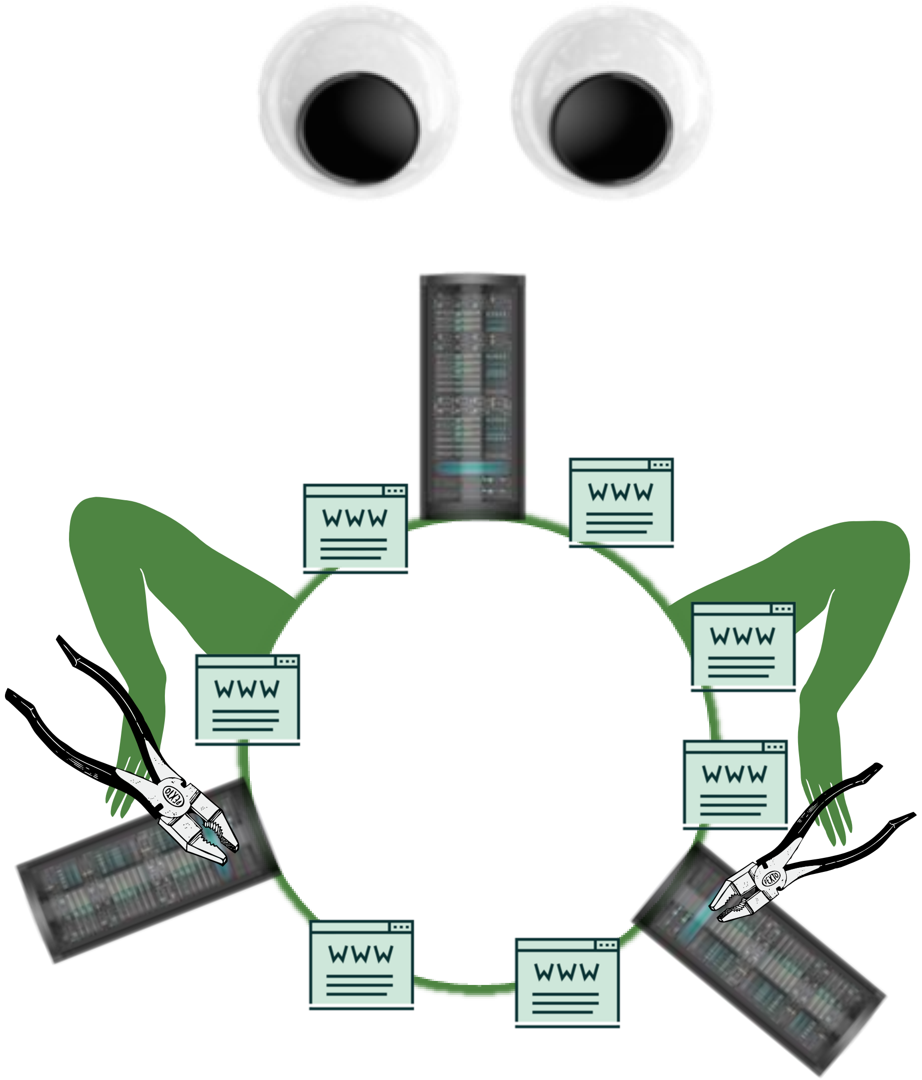
Hash & Adjust: Competitive Demand-Aware Consistent Hashing

Arash Pourdamghani
Joint work with Chen Avin, Robert Sama, Maryam Shiran, Stefan Schmid

OPODIS'24



consistent **Hash**ing **&** self-**Adjust**ing

Motivation

- **Consistent Hashing** [Karger et al., STOC 1997] is an essential part of today's load balancers:
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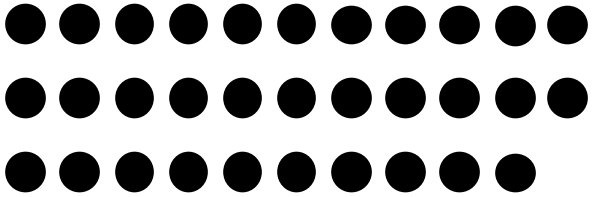

A set of m **items**(balls)

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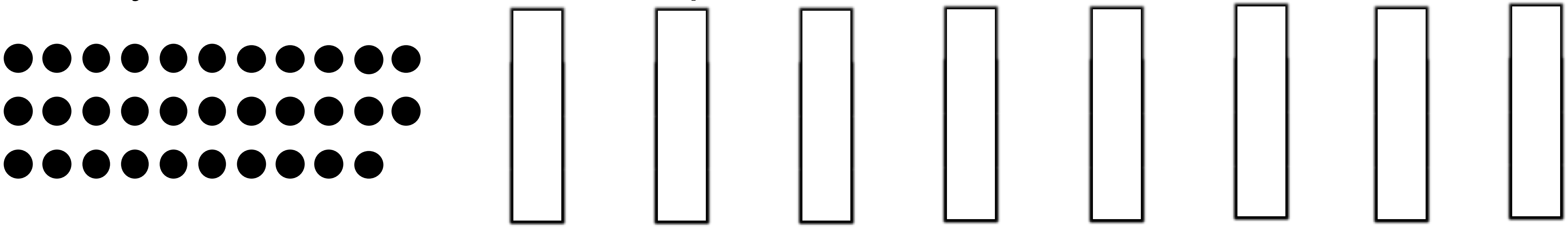

A set of m **items**(balls) need to be assigned to n **servers**(bins)

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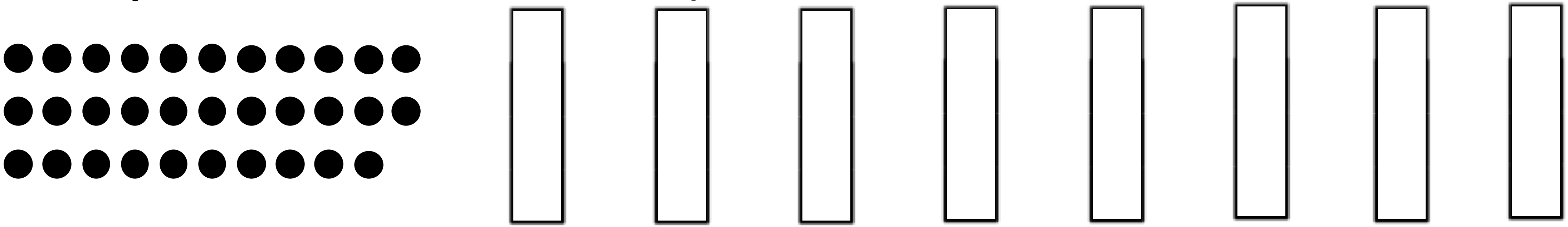

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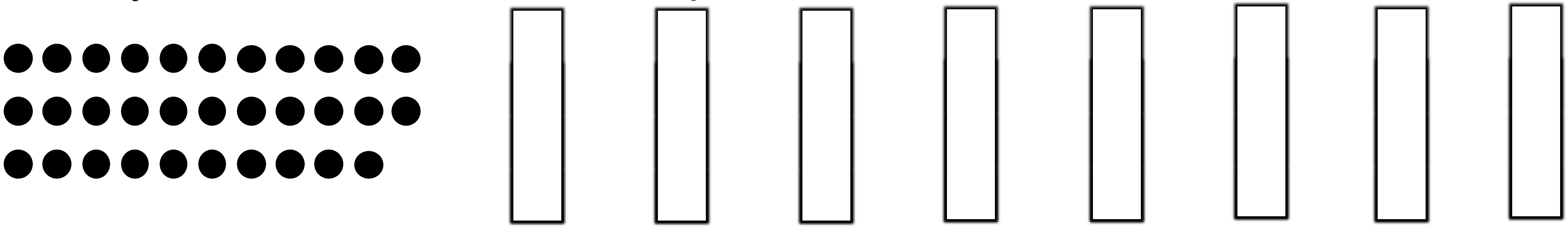

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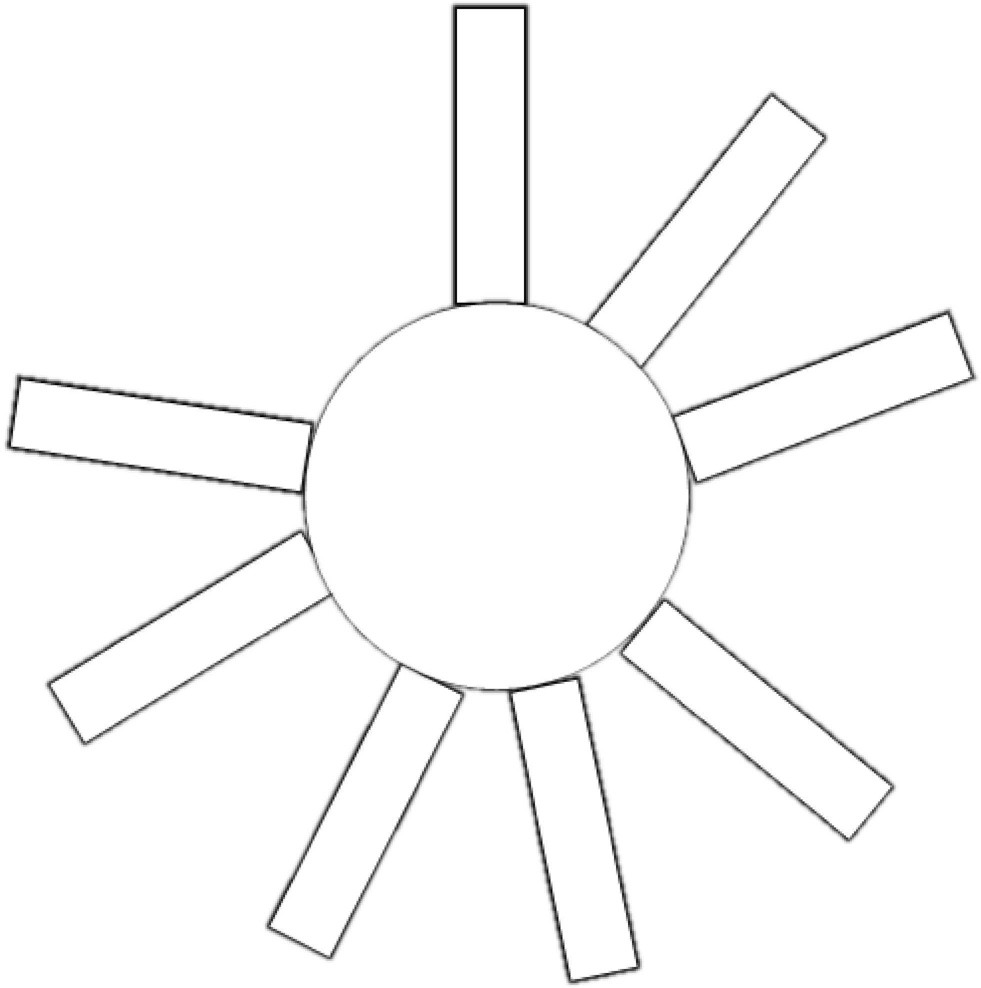
- Goals:
  - Minimize load (the number of items in each server) of servers AND access cost (number of accessed servers, accessing first server costs 1)
  - Supporting dynamic item/server insertion/deletion, and item access (search)

Consistent Hashing Model

- Hash servers to a circle



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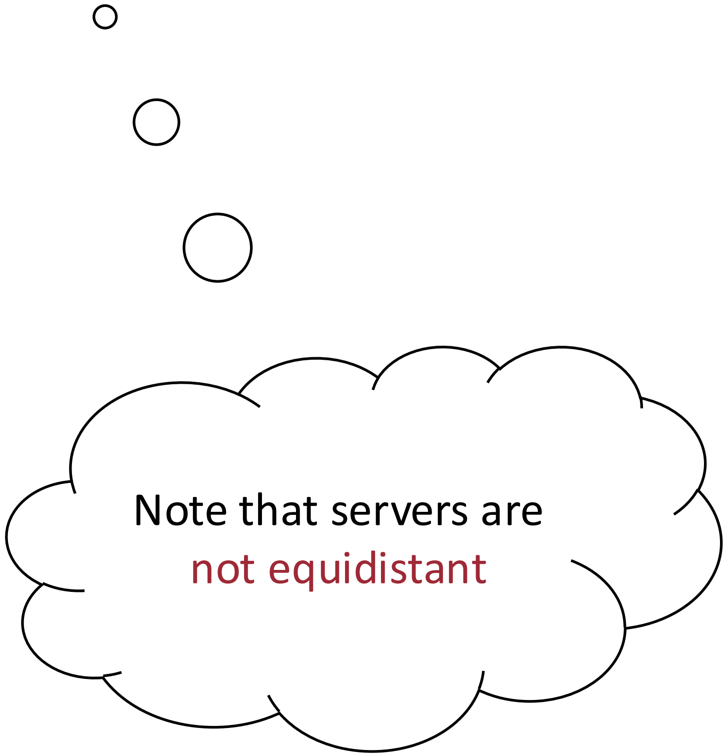

