Karma:
Resource Allocation for Dynamic Demands


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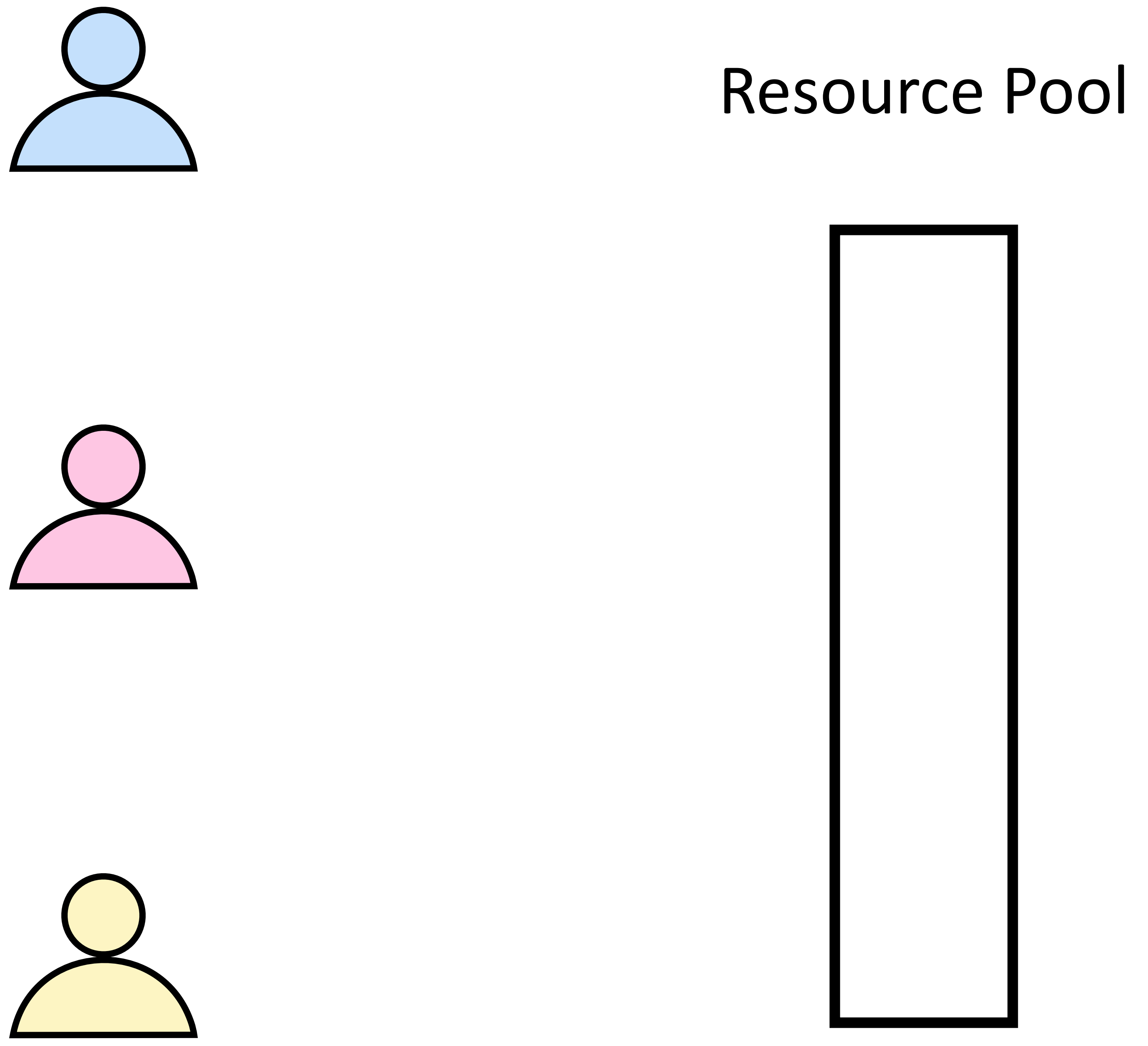
Cornell University

Columbia University

Yale University

Resource allocation is a fundamental problem

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



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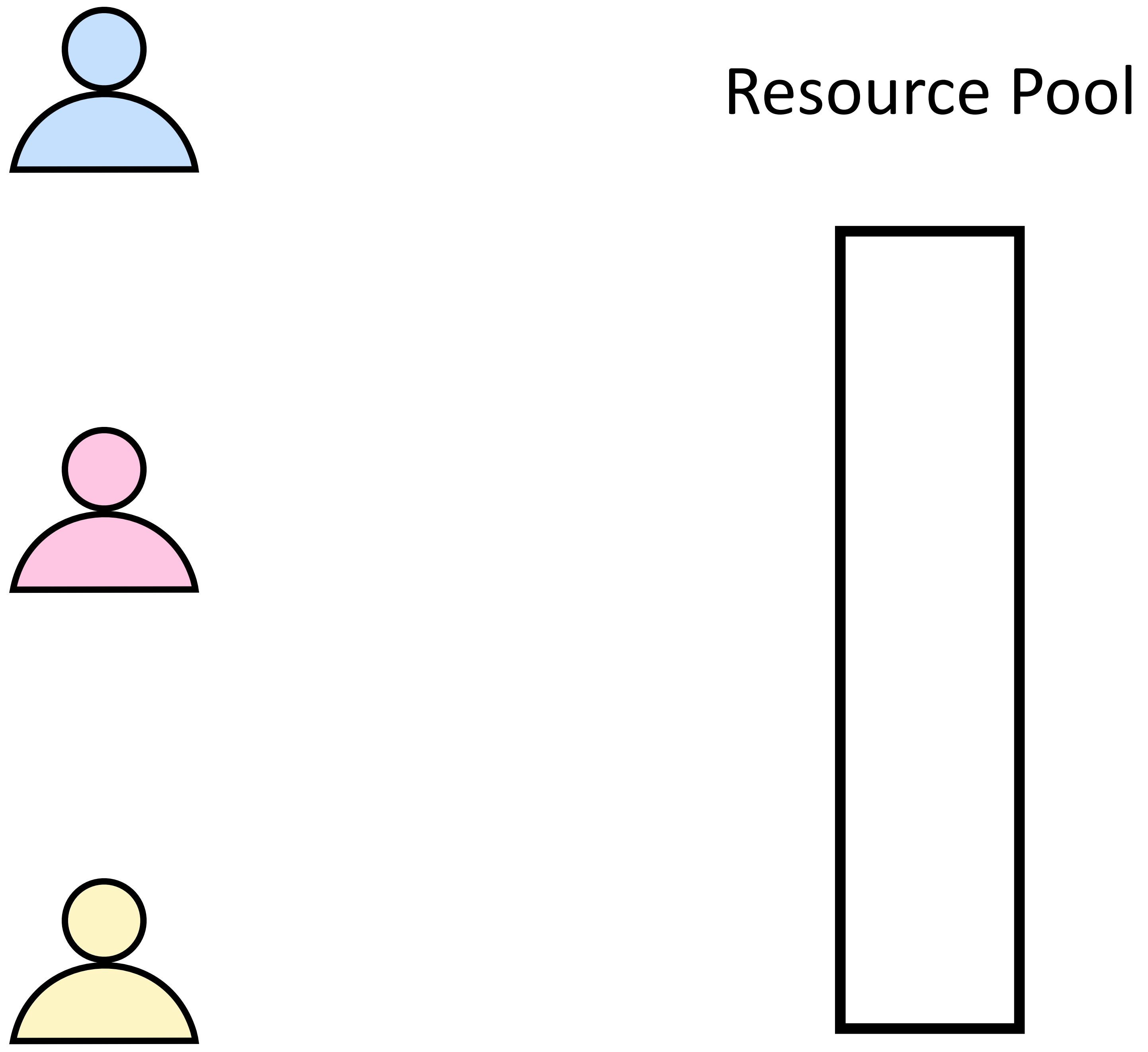

Key Desirable Properties

Resource allocation is a fundamental problem

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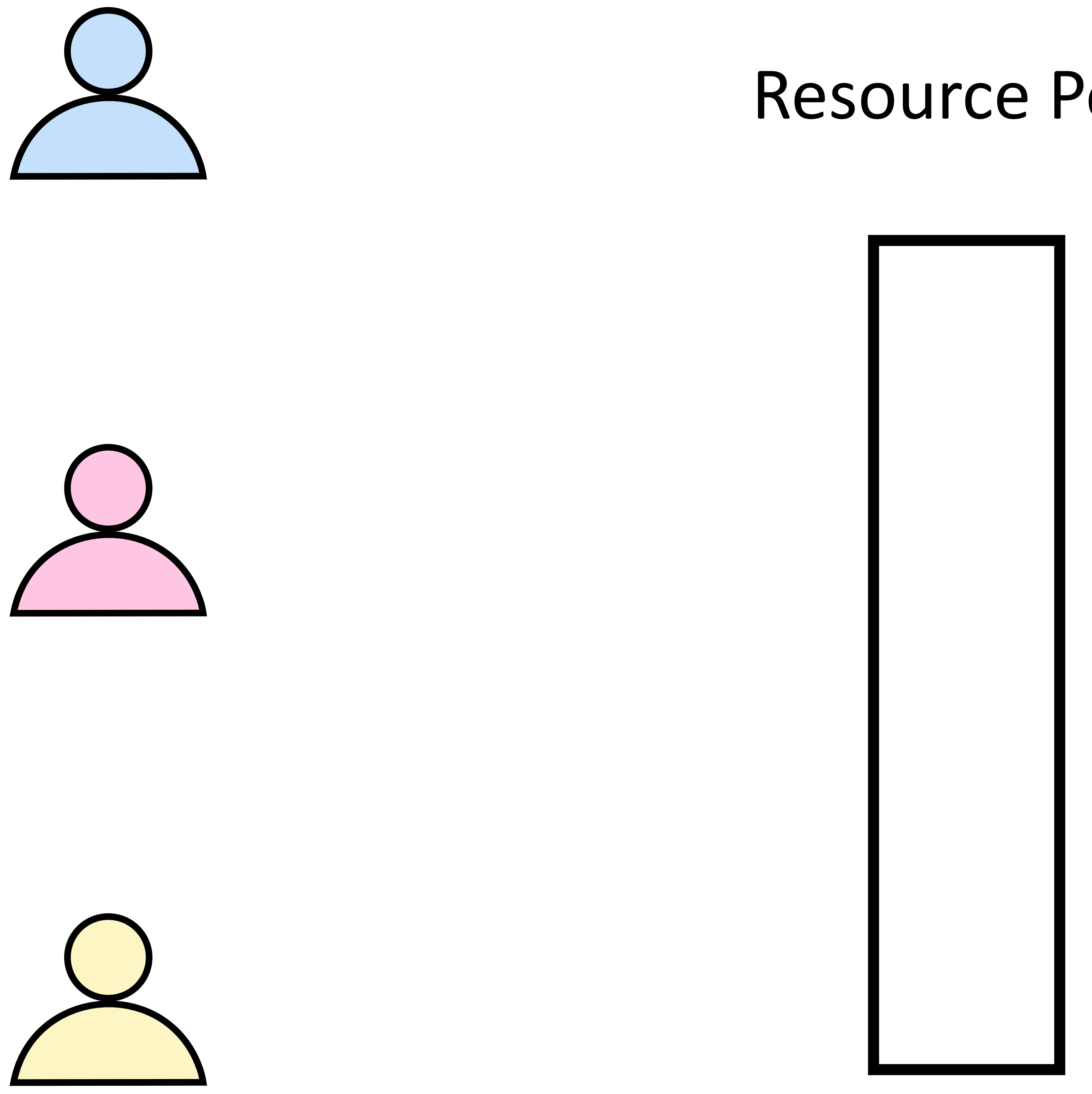
Resource Pool



Key Desirable Properties

Pareto efficiency

Resources should not remain unused if there is demand

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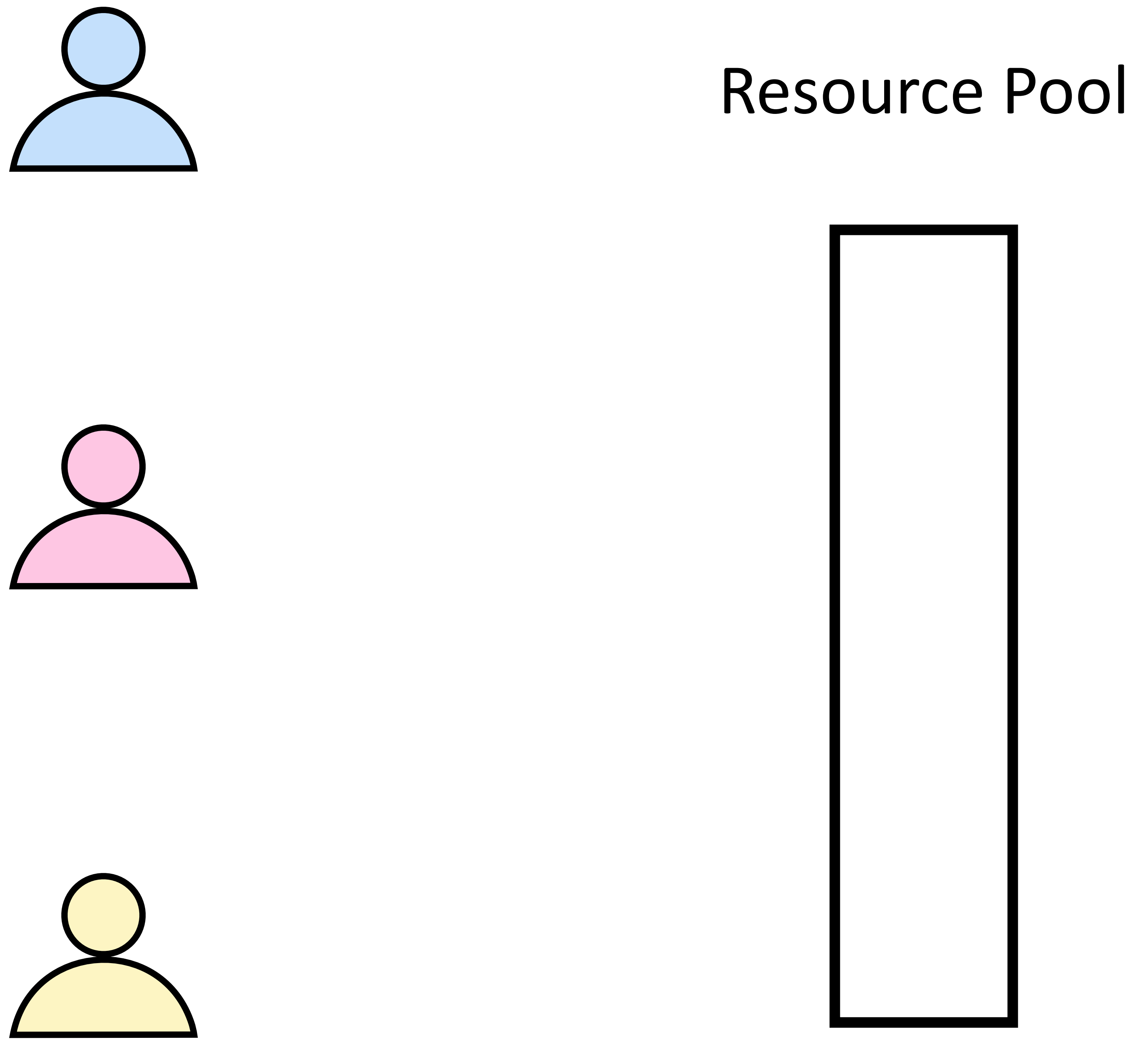

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Selfish users cannot increase their allocation by lying
(selfish ≠ adversarial)

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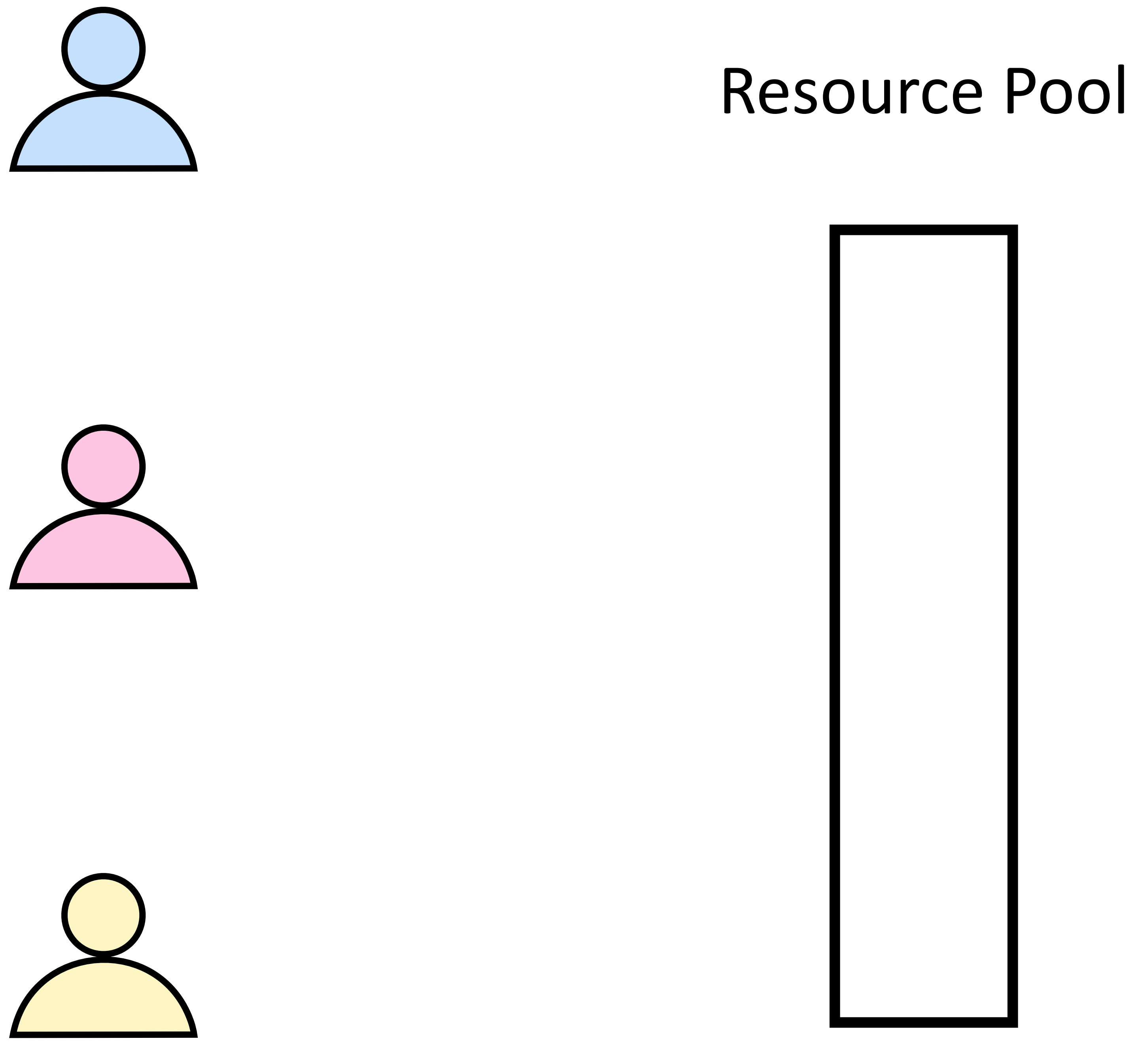

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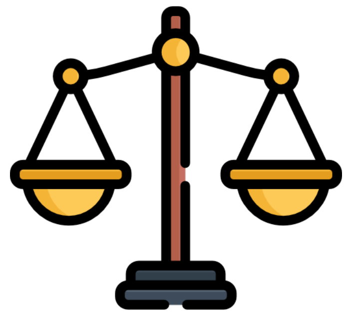

Fairness

Balanced resource allocations across users

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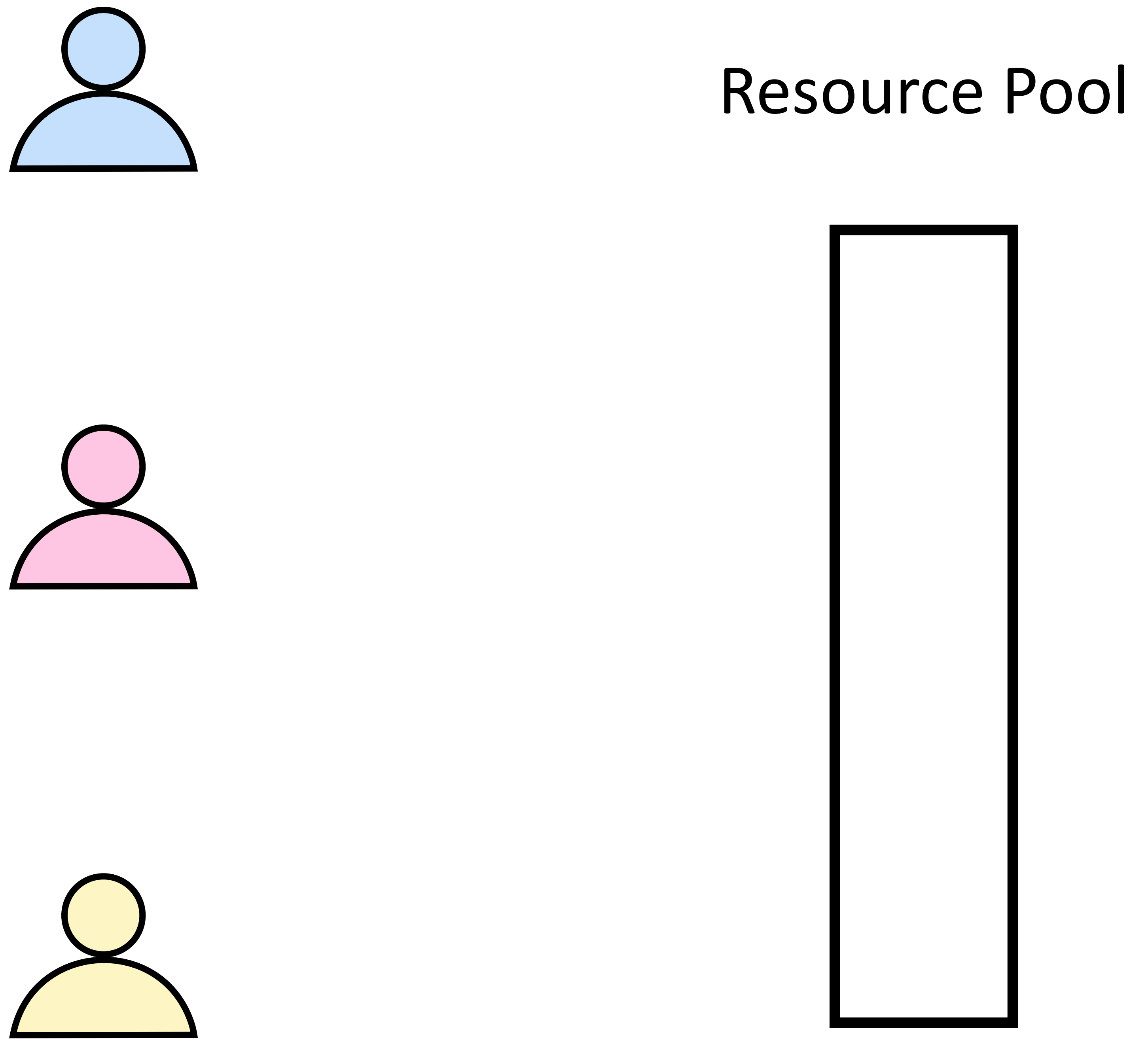

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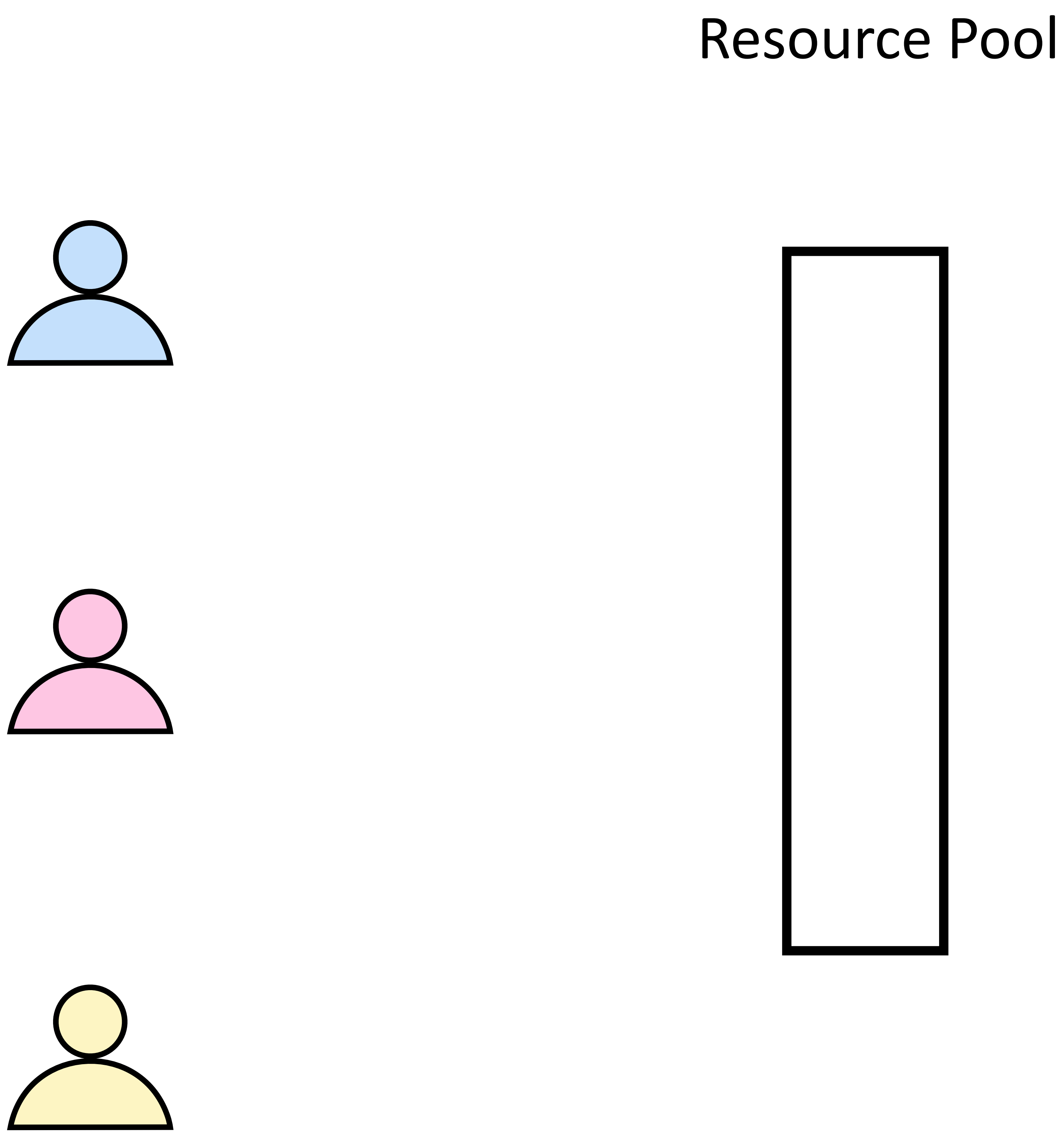
Balanced resource allocations across users

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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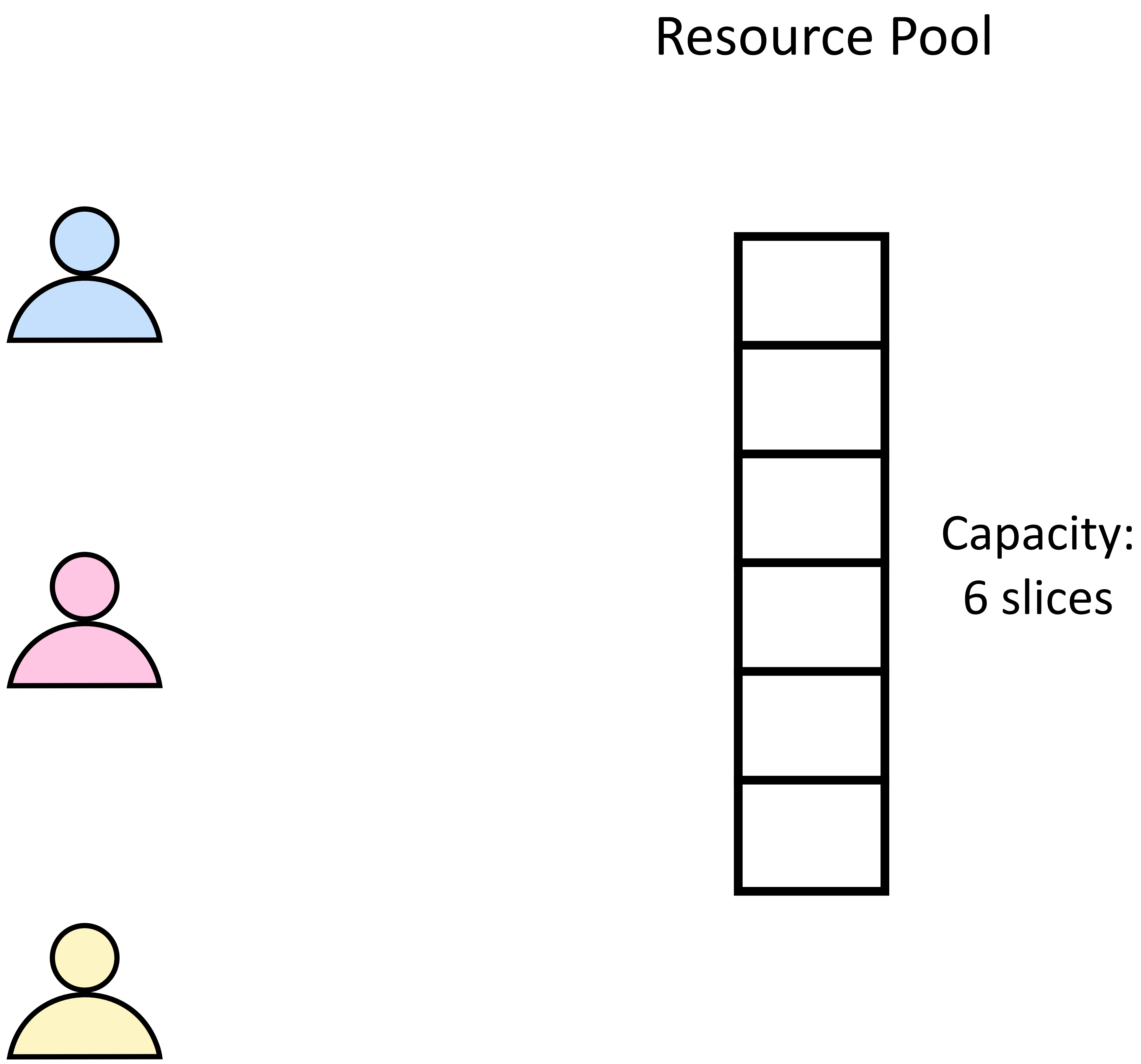

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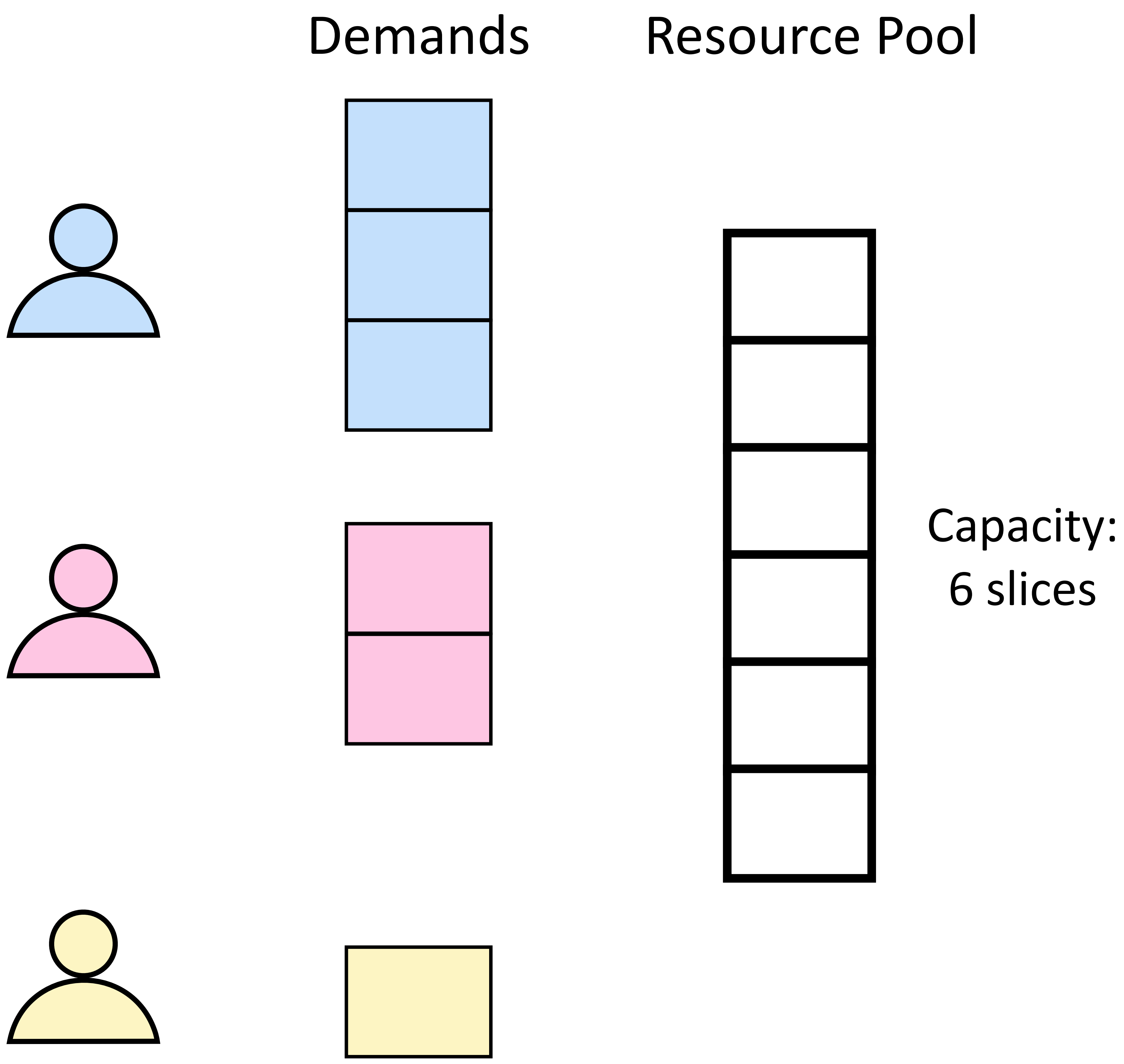

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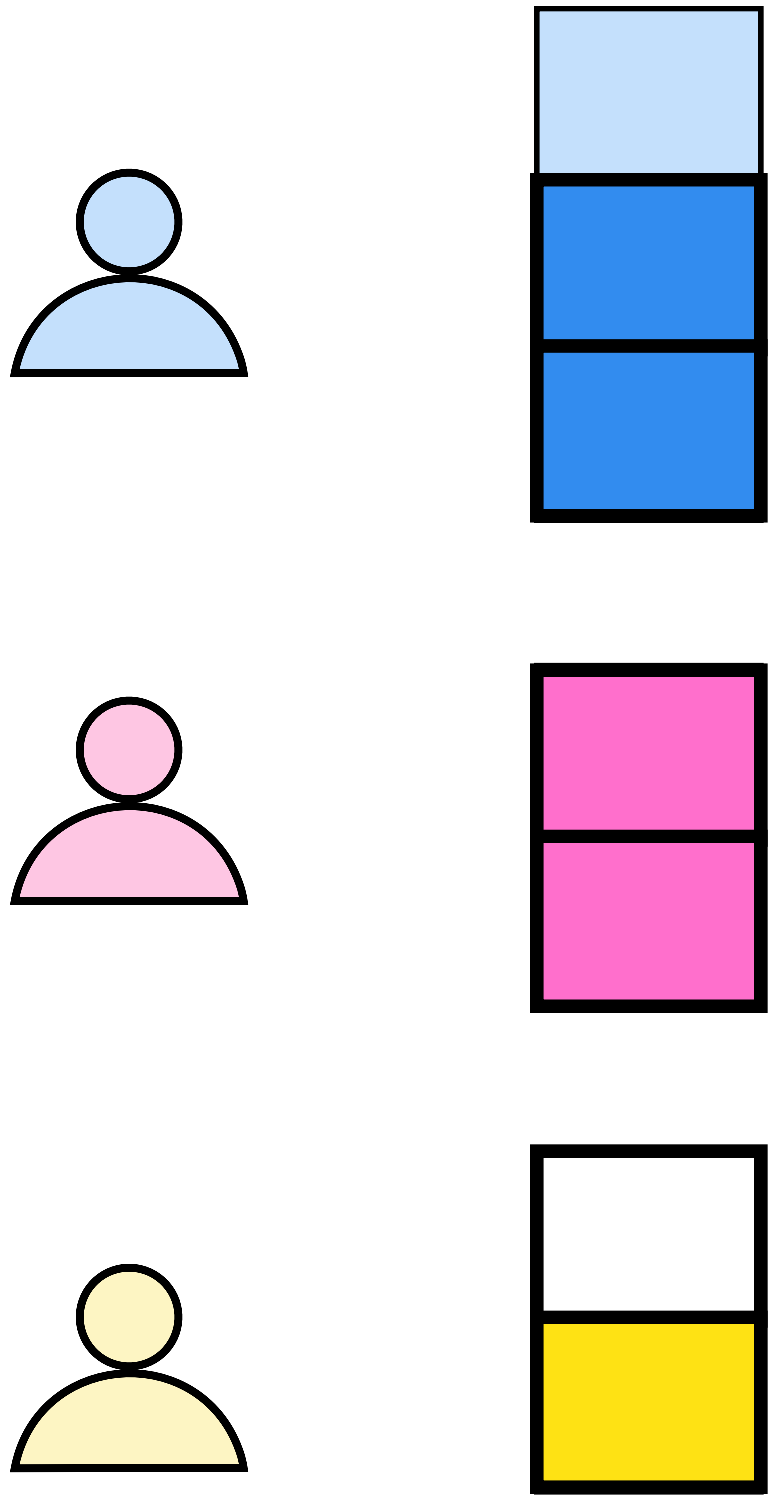
Demands Resource Pool



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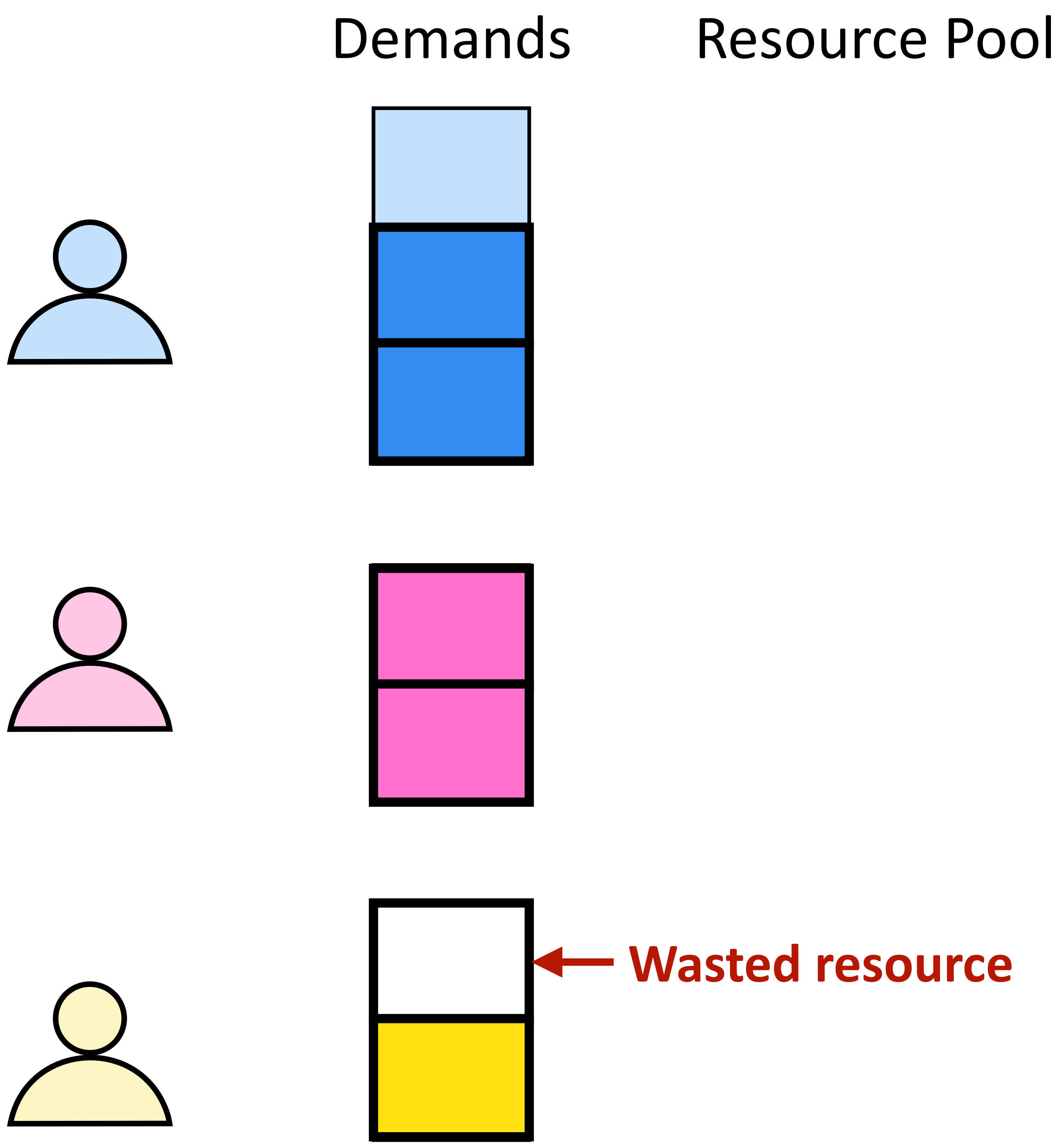

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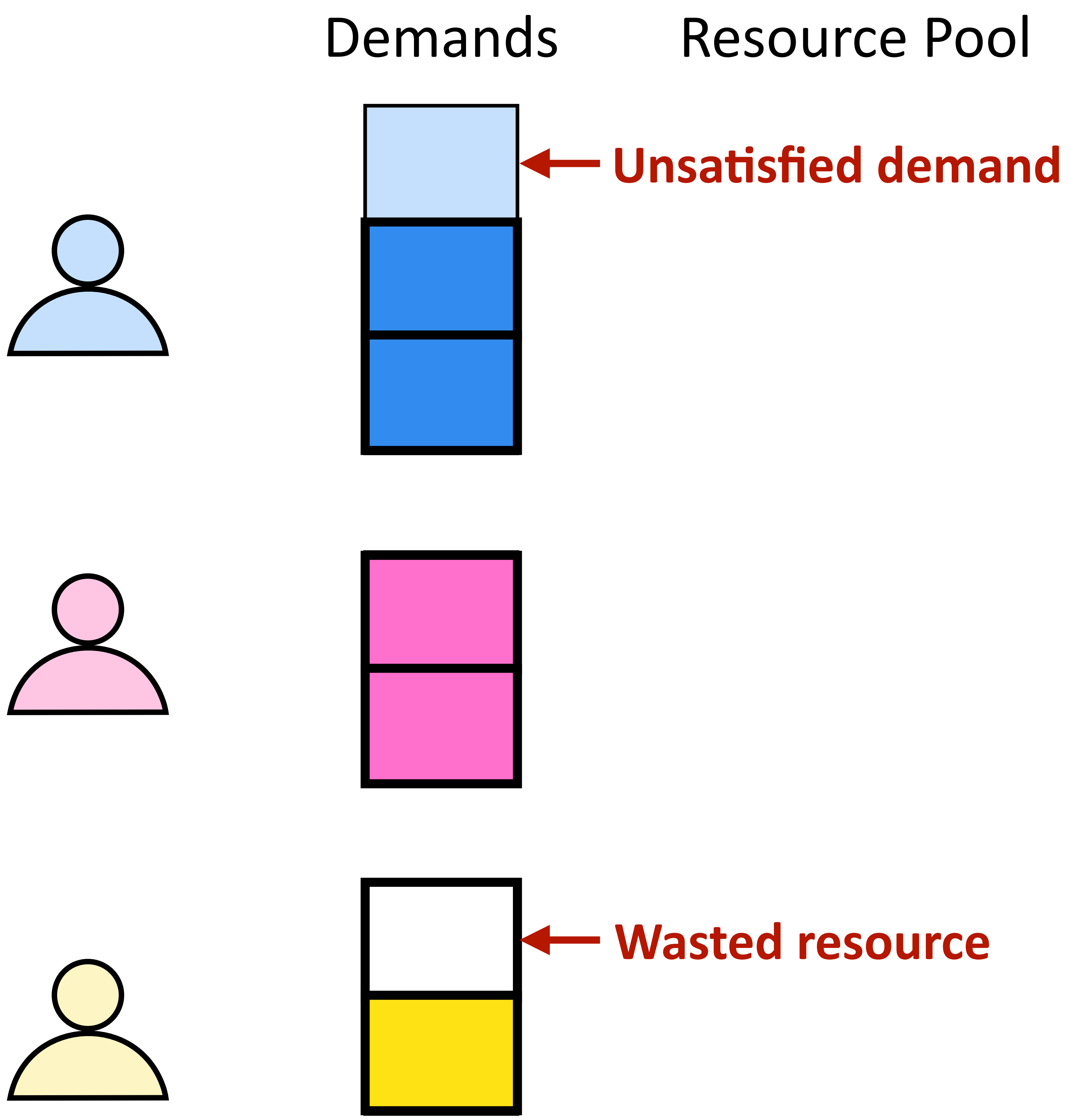

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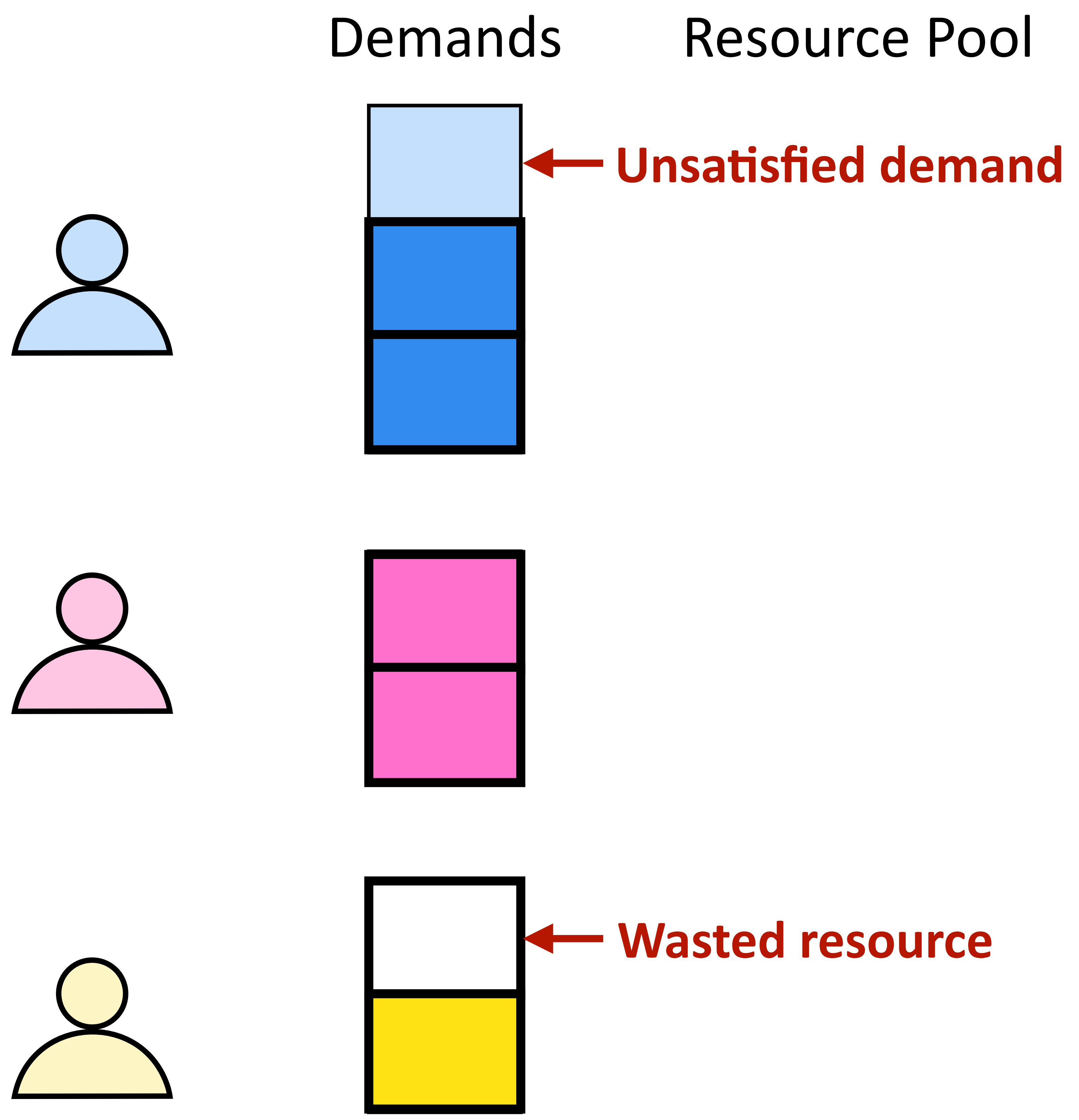

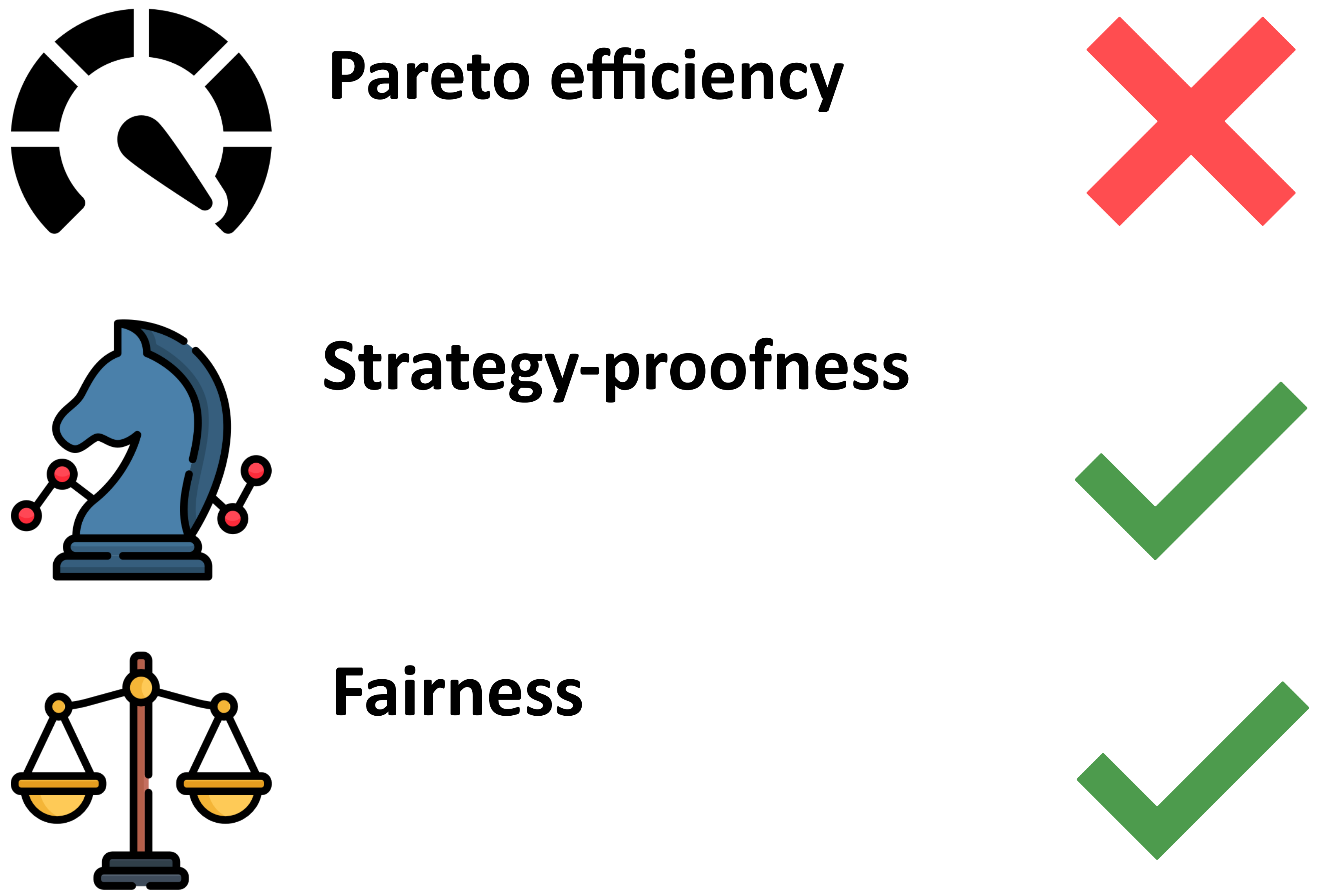

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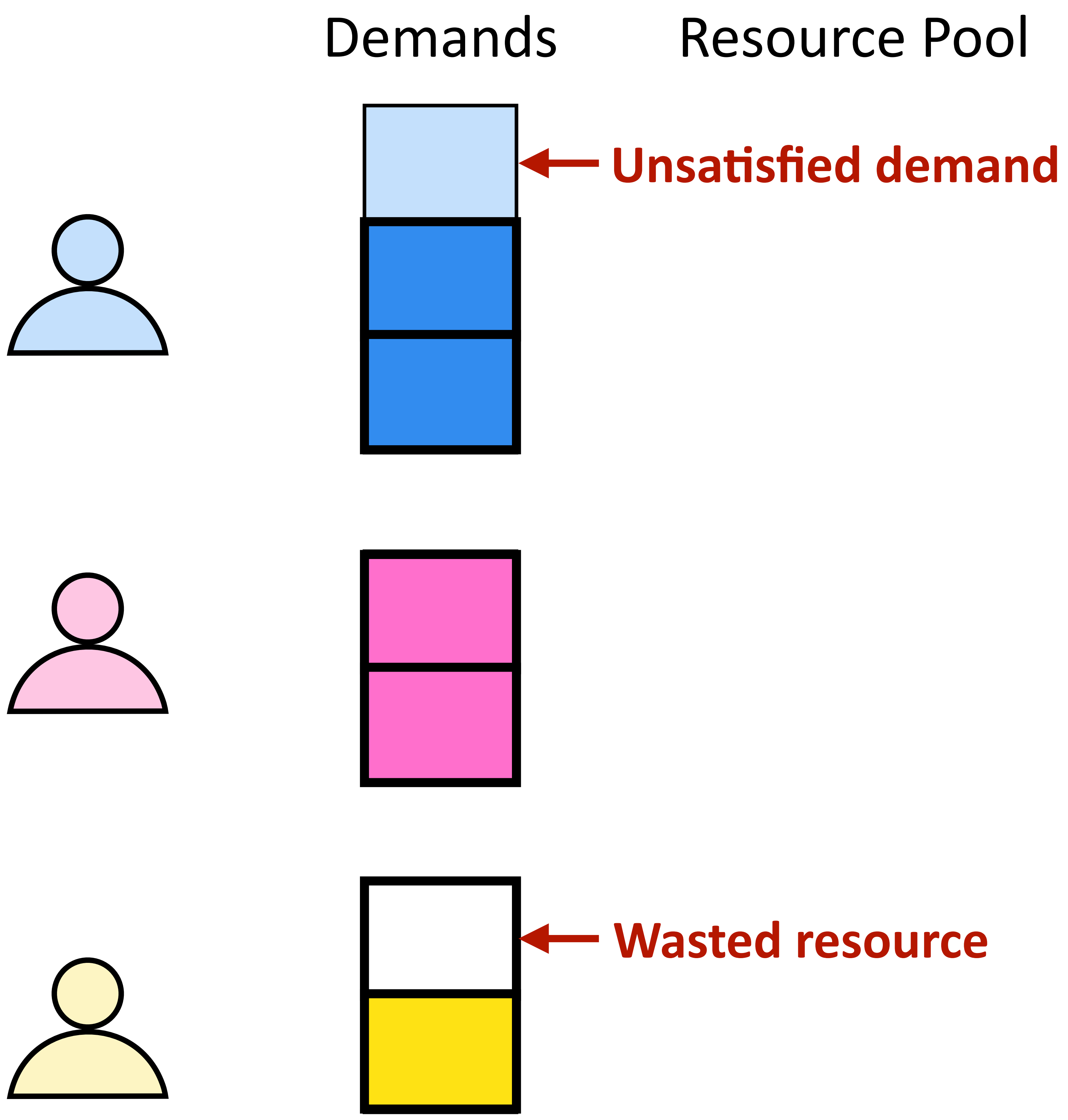
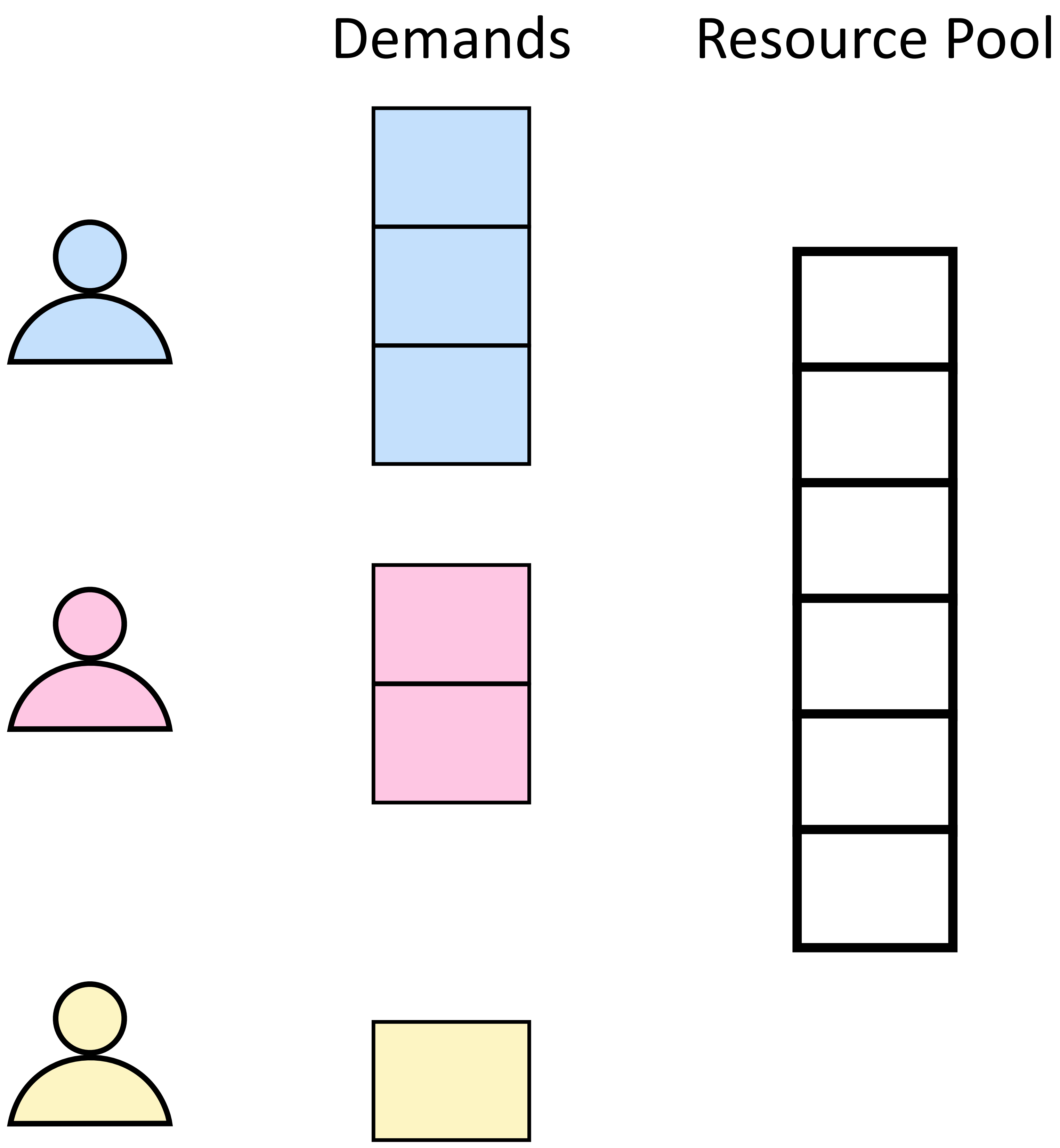


