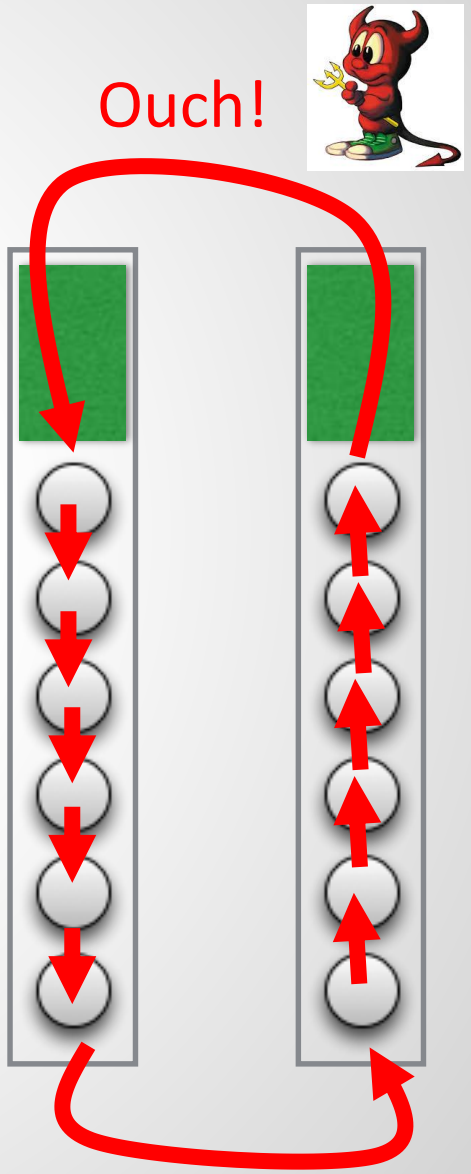

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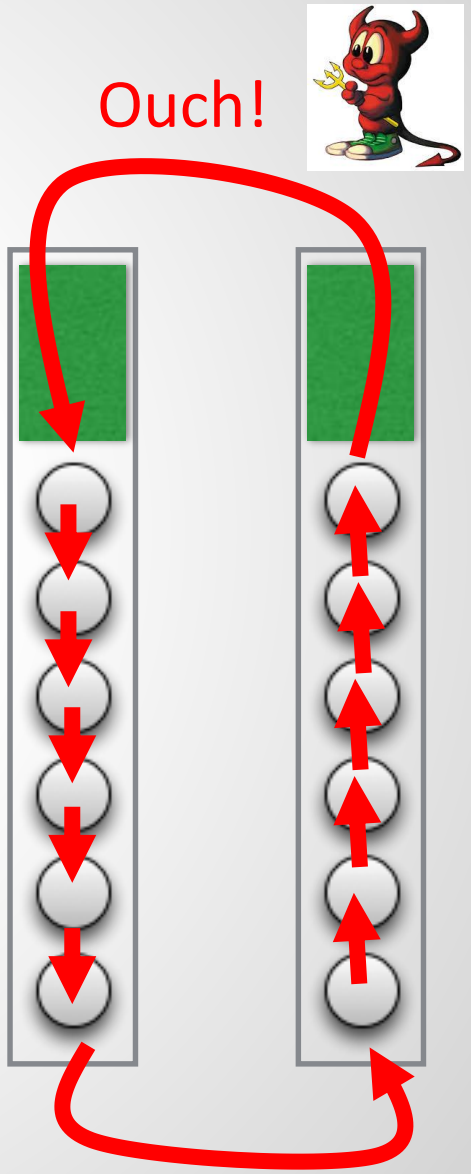
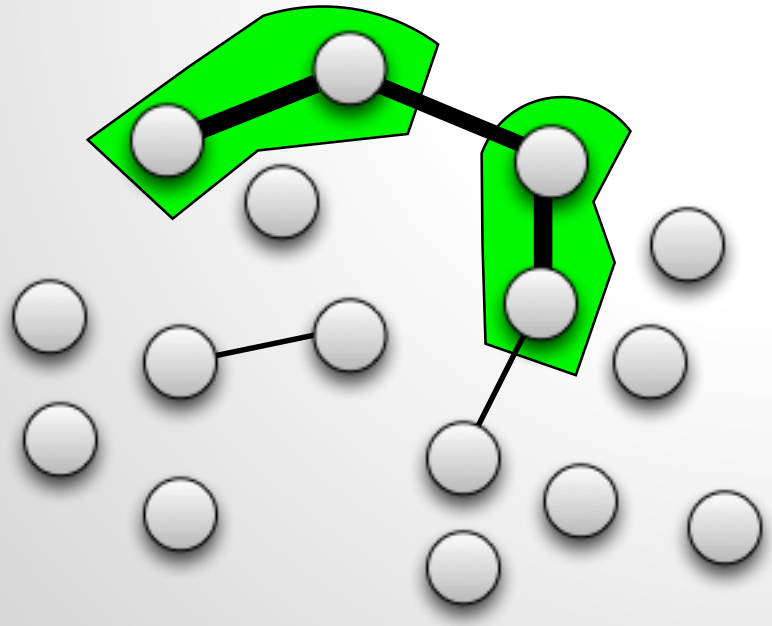
- OFF can safely move to a partition which will be asked least frequently (once and forever)! Pigeon-hole principle: pays only every k-th time (i.e. k times less)