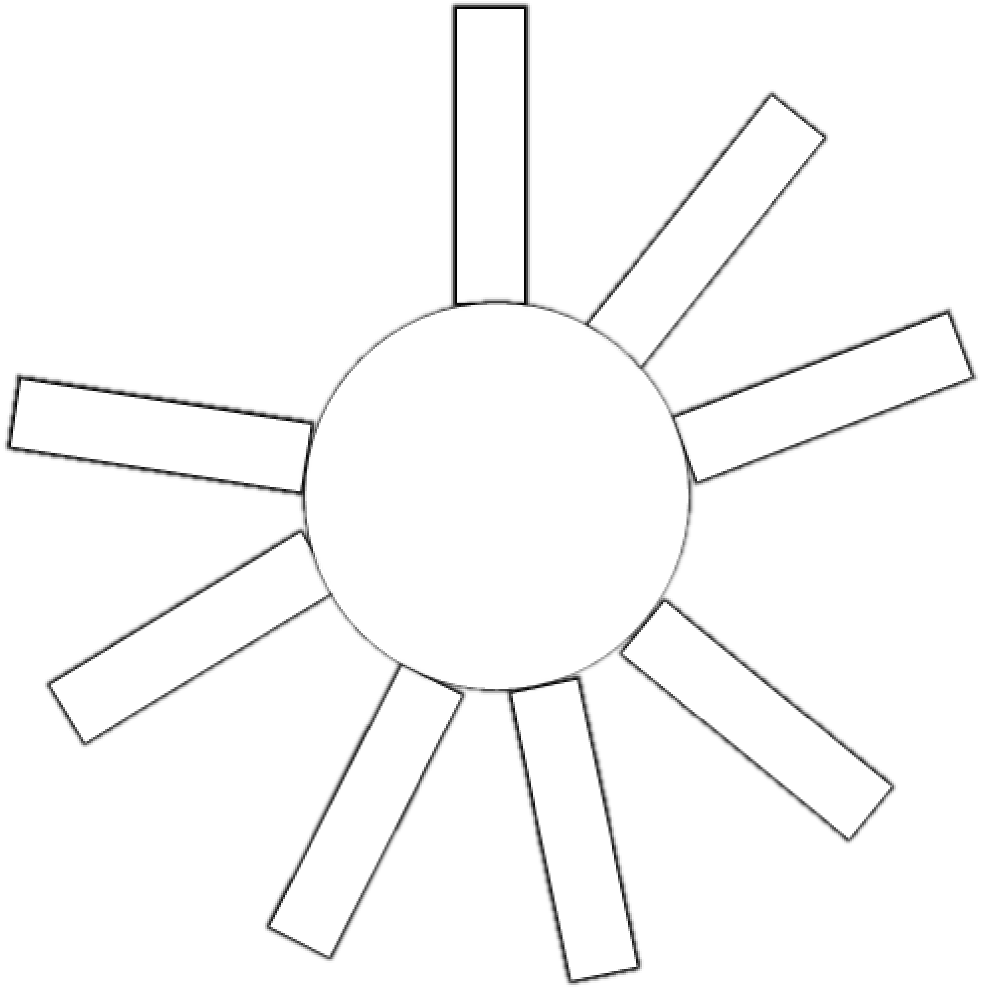

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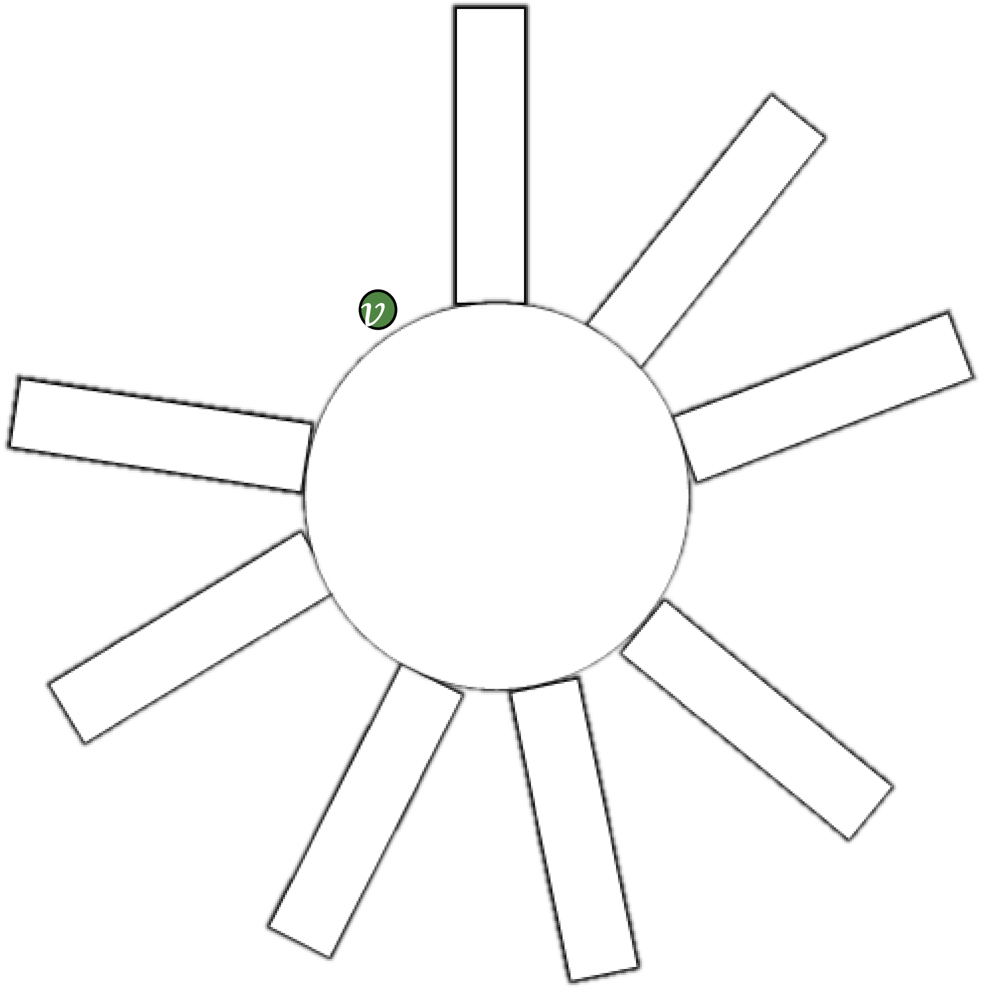

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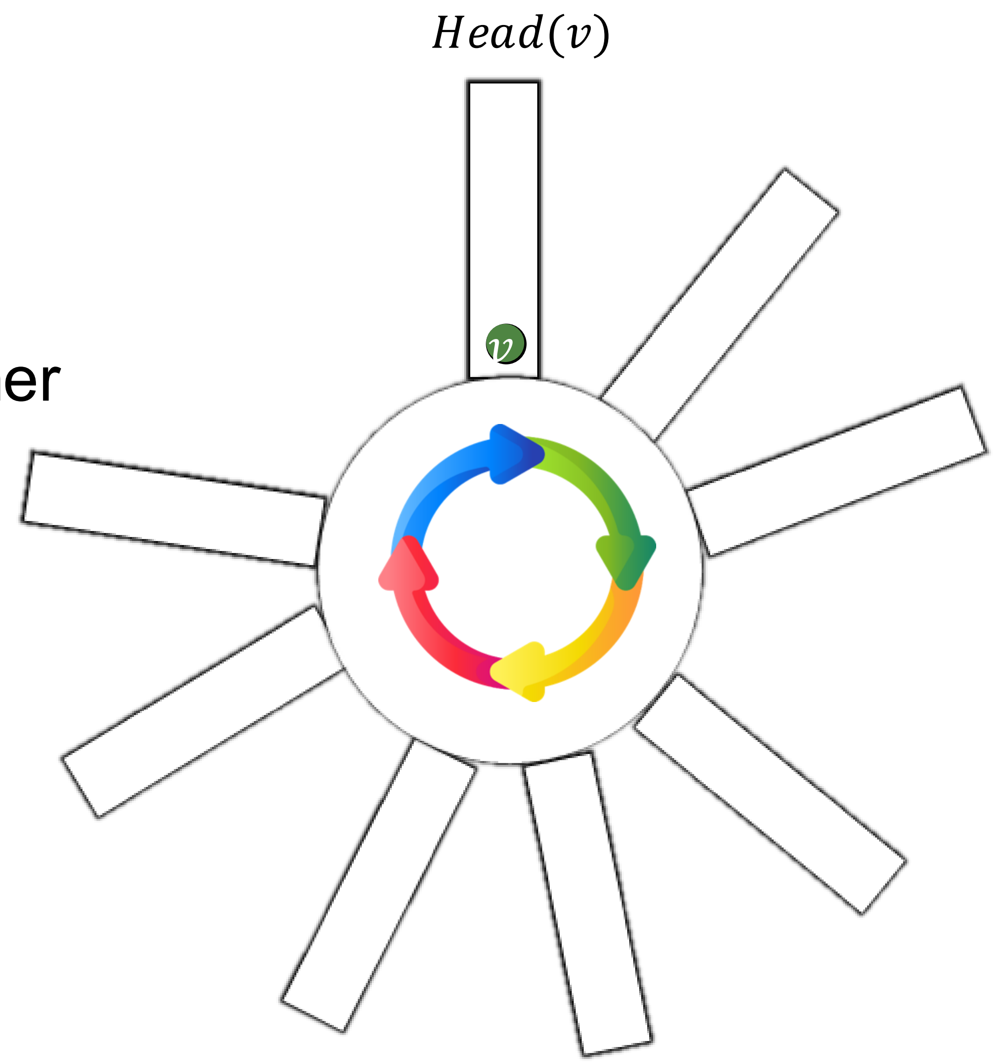

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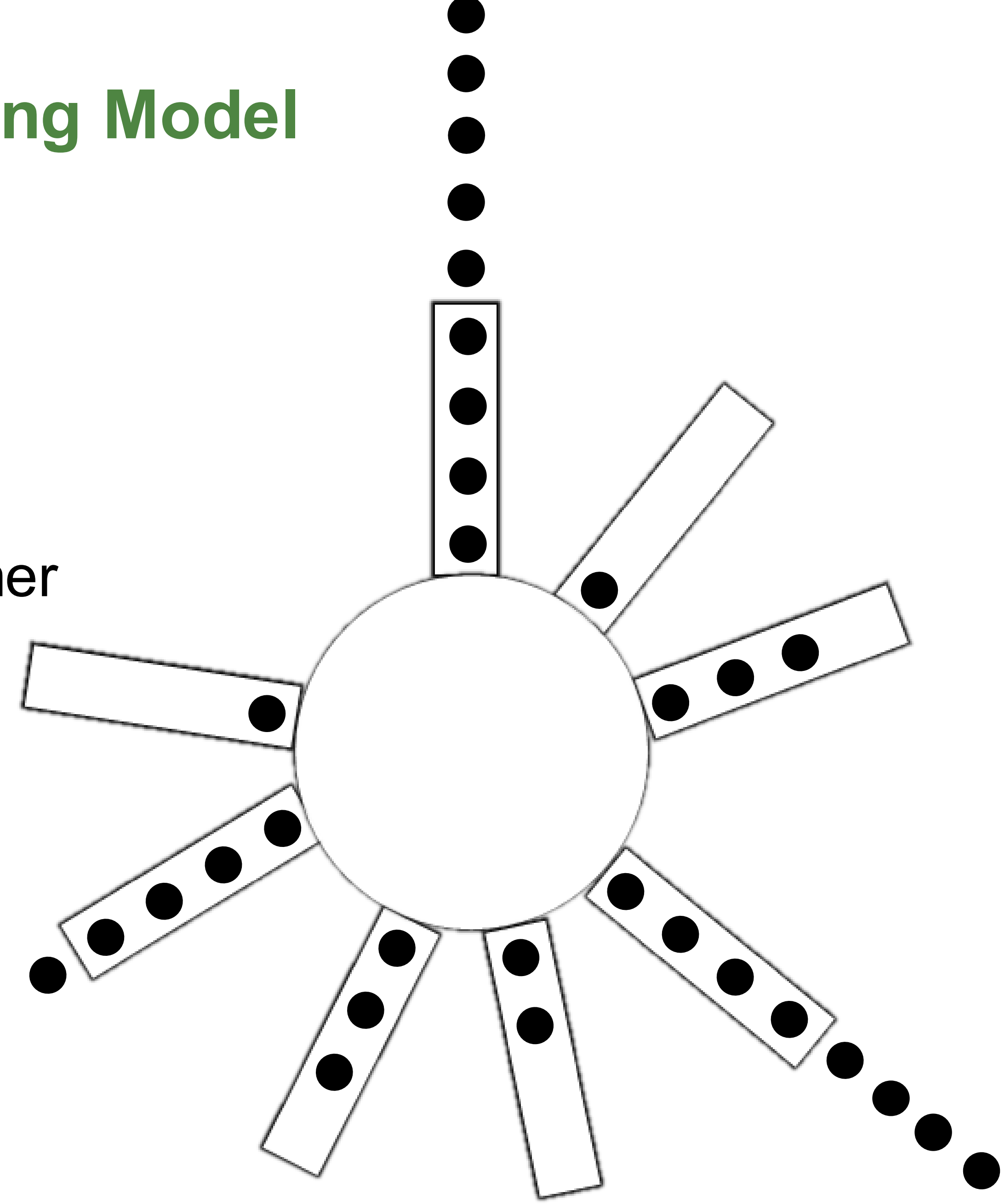