- Pareto efficiency
- Strategy-proofness
- Fairness

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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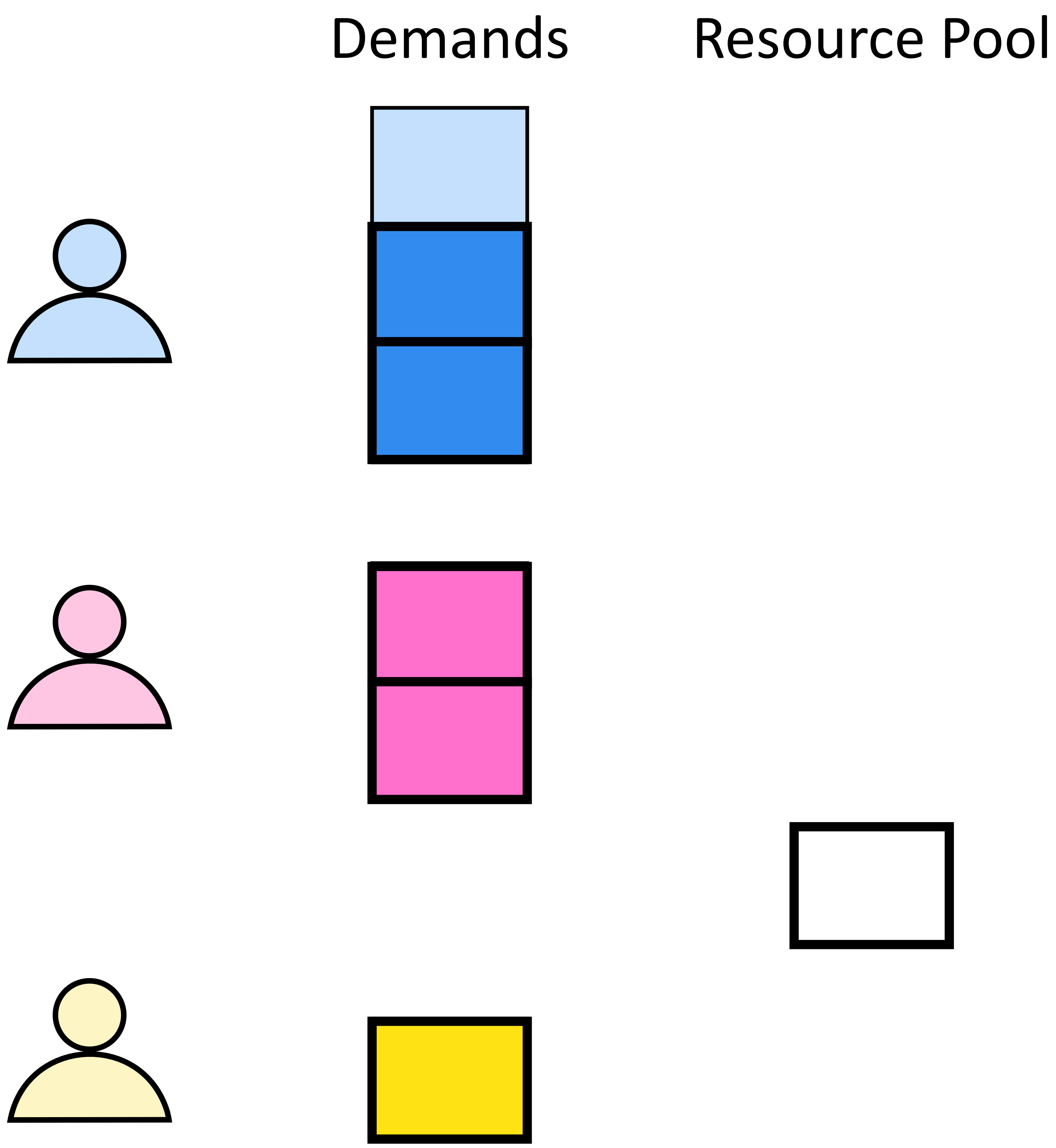

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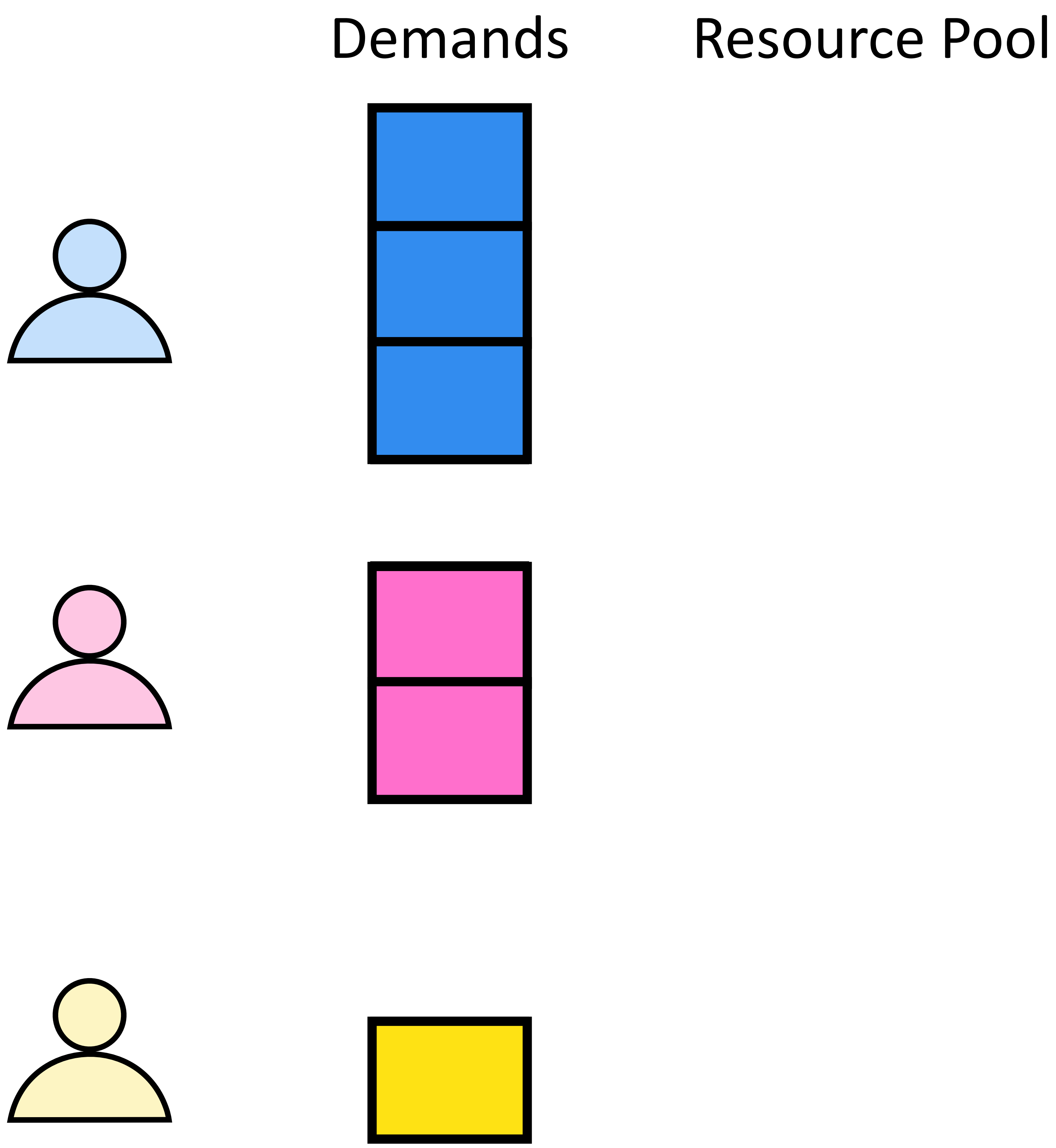

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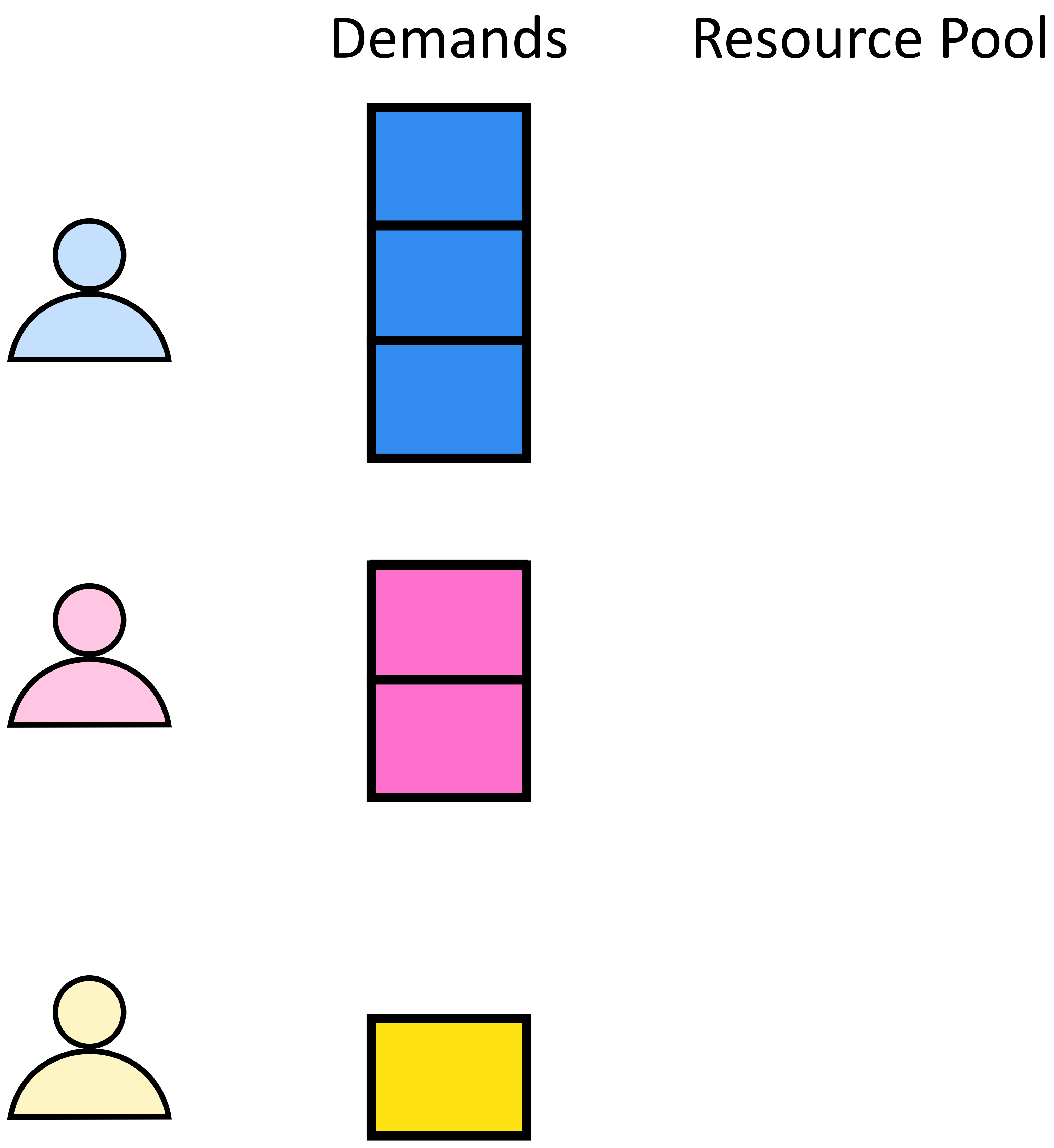

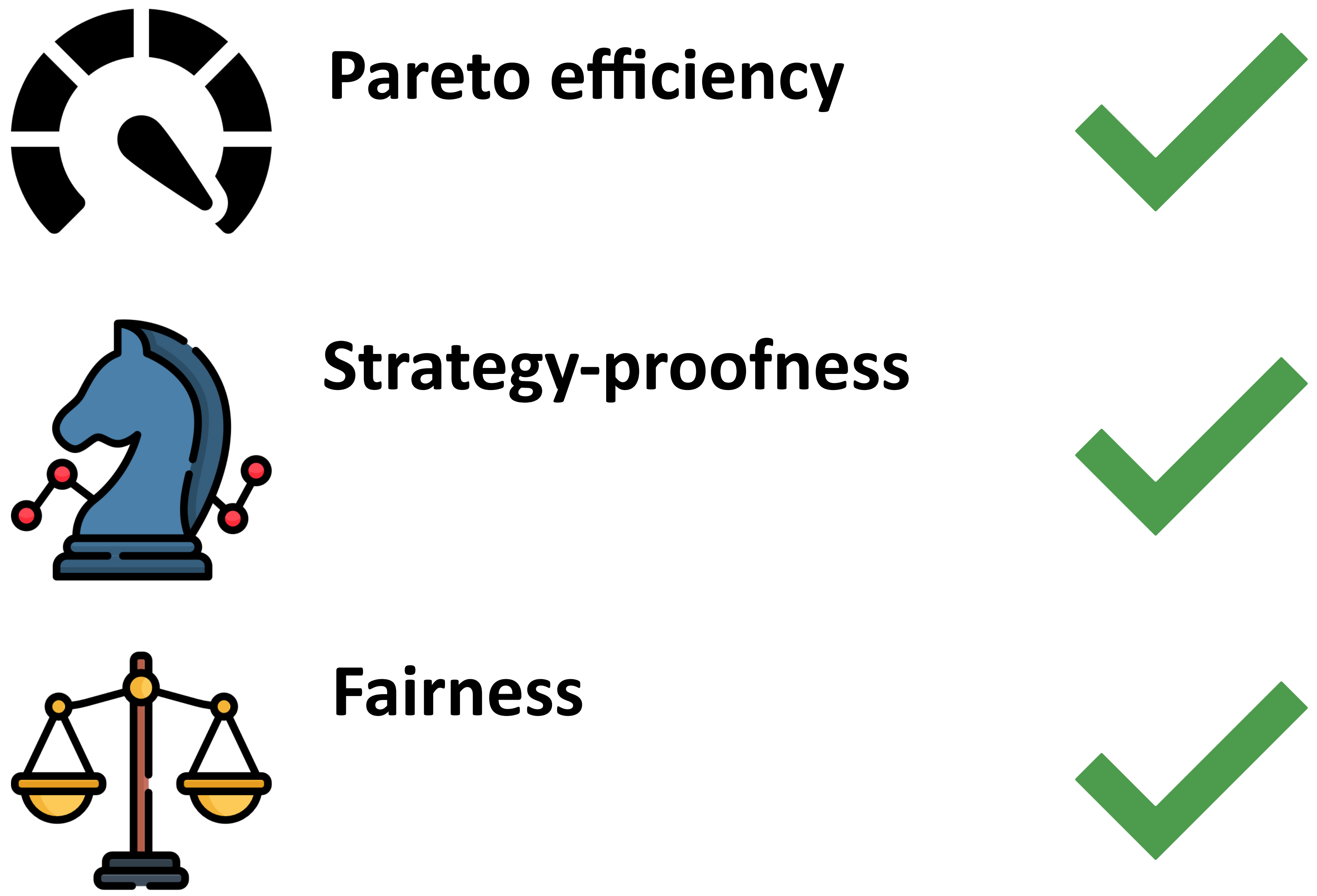

Classical result: Max-min fairness satisfies Pareto efficiency, strategy-proofness and fairness

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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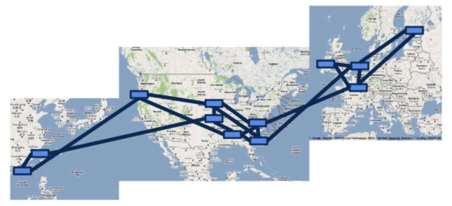
Inter-datacenter Network Links



Dynamic demands are the norm in real world deployments

Analysis of real world workloads

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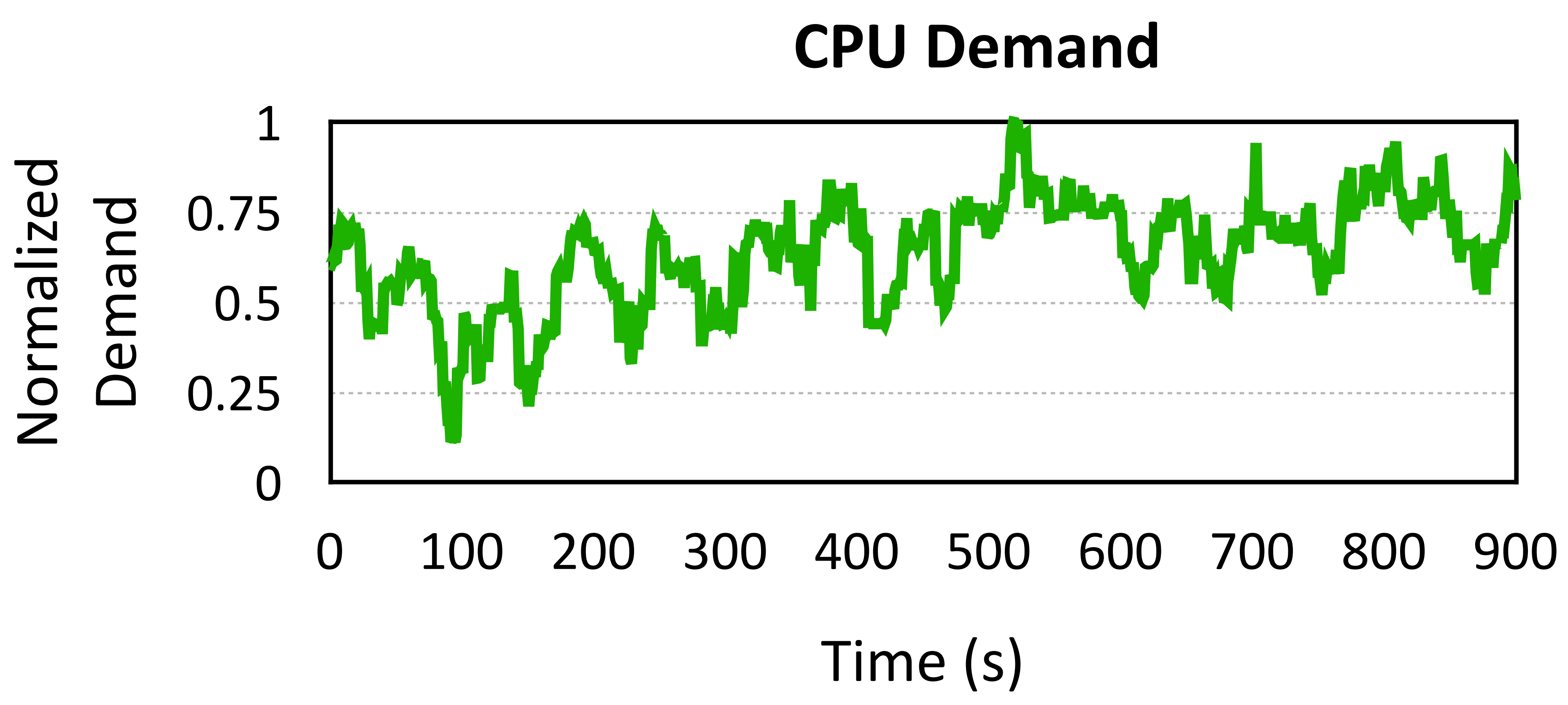

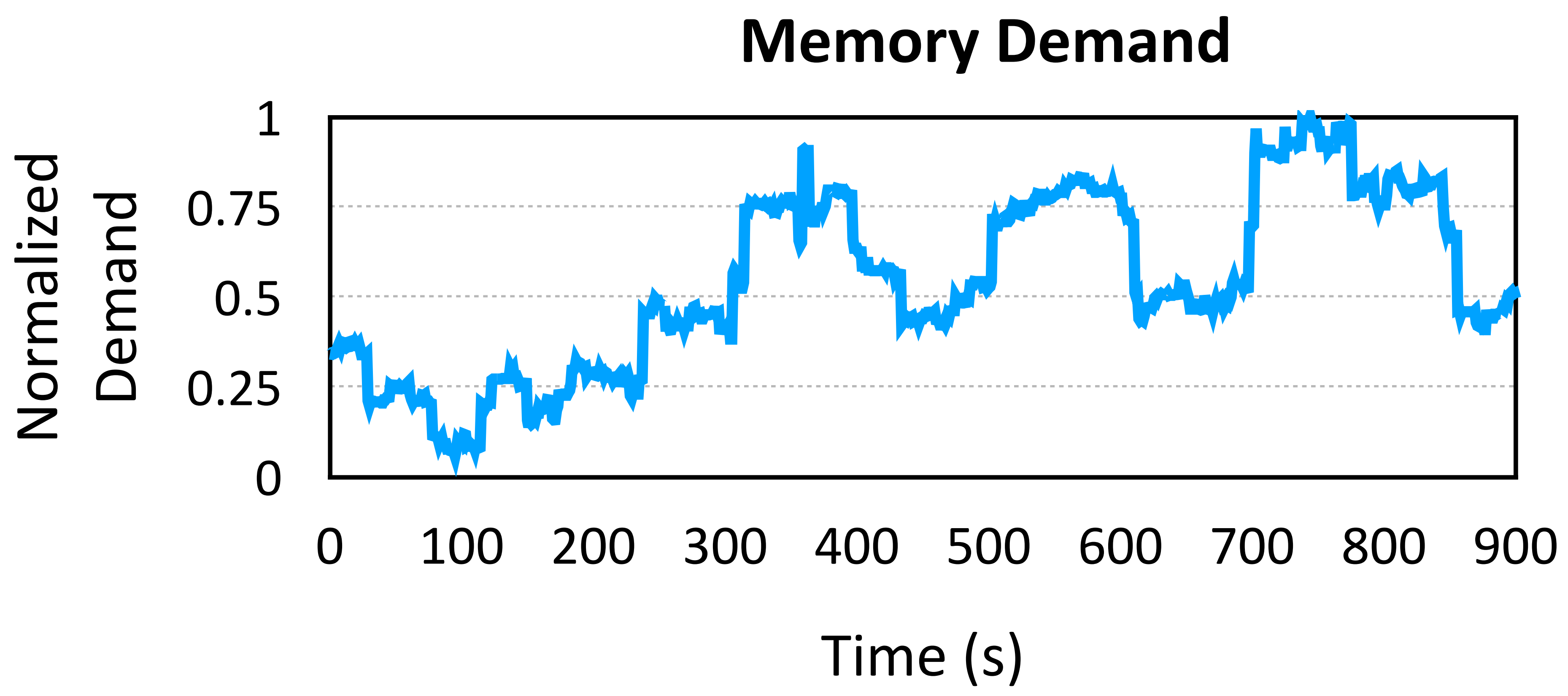

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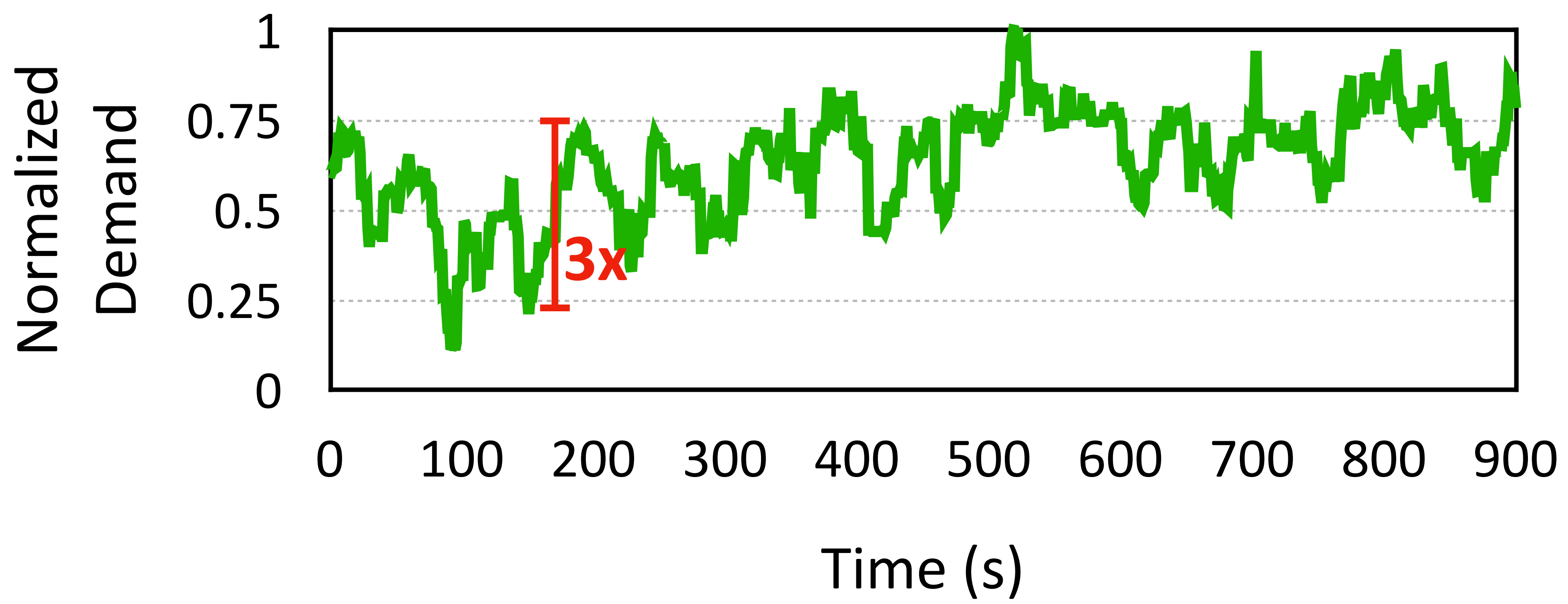
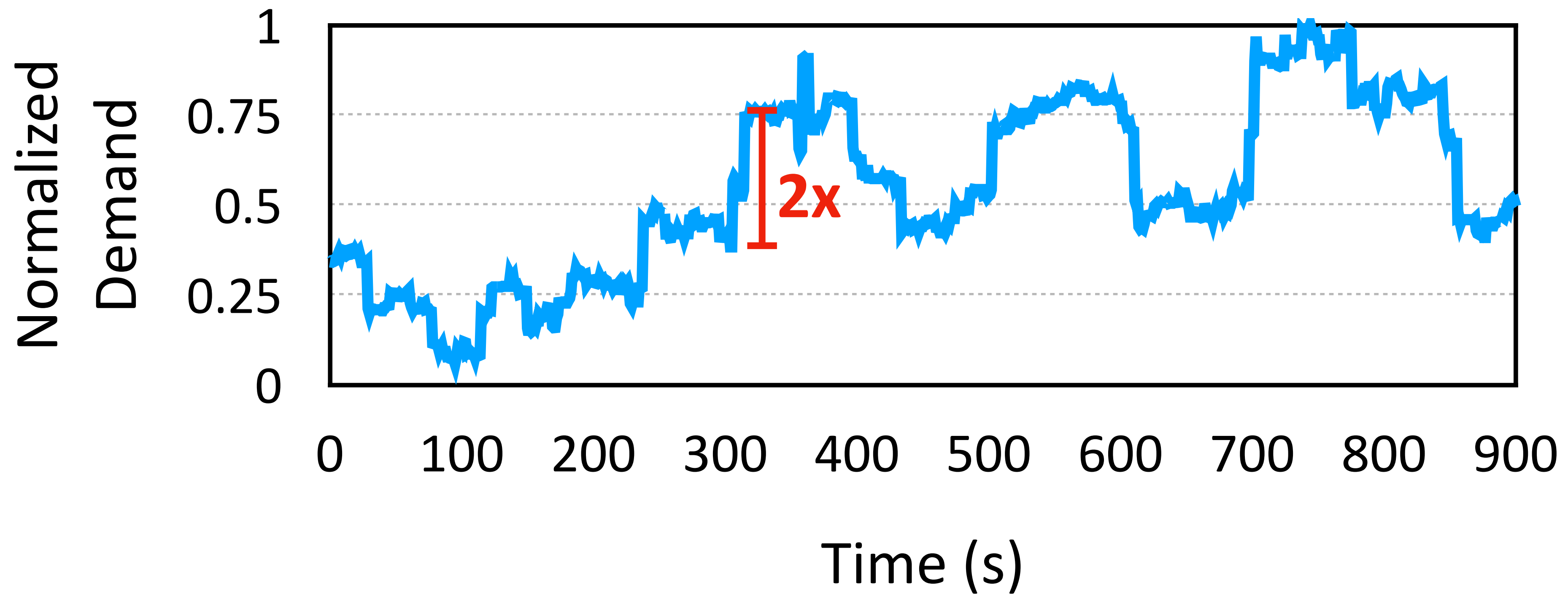
CPU Demand



Memory Demand



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

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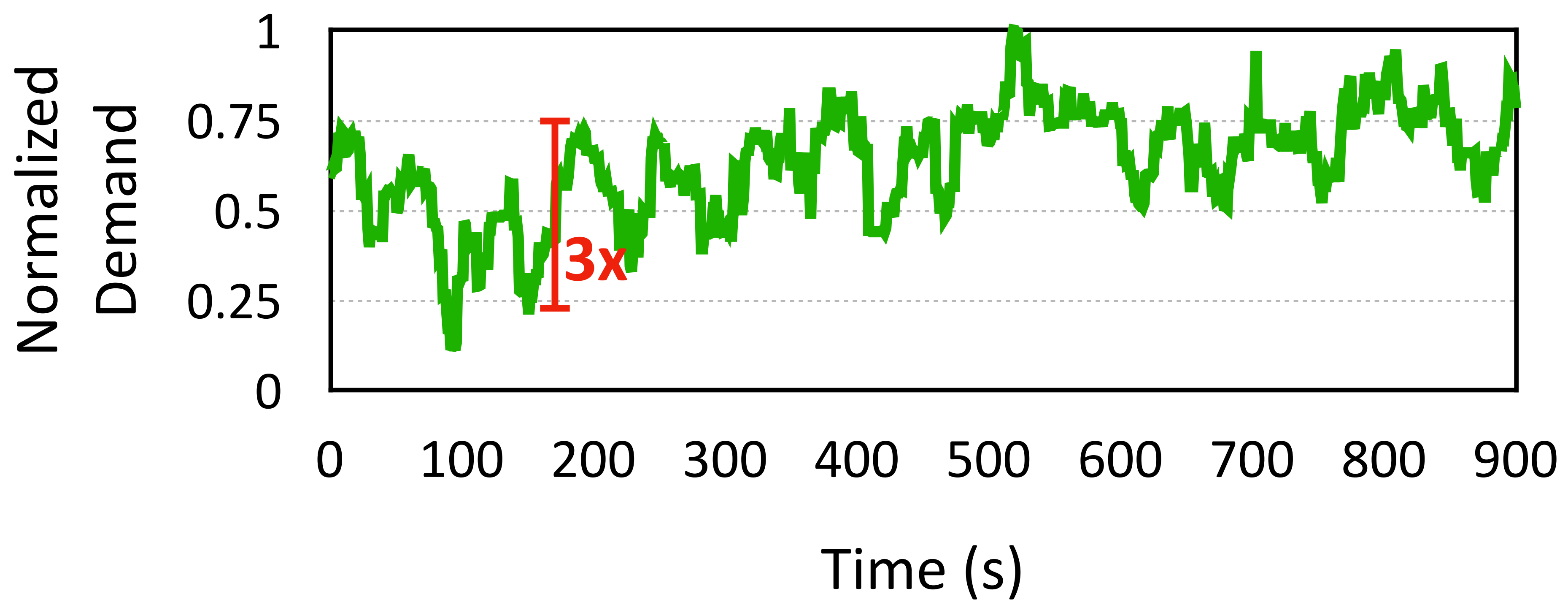

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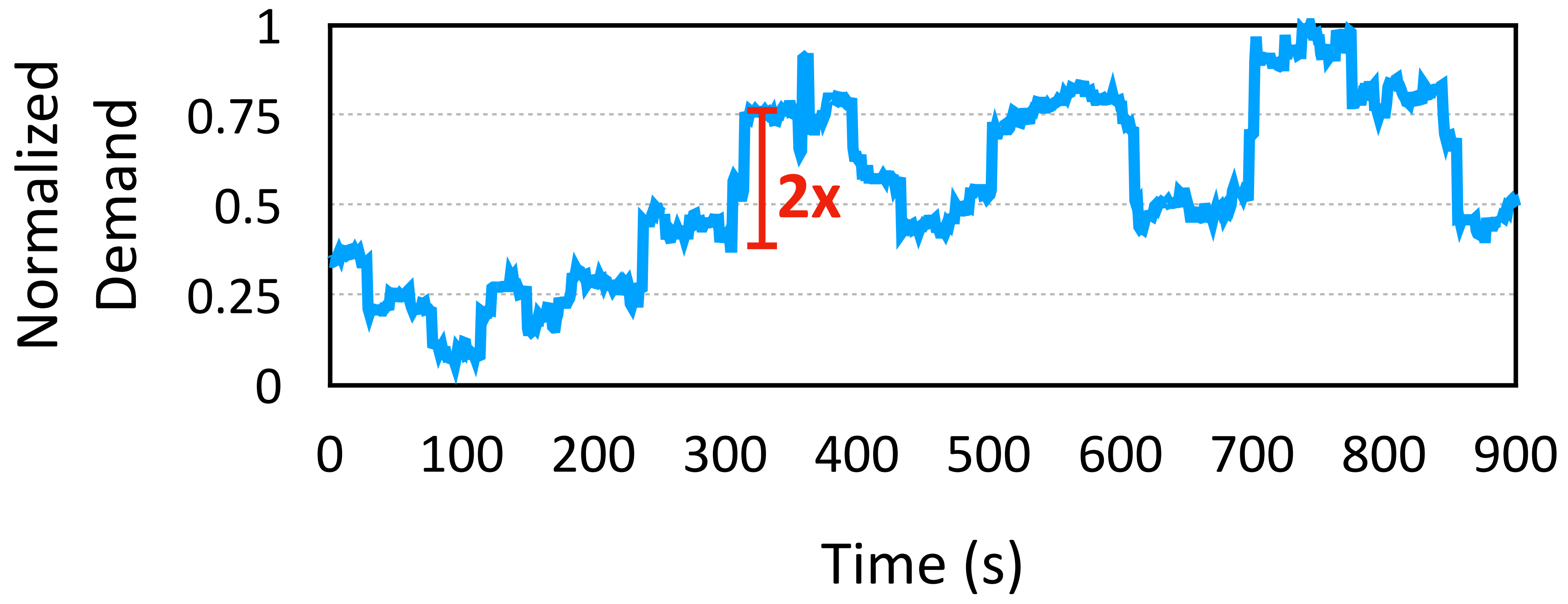

2-3x variation in demands over 10s of seconds

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

Dynamic demands are the norm in real world deployments

Shared Analytics Clusters

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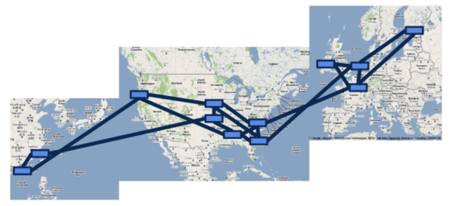
In-memory Key-Value Caches



Inter-datacenter Network Links

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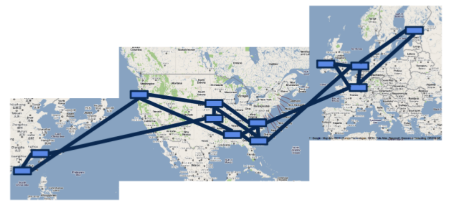
In-memory Key-Value Caches

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

[Microsoft, Abuzaid et al., NSDI’21]

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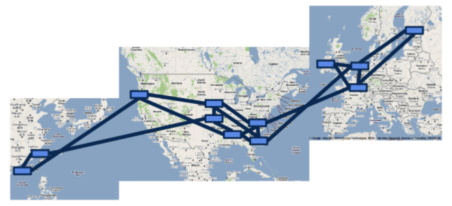

Inter-datacenter Network Links

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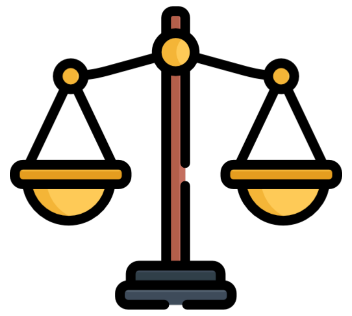
Significant variation in user demands over time in real workloads

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


Pareto efficiency


Strategy-proofness


Fairness

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

Max-min fairness
based on demands at t=0

Pareto efficiency

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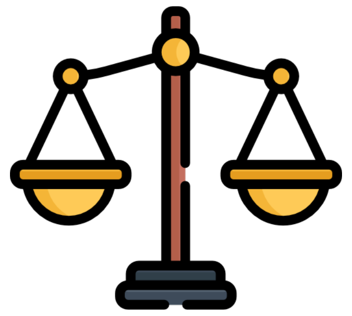

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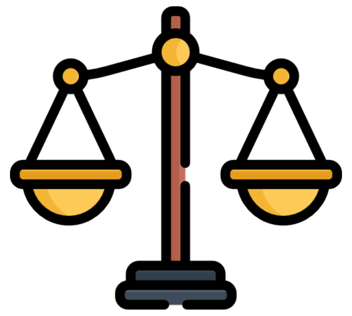
Fairness

(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	✗	
Fairness		

(Explained in paper)

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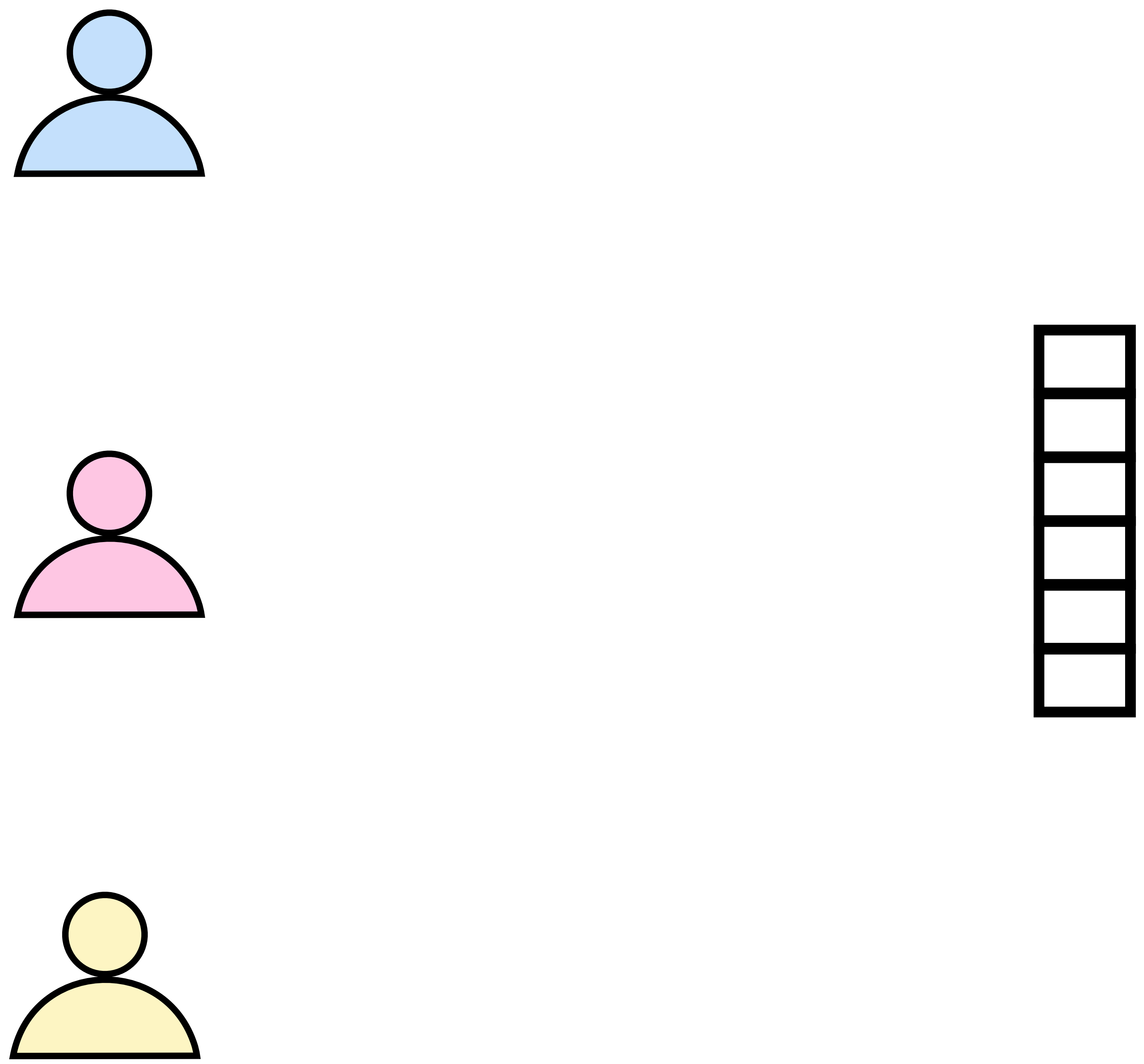
Max-min fairness under dynamic demands: looses one or more of its properties

Running Example

Demands

Resource Pool



Max-min fairness based on demands at t=0

Max-min fairness applied periodically

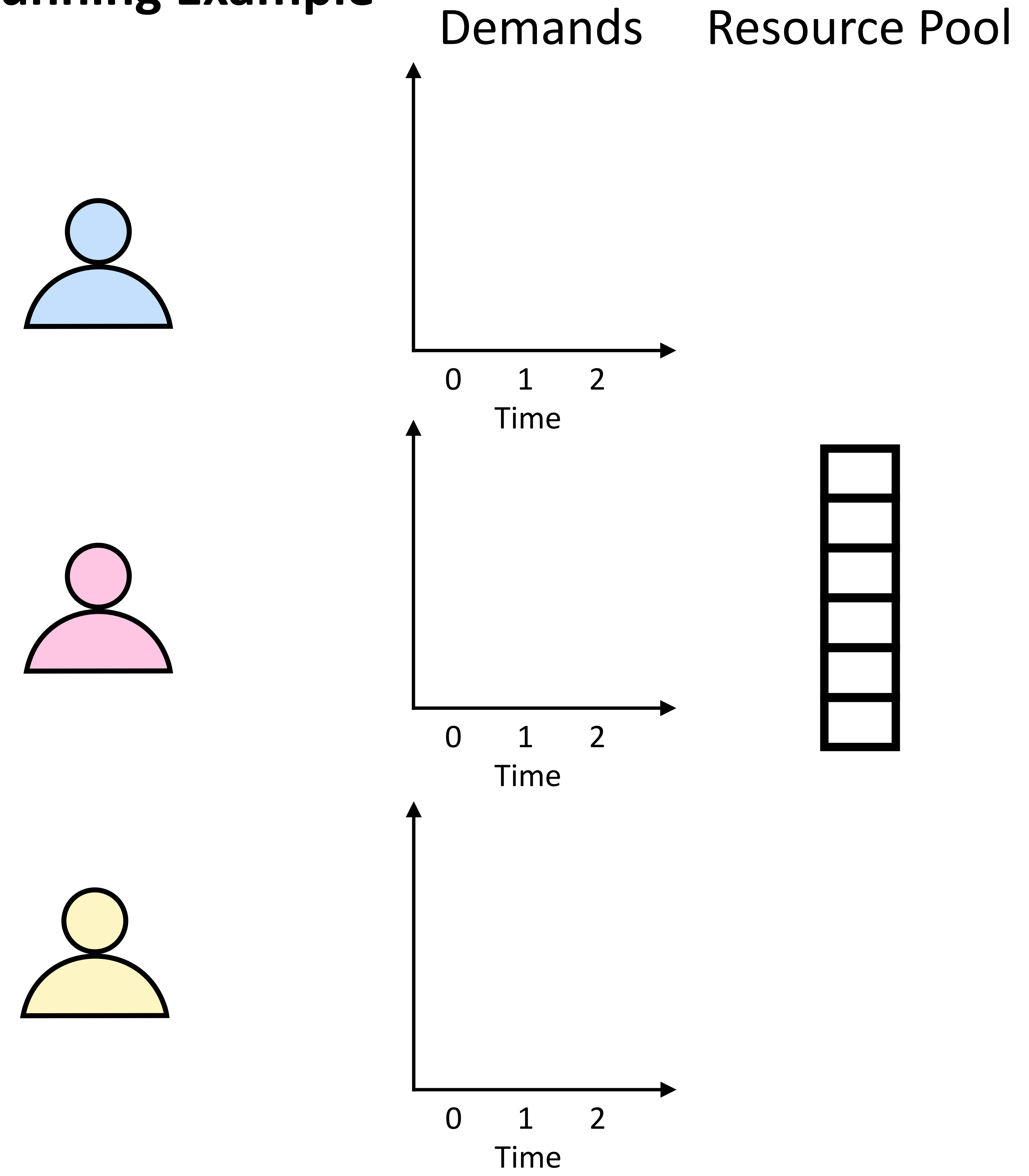
Pareto efficiency ✗

Strategy-proofness ✗

Fairness

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

Running Example



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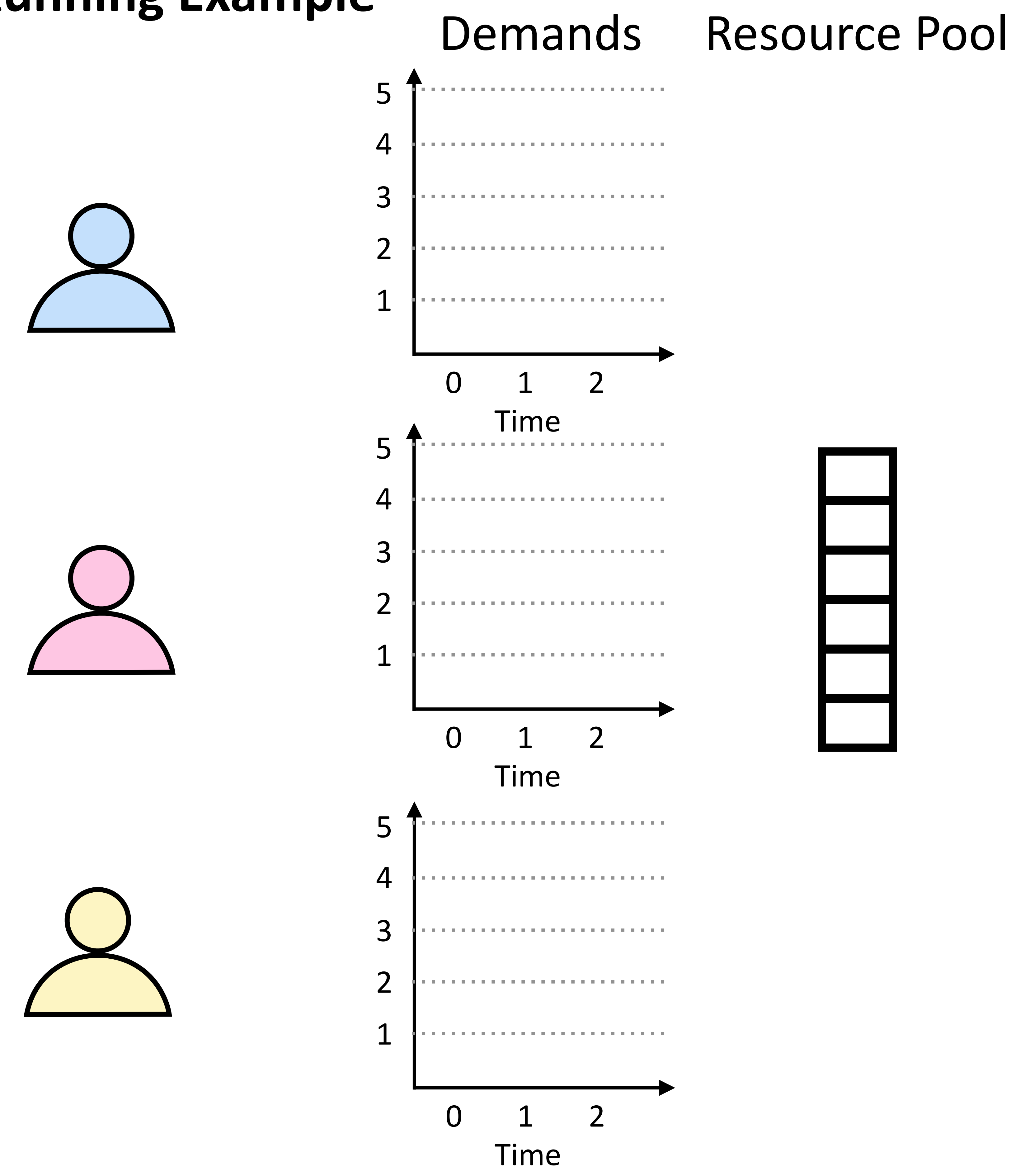

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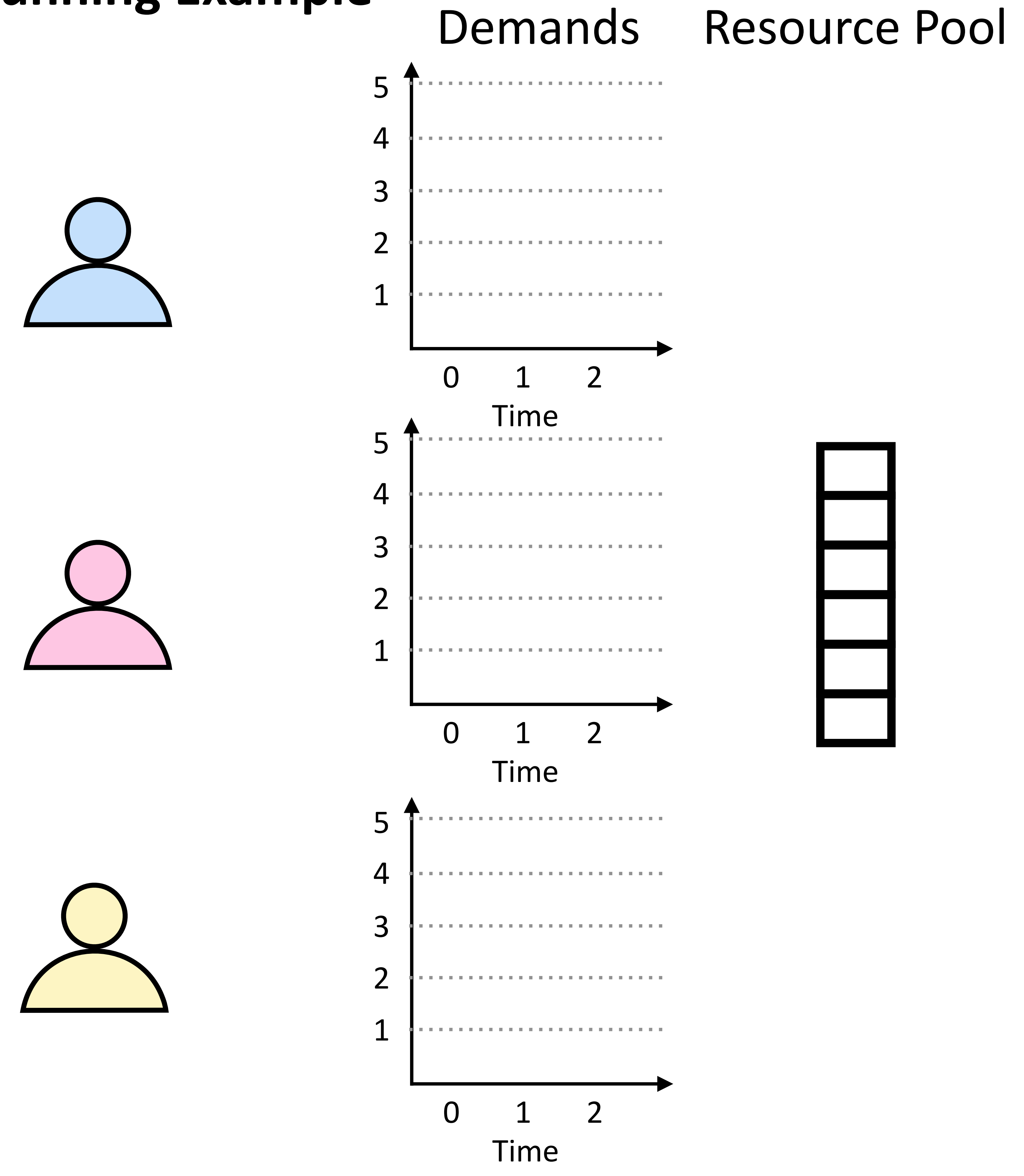

