Karma:
Resource Allocation for Dynamic Demands

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Éva Tardos

Cornell University

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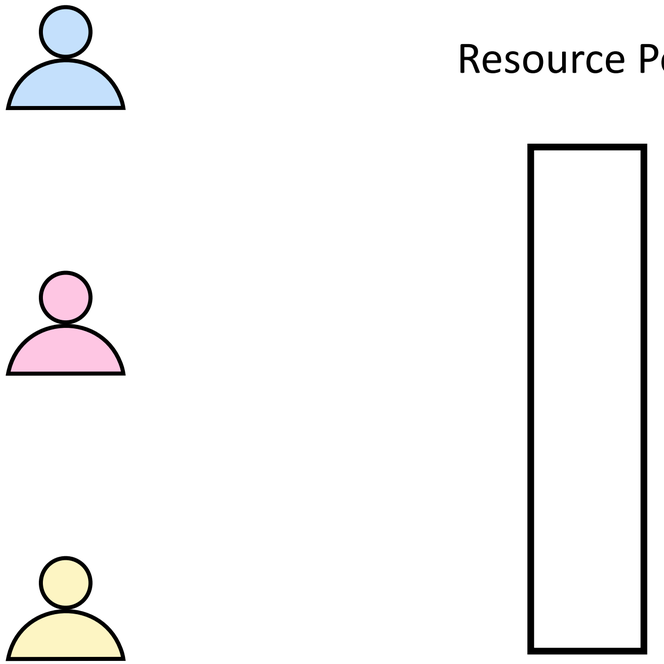
Resource allocation is a fundamental problem

Allocating a resource (e.g. CPU, Memory) with a fixed capacity across multiple users



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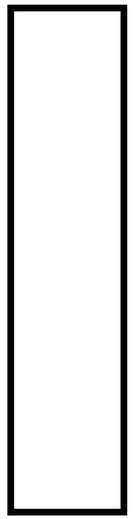

Key Desirable Properties

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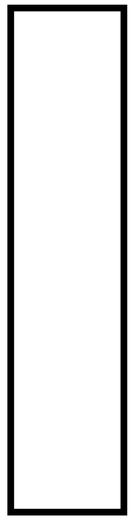

Key Desirable Properties

Pareto efficiency

Resources should not remain unused if there is demand

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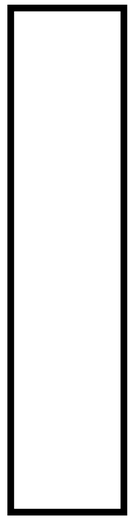

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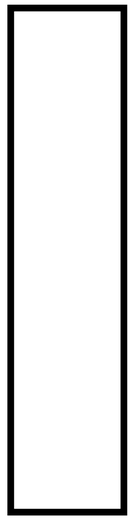

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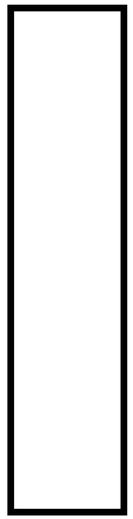

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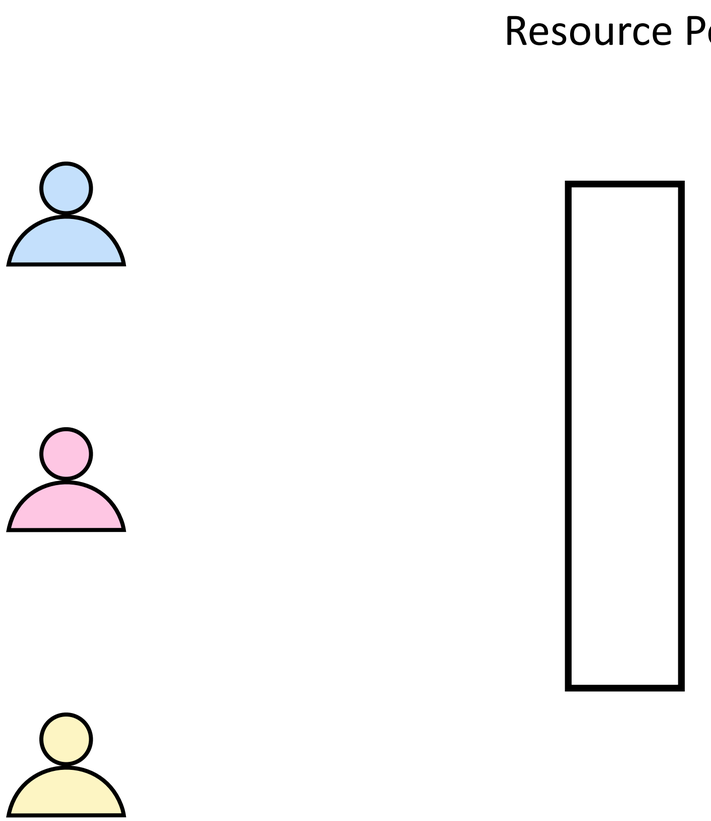
**Two popular resource allocation mechanisms (for single resource type):
strict partitioning and max-min fairness**

Strict partitioning

Allocating the resource equally across all users (“fair share”) **independent of their demands**



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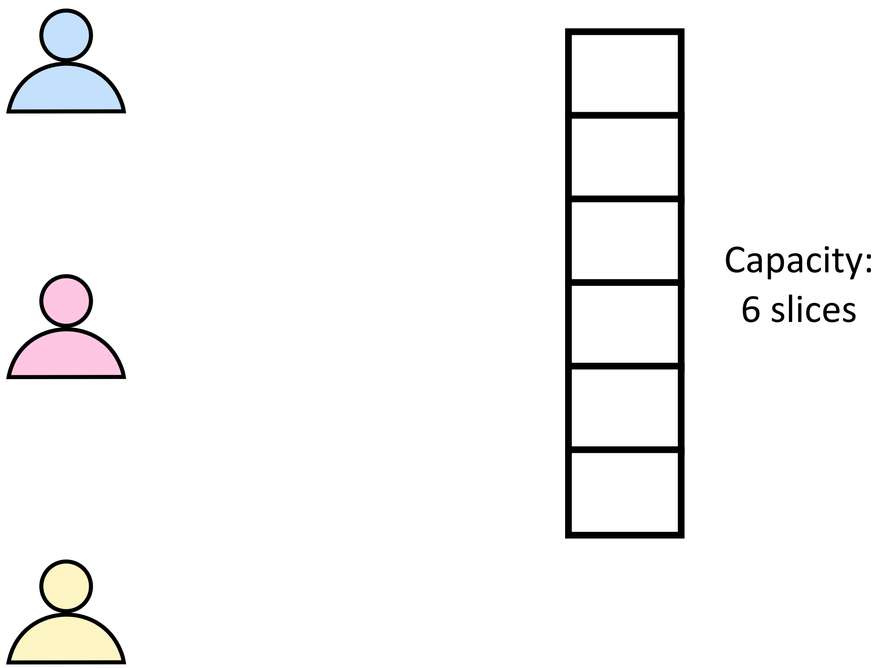

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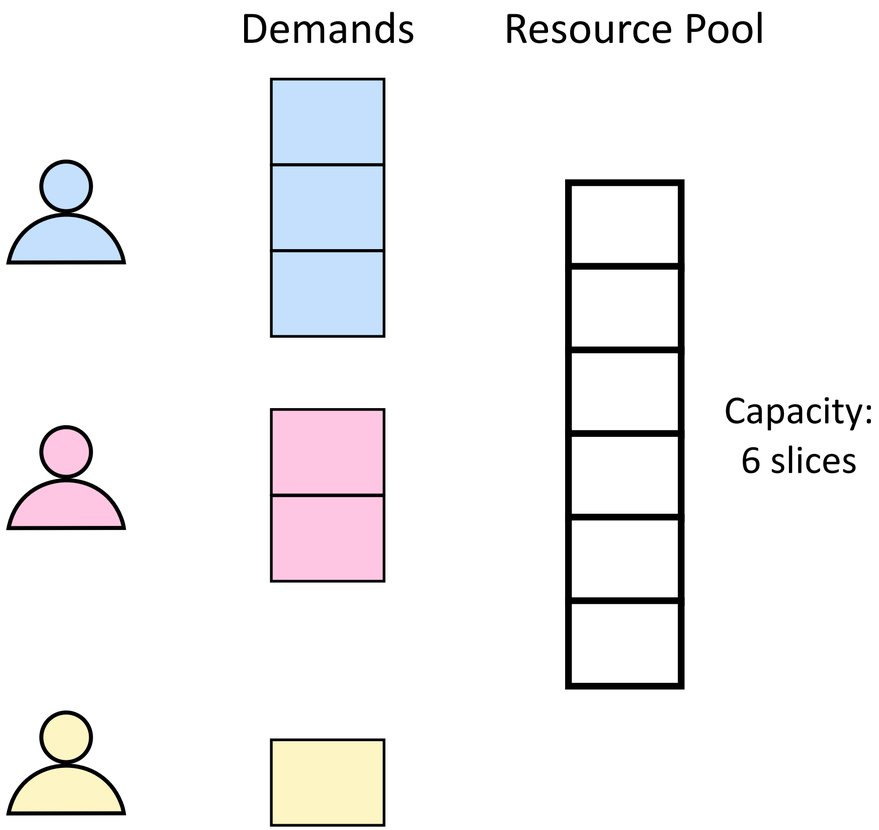

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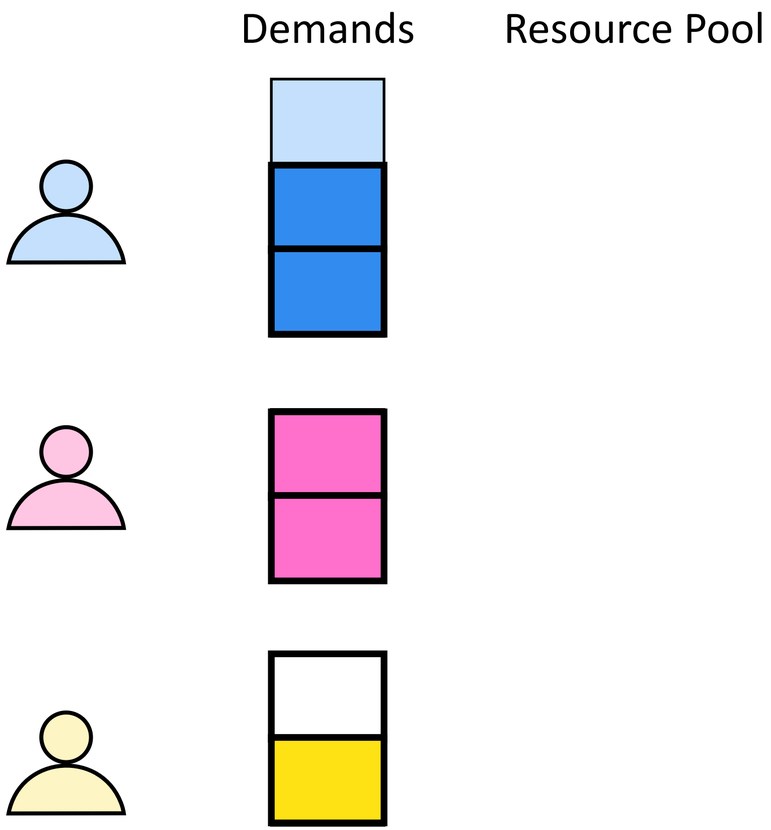

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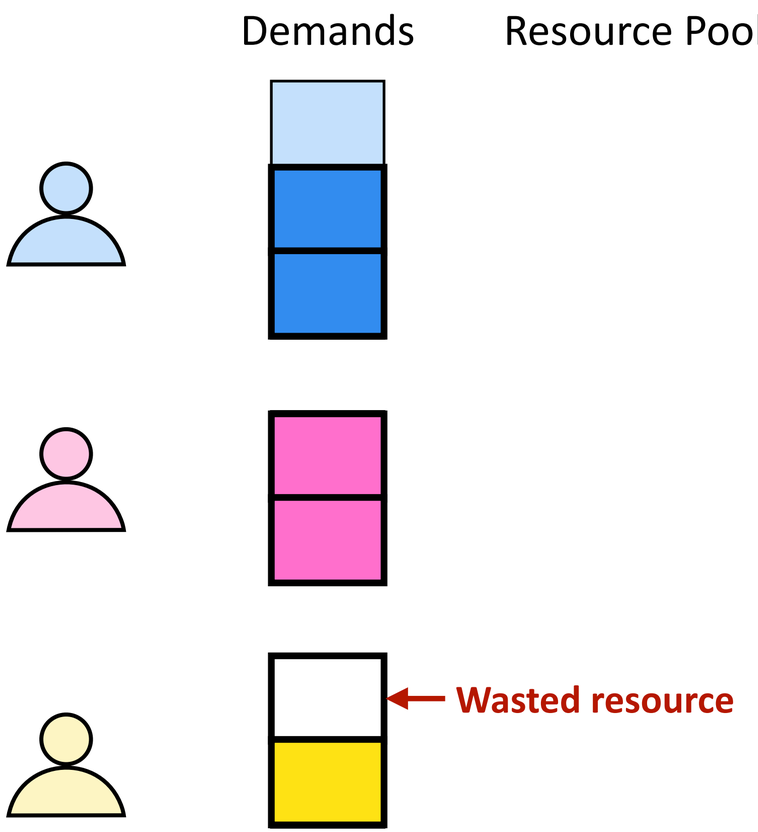

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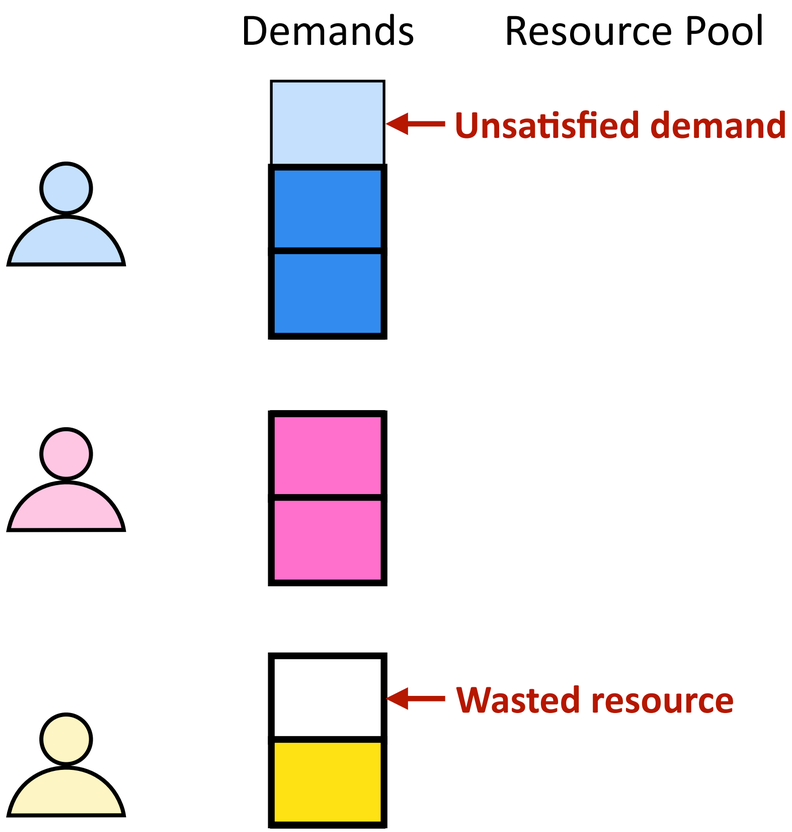

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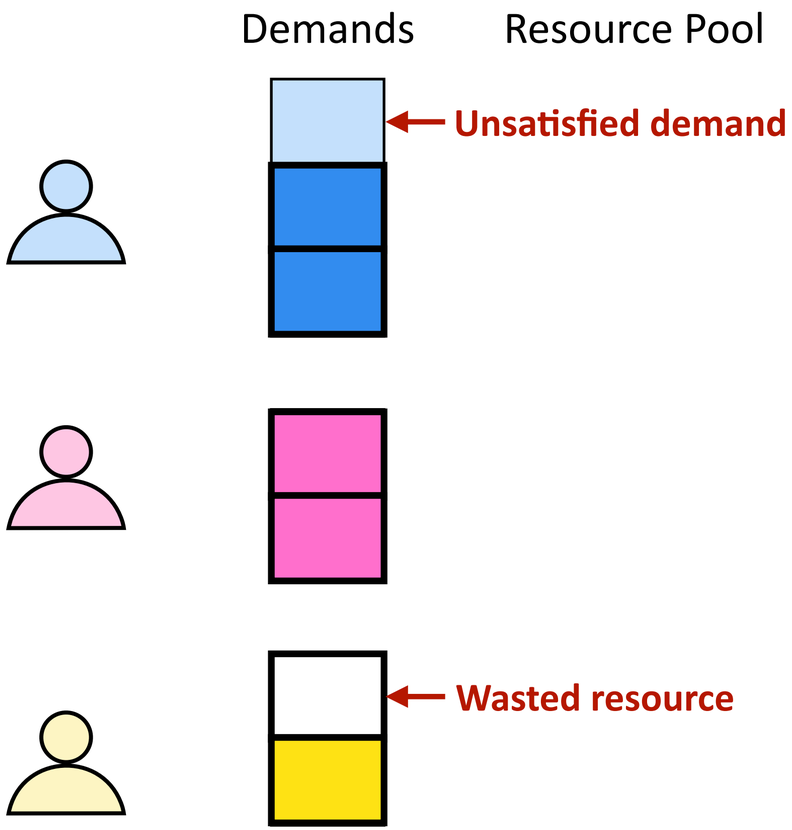

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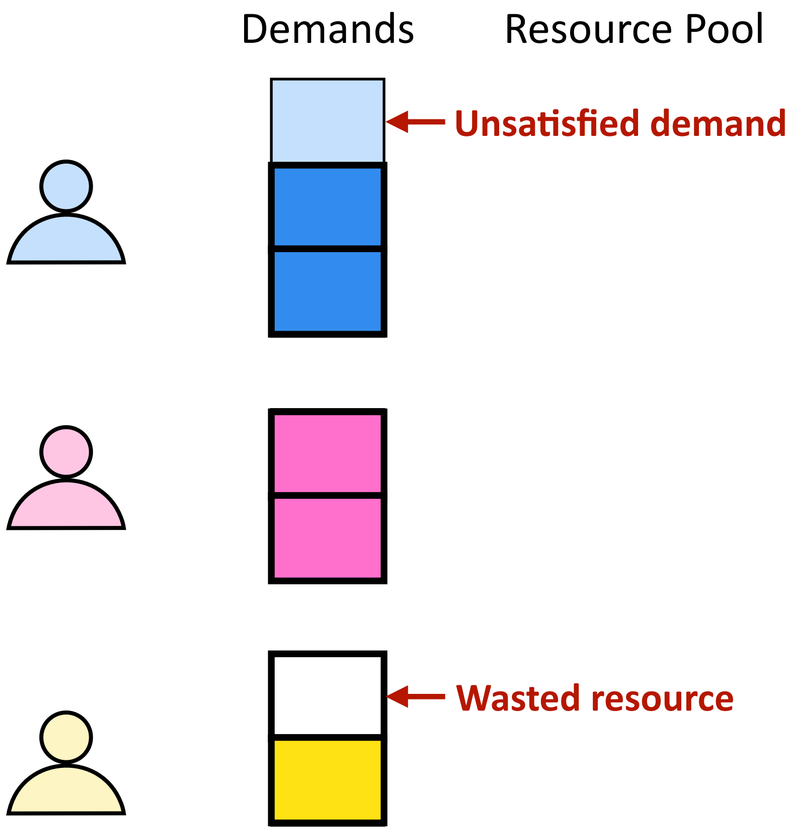

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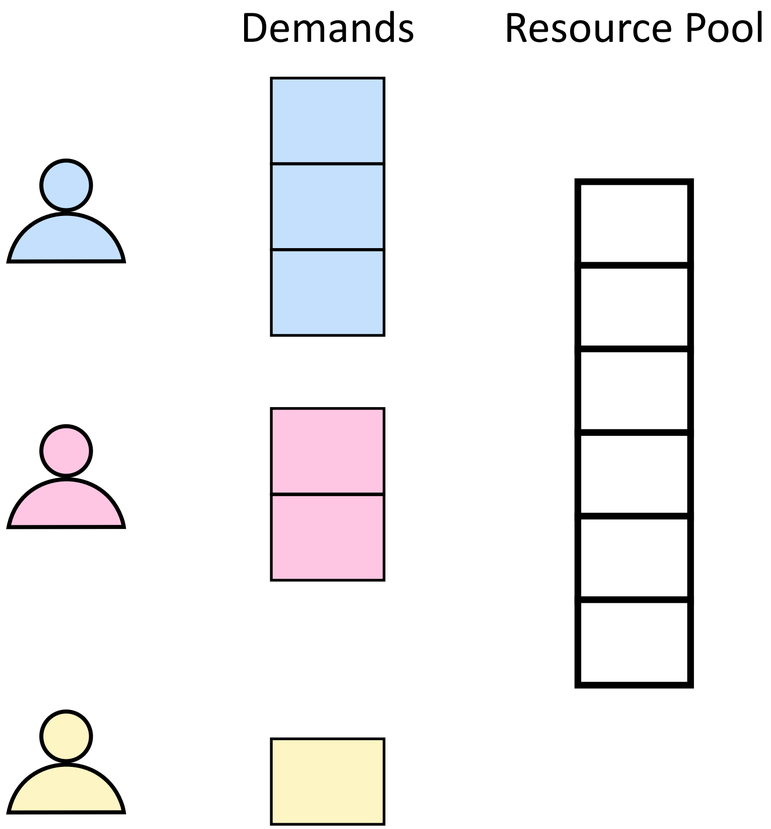
Strict partitioning does not guarantee Pareto efficiency

Max-min Fairness alleviates the limitations of strict partitioning (under an assumption)

Maximizing minimum allocation across users while ensuring allocation ≤ demand for each user



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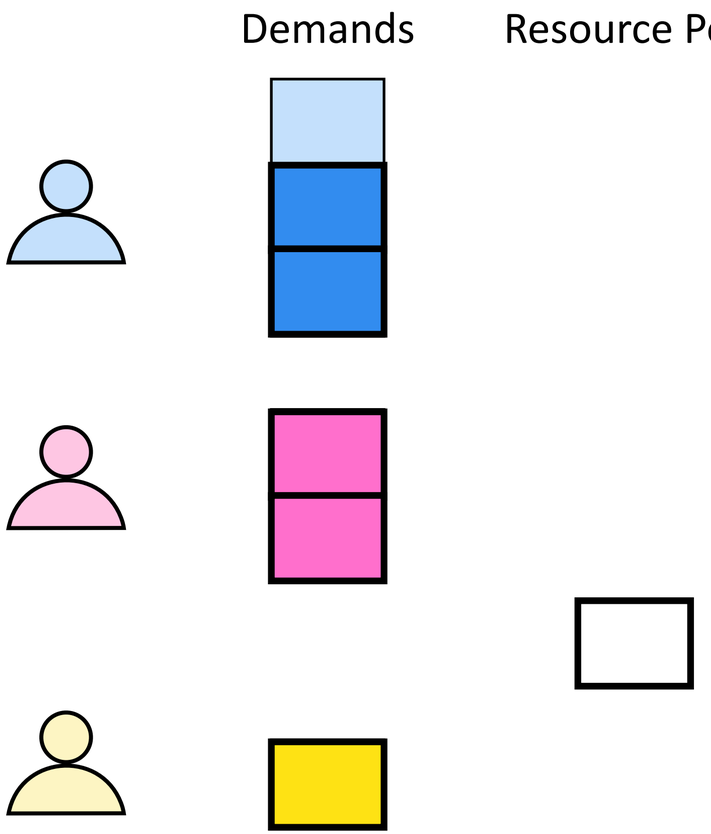

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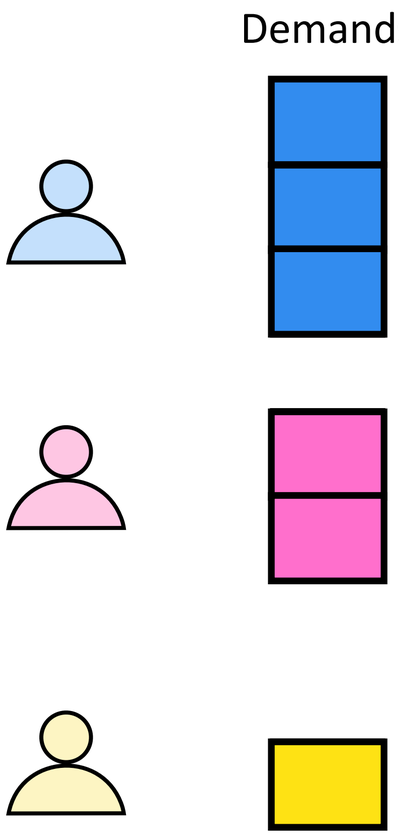

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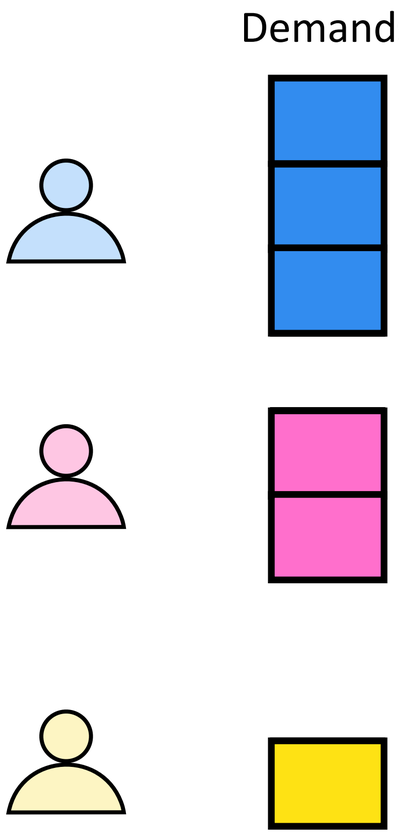

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Classical result: Max-min fairness satisfies Pareto efficiency, strategy-proofness and fairness

Underlying assumption: User demands are static

Dynamic demands are the norm in real world deployments

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Shared Analytics Clusters

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In-memory Key-Value Caches

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Analysis of real world workloads

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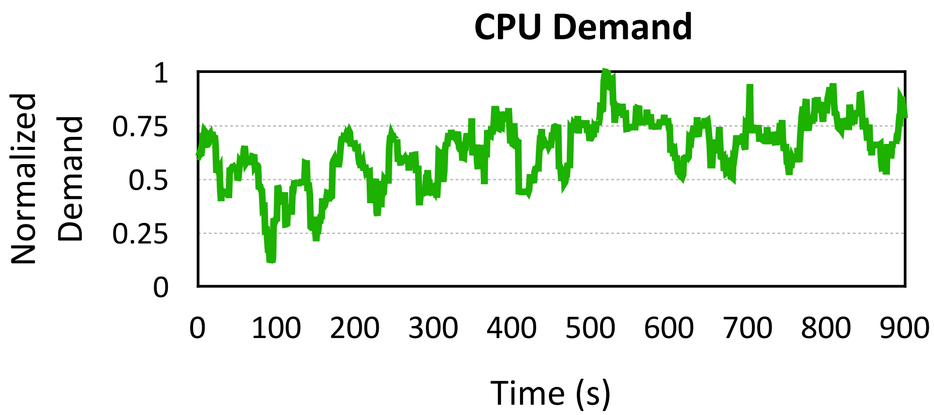

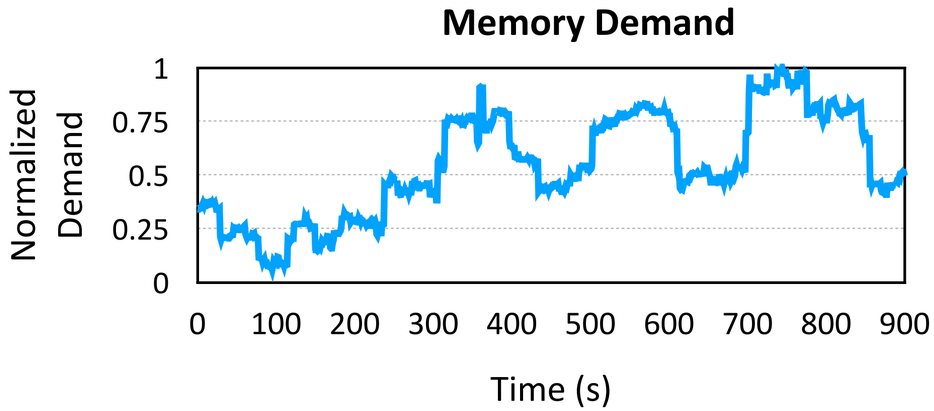

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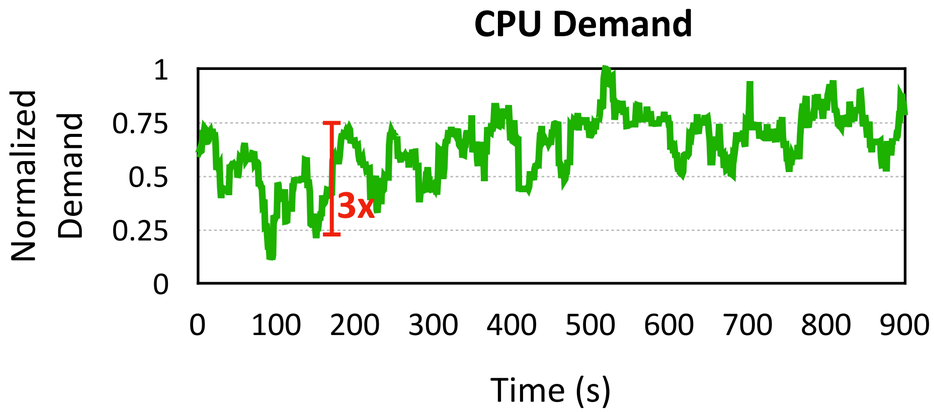

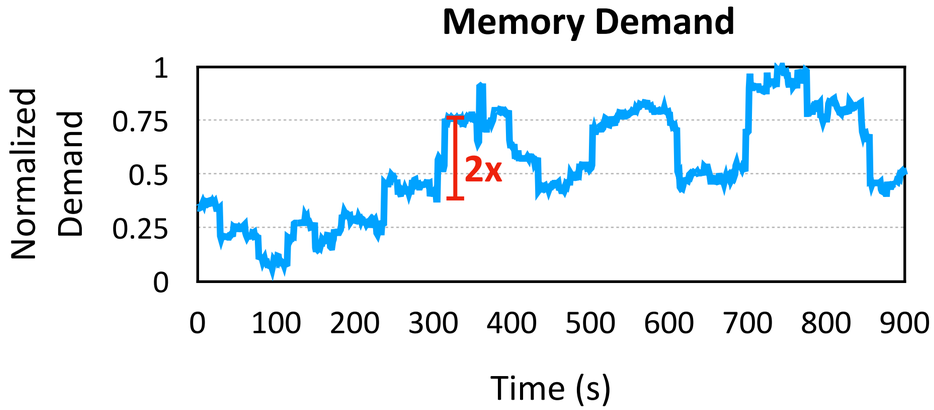

2-3x variation in demands over 10s of seconds

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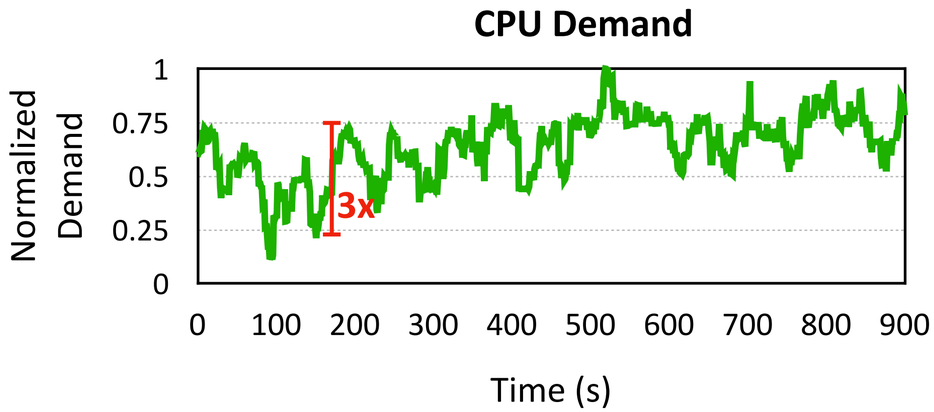

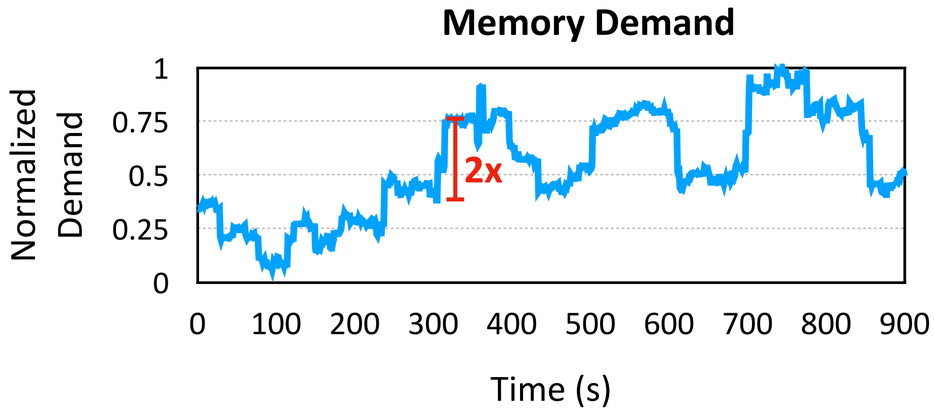

2-3x variation in demands over 10s of seconds

40-70% of users have standard deviation of demands > 1/2 mean

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More than 5x variation in demands within an hour

[Twitter, Yang et al., OSDI'20]

Inter-datacenter Network Links

35% variation in demands over 5 minute intervals

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Significant variation in user demands over time in real workloads

Max-min fairness under dynamic demands: looses one or more of its properties

Pareto efficiency

Strategy-proofness

Fairness

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Max-min fairness
based on demands at t=0

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Pareto efficiency ✗

Strategy-proofness ✗

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(Explained in paper)

Max-min fairness under dynamic demands: looses one or more of its properties

	Max-min fairness based on demands at t=0	Max-min fairness applied periodically
Pareto efficiency	✗	
Strategy-proofness	✗	
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(Explained in paper)

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Running Example

Demands

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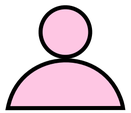

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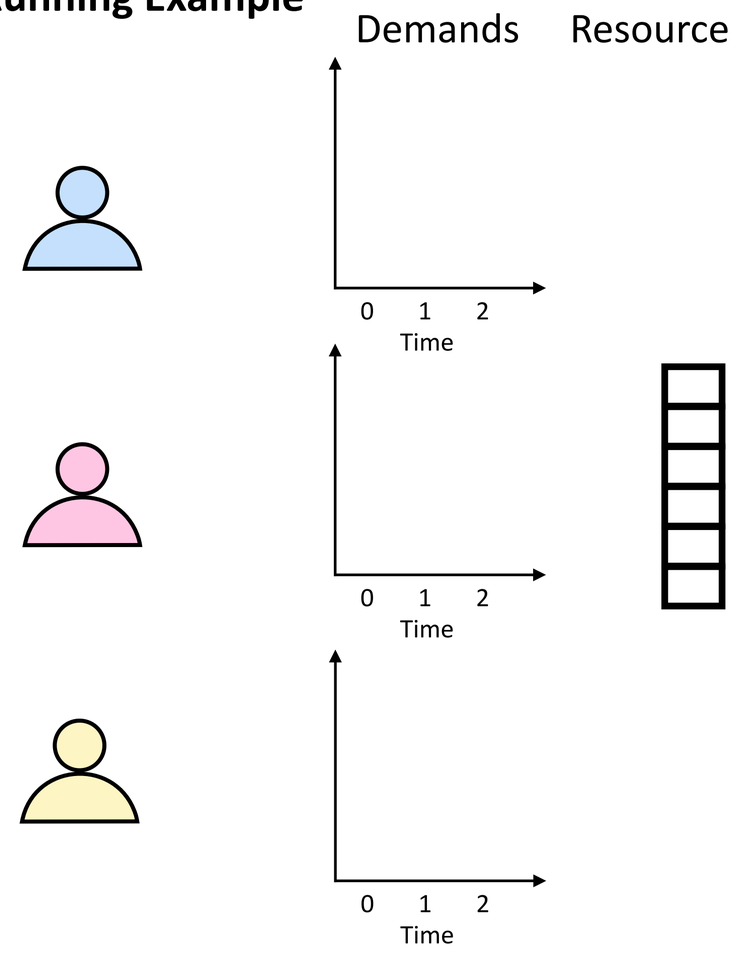