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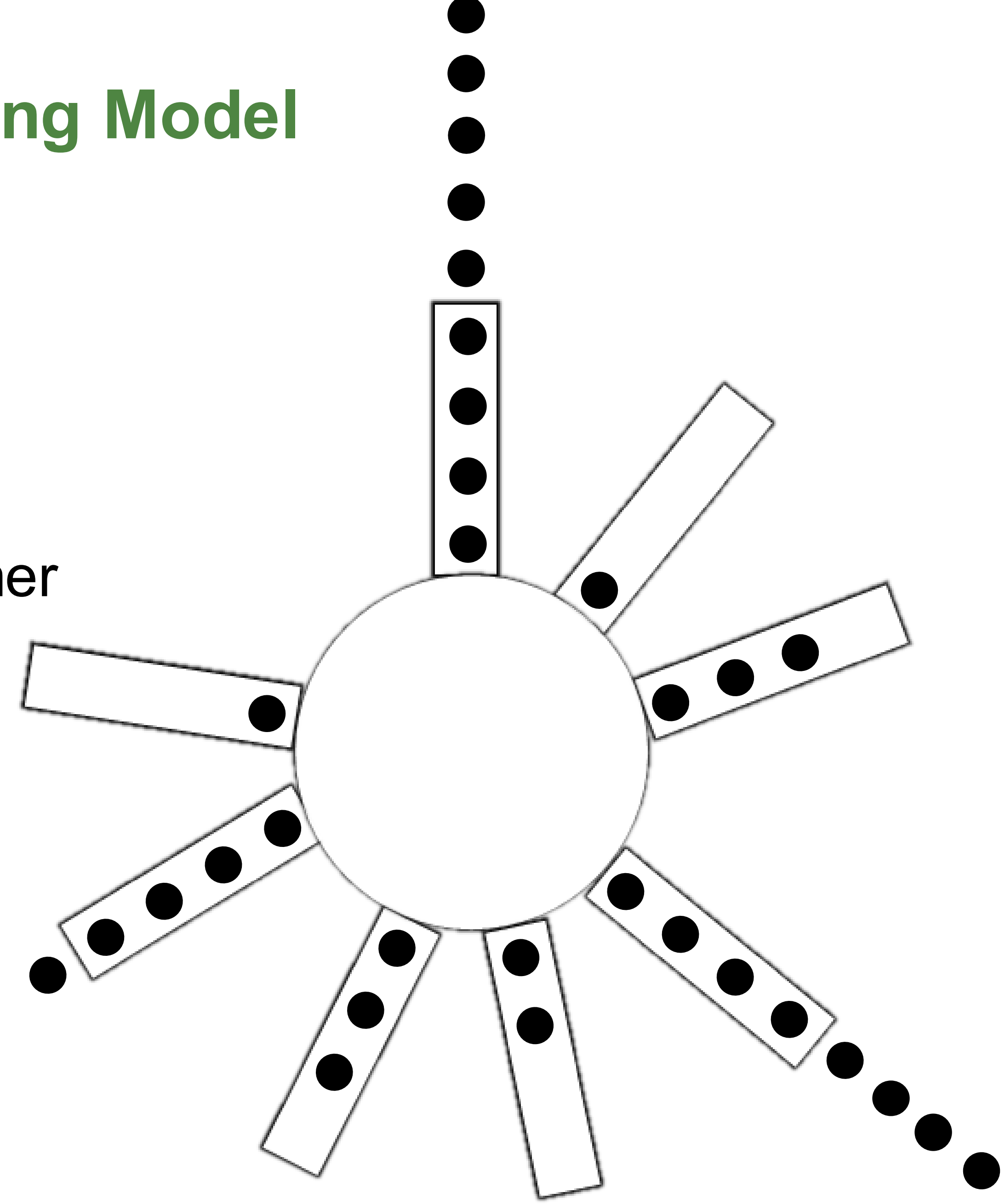
Challenge:

- $O(\frac{\log n}{\log \log n})$ w.h.p. gap between min and max load



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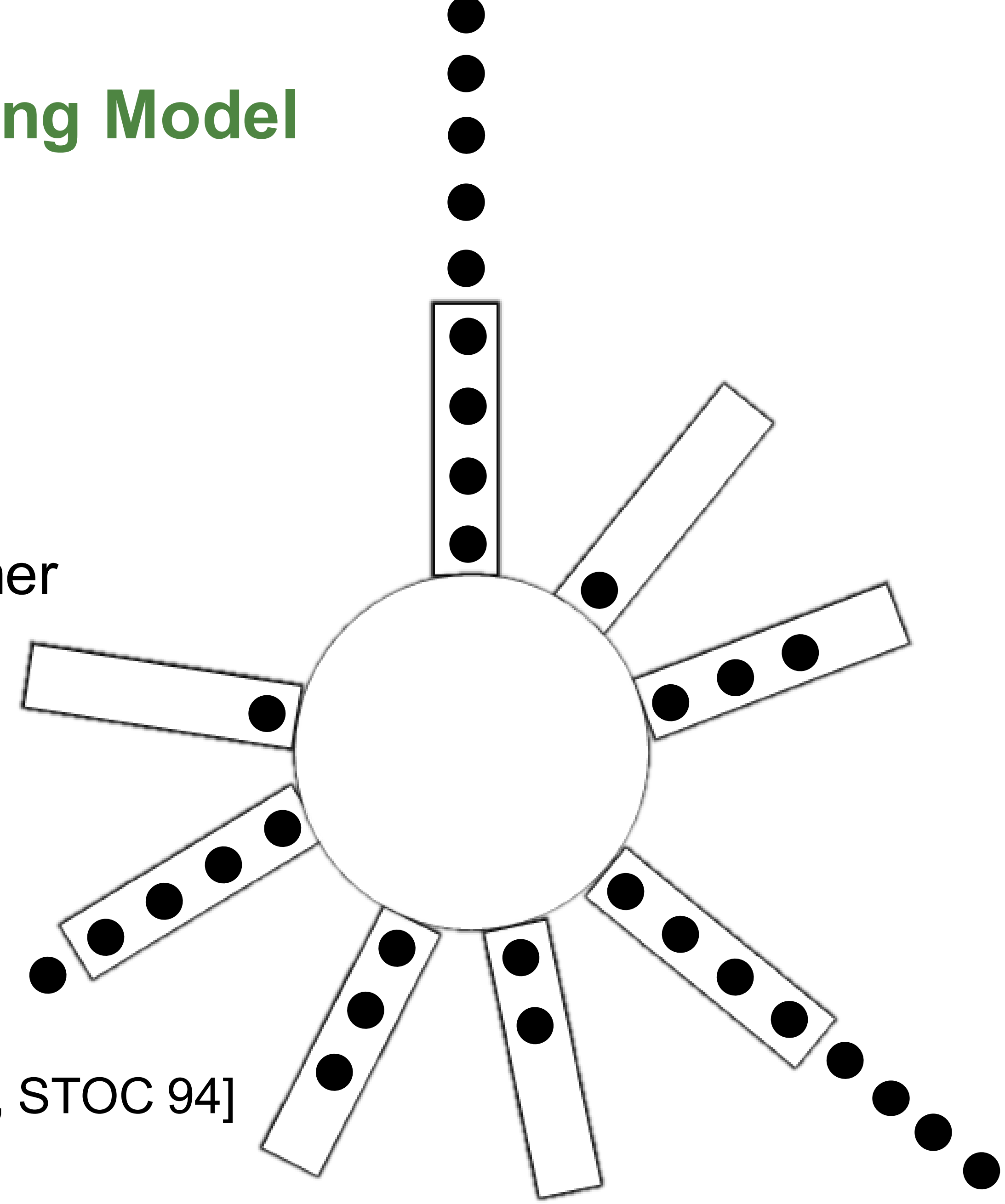
Challenge:

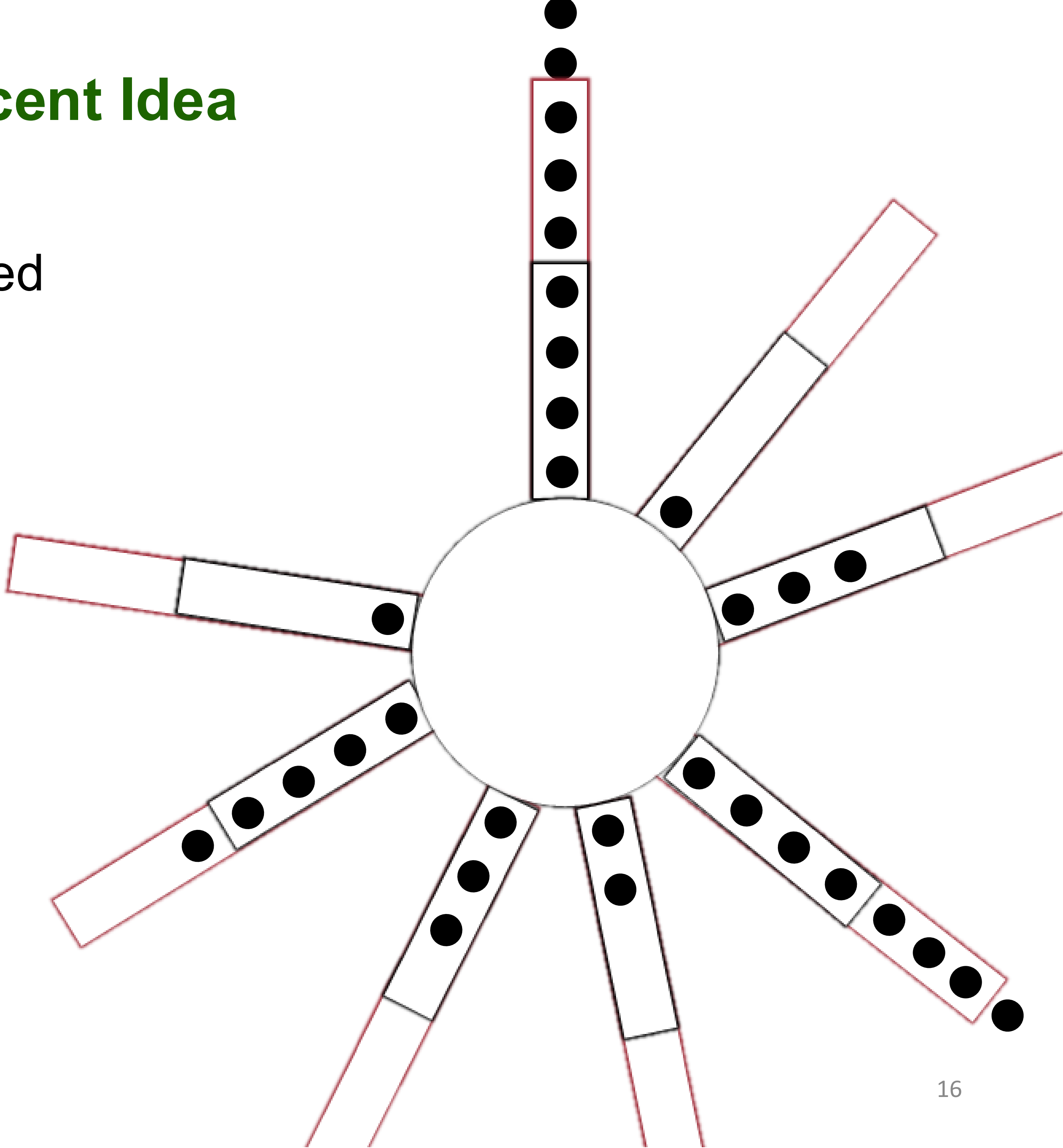
- $O(\frac{\log n}{\log \log n})$ w.h.p. gap between min and max load

- Other works reduced the gap:
  - E.g., by using “power of two choices” [Azar et al., STOC 94]
  - But the gap is still non-constant



A Recent Idea

- [Mirrokni et al., SODA 2018] suggested bounding capacity to $c = \left\lceil \frac{m}{n} \right\rceil * \beta$



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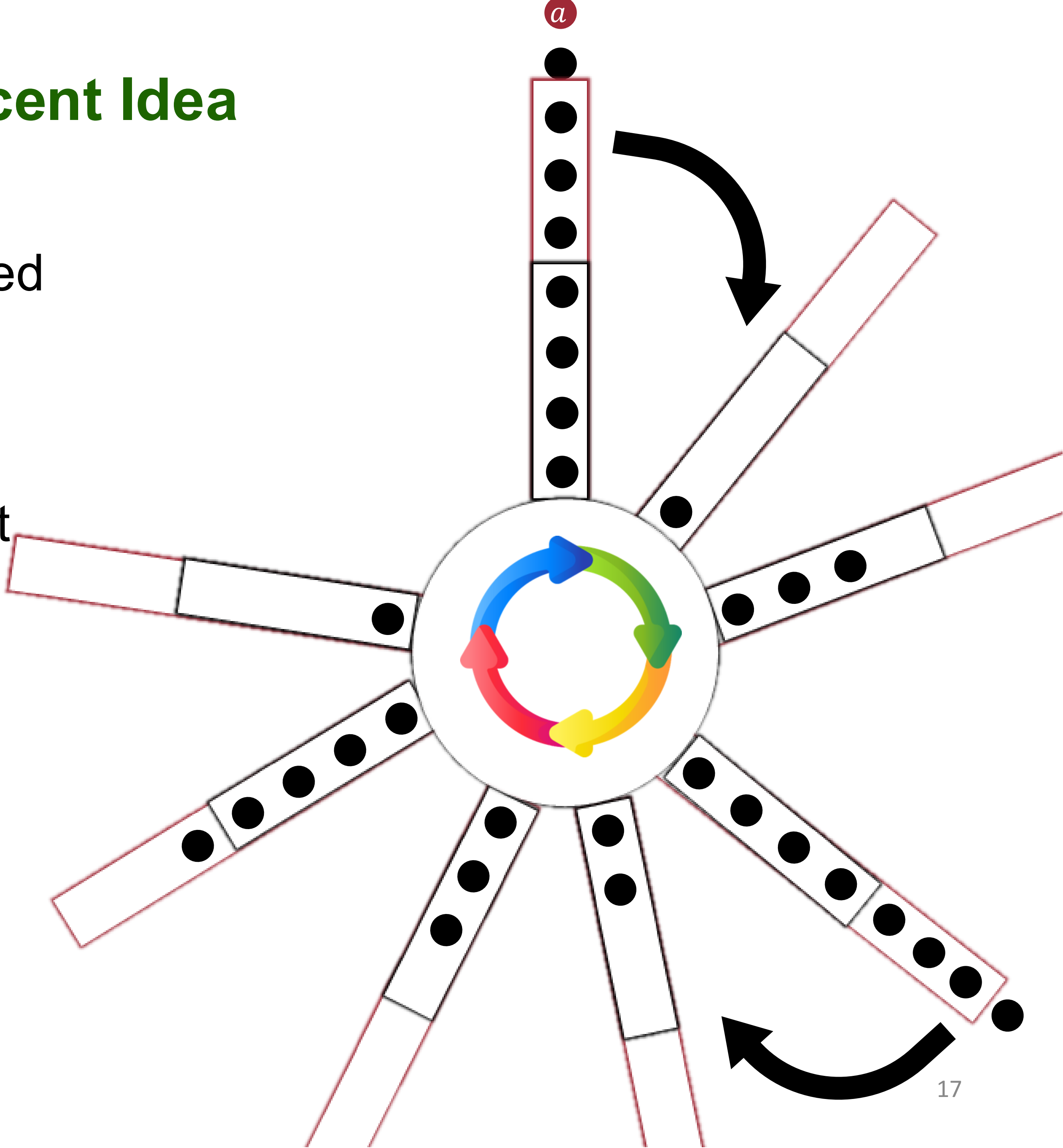