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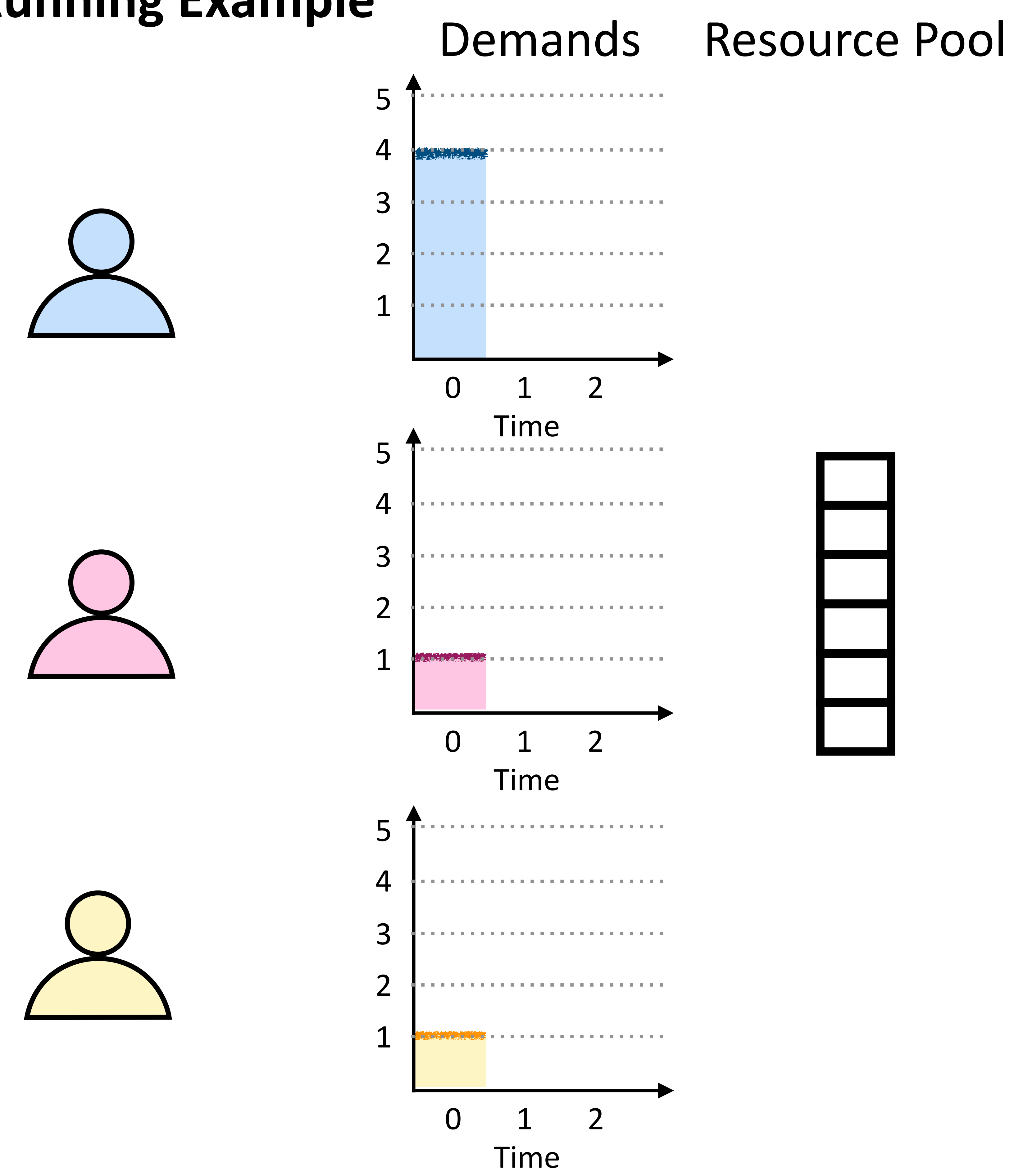

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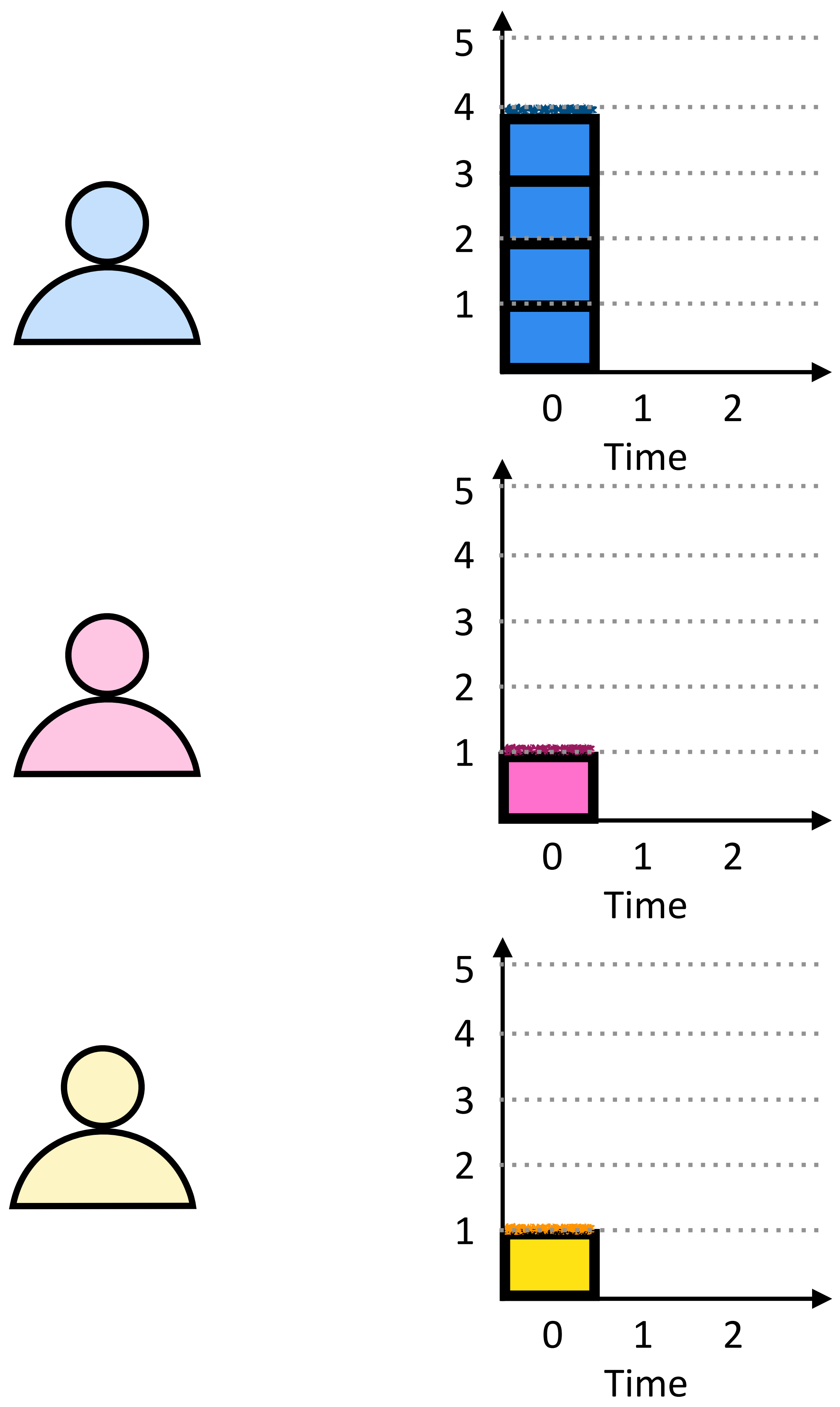
Max-min fairness under dynamic demands: looses one or more of its properties

Running Example

Demands Resource Pool



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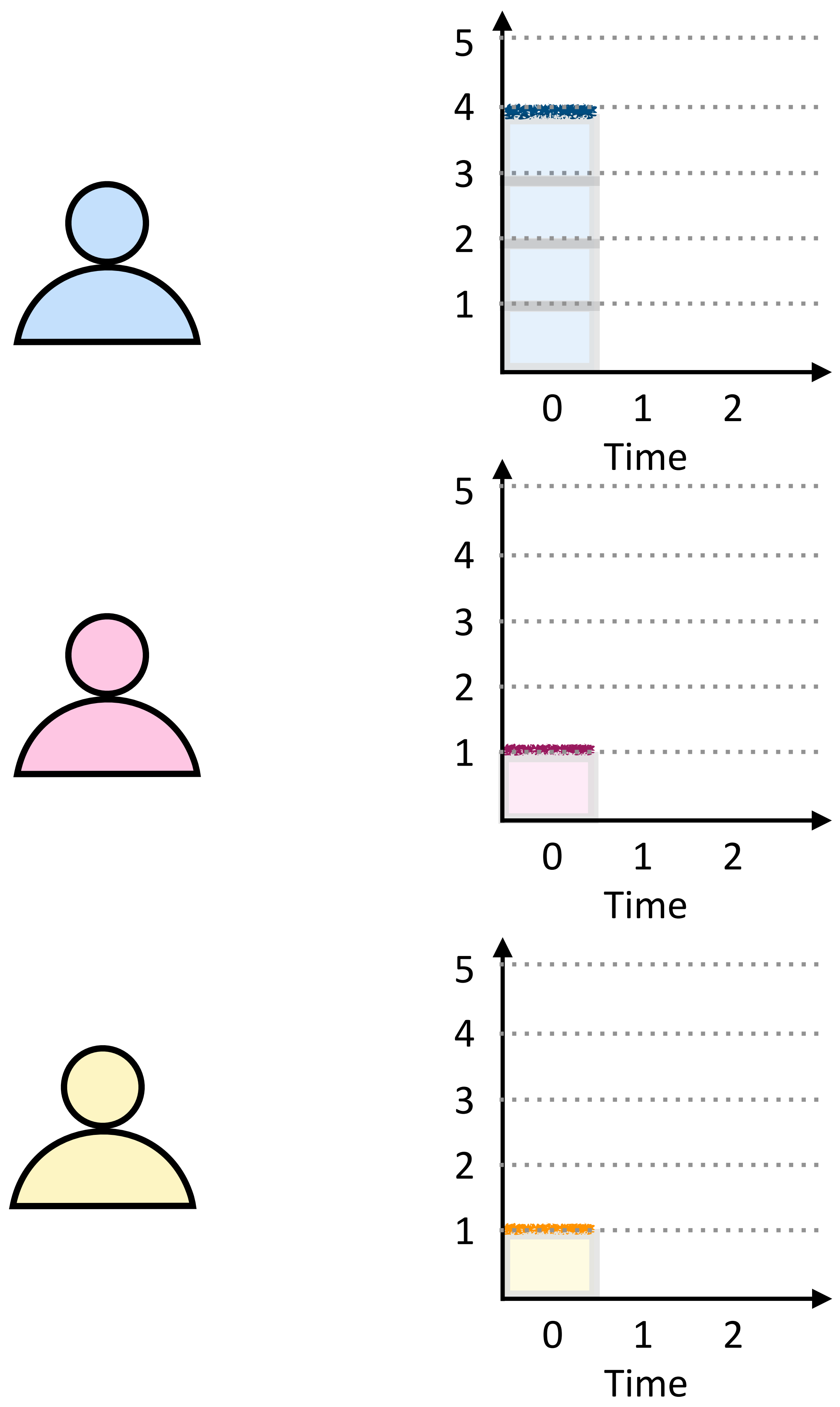
Running Example

Demands | Resource Pool



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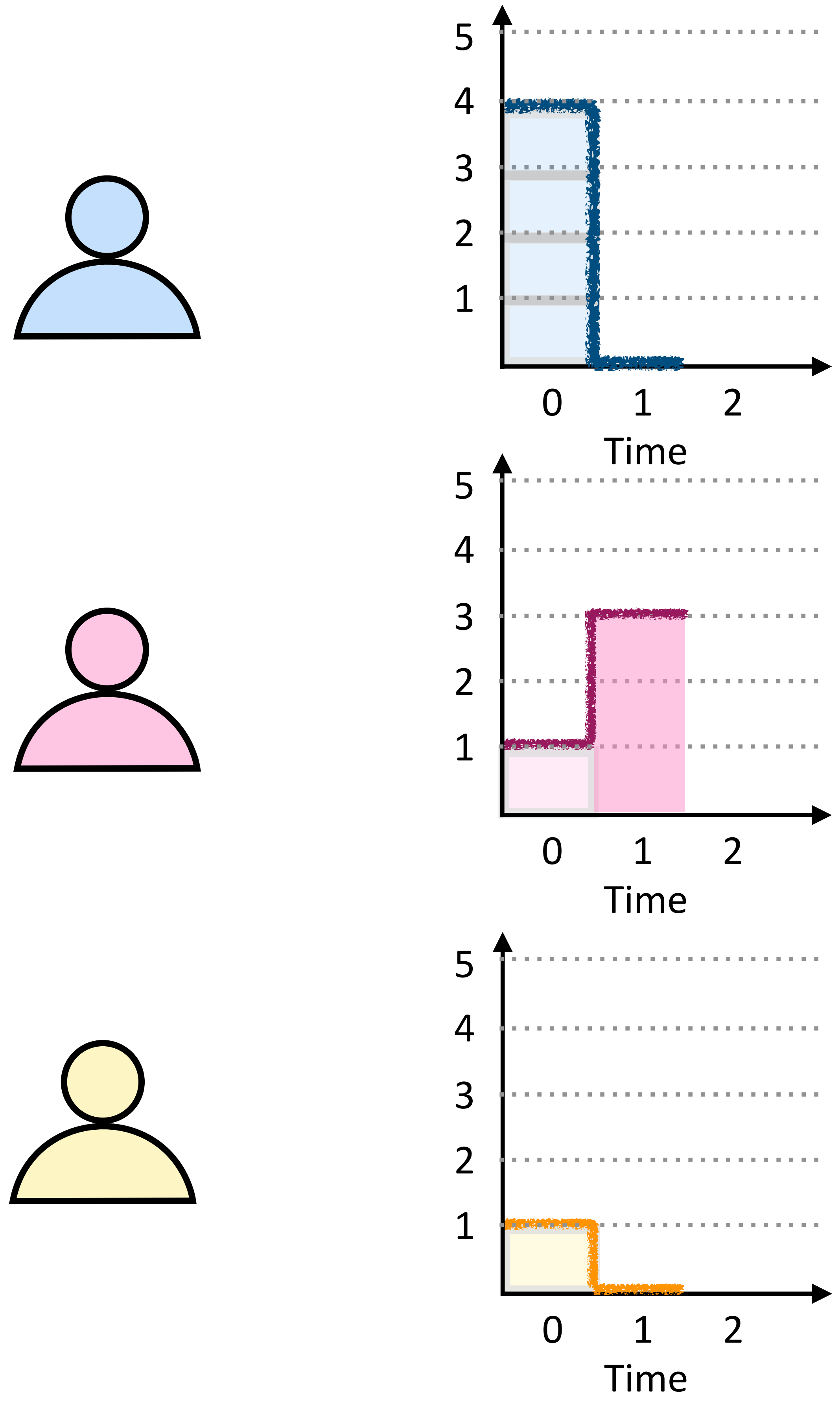
Running Example

Demands   Resource Pool



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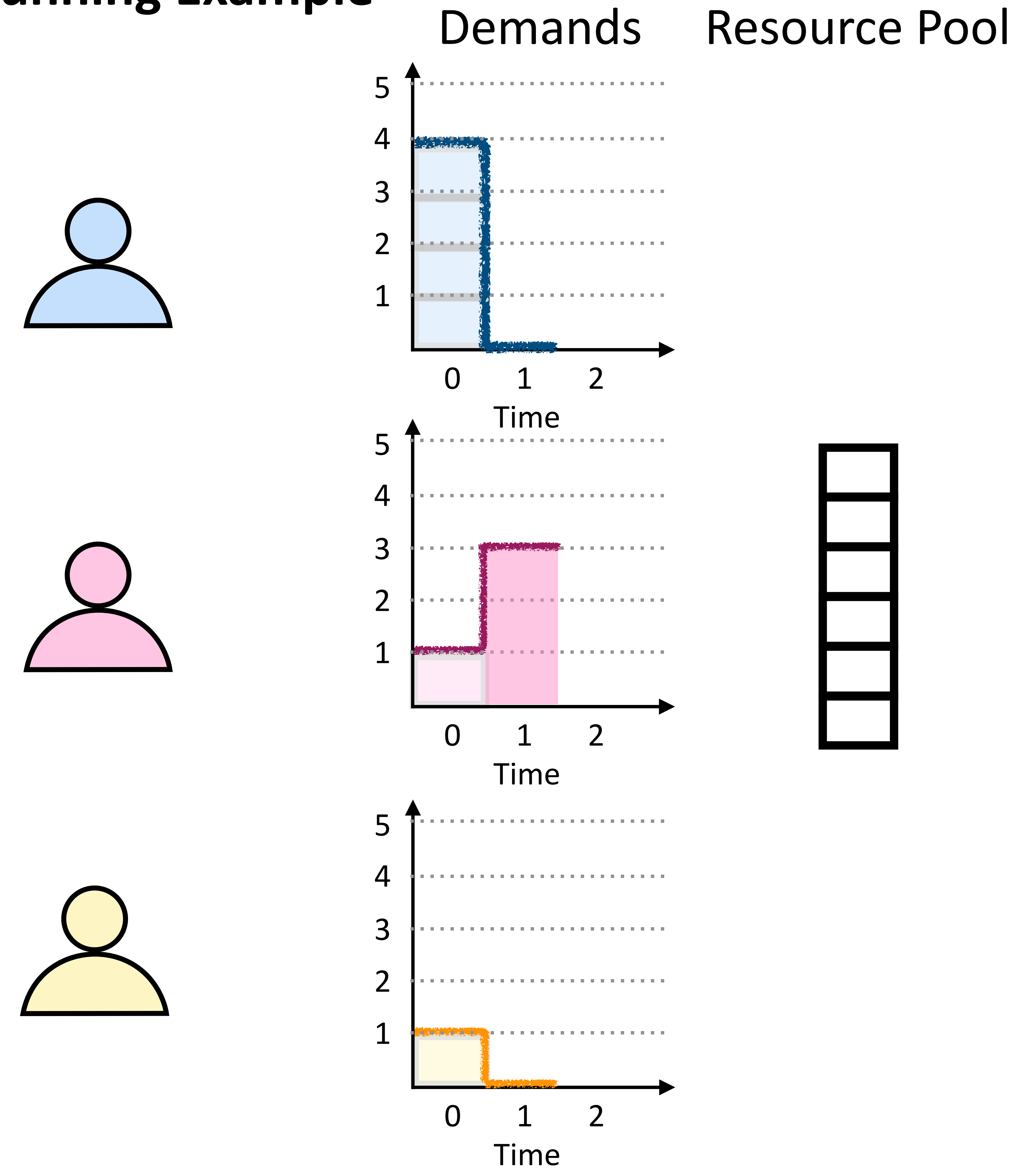

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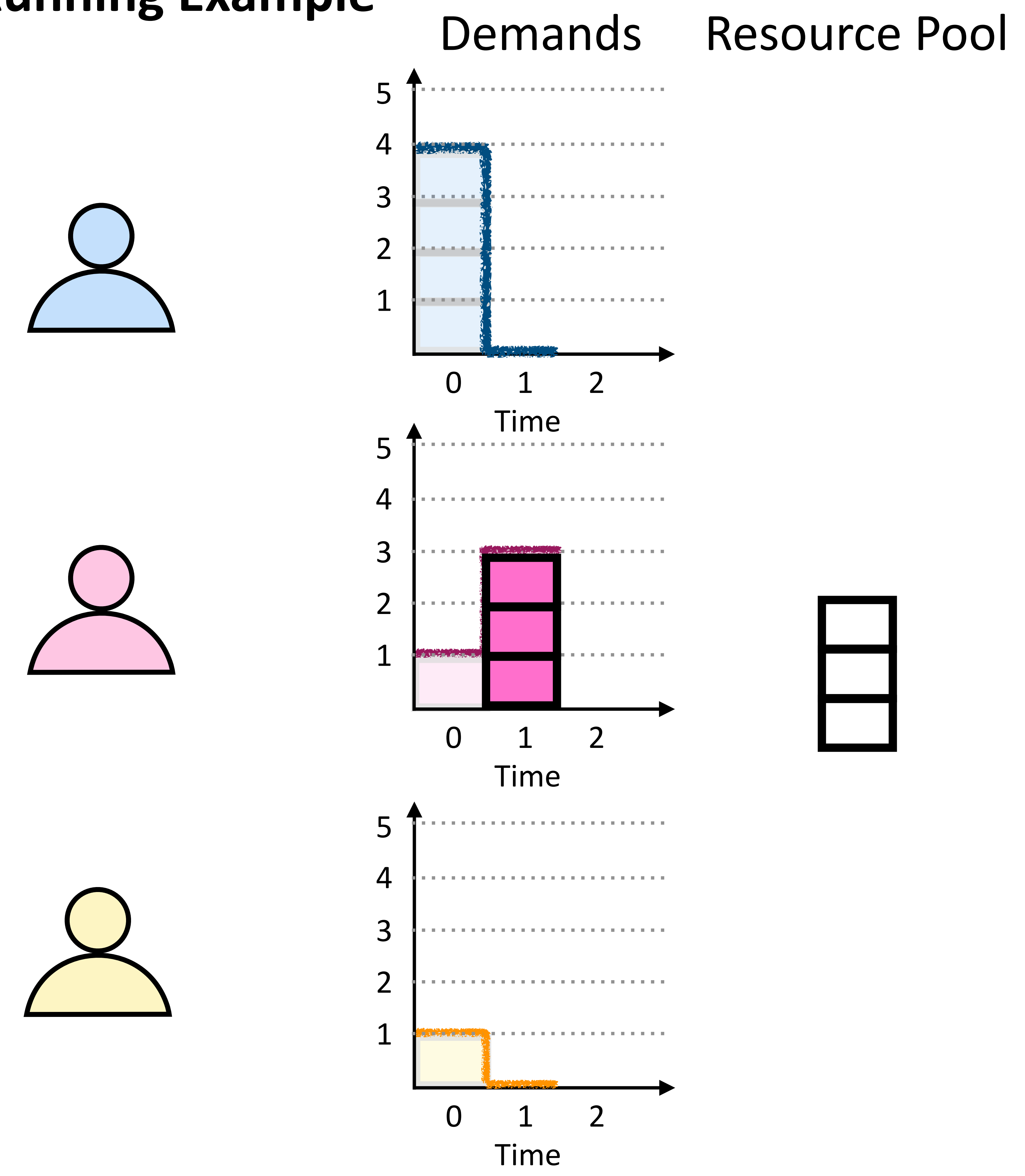
Strategy-proofness ✗

Fairness

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

Running Example



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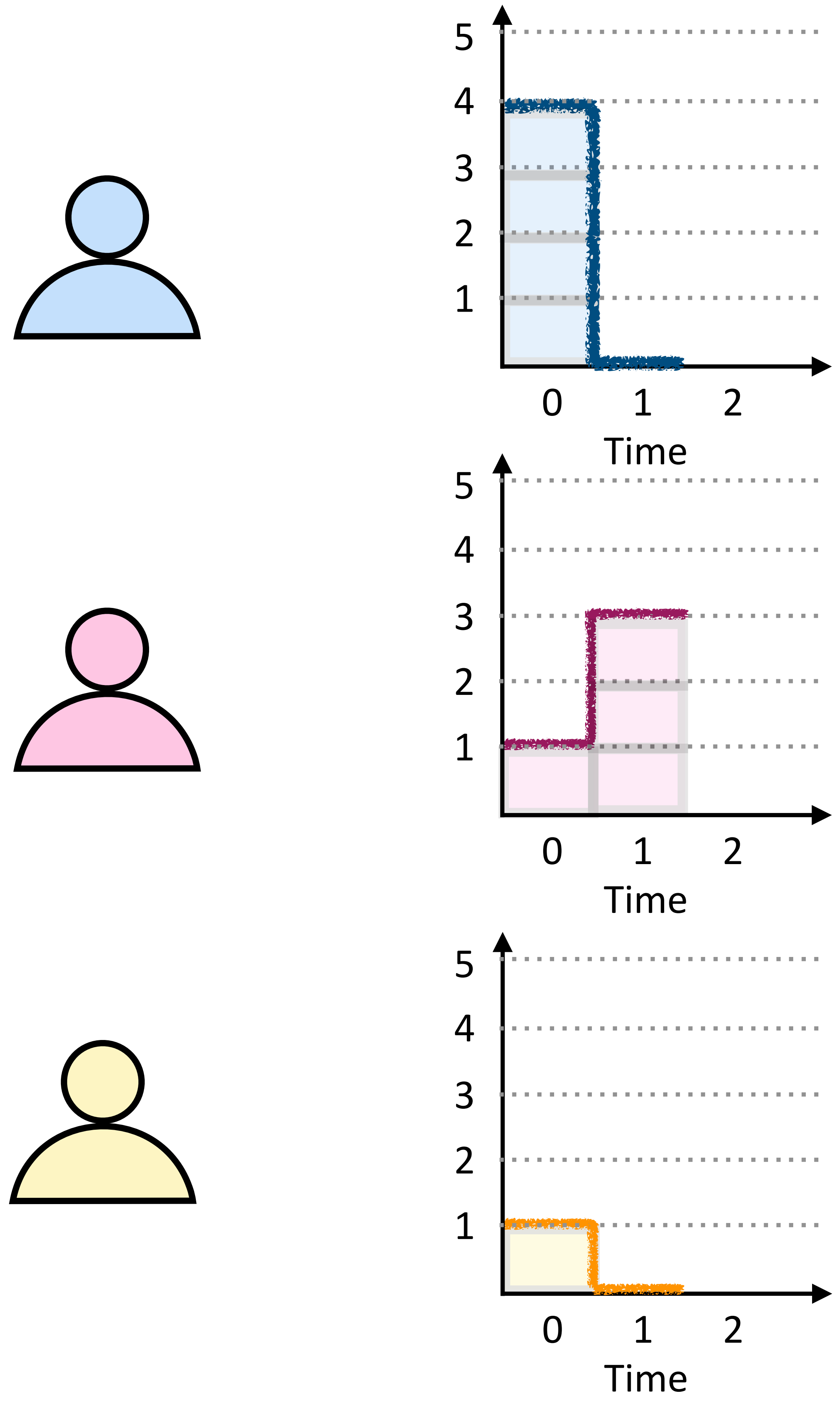

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Pareto efficiency

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Fairness

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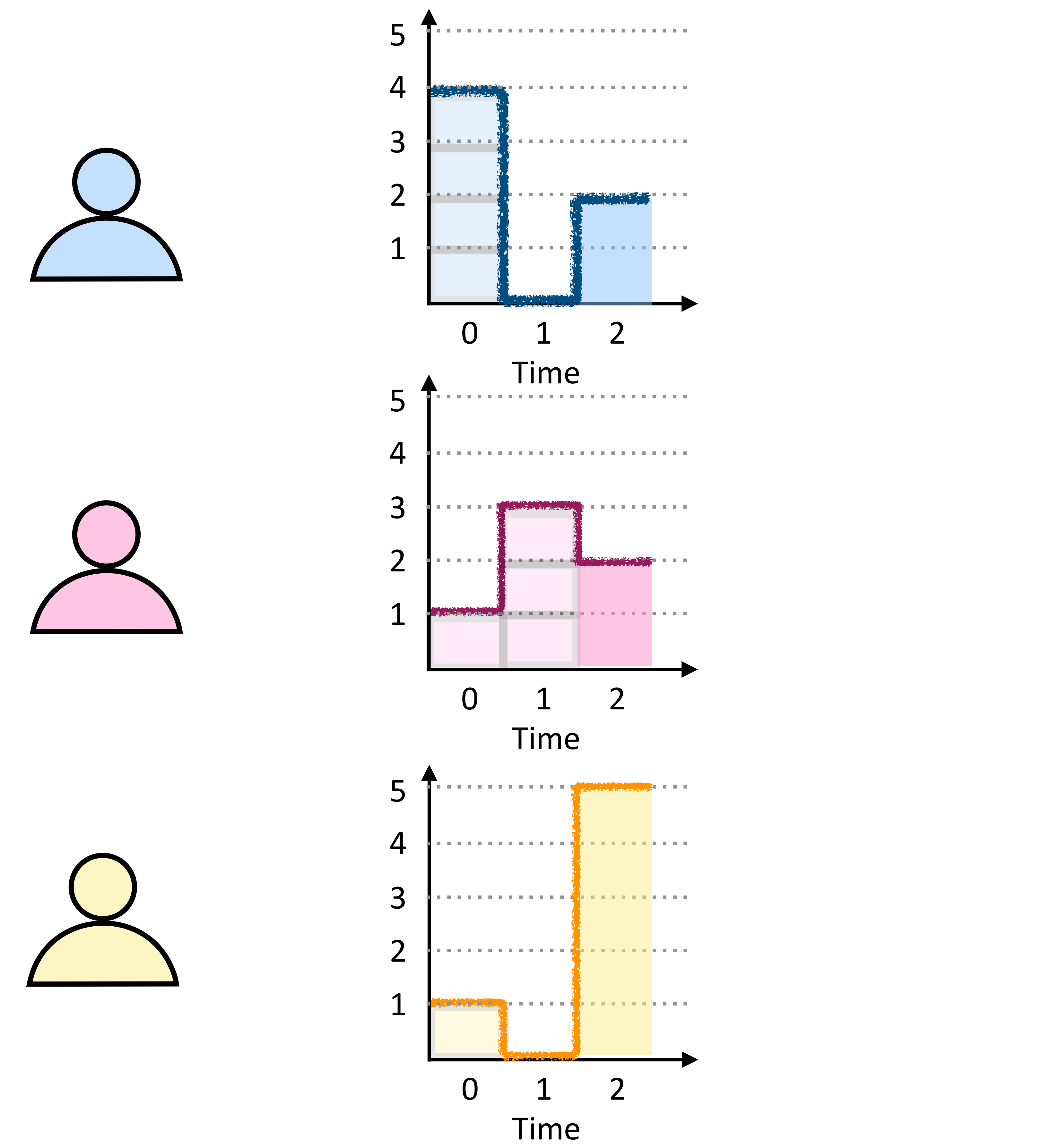
Running Example



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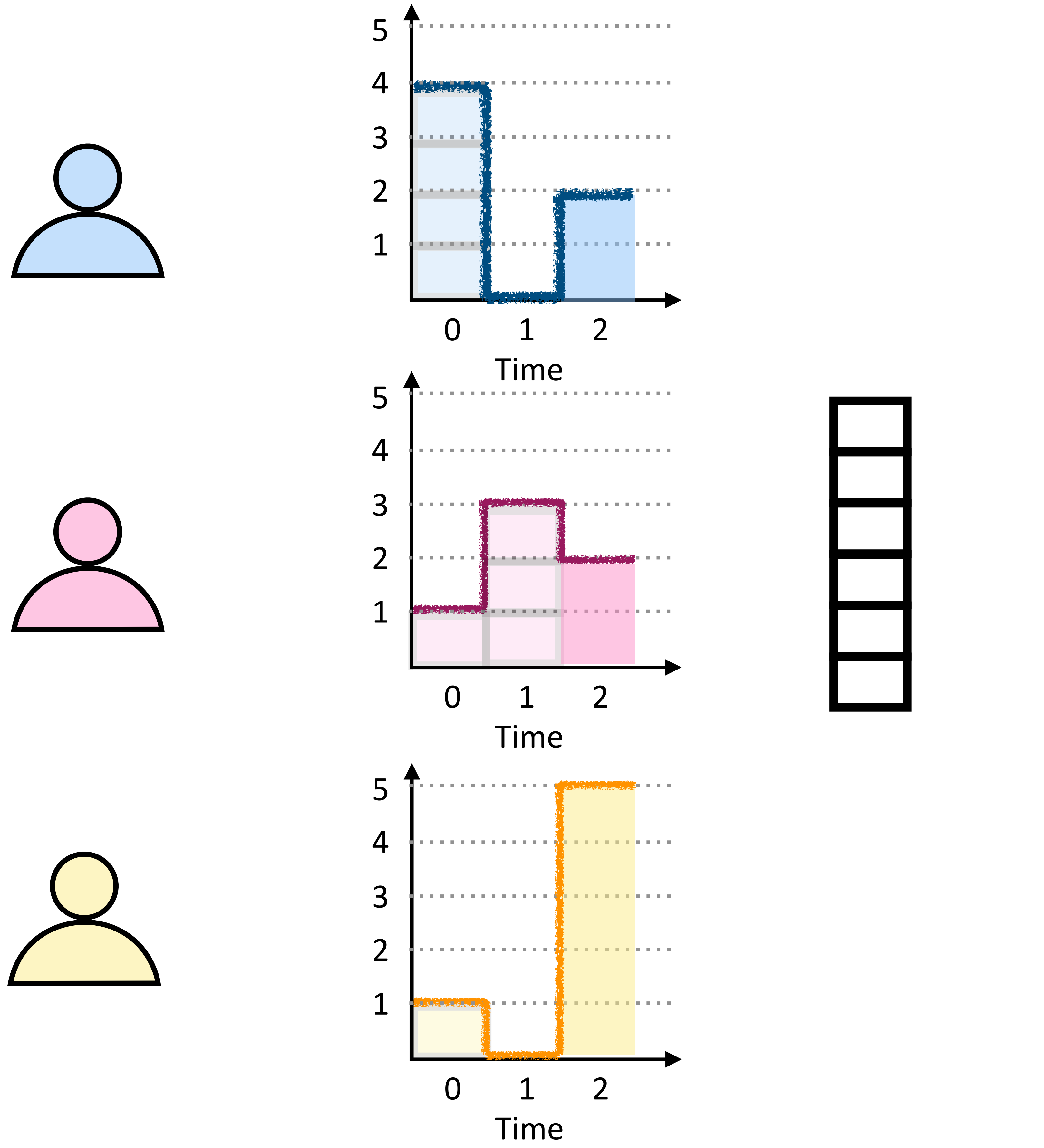

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Demands

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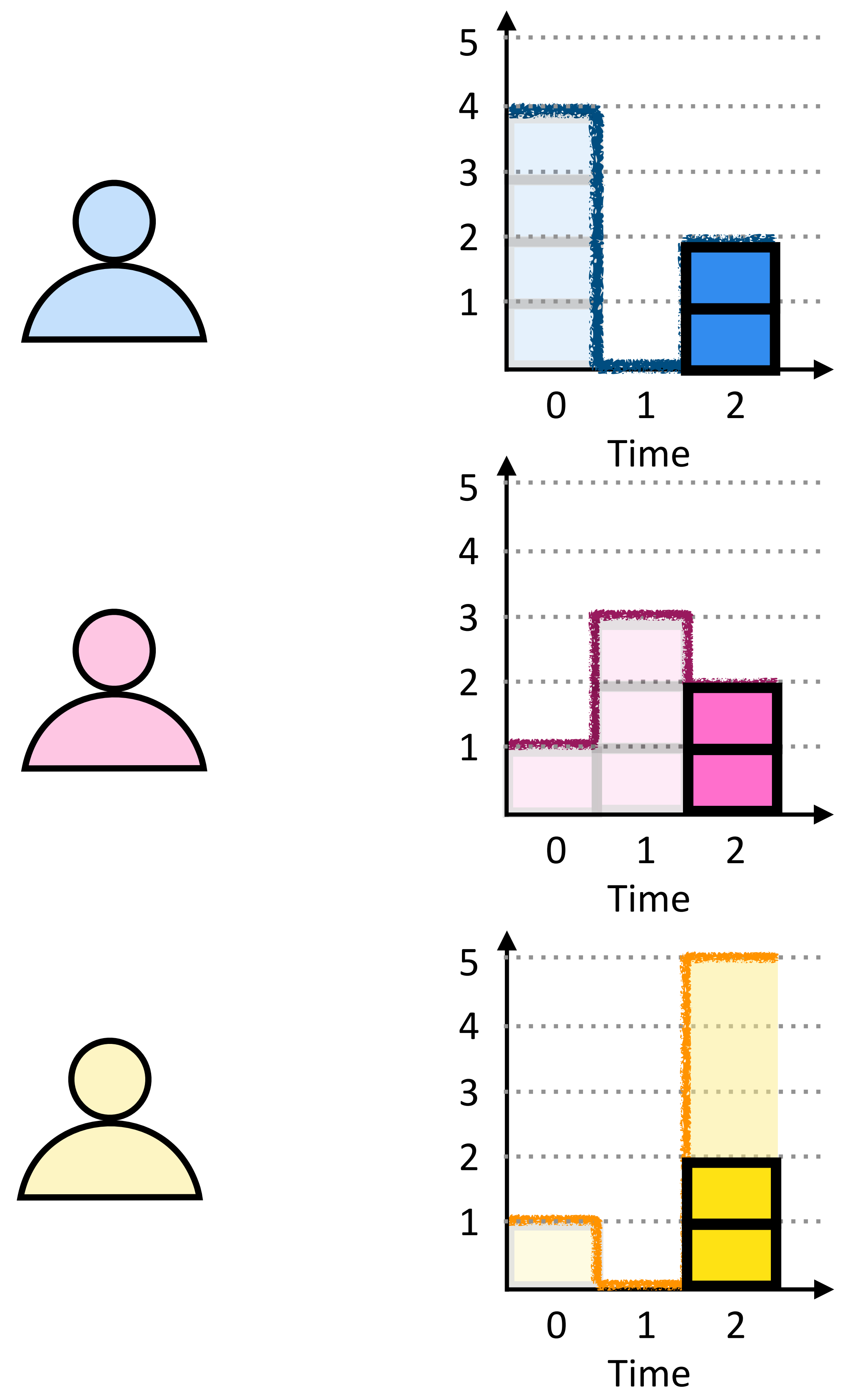

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Running Example

Demands

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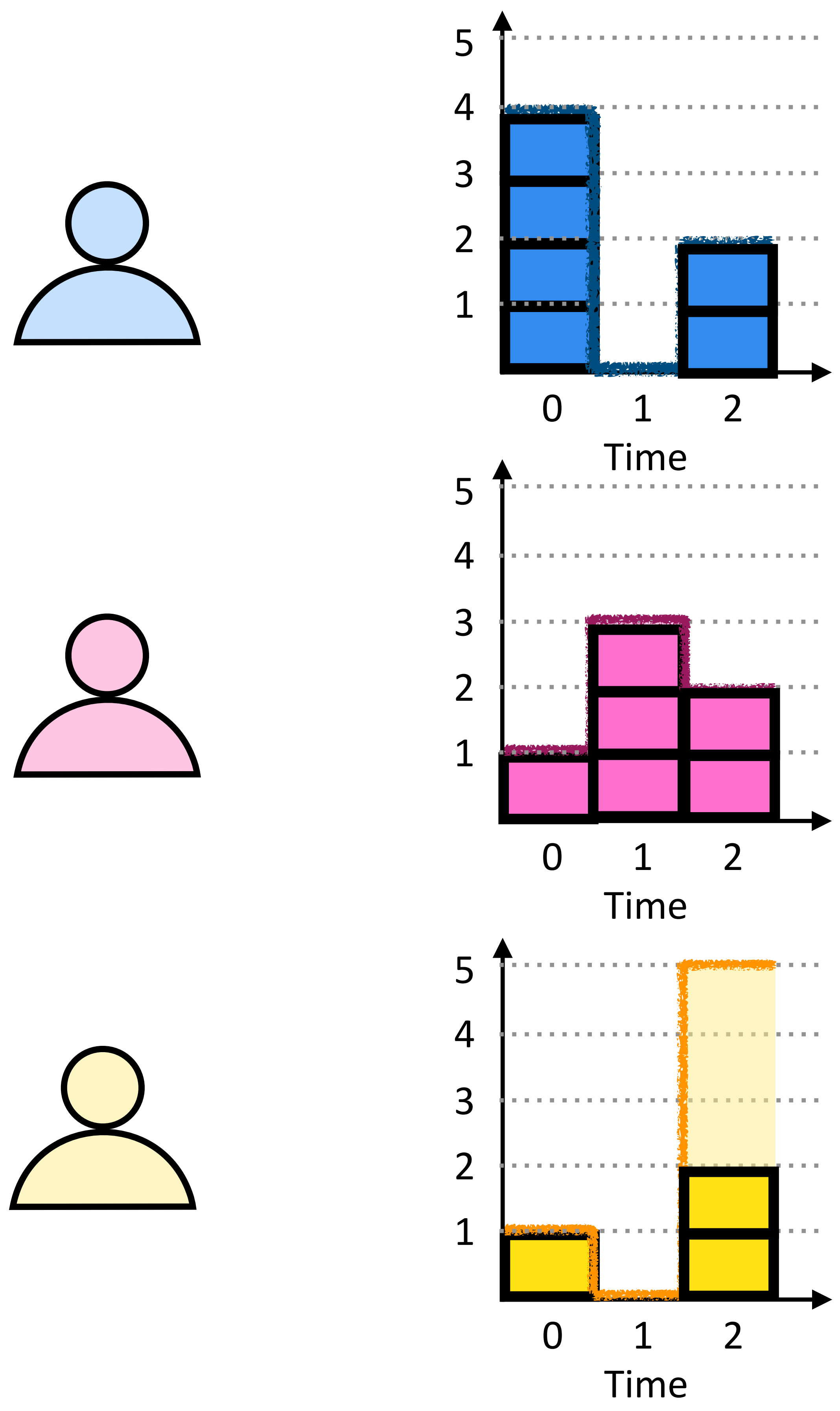

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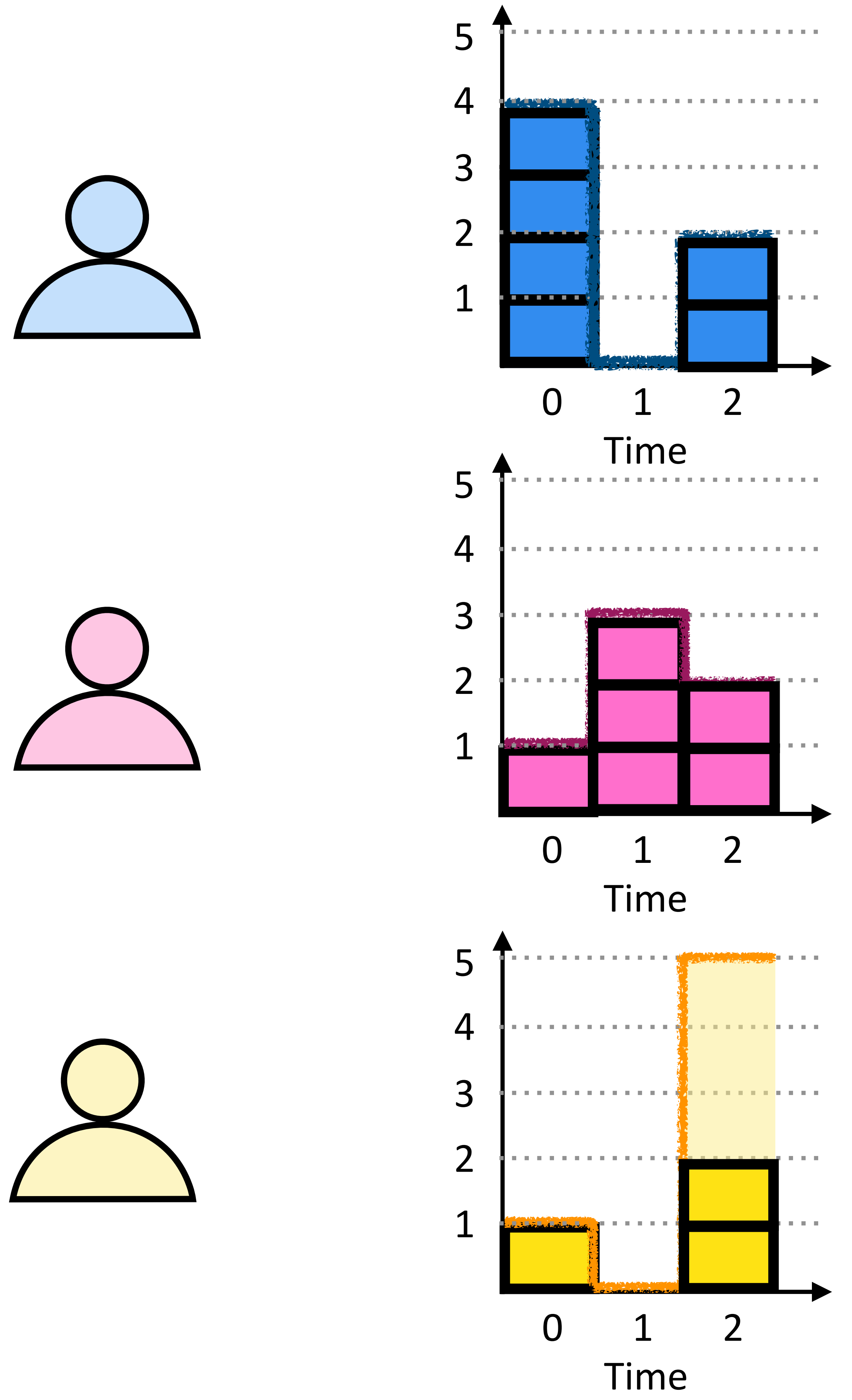
Max-min fairness under dynamic demands: looses one or more of its properties

Running Example

Demands   Total Allocation



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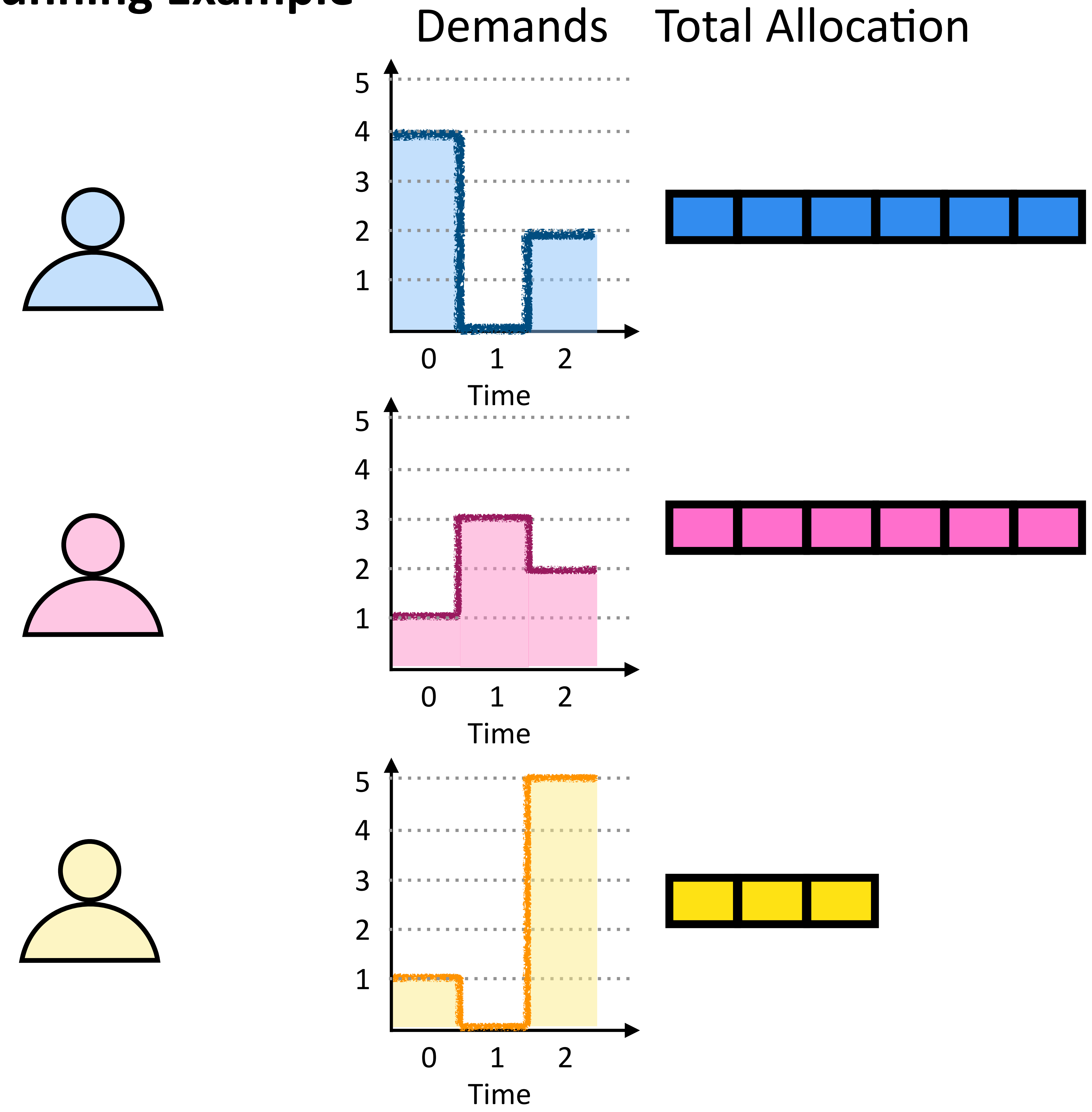
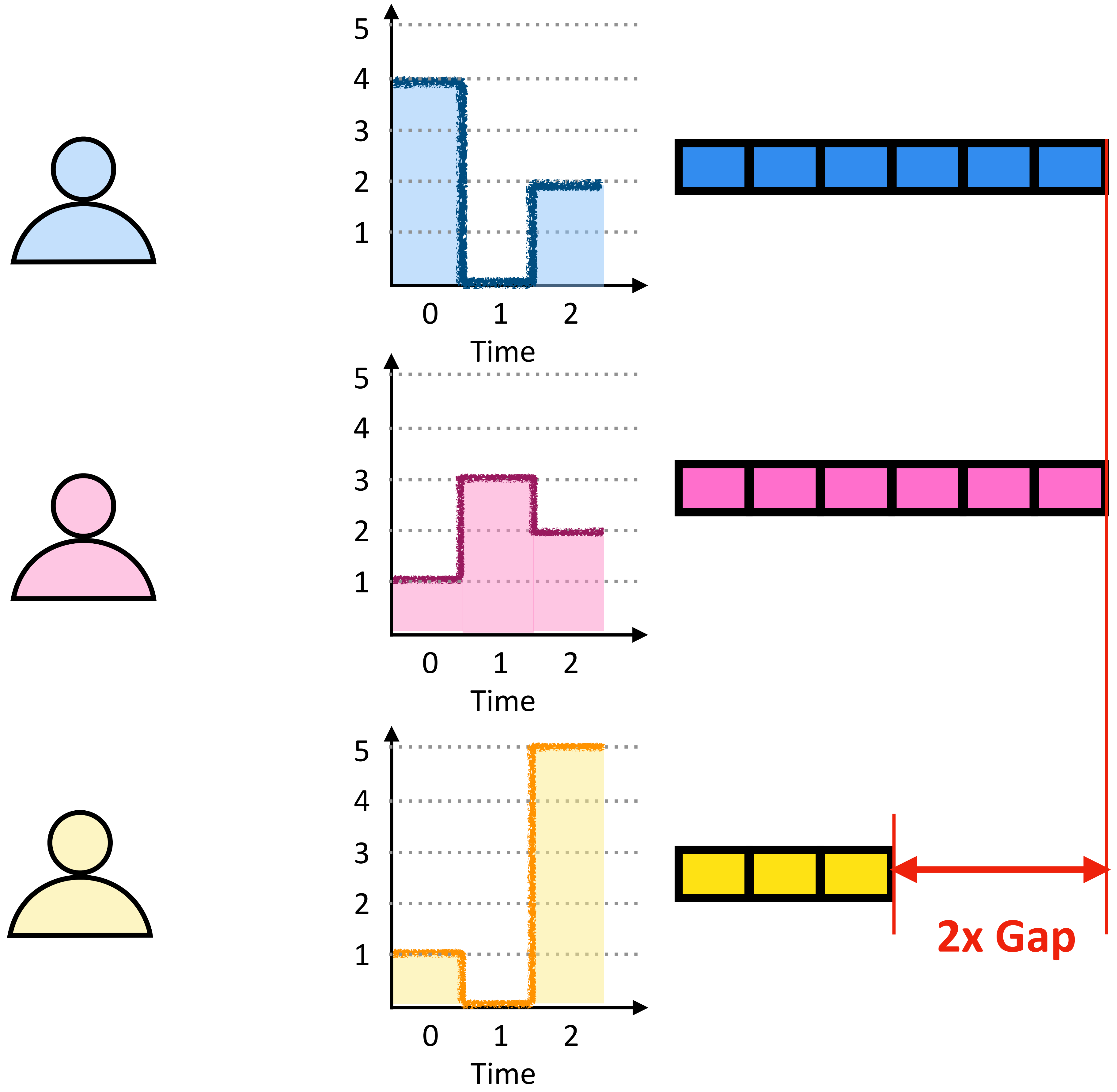
Running Example