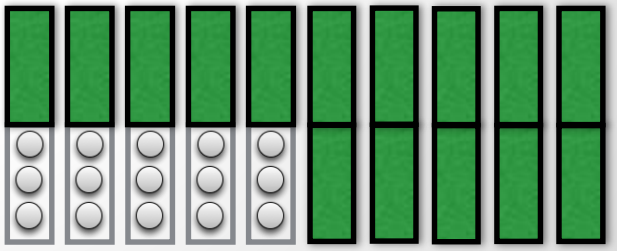


Online *Re*Partitioning: Overview of Results

- k=2 (online matching)
  - Greedy algorithm 7-competitive
  - Lower bound: 3-competitive

- $O(k \log k)$ -competitive algorithm CREP for 4-augmentation
  - based on on growing components





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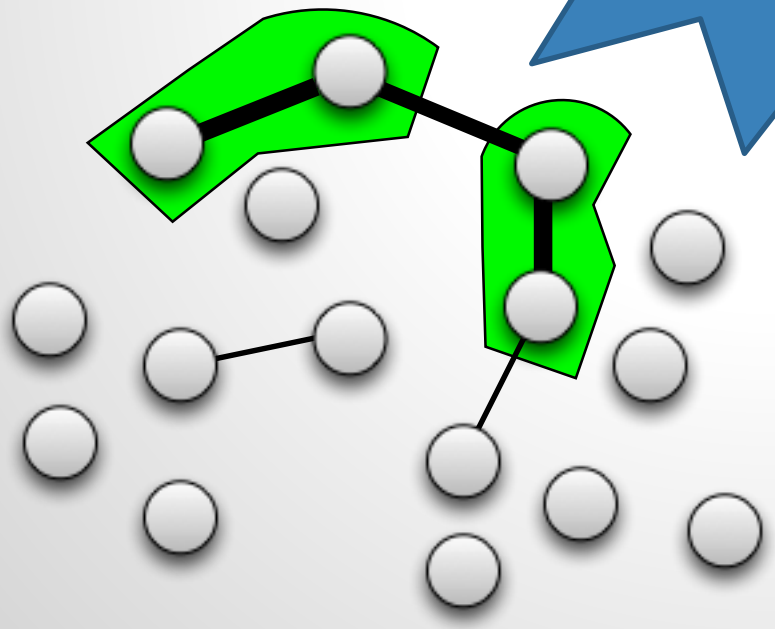
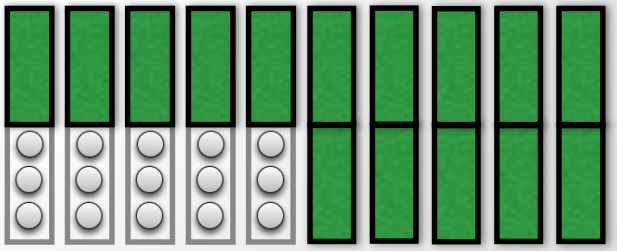
Open question: what about less augmentation?