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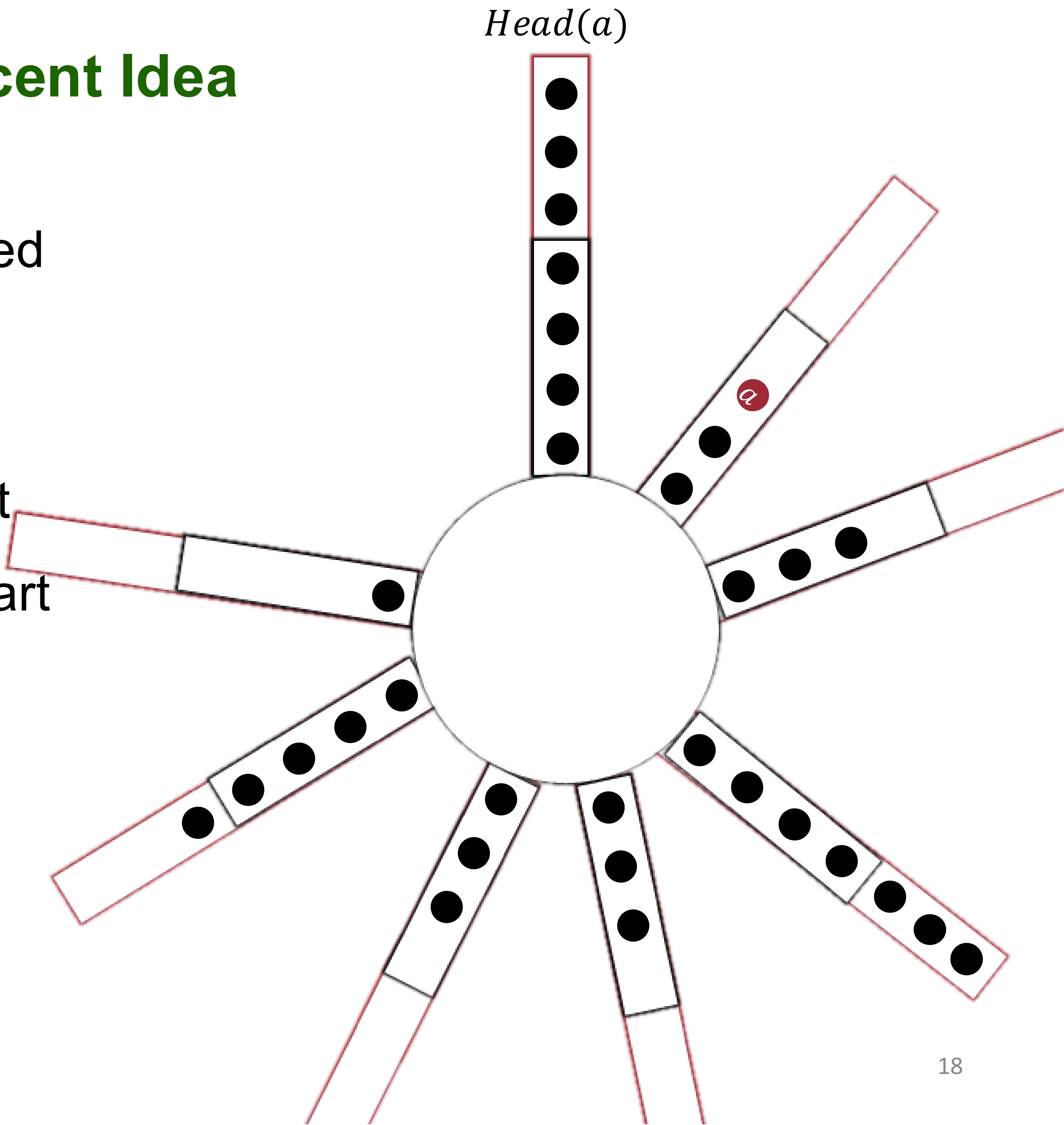
- [Mirrokni et al., SODA 2018] suggested bounding capacity to $c = \left[\frac{m}{n}\right] * \beta$
- Allow extra items to be moved to next servers, and to access a node, we start from its head



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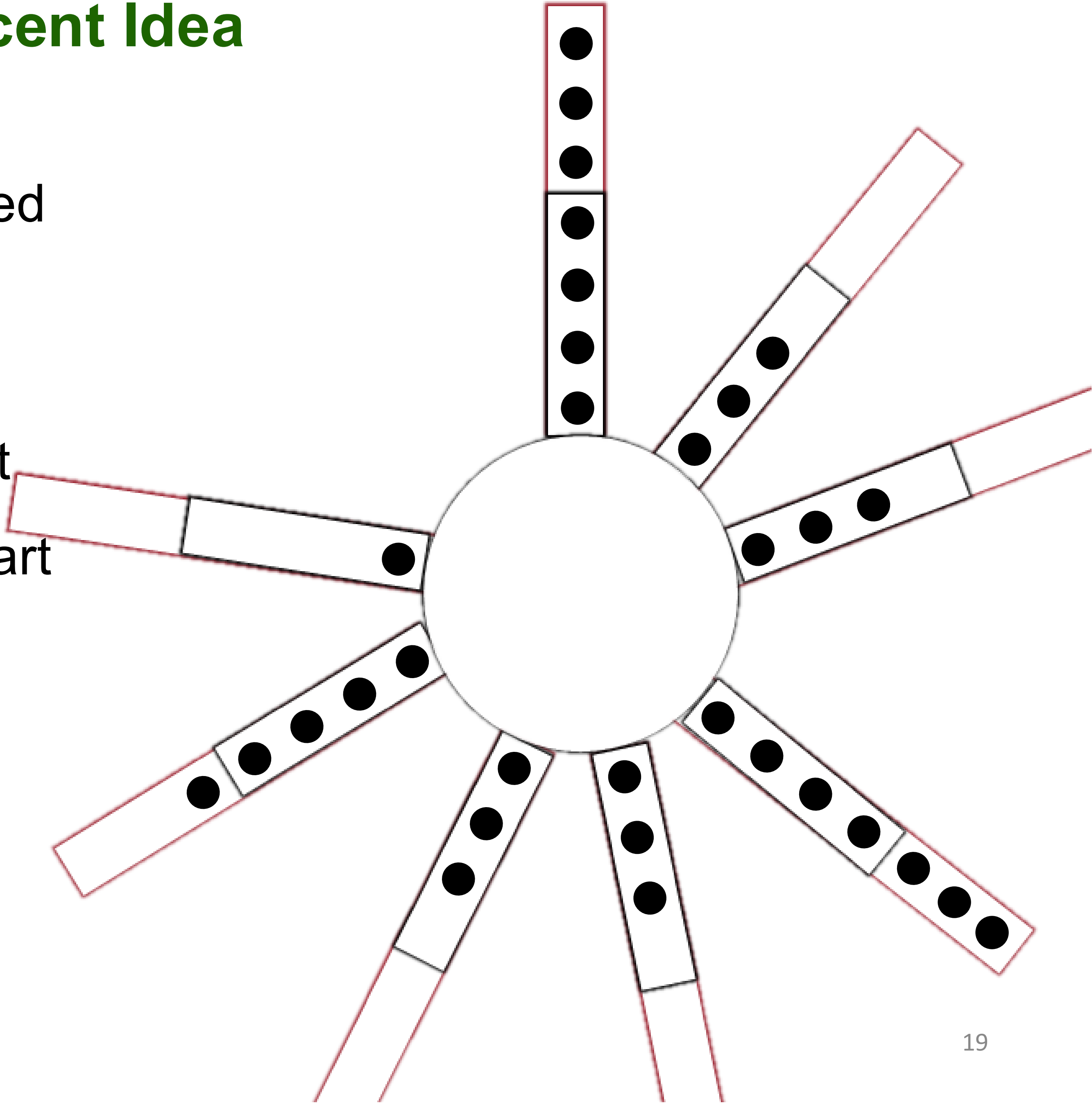

Challenges:

- Storage utilization is far from optimal

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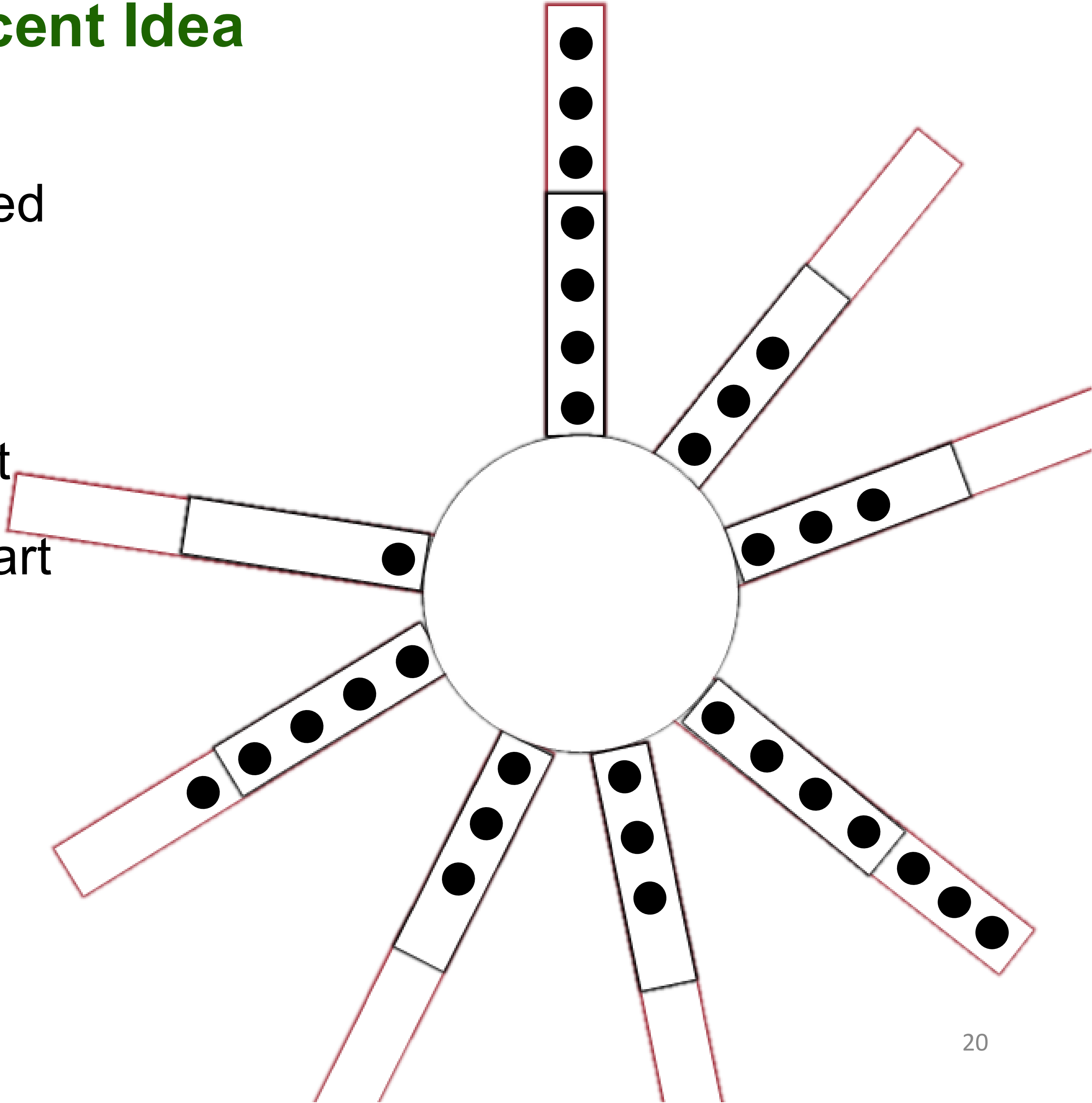
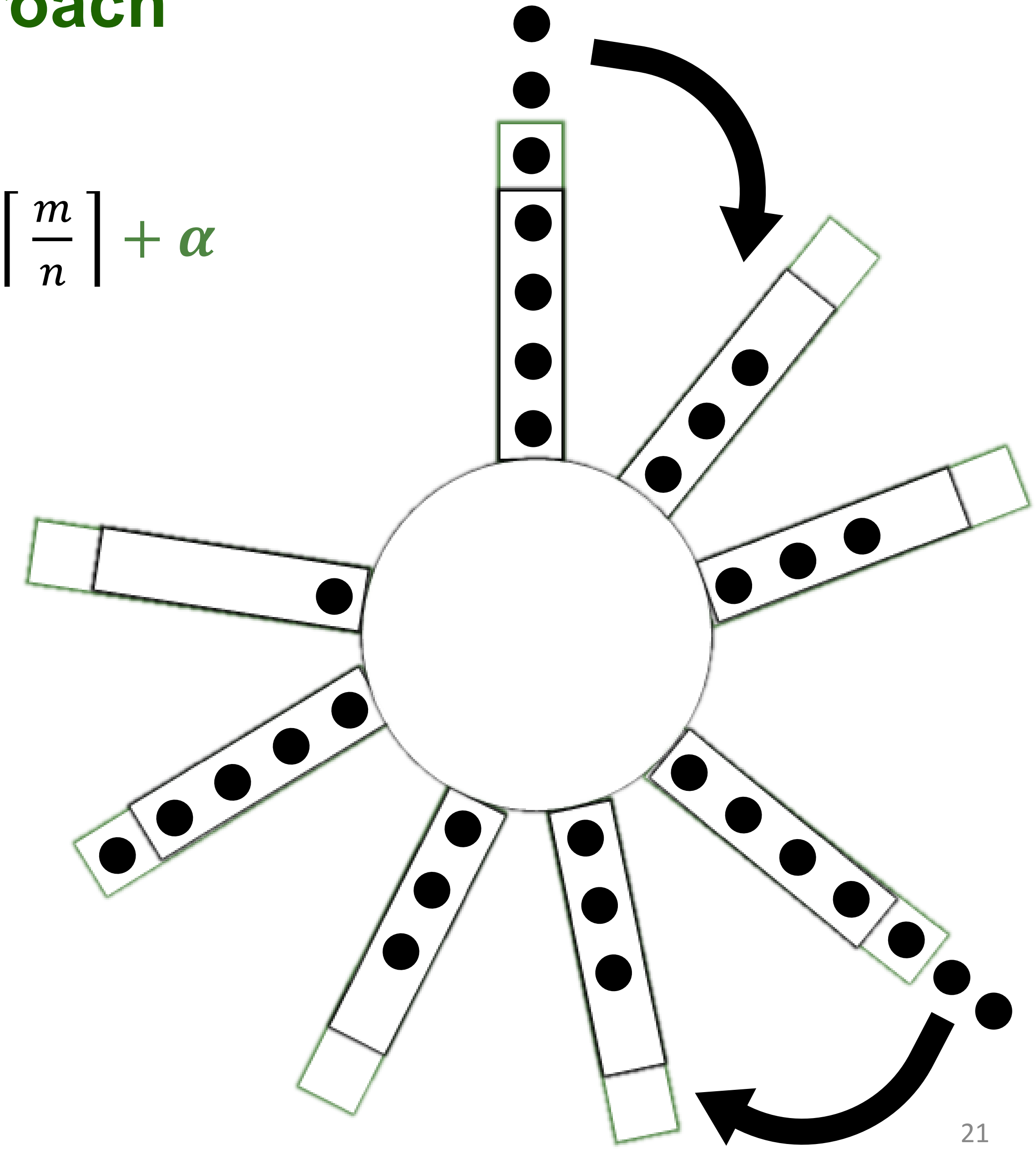