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

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

Running Example



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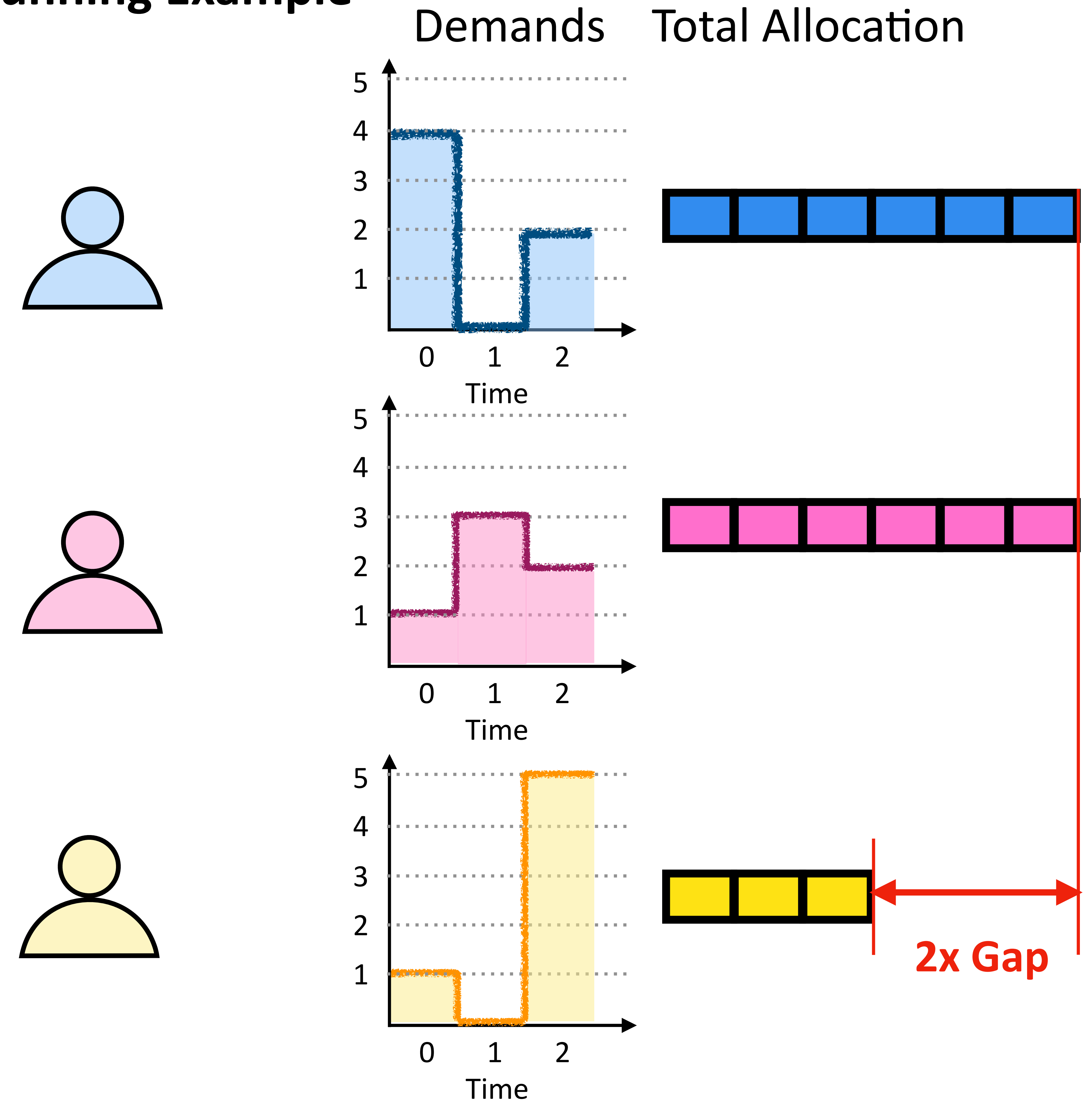

For n users, a user can get Ω(n) more allocation than others

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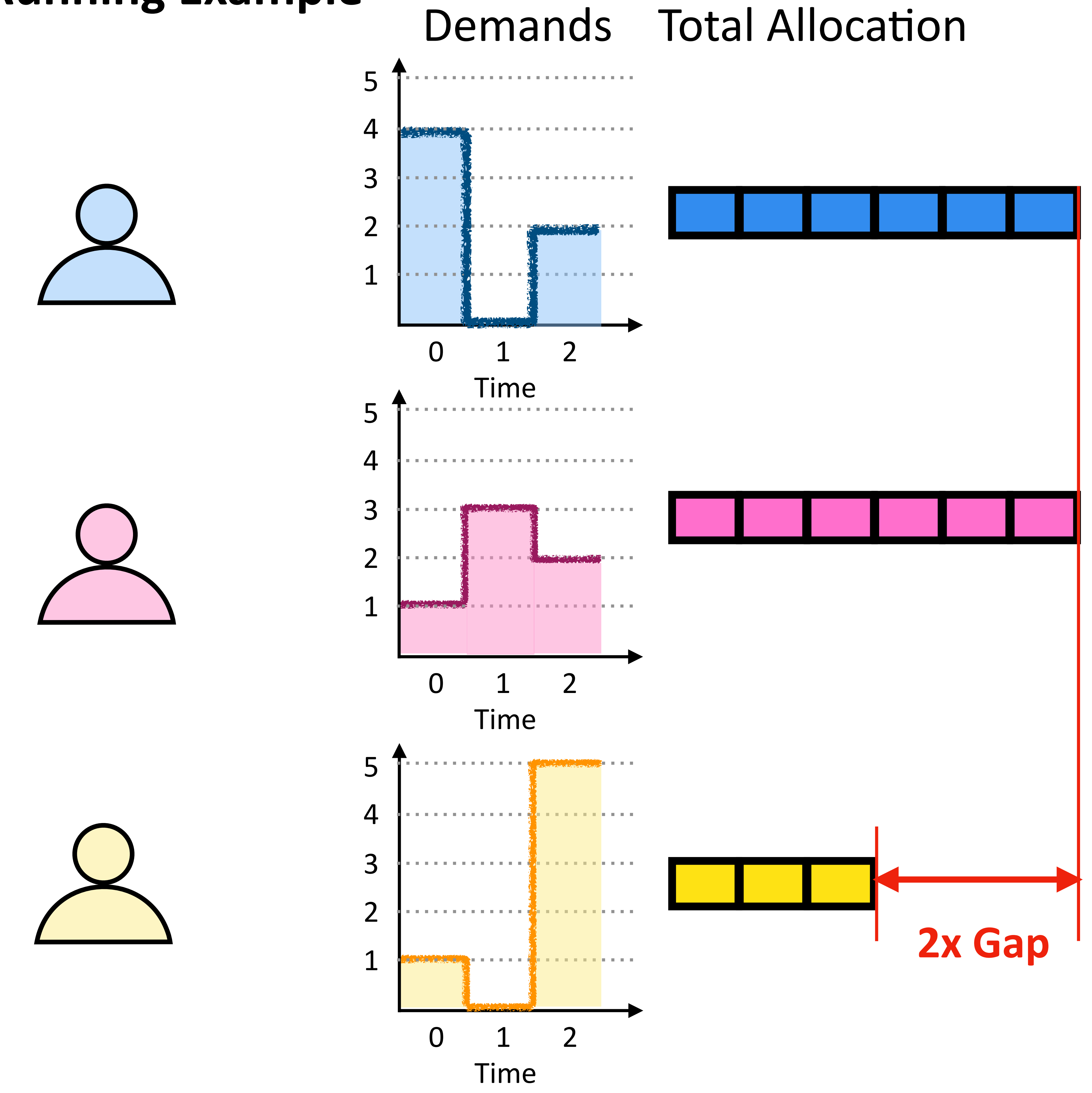

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Need to revisit classical resource allocation problem under dynamic demands

Karma: Revisiting the classical resource allocation problem under dynamic demands

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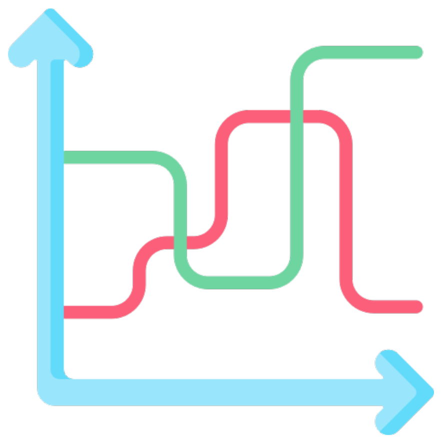

New resource allocation algorithm for dynamic demands

Karma: Revisiting the classical resource allocation problem under dynamic demands

New resource allocation algorithm for dynamic demands

Theoretical guarantees

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Prototype implementation and evaluation

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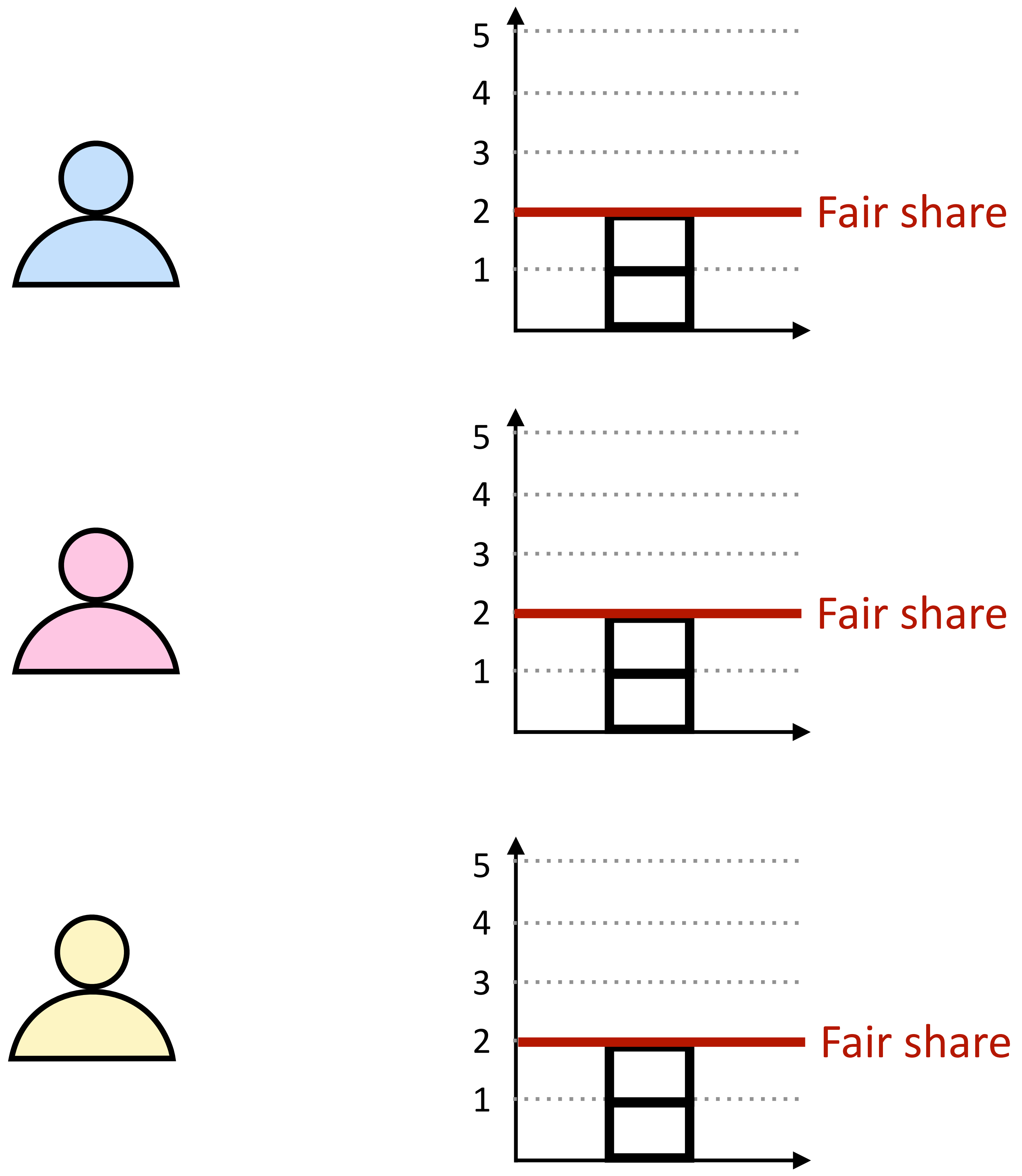
Prototype implementation and evaluation

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



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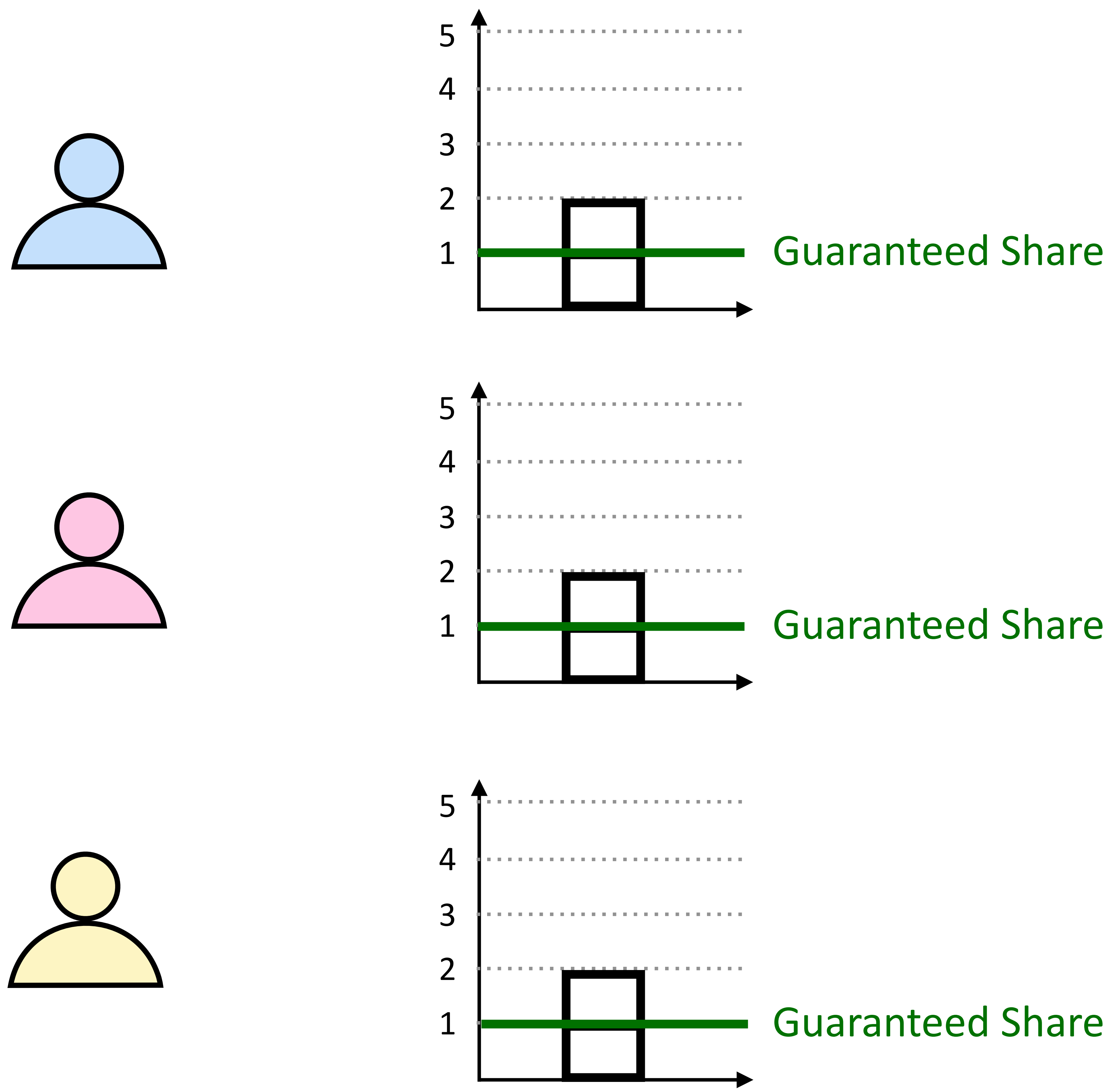

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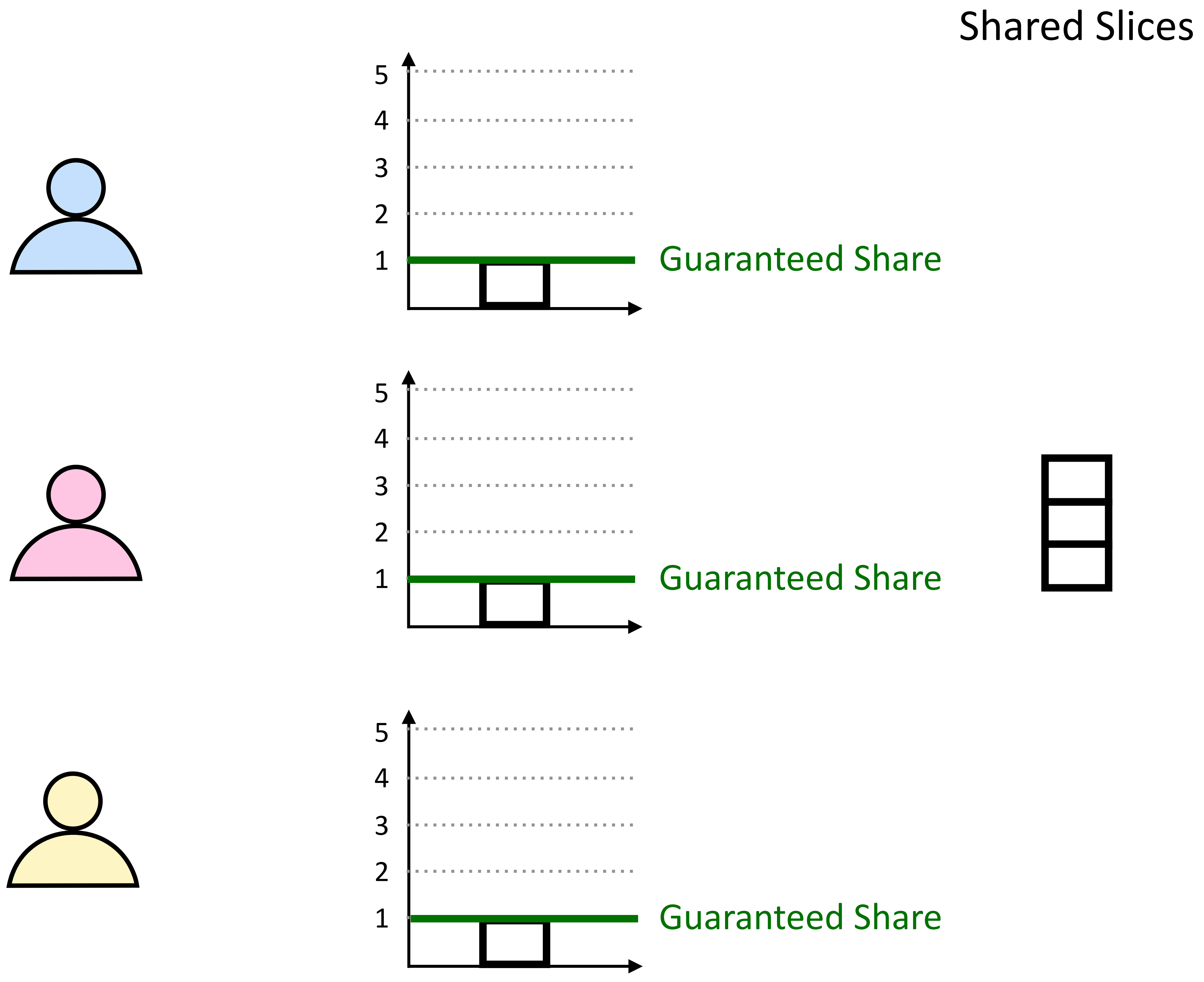

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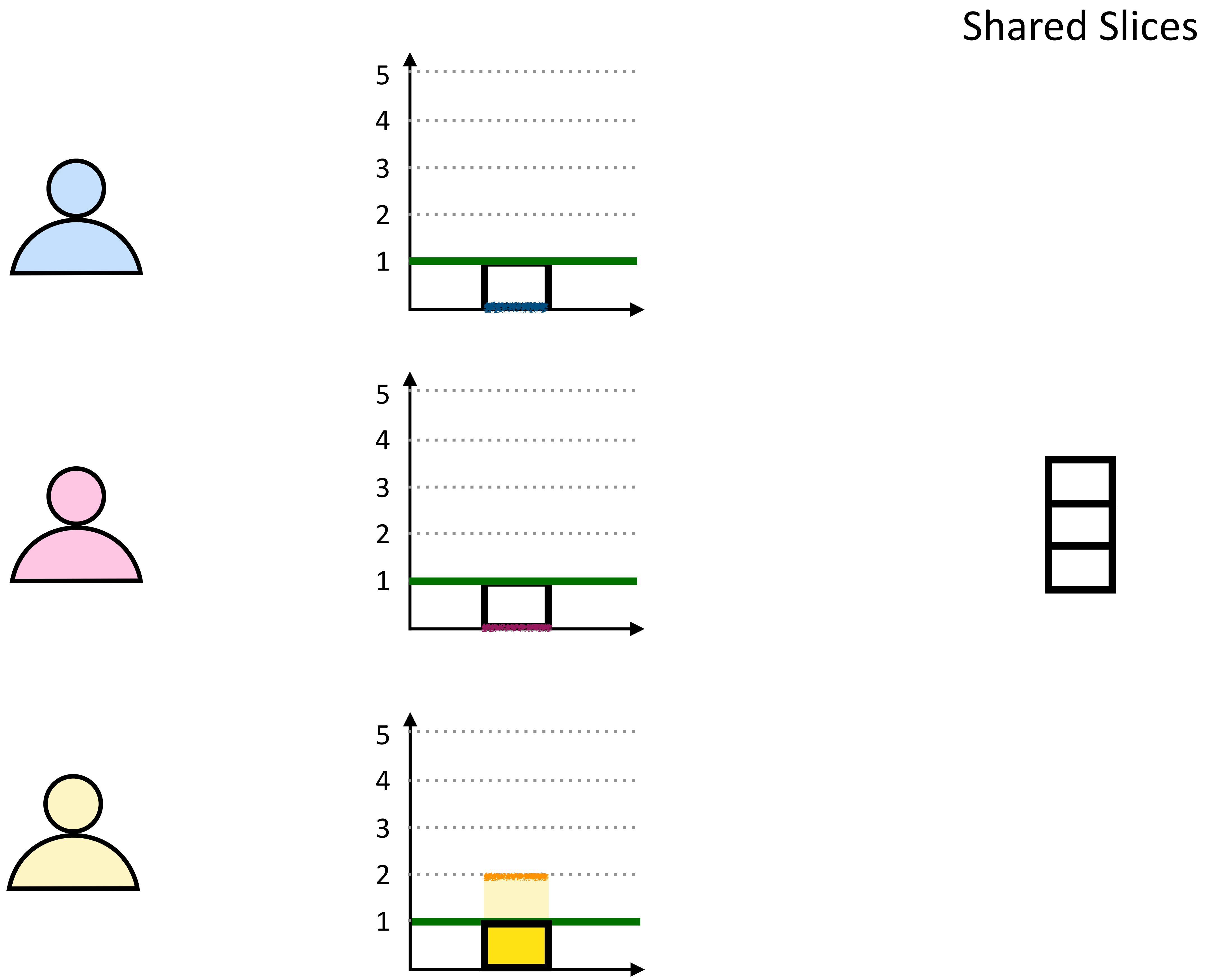

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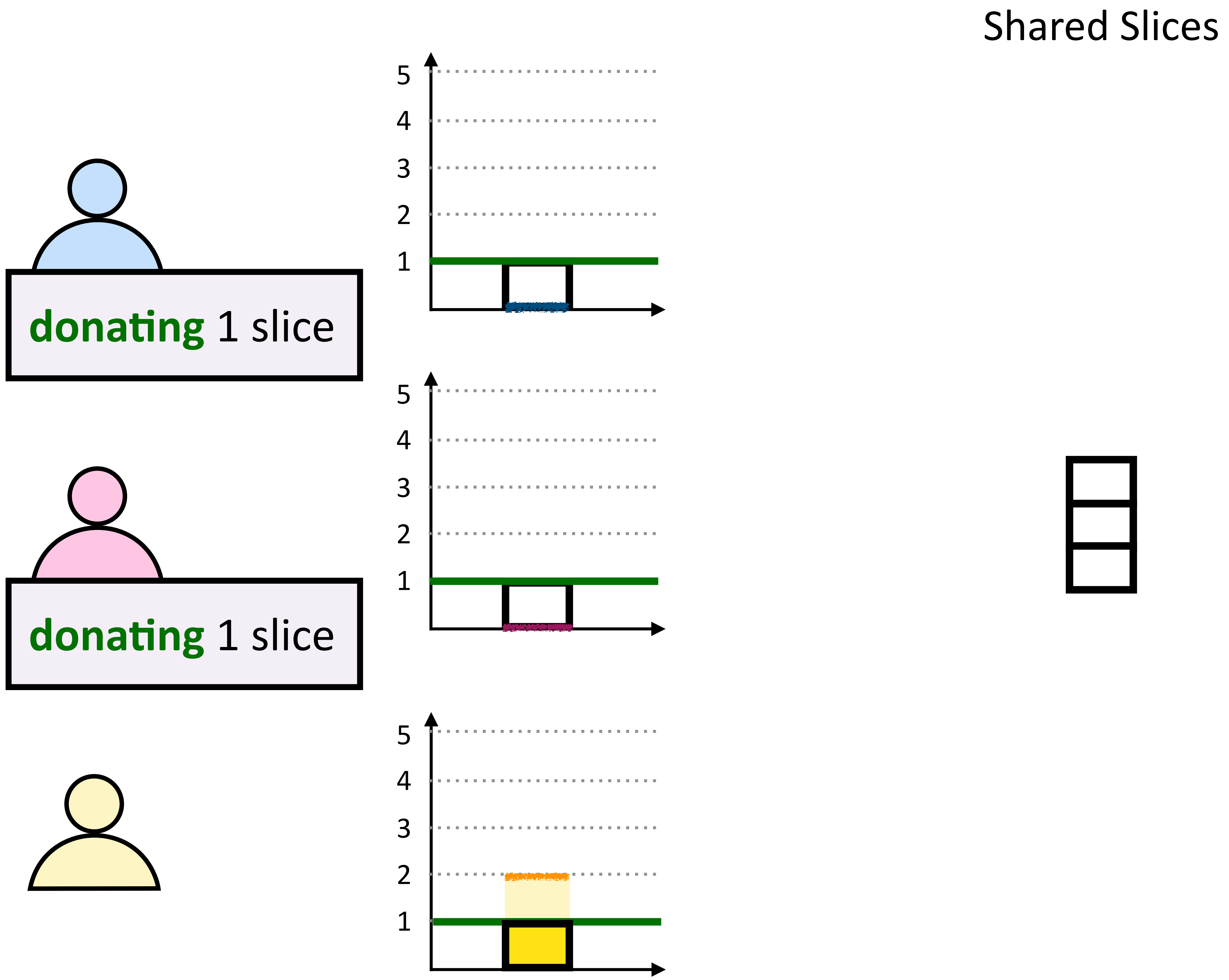

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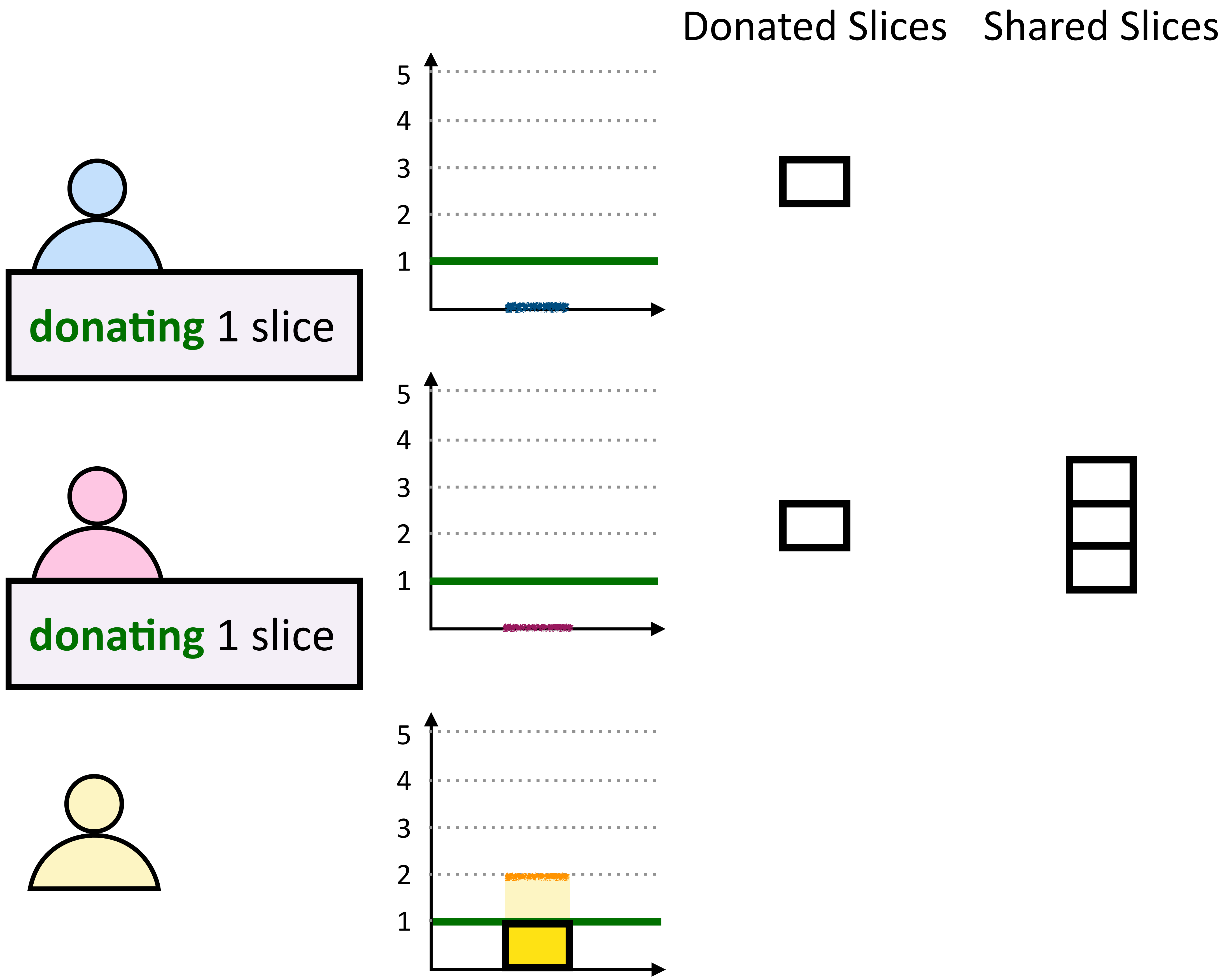

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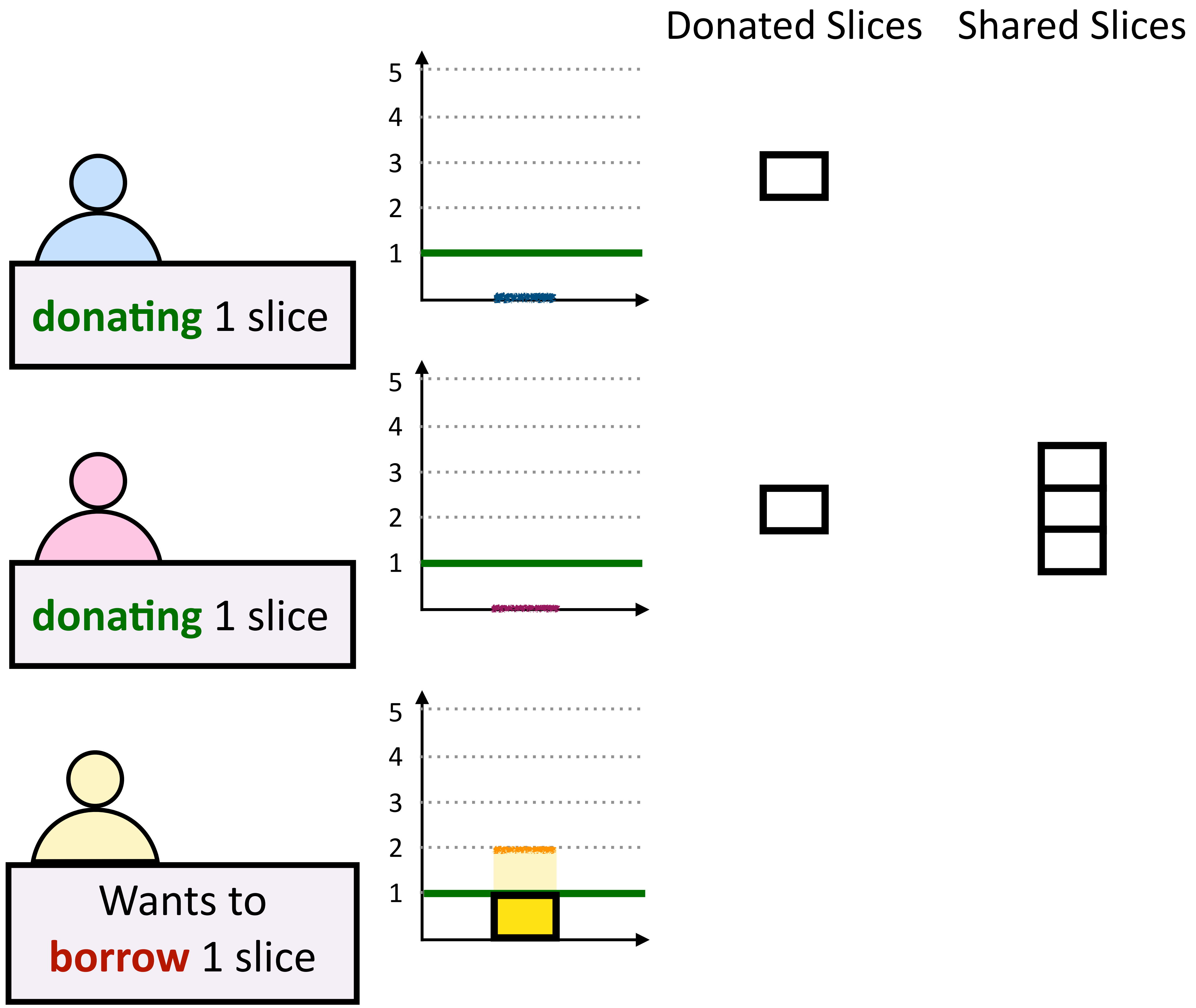
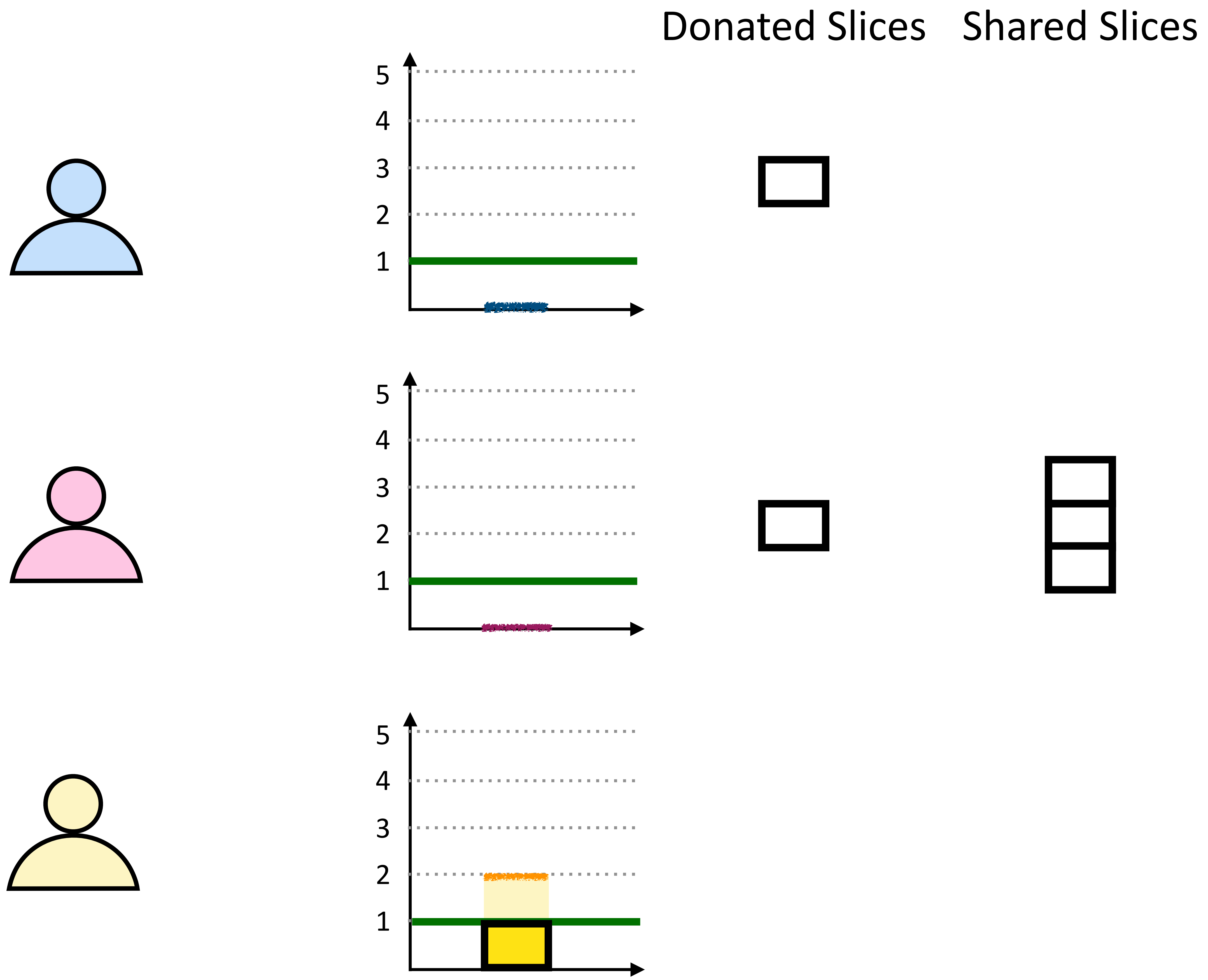


Karma key idea #2: "credits" for resource allocation



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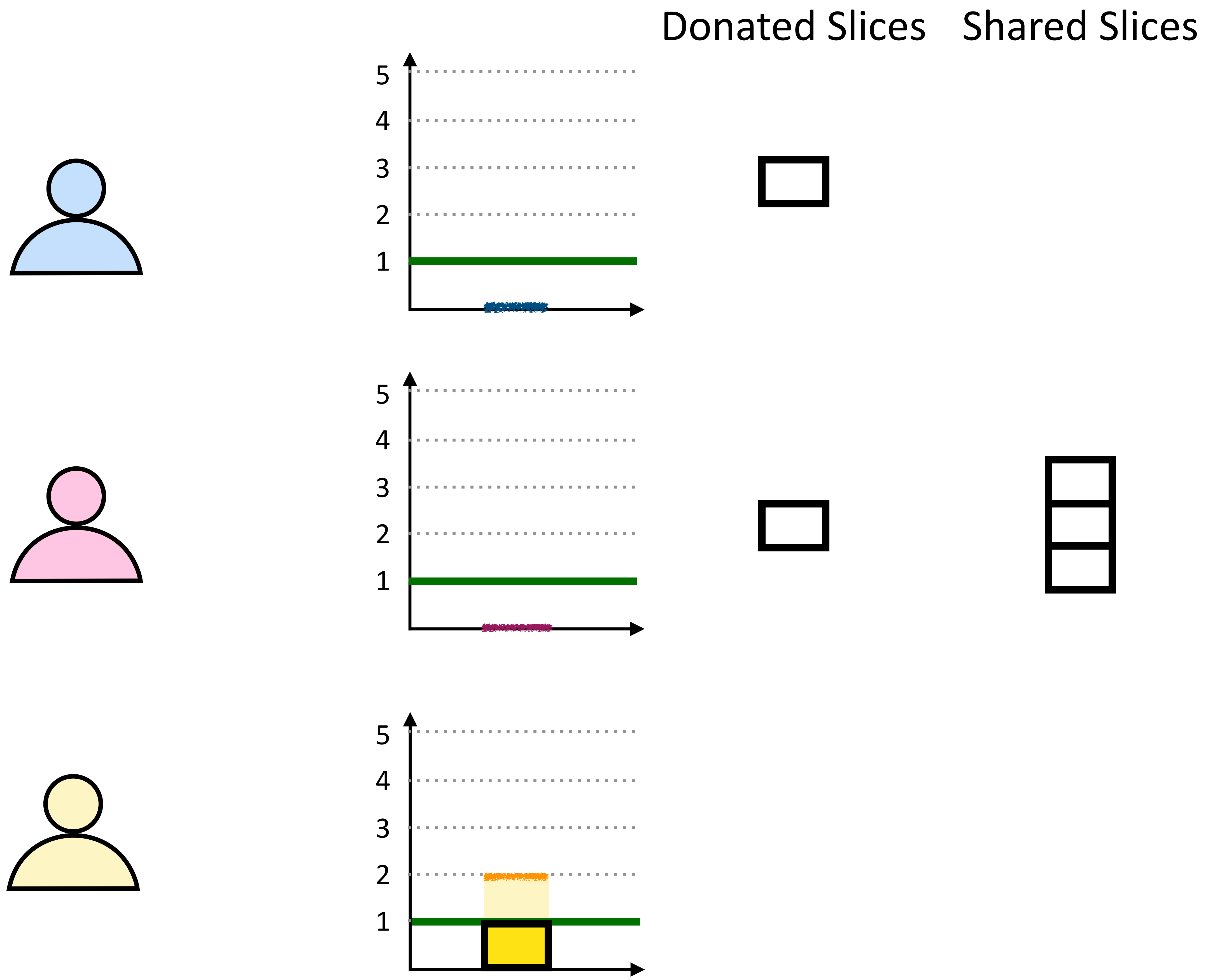

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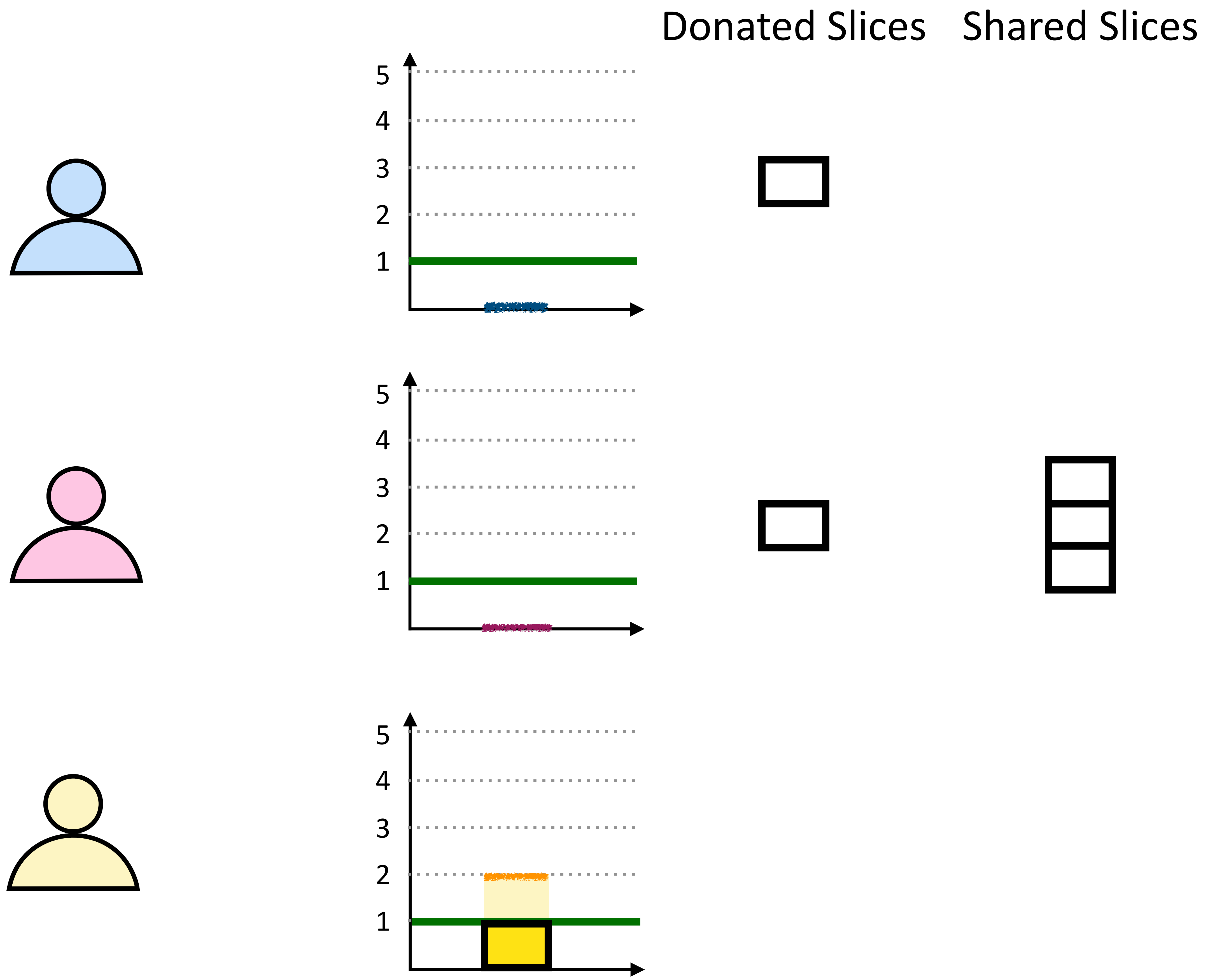

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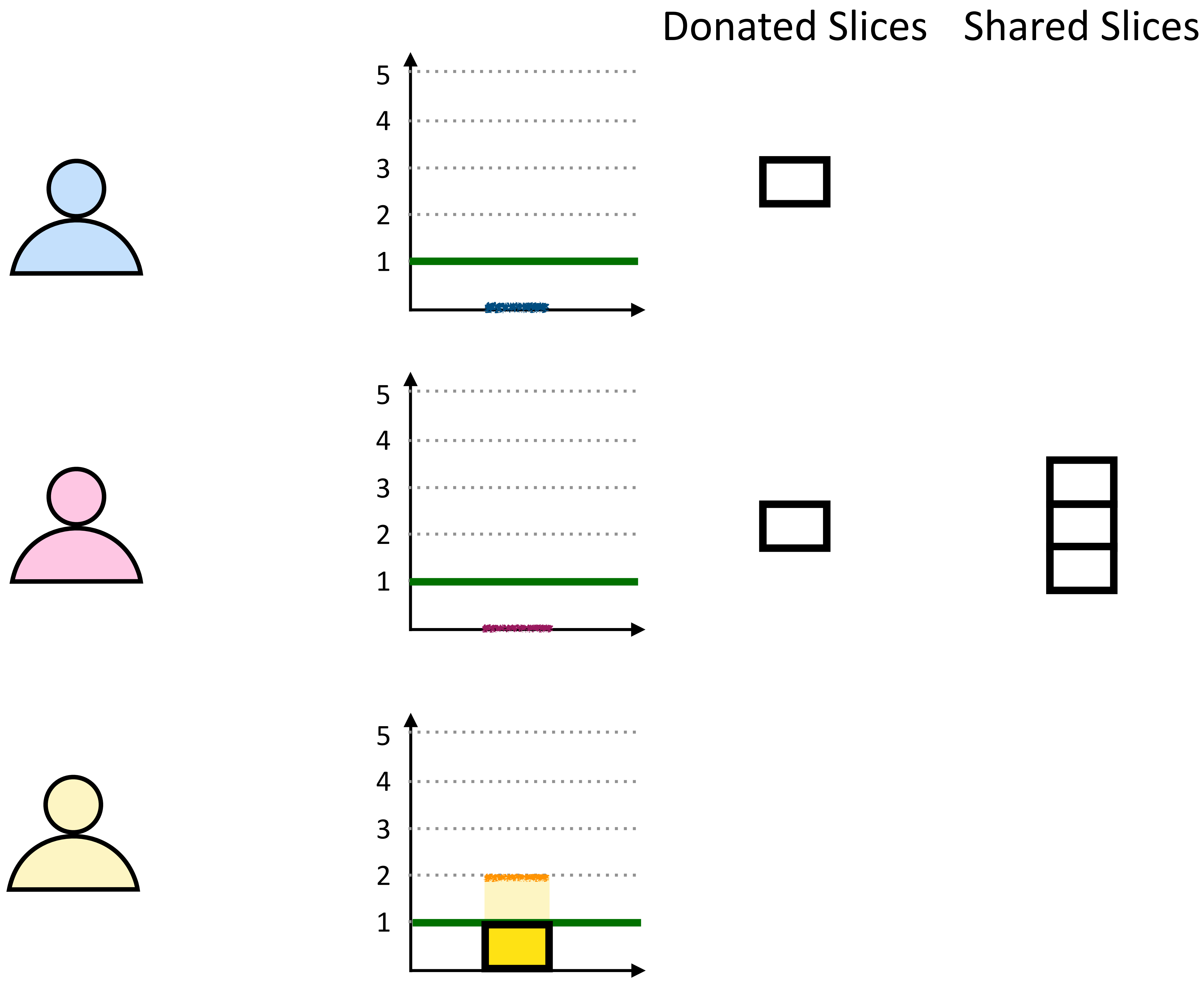

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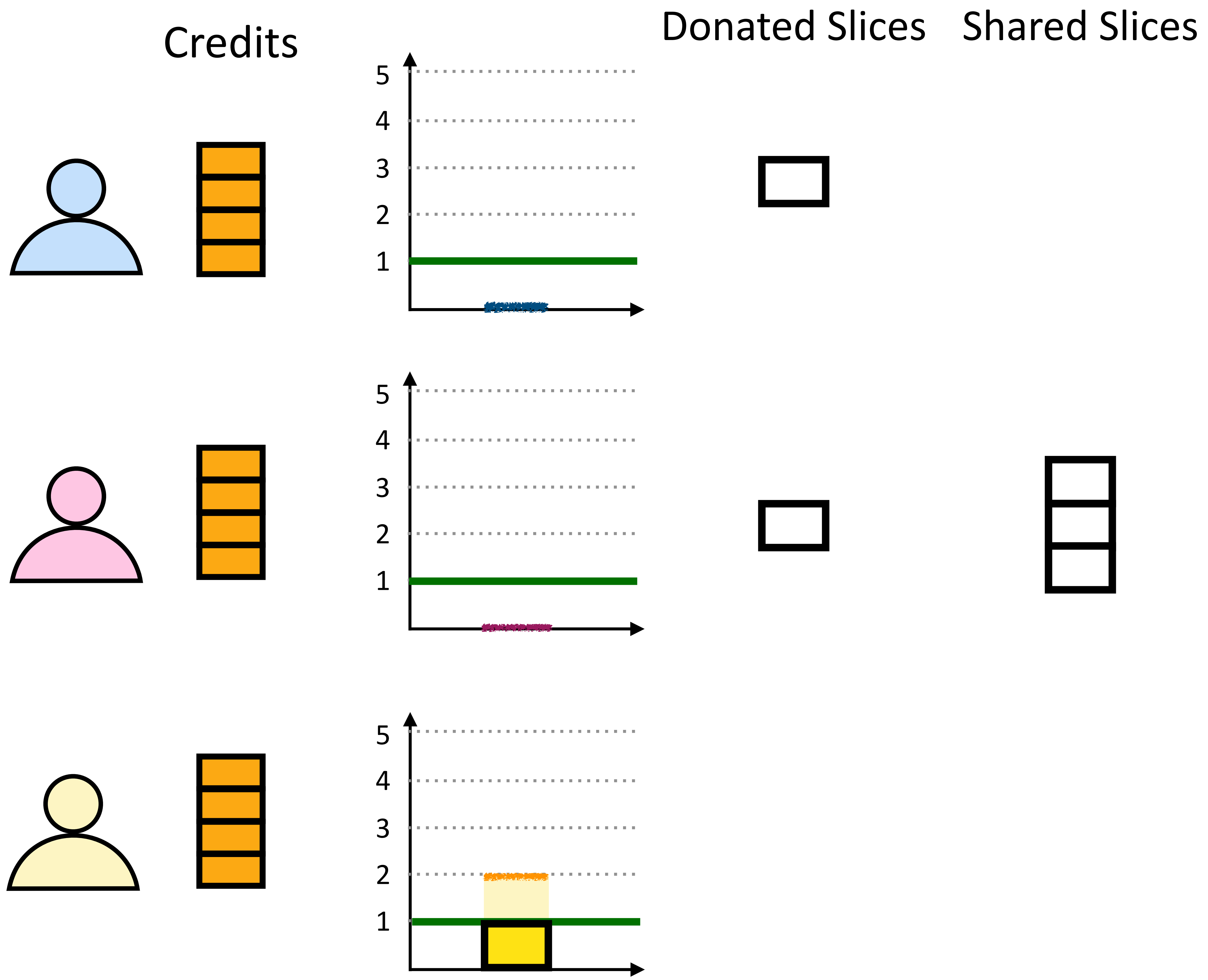

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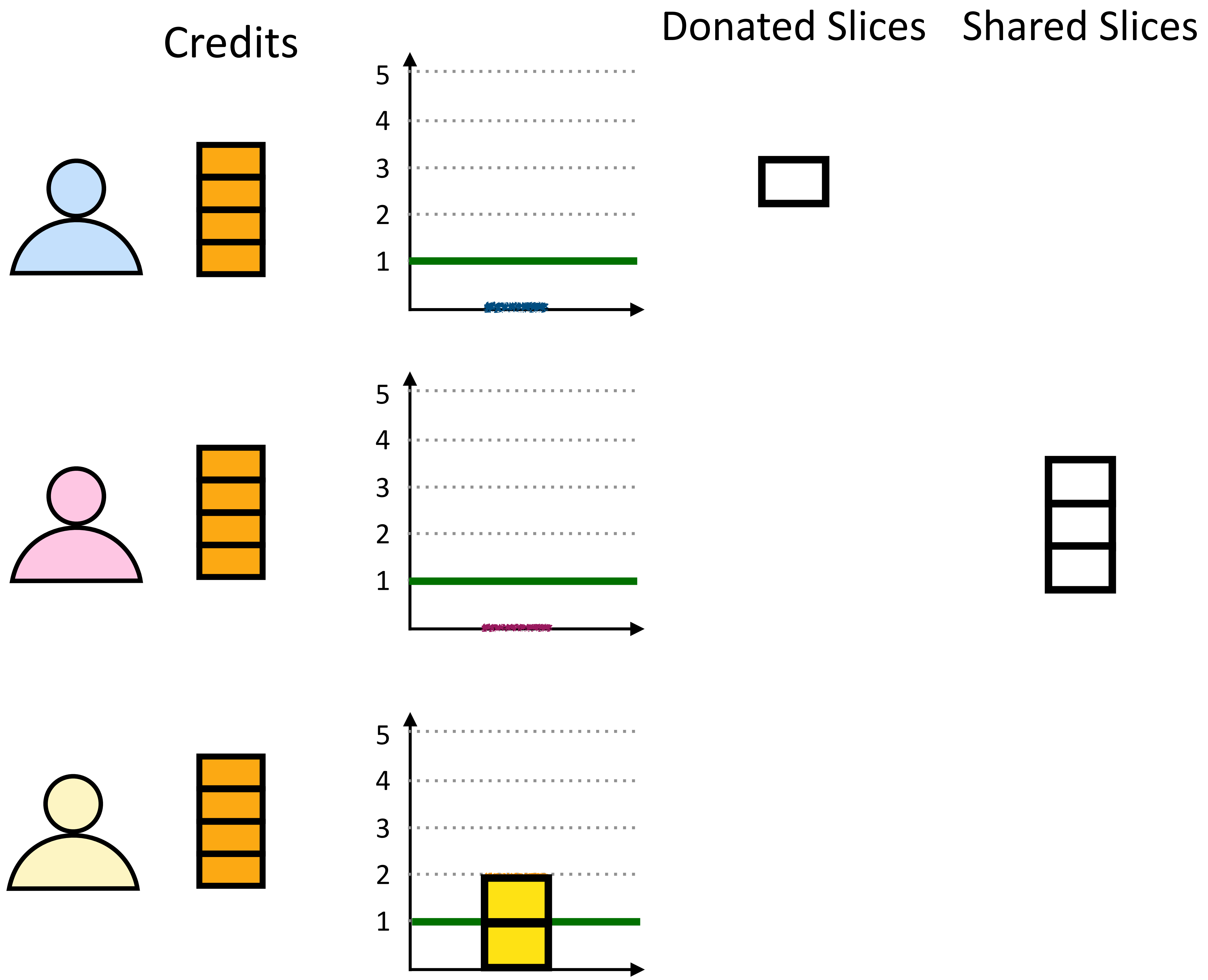