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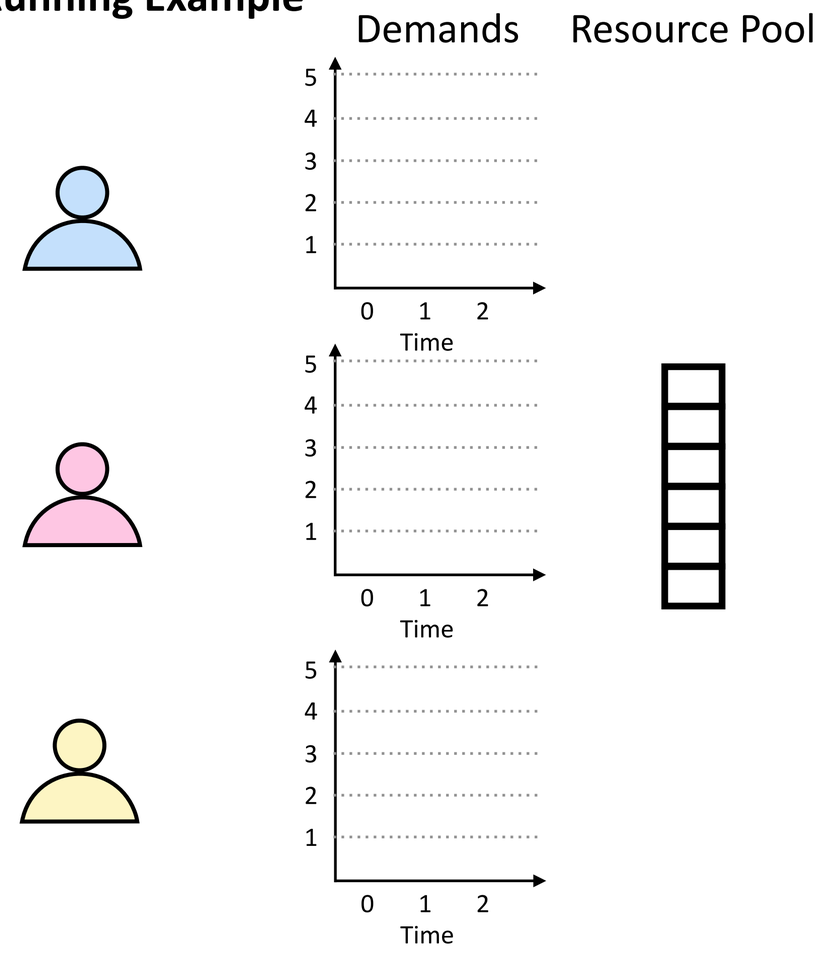

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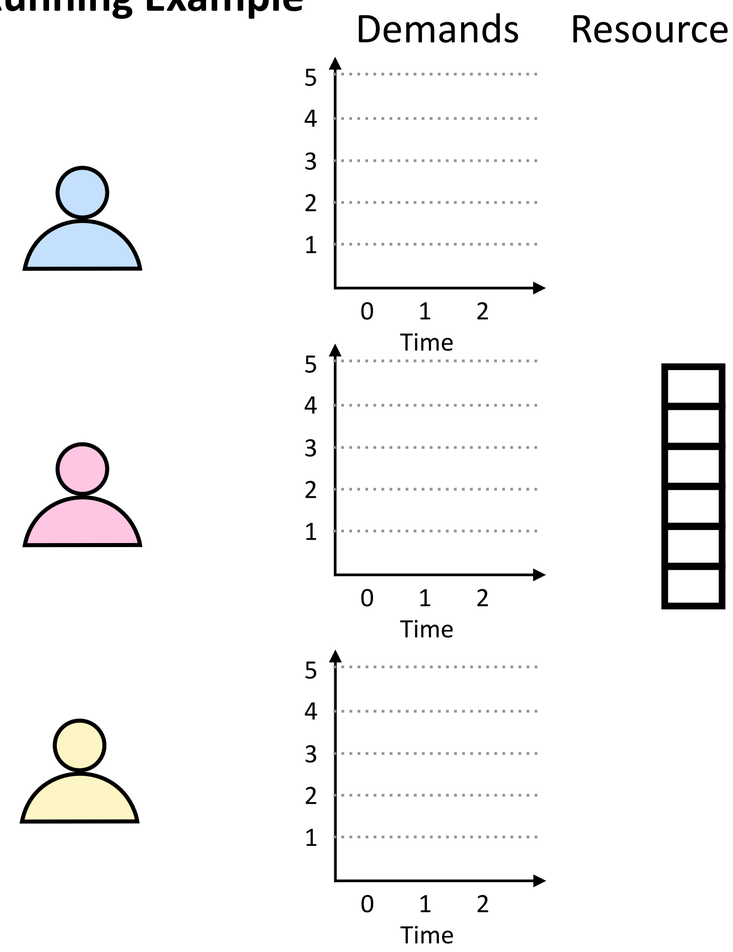

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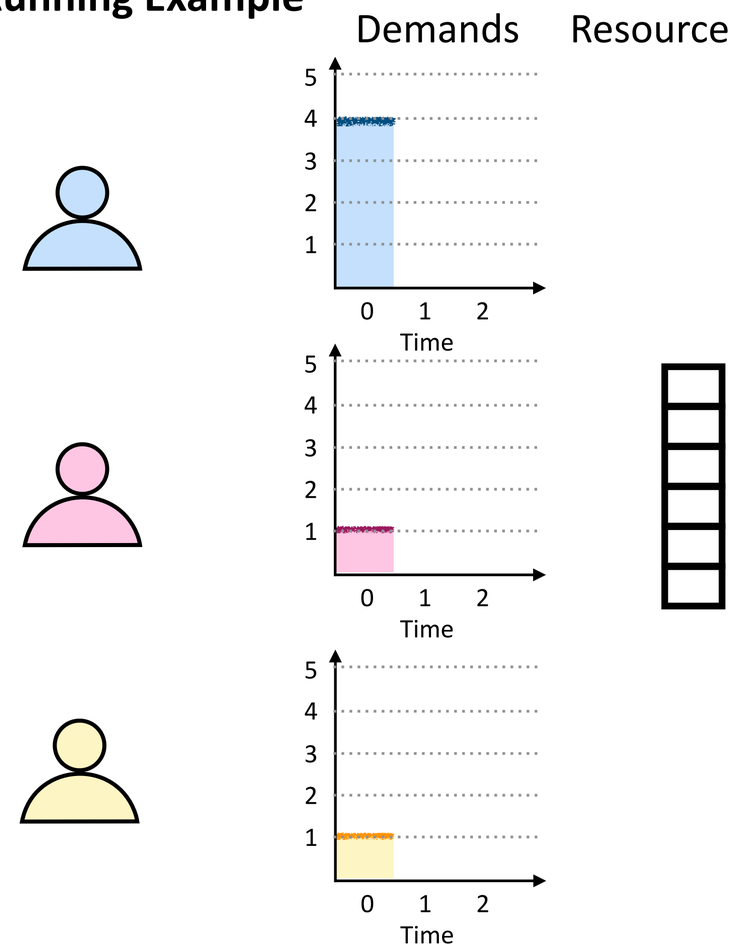

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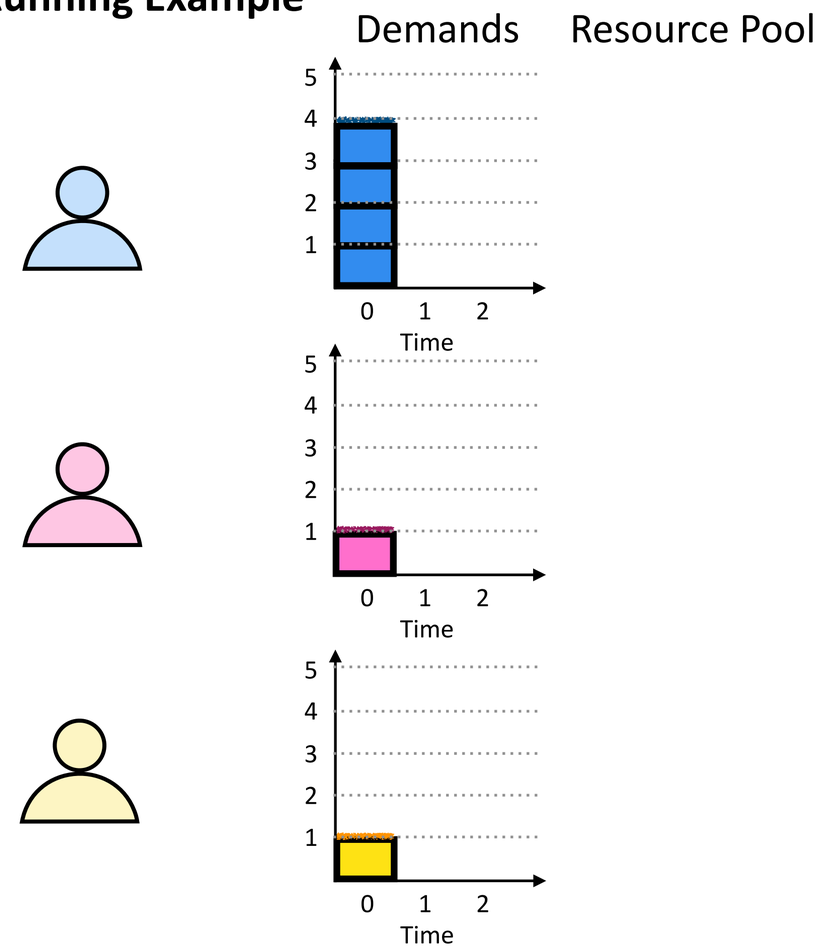

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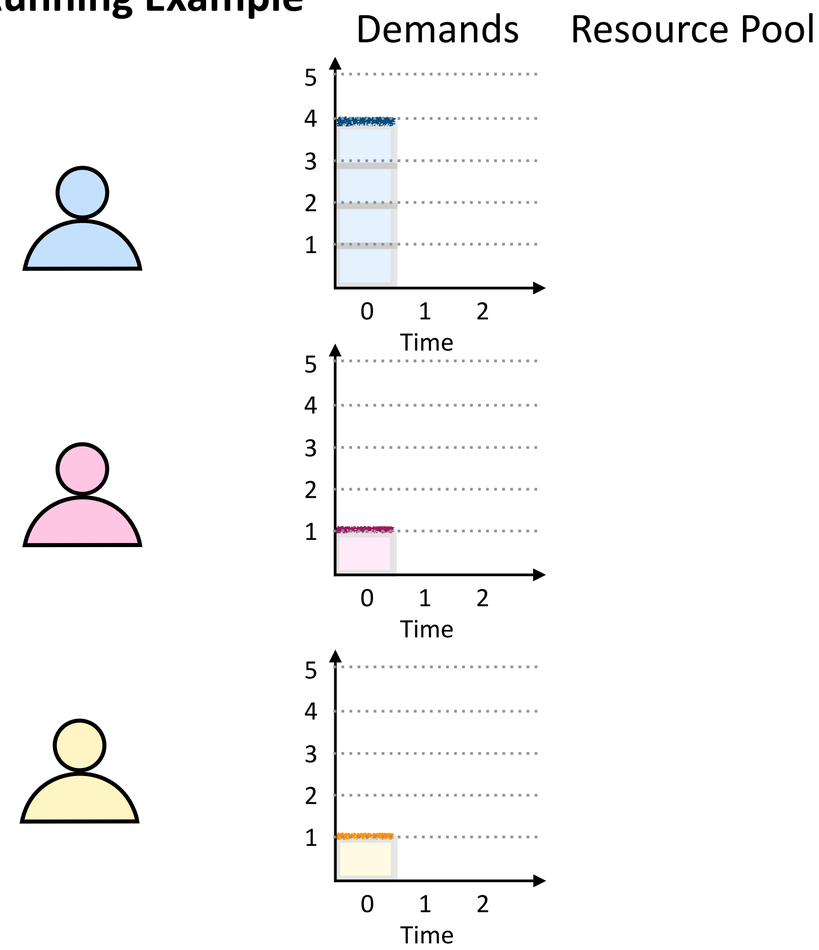

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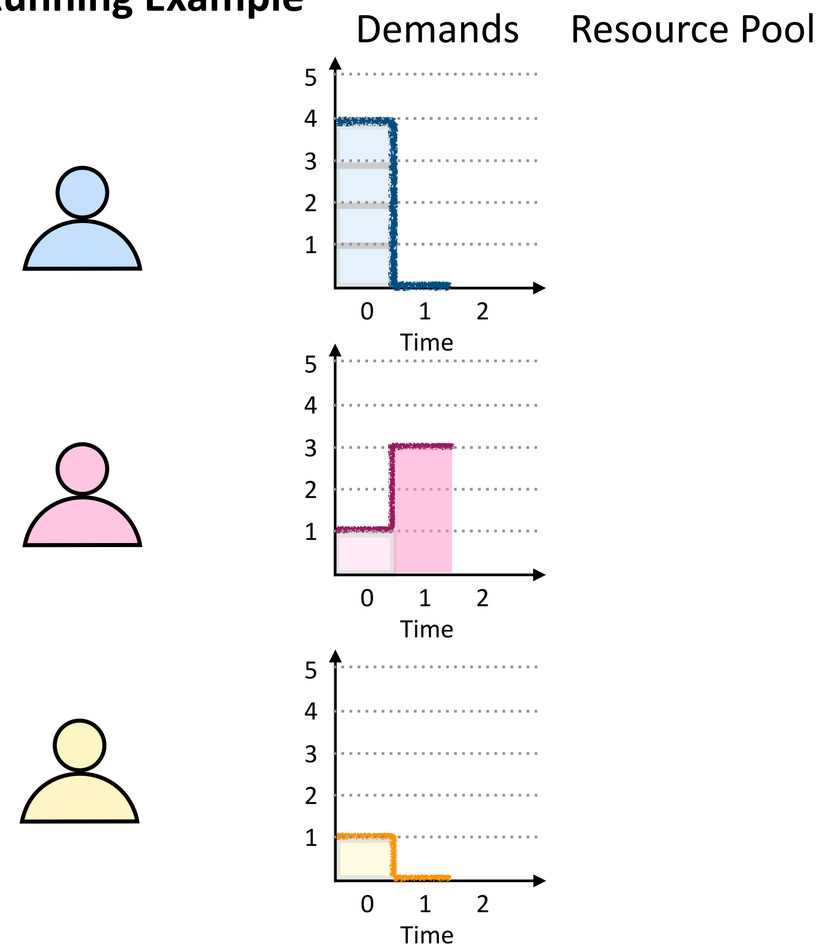

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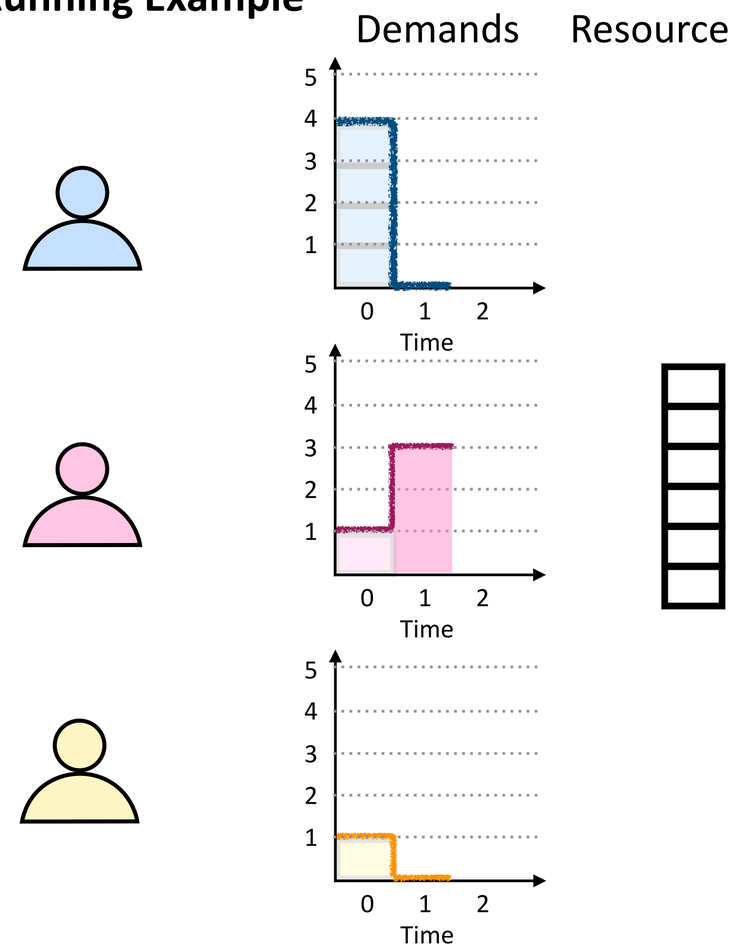

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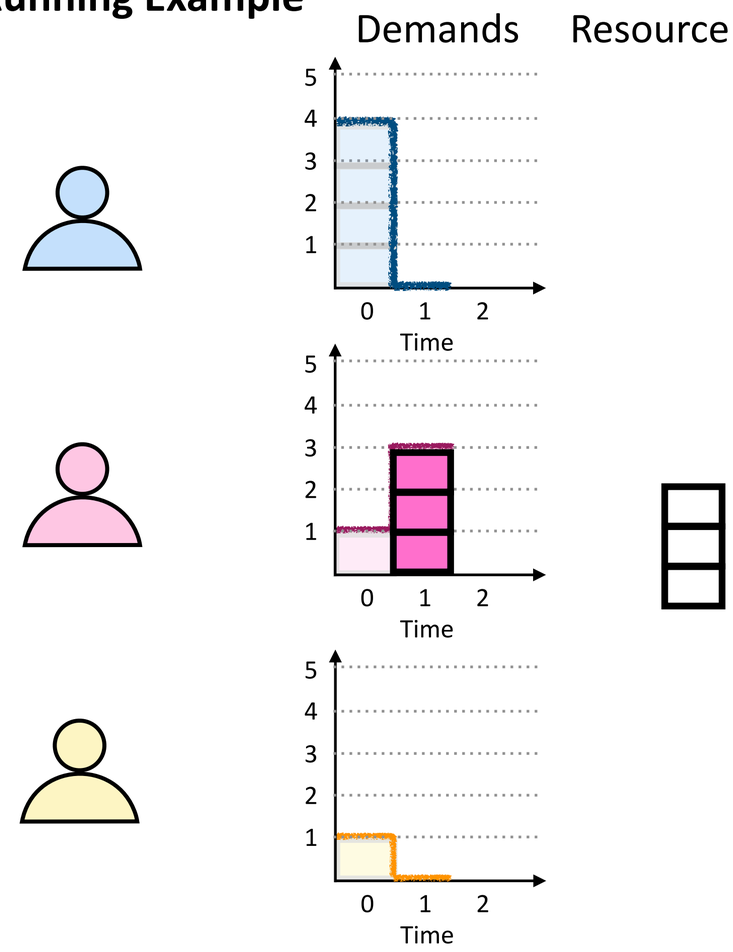

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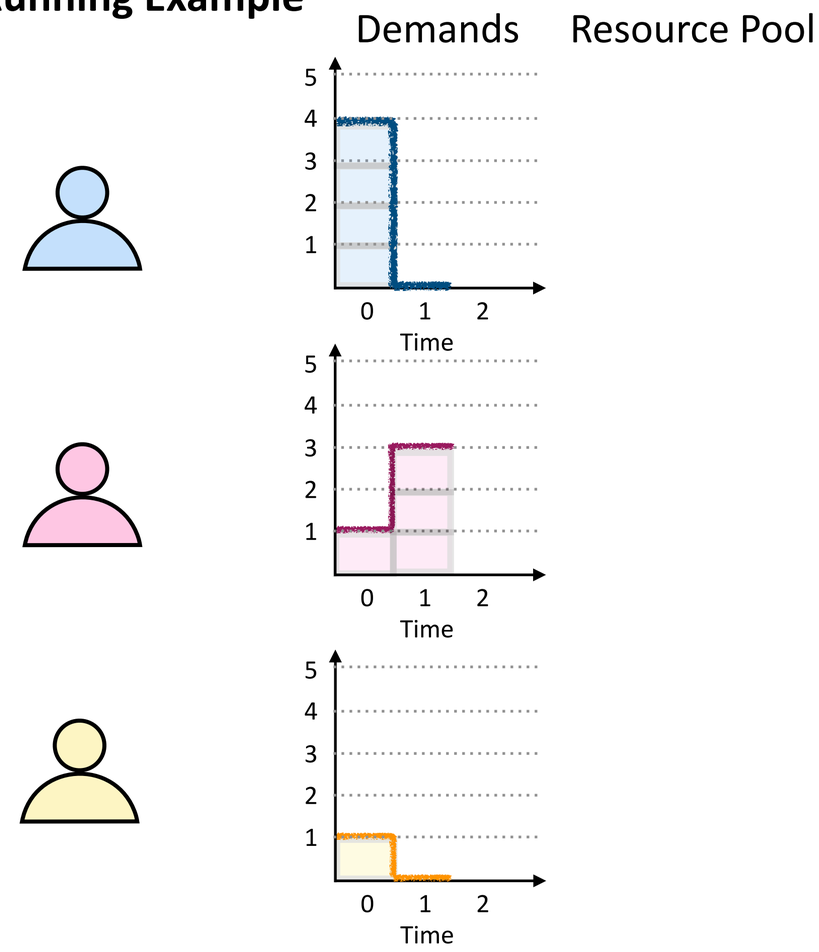

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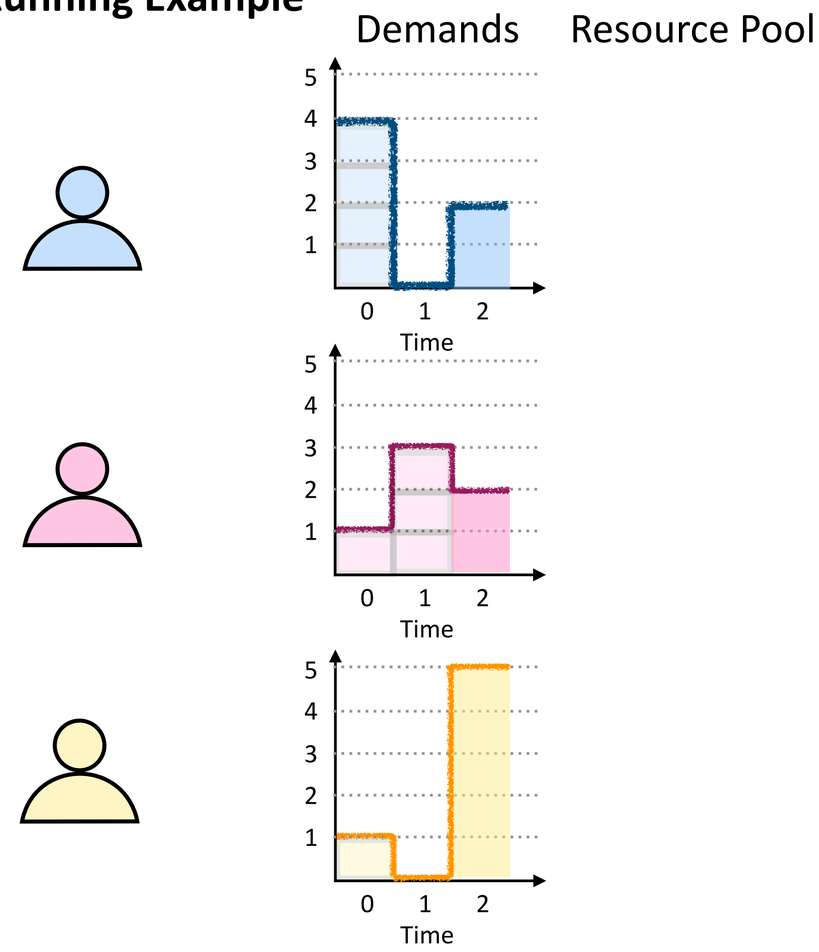

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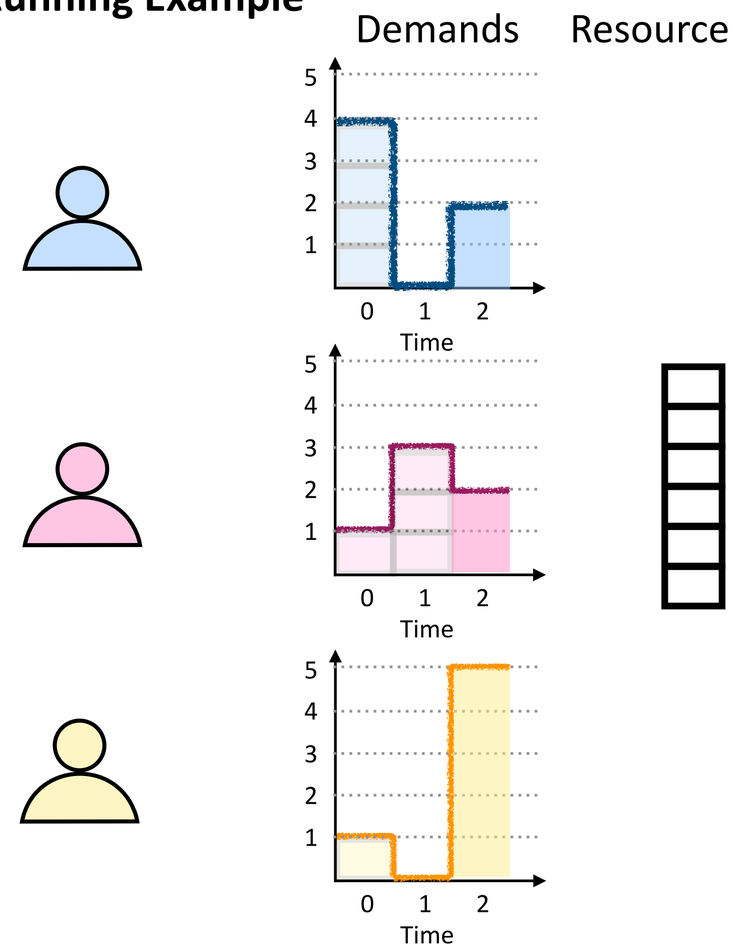

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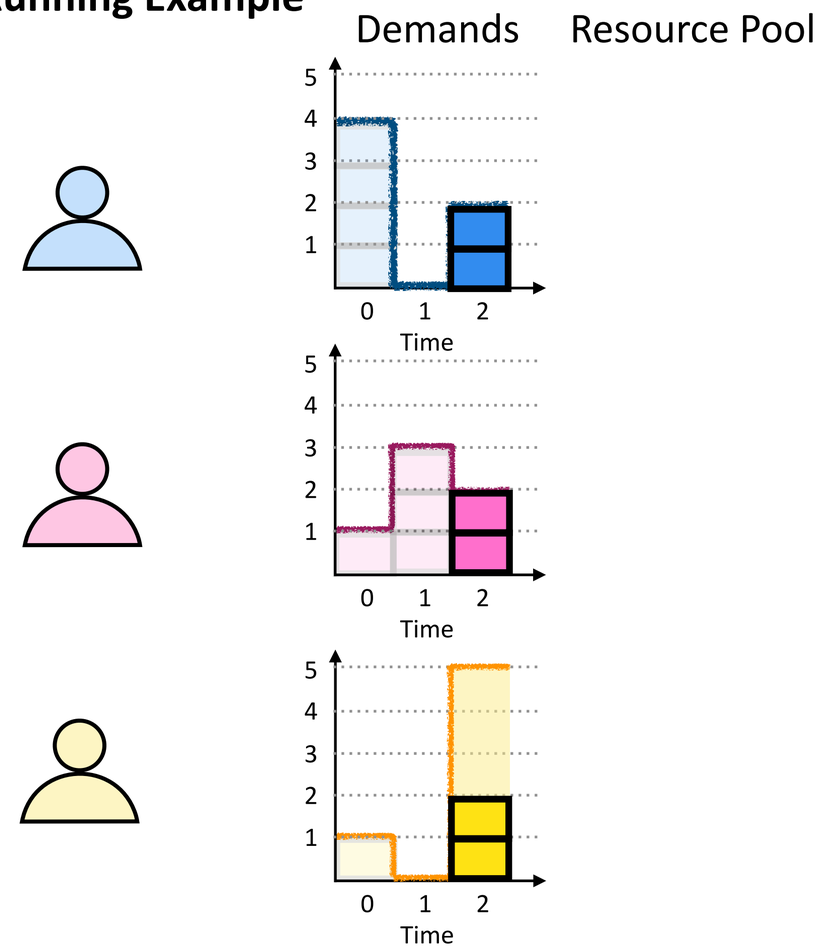

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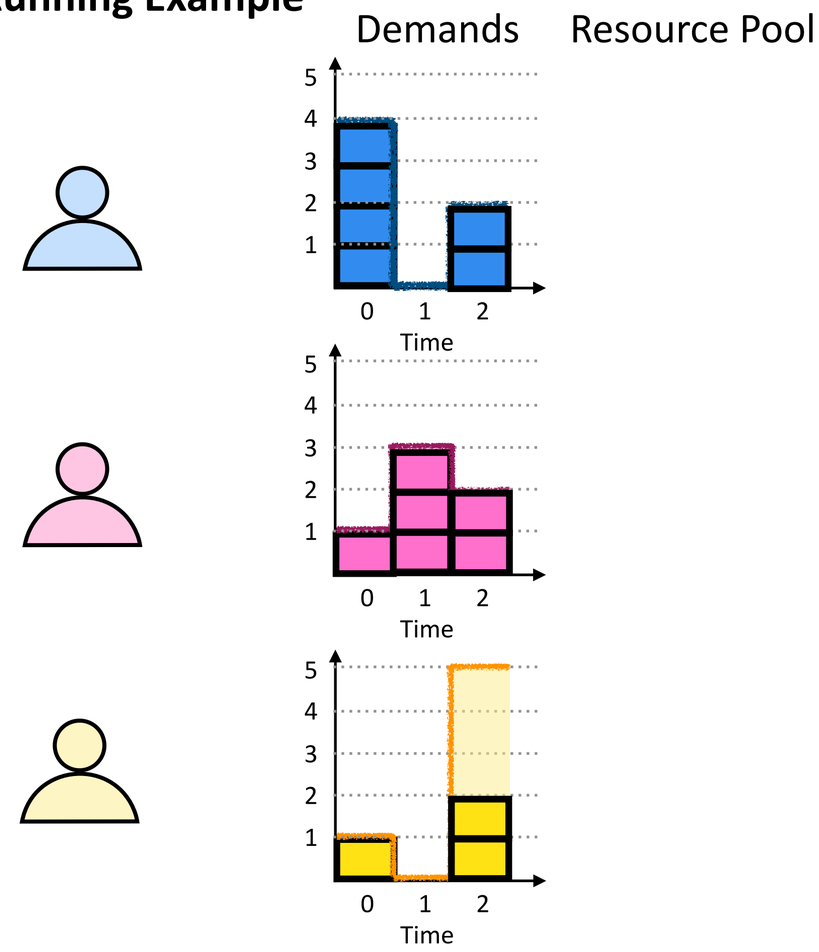

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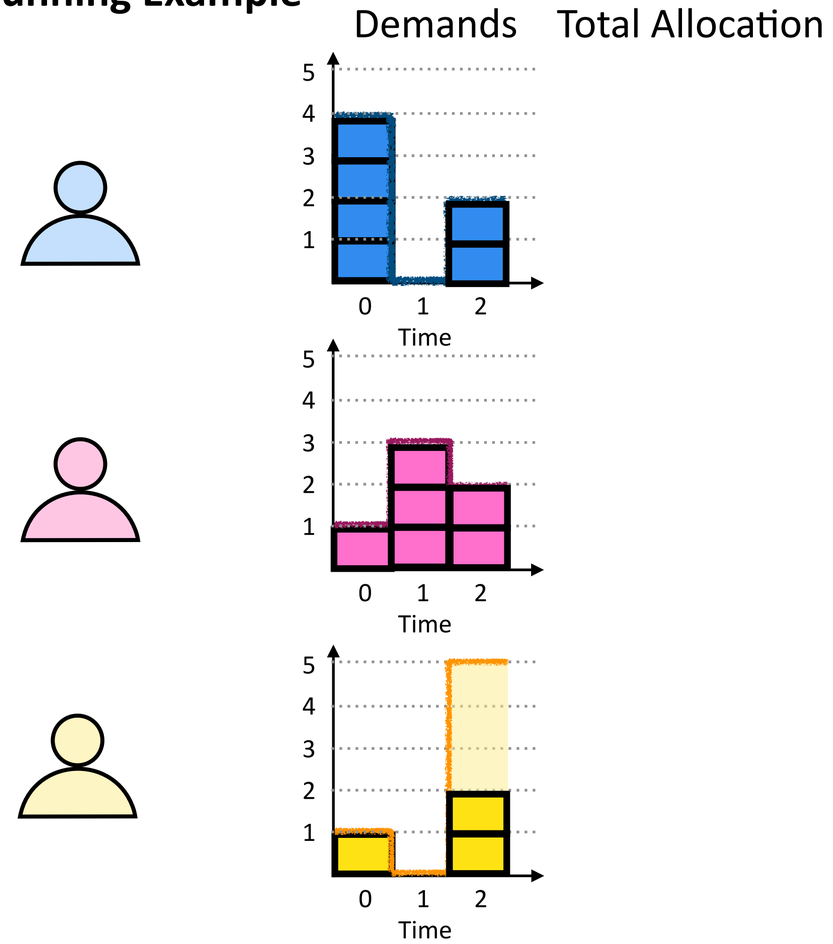

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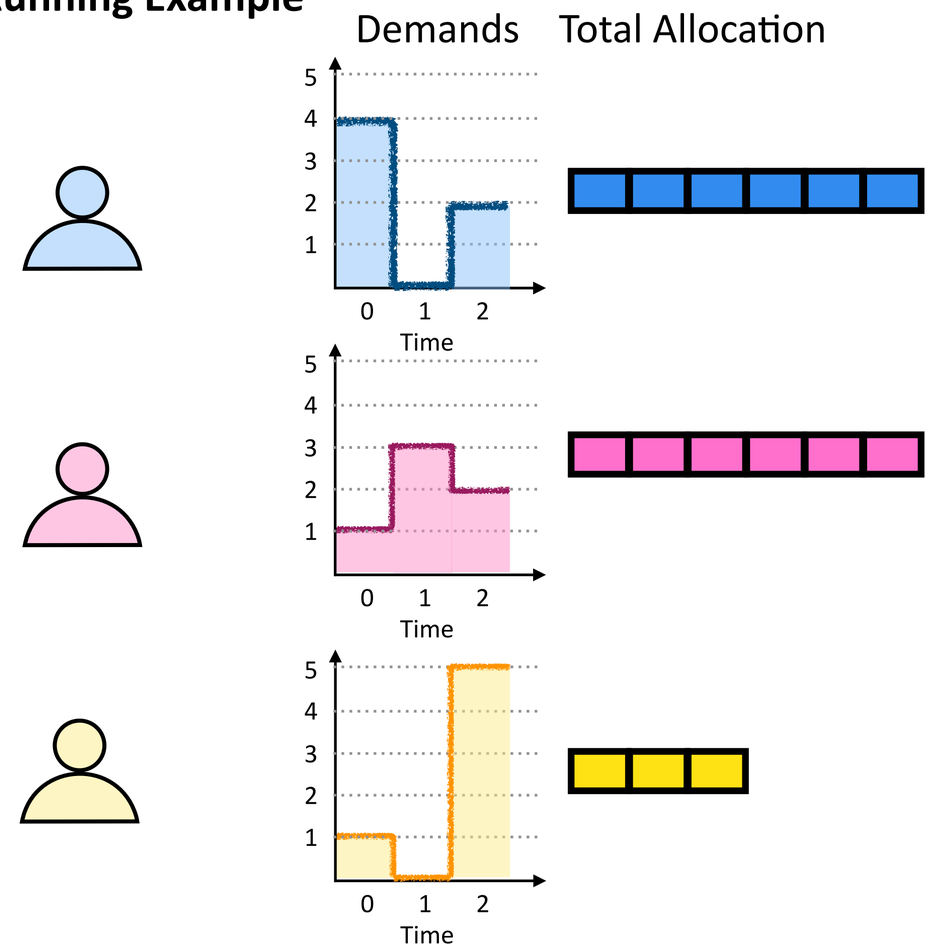