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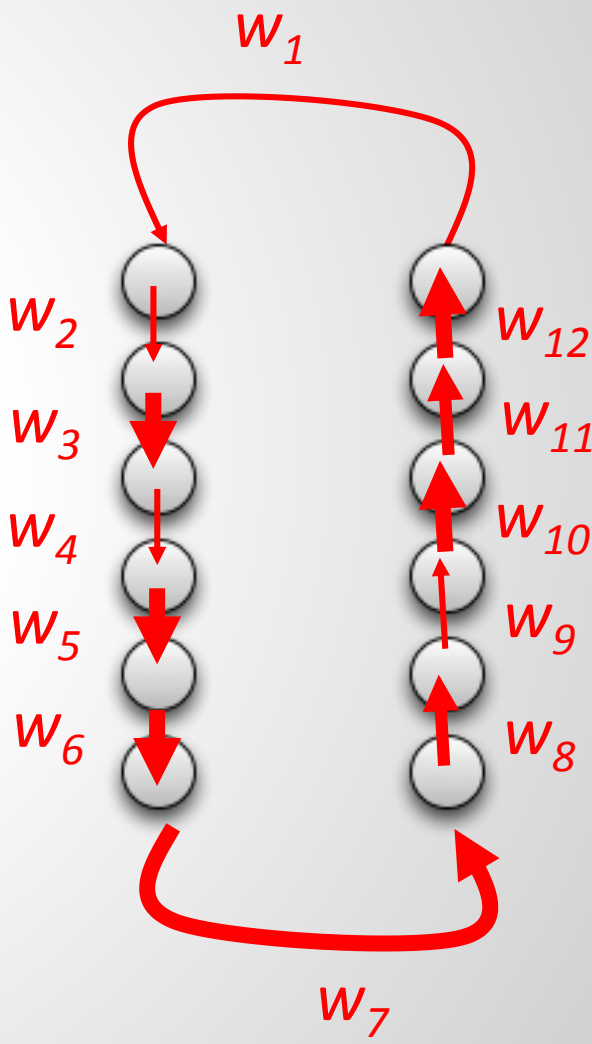
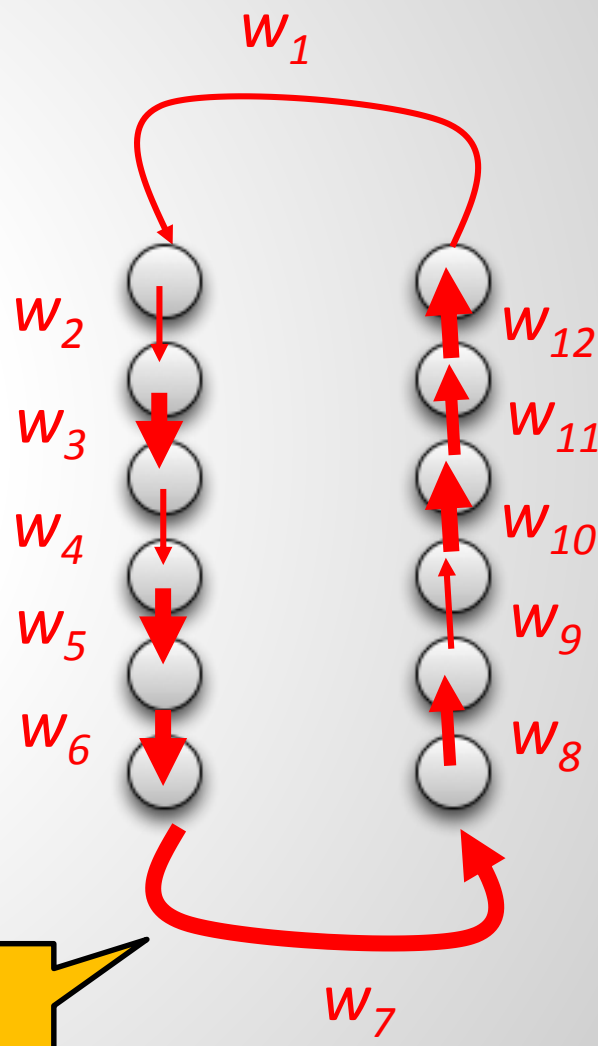
  - Adversary needs to sample i.i.d. from this distribution
  - Moreover: Adversary knows (deterministic or randomized) «learning» algorithm
- Let's start simple: communication along ring only
  - I.e., adversary picks distribution over ring