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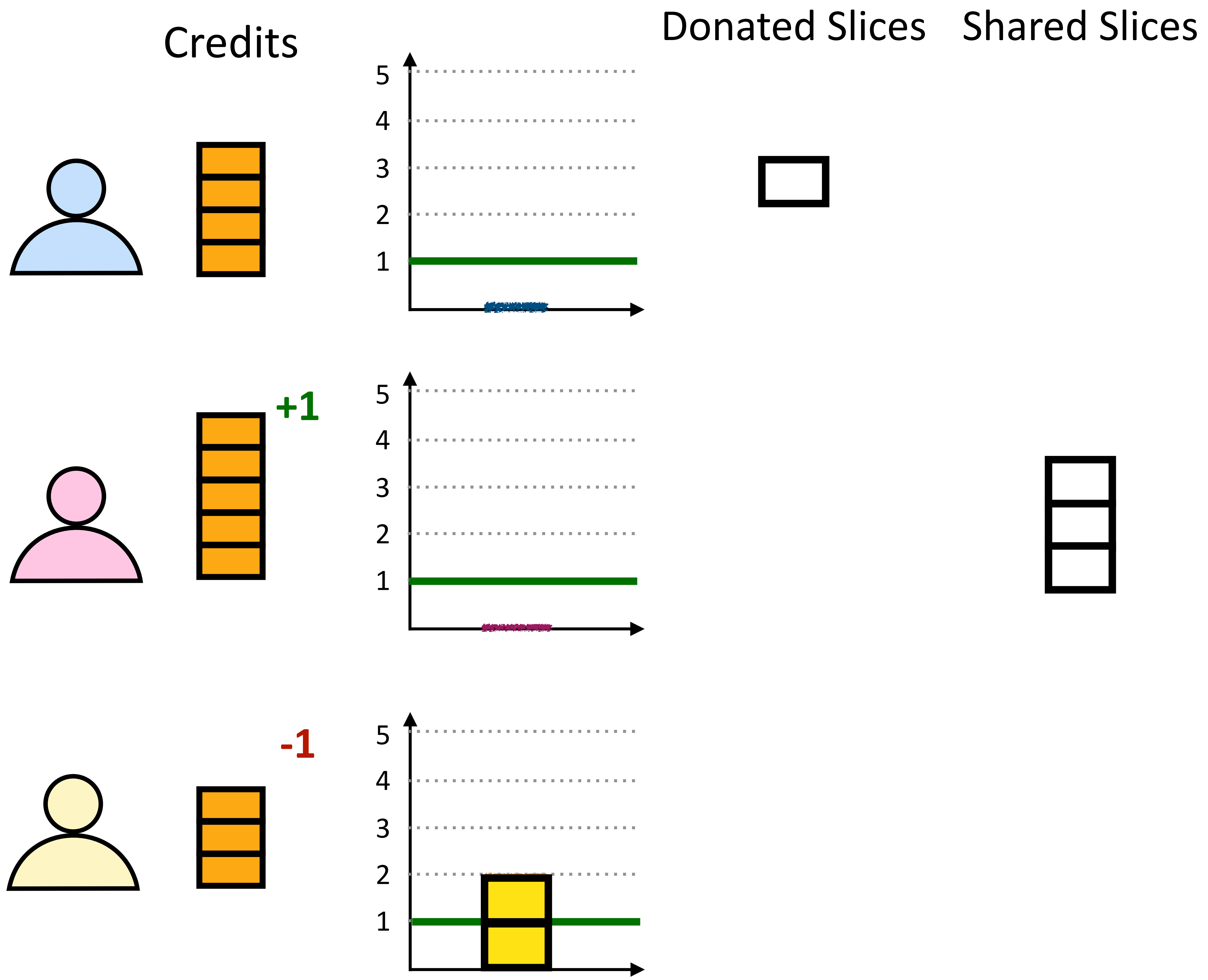

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Karma allocation algorithm

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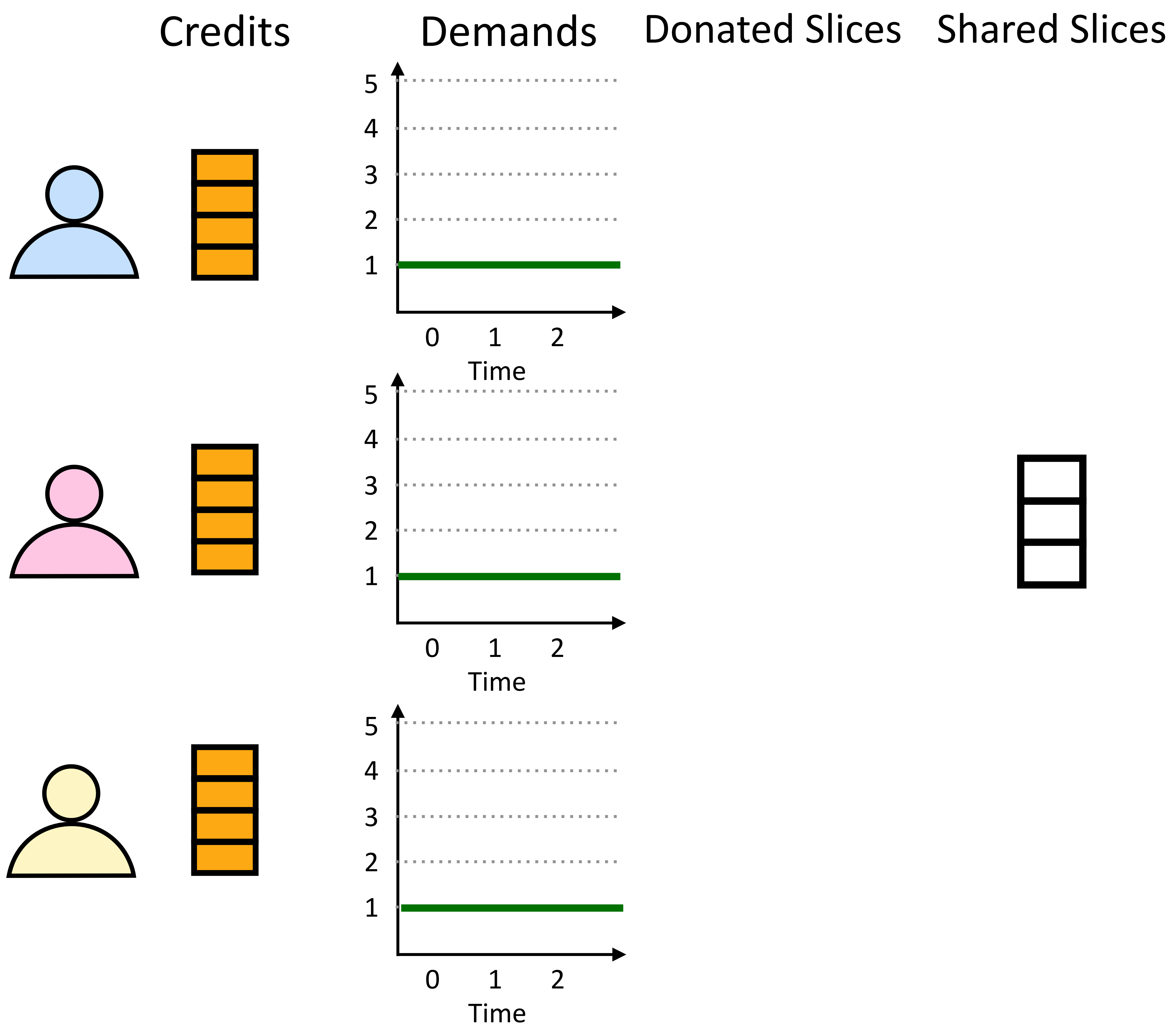

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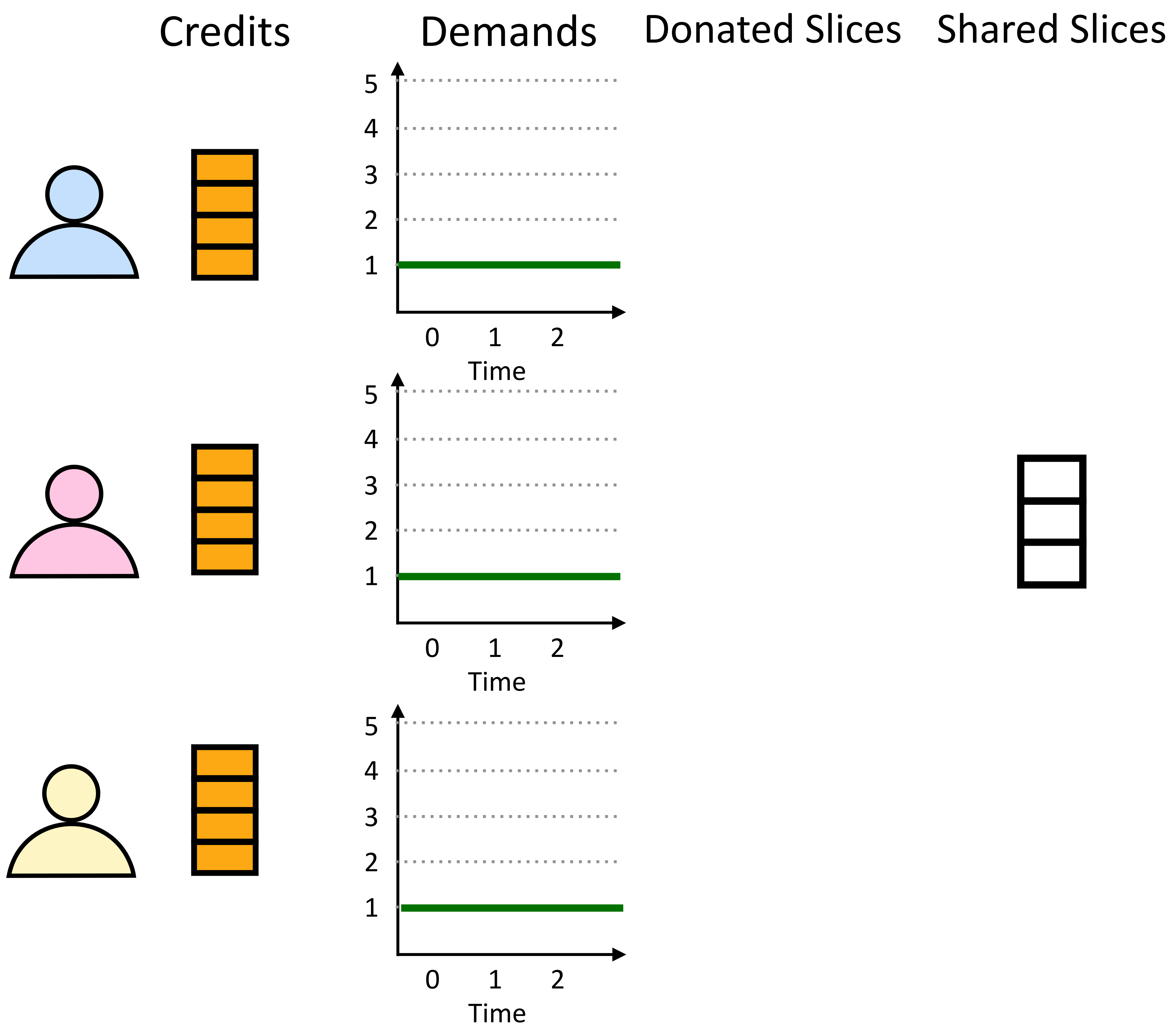

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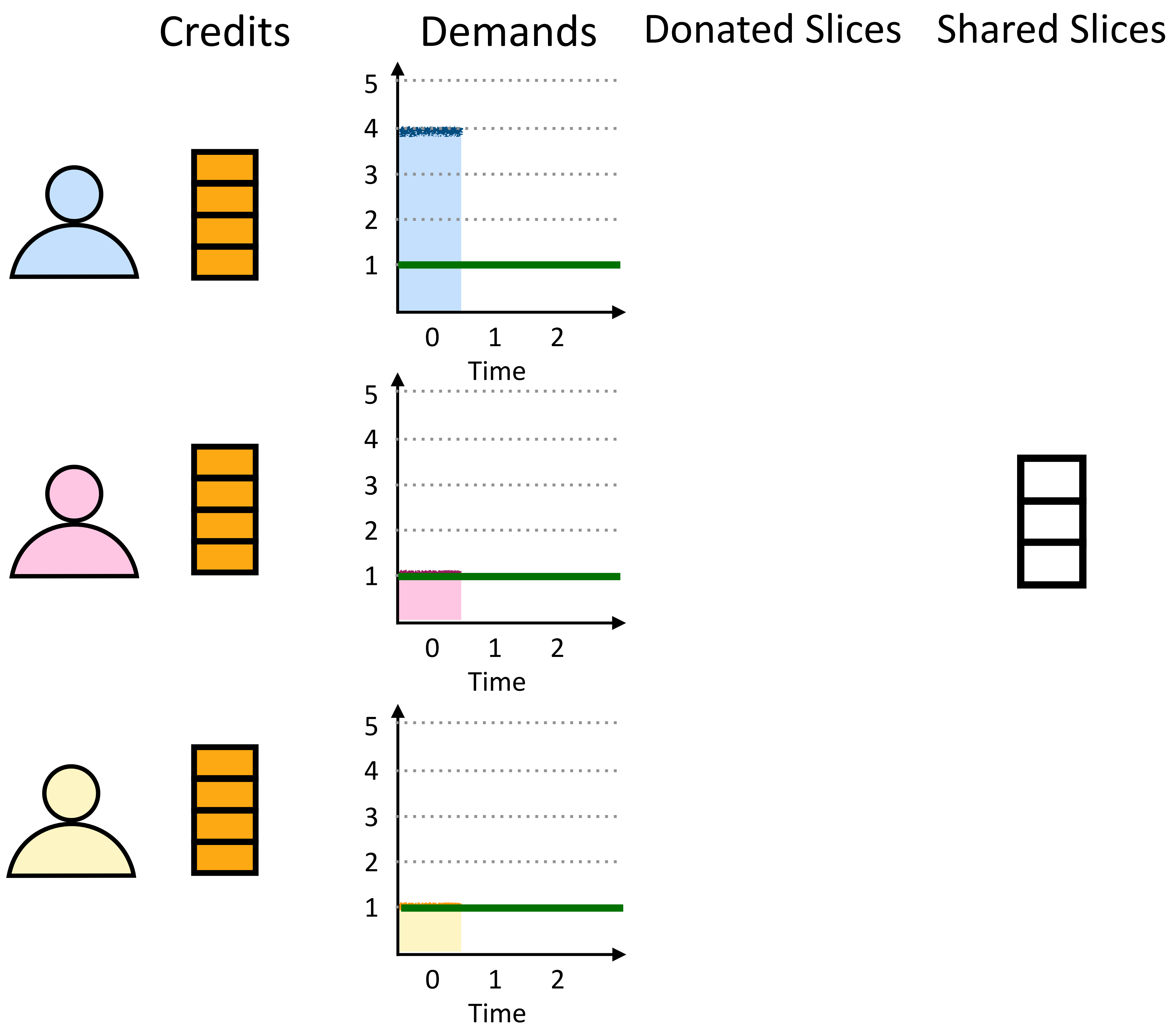

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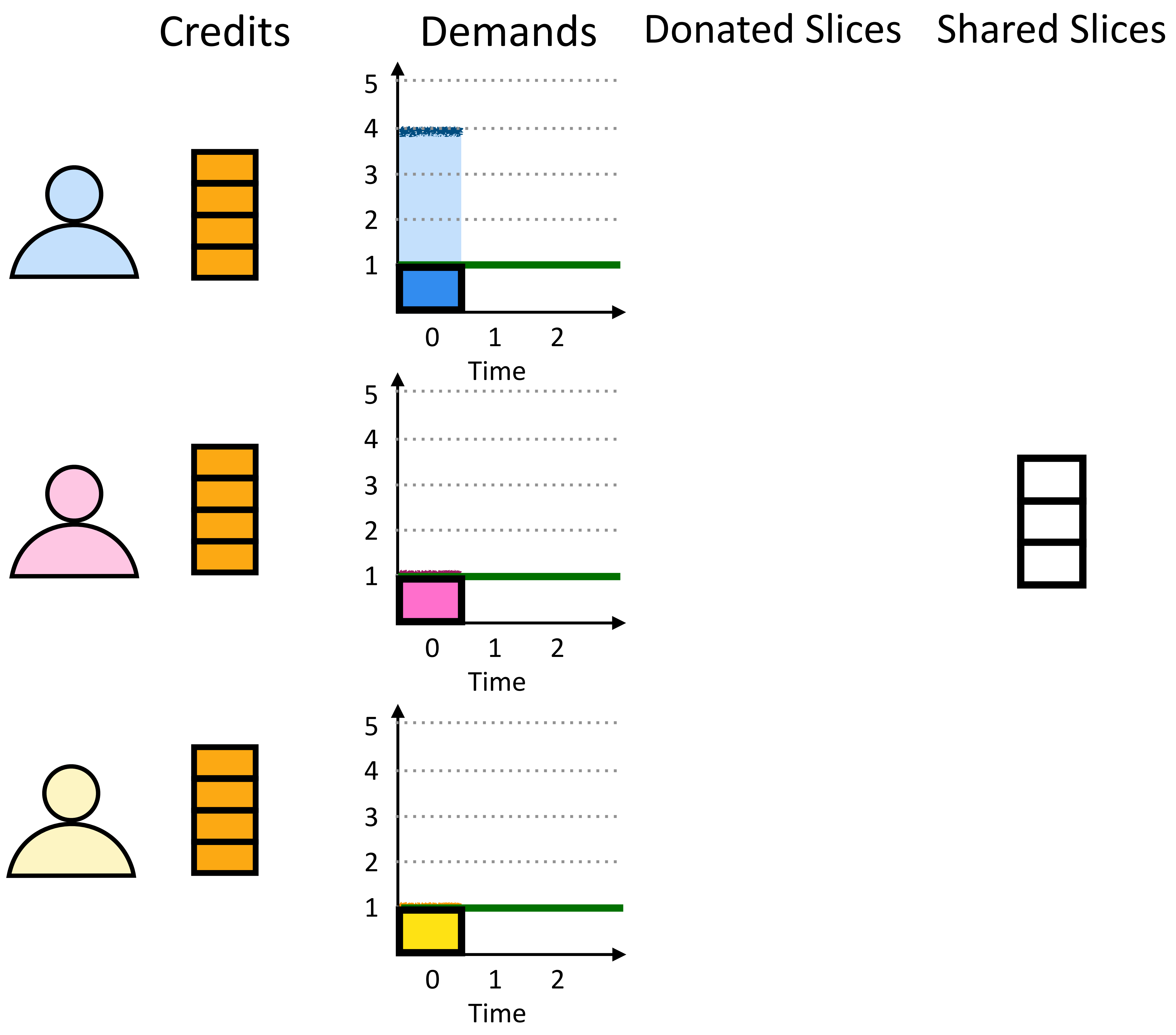

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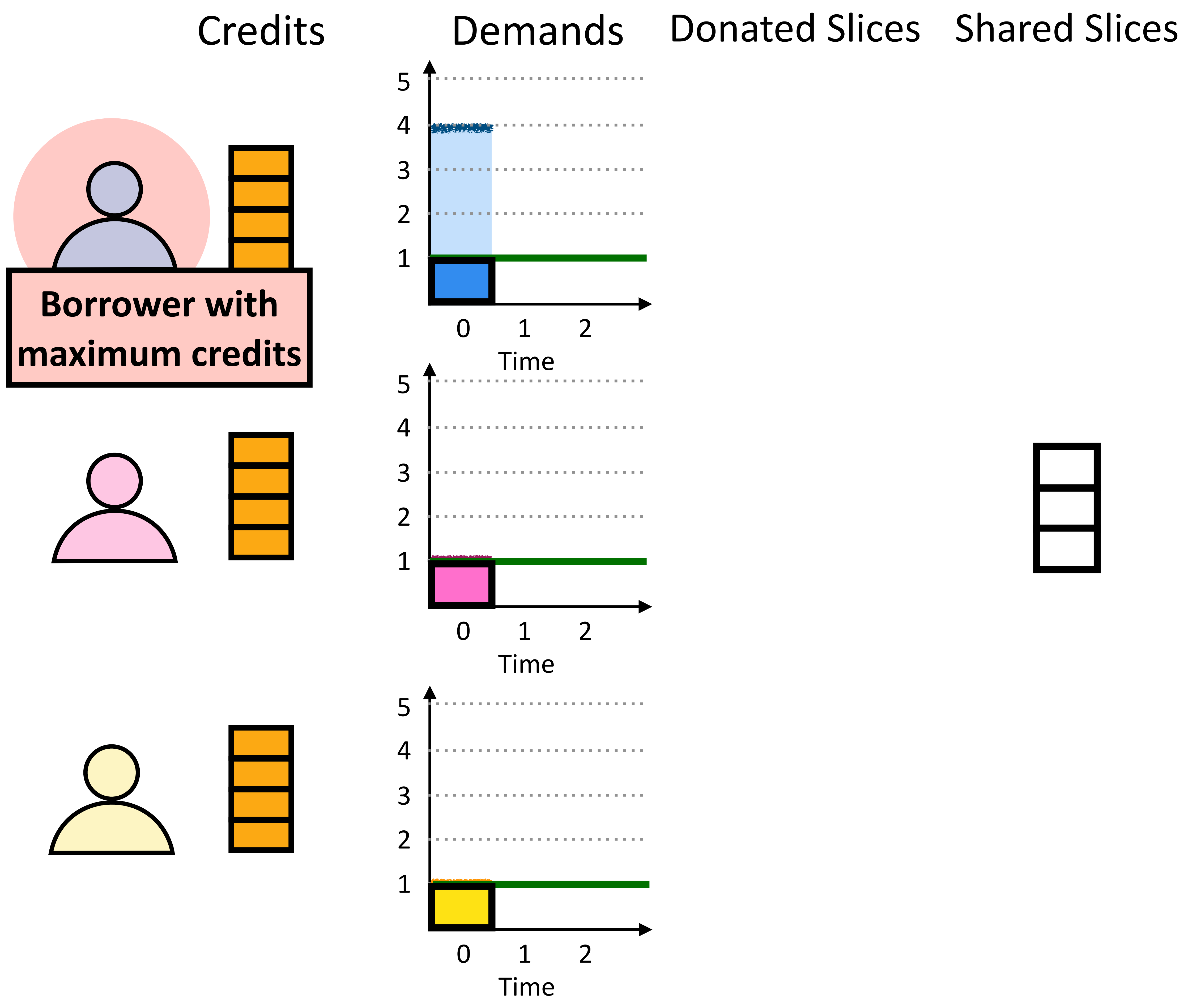

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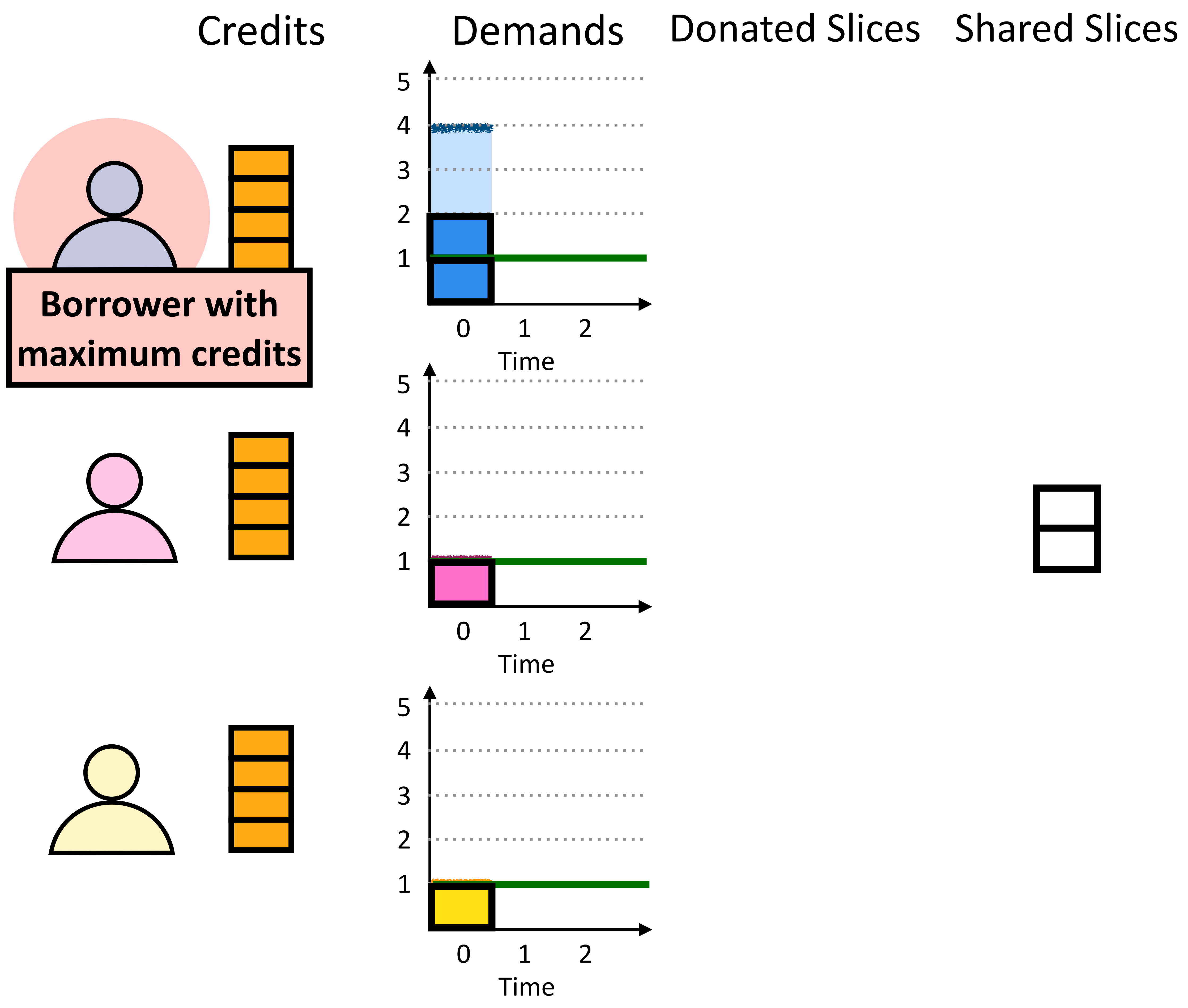

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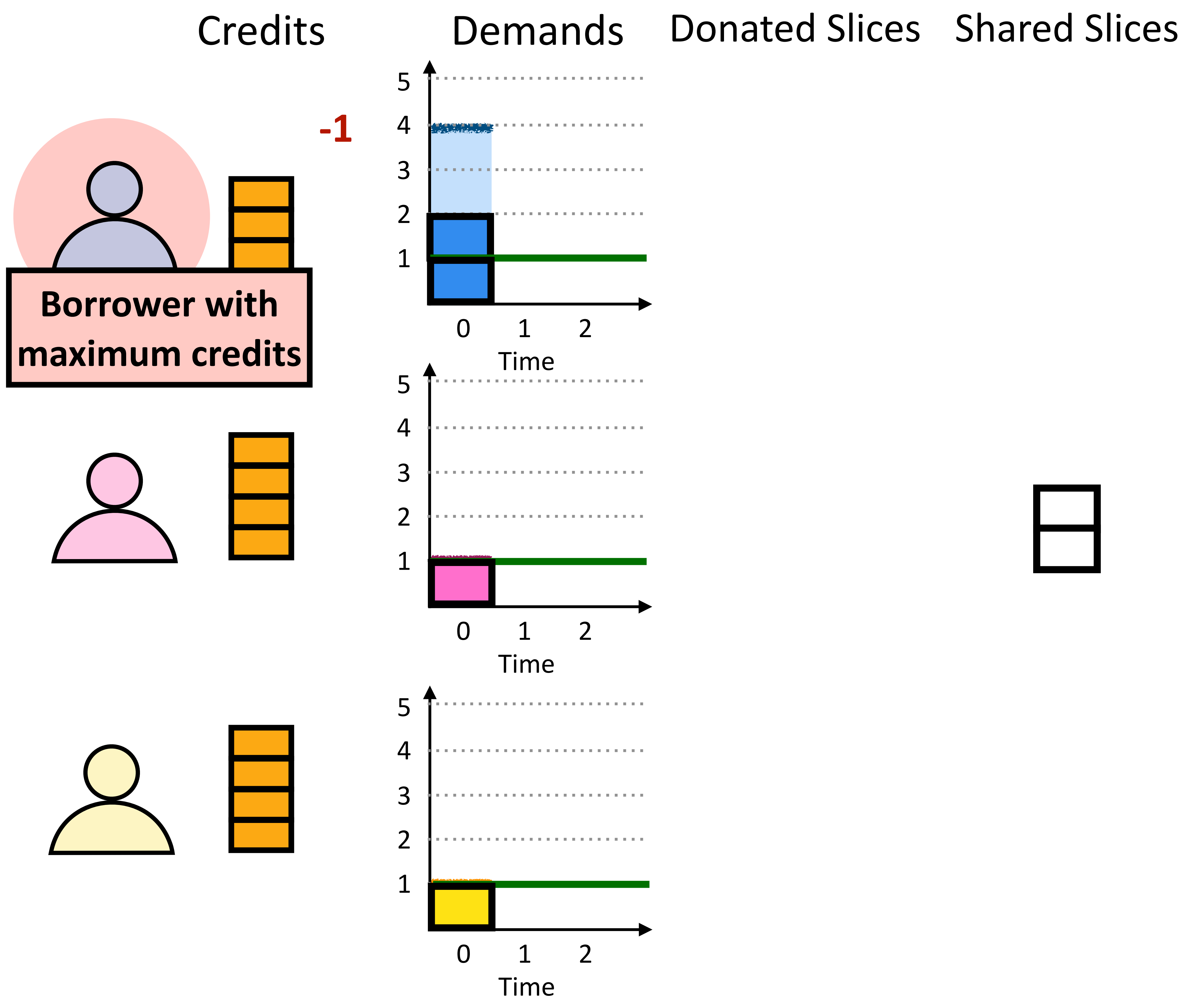

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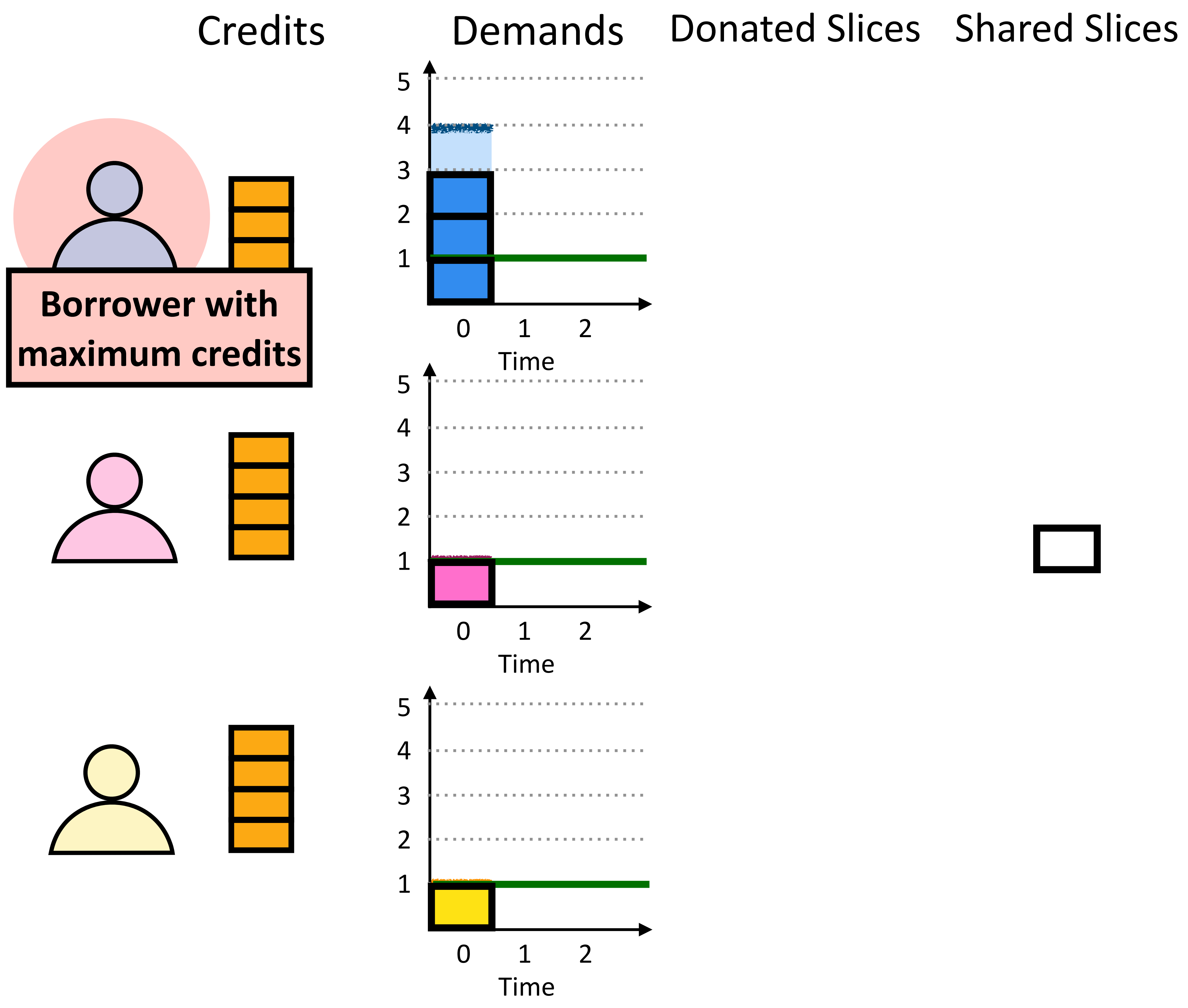

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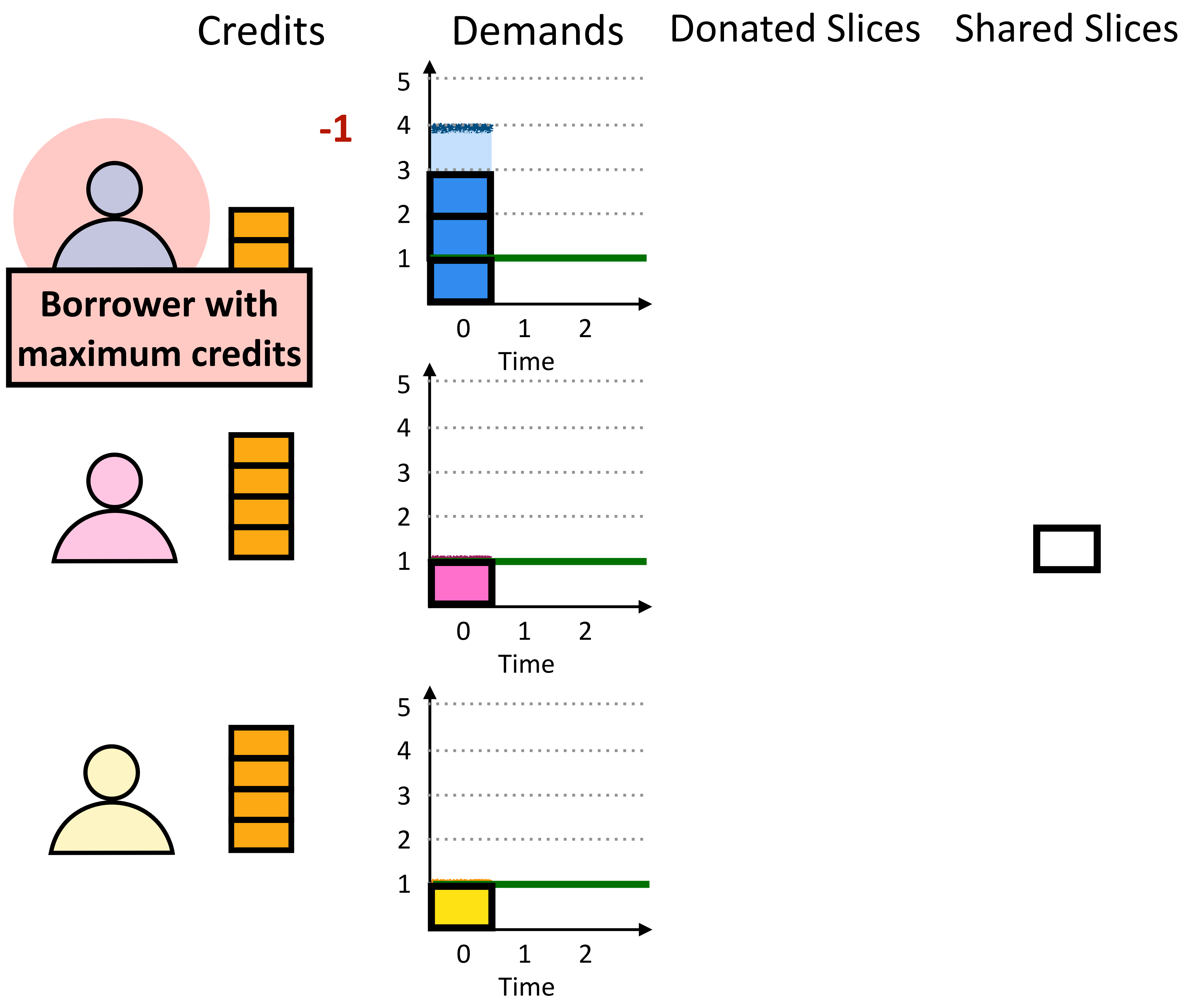

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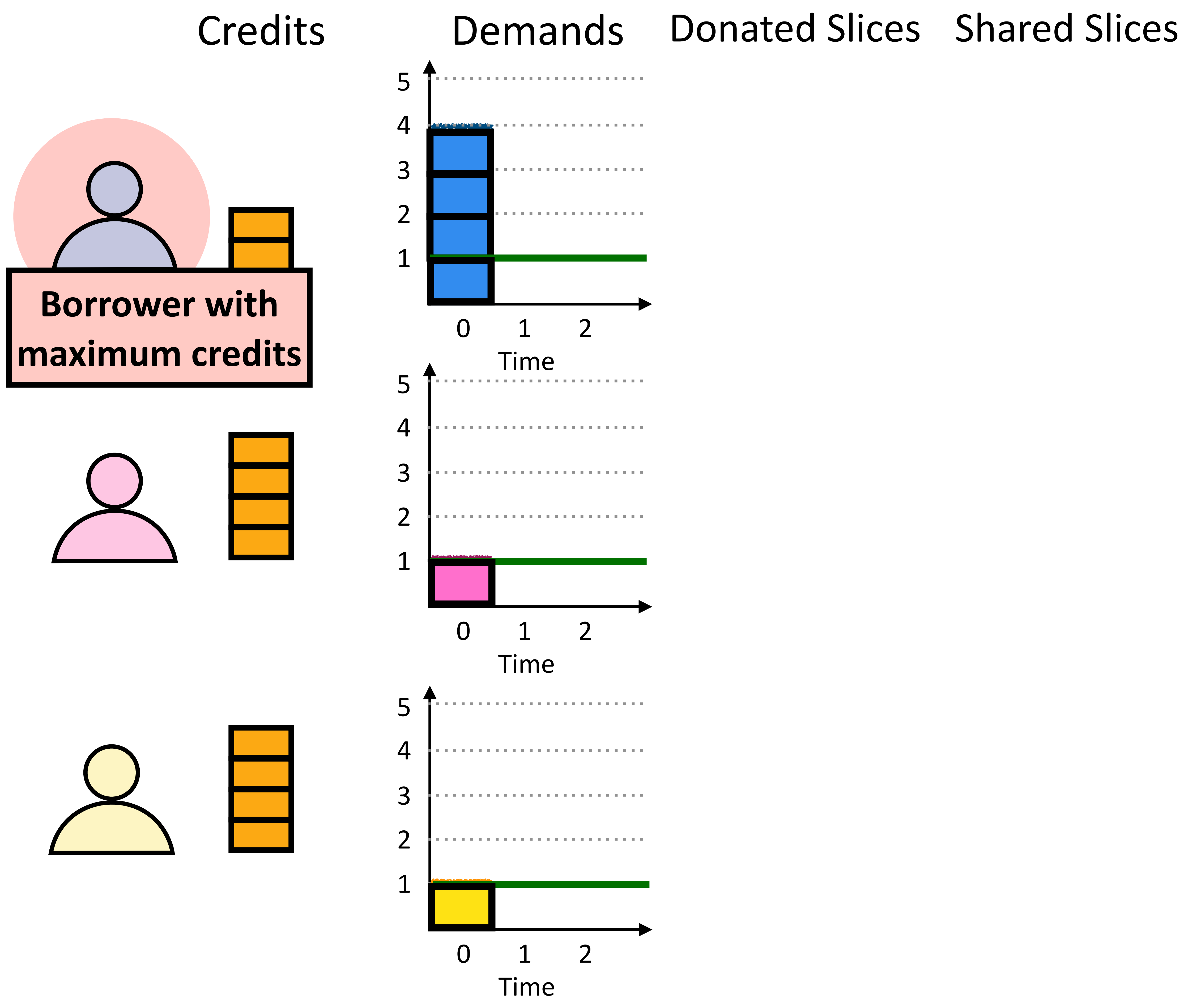

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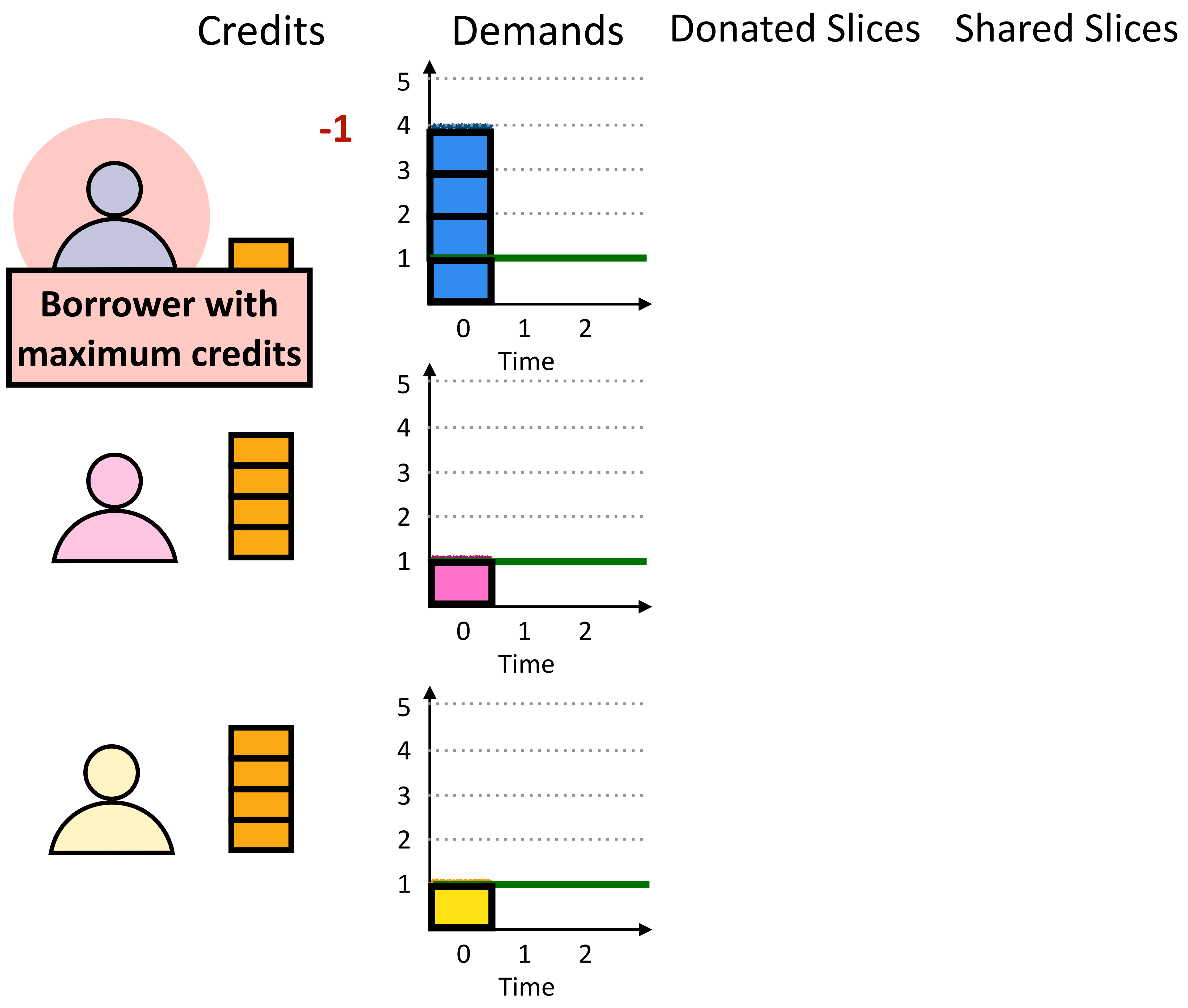

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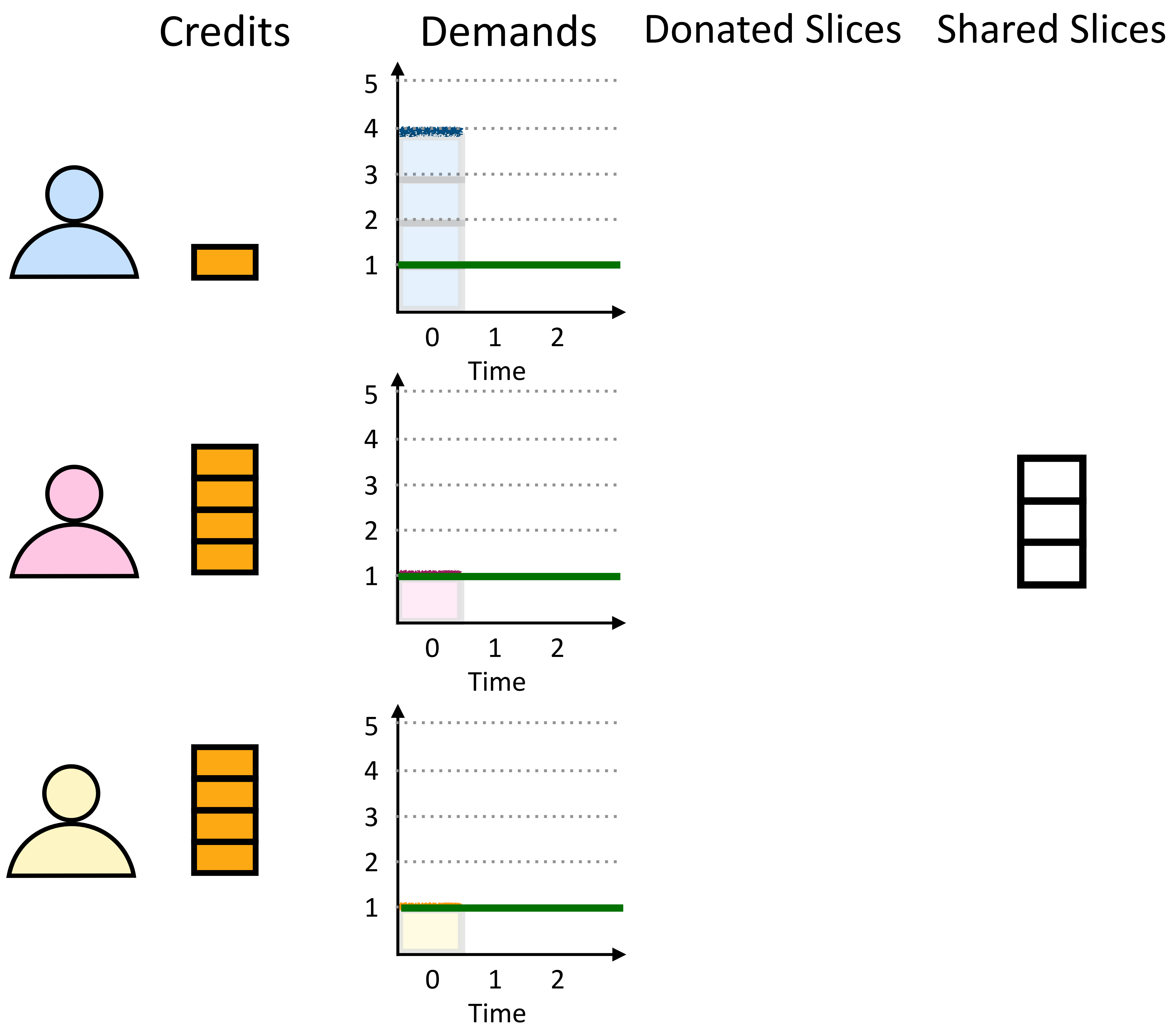

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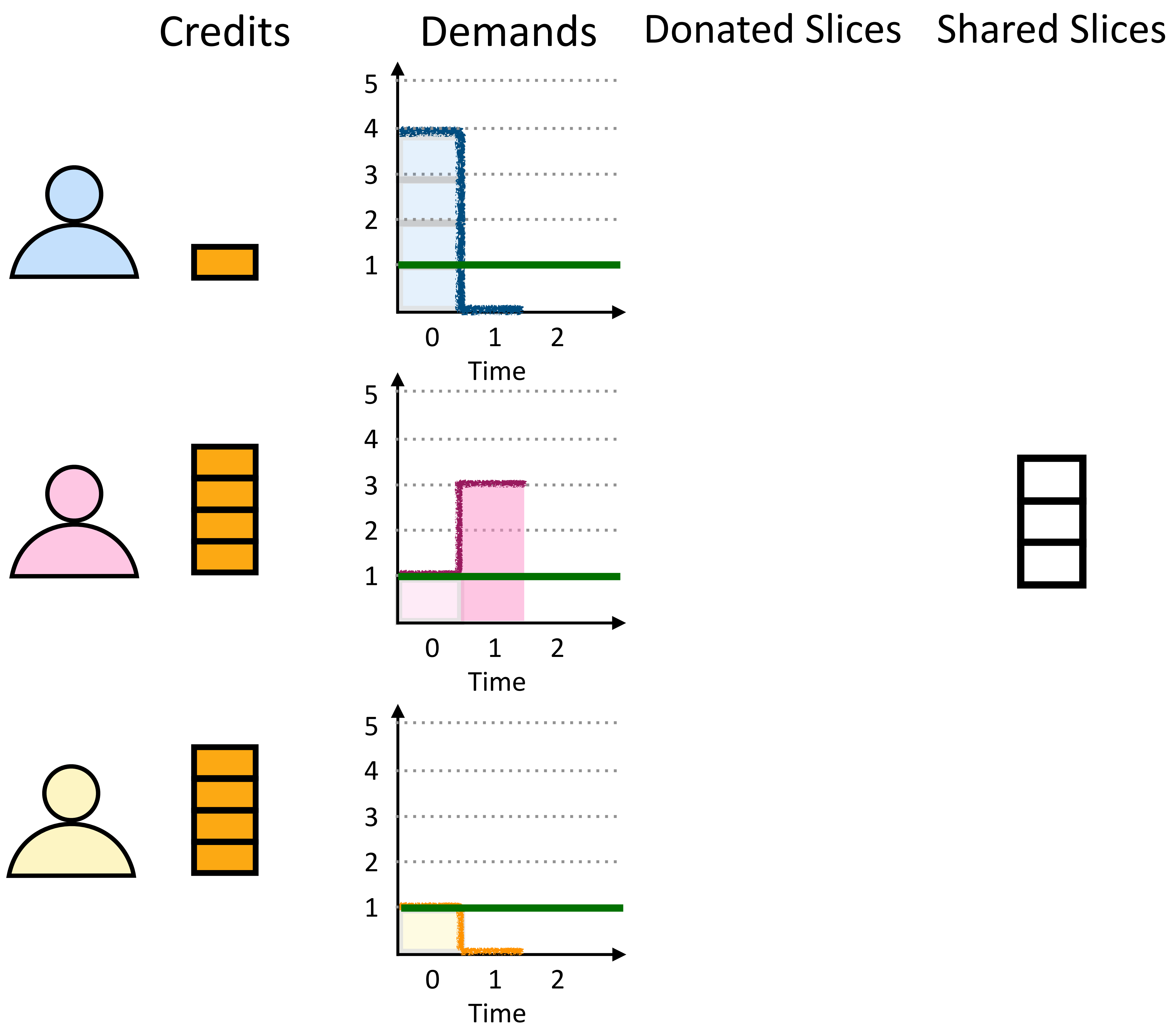

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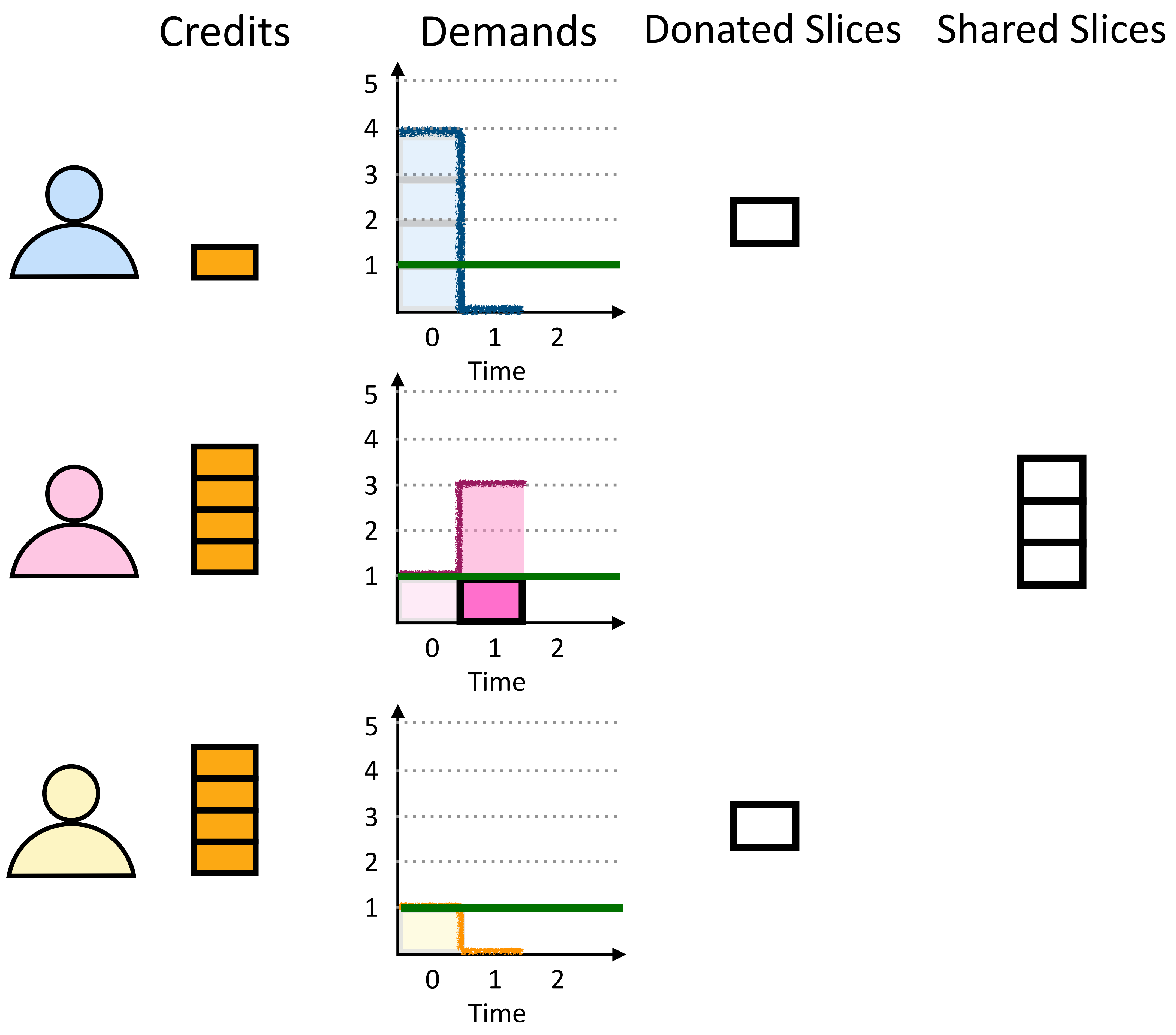