Challenges:

- Storage utilization is far from optimal
- Access cost is increased significantly

Our Approach

- Each server has a bounded capacity $c = \left\lceil \frac{m}{n} \right\rceil + \alpha$



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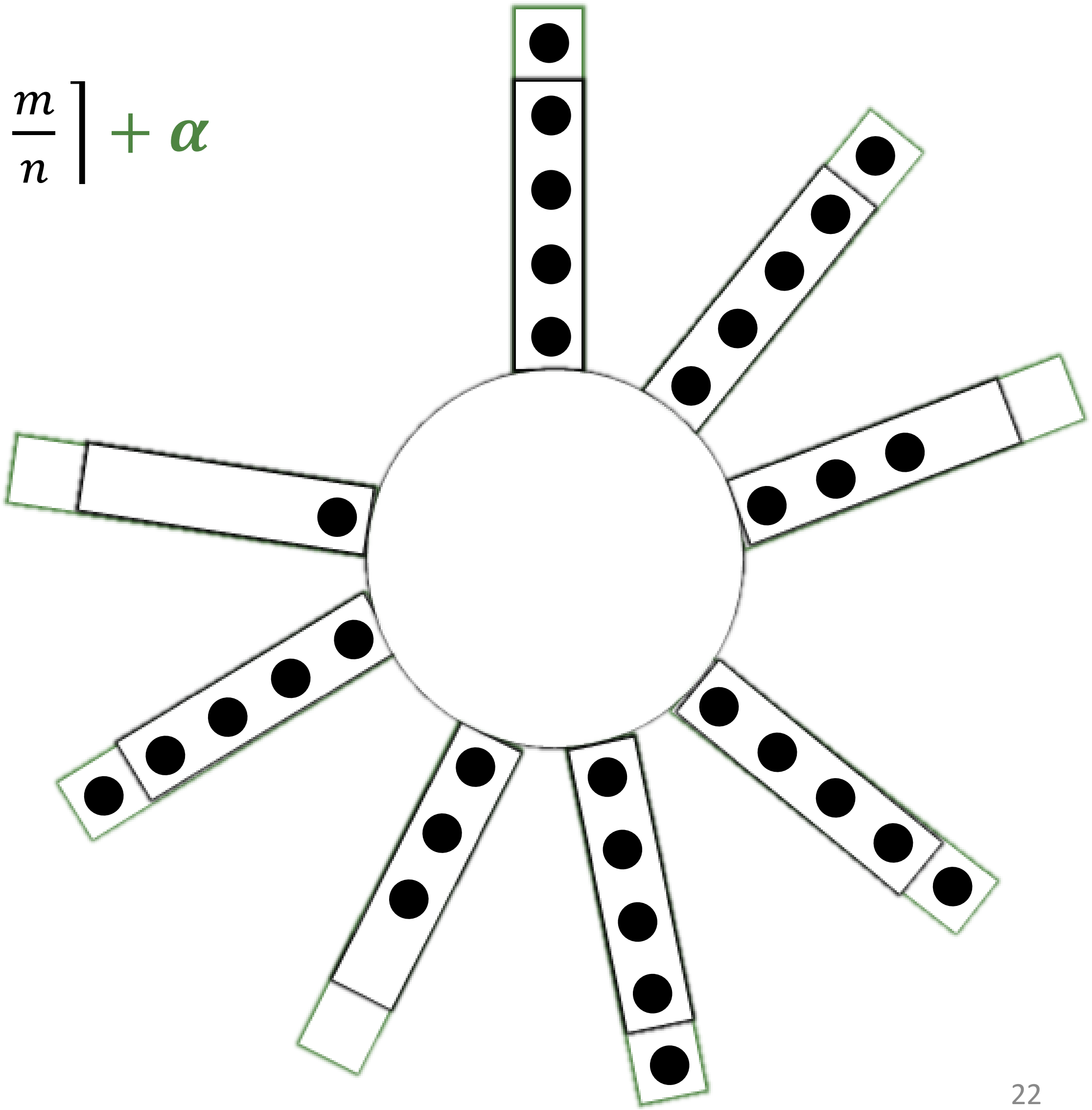

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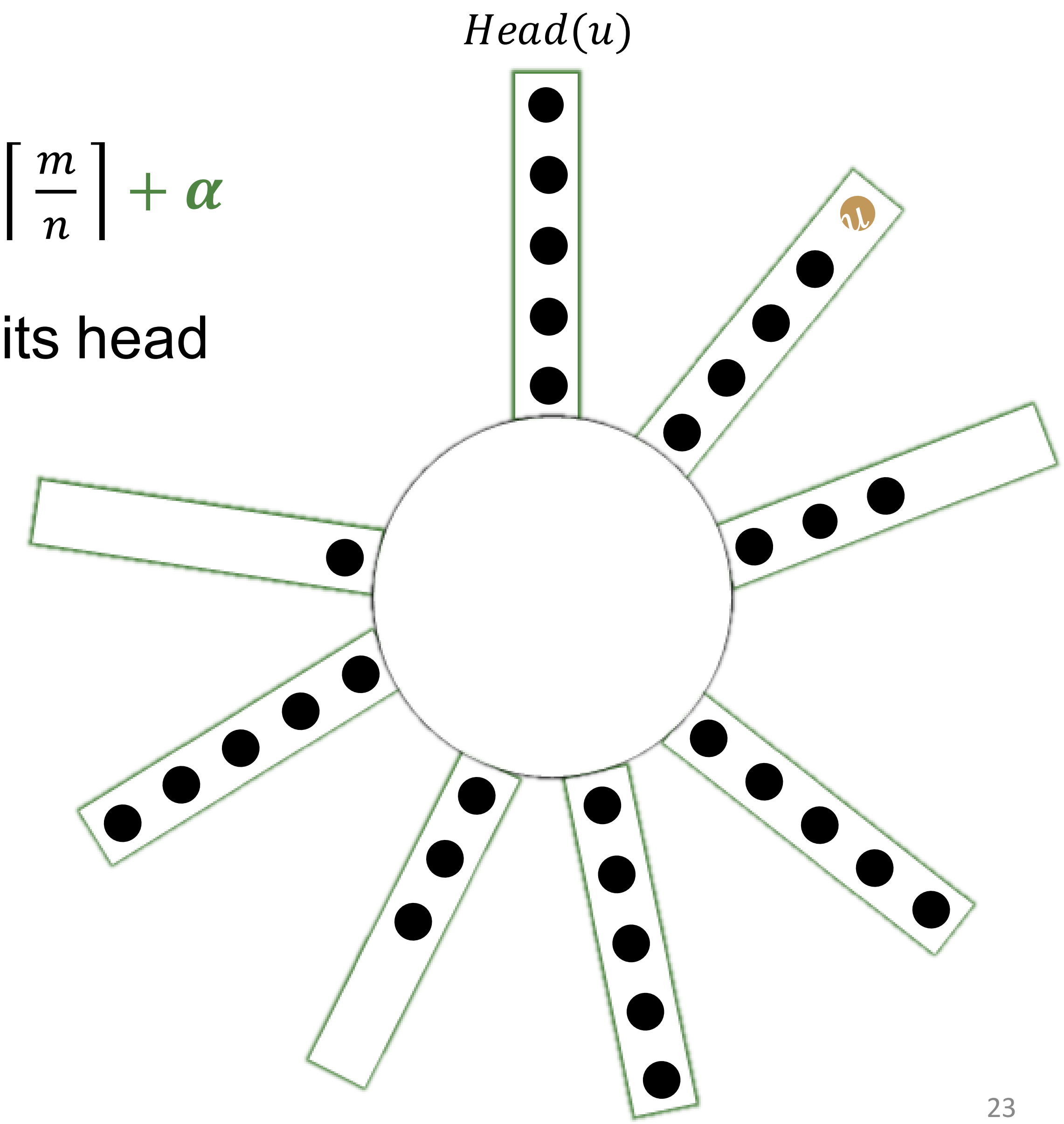