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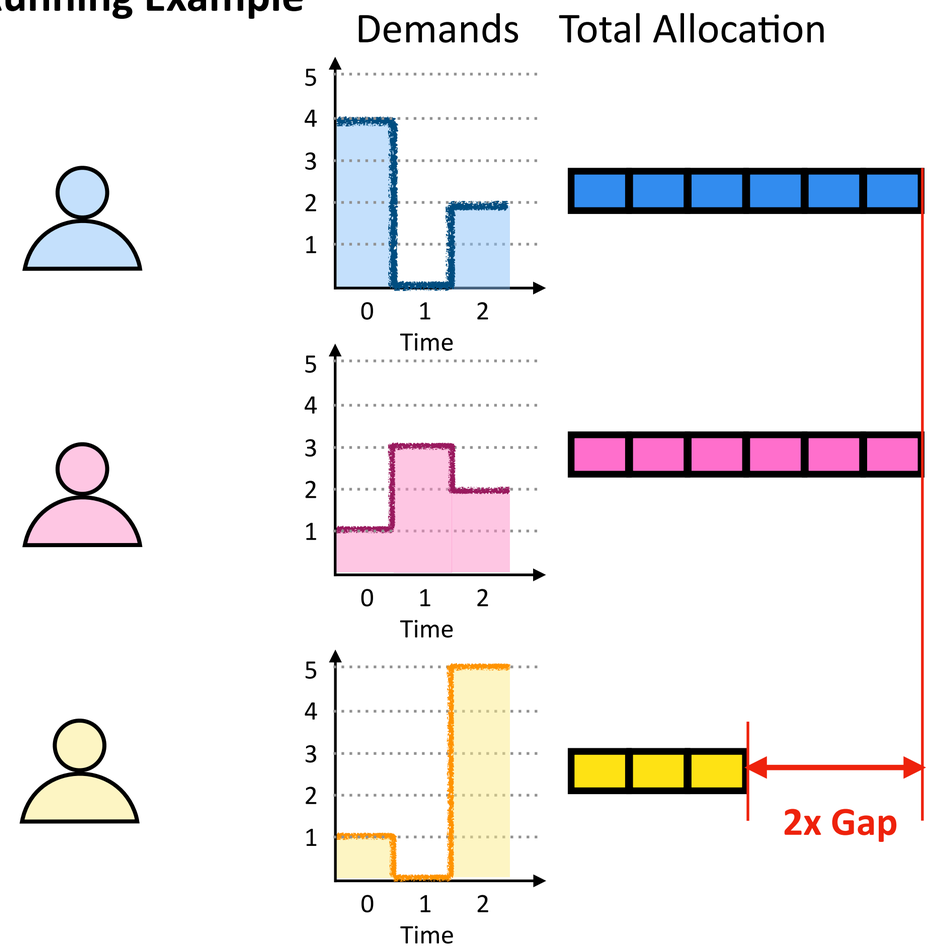
Max-min fairness under dynamic demands: looses one or more of its properties

Running Example



Max-min fairness based on demands at t=0

Max-min fairness applied periodically

Pareto efficiency ✗

Strategy-proofness ✗

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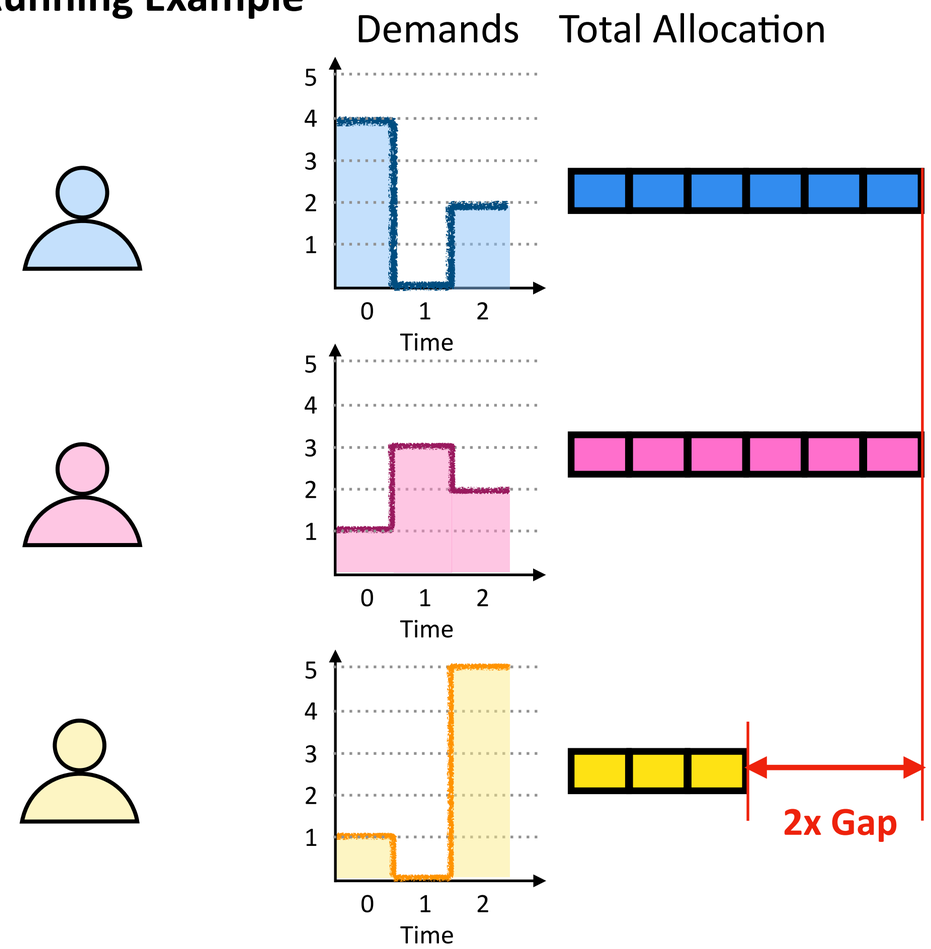

Pareto efficiency ✗

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For n users, a user can get Ω(n) more allocation than others

Max-min fairness under dynamic demands: looses one or more of its properties

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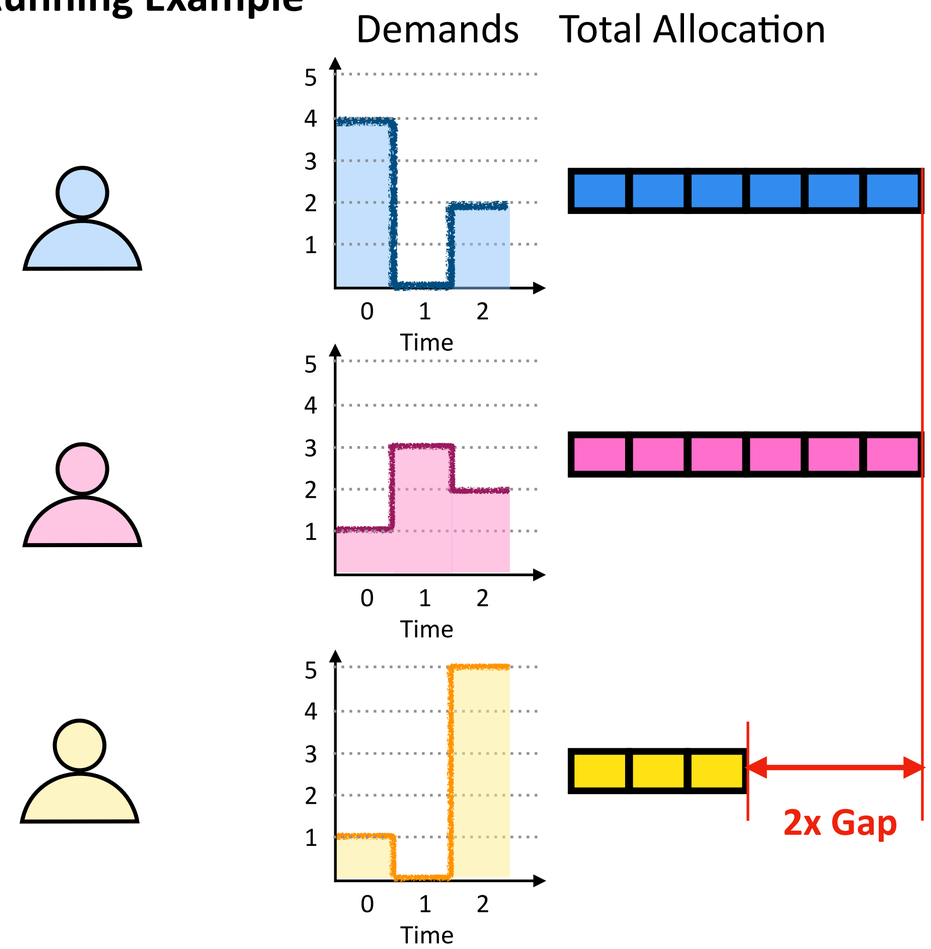

	Max-min fairness based on demands at t=0	Max-min fairness applied periodically
Pareto efficiency	✗	✓
Strategy-proofness	✗	✓
Fairness	✓	✗

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Running Example

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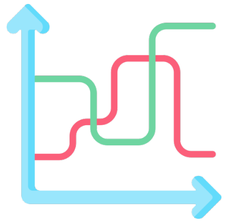
Strategy-proofness	✗	✓
Fairness		✗

For n users, a user can get Ω(n) more allocation than others

Need to revisit classical resource allocation problem under dynamic demands

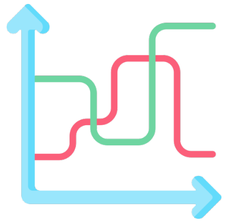
Karma: Revisiting the classical resource allocation problem under dynamic demands

Karma: Revisiting the classical resource allocation problem under dynamic demands



New resource allocation algorithm for dynamic demands

Karma: Revisiting the classical resource allocation problem under dynamic demands



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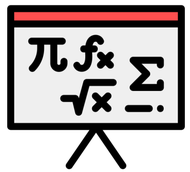

Theoretical guarantees

Pareto efficiency

Strategy-proofness

Fairness

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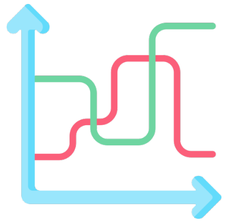

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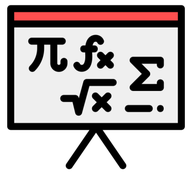

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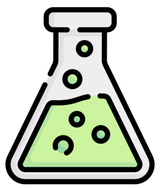
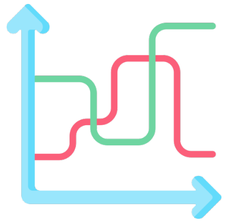


Prototype implementation and evaluation

Karma: Revisiting the classical resource allocation problem under dynamic demands



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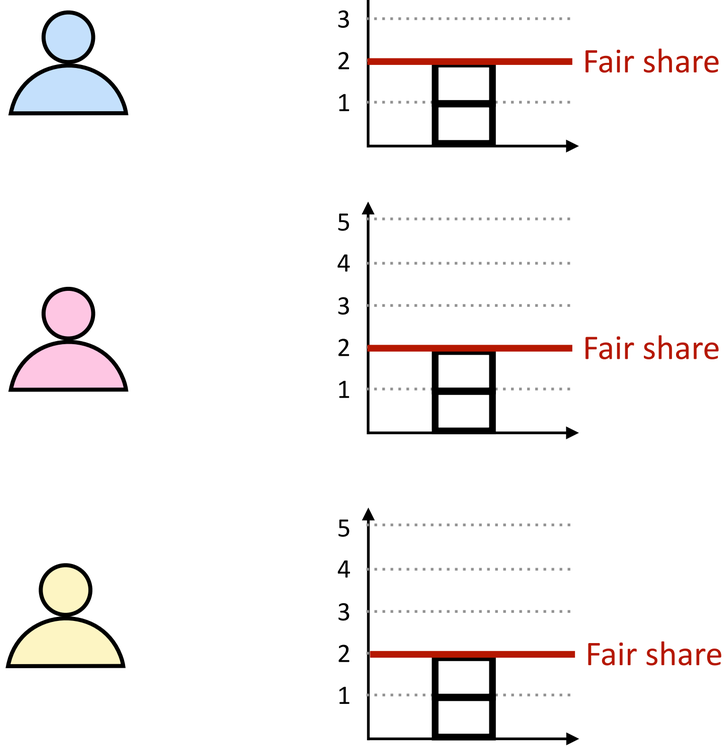
Prototype implementation and evaluation

Karma key idea #1: *donated slices* and *shared slices*



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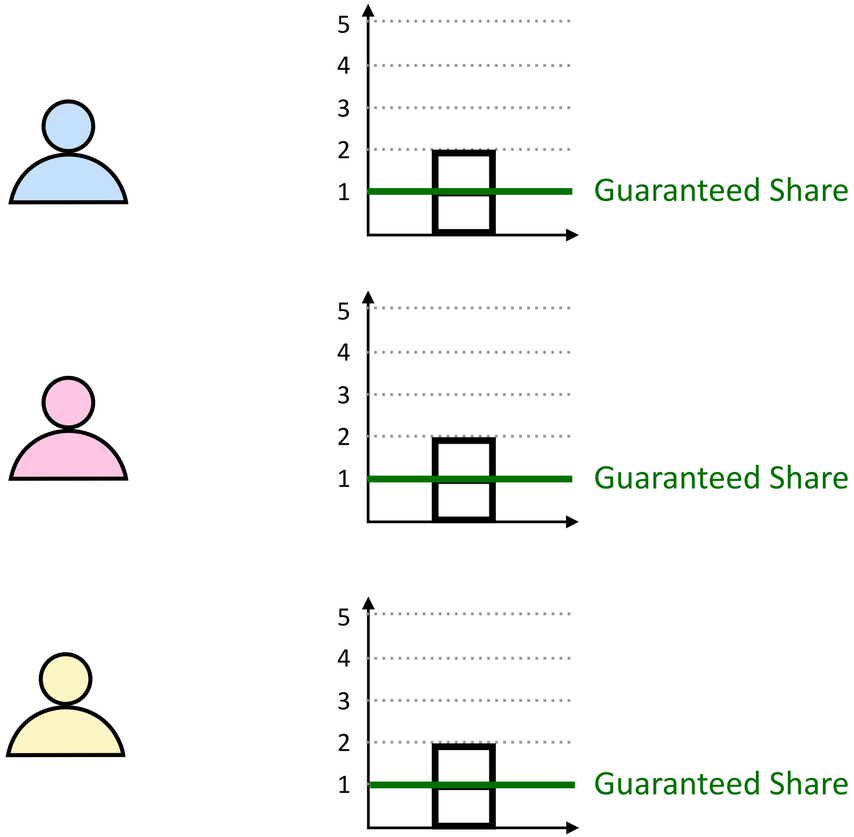

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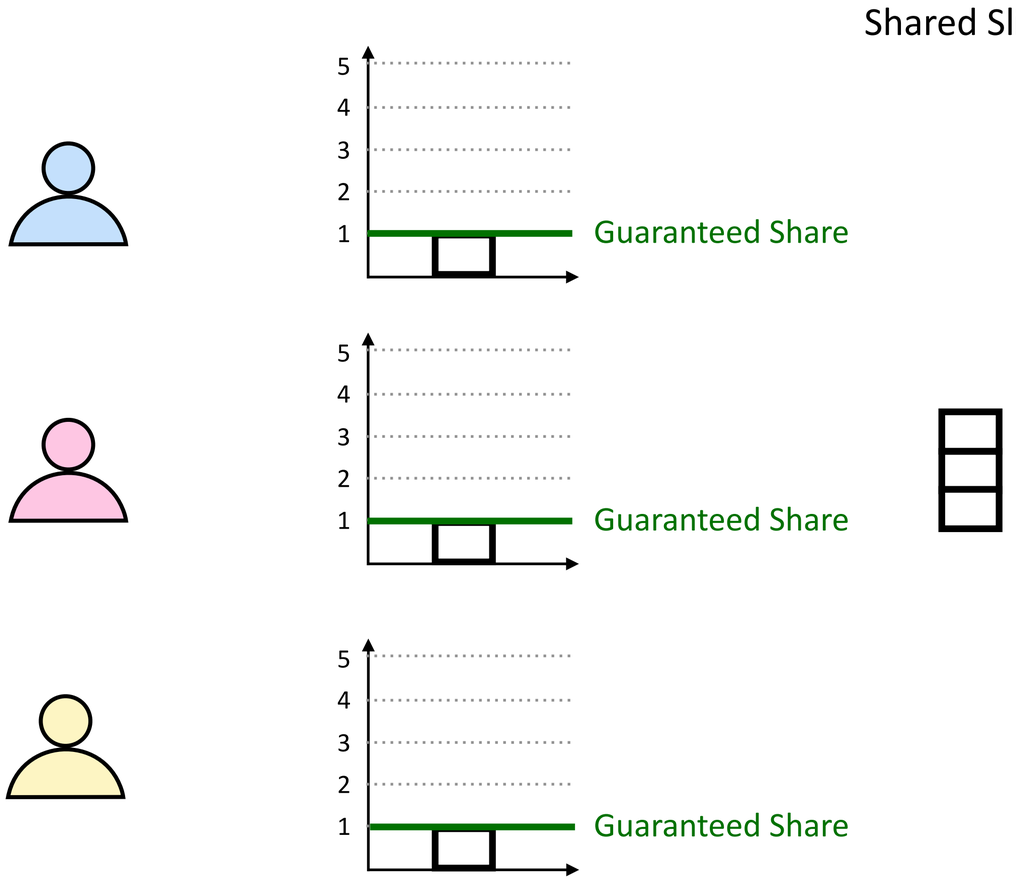

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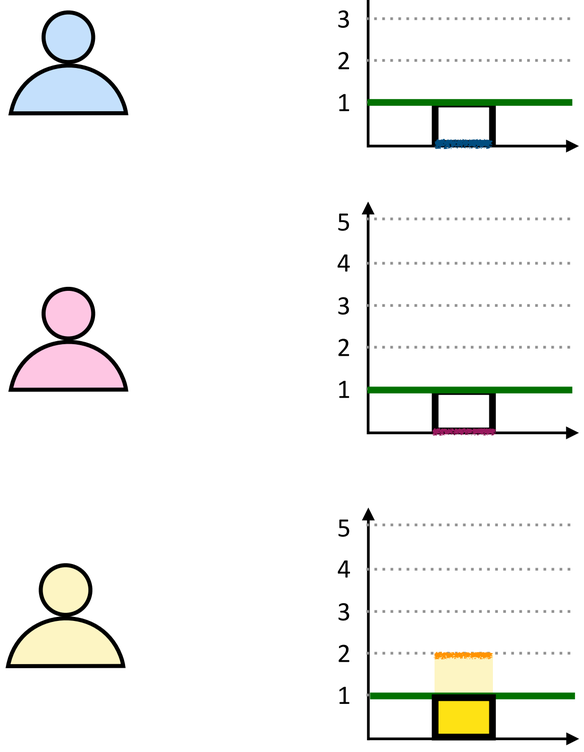

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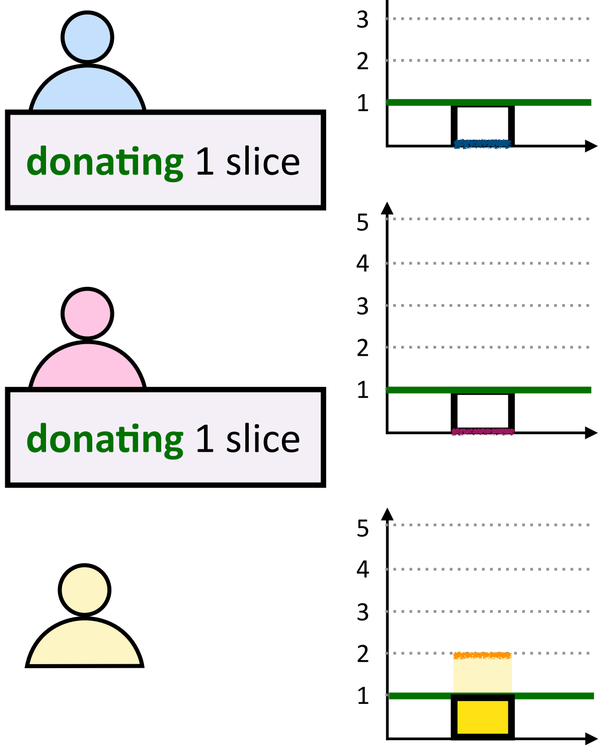
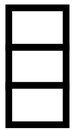


Shared Slices



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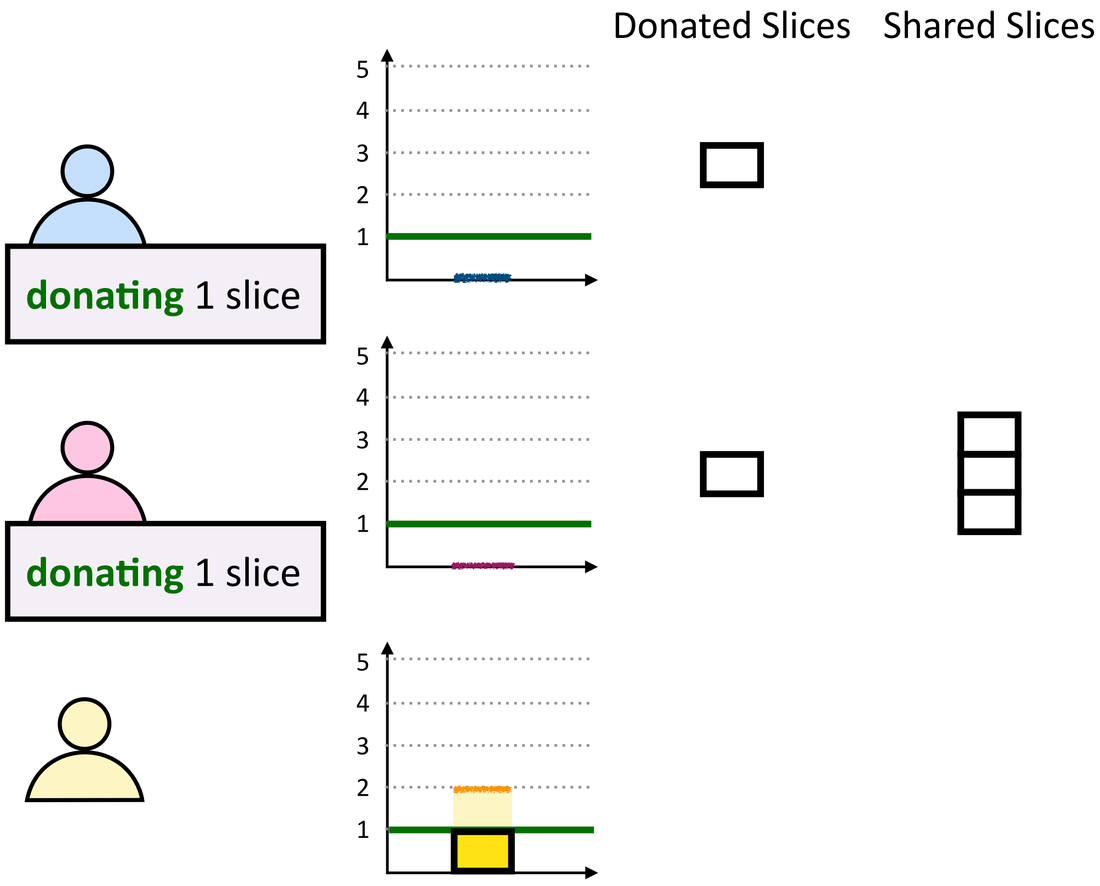

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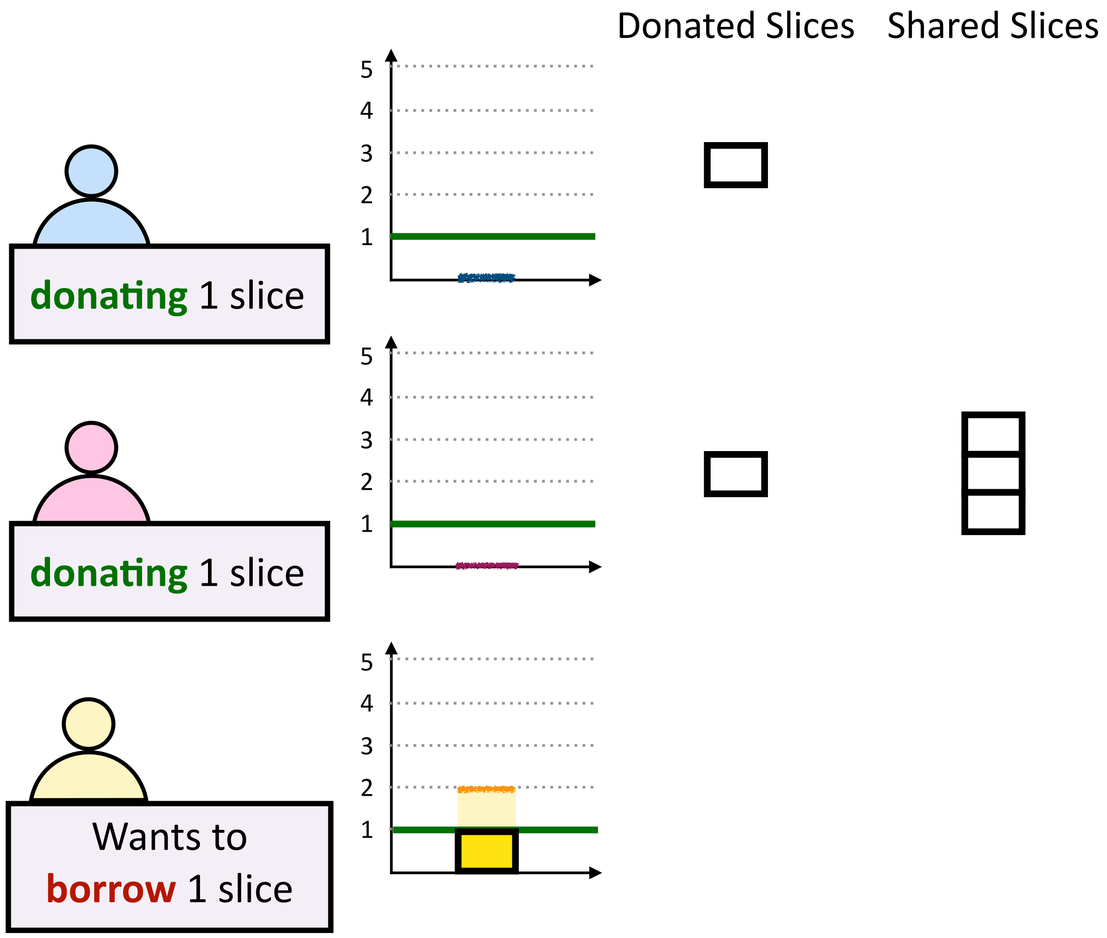
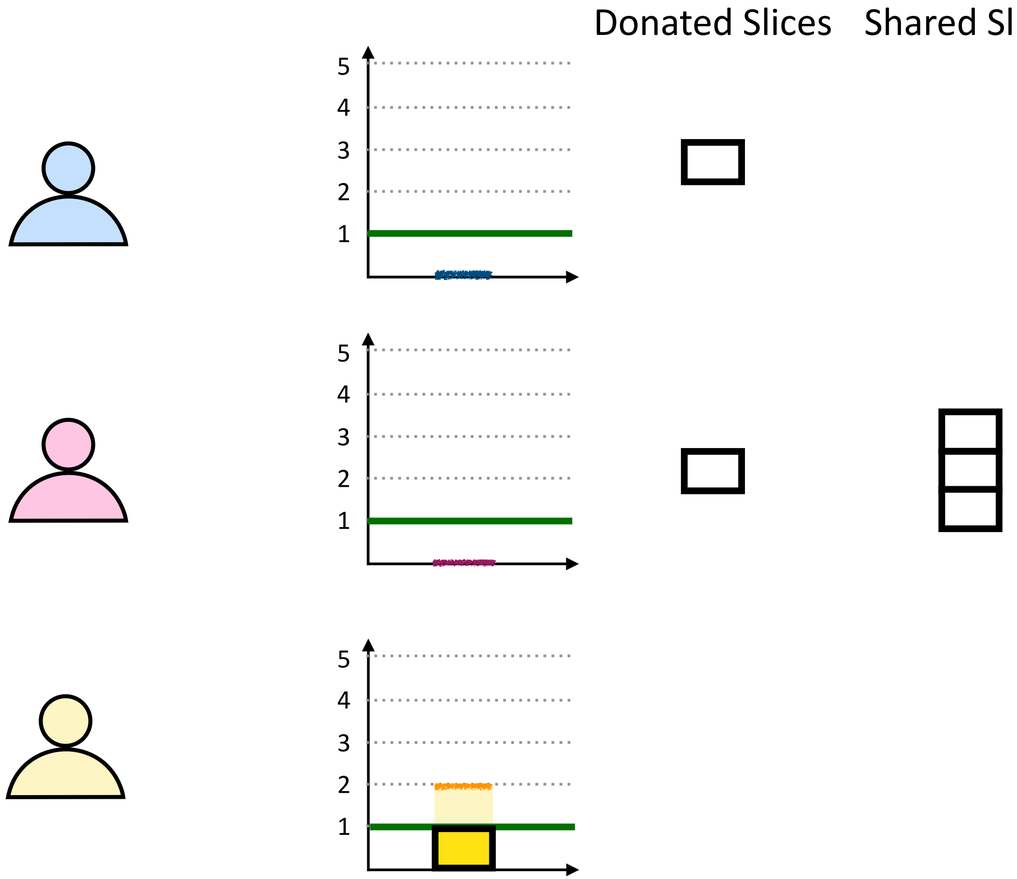


Karma key idea #2: “credits” for resource allocation



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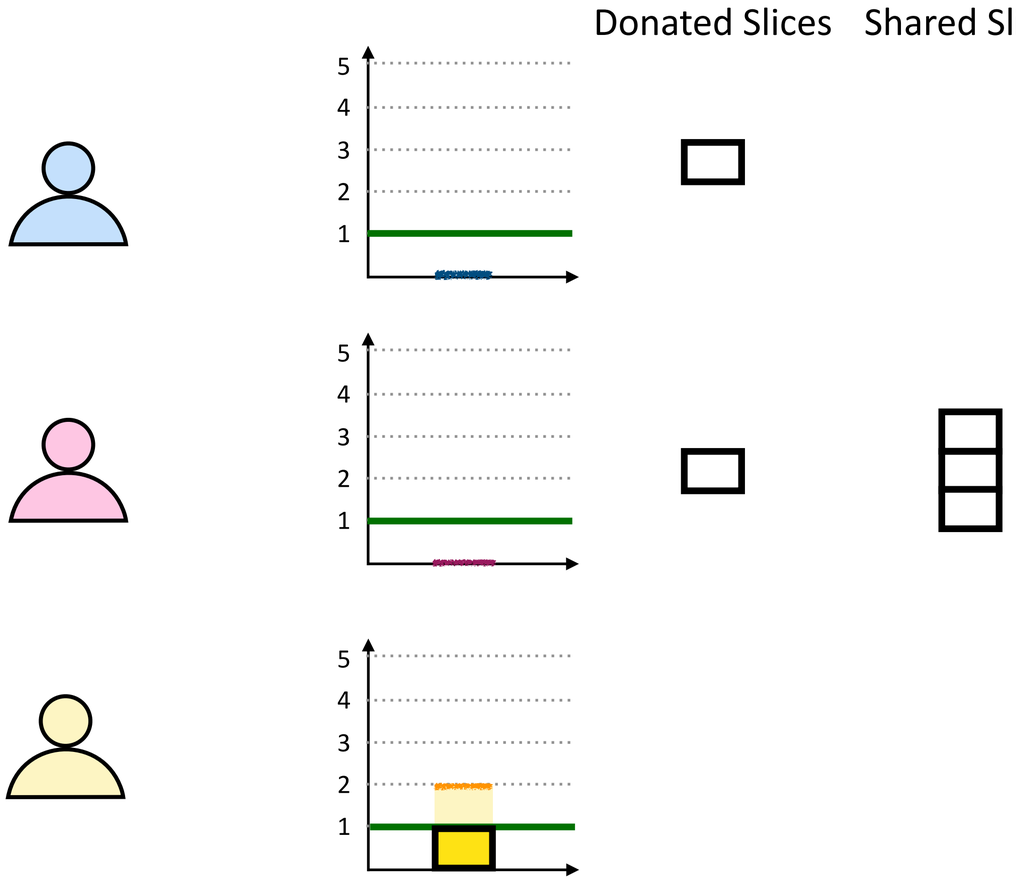

-1 credit for **borrowing** a slice

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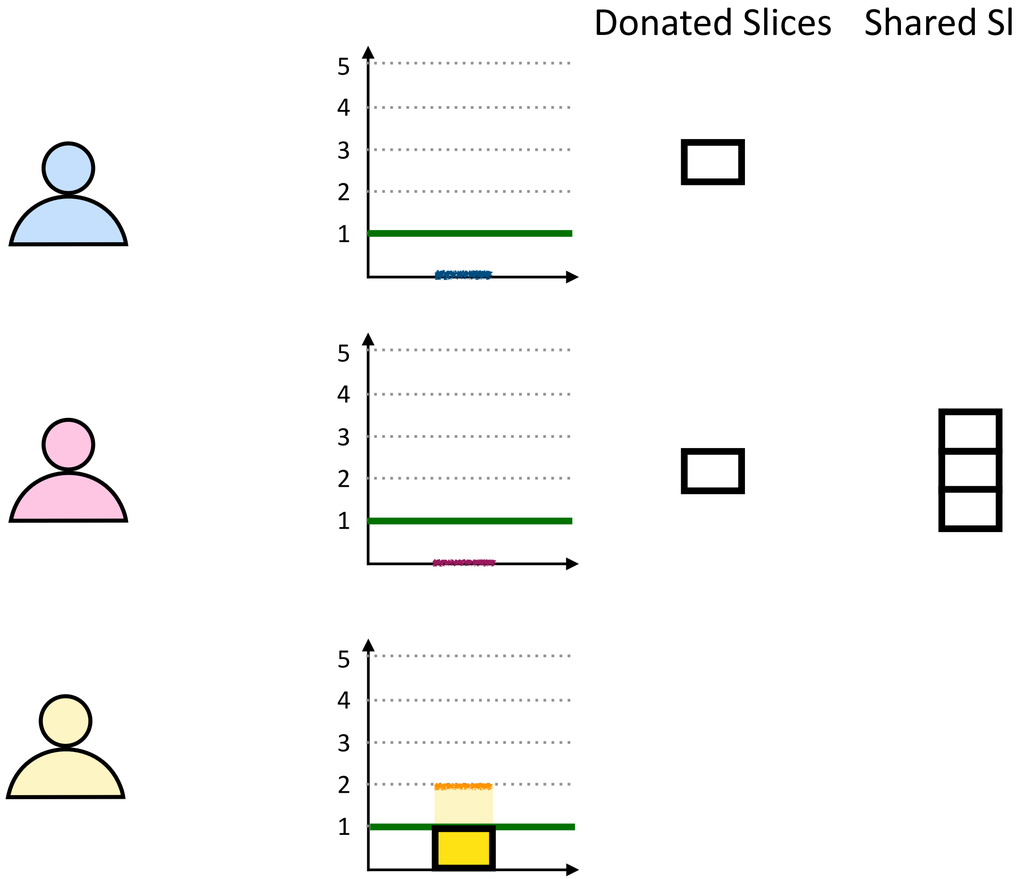