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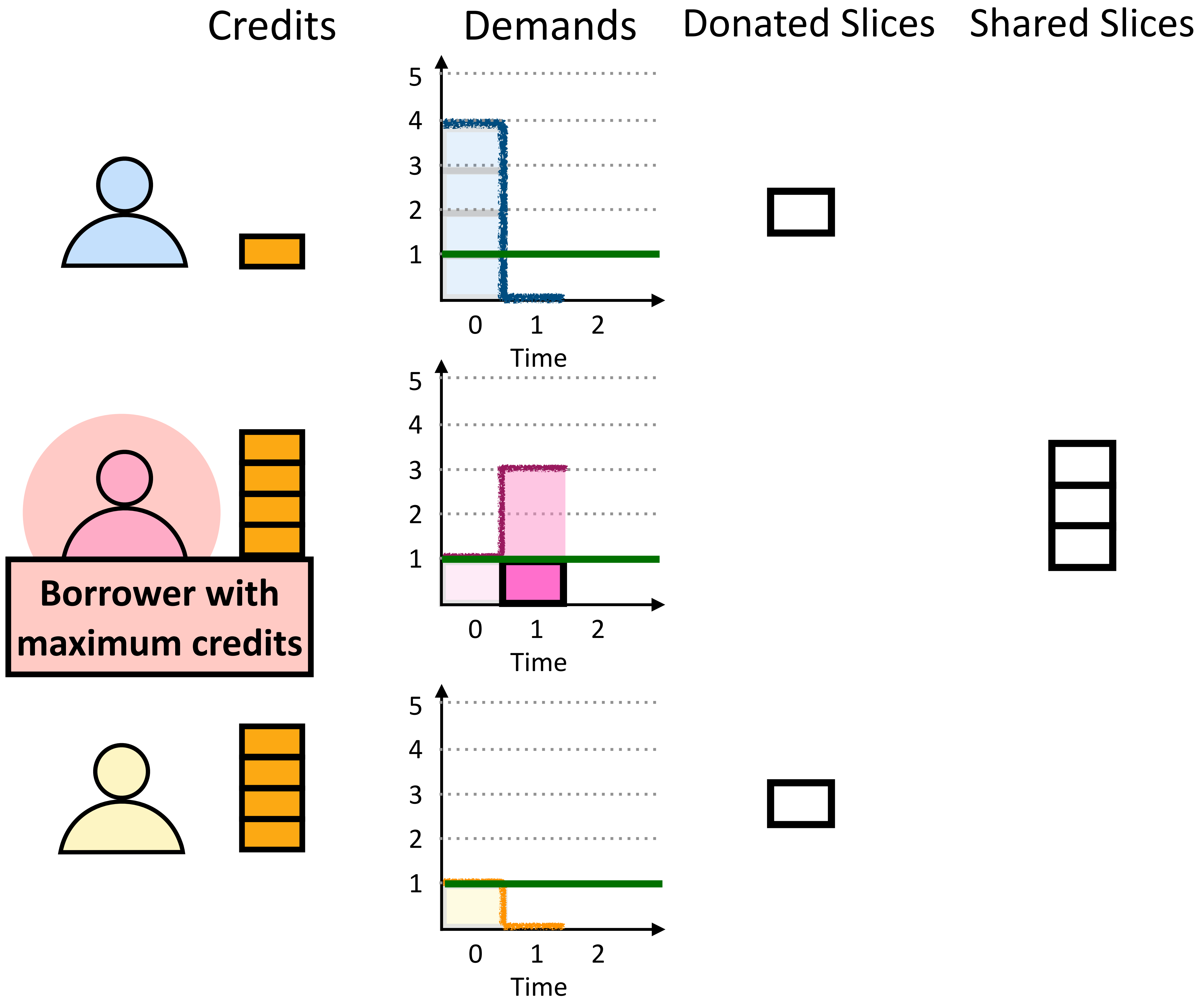

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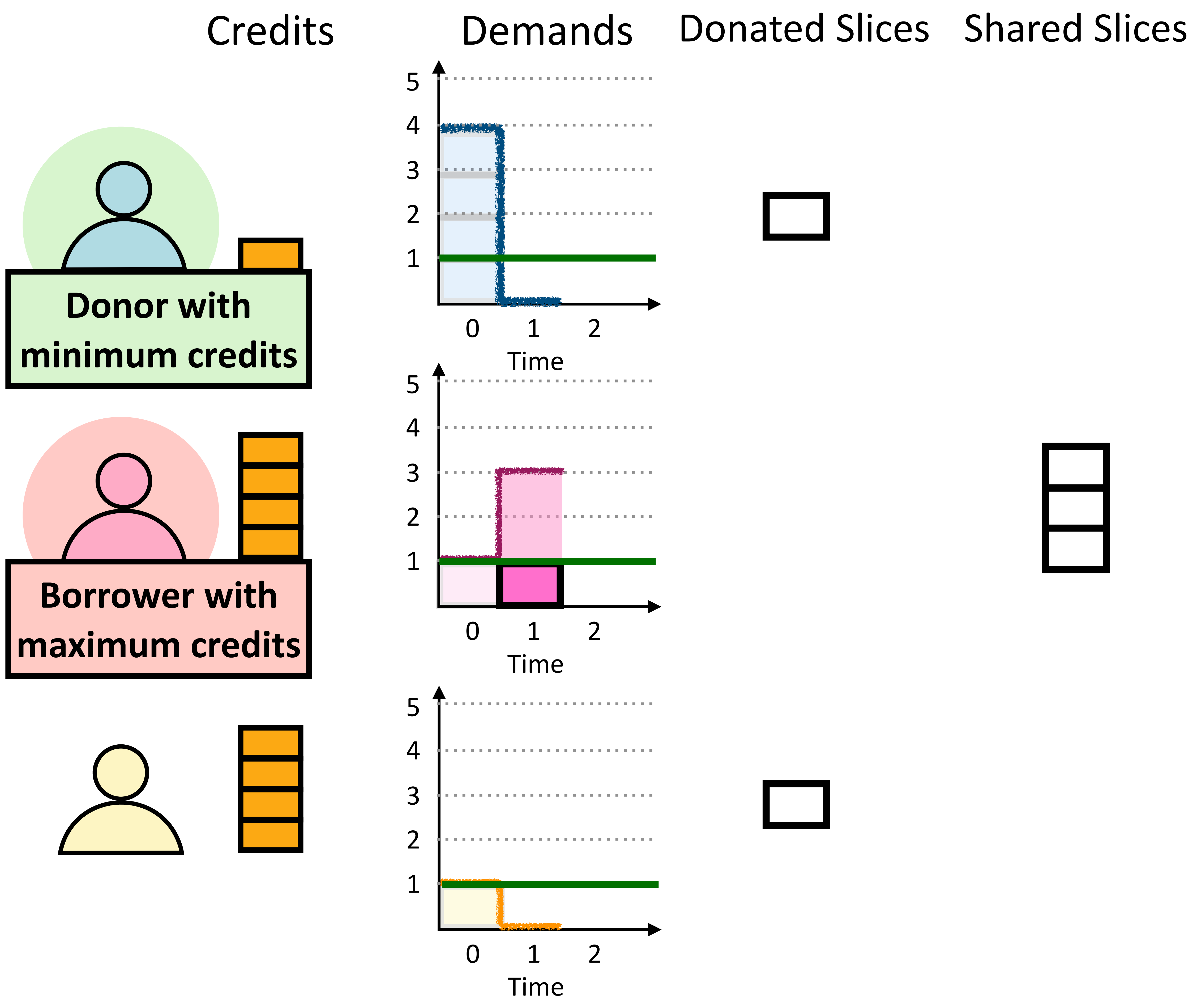

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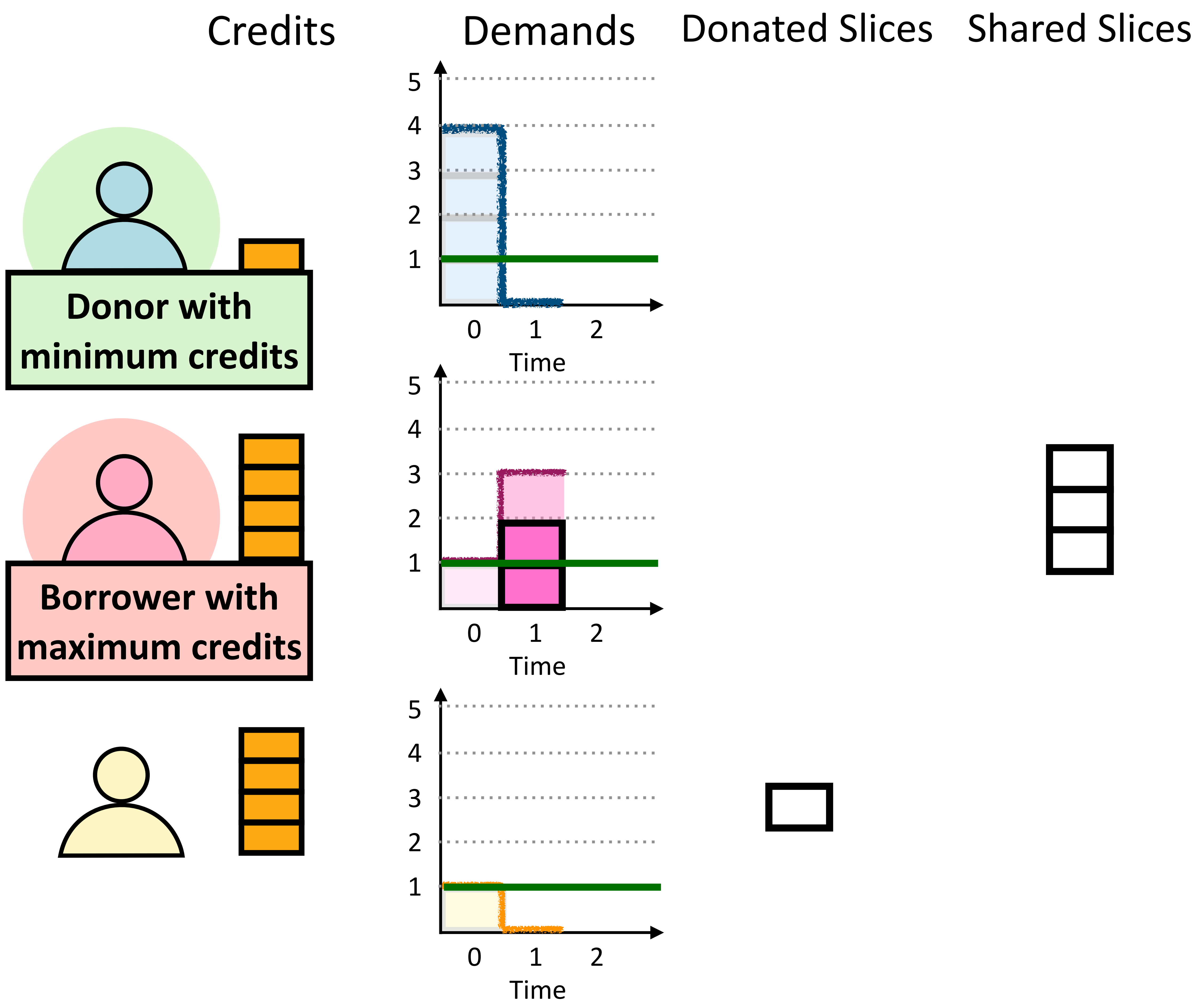

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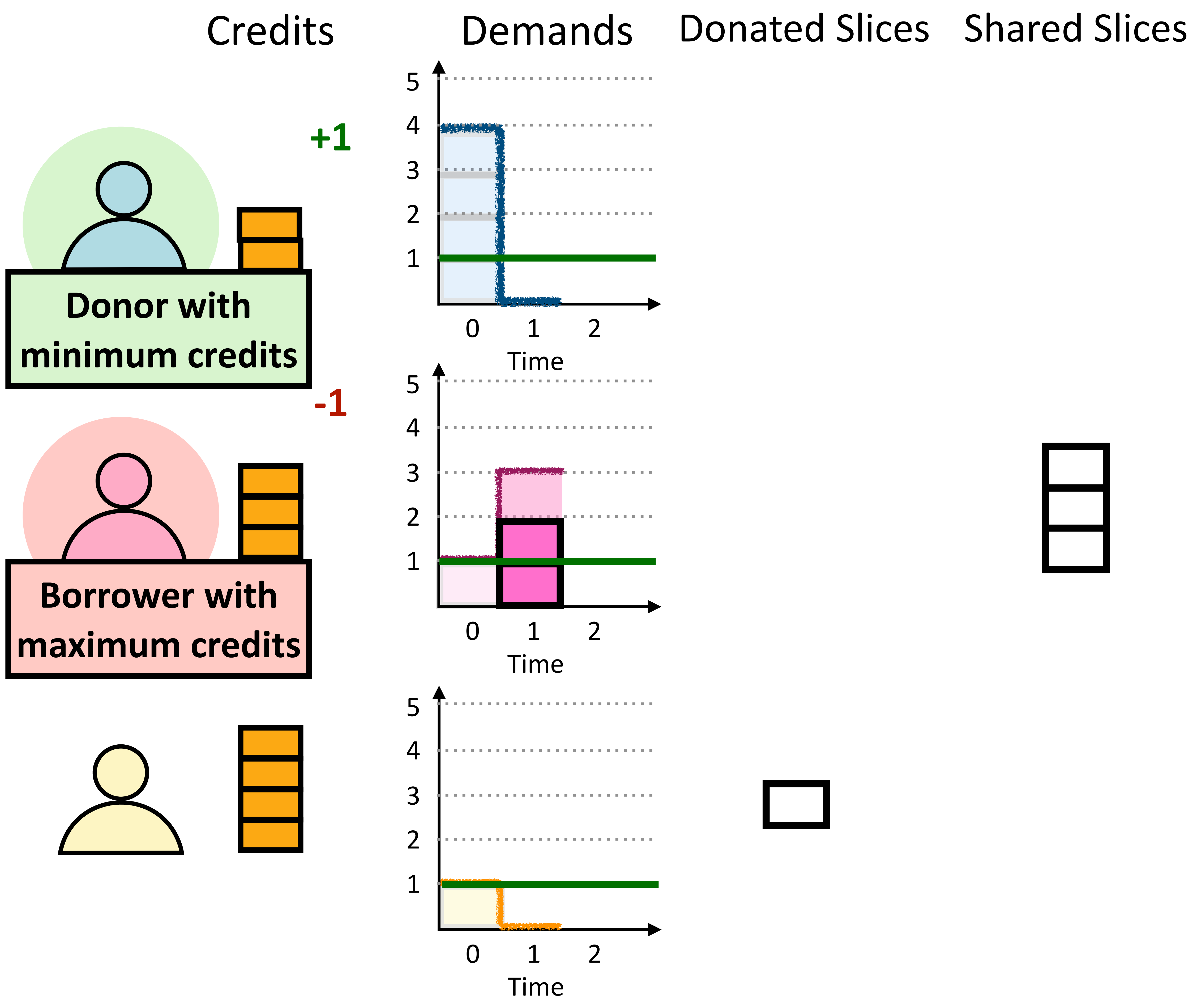

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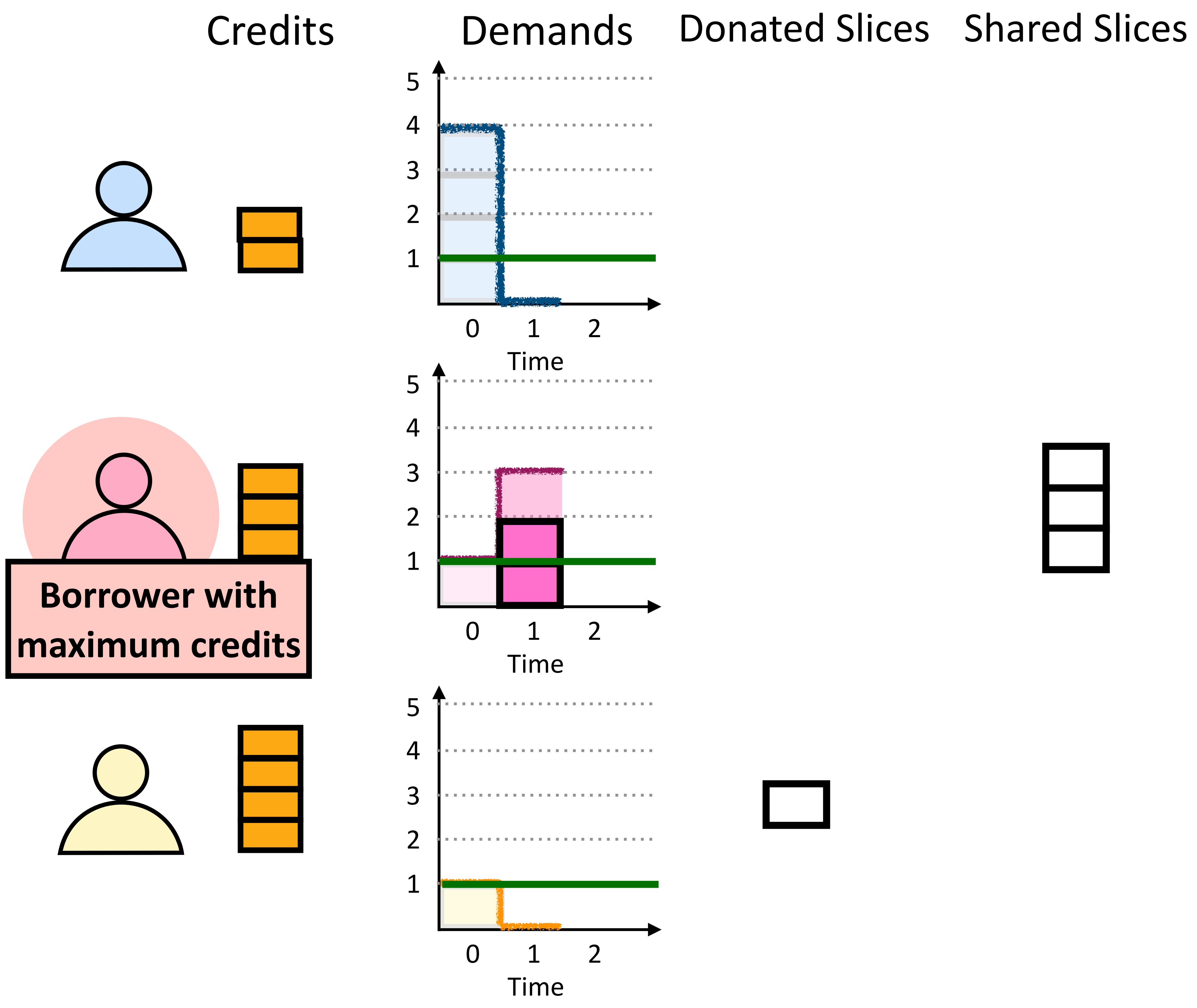

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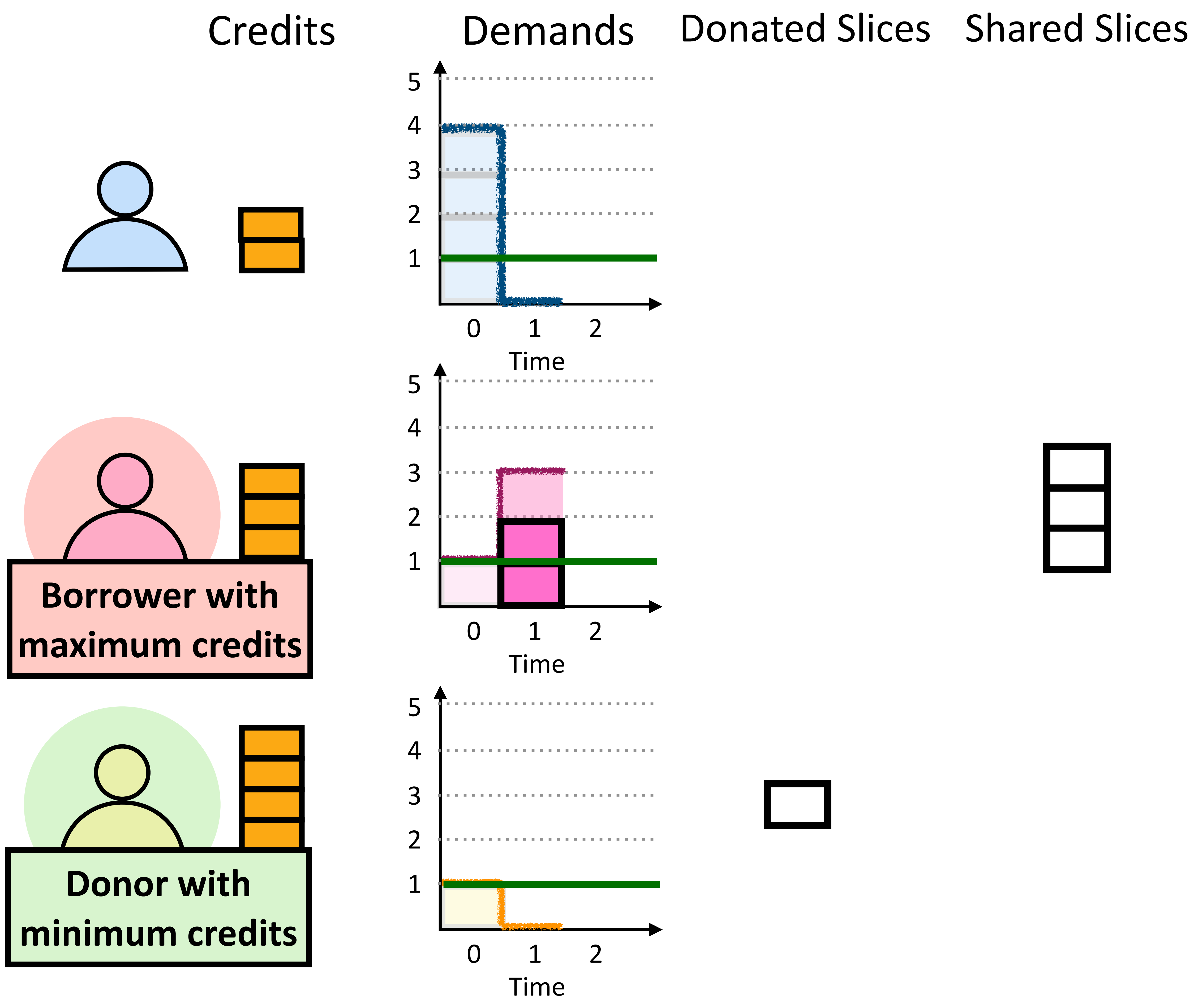

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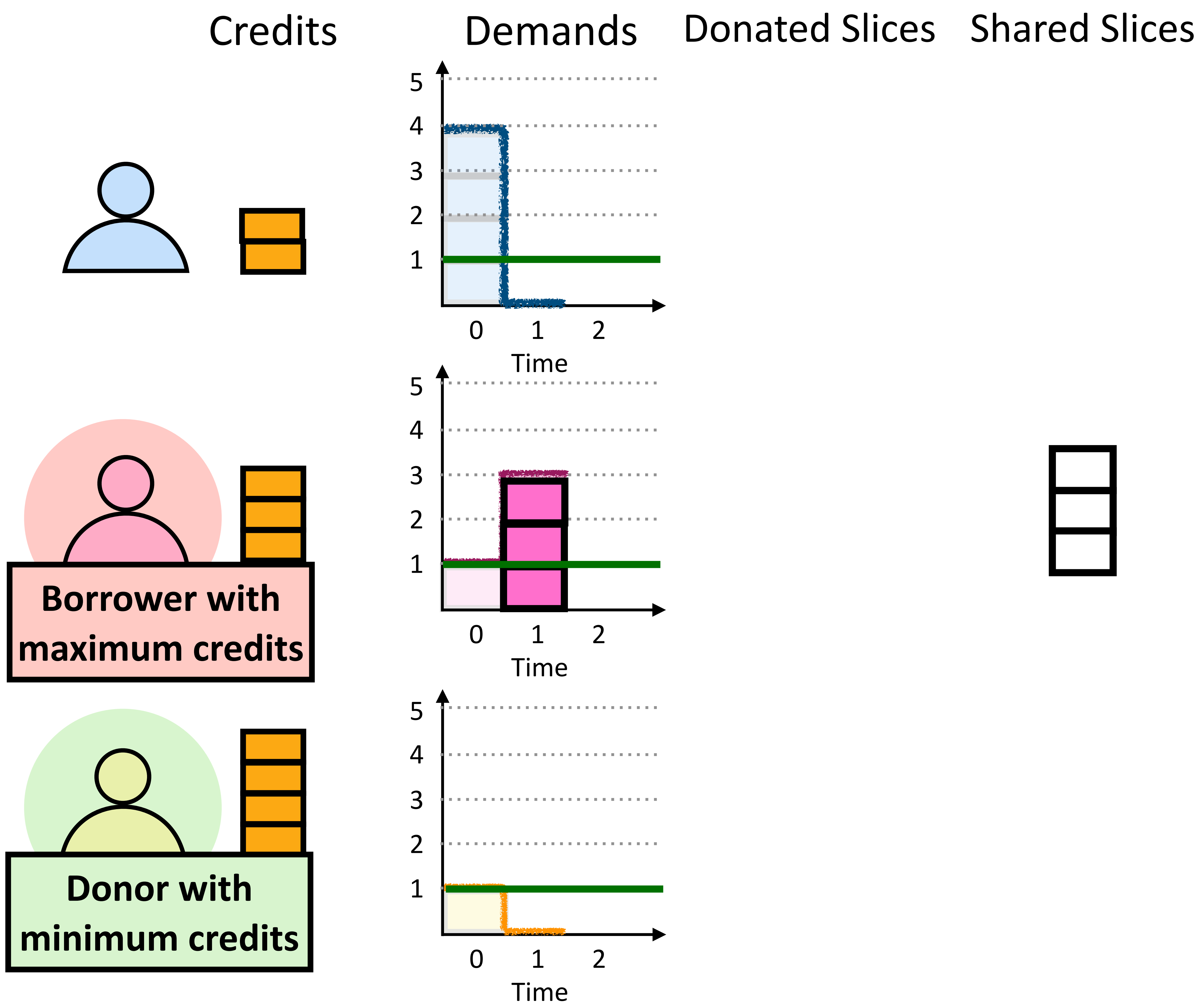

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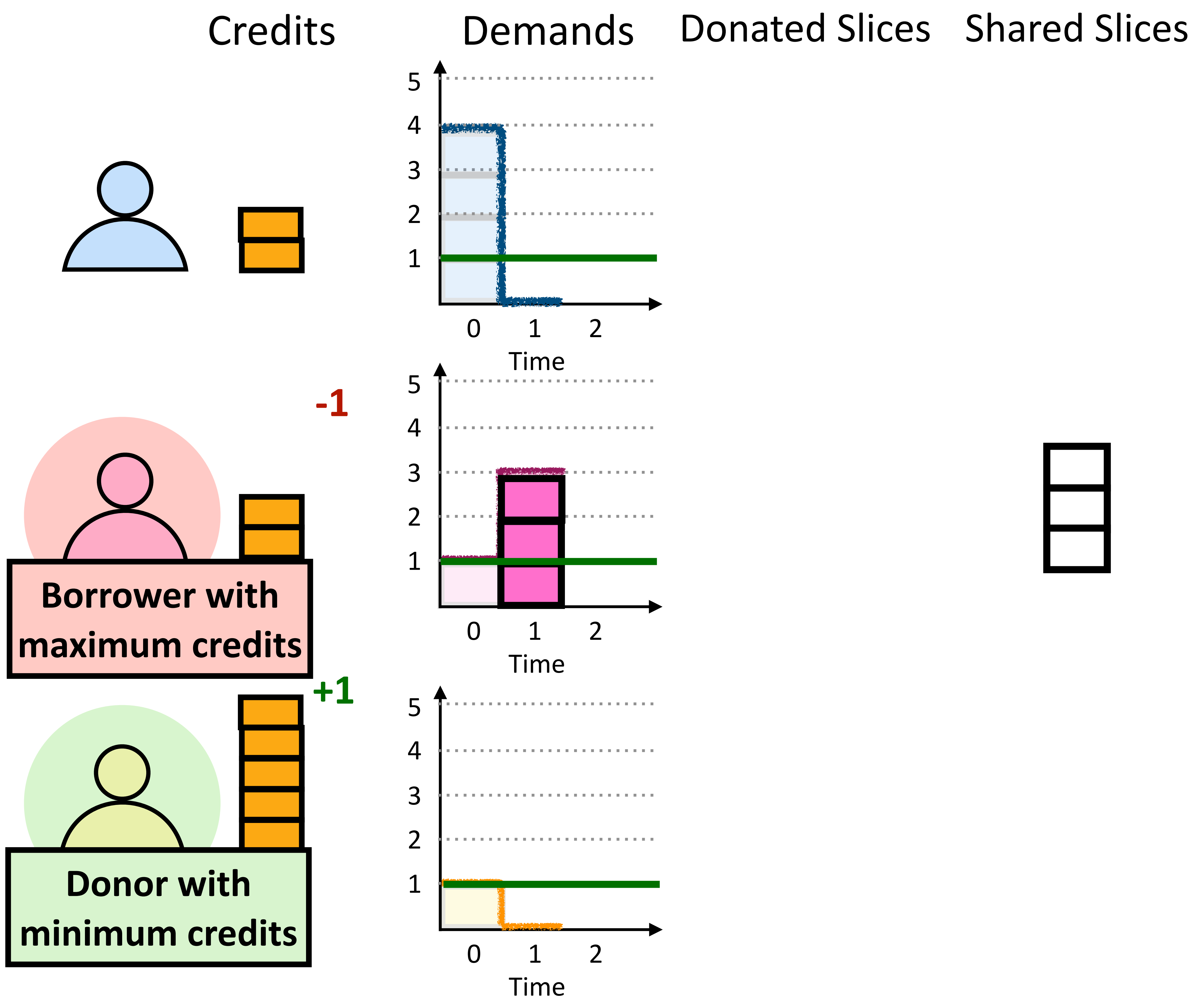

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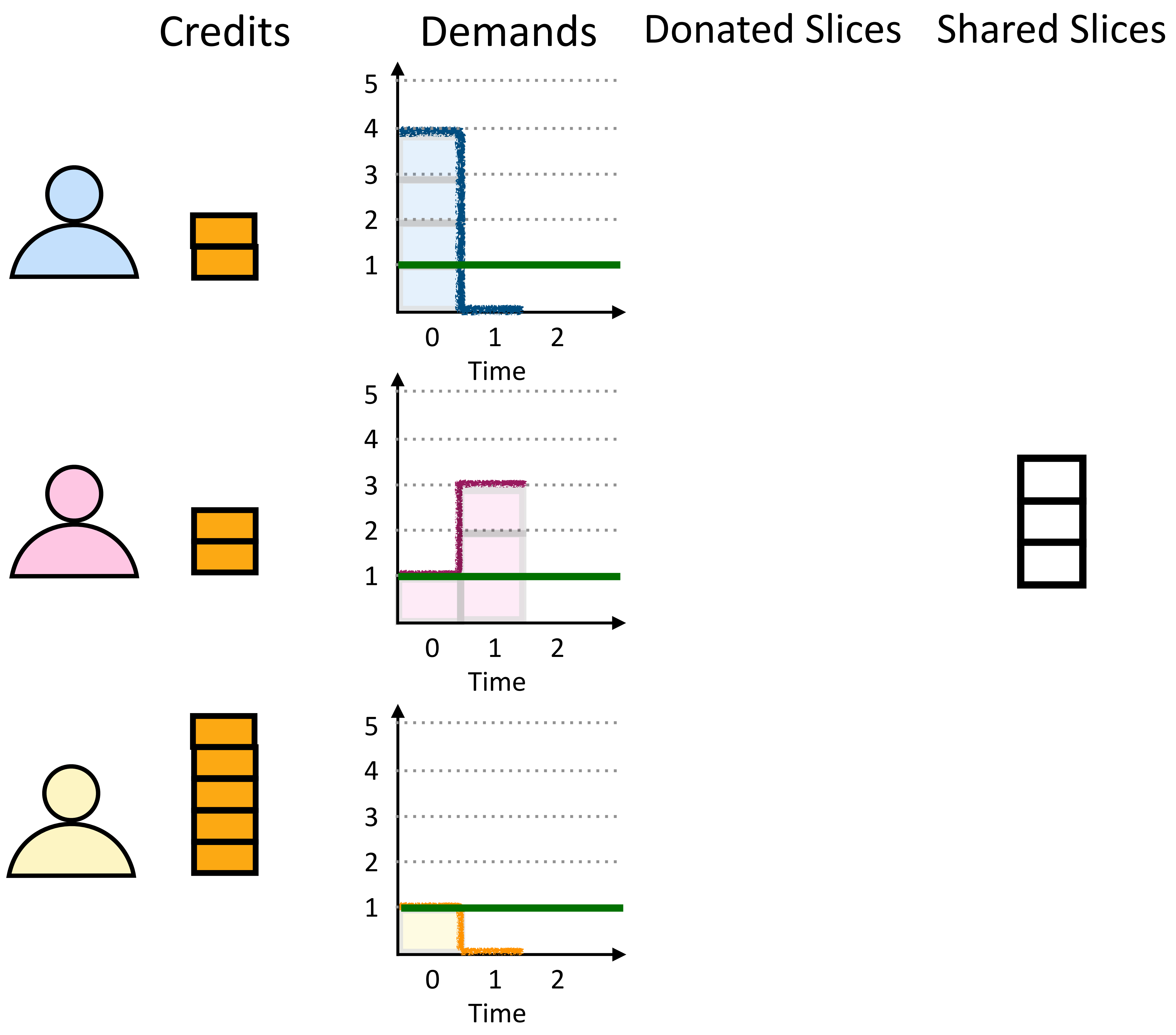

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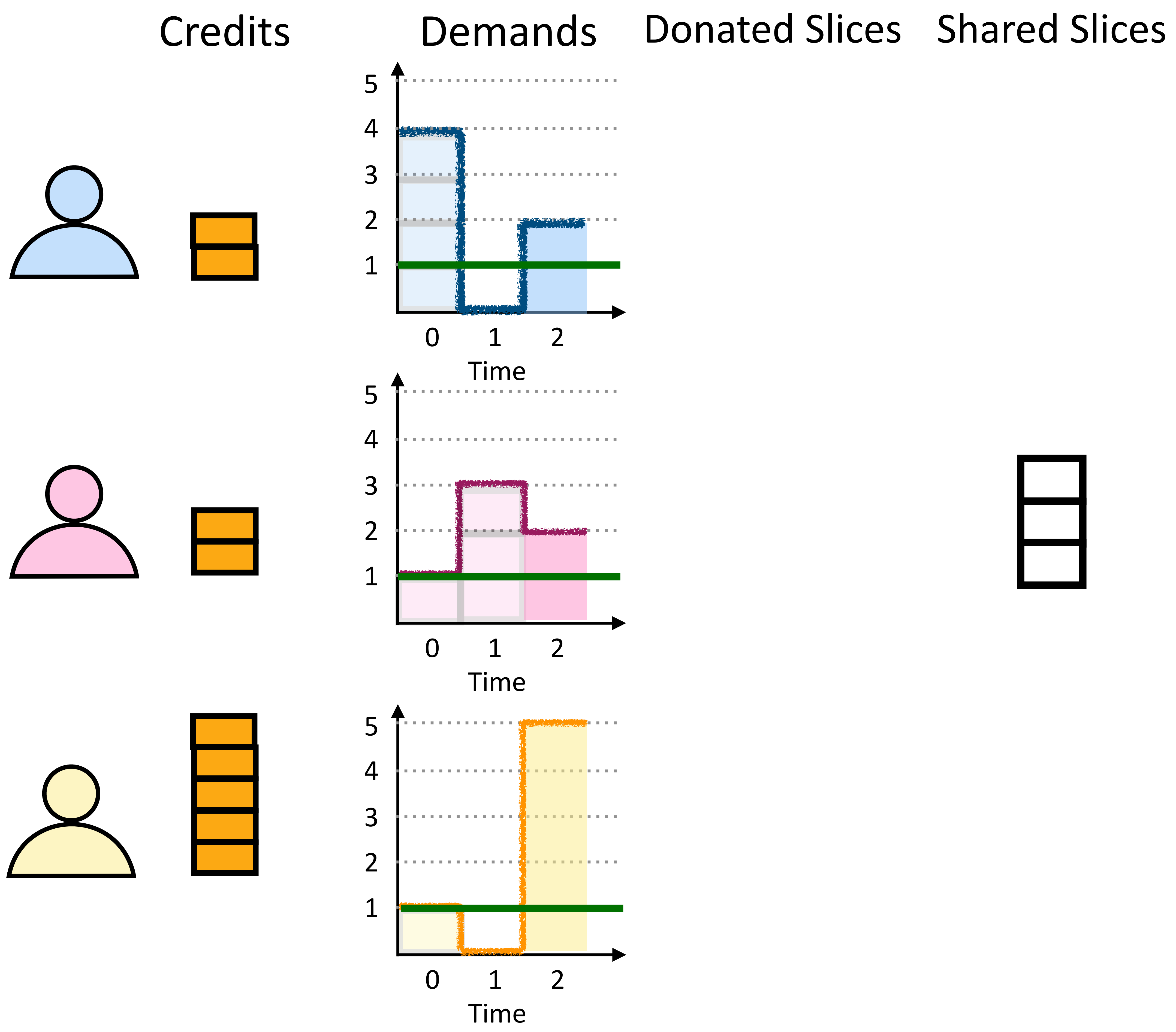

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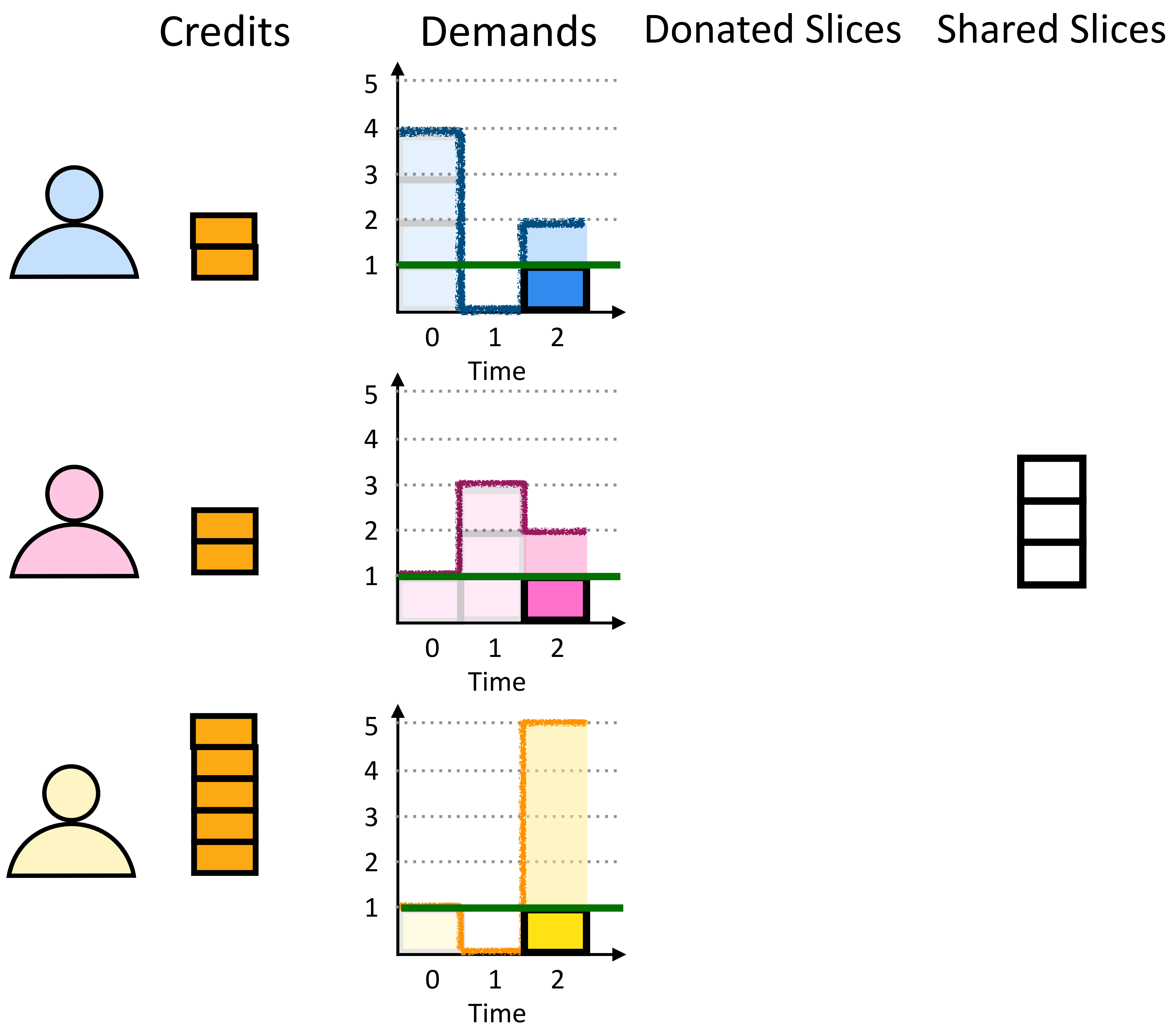

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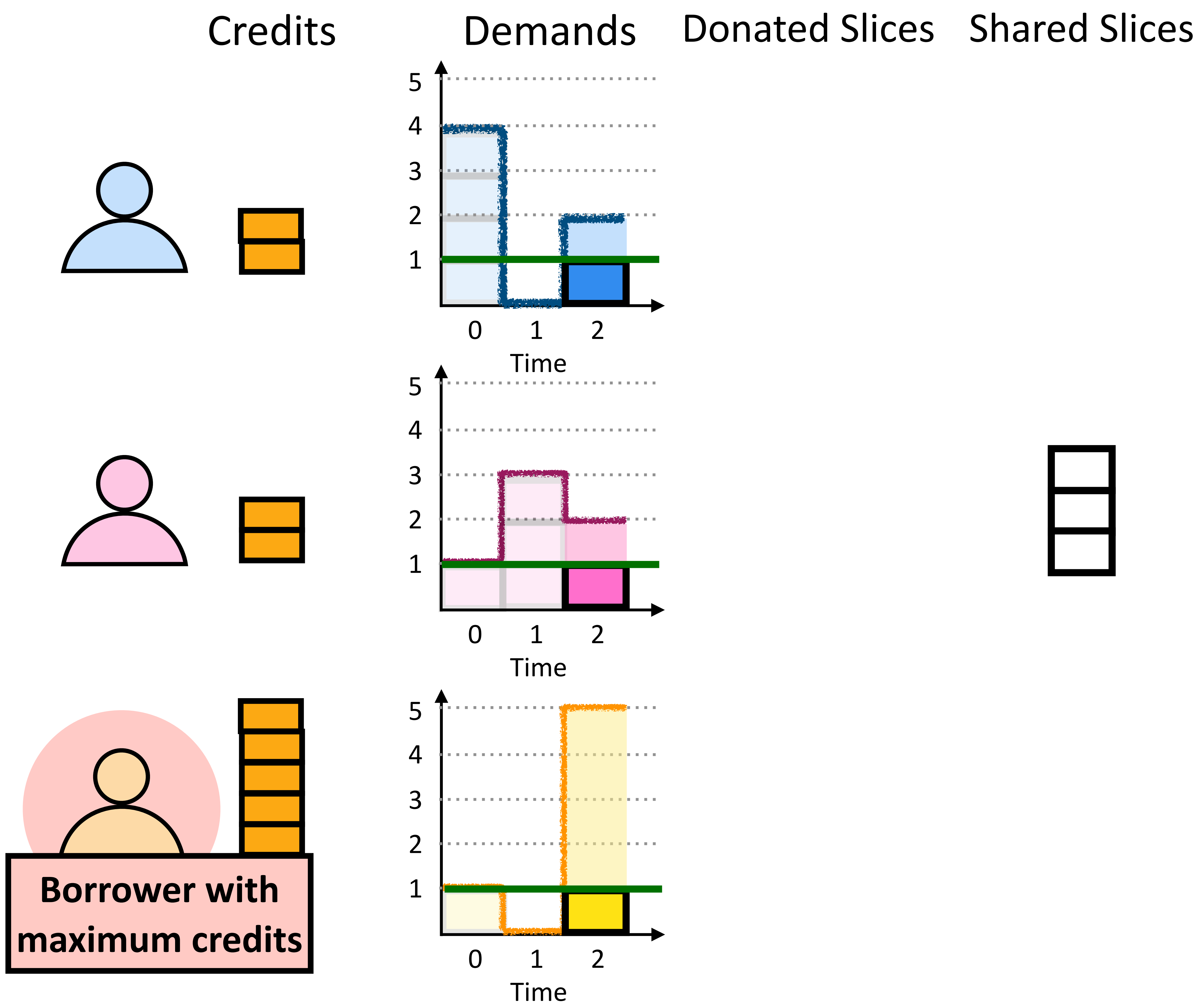

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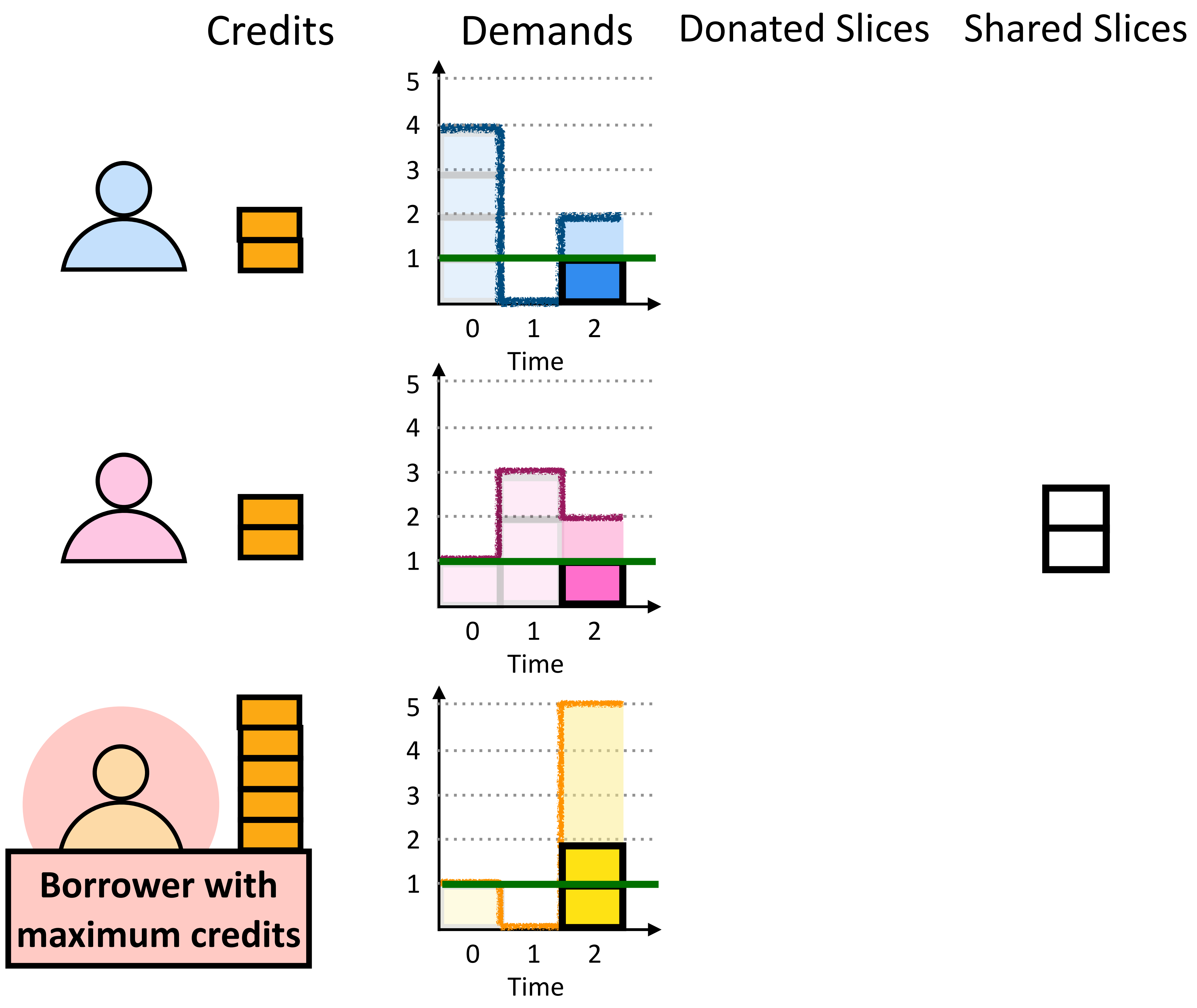
(Repeat until demands satisfied or resources exhausted)

Karma allocation algorithm

Running Example



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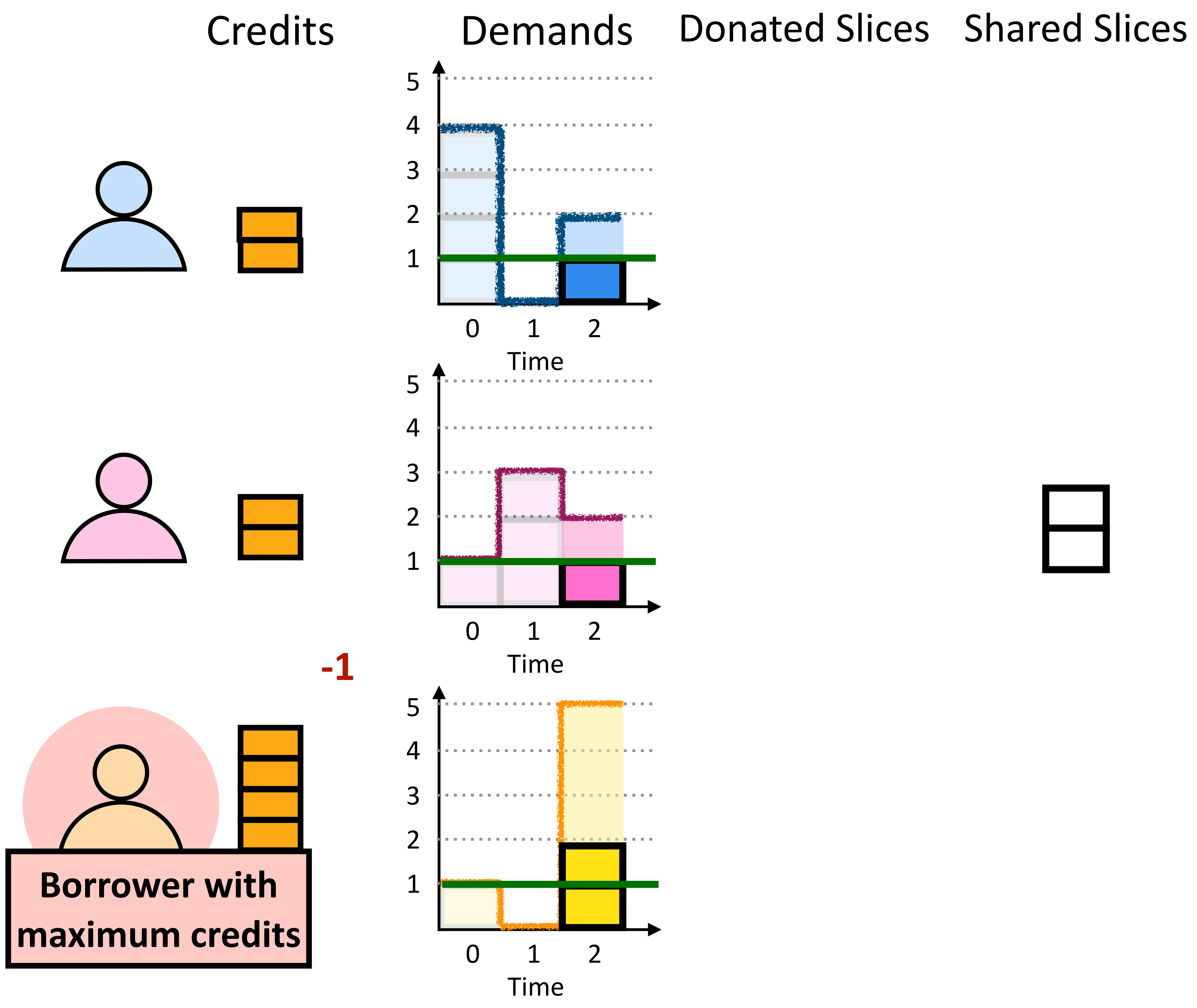

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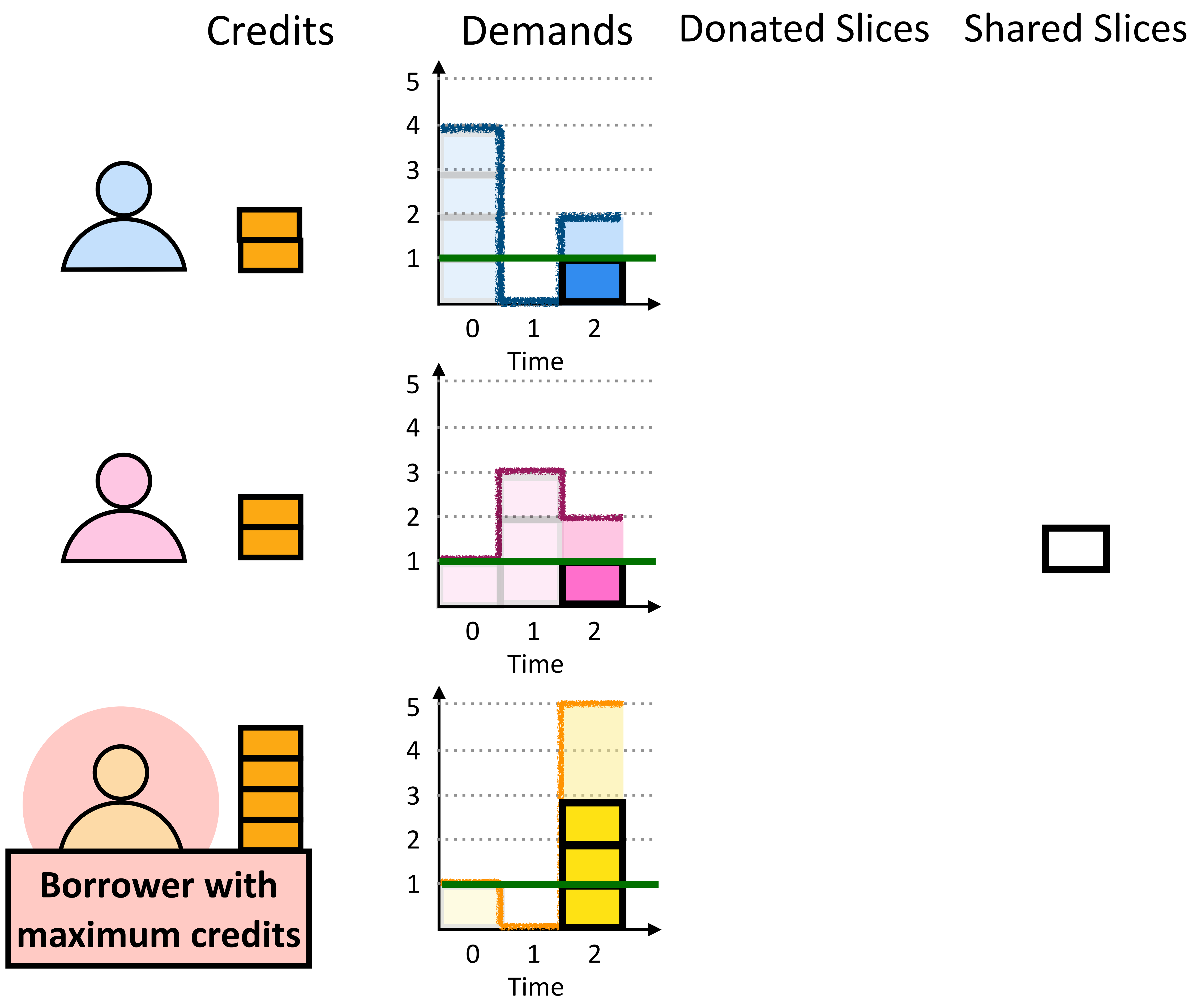