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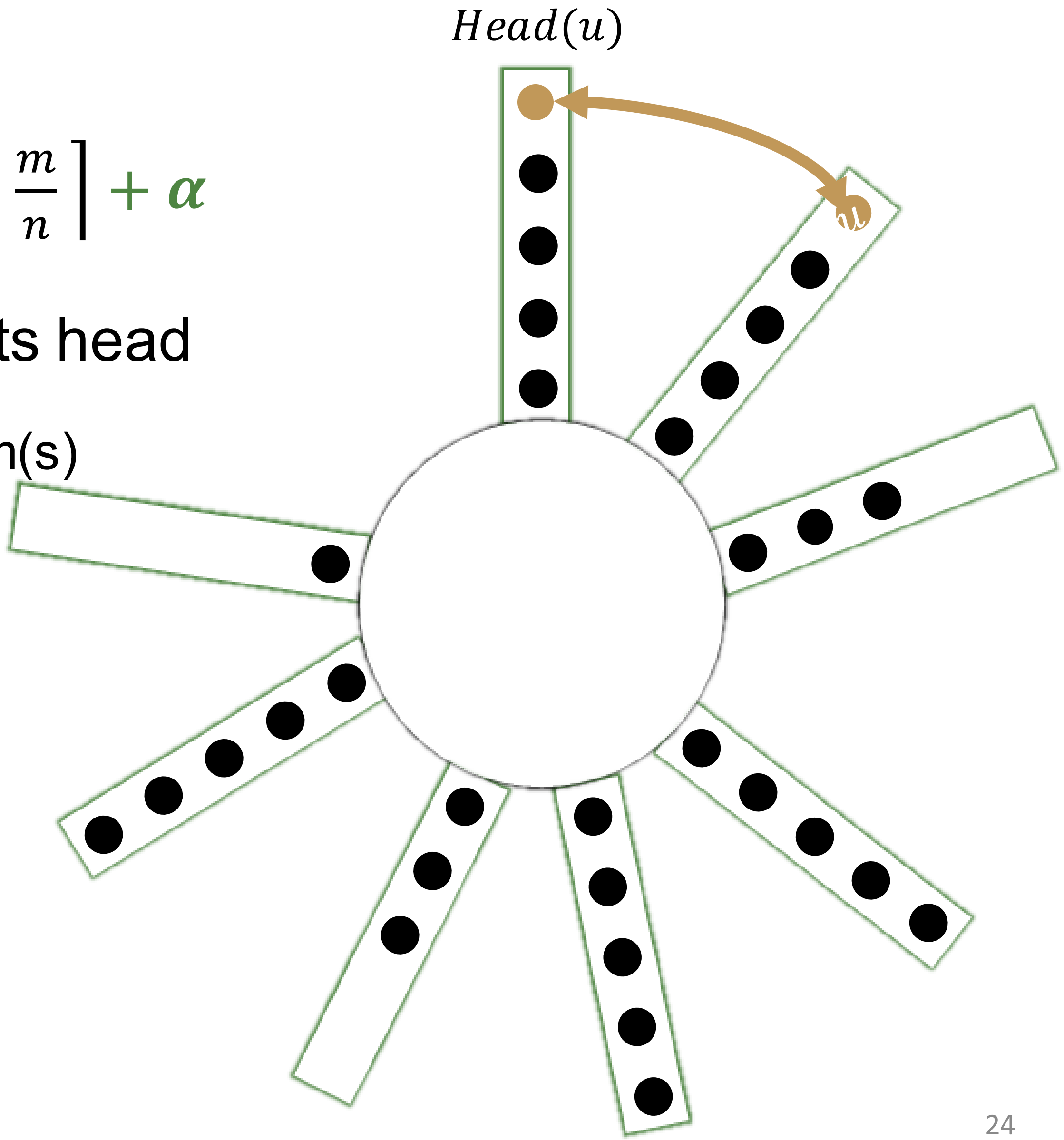
- Bring the recently accessed item back to its head
  - By swapping with (the) least recently used item(s)



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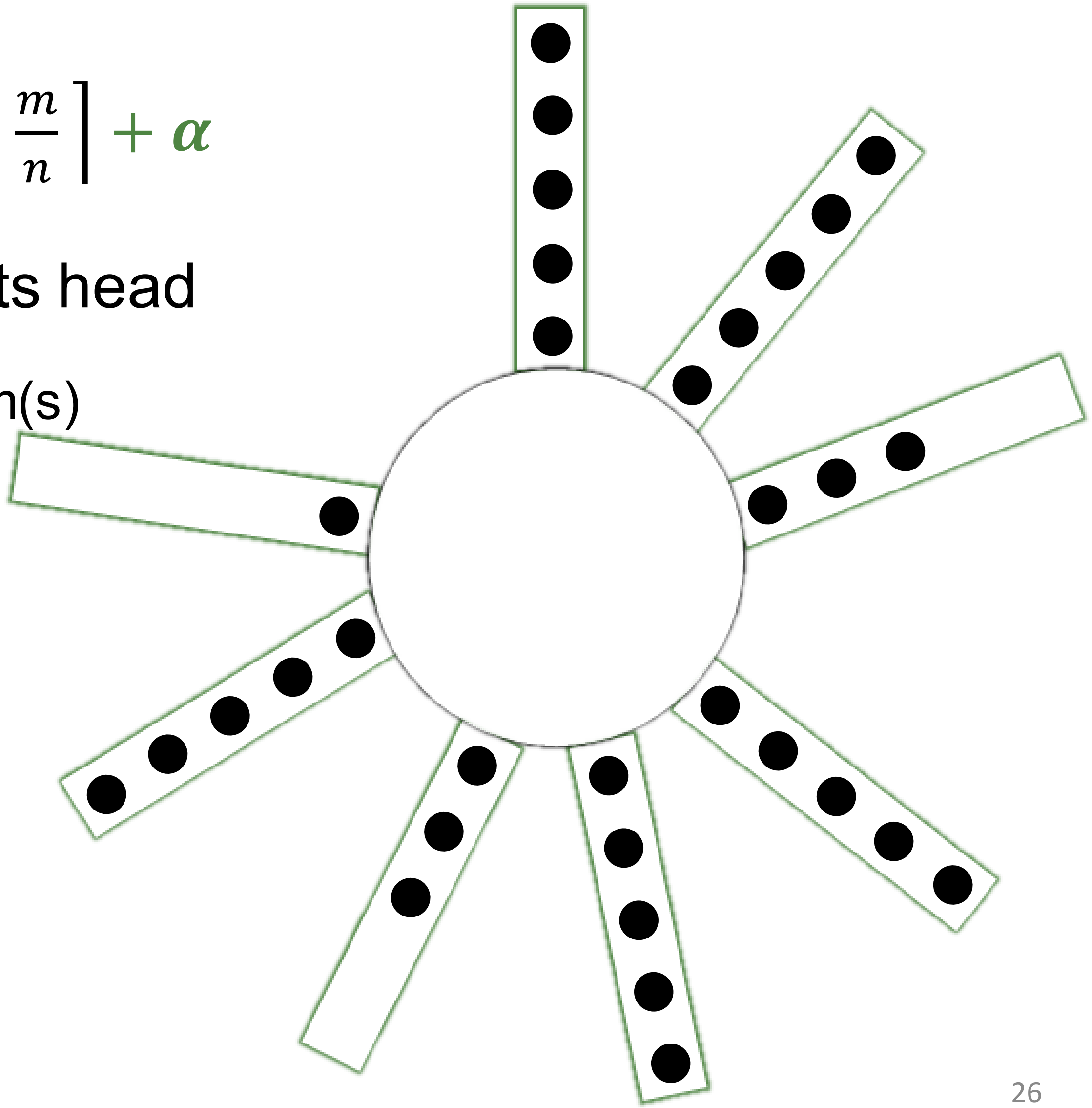
Benefits:

- Storage utilization is near-optimal



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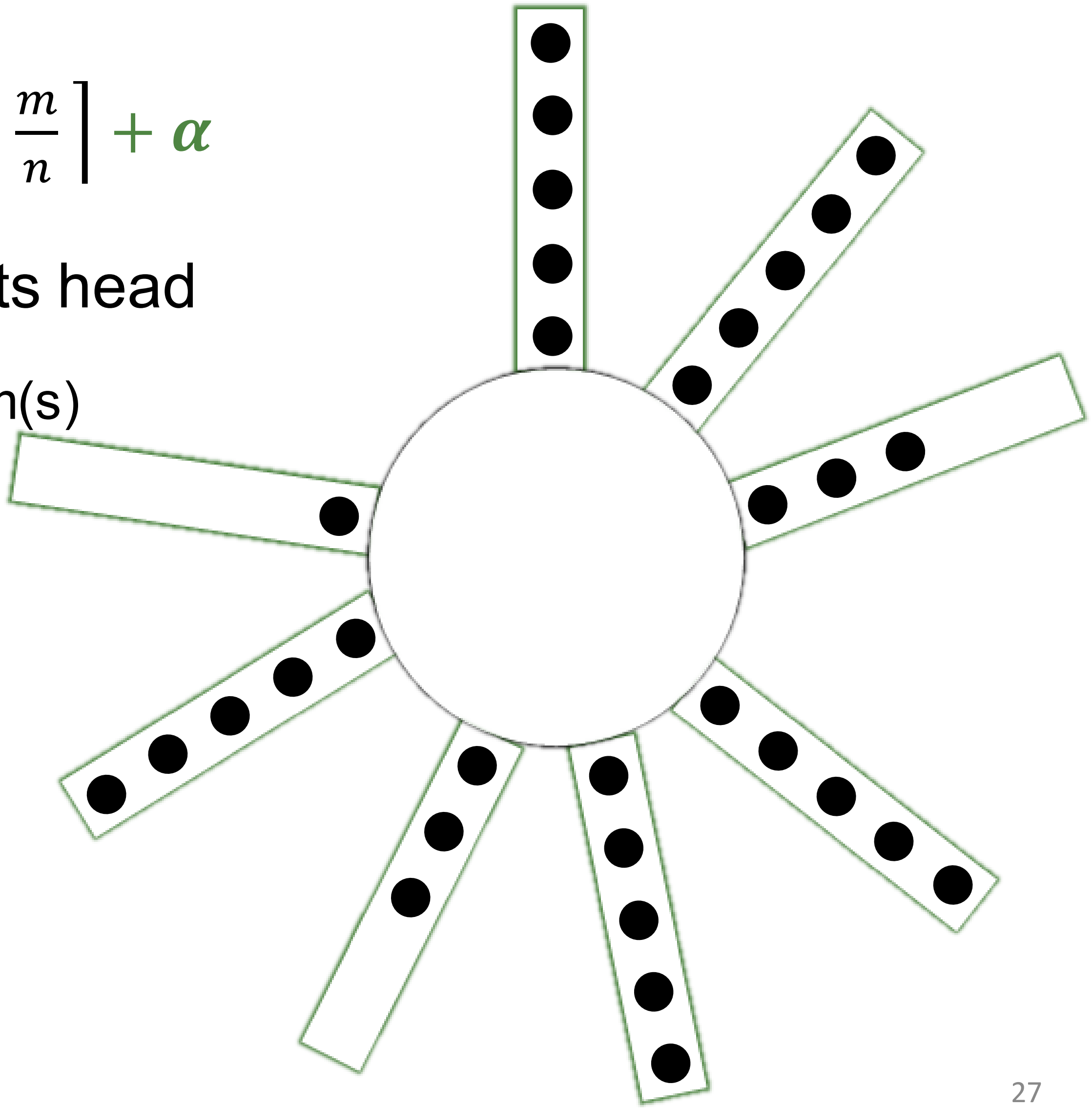


Benefits:

- Storage utilization is near-optimal
- Our approach is constant competitive*
  - $Cost$: access + reconfiguration cost
  - $Cost_{ALG} \leq \alpha \cdot Cost_{OPT}$

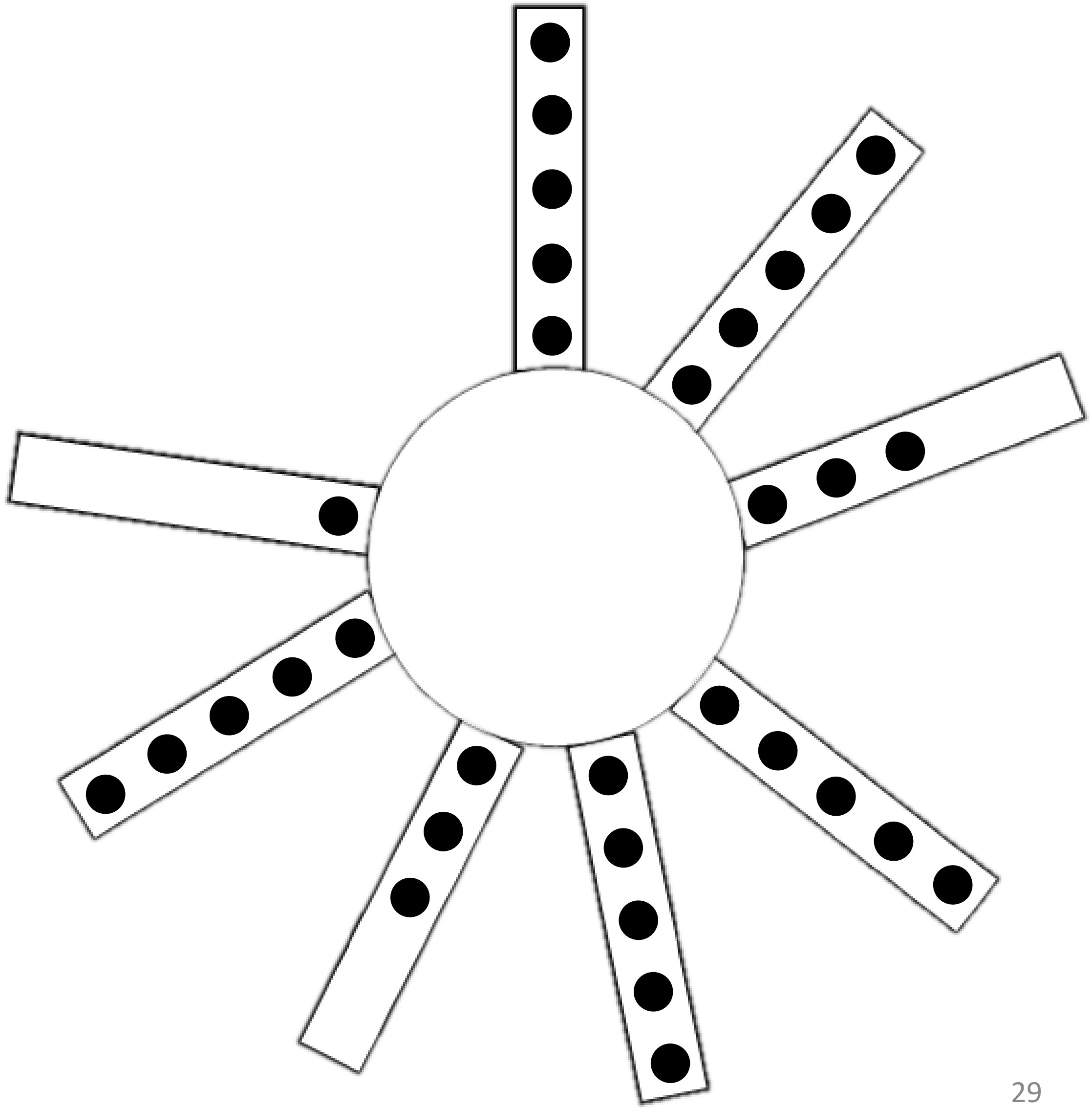
  * Given well-behaved inputs

Related work Recap

Data structure	Access Cost	Storage Utilization
Traditional [Karger et al., STOC 1997]	Low	Low
With Bounded Loads [Mirrokni et al., SODA 2018]	High	Medium
Our Work [Hash & Adjust]	Low	High

Analysis: Access Operations

Thm 1: Considering access requests, our algorithm is $2 \cdot (1 + \omega)$ competitive, where ω is the constant cost of moving items between two adjacent servers.