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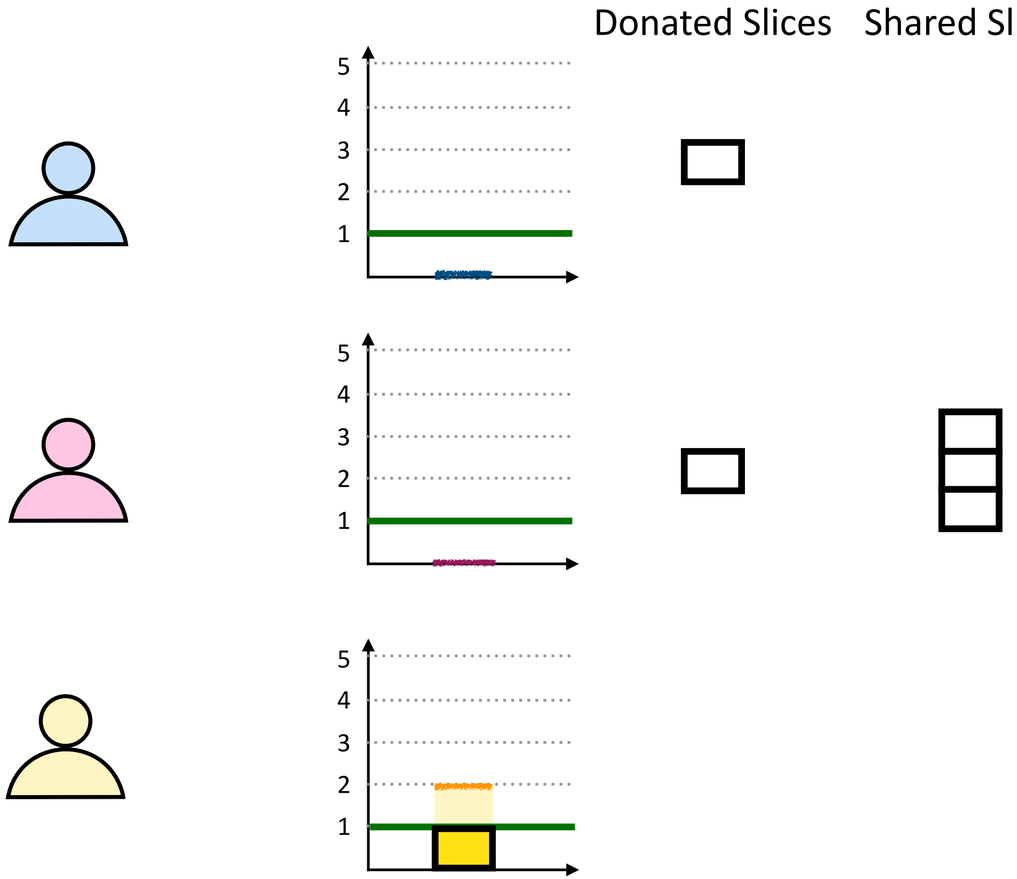

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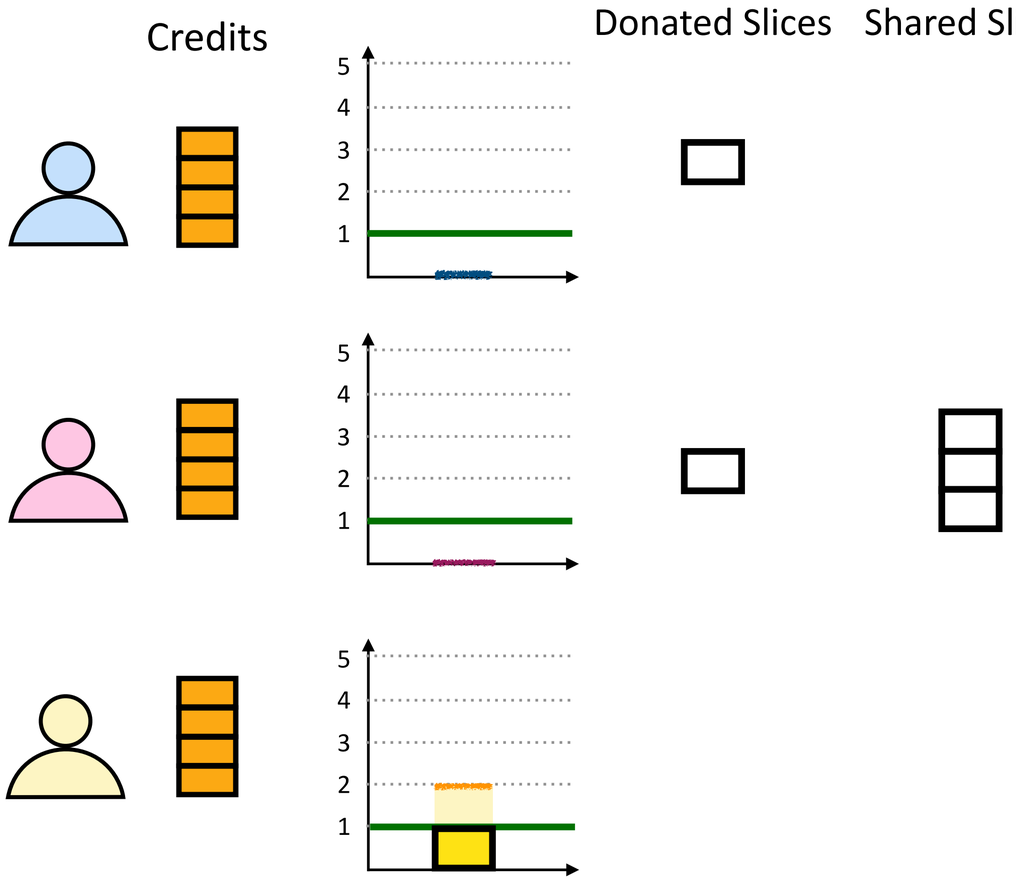

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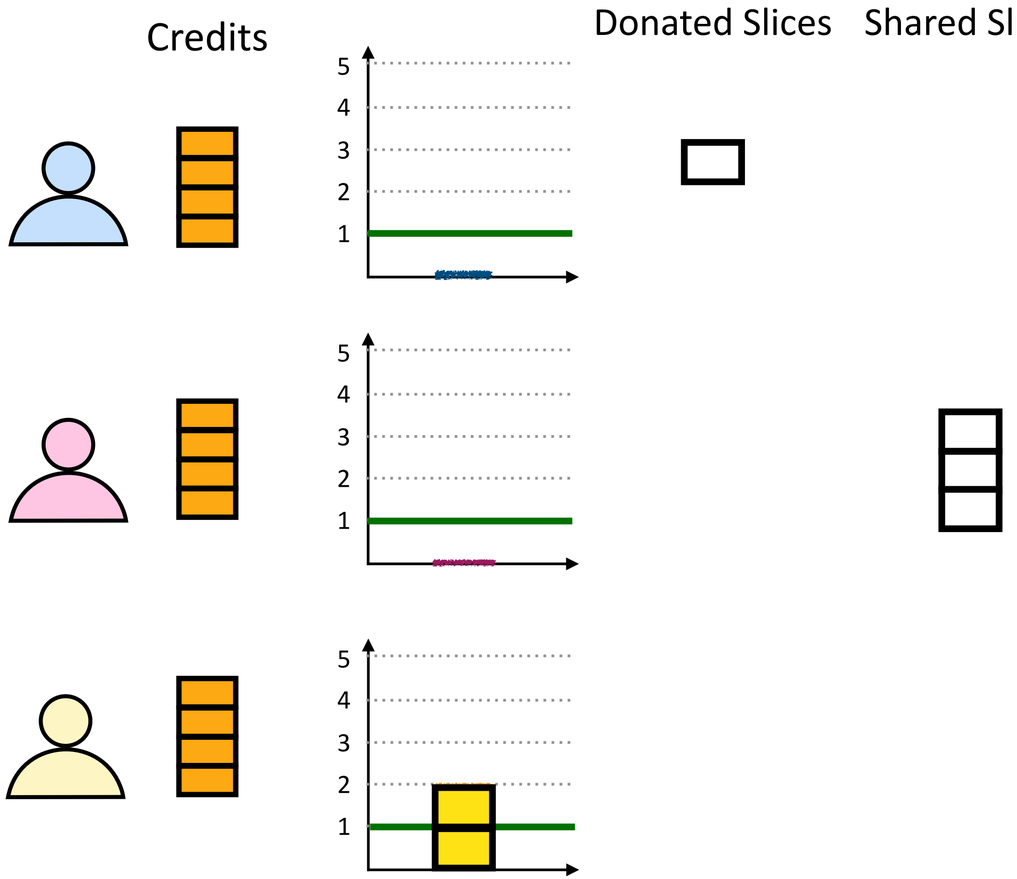

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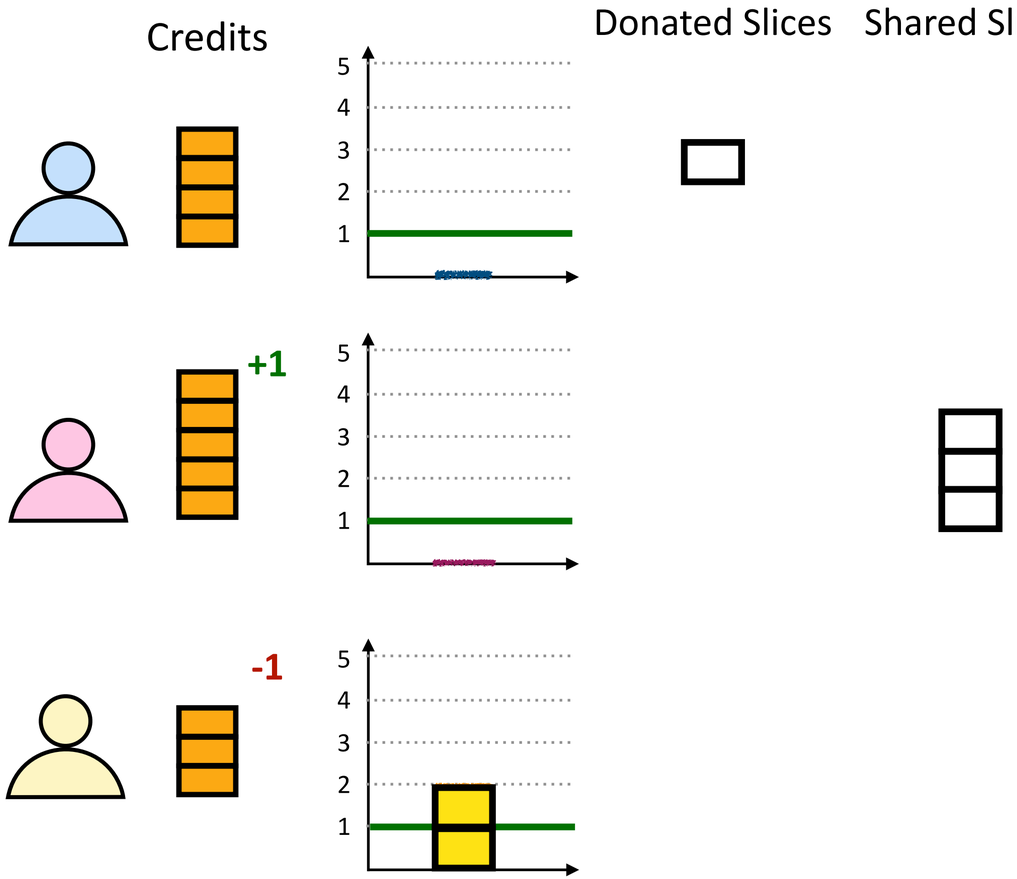

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Karma allocation algorithm

Karma allocation algorithm

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Karma allocation algorithm

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Karma allocation algorithm

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Karma allocation algorithm

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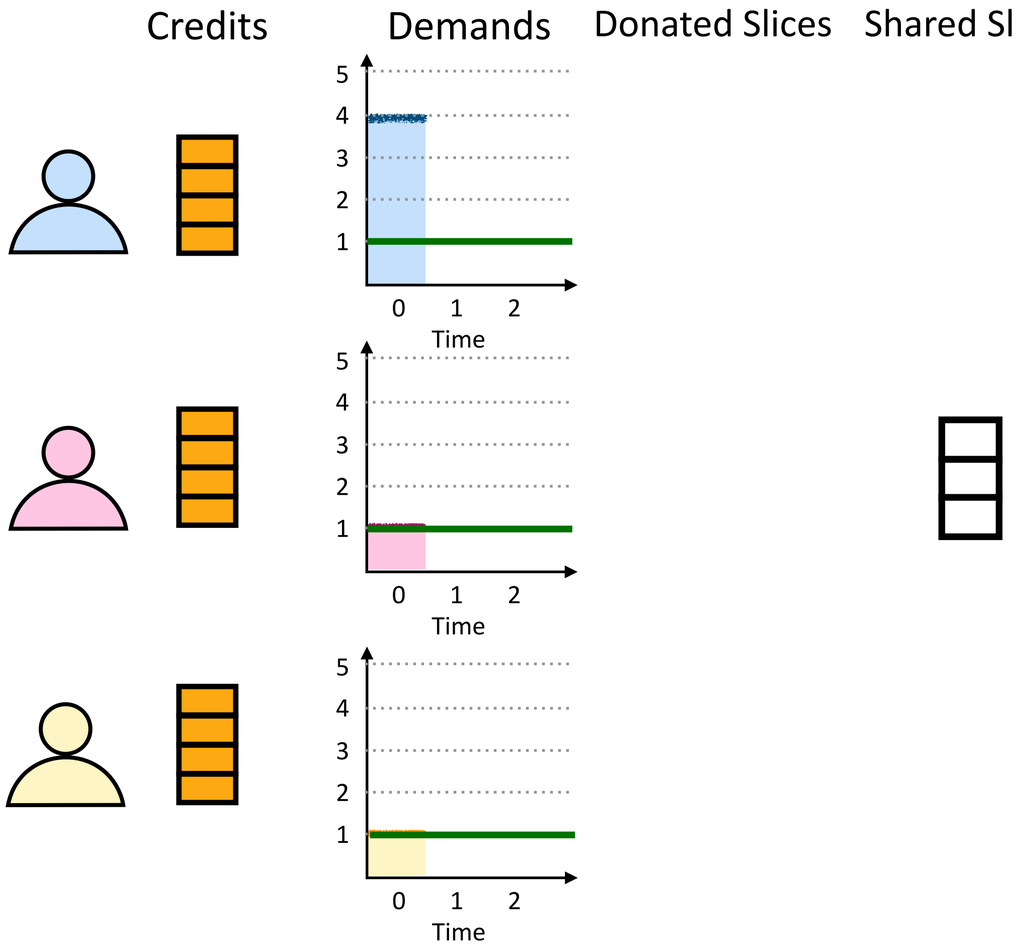

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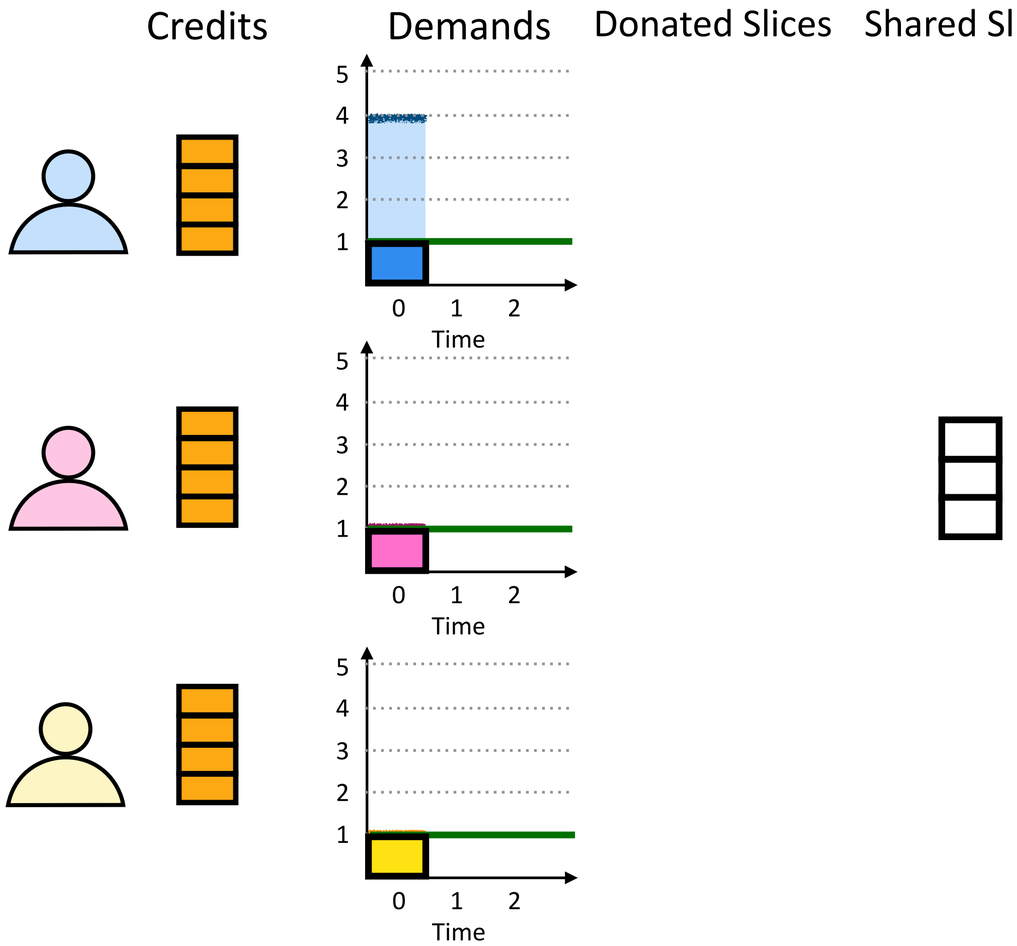

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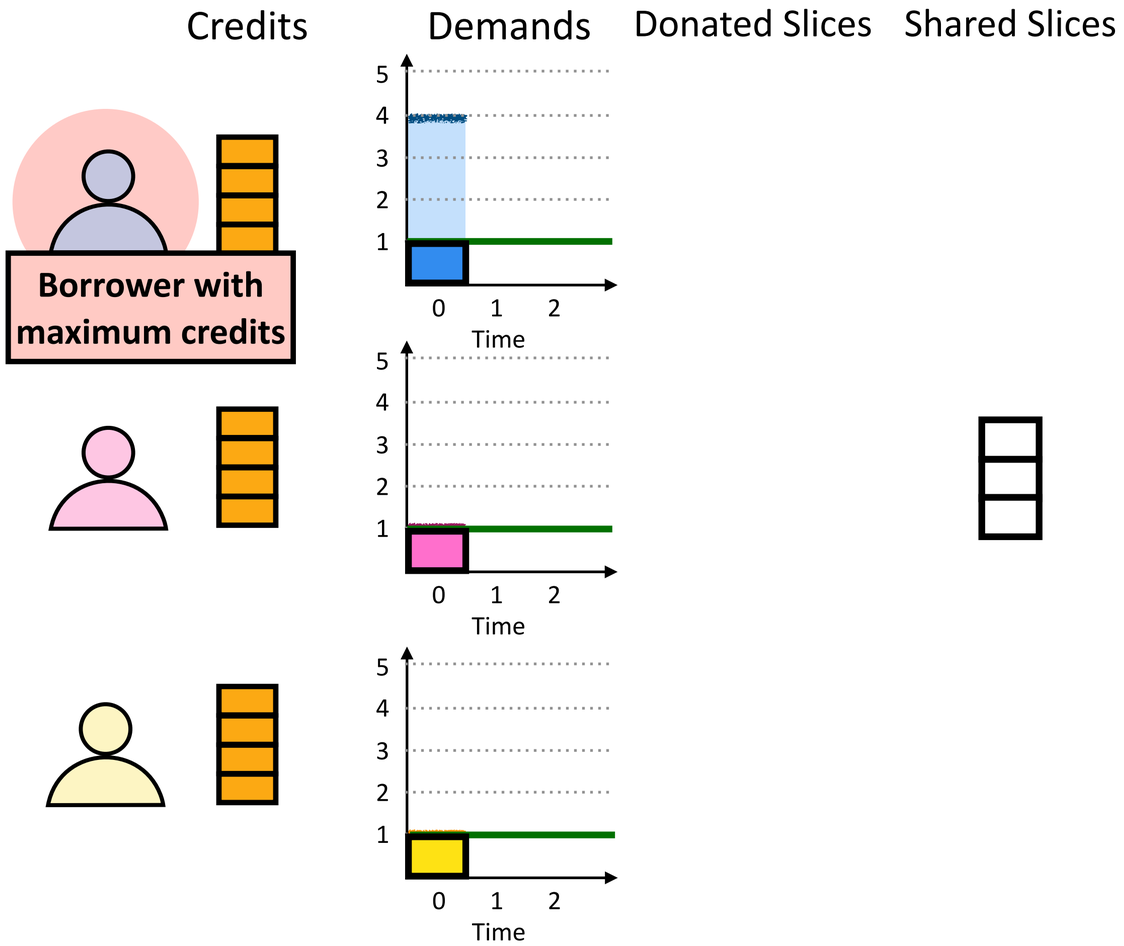

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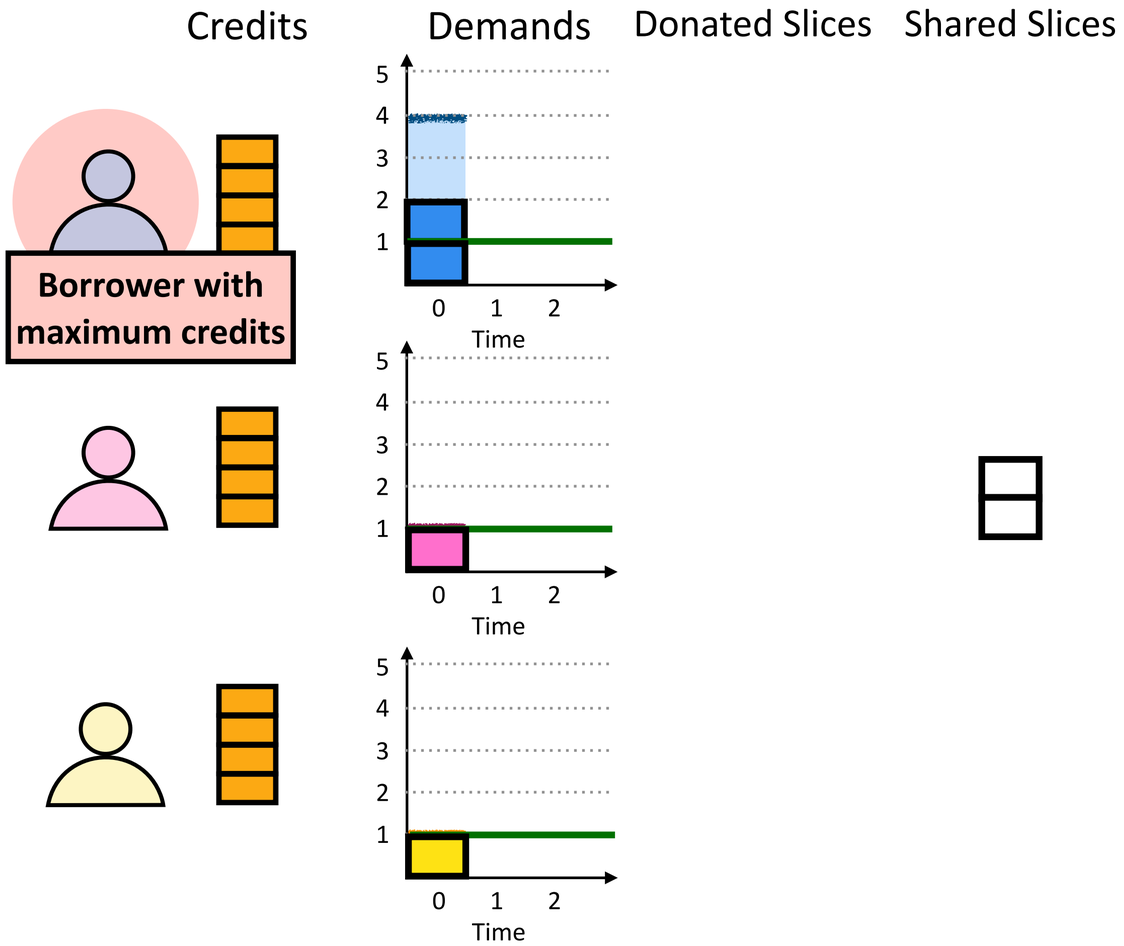

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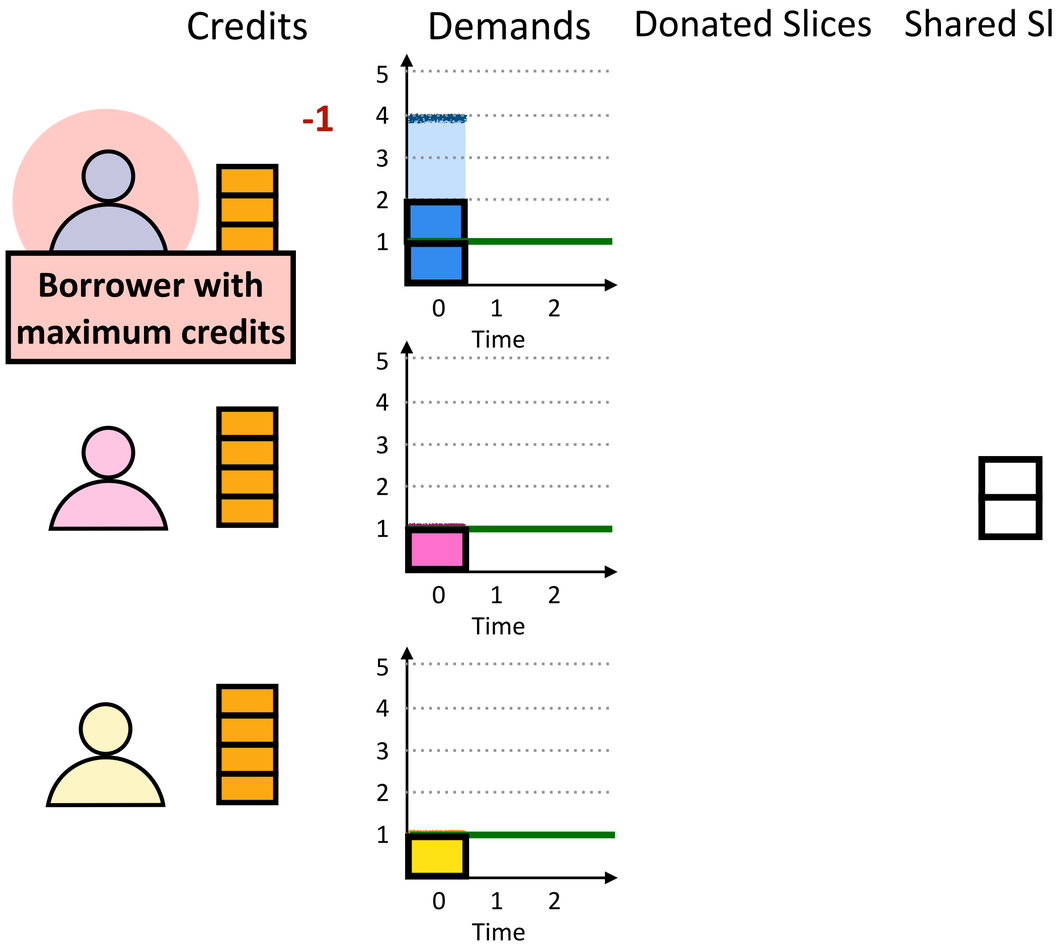

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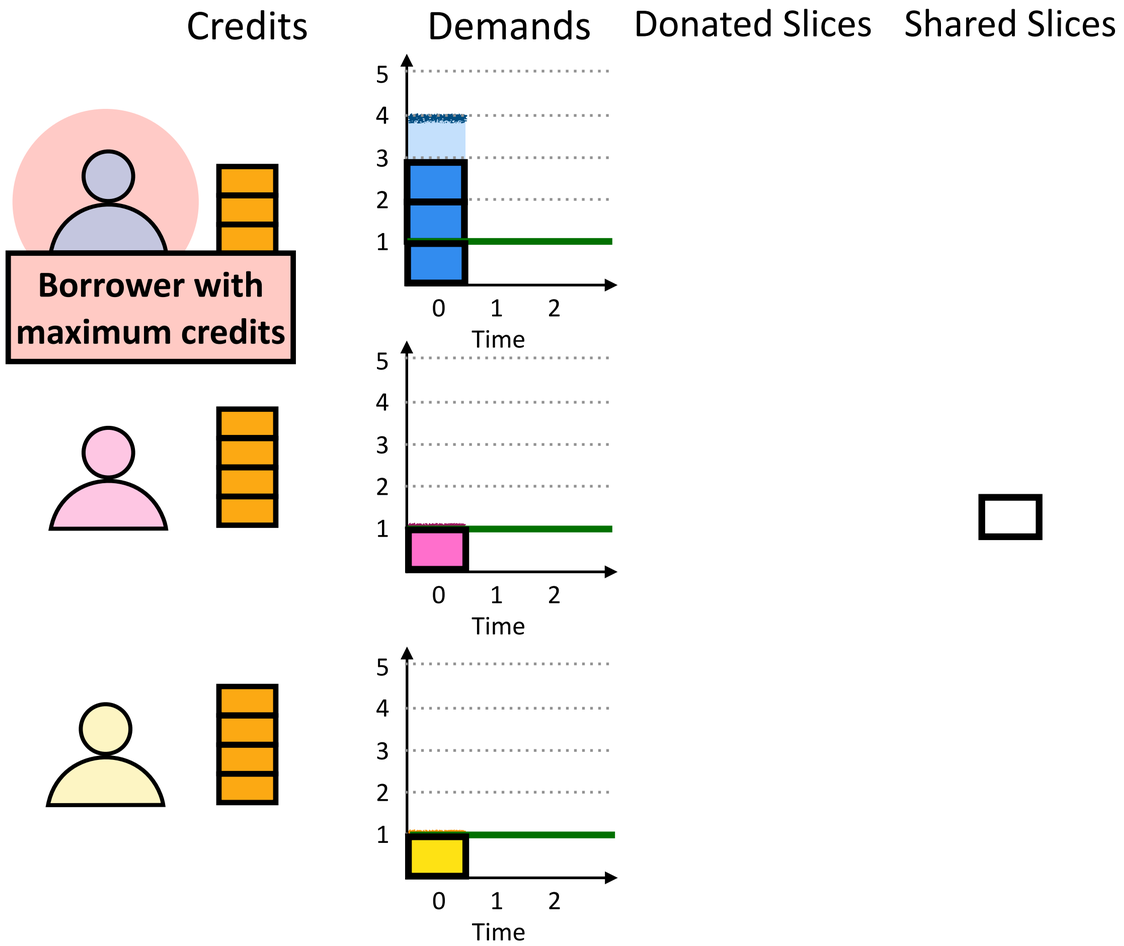

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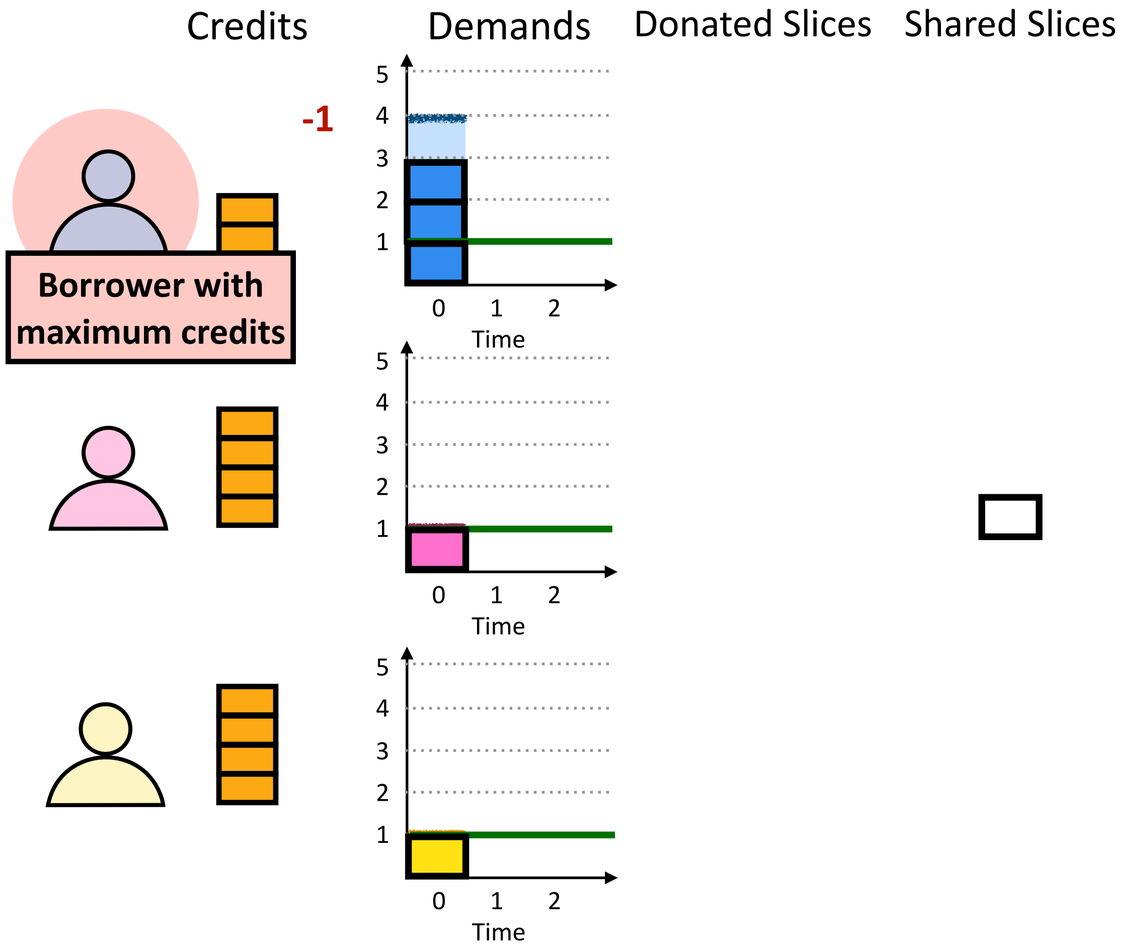

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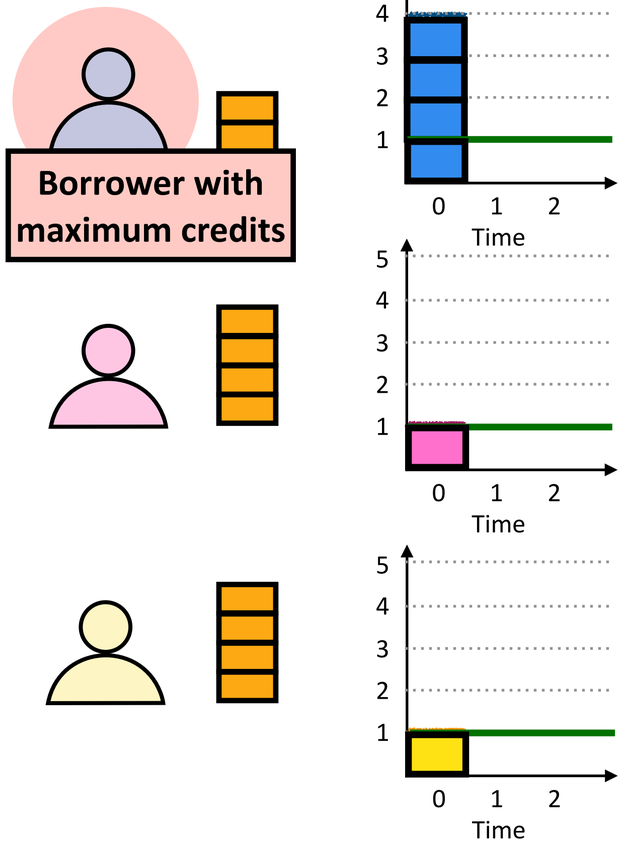
Karma allocation algorithm