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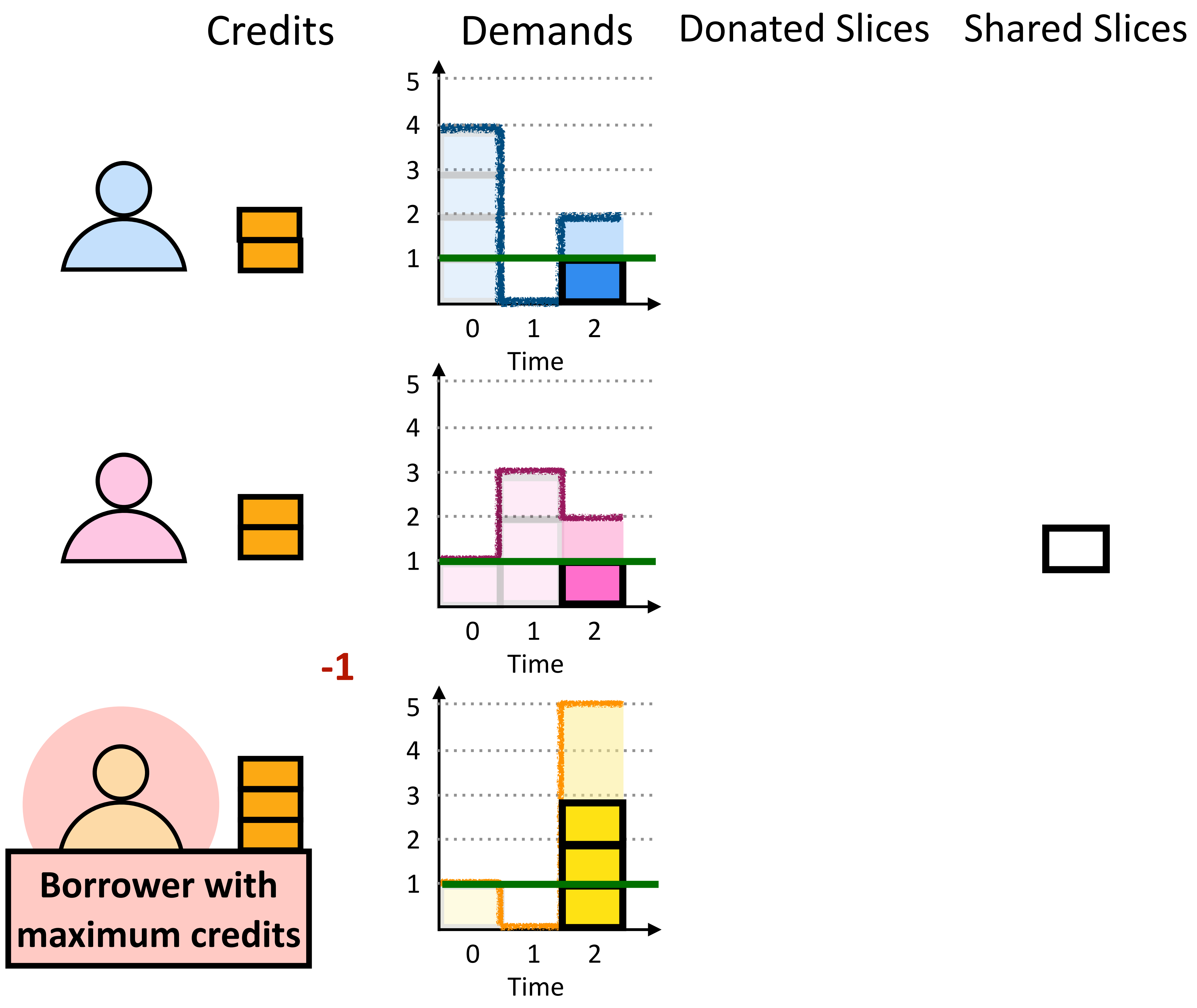

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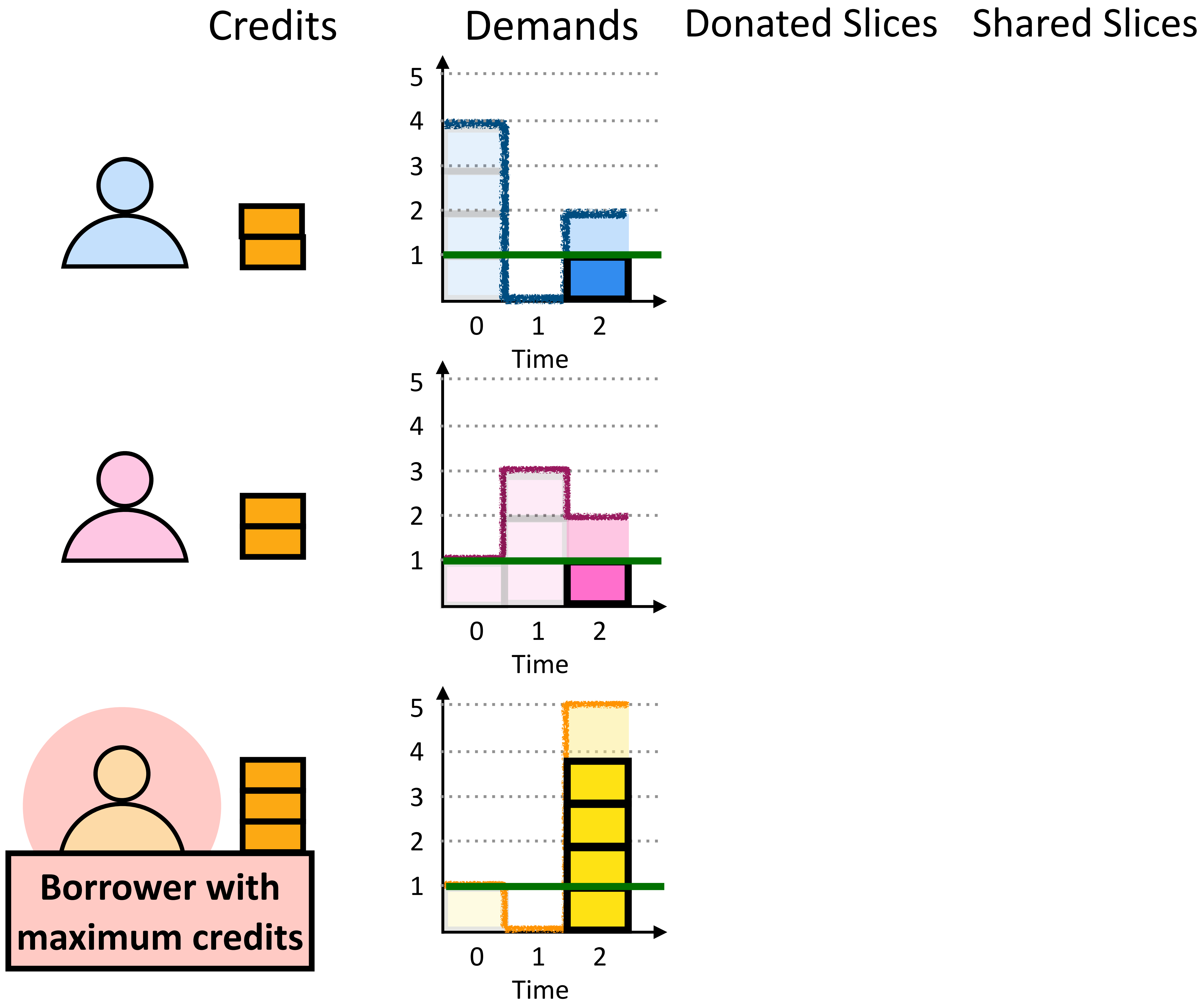

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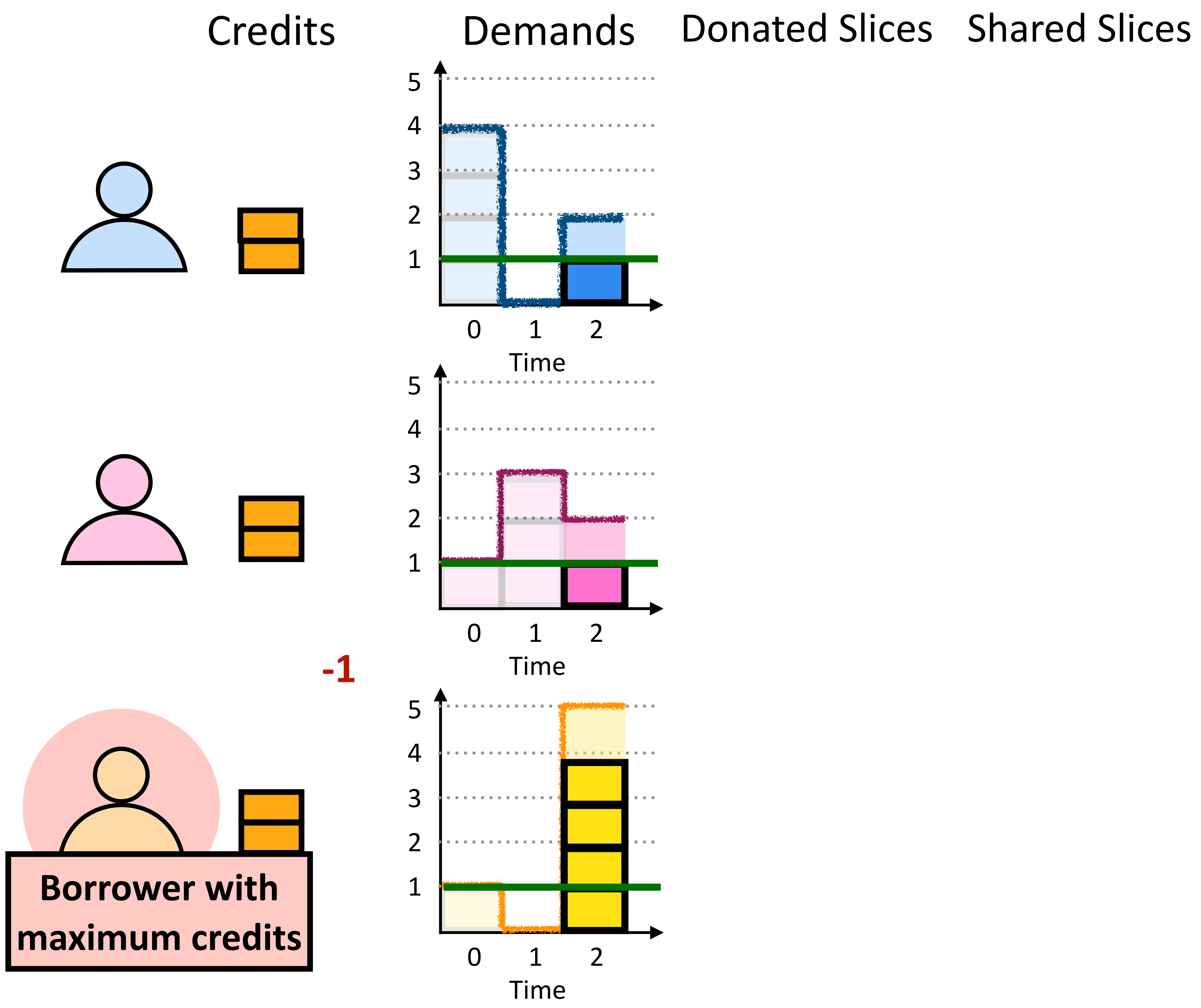

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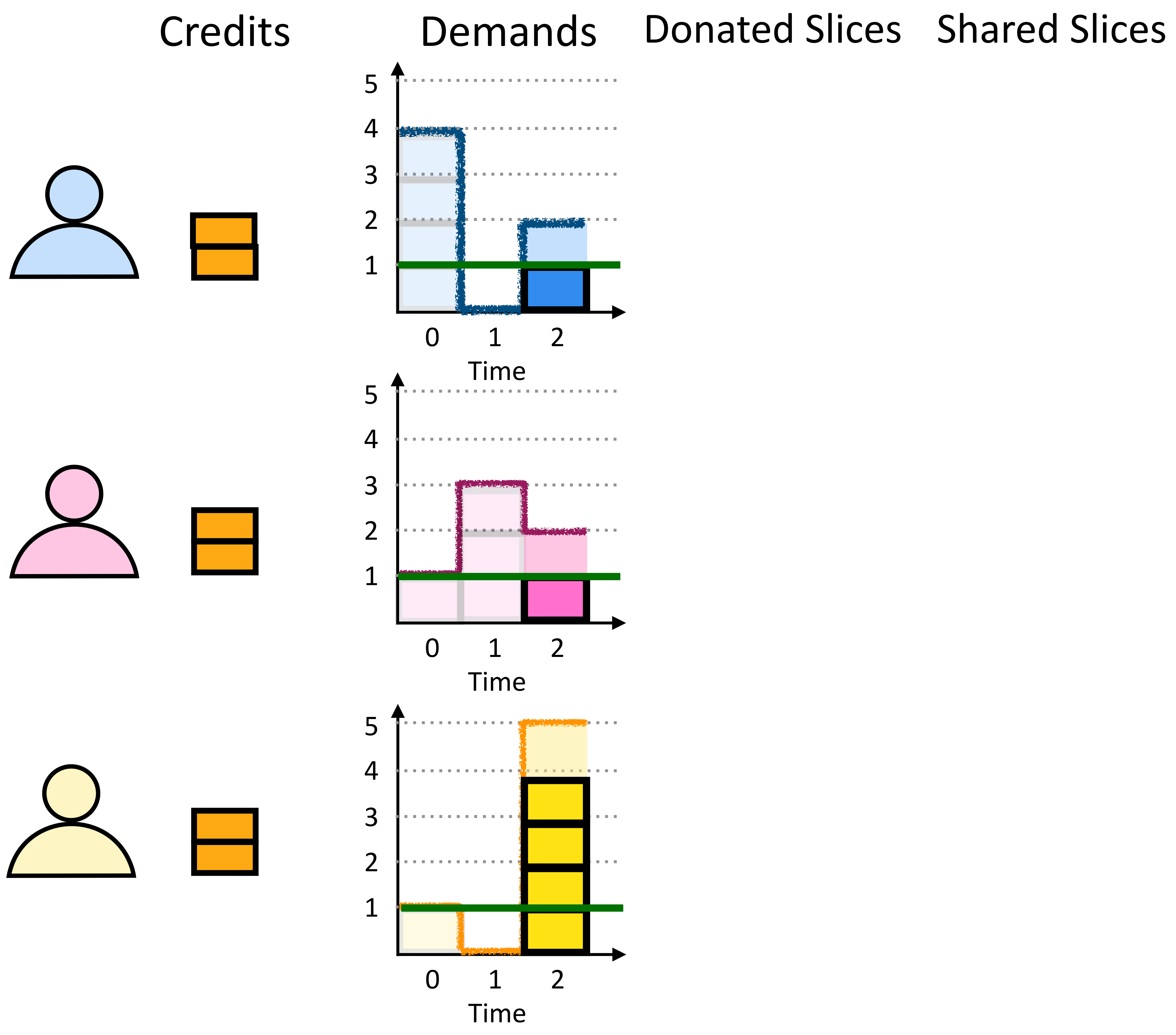

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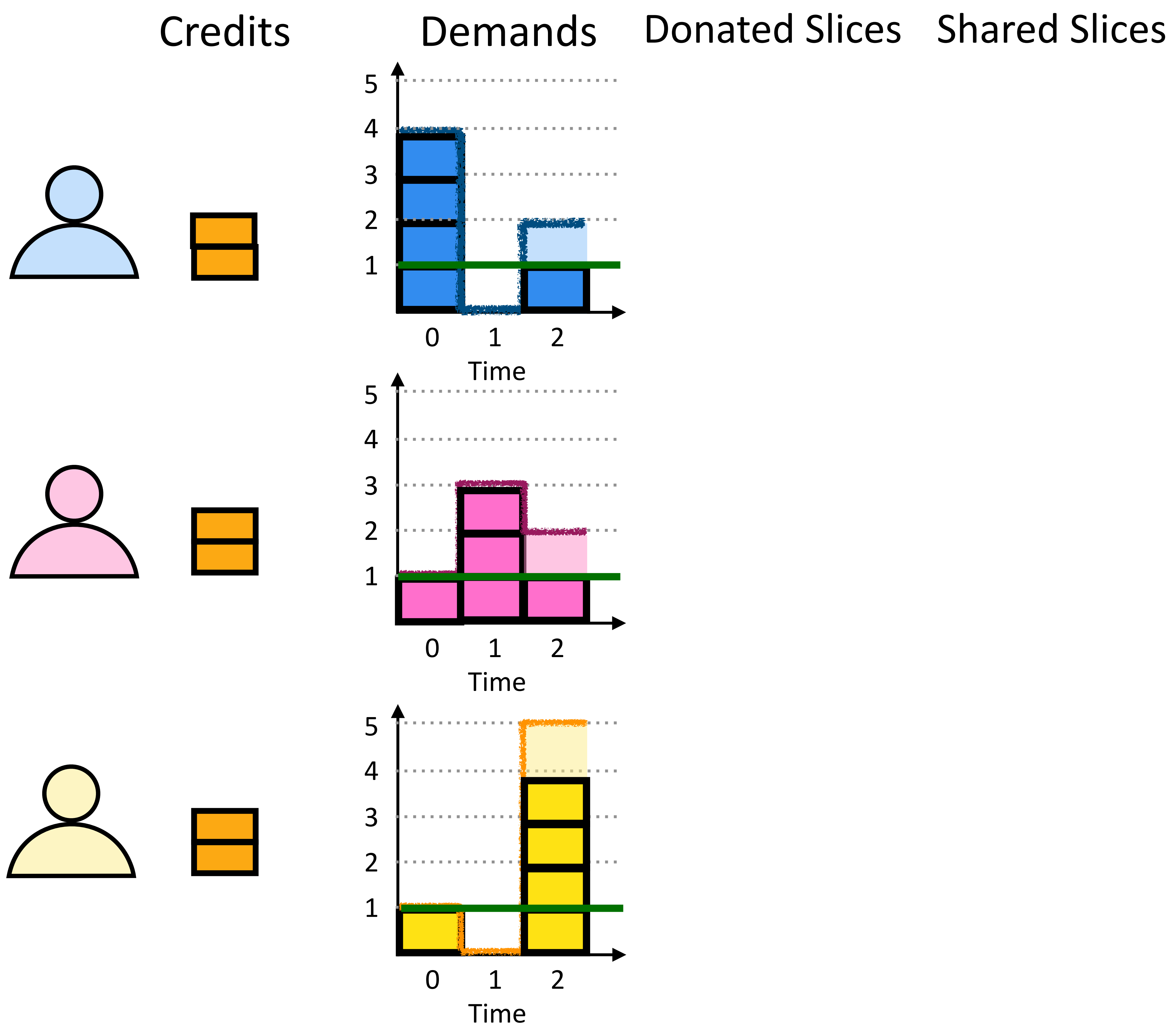

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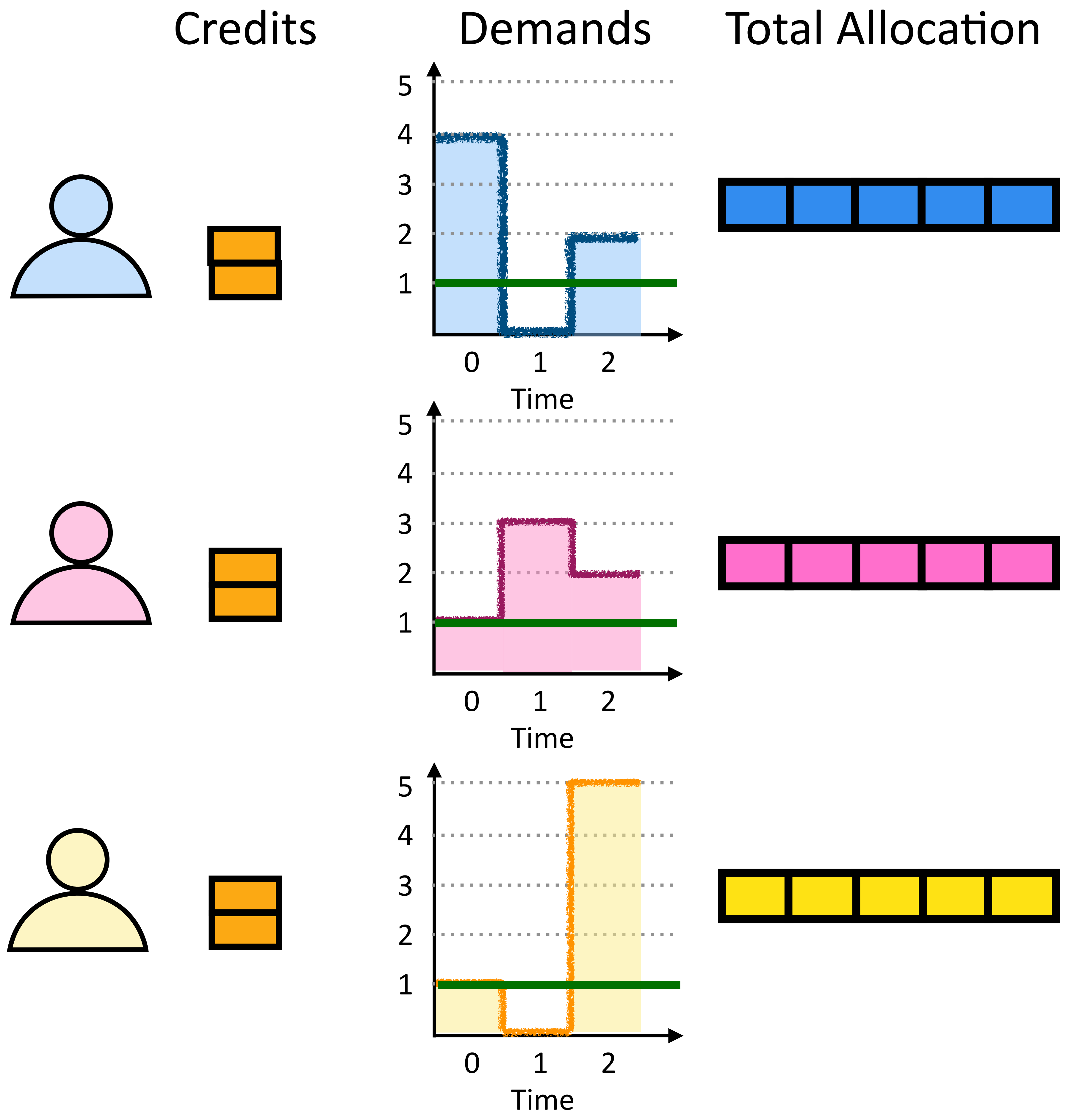

Karma allocation algorithm

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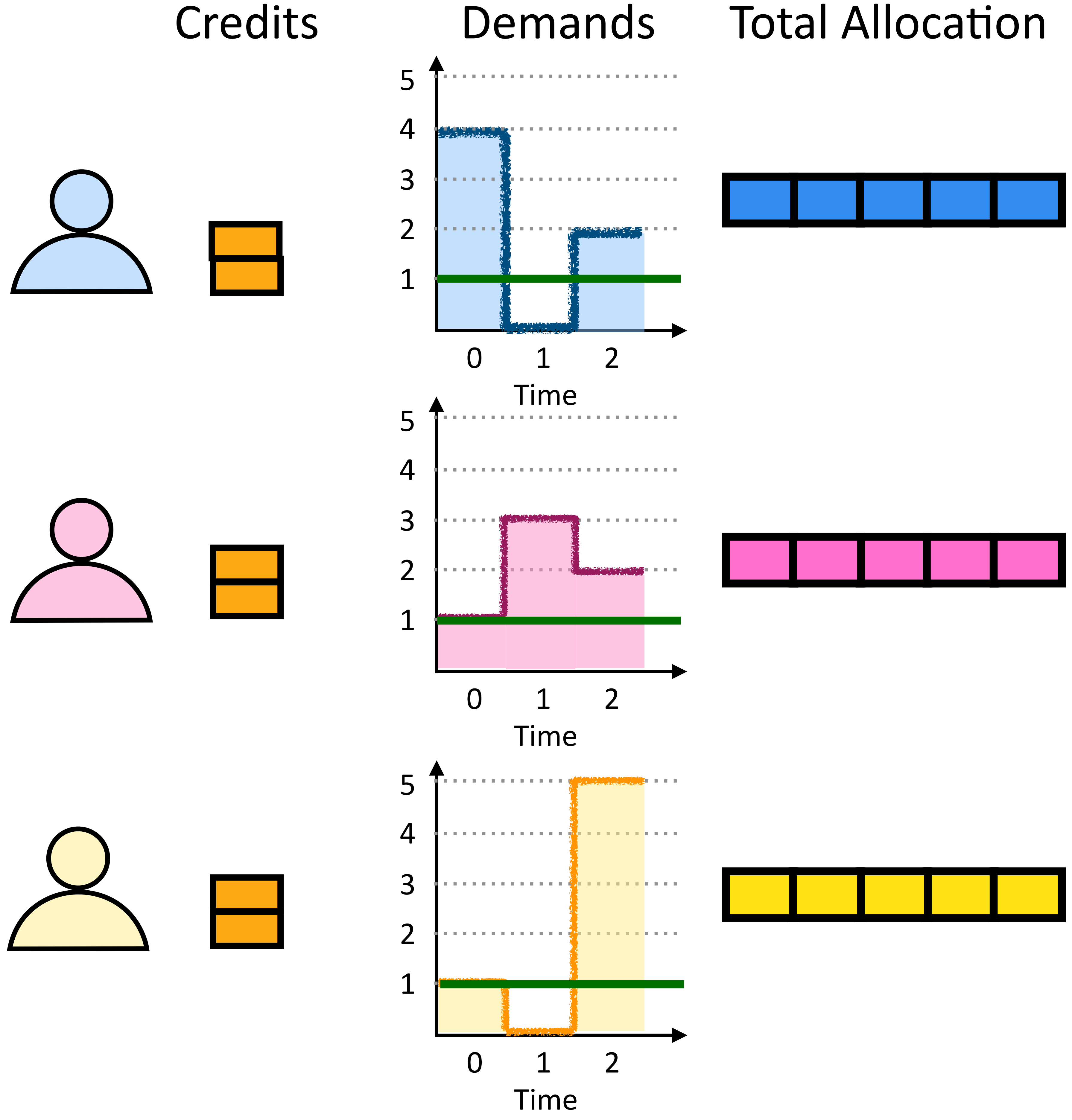
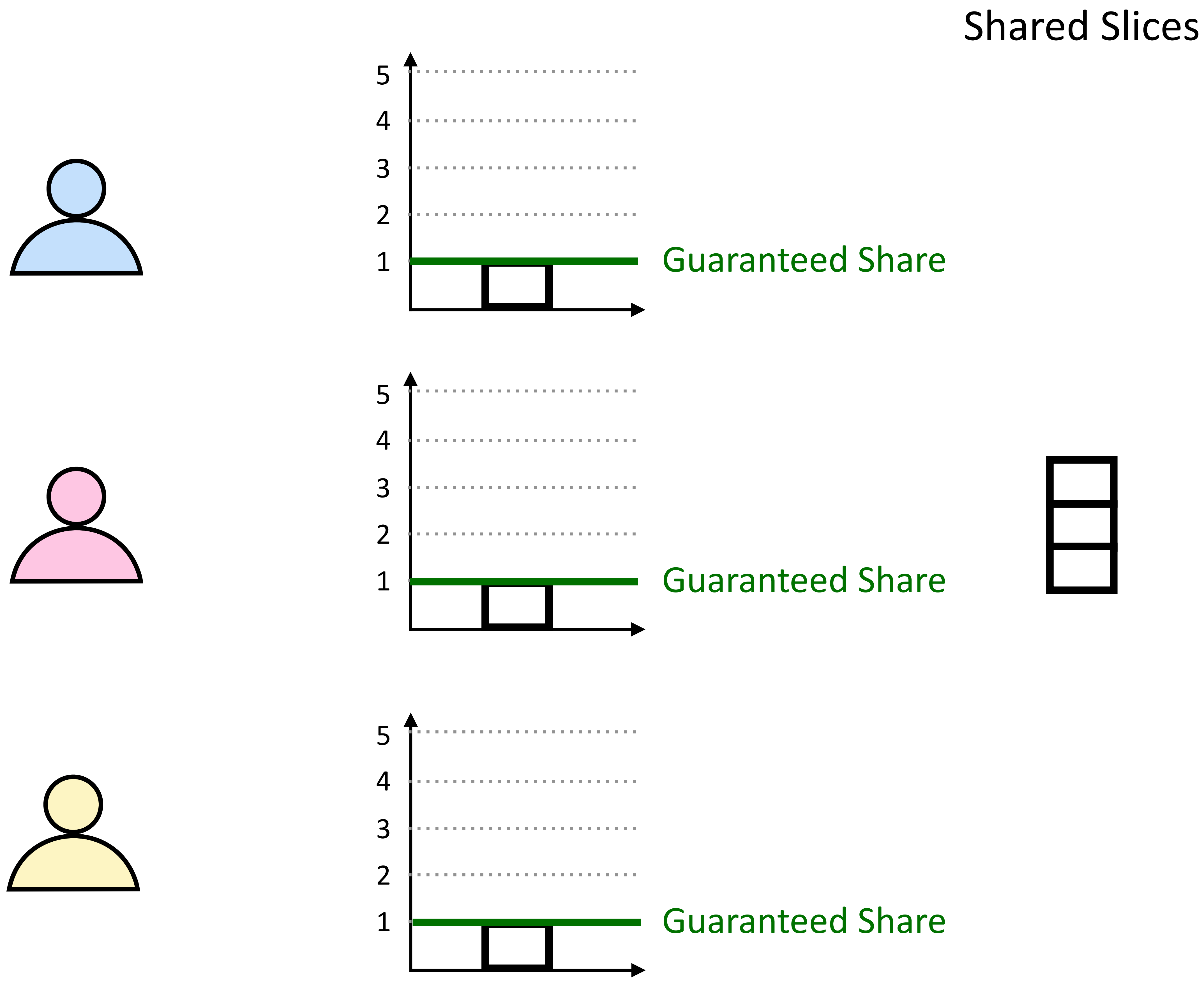


Equal total allocations!

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



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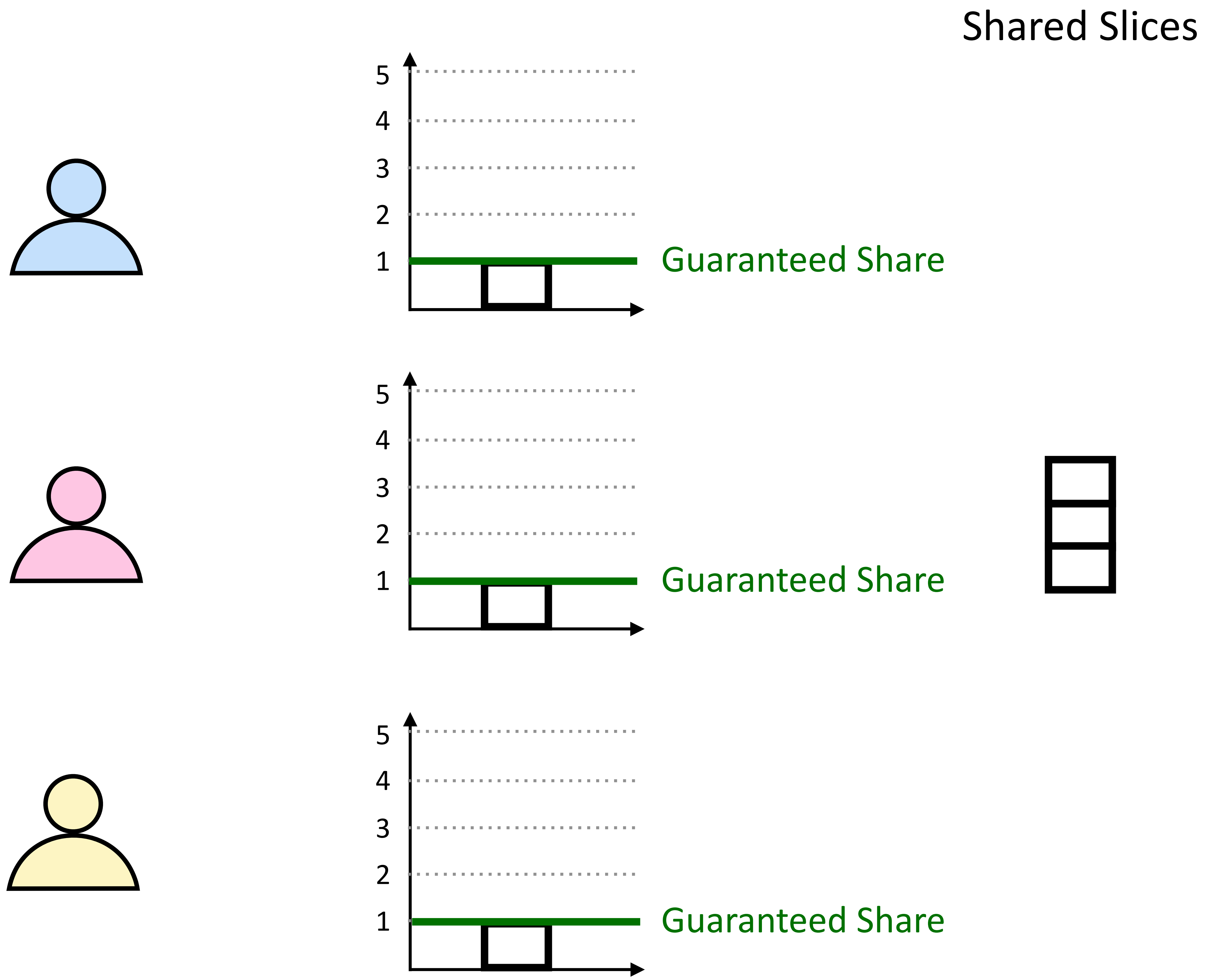

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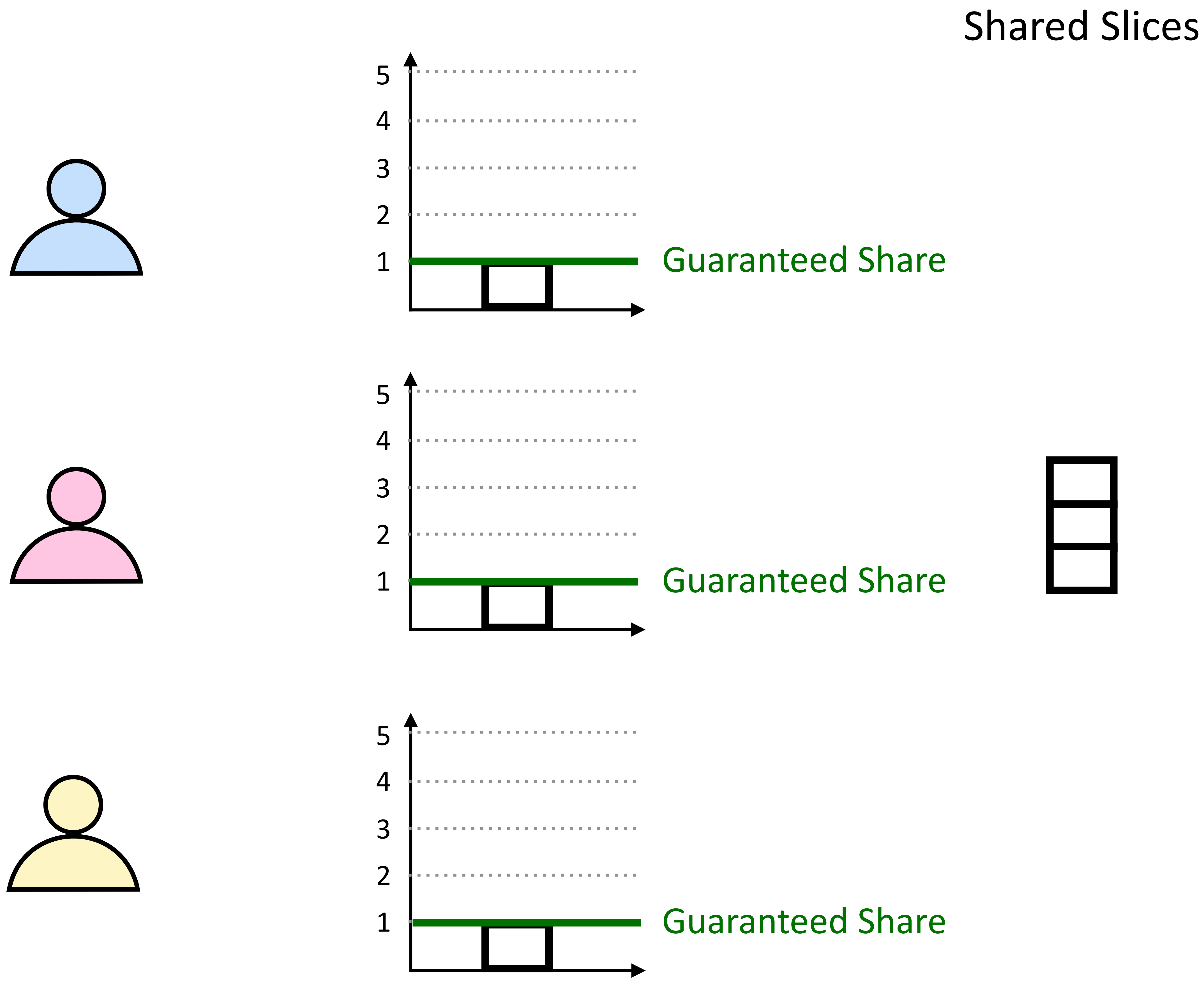

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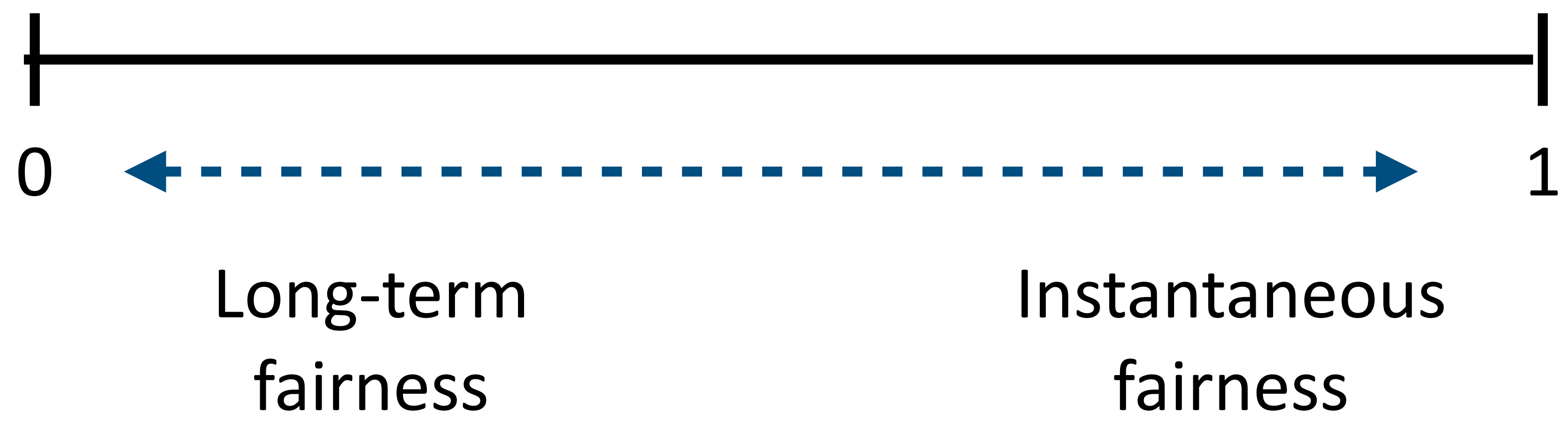

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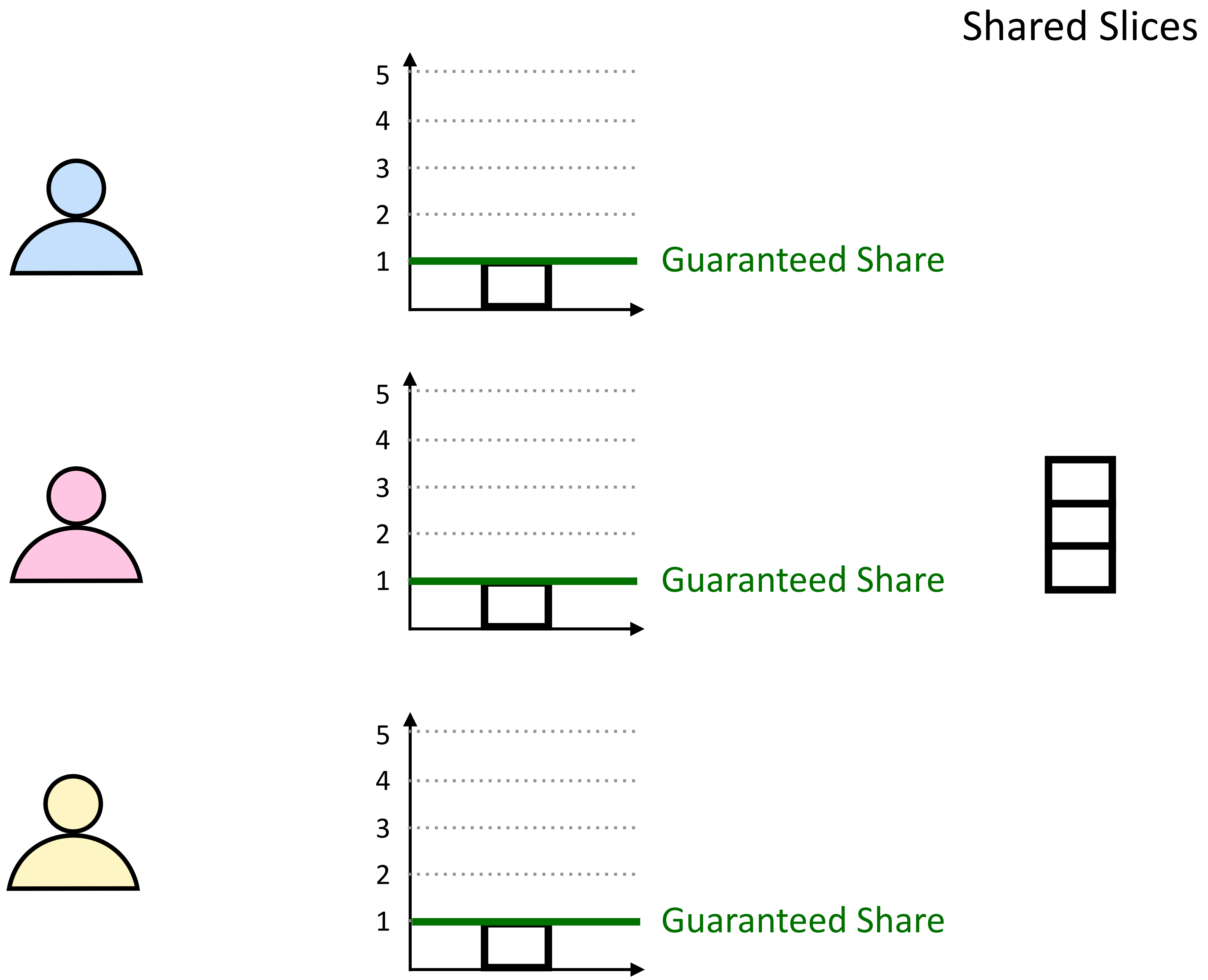

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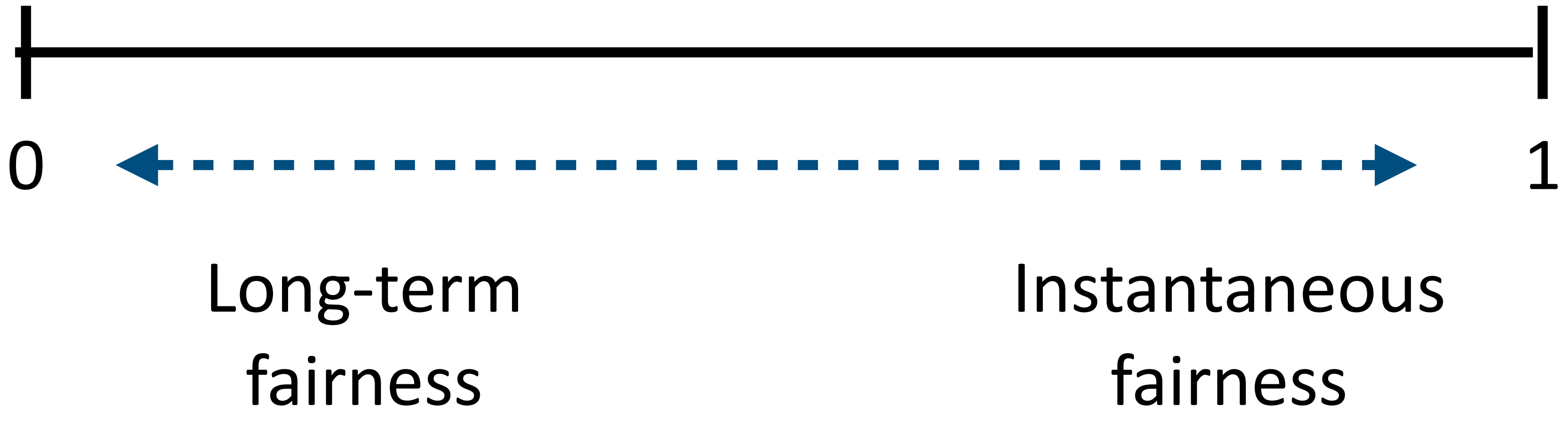
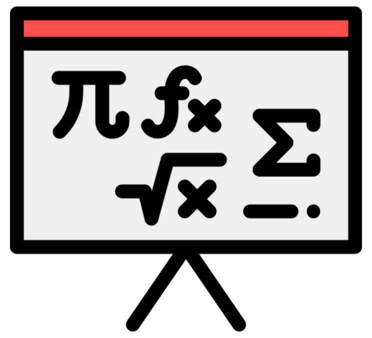


(See paper for more details)

Karma: Revisiting the classical resource allocation problem under dynamic demands

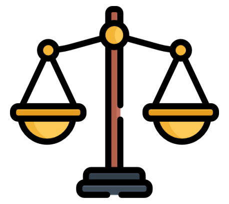
New resource allocation algorithm for dynamic demands



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

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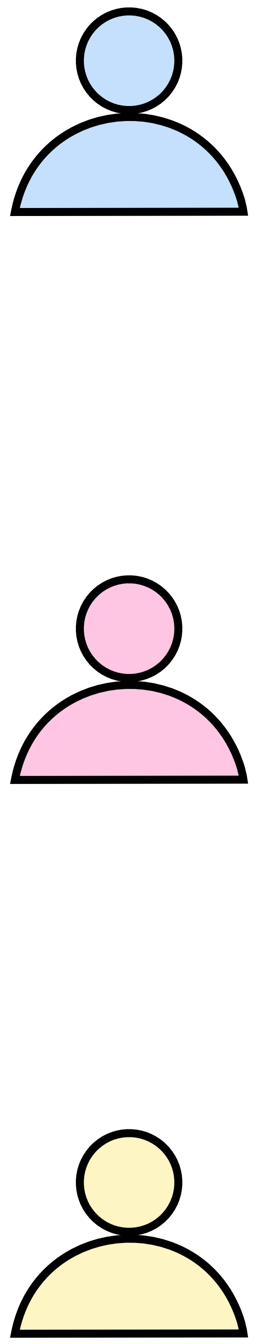
Karma provides powerful strategy-proofness properties

Strategy-proofness

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



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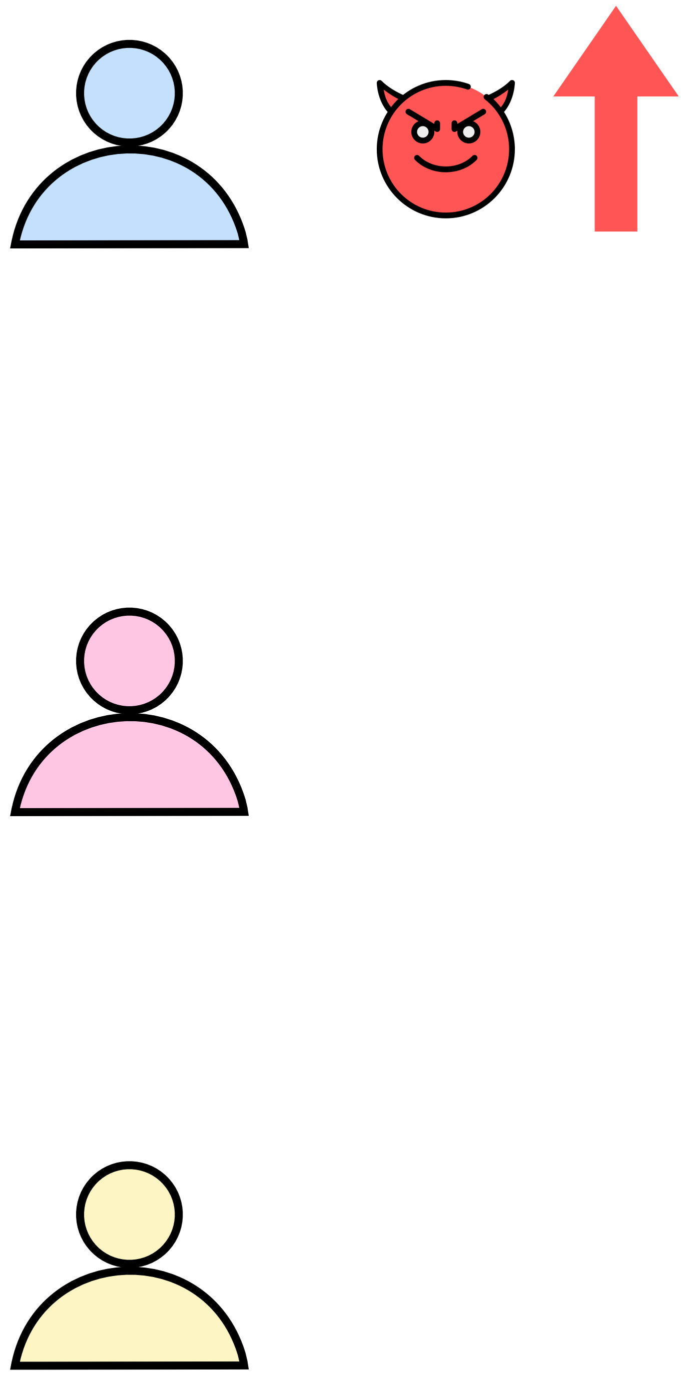

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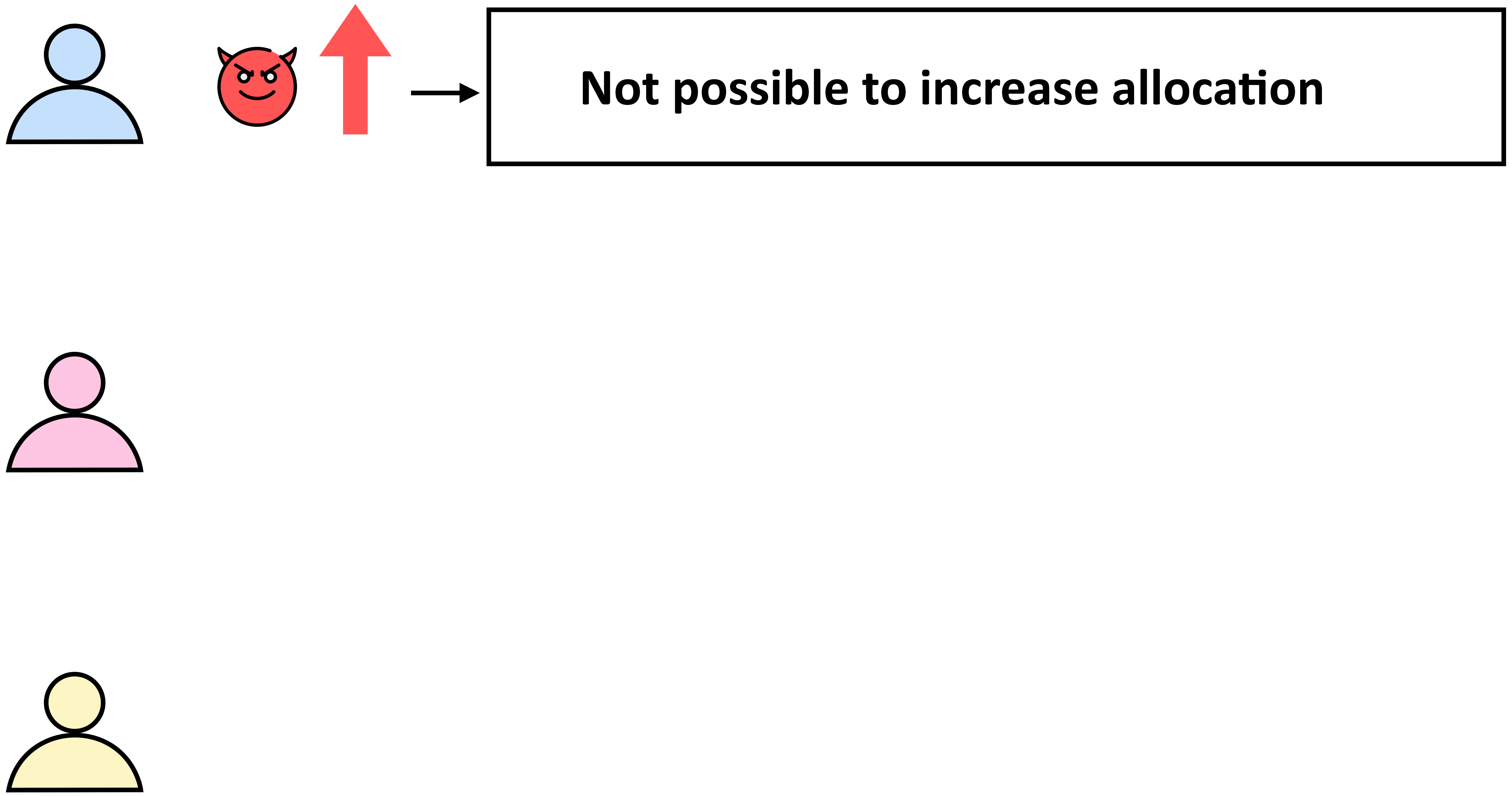