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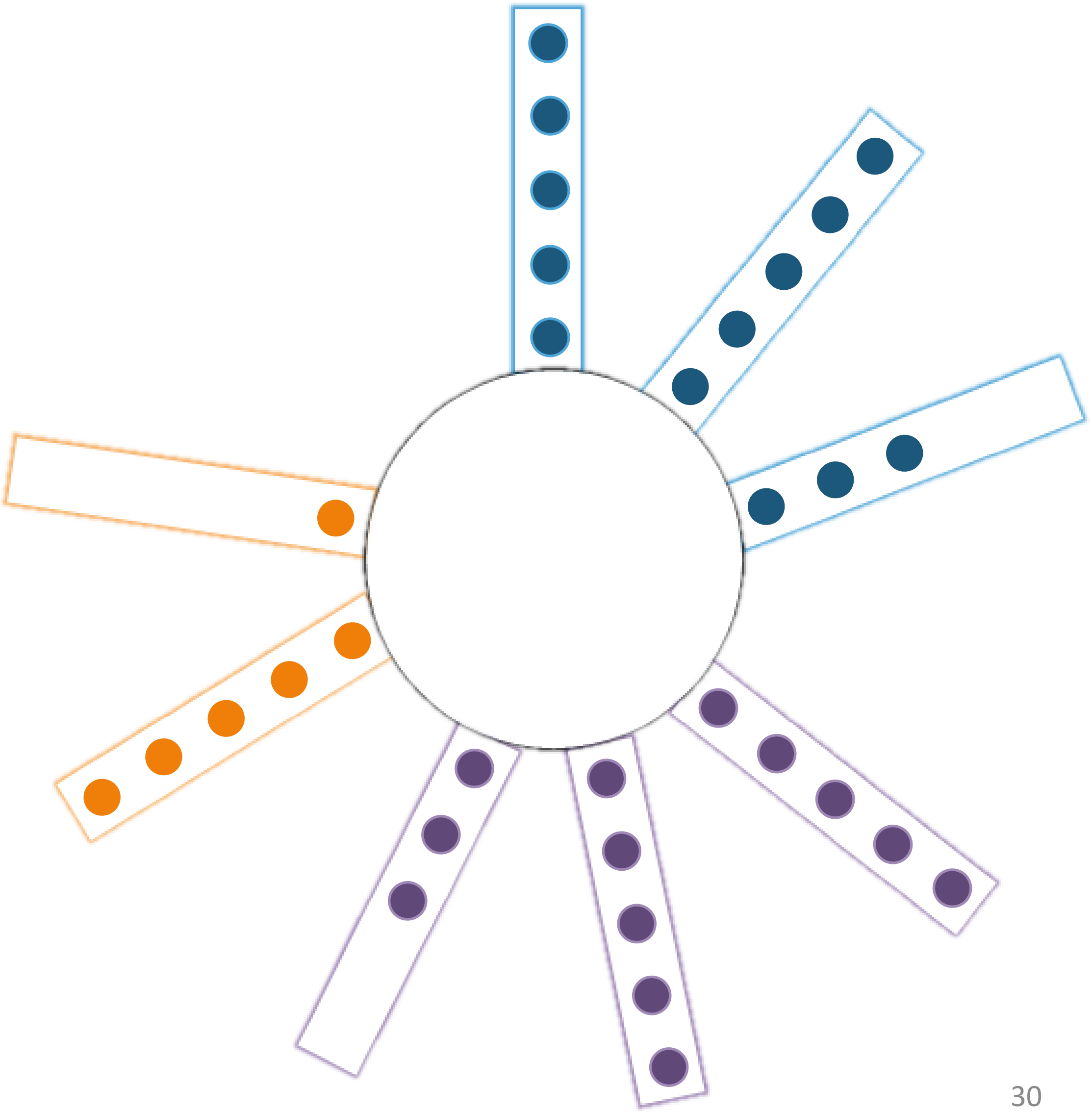
Lem 1: Decomposing into *Serverlists* is always possible



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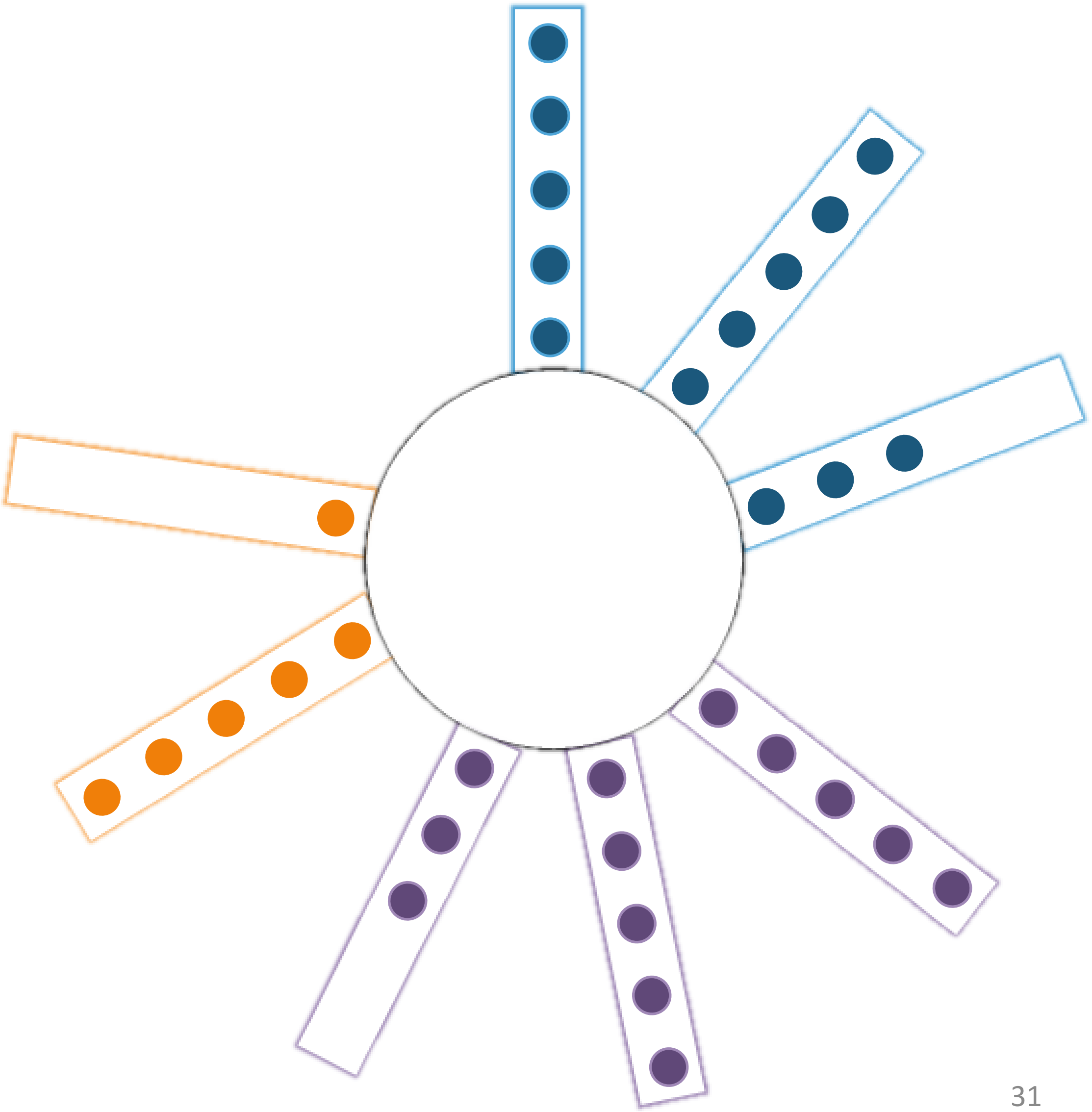
Proof idea: because of extra capacity, we always have non-full servers, and we can not jump over them



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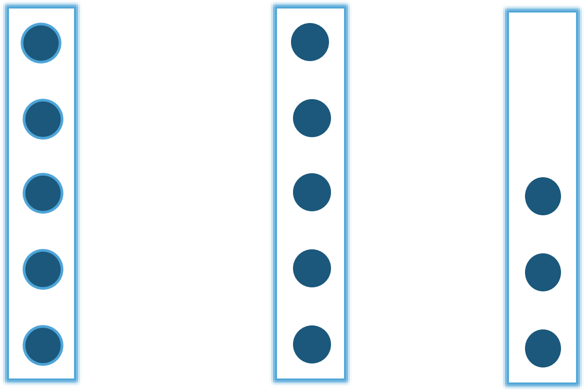

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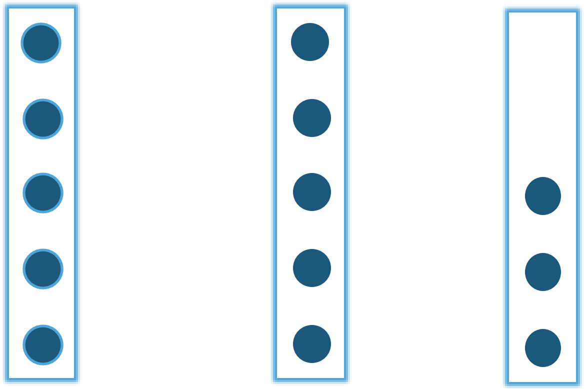

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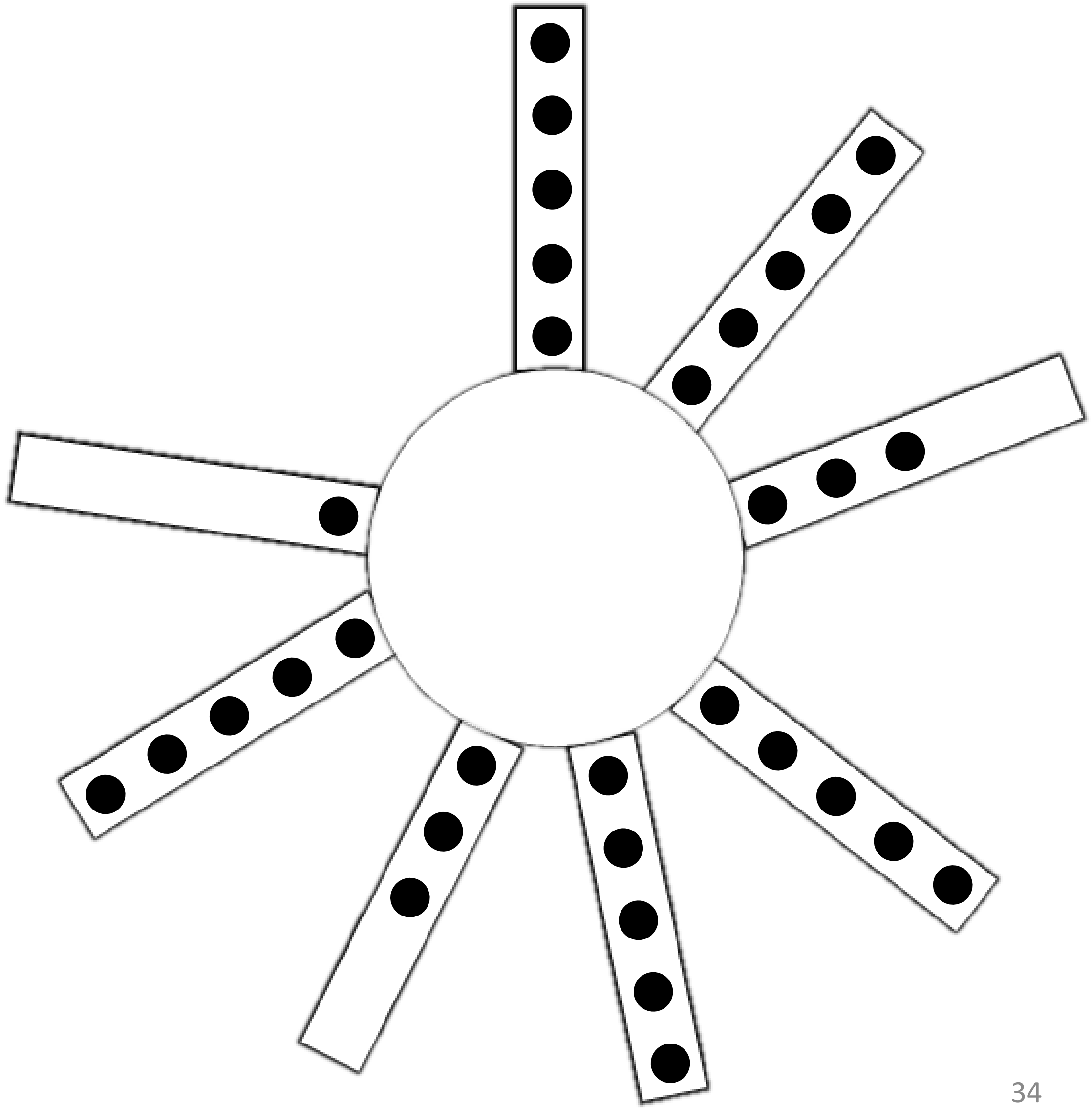
Proof idea: Potential function analysis based on inversions

Analysis: Other Operations

Well-behaved request sequence:

A sequence that insertion/deletions happen after each $\sum_{i=1}^{n-1} e^{\frac{\alpha^2}{m^2}(i+1)}$ access request

Thm 2: Hash & Adjust is constant competitive, in expectation, considering a well-behaved request sequence.