Learning Variant

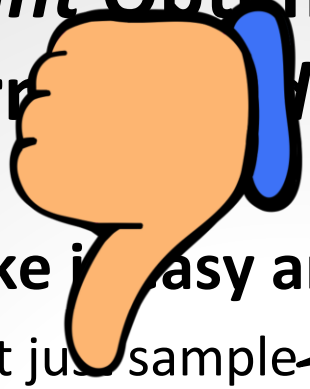
- Adversary cannot choose request sequence but only the distribution
  - Adversary needs to sample i.i.d. from this distribution
  - Moreover: Adversary knows (deterministic or randomized) «learning» algorithm
- Let's start simple: communication along ring only
  - I.e., adversary picks distribution over ring



The Crux: *Joint* Optimization of Efficient Learning *and* Searching

- **Naive idea 1: Take it easy and first learn distribution**
  - Do not move but just sample requests in the beginning: until exact distribution has been learned whp
  - Then move to the best location for good

The Crux: *Joint* Optimi
Learn



Waiting can be very costly: maybe start configuration is very bad and others similarly good! Not competitive! Need to move early on, away from bad locations!

- **Naive idea 1: Take i asy an**
  - Do not move but just sample requests in the beginning: until exact distribution has been learned whp
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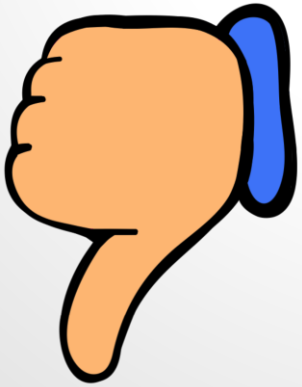


Bad: if requests are uniform at random, you should not move! Migration costs cannot be amortized. Crucial difference to classic distribution learning problems: guessing costs!

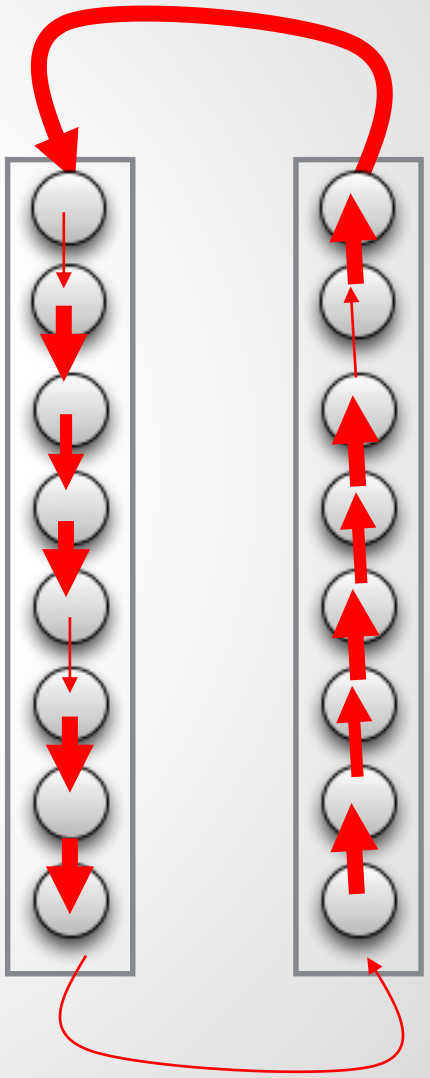
The Crux: *Joint* Optimization of Efficient Learning *and* Searching

- **Naive idea 1: Take it easy and first learn distribution**
  - Do not move but just sample requests from the beginning: until exact distribution has been learned
  - Then move
- **Naive idea … lowest cost configuration**
  - Bad, e.g., if requests are distributed uniformly at random: better not to move at all (moving costs cannot be amortized)

Only move when it pays off! But e.g., how to differentiate between uniform and „almost uniform“ distribution?