Running Example

Credits | Demands | Donated Slices | Shared Slices



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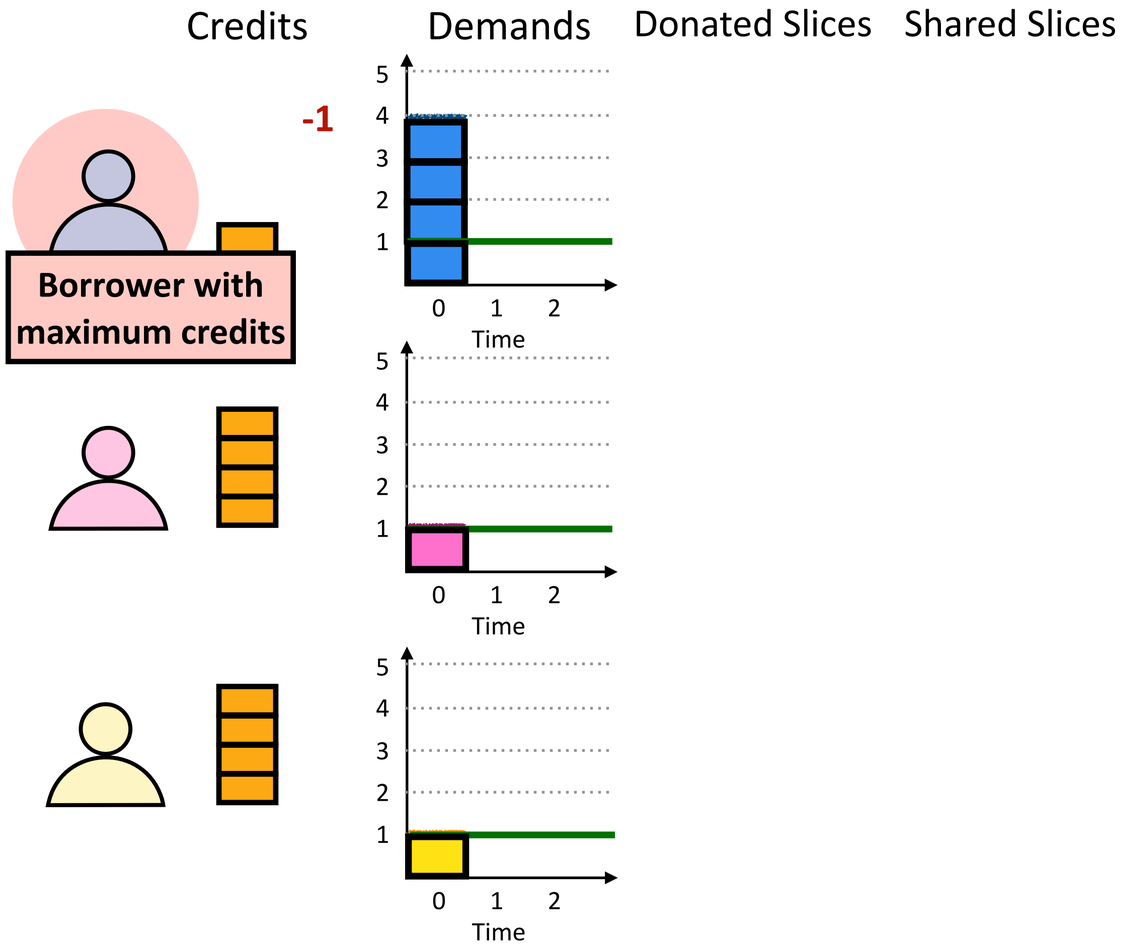

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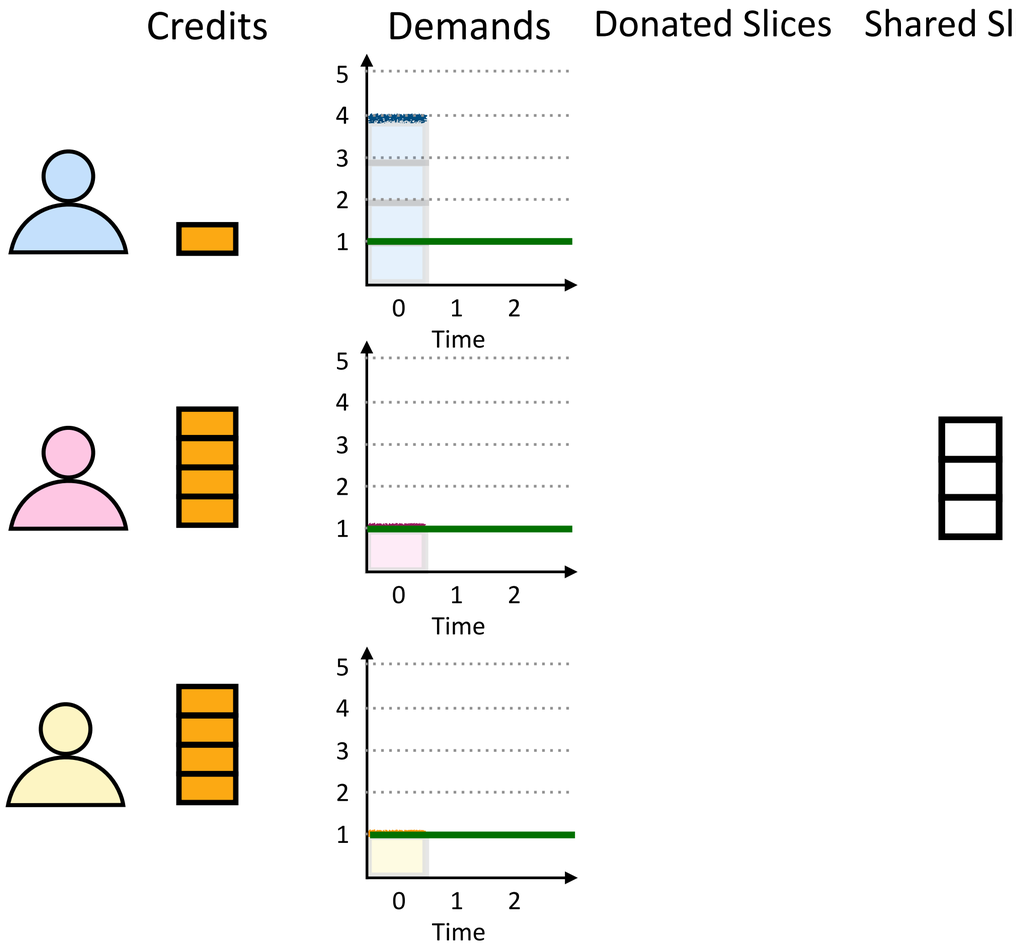

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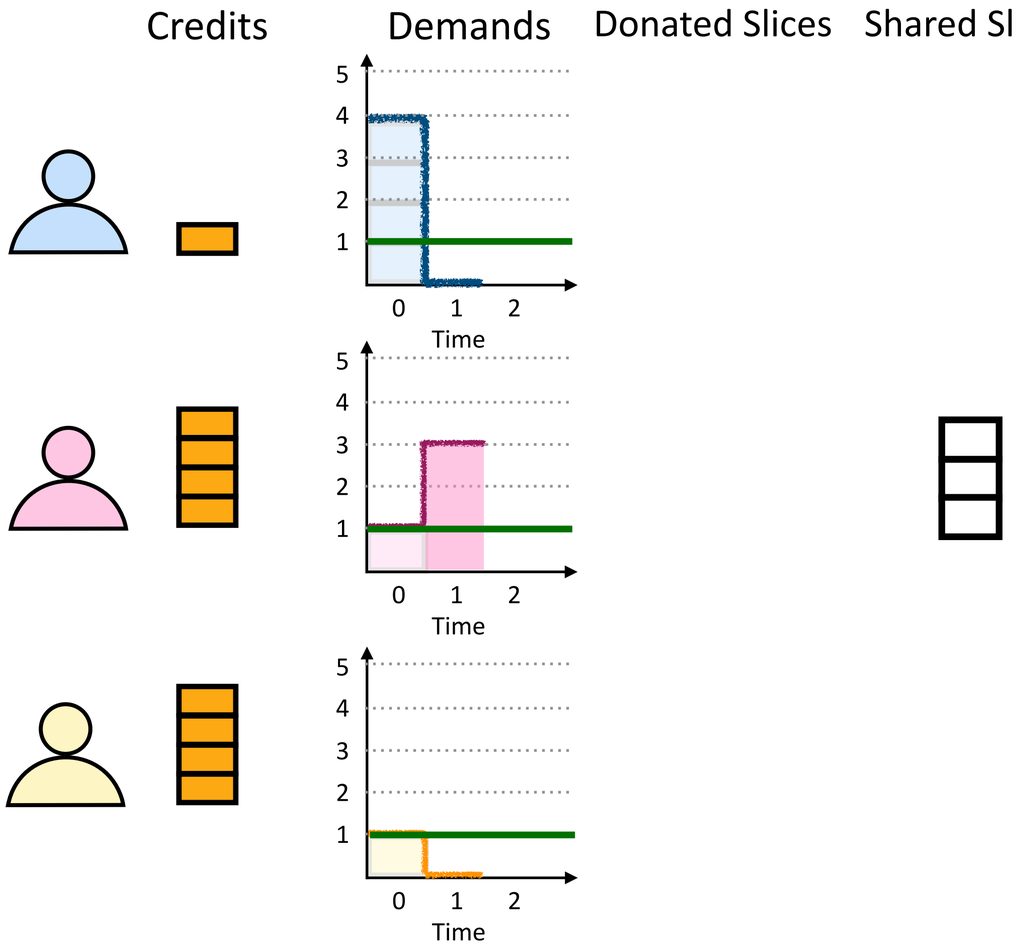

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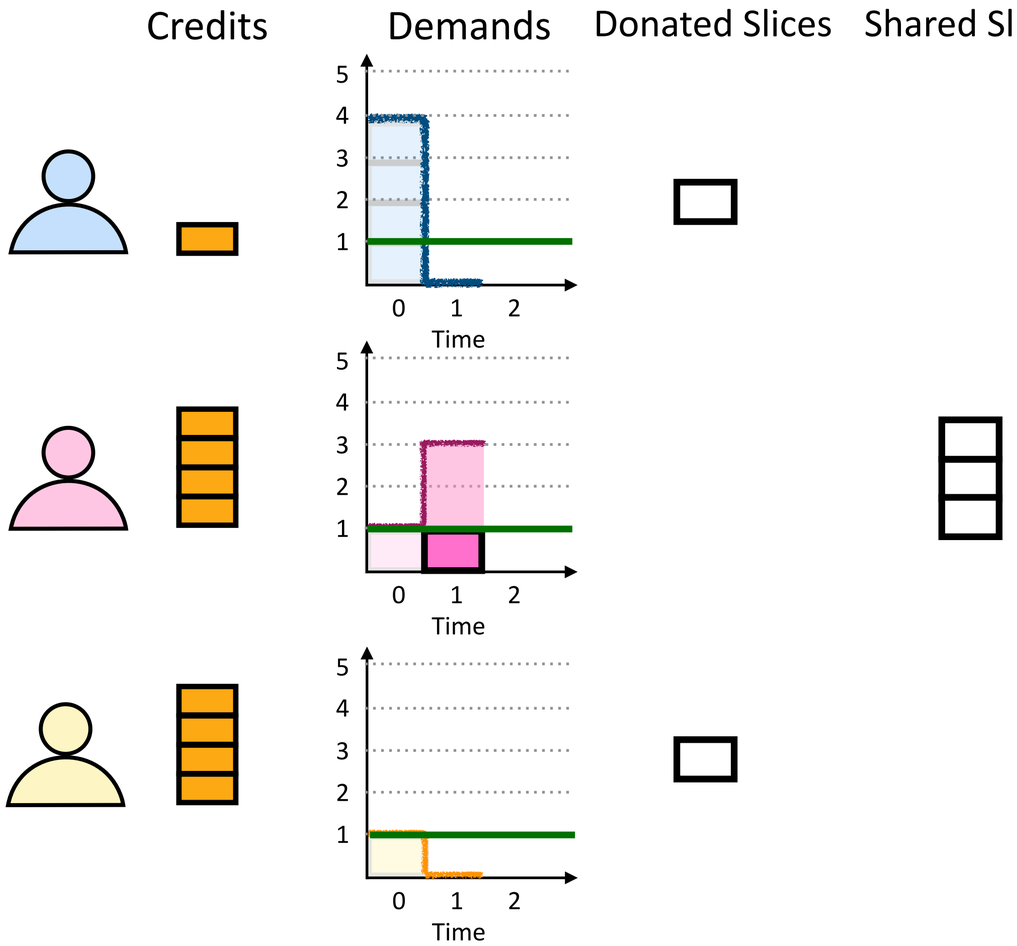

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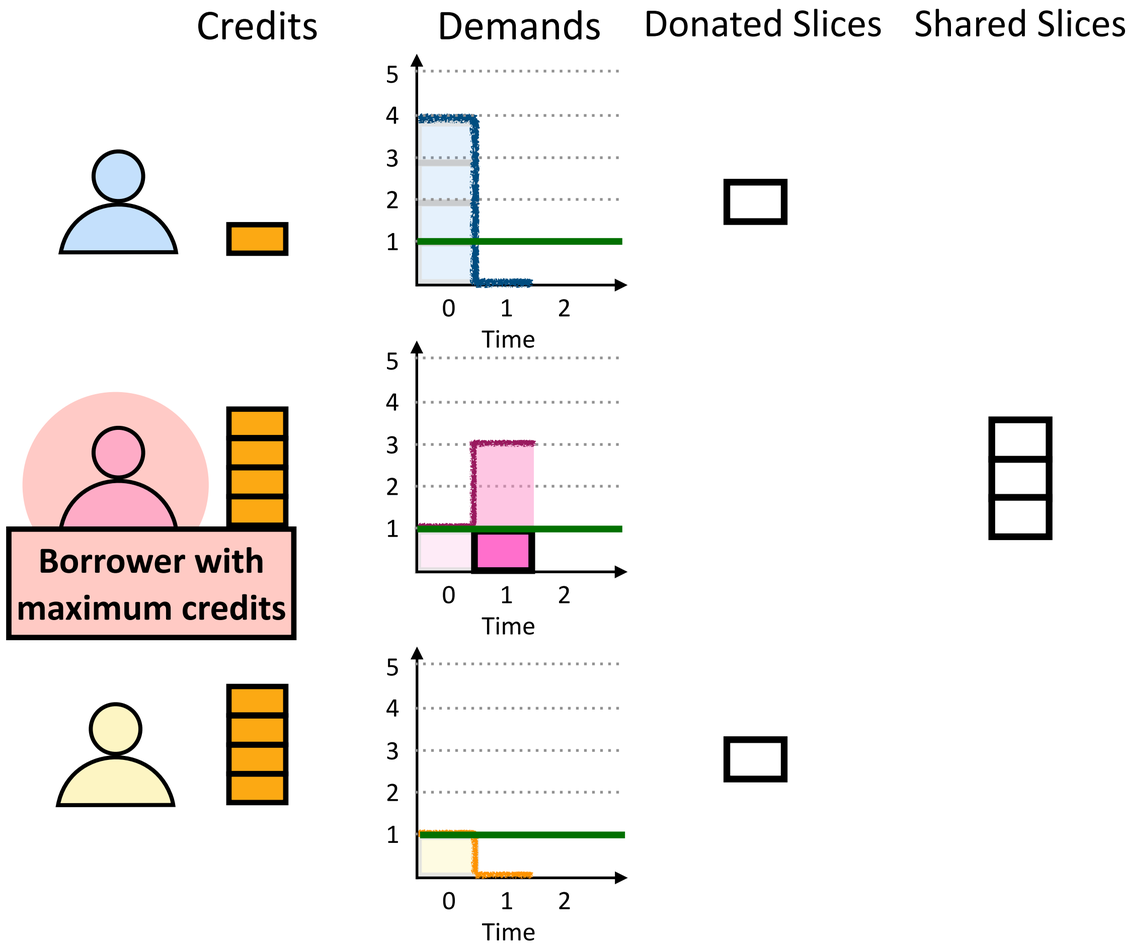

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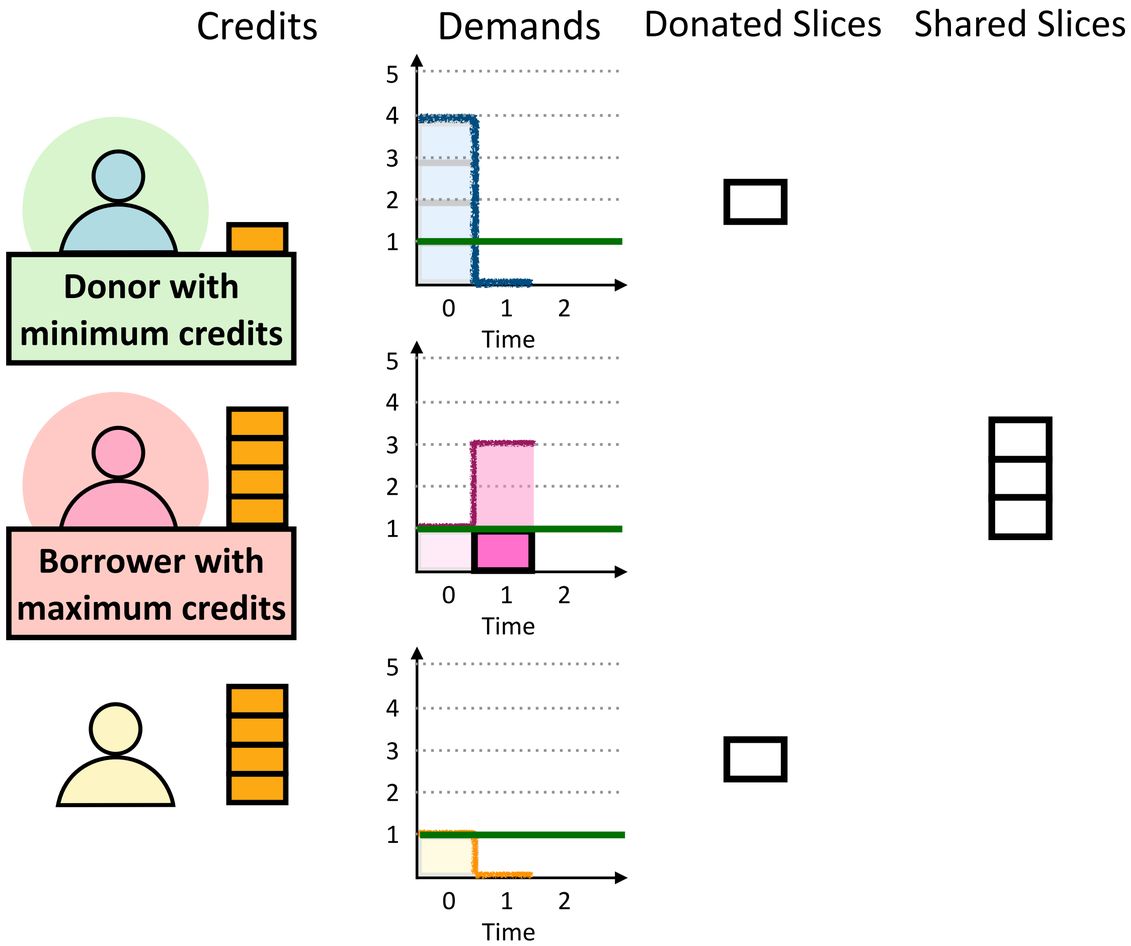

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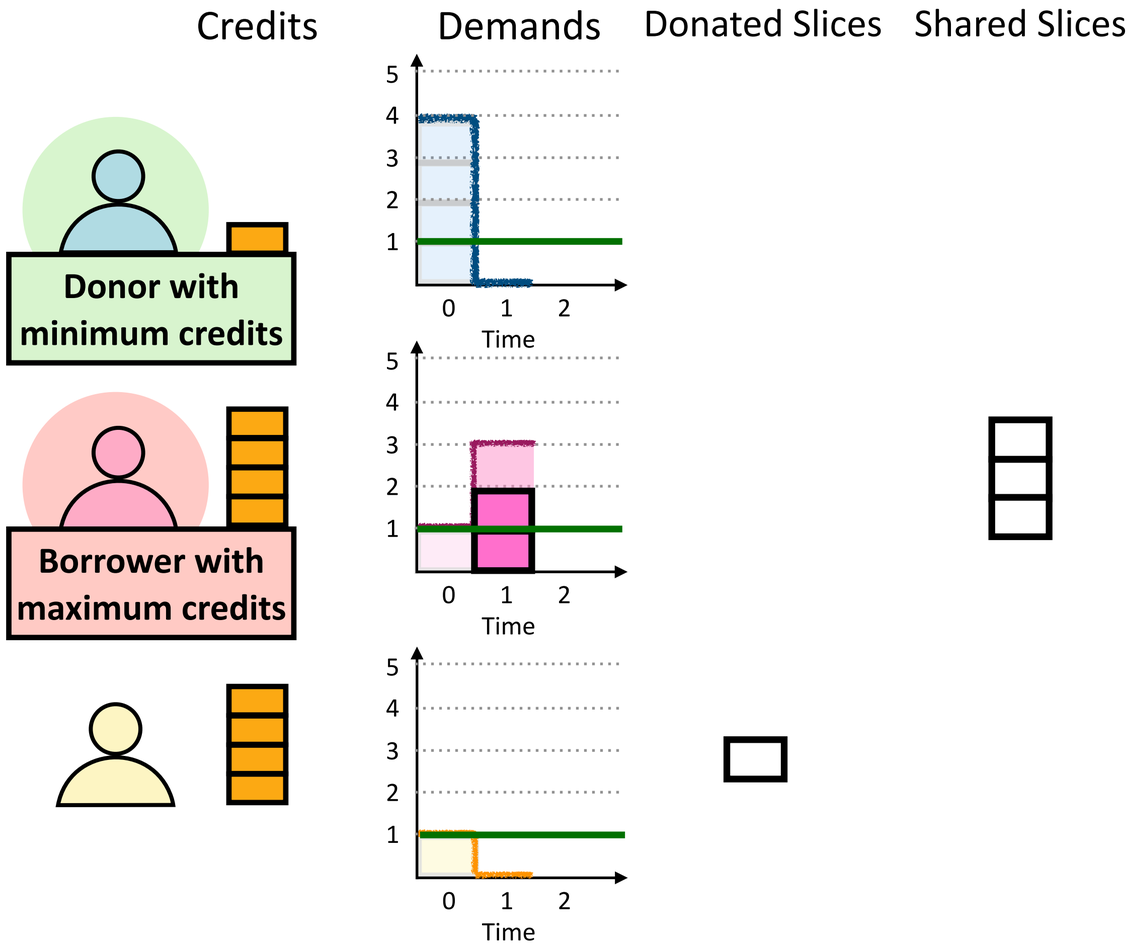

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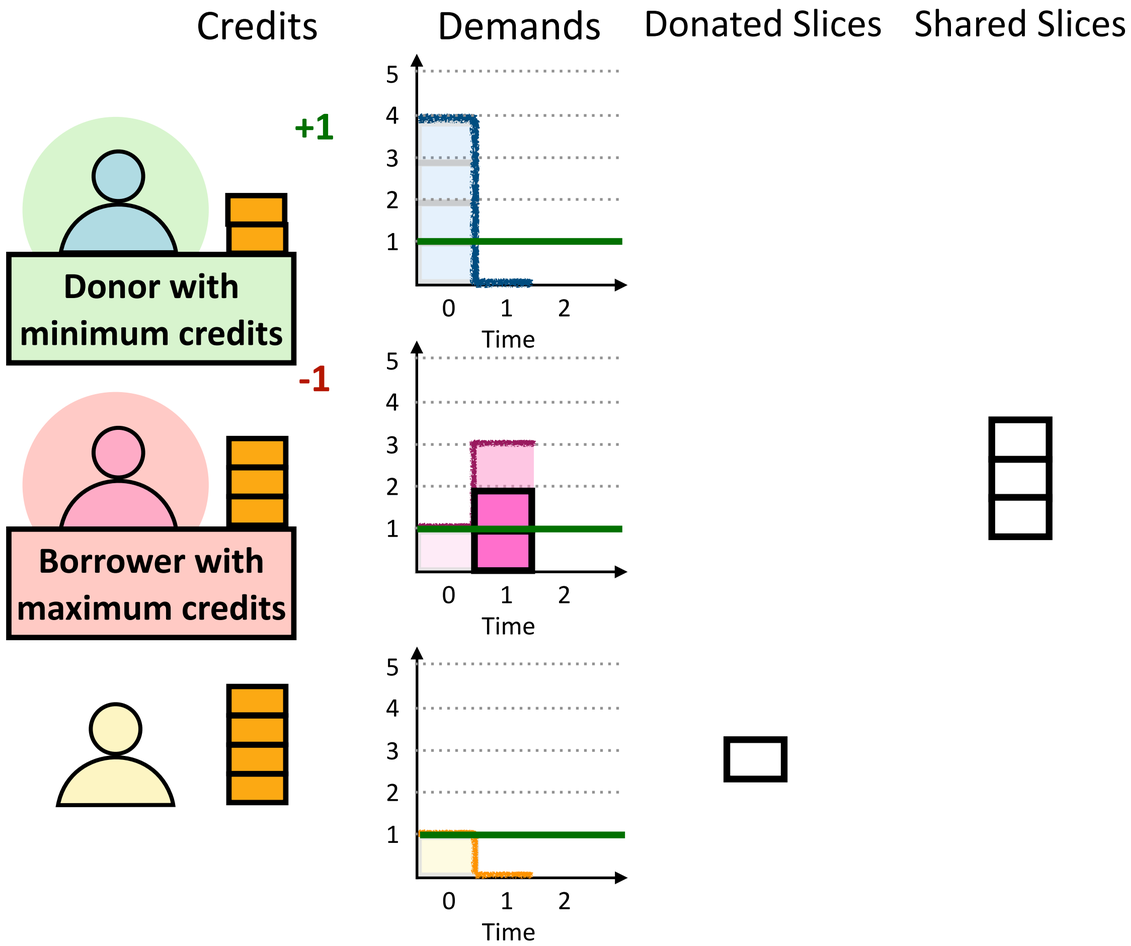

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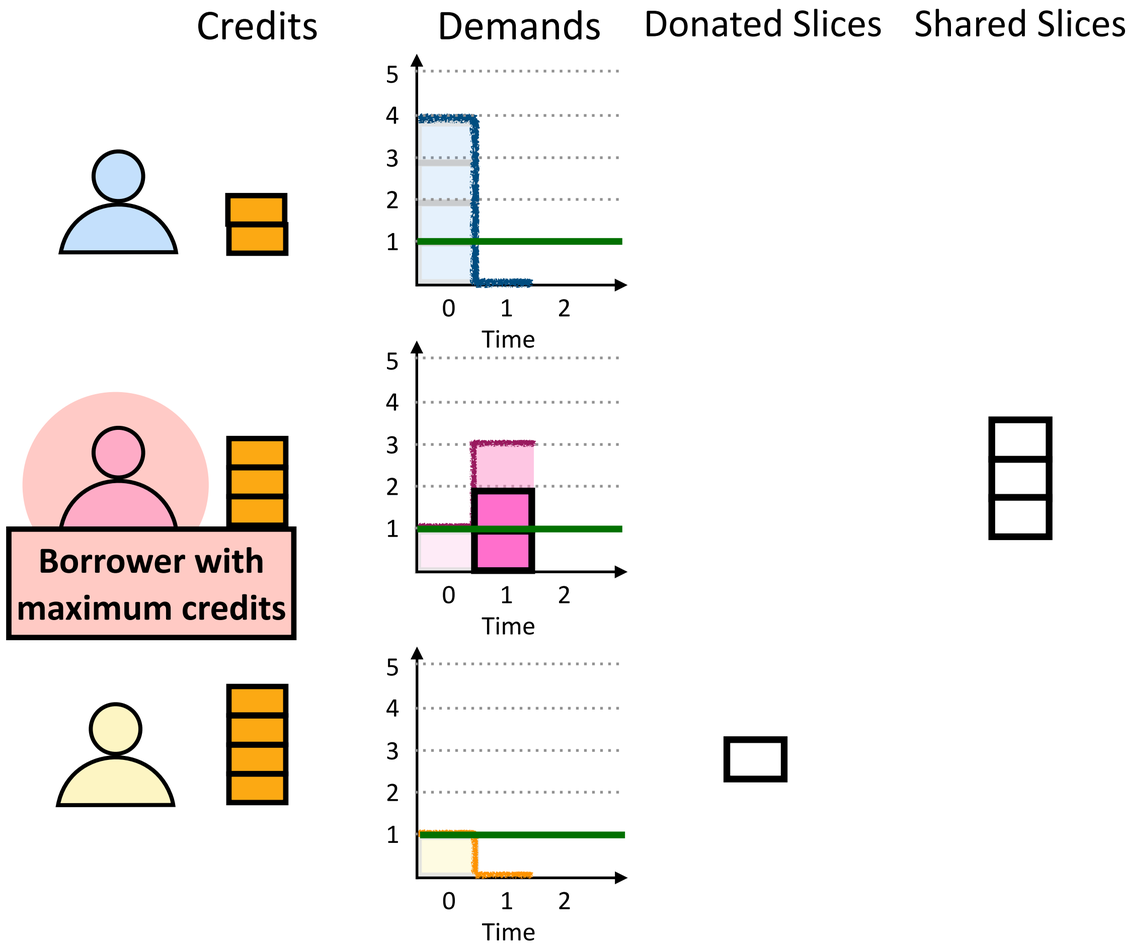
(Repeat until demands satisfied or resources exhausted)

Karma allocation algorithm

Running Example



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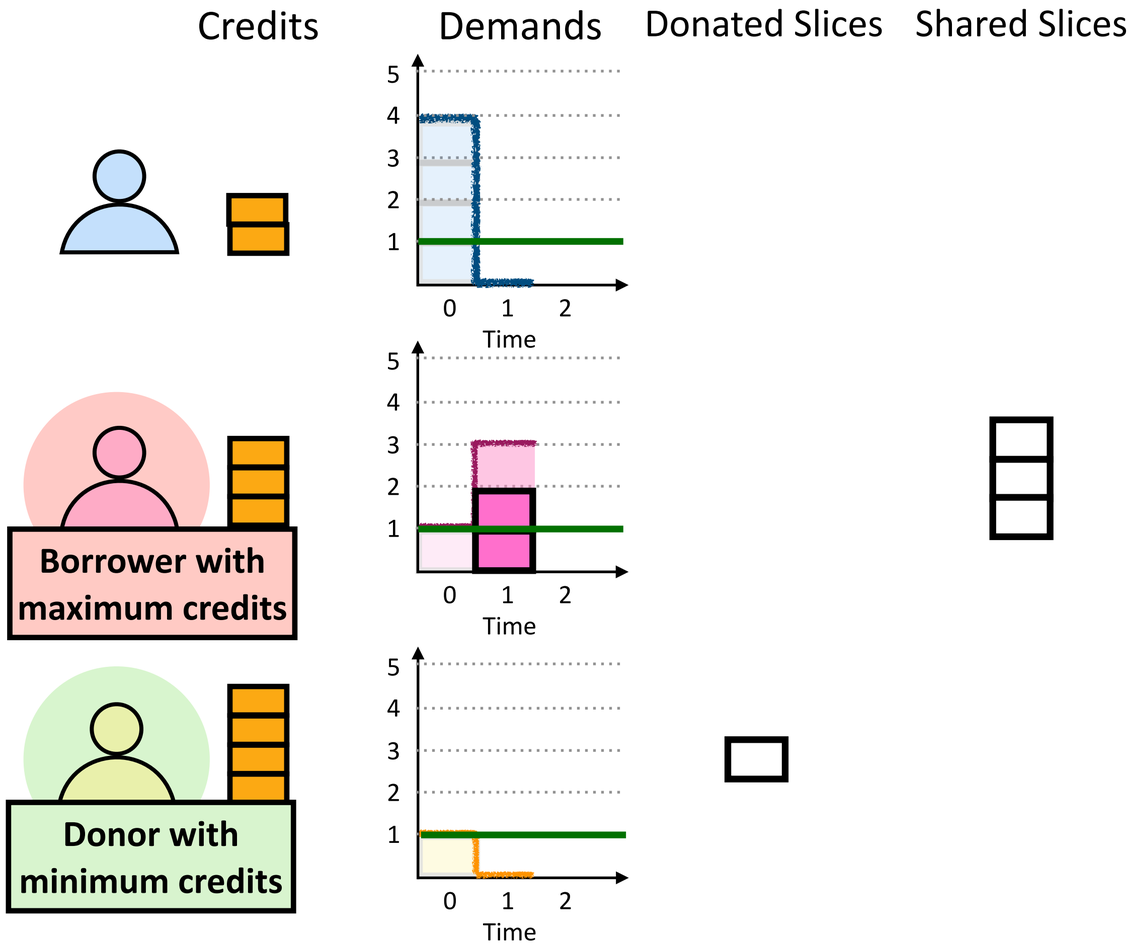

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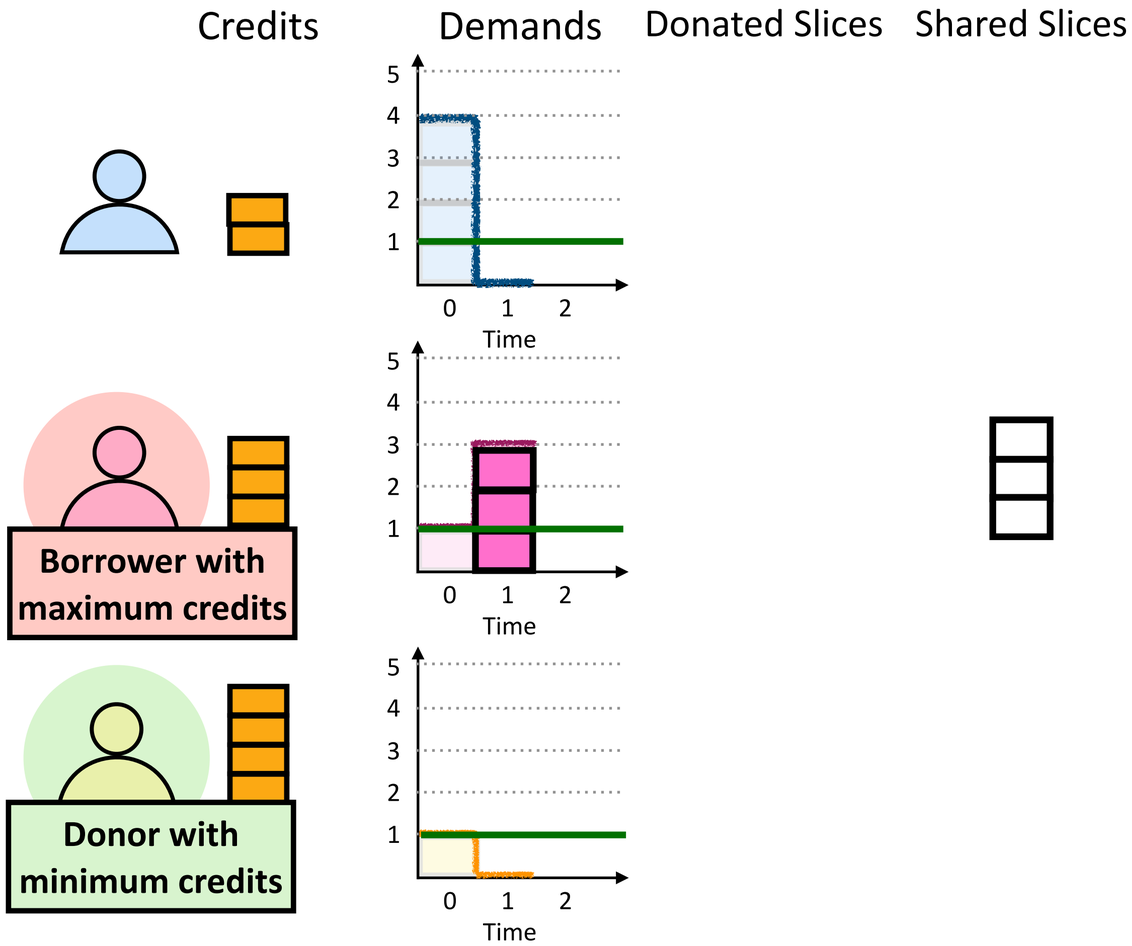