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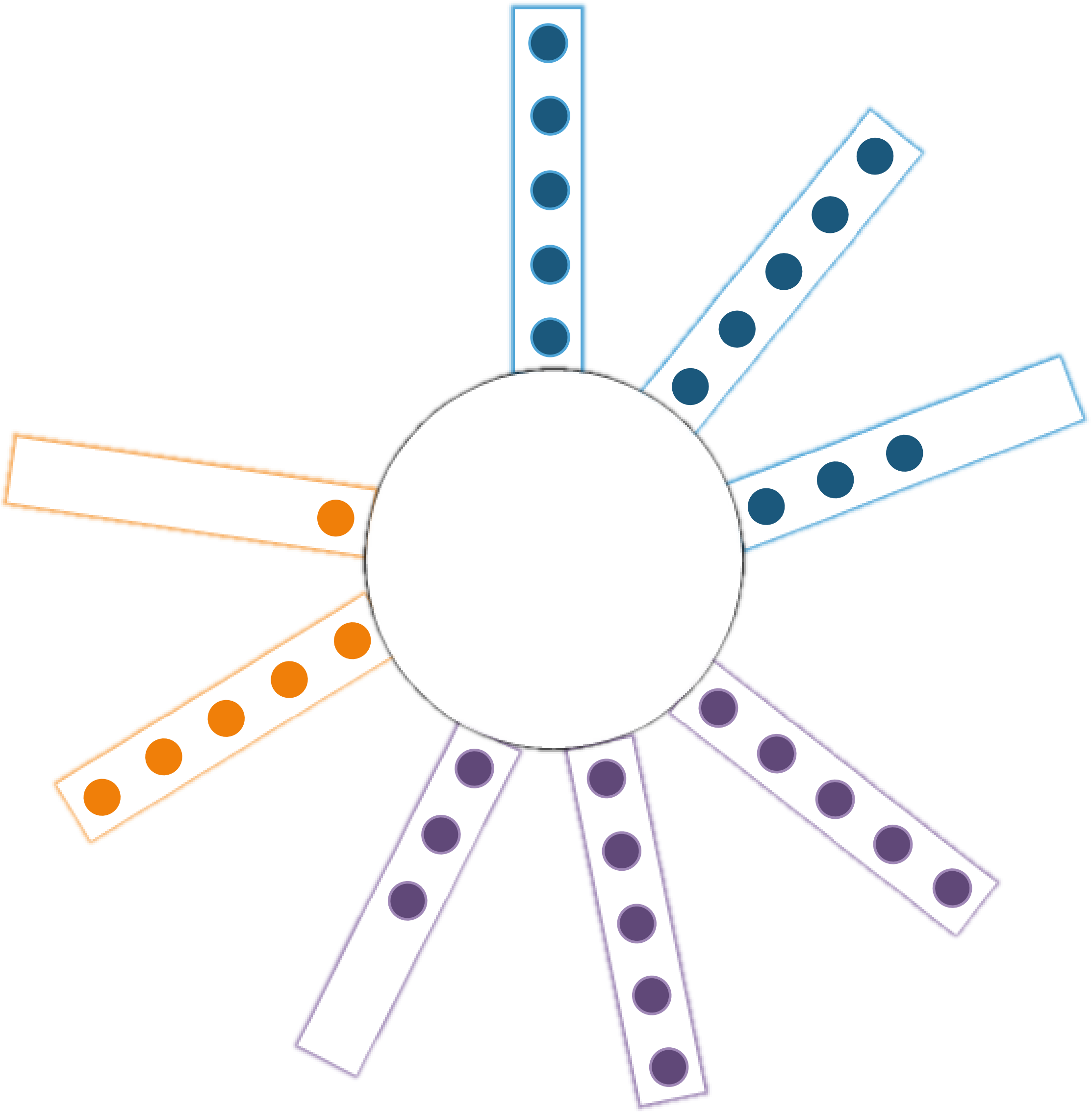
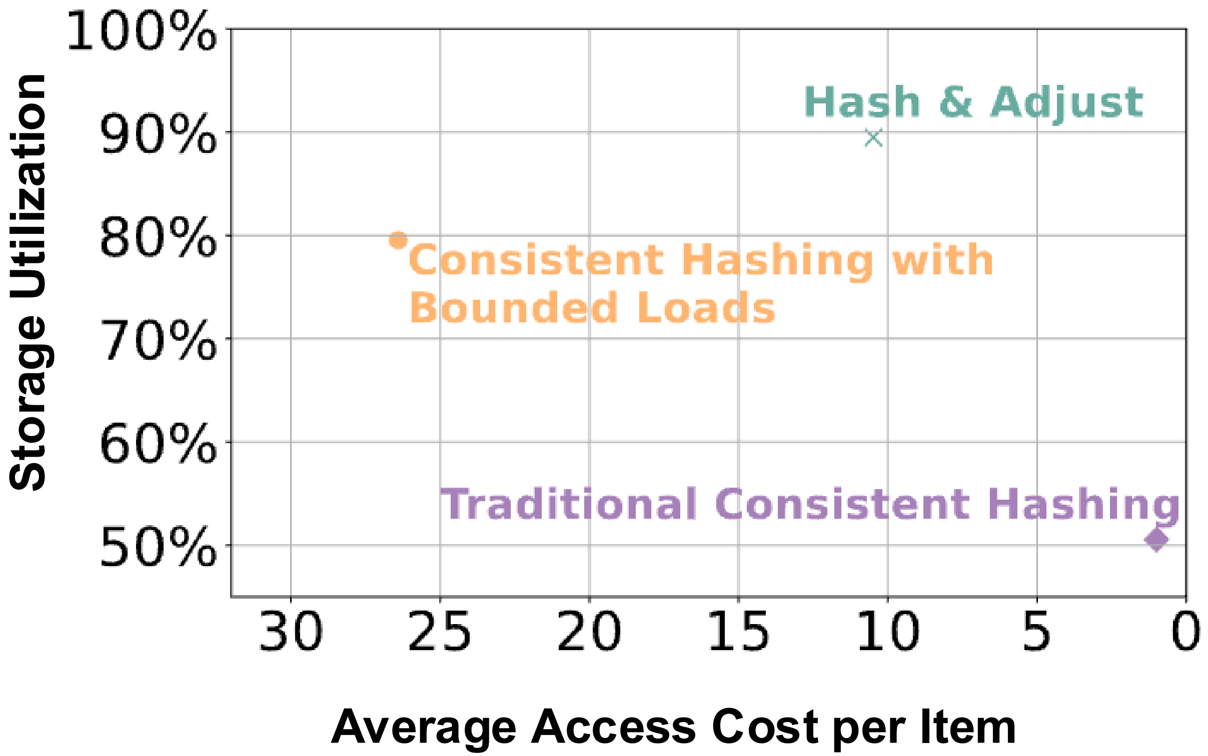
Proof sketch: Expected maximum length of an a *Serverlists is* $\sum_{i=1}^{n-1} e^{\frac{\alpha^2}{m^2}(i+1)}$



Some Empirical Results



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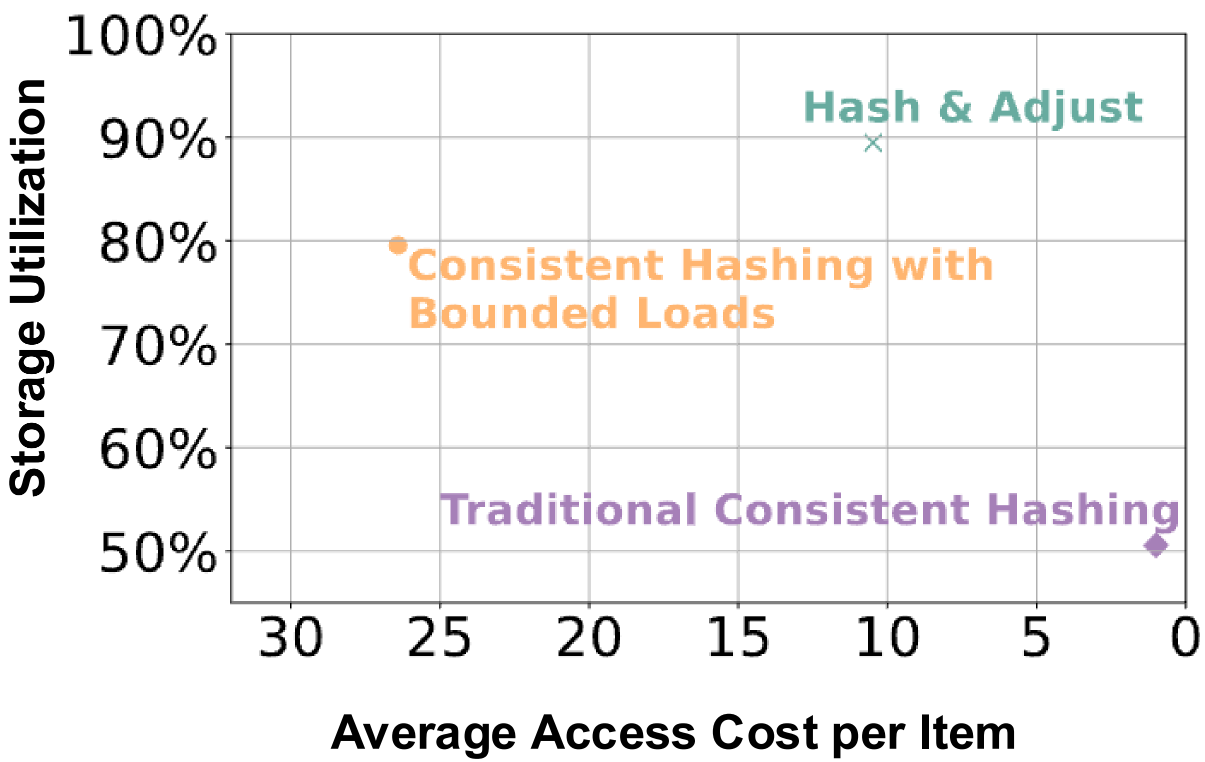

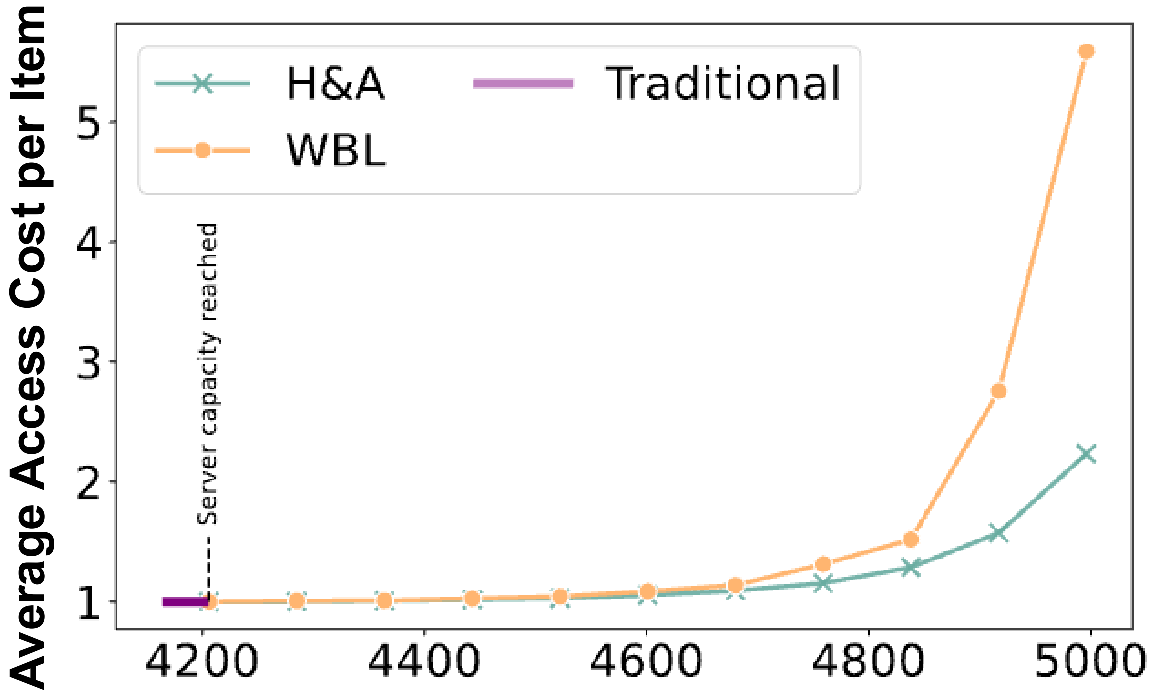

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Based on a dataset from CAIDA, and fixing capacity of all algorithms

Future Work

- Rendering other distributed data structures self-adjusting
- Incorporating the algorithm in open-source load balancers like HAproxy

Full paper:
https://arxiv.org/pdf/2411.11665

Our group's website:
tu.berlin/en/eninet

My website:
pourdamghani.net