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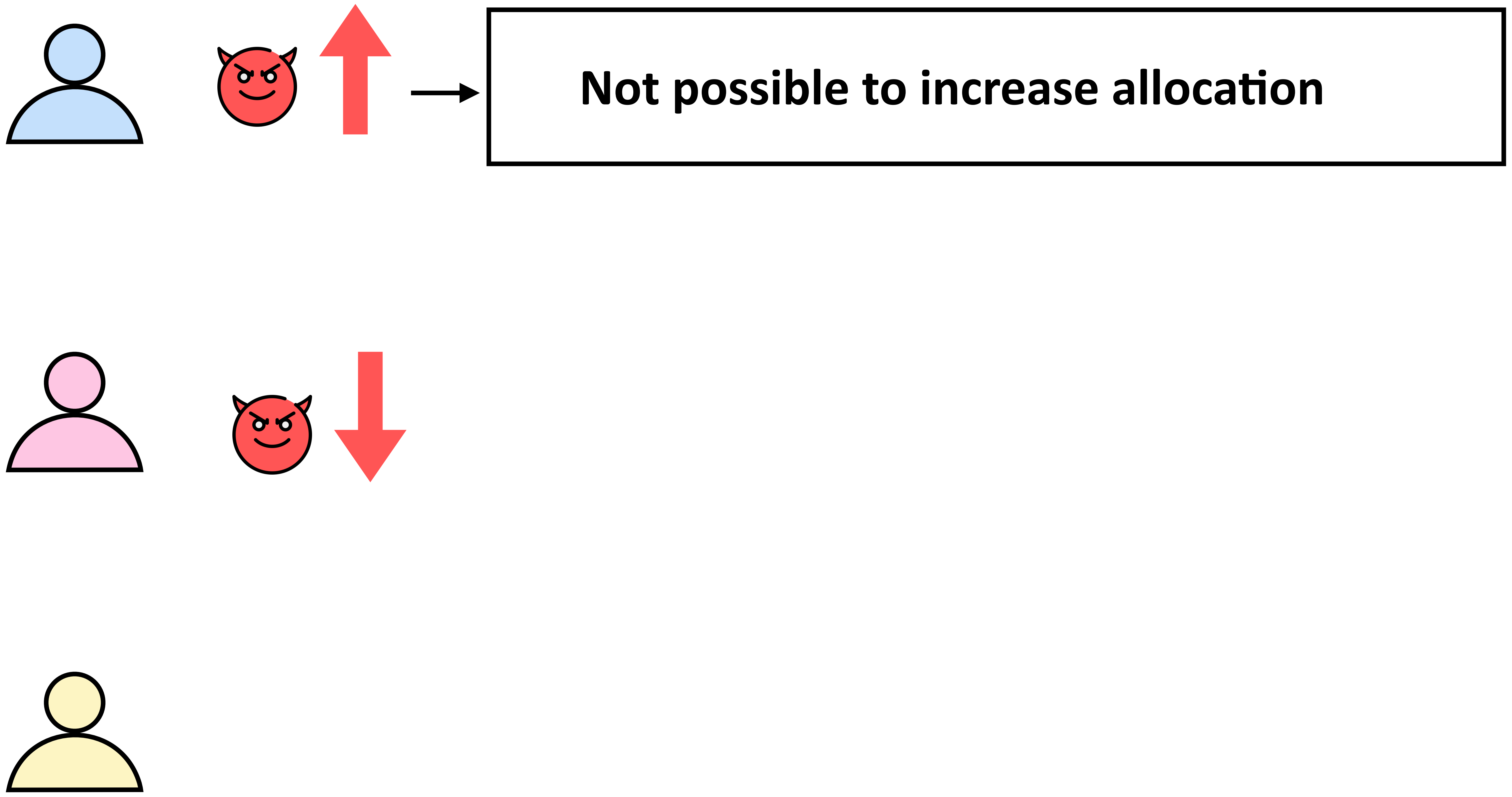

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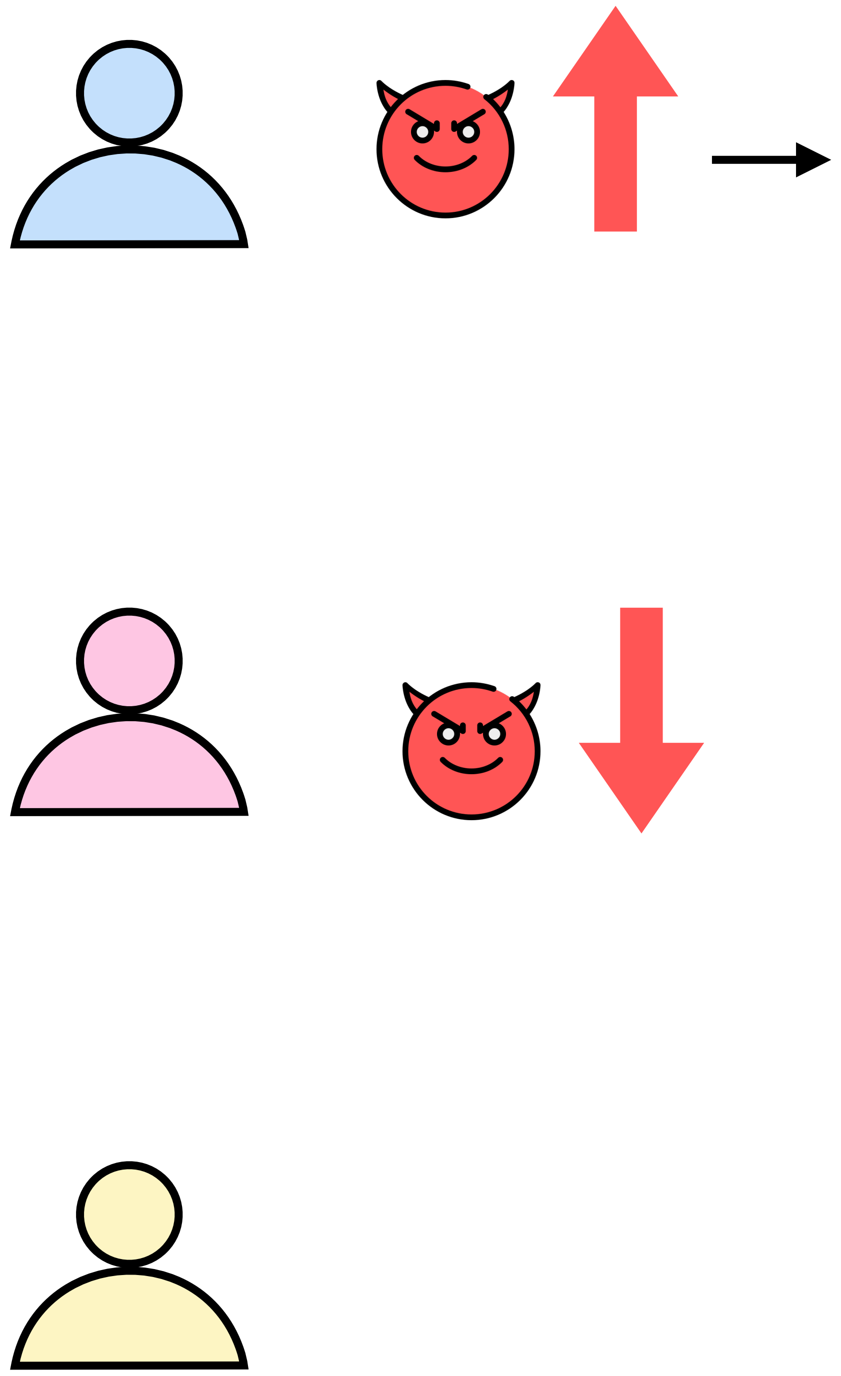

Not possible to increase allocation

Perfect knowledge of
future demands of **all users**

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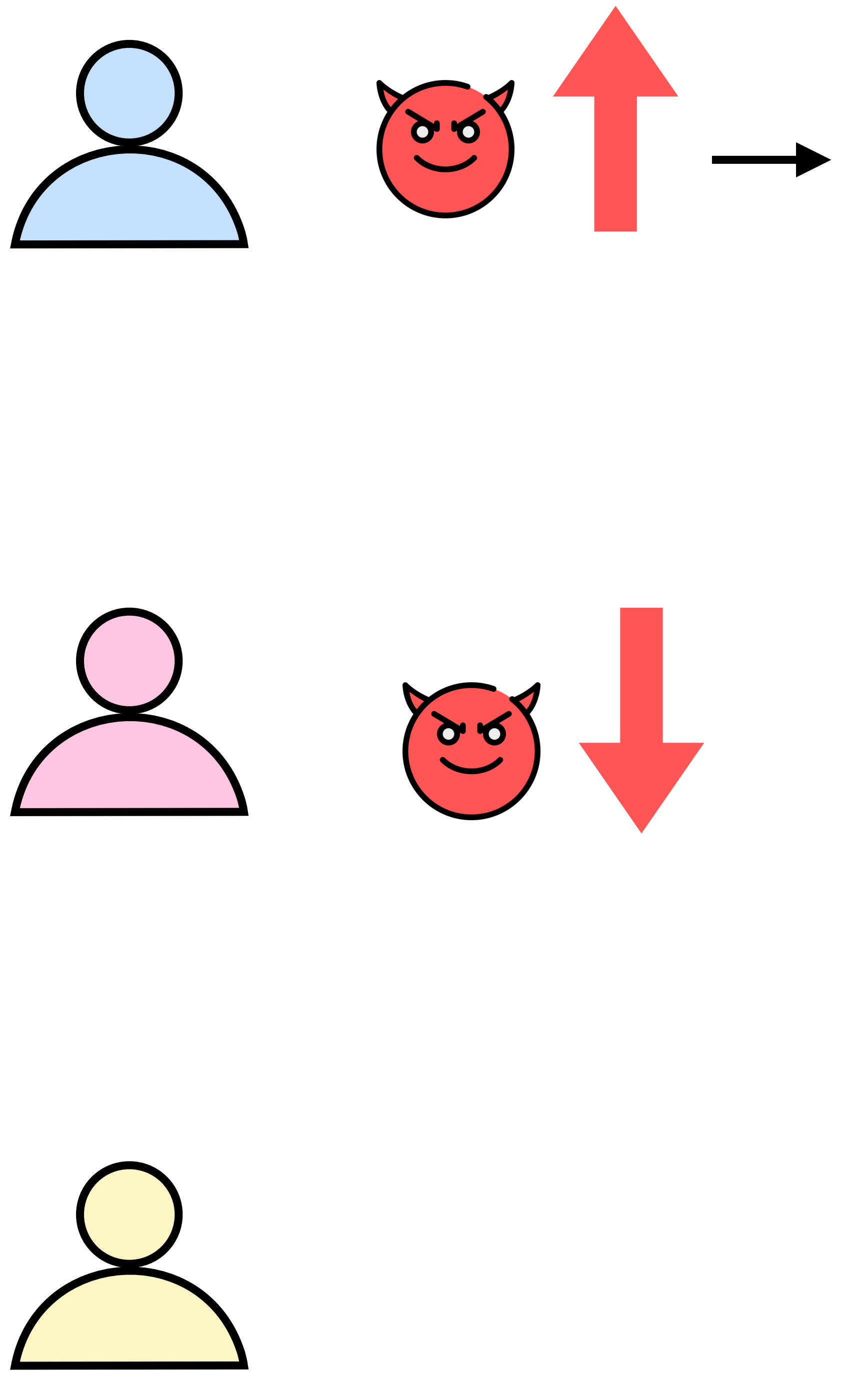

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No more than 1.5x increase in allocation

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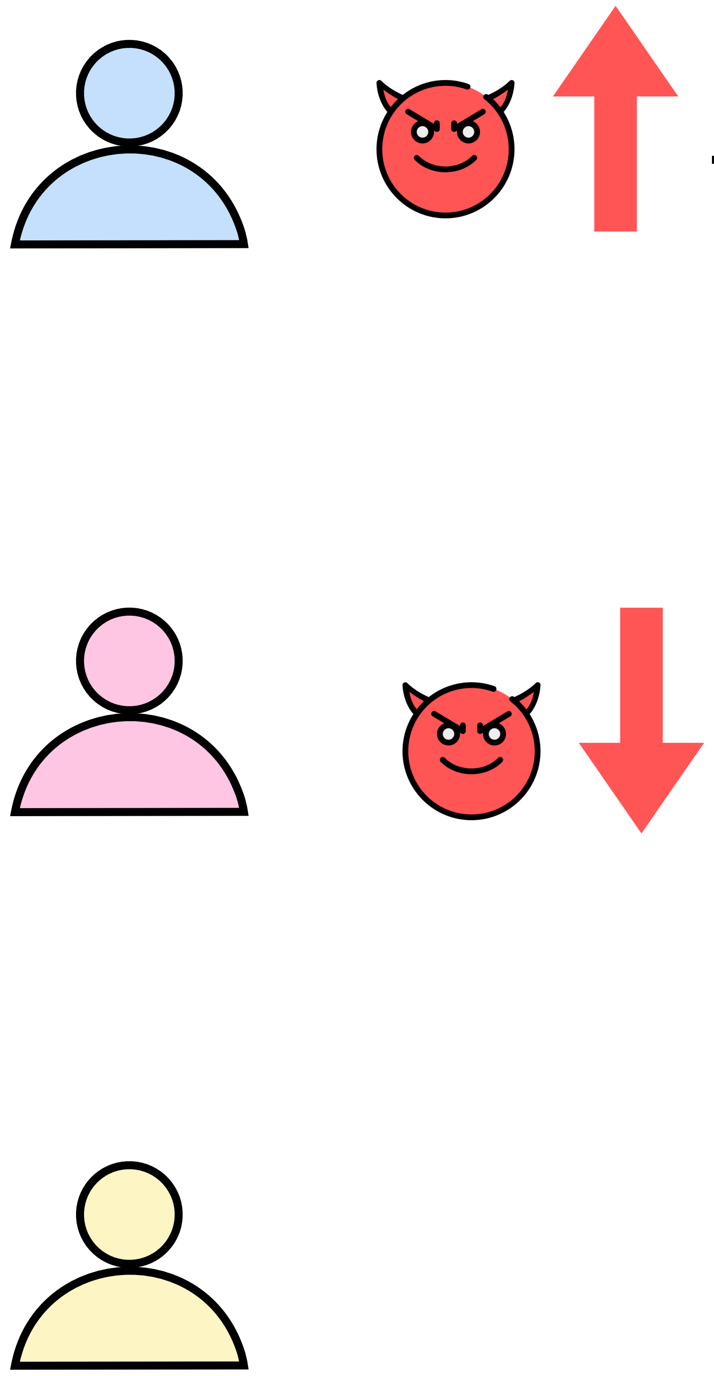

Not possible to increase allocation

Perfect knowledge of
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Far from realistic

No more than 1.5x increase in allocation

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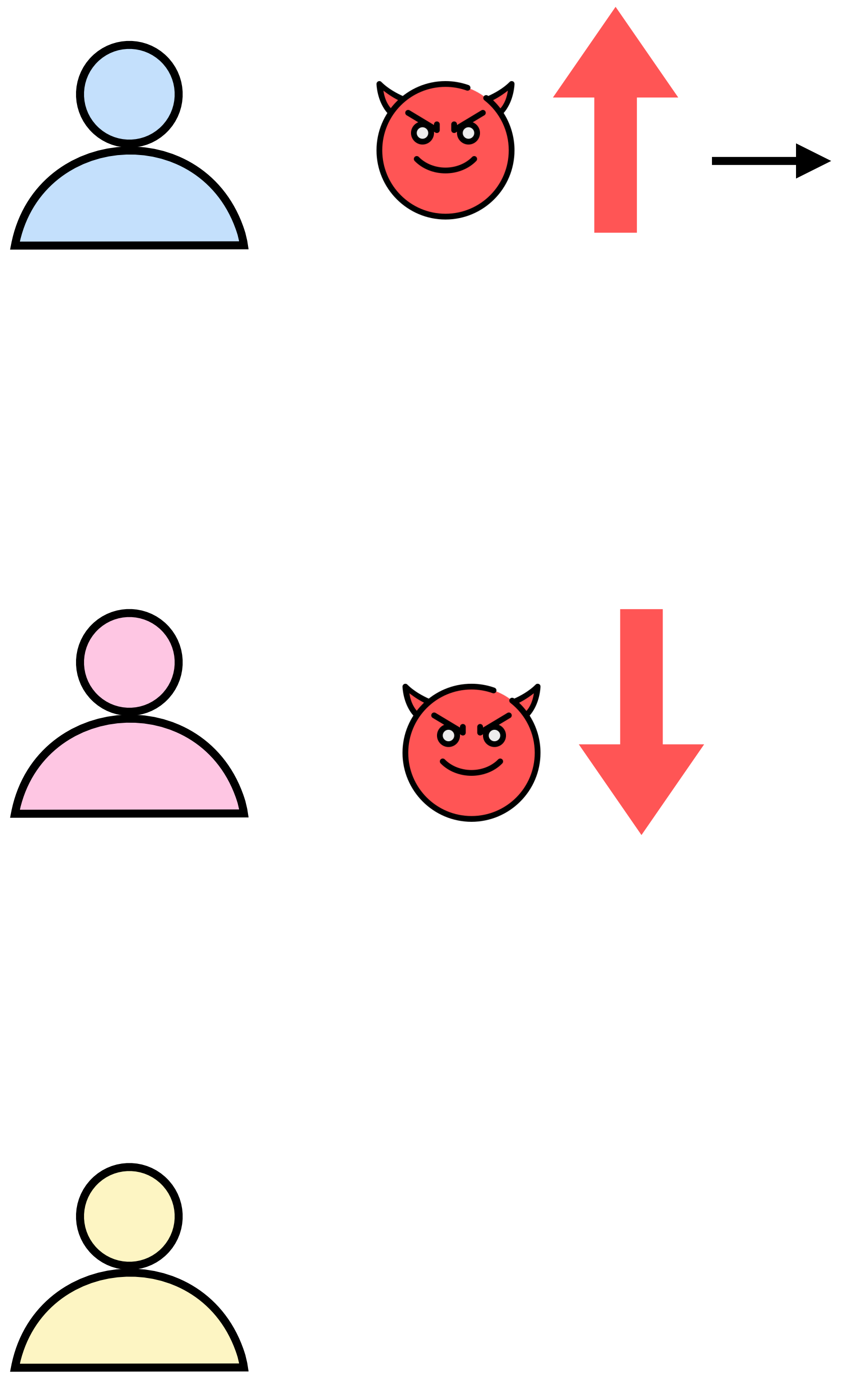

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Any imprecision in knowledge of
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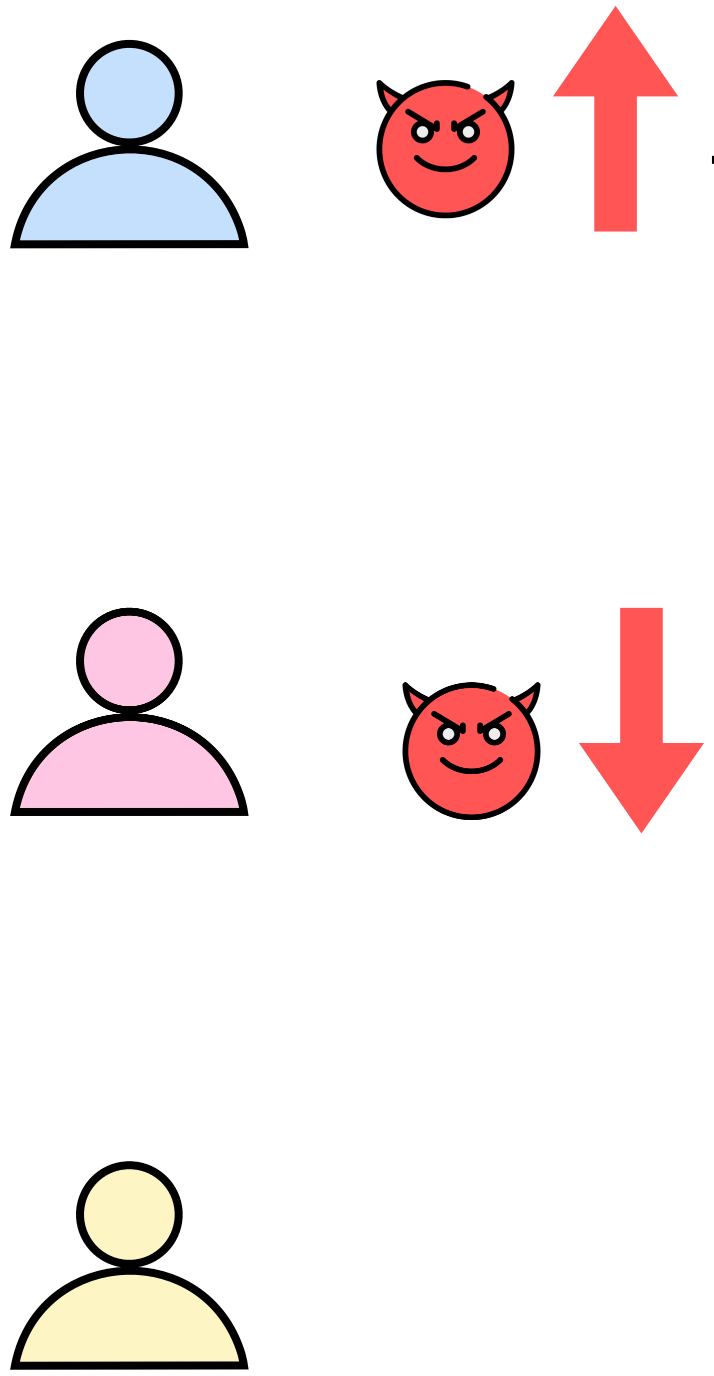

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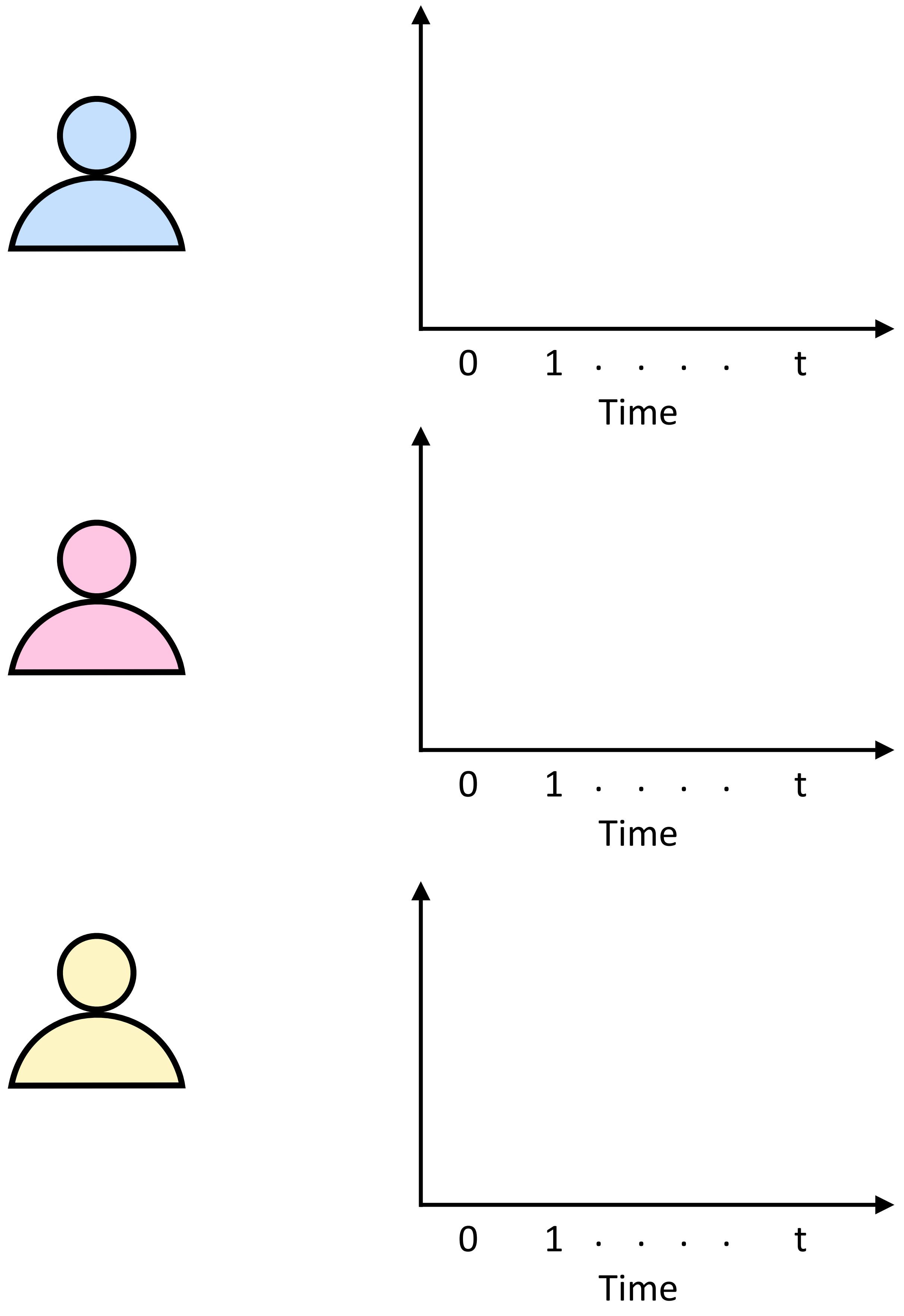
As much as Ω(n) factor decrease in allocation

Karma maximizes the minimum total allocation (given past allocations)

Fairness

Balanced resource allocations across users



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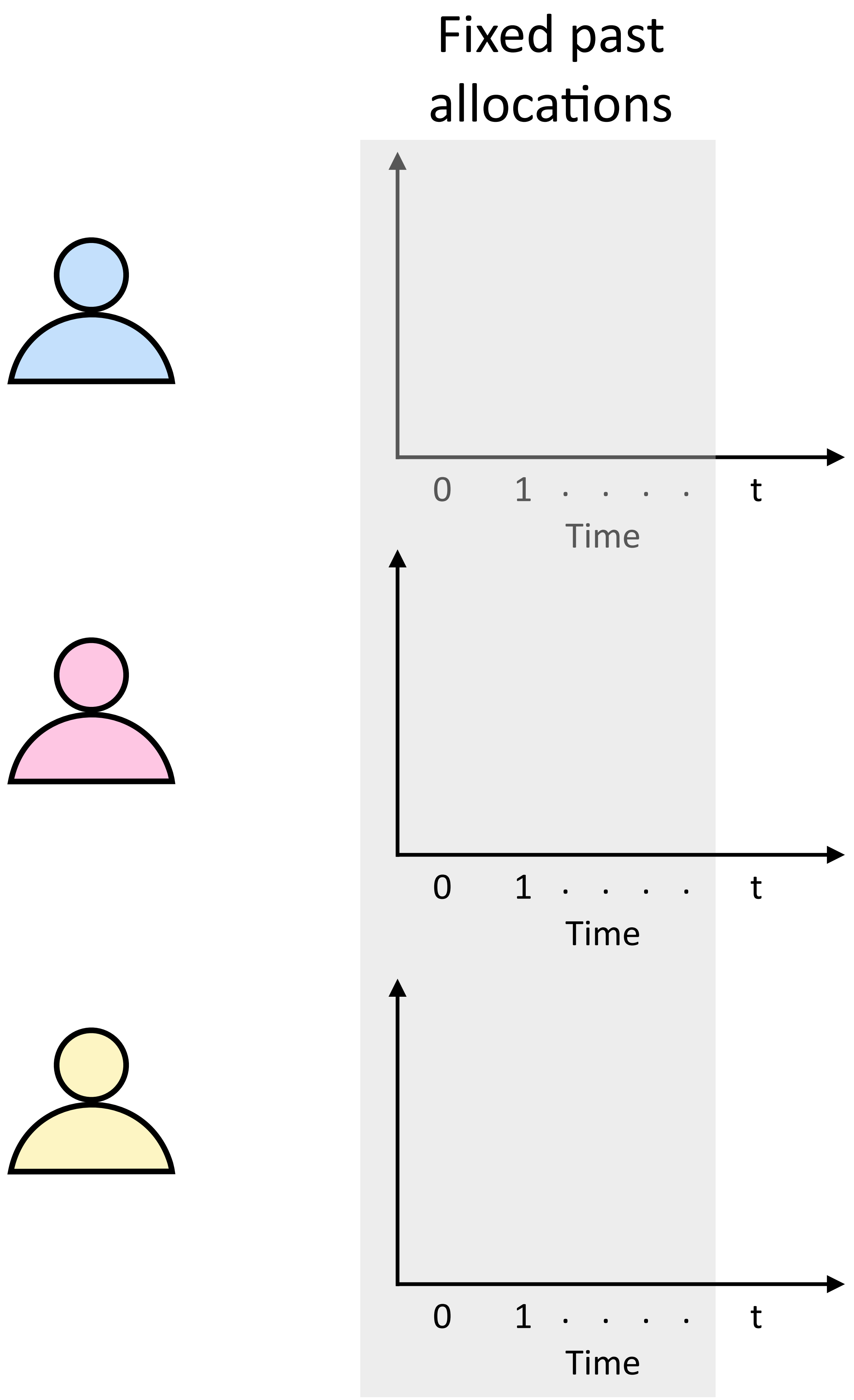

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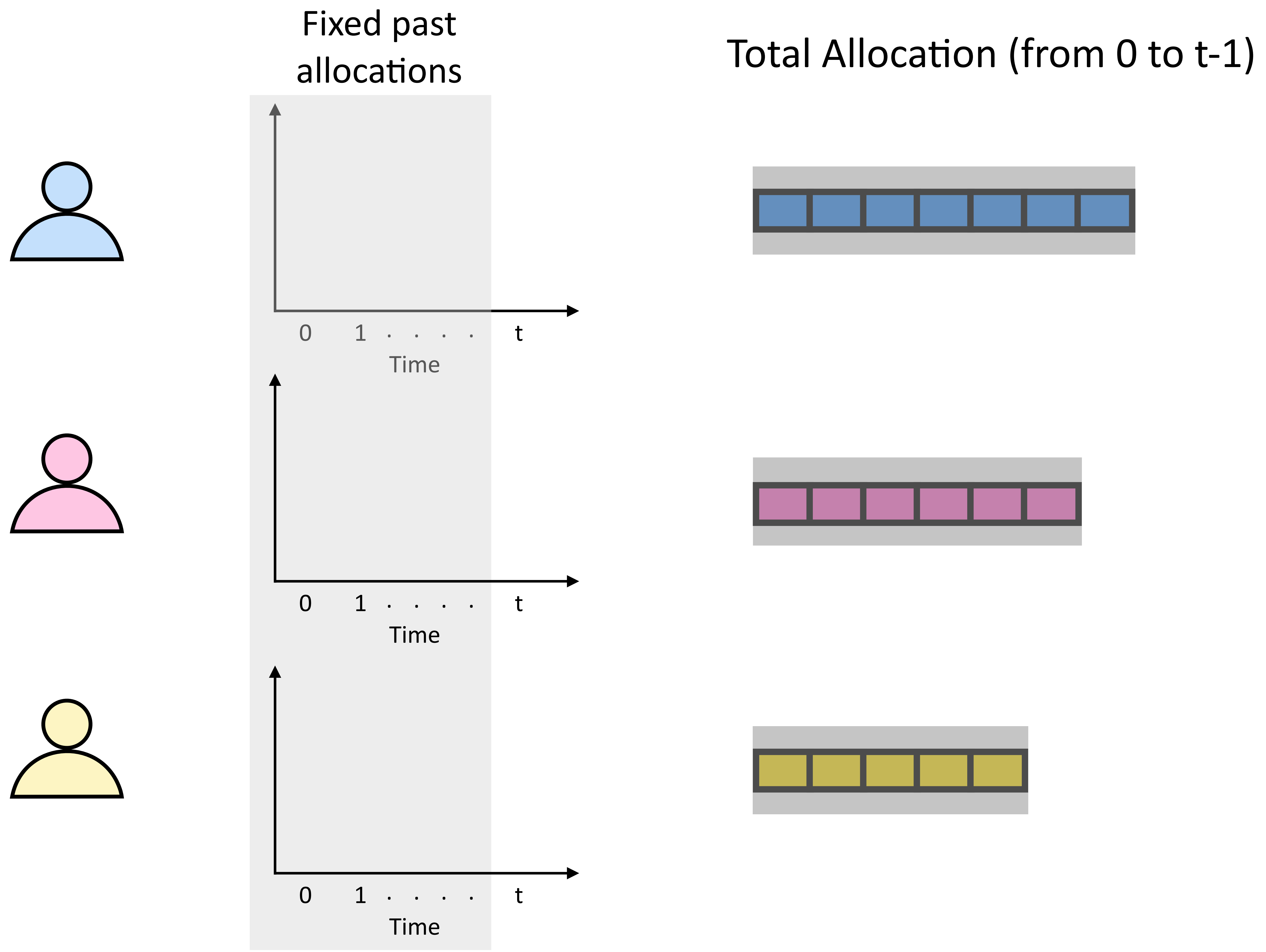

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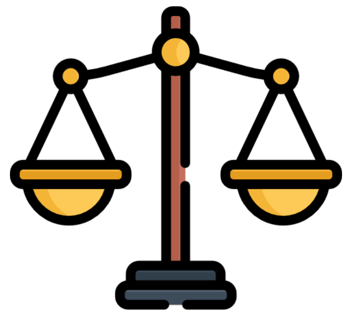

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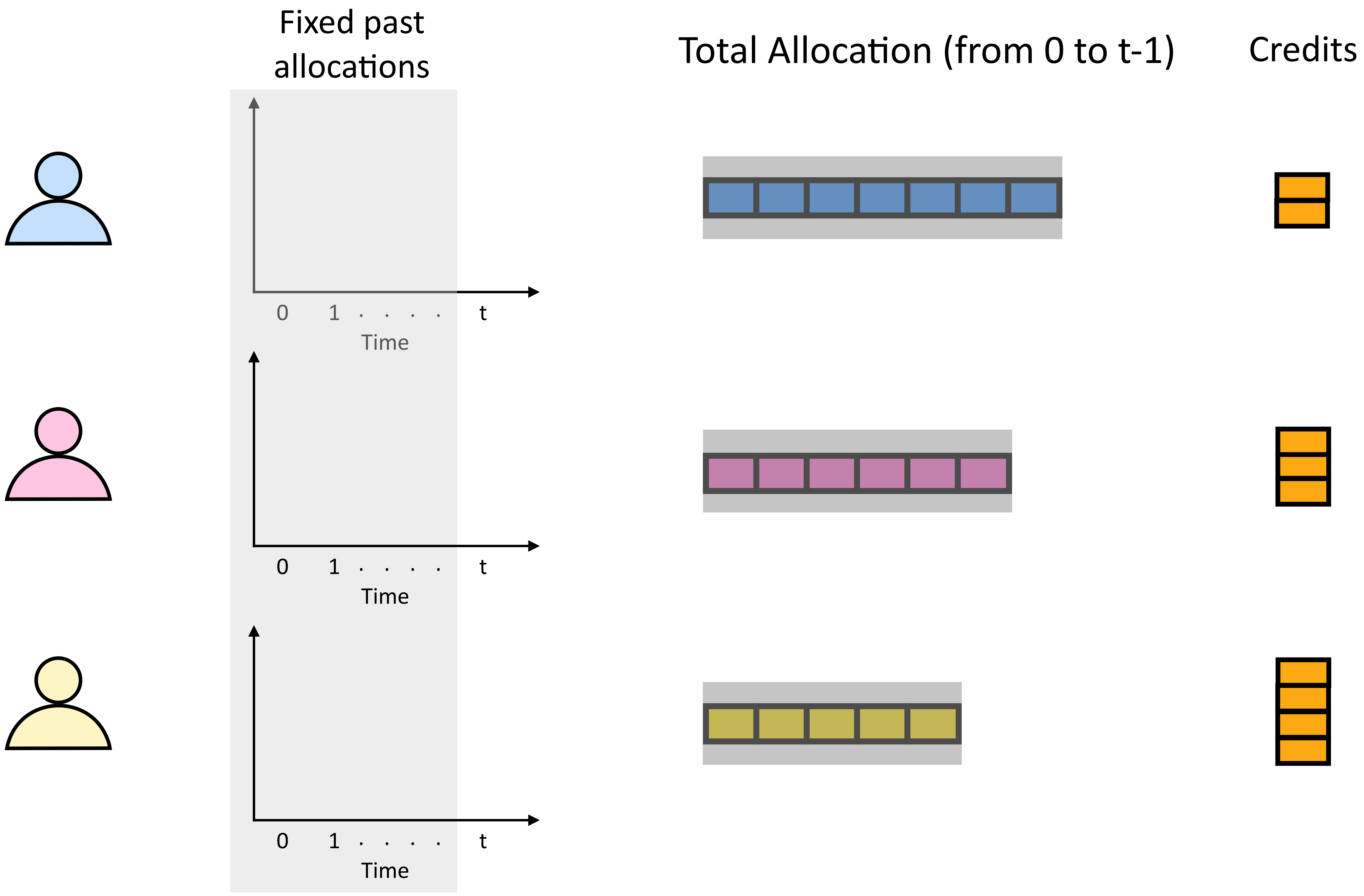
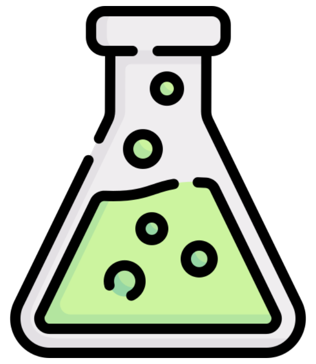


Karma: Resource Allocation for Dynamic Demands

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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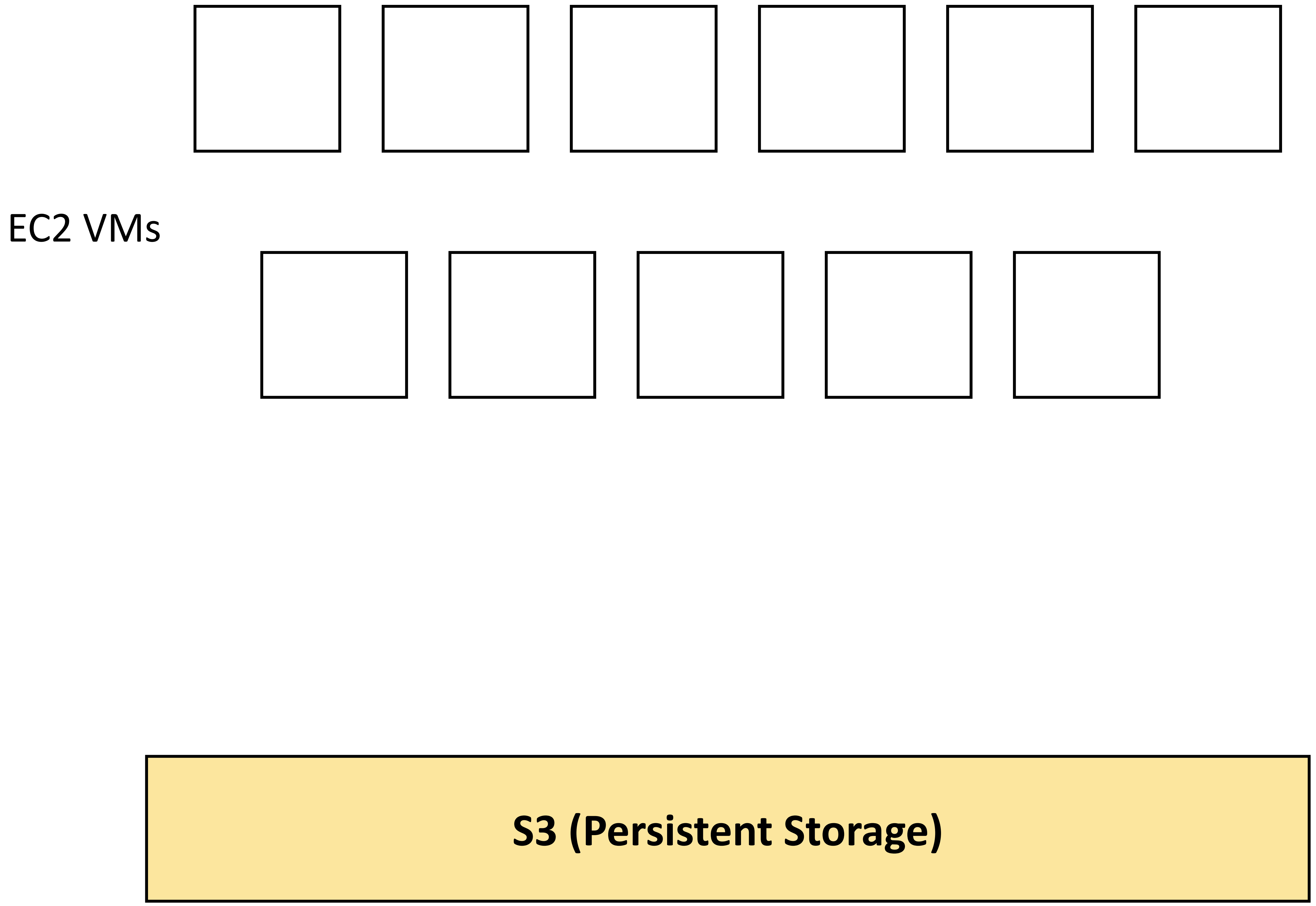

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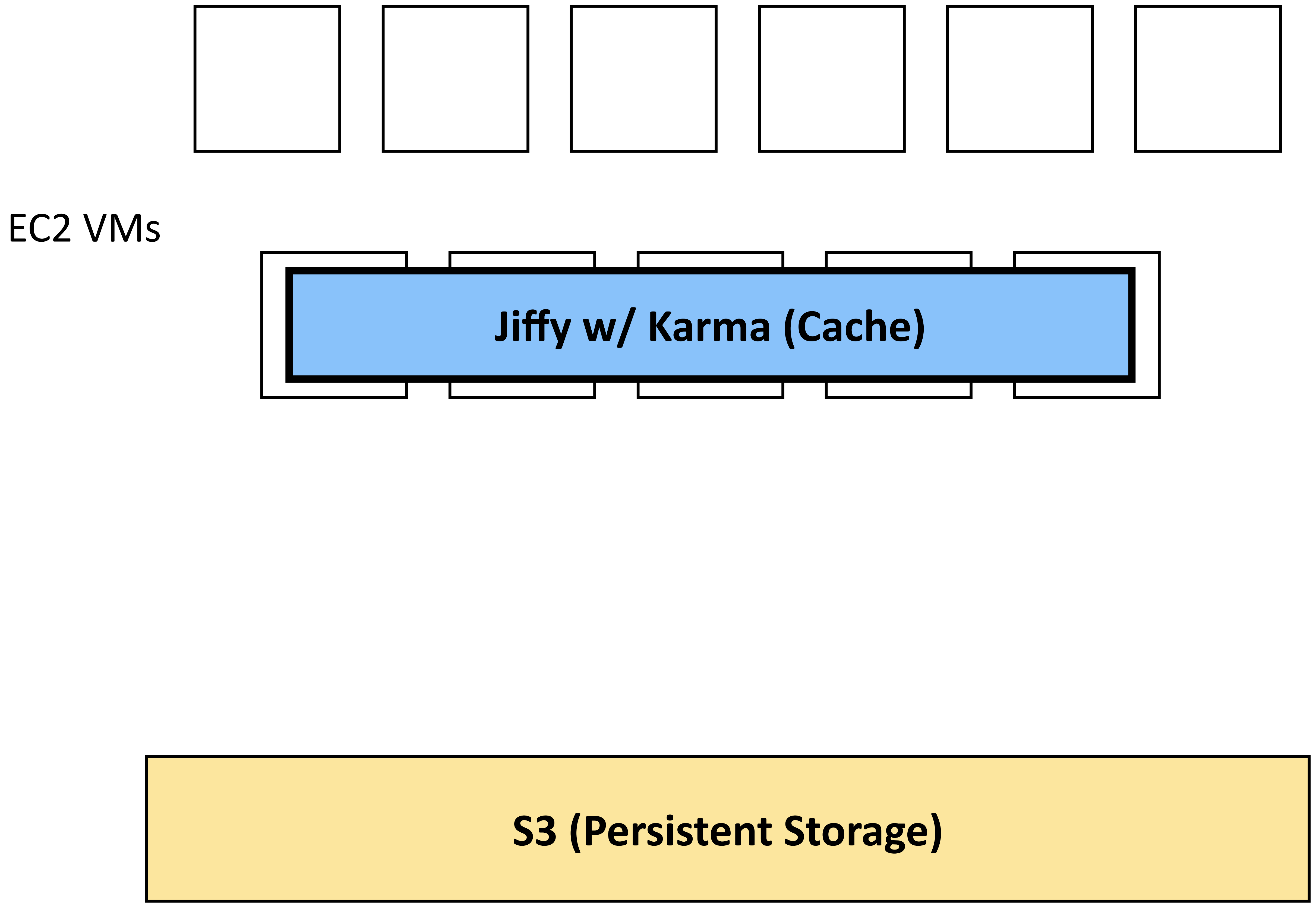

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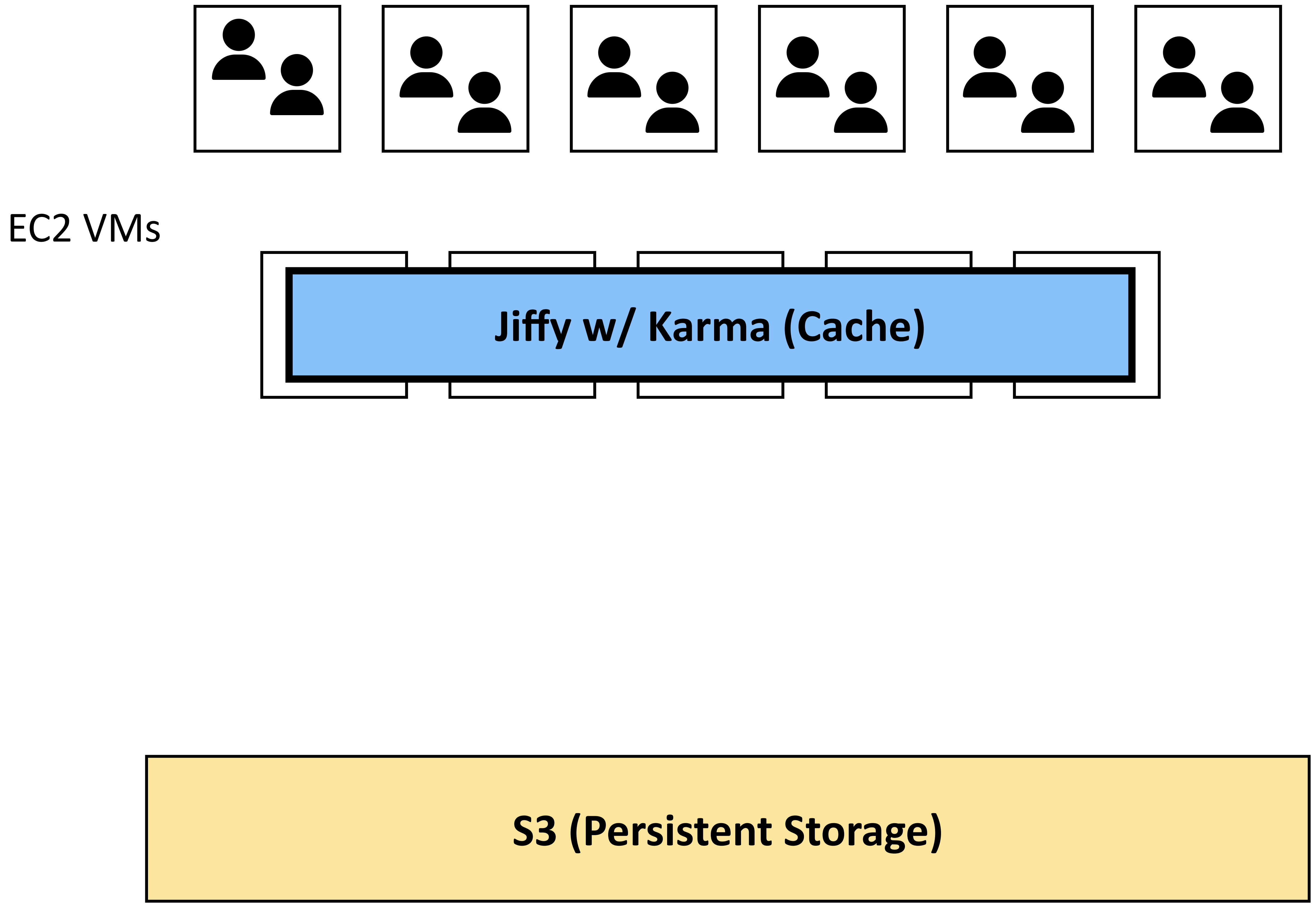

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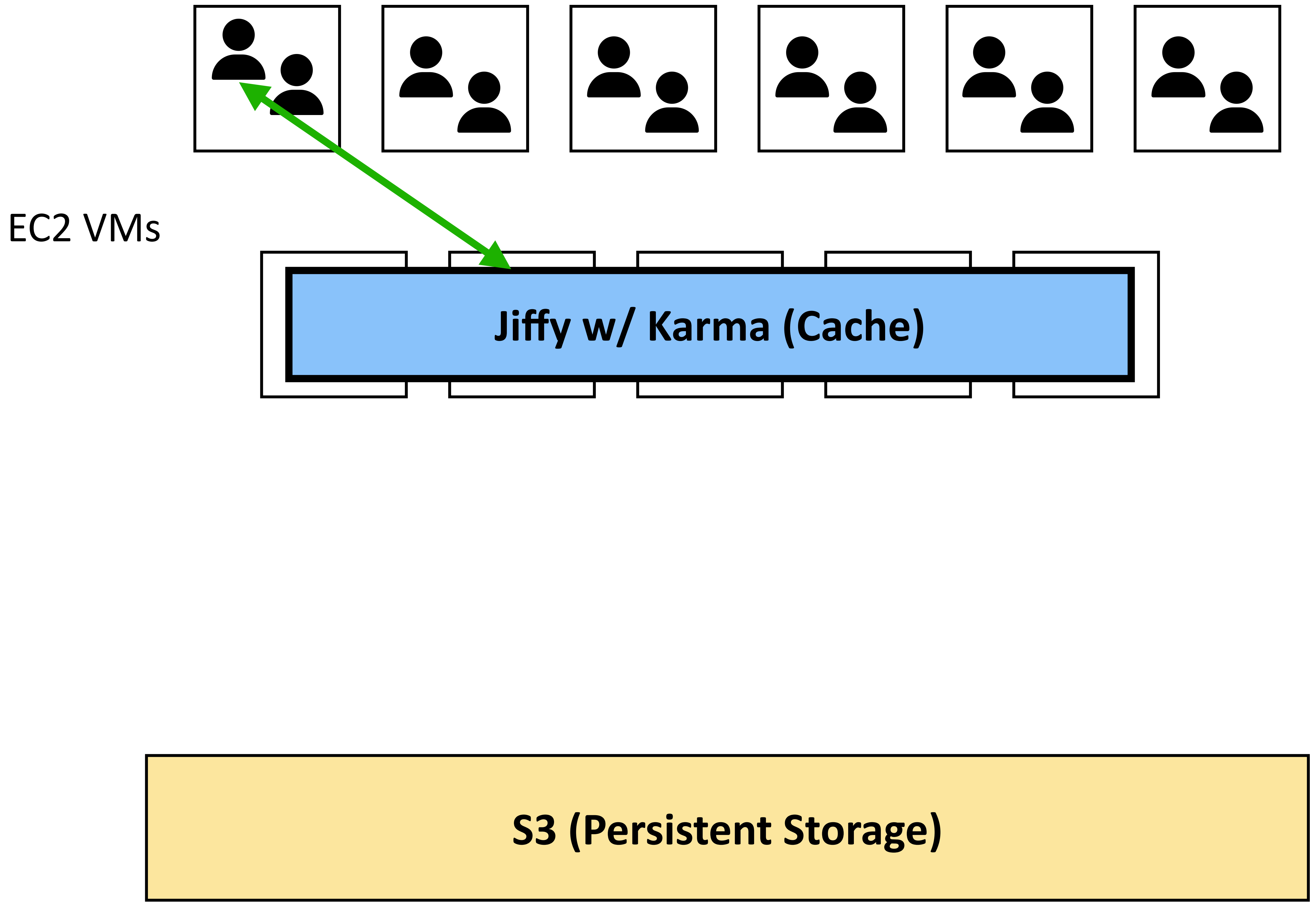

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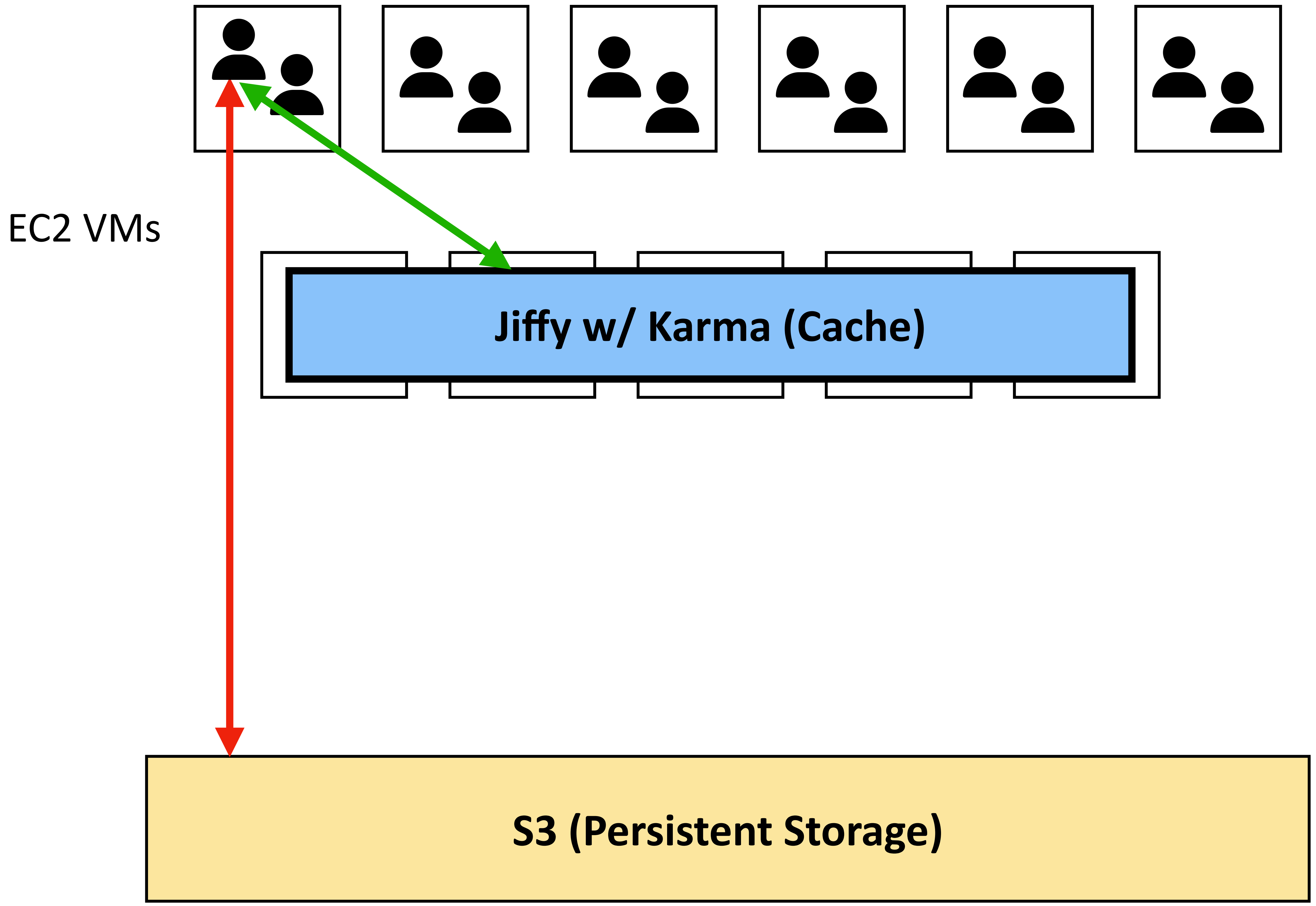

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