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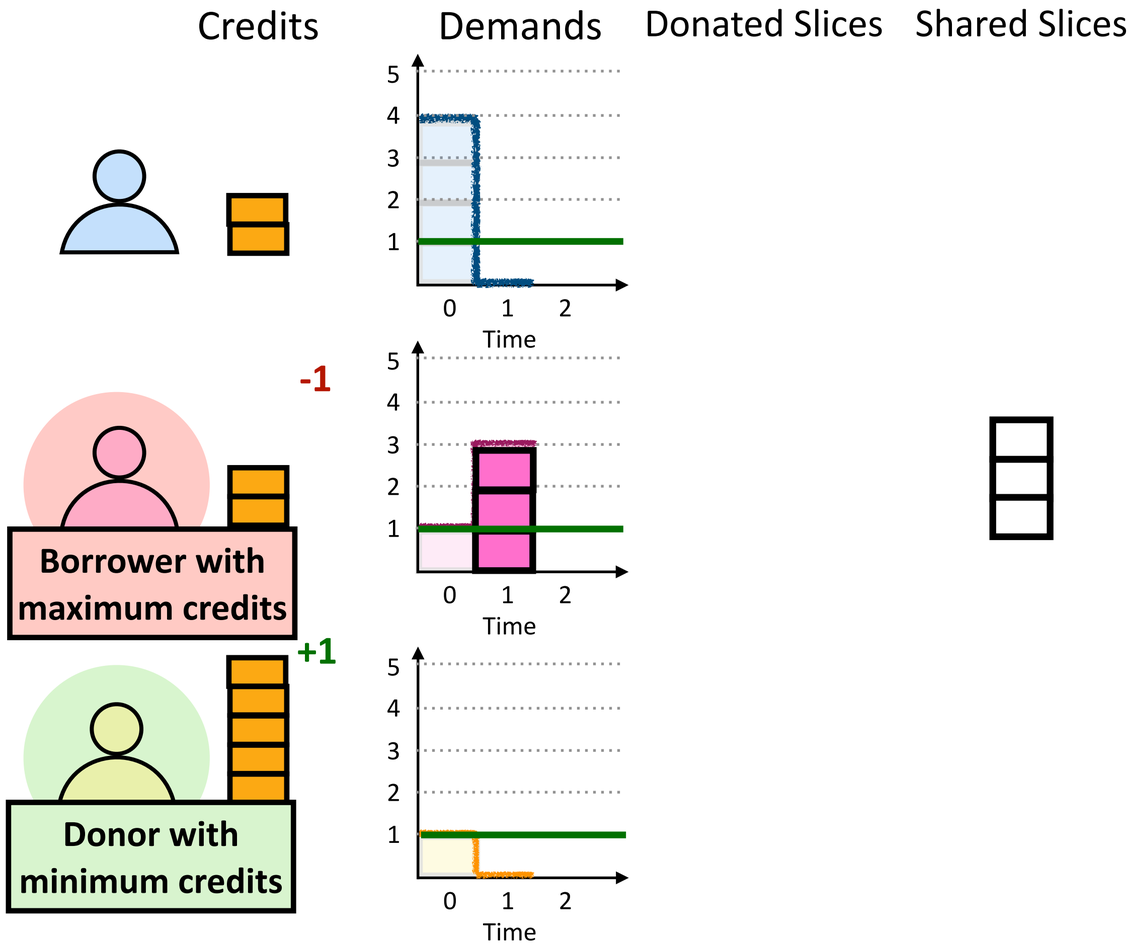

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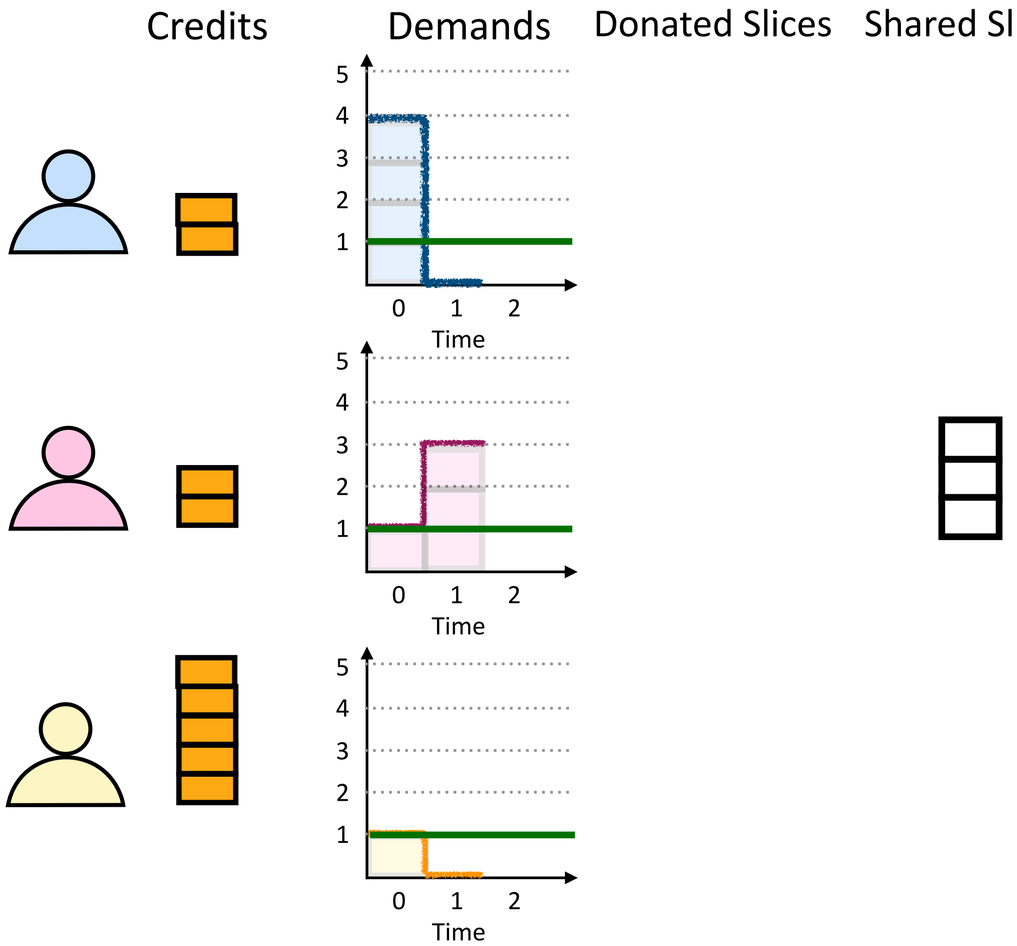

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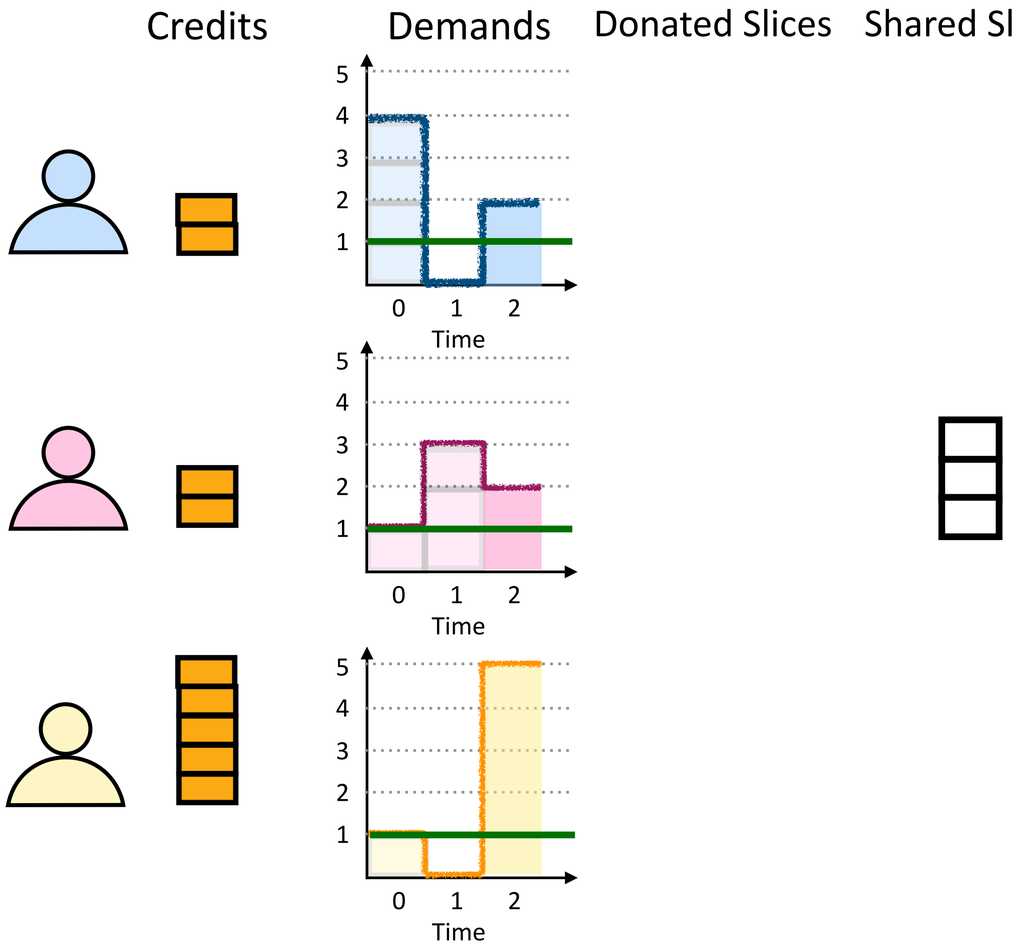

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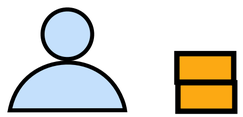
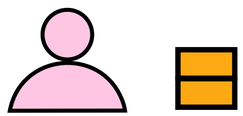
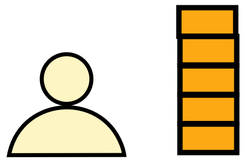
Karma allocation algorithm

Running Example

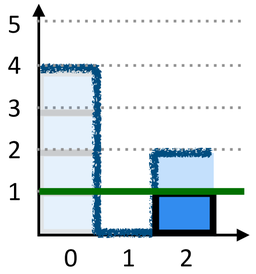
Credits

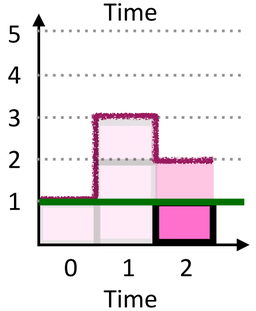


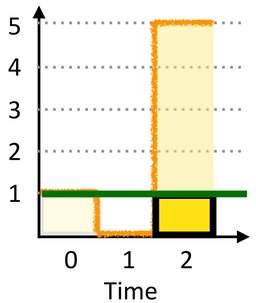




Demands

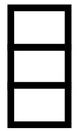






Donated Slices

Shared Slices



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Karma allocation algorithm

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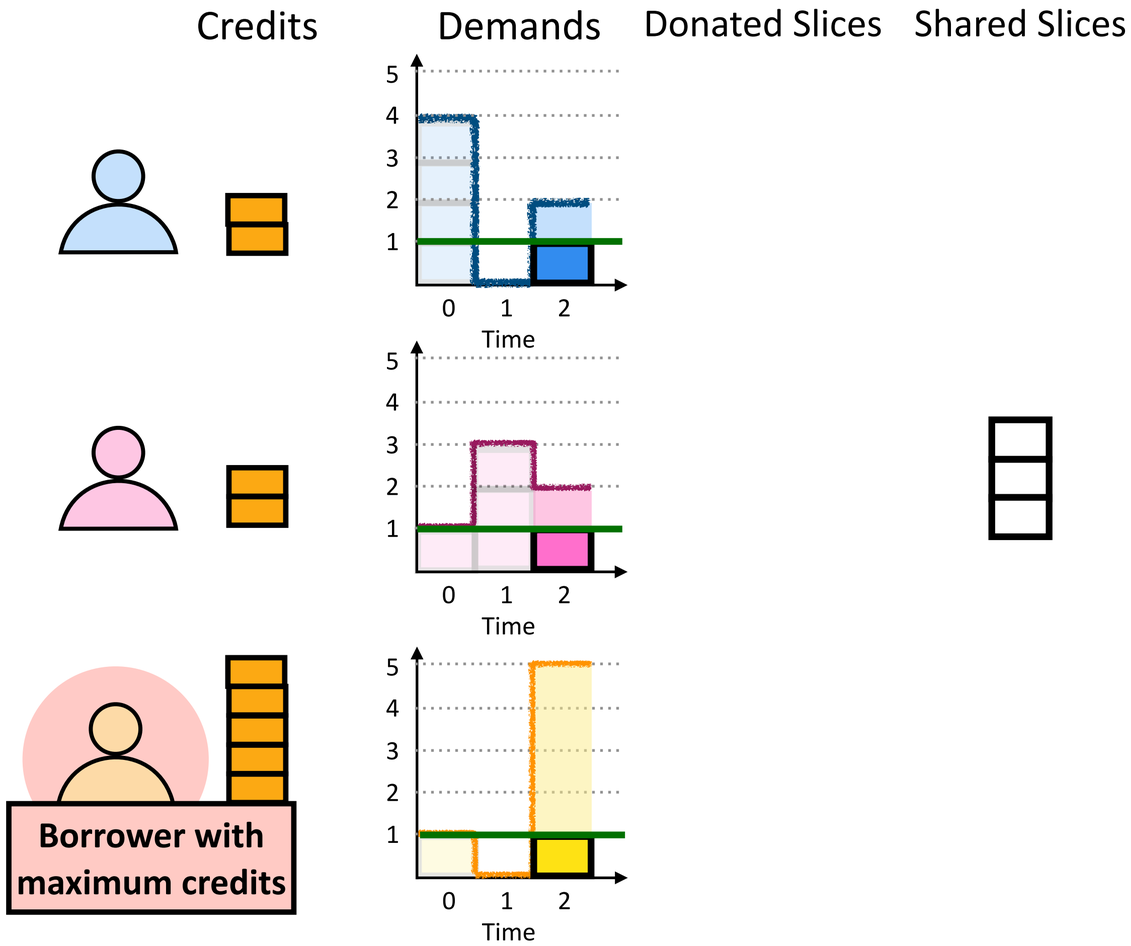

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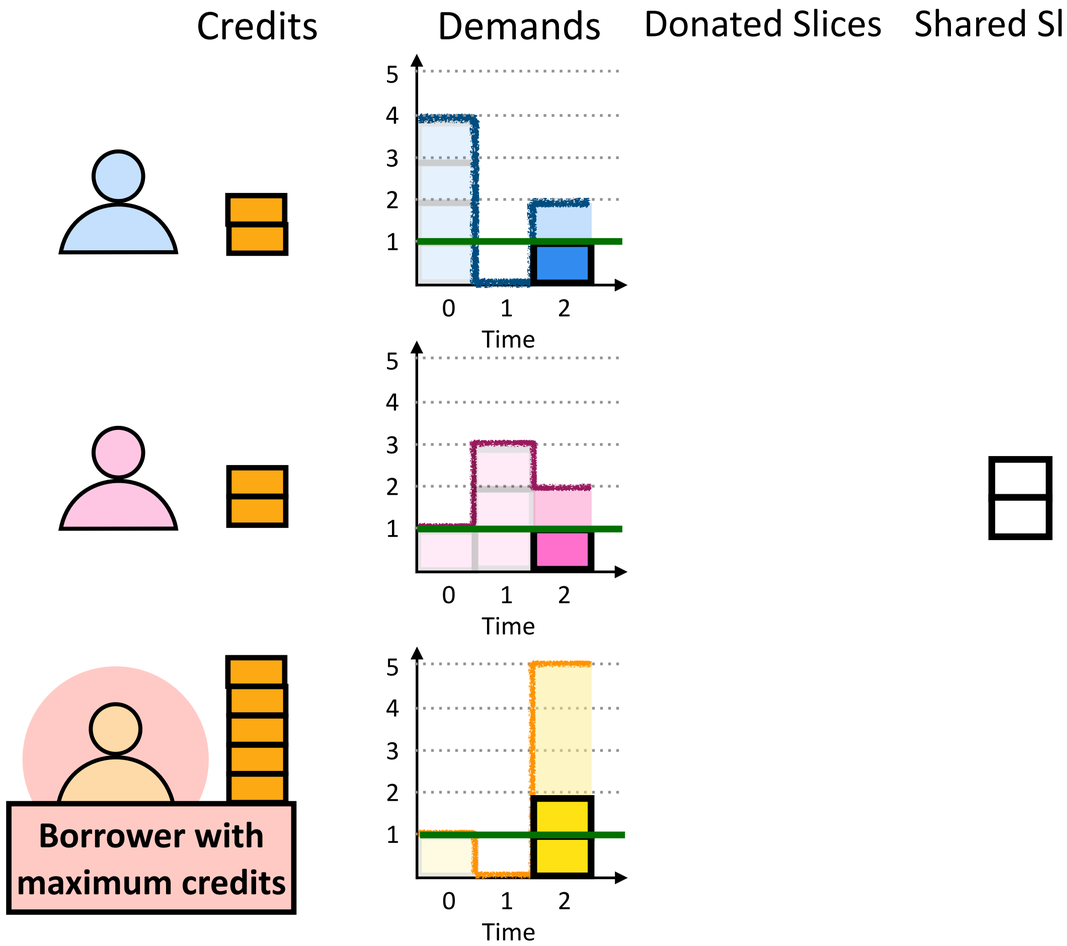

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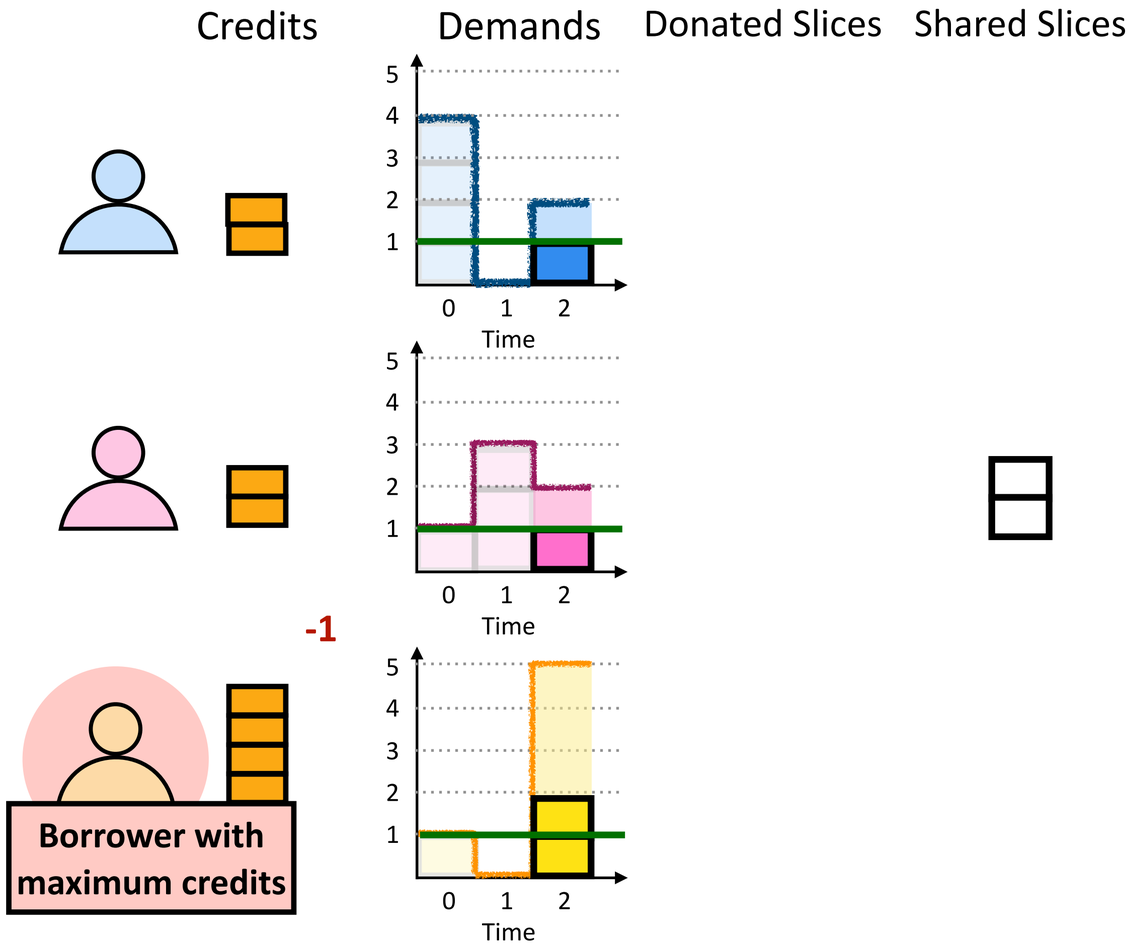

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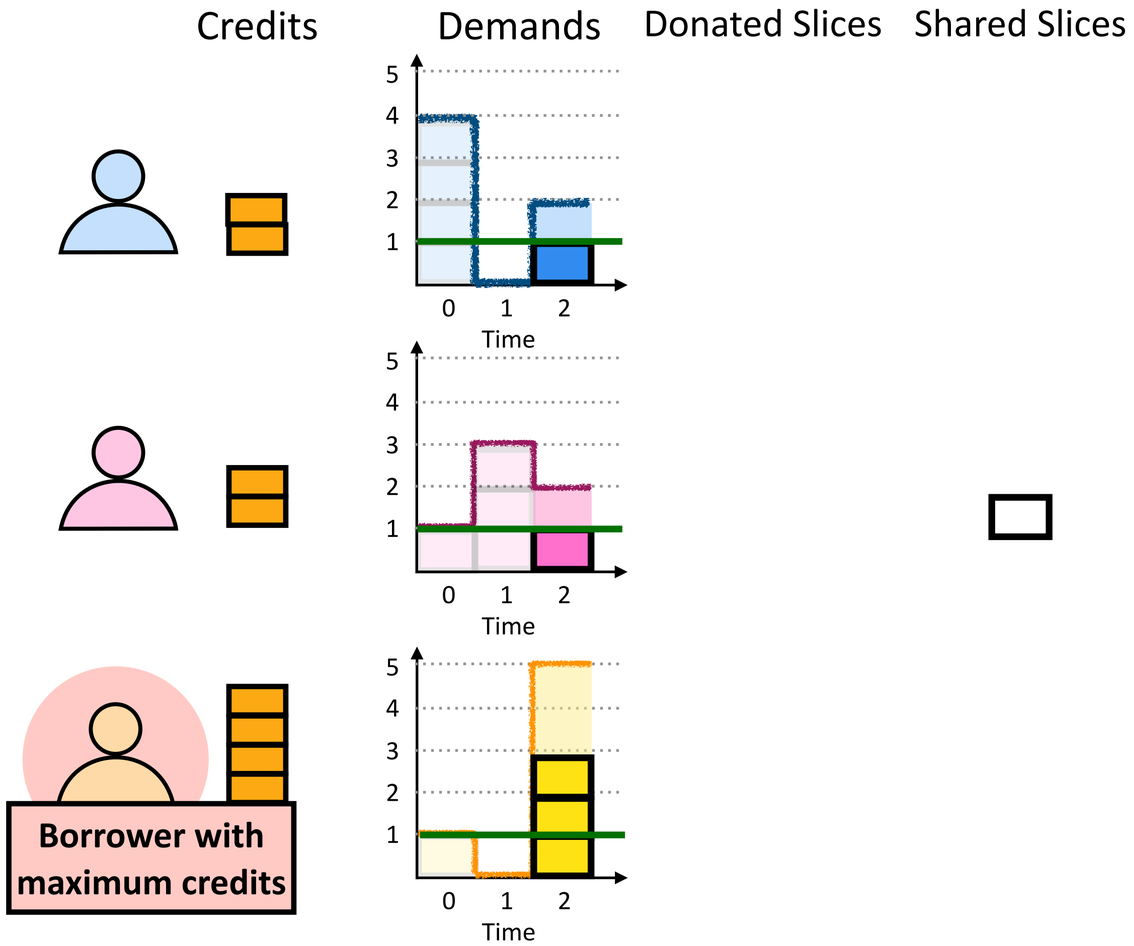

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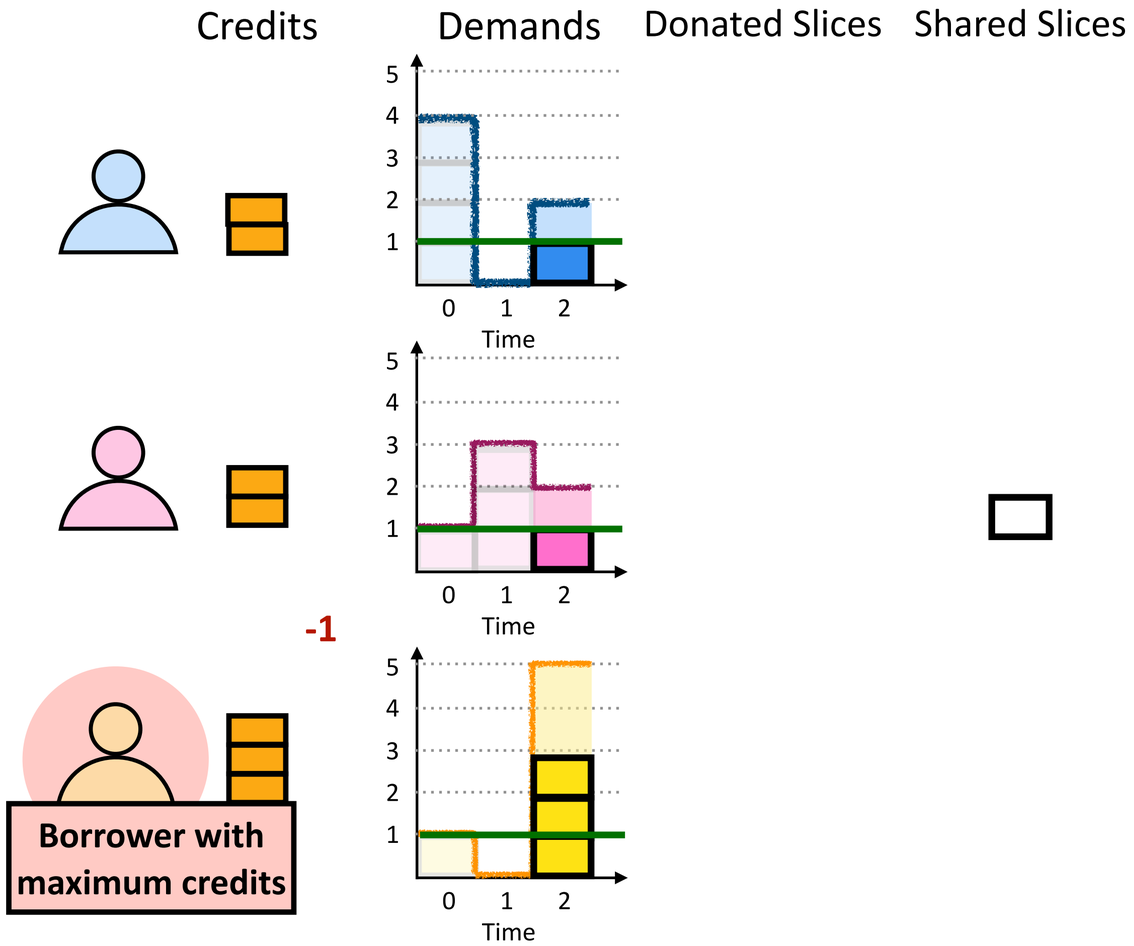

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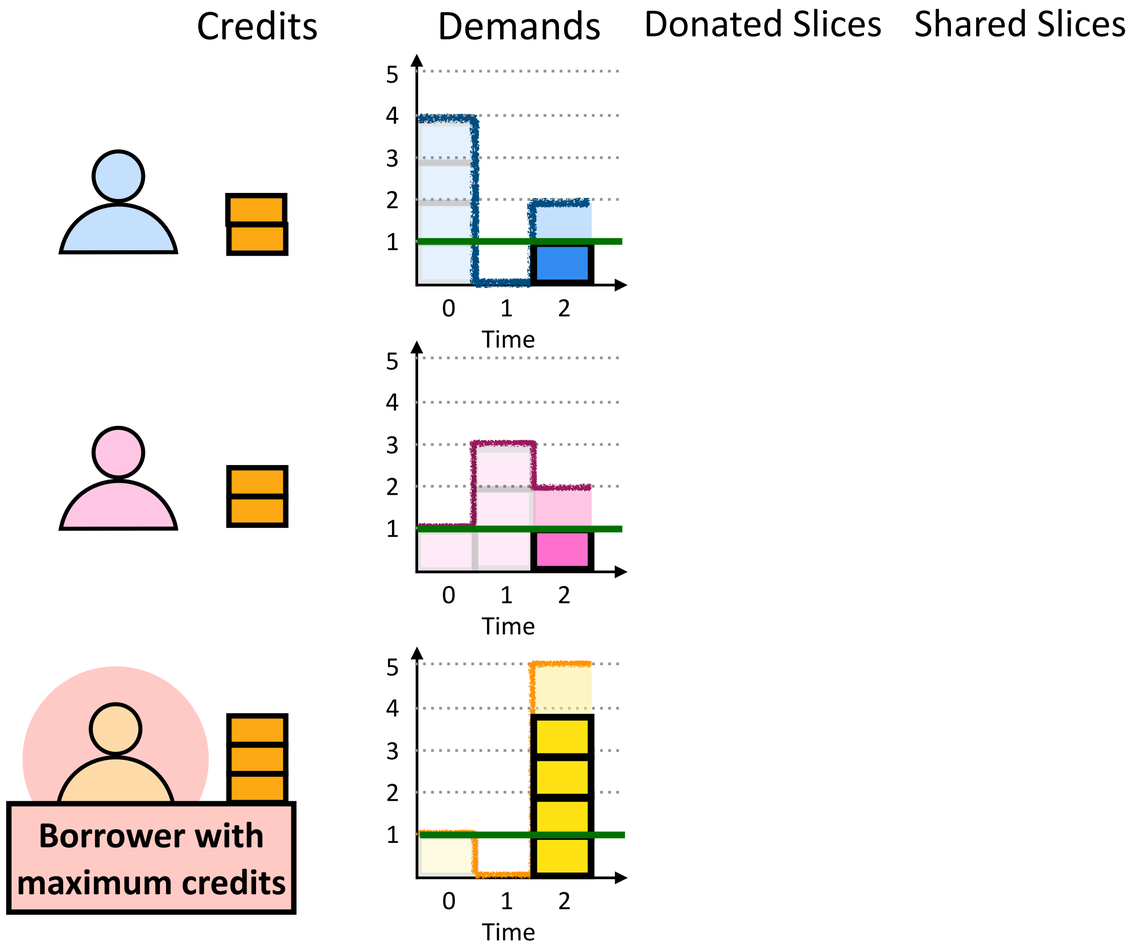

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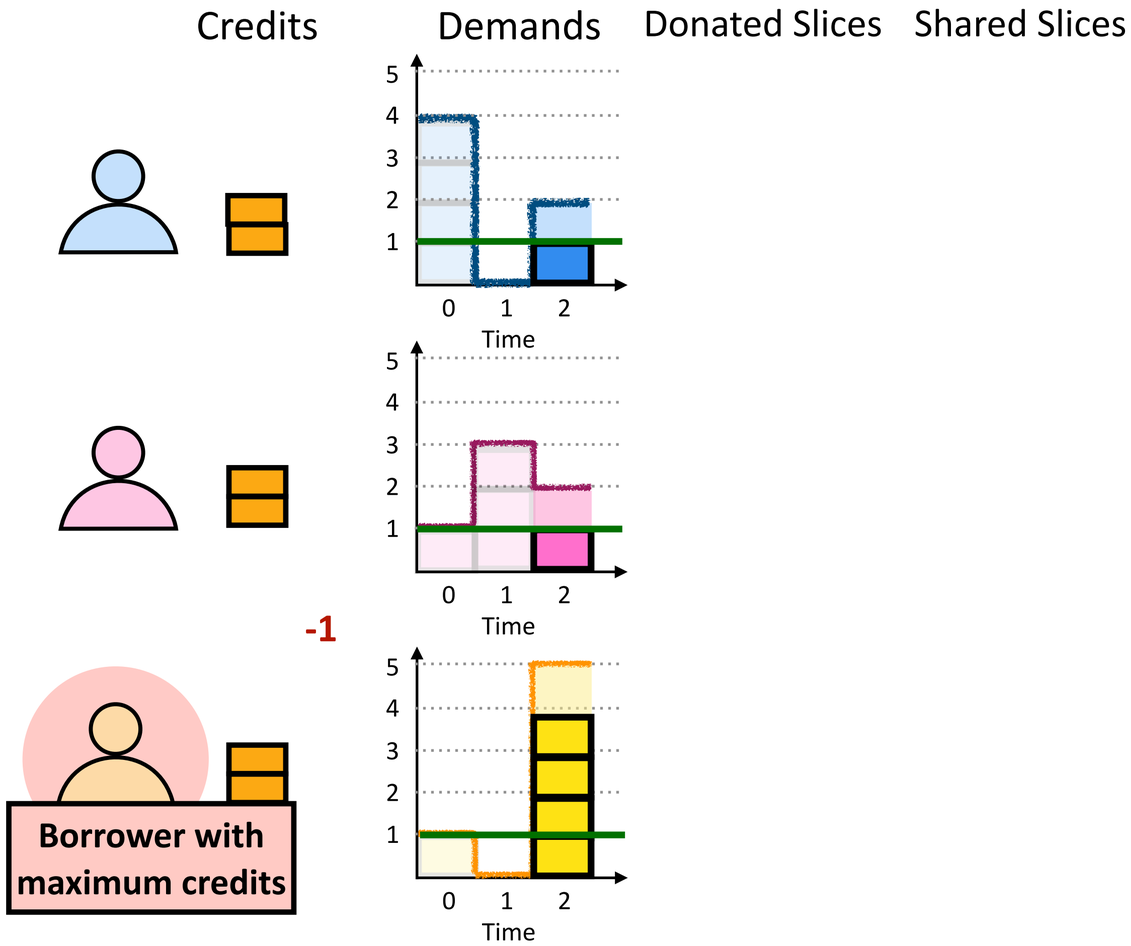

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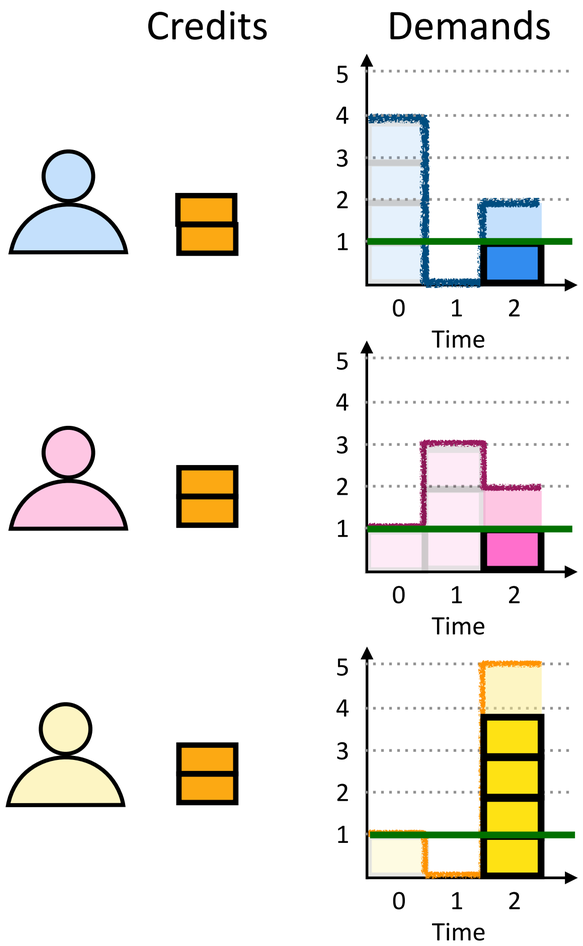