Learning Algorithm: Rotate Locally!

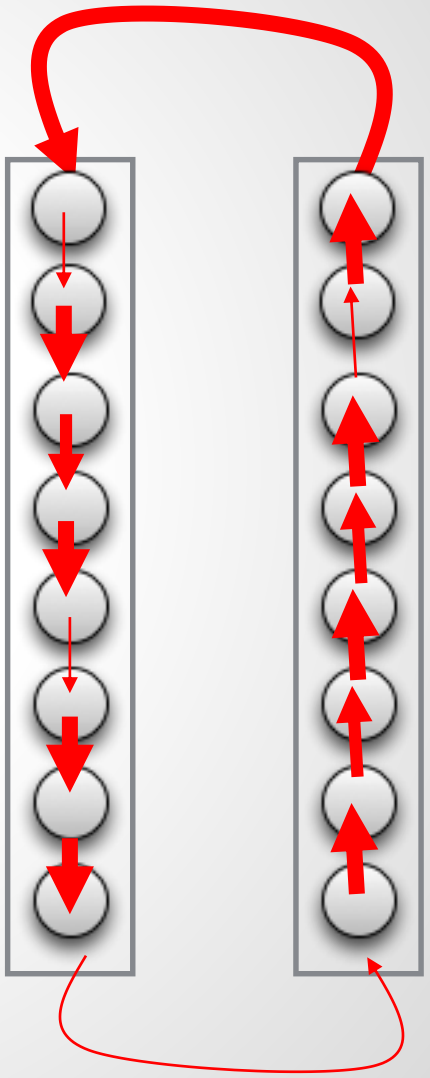
- Mantra of our algorithm: Rotate!
  - Rotate early, but not too early!
  - And: rotate locally



Learning Algorithm: Rotate Locally!

Define **conditions** for configurations: if met, **never go back** to it (we can afford it w.h.p.: seen enough samples)

- ❏ Mantra of the algorithm: Rotate!
  - ❏ Rotate early, but not too early!
  - ❏ And: rotate locally



Learning Algorithm: Rotate Locally!

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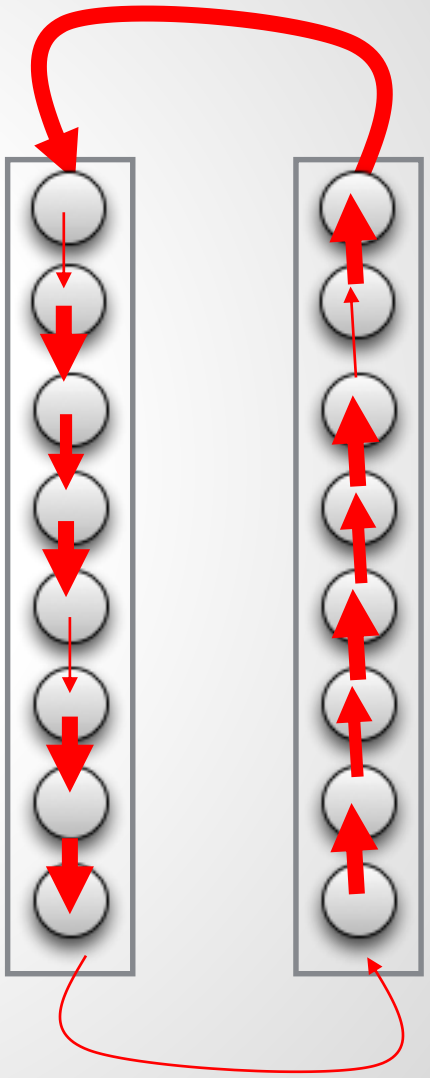
If current configuration is **eliminated**, go to **nearby configuration** (in directed manner: no frequent back and forth)!