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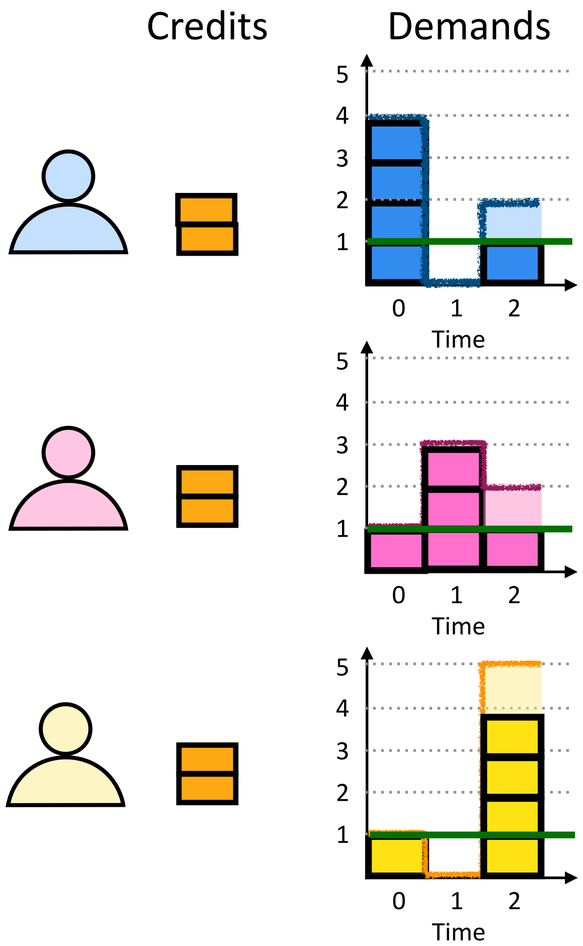

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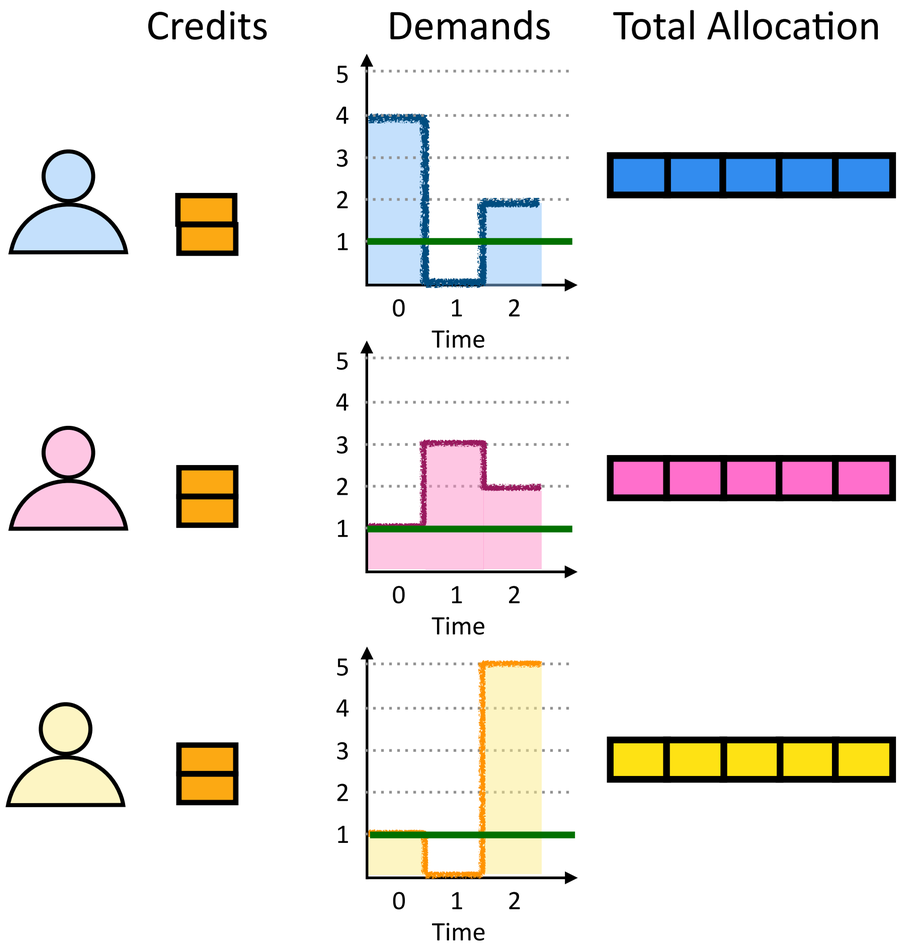

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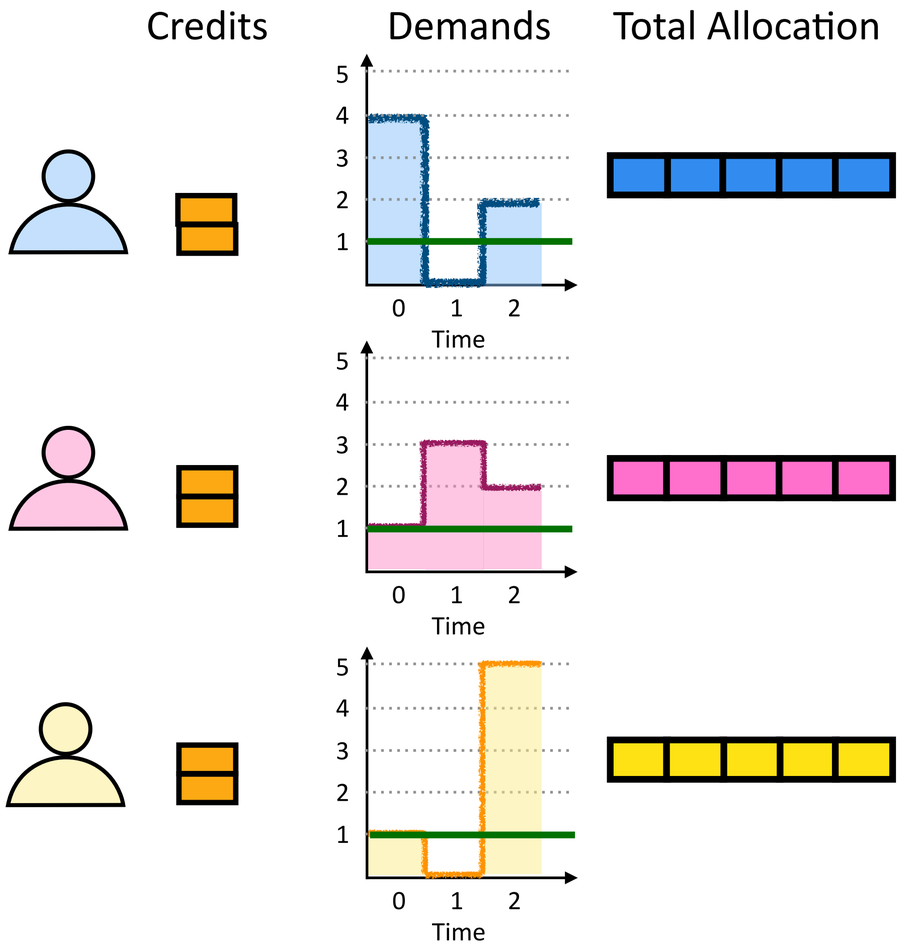
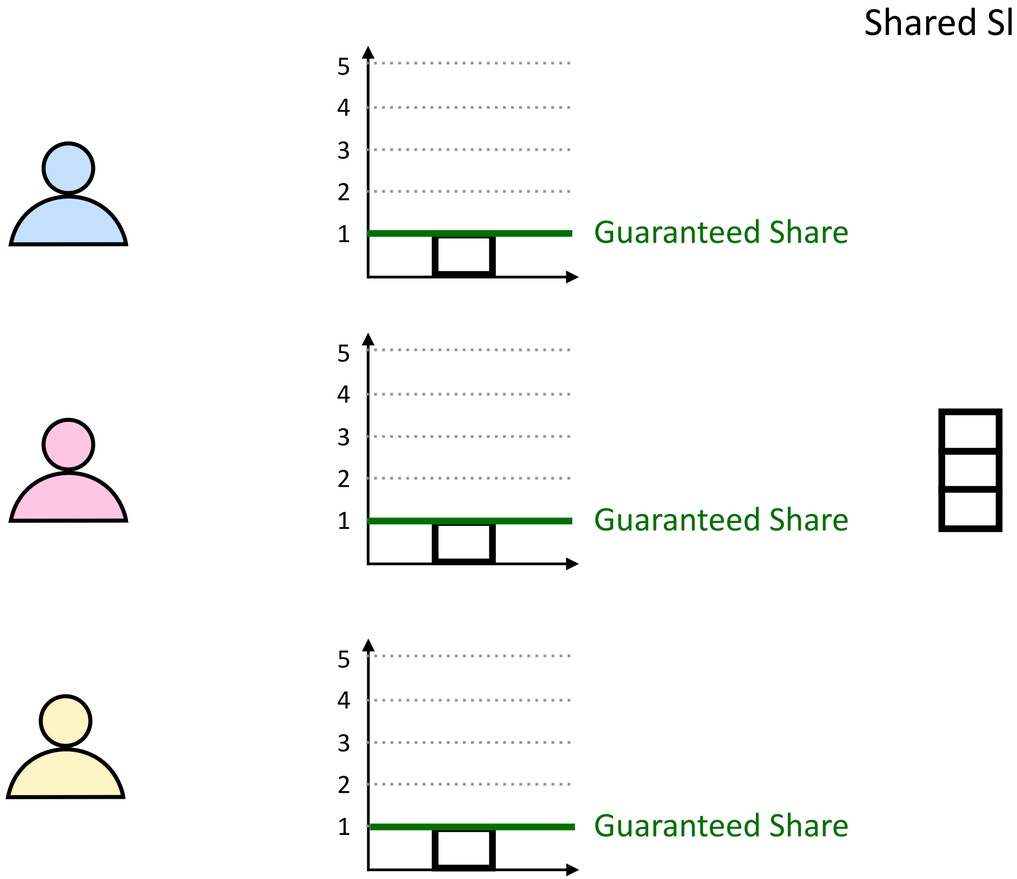


Equal total allocations!

Karma parameterizes the trade-off between instantaneous and long-term fairness



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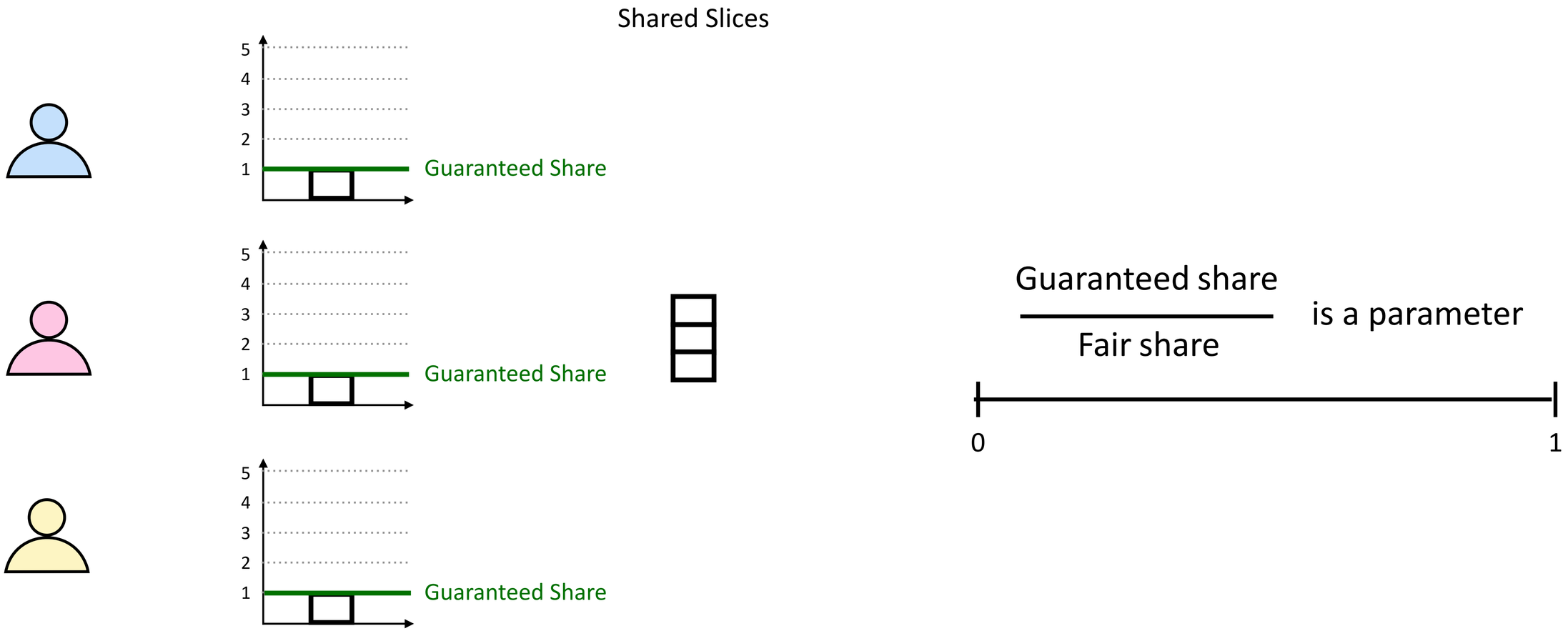

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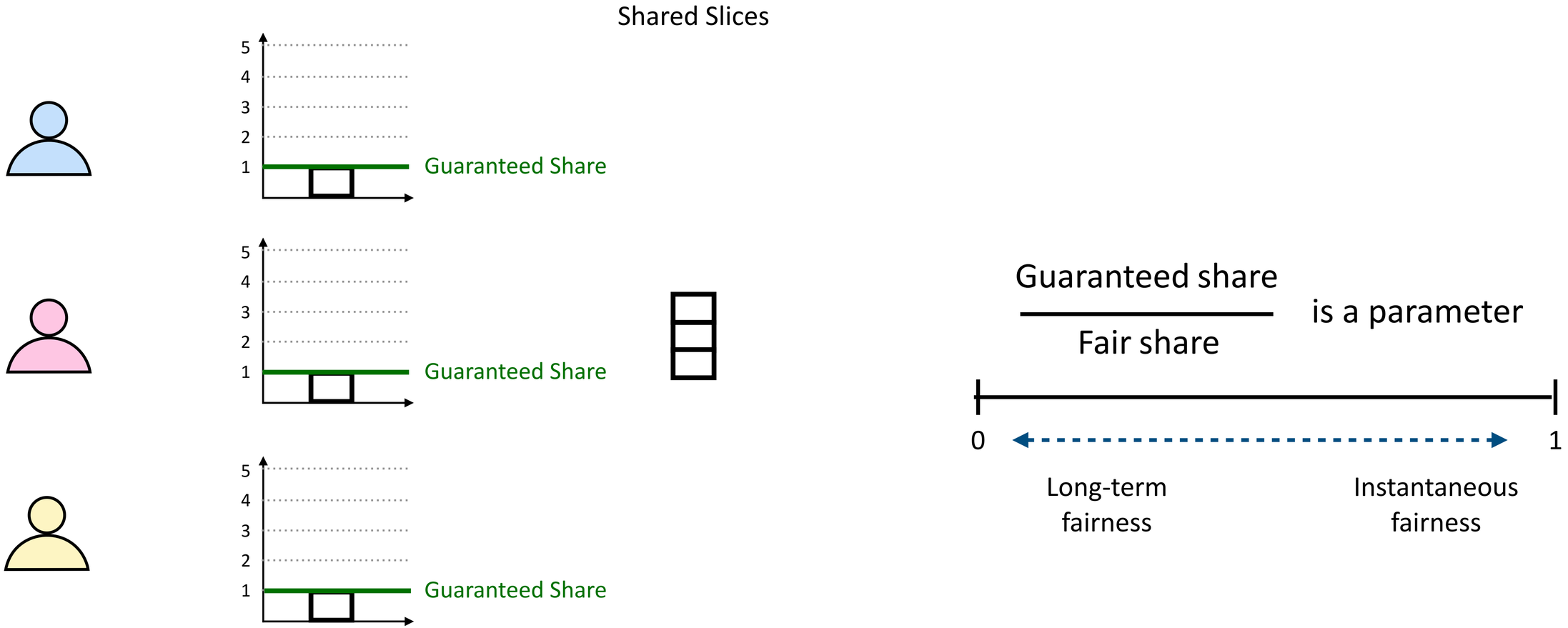

Guaranteed share / Fair share is a parameter

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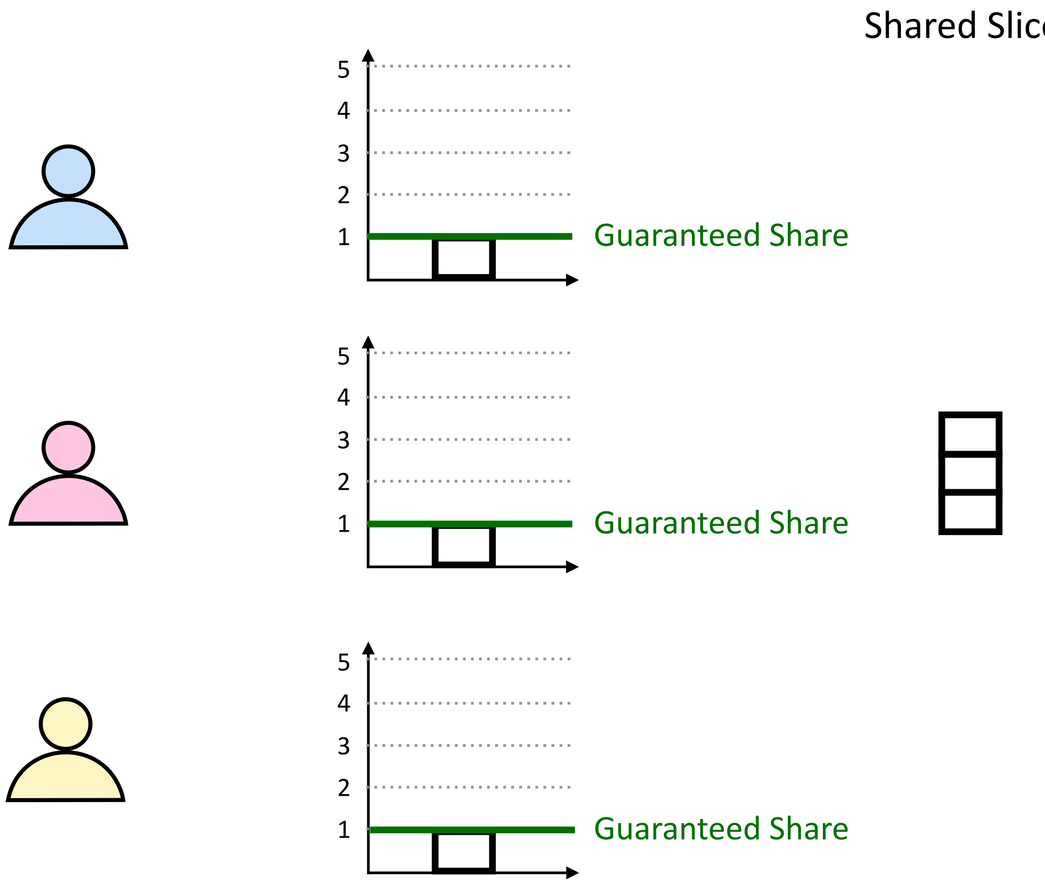
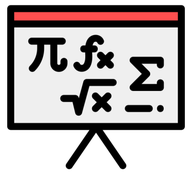


Guaranteed share / Fair share is a parameter

(See paper for more details)

Karma: Revisiting the classical resource allocation problem under dynamic demands

New resource allocation algorithm for dynamic demands



Theoretical guarantees

Pareto efficiency

Strategy-proofness

Fairness

Prototype implementation and evaluation

Karma is Pareto efficient

Pareto efficiency

Resources should not remain unused when there is demand

Karma is Pareto efficient

Pareto efficiency

Resources should not remain unused when there is demand

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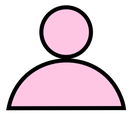
Karma provides powerful strategy-proofness properties

Strategy-proofness

Selfish users cannot increase their allocation by lying
(selfish ≠ adversarial)



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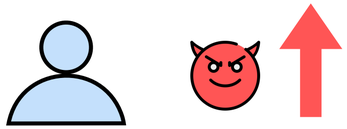

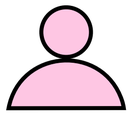

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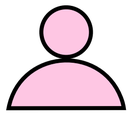

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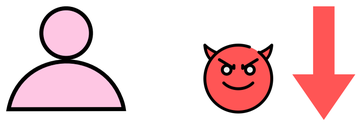

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Perfect knowledge of
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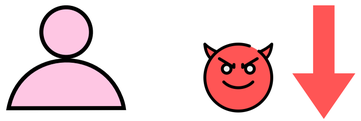

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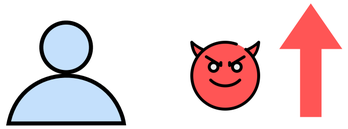

Not possible to increase allocation

Perfect knowledge of
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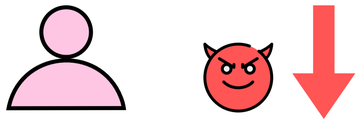
Far from realistic



No more than 1.5x increase in allocation

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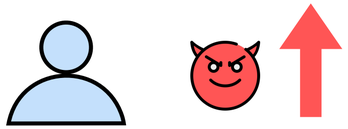

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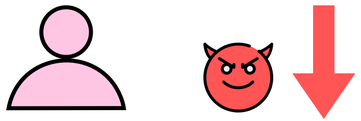

No more than 1.5x increase in allocation

<u>Any</u> imprecision in knowledge of
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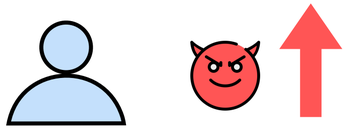

Not possible to increase allocation

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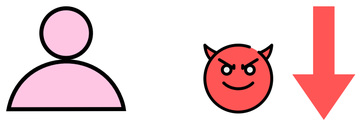
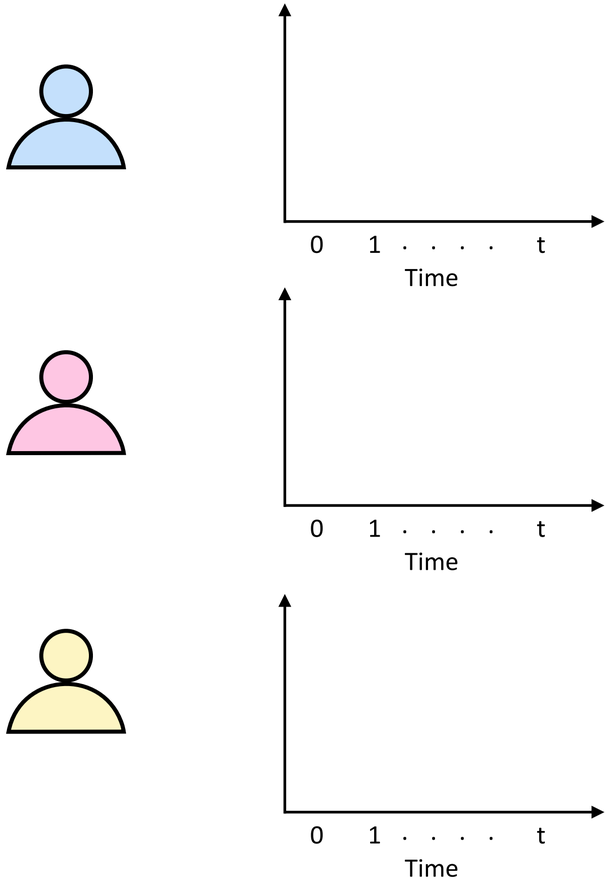
As much as Ω(n) factor decrease in allocation



Karma maximizes the minimum total allocation (given past allocations)

Fairness

Balanced resource allocations across users



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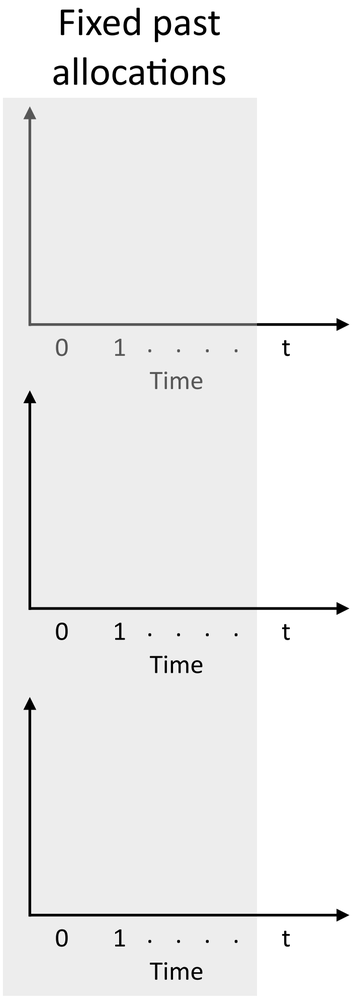

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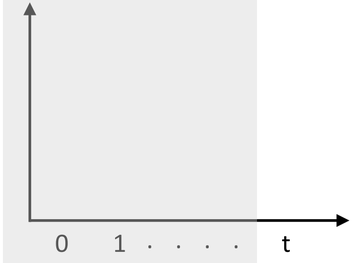
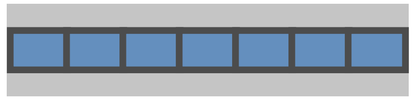
Fairness

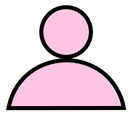
Balanced resource allocations across users

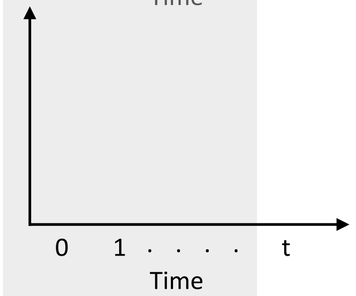
Fixed past allocations

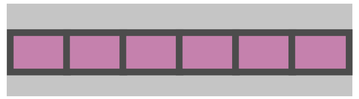
Total Allocation (from 0 to t-1)

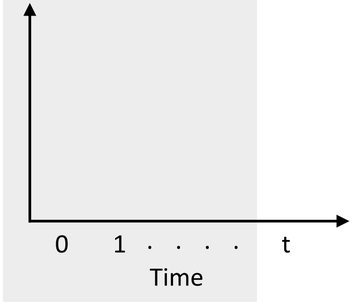








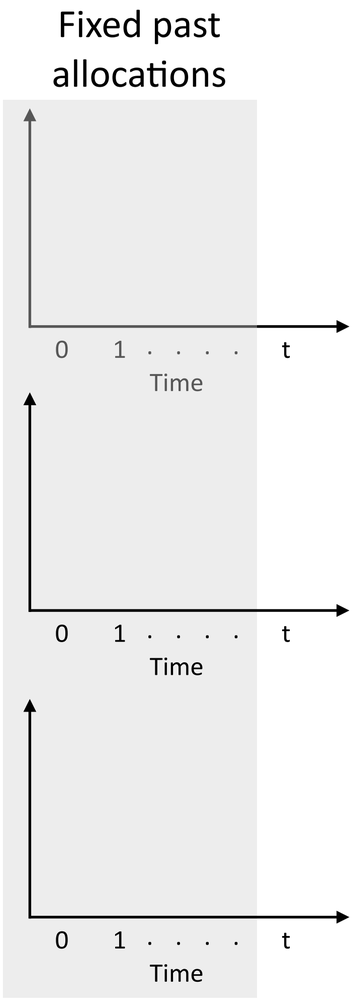




Karma maximizes the minimum total allocation (given past allocations)

Fairness

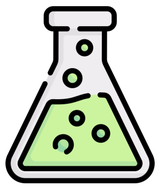
Balanced resource allocations across users



Karma: Resource Allocation for Dynamic Demands

New credit-based resource allocation algorithm

Strong theoretical guarantees



Prototype implementation and evaluation

Karma implementation & evaluation

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Implemented in distributed elastic memory system (Jiffy [Eurosys'22])

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Evaluated in-memory key-value cache scenario

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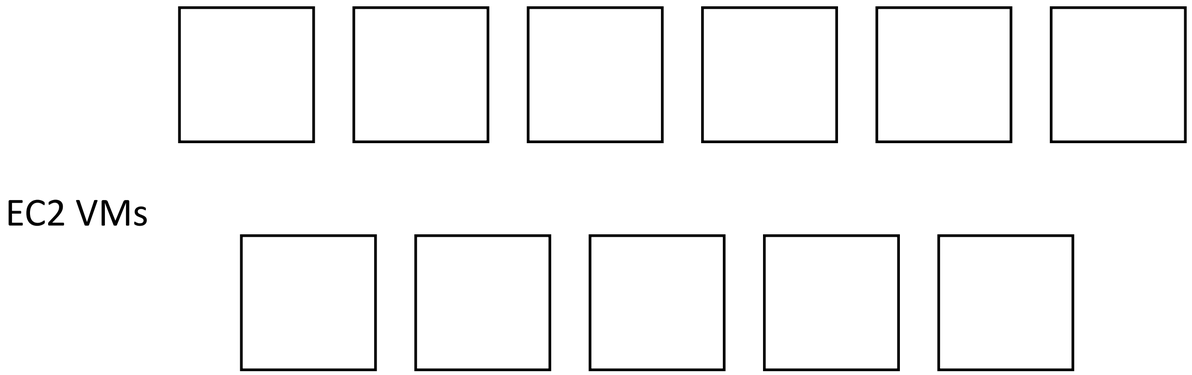
Experimental Setup



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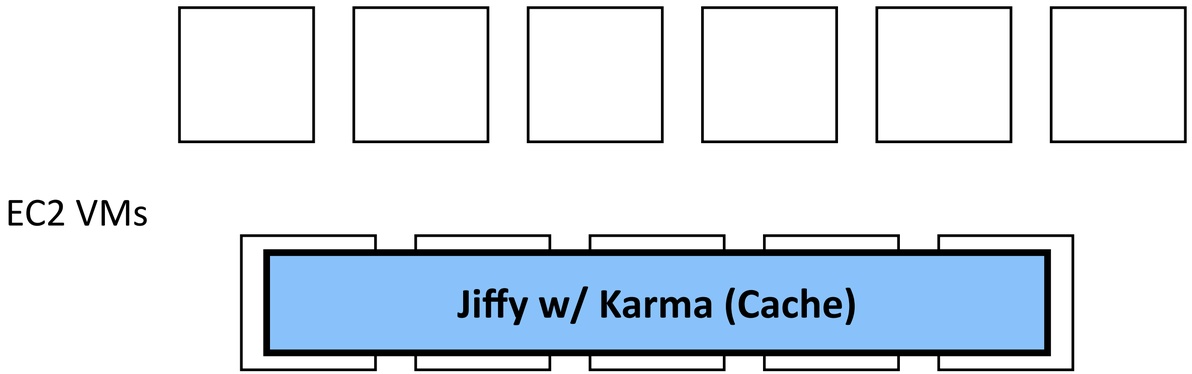

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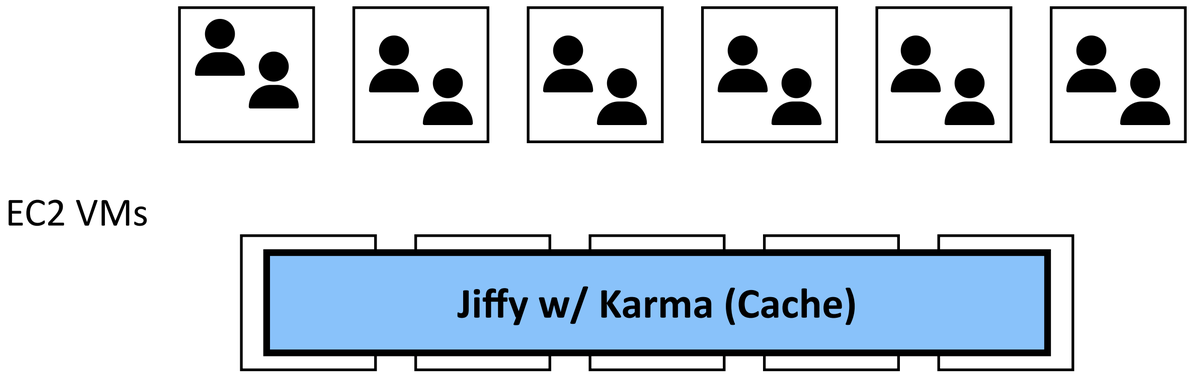

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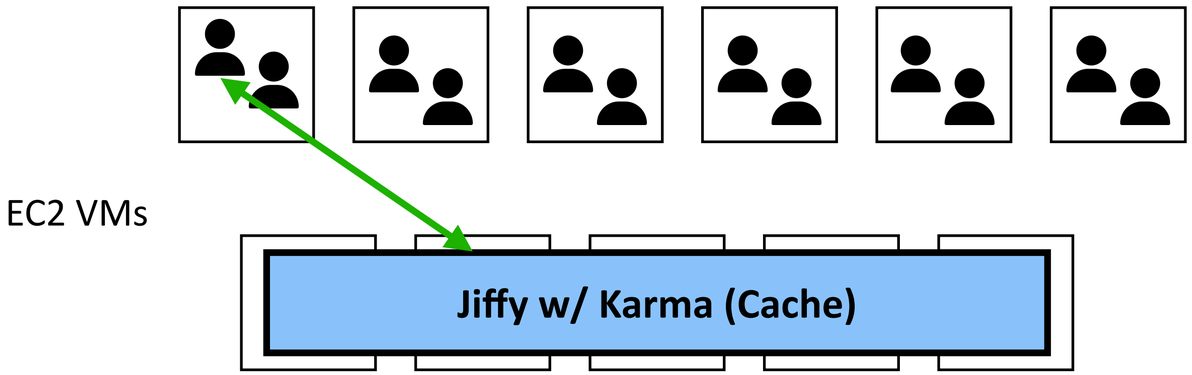

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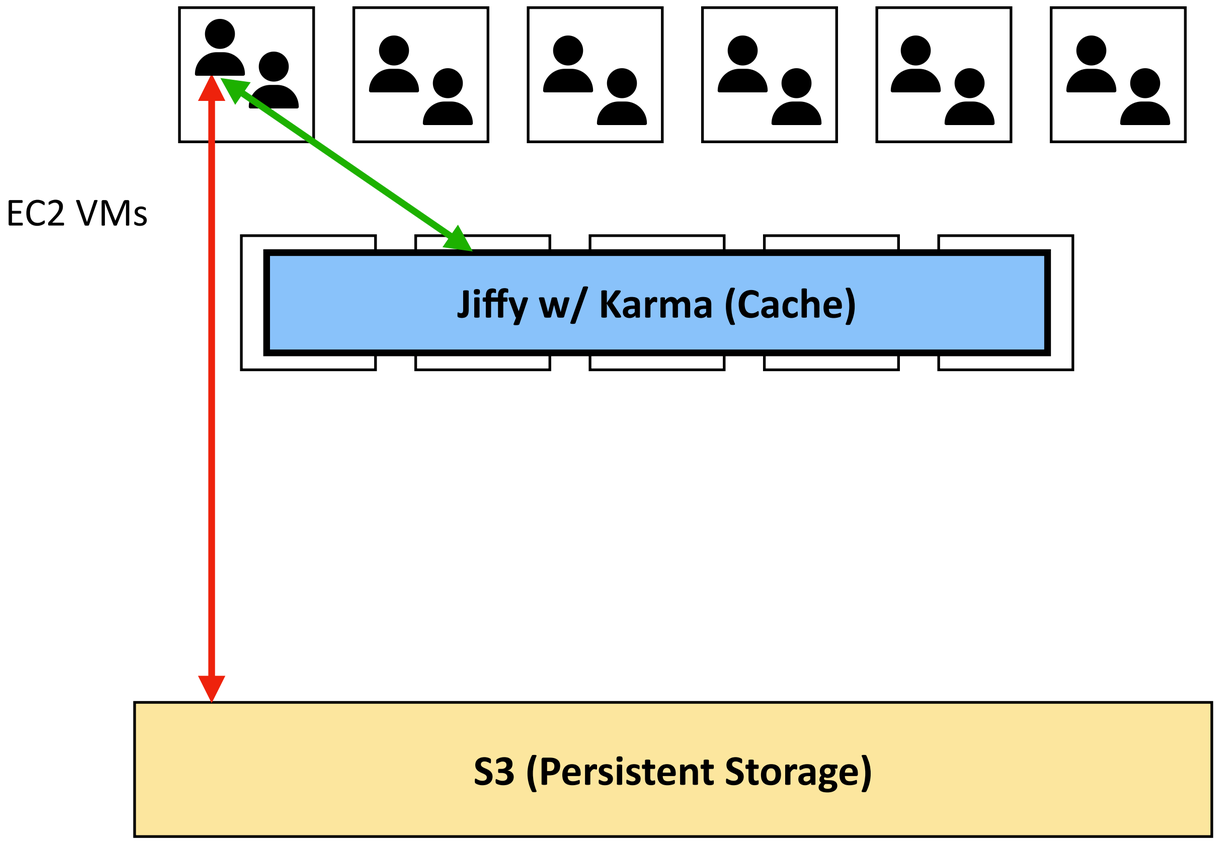

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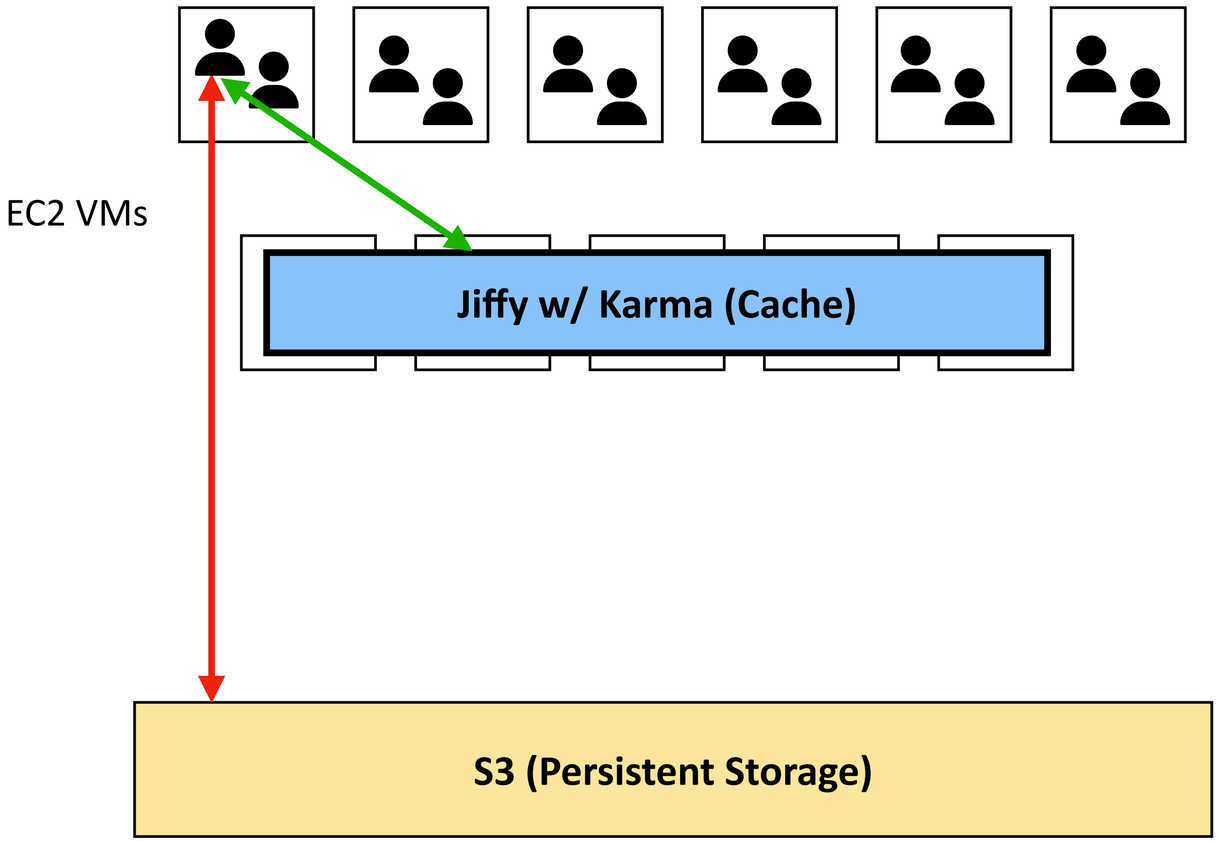

Workload

Dynamic demands -> vary working set size

Demands taken from Snowflake dataset

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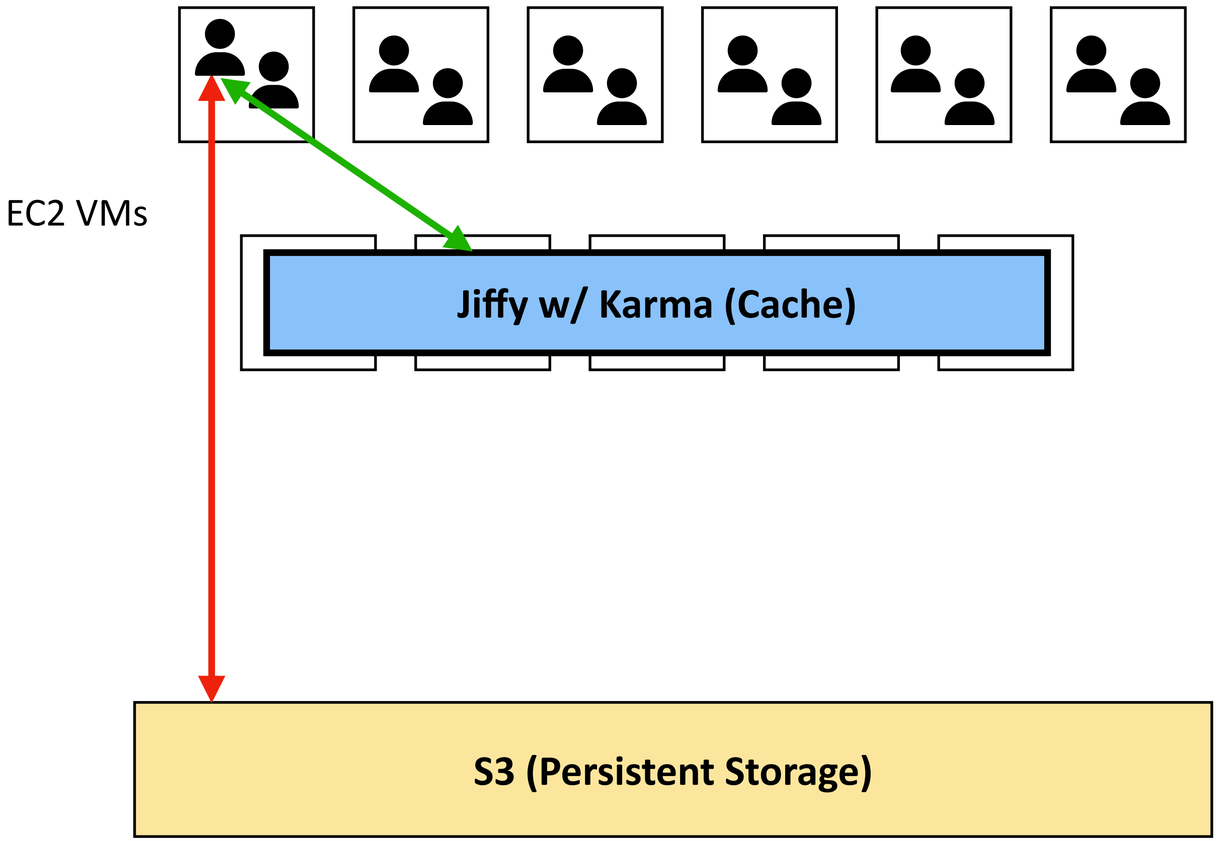

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(See paper for details)

Glimpse of Karma evaluation results

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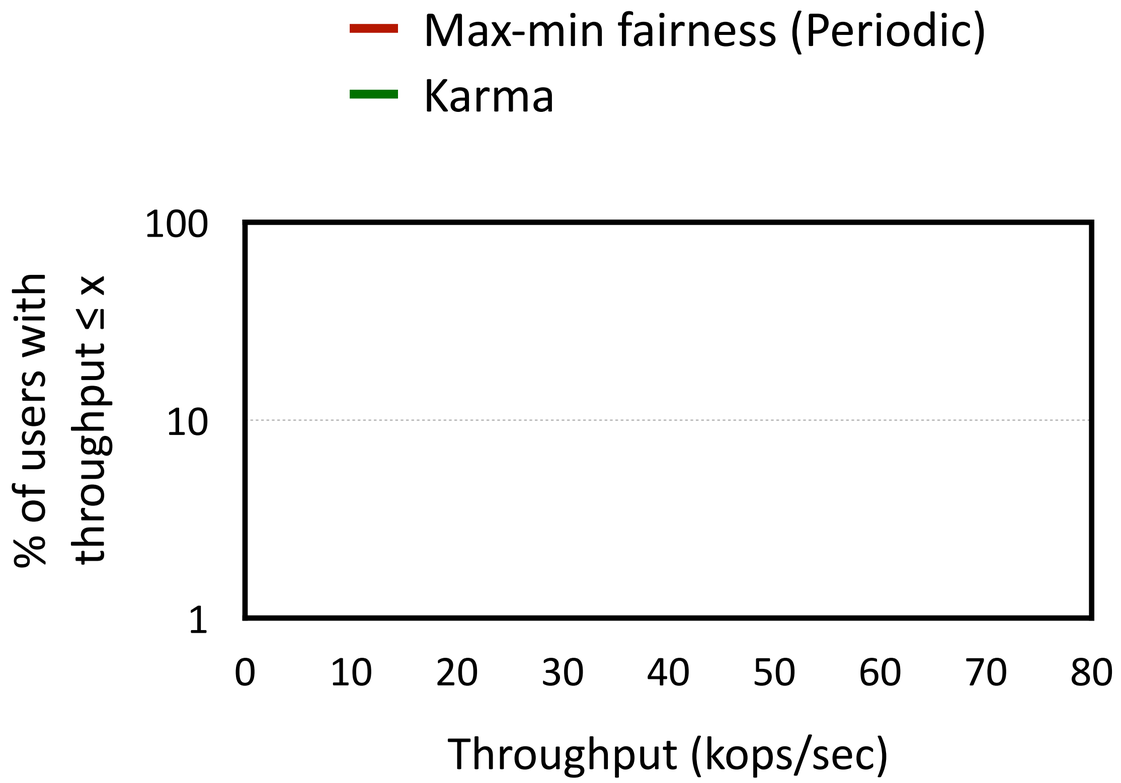

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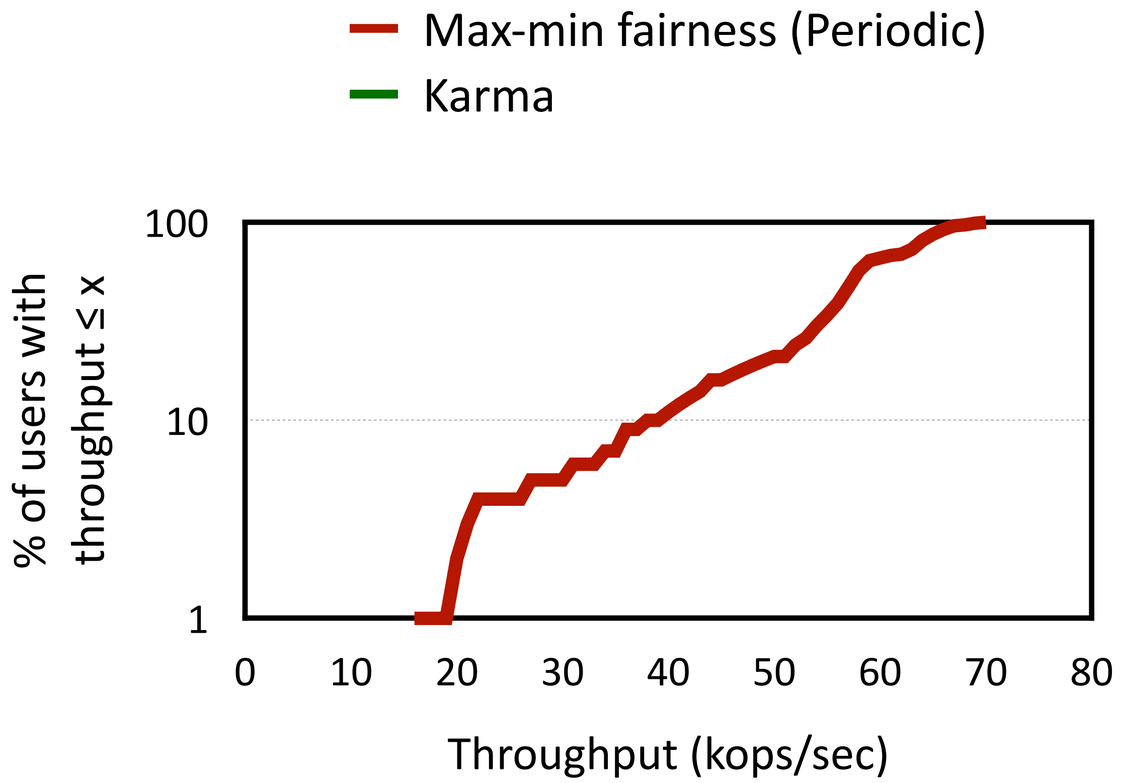

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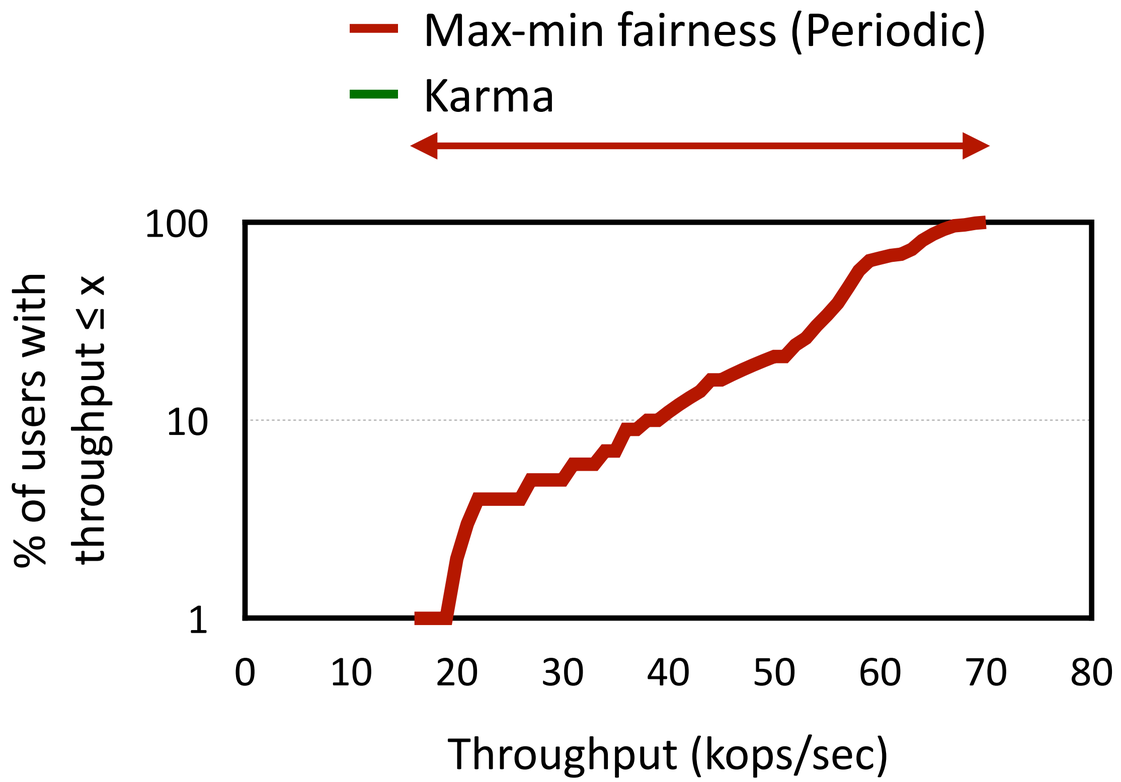

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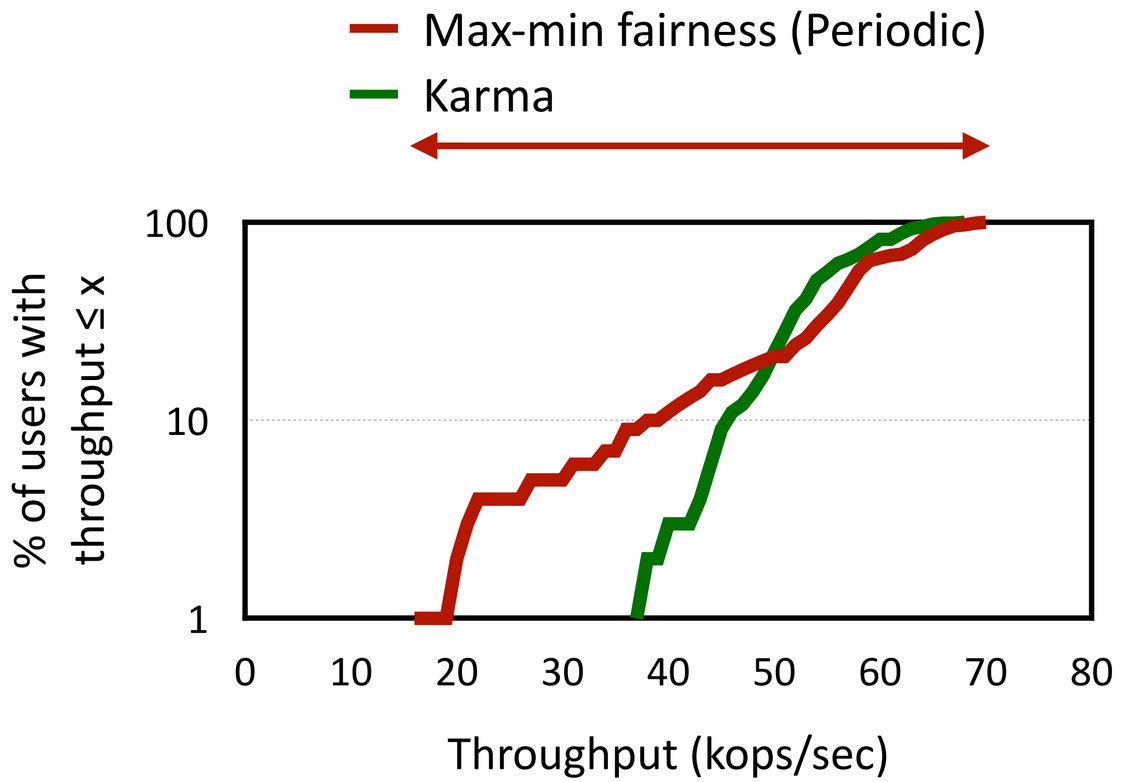

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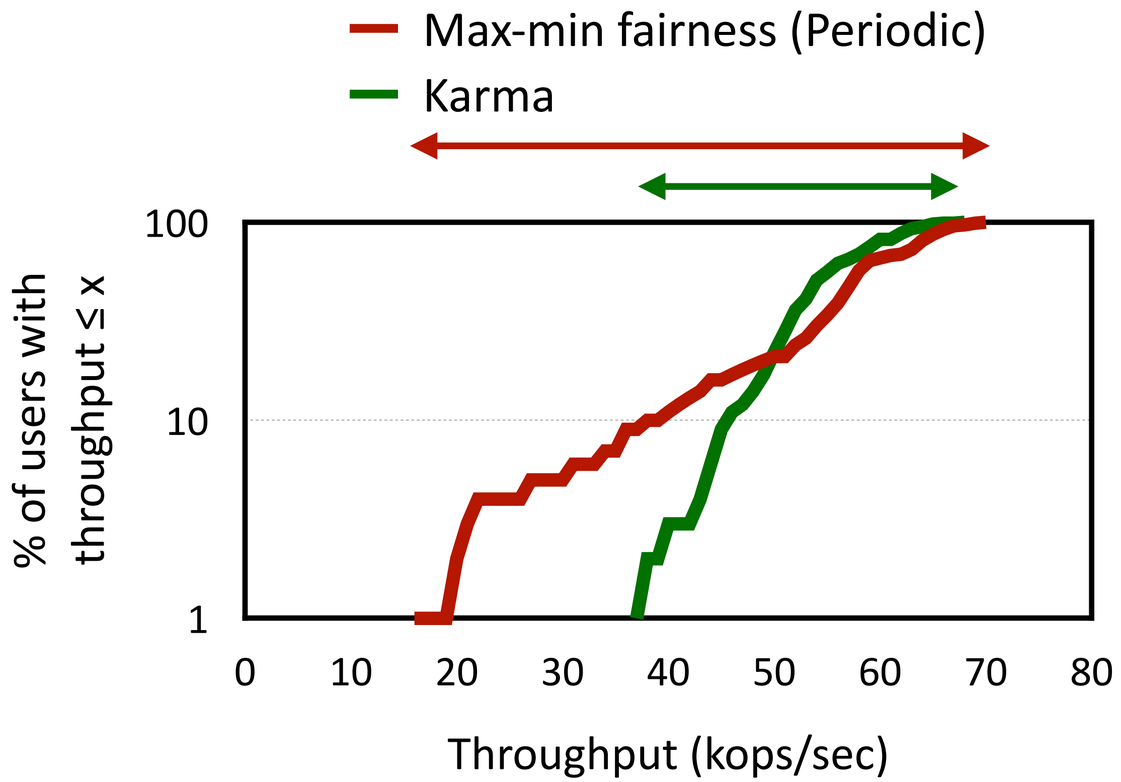

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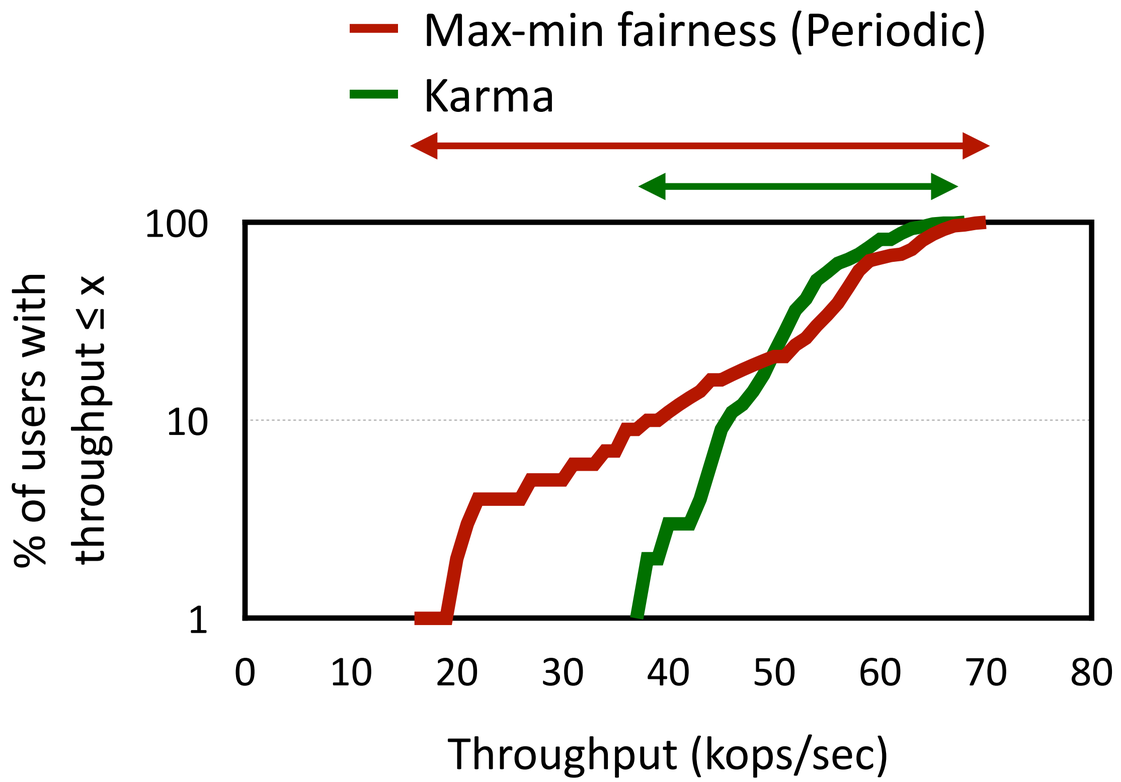

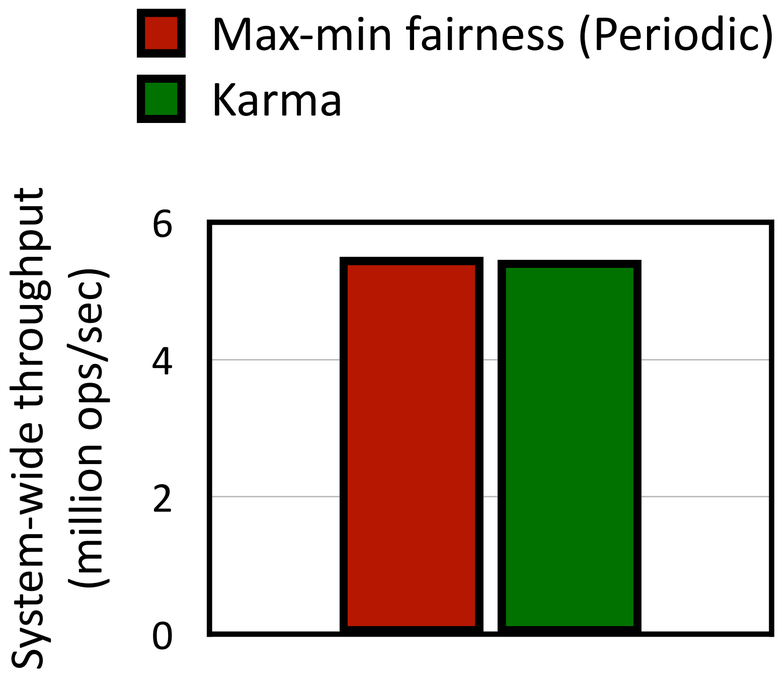

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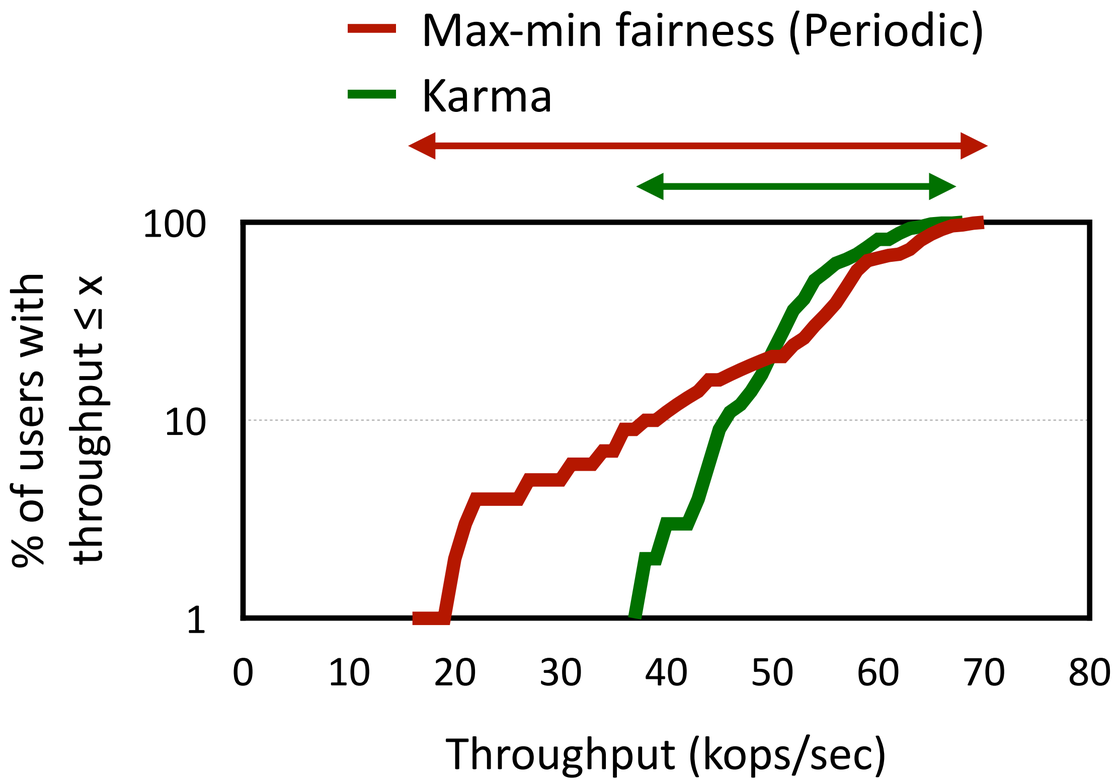

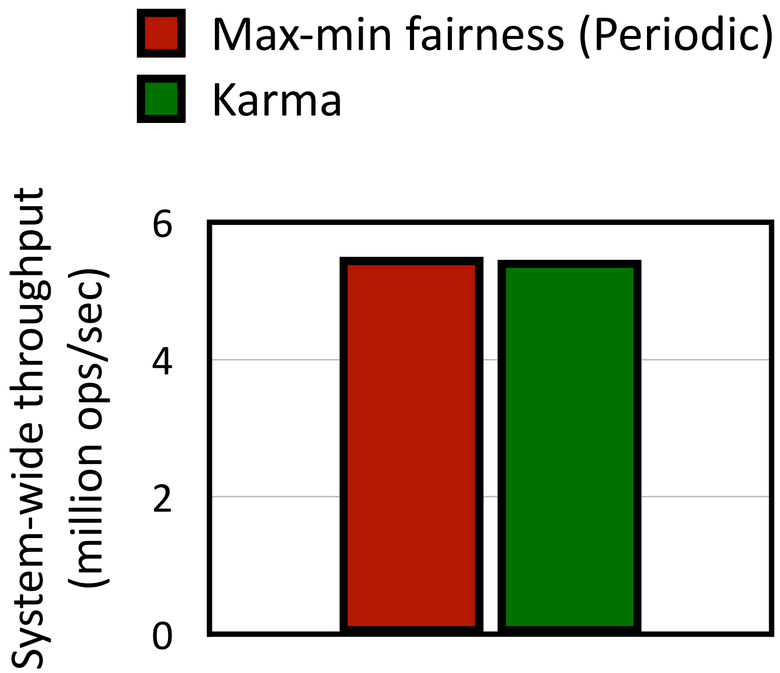

Karma minimizes disparity across users
(while maintaining high average performance)

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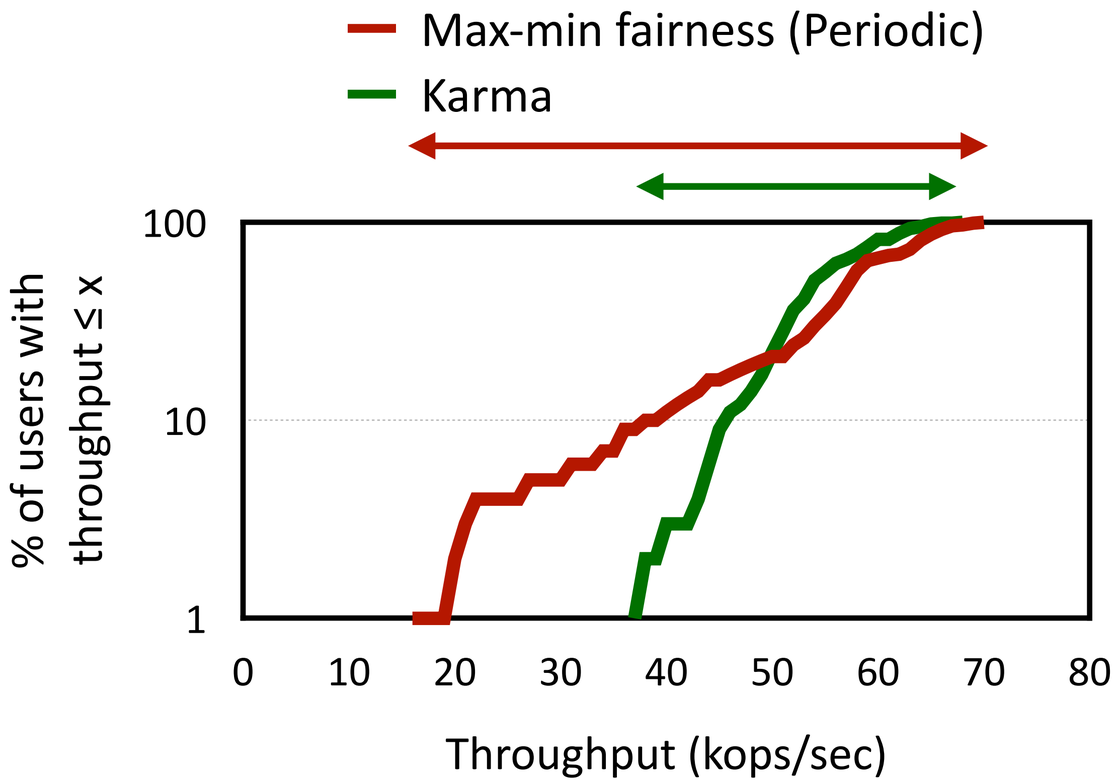

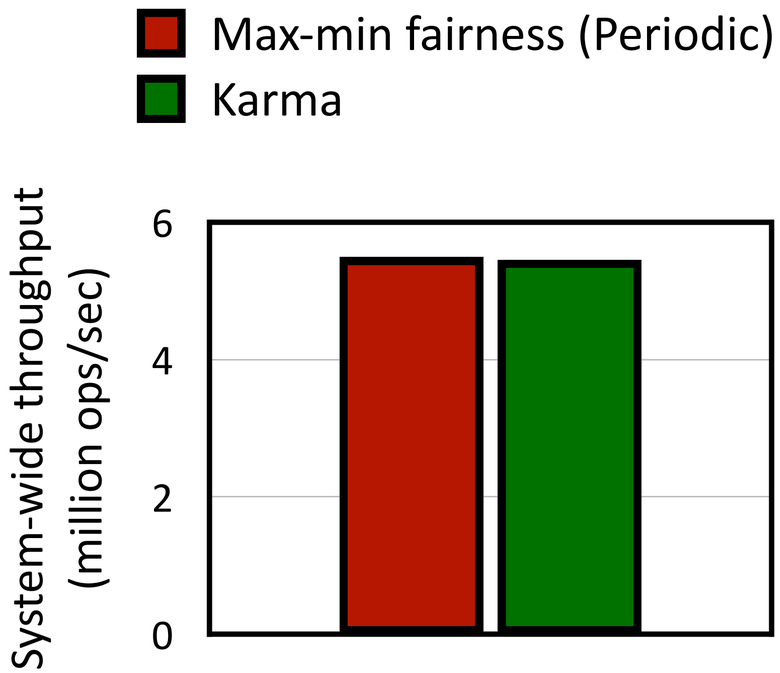

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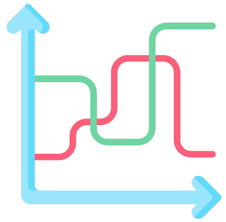
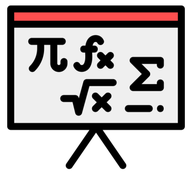
(See paper for more detailed evaluation results)

Karma: Revisiting the classical resource allocation problem under dynamic demands



New resource allocation algorithm for dynamic demands

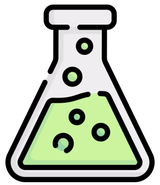


Theoretical guarantees

Pareto efficiency

Strategy-proofness

Fairness



Prototype implementation and evaluation

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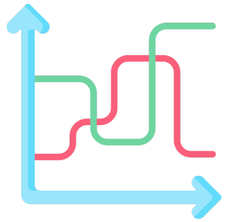

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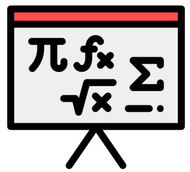

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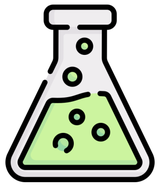

Prototype implementation and evaluation

Karma opens many interesting avenues for future research, both in systems and in theory

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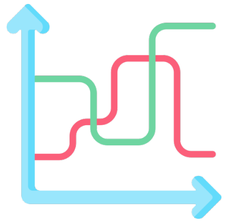

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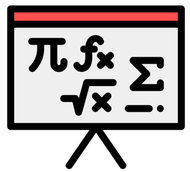

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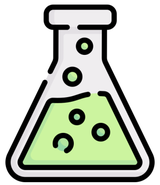

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https://github.com/resource-disaggregation/karma

Midhul Vuppalapati (midhul@cs.cornell.edu)