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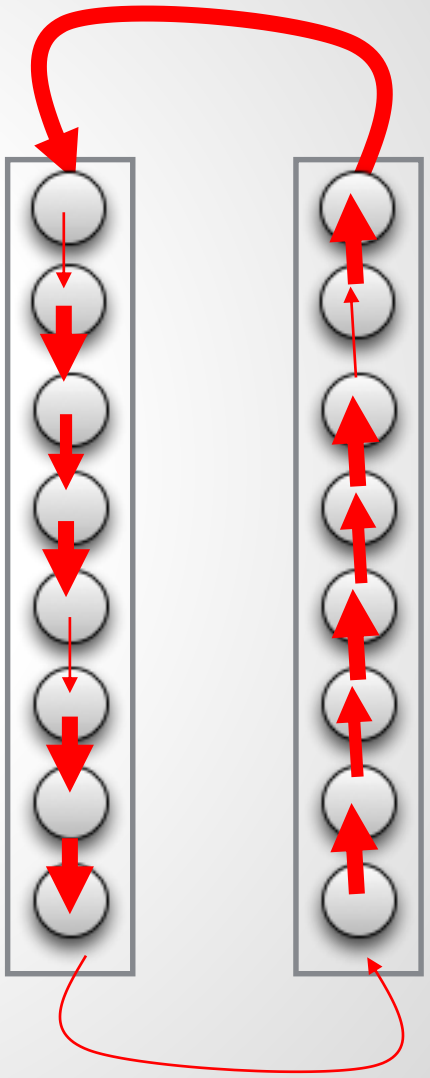
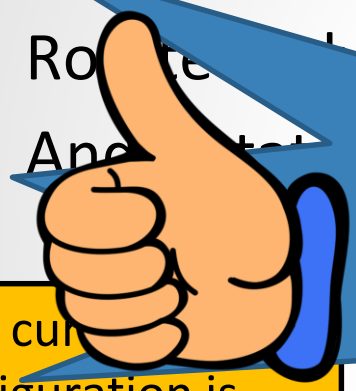
Growing radius strategy: allow to move further only once amortized!



Learning Algorithm: Rotate Locally!

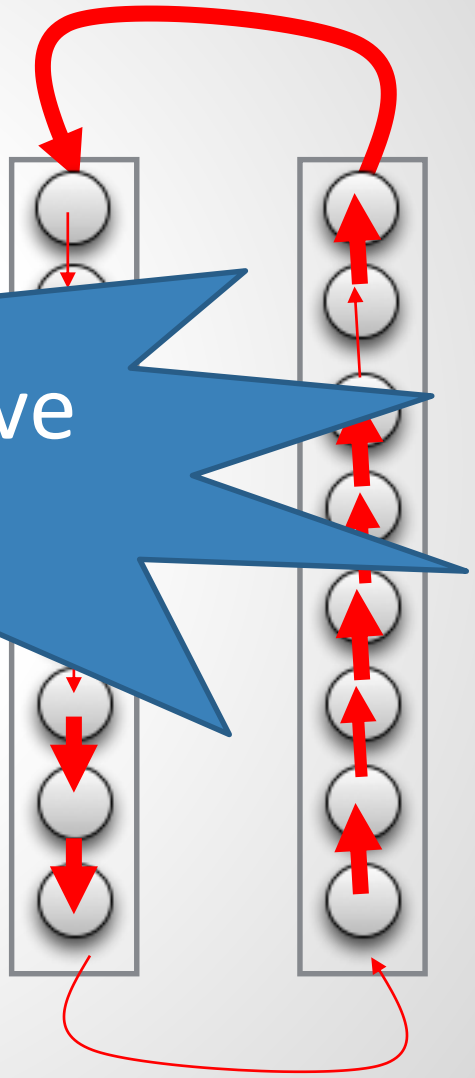
- Mantra: Rotate!
  - Ro[illegible] but r[illegible] ea[illegible]
  - An[illegible]



log(n)-competitive w.h.p.

If cu[illegible] configuration is eliminated, go to nearby configuration (in directed manner: no frequent back and forth)!

mo[illegible]er c[illegible] onc[illegible]ortized!



Conclusion

- Dynamic repartitioning: a natural new problem!
- Competitive ratio super-linear in k: ok in practice (independent of number of servers!)
- Open questions:
  - Online variant: With less augmentation? Randomized?
  - Learning variant: General communication pattern, beyond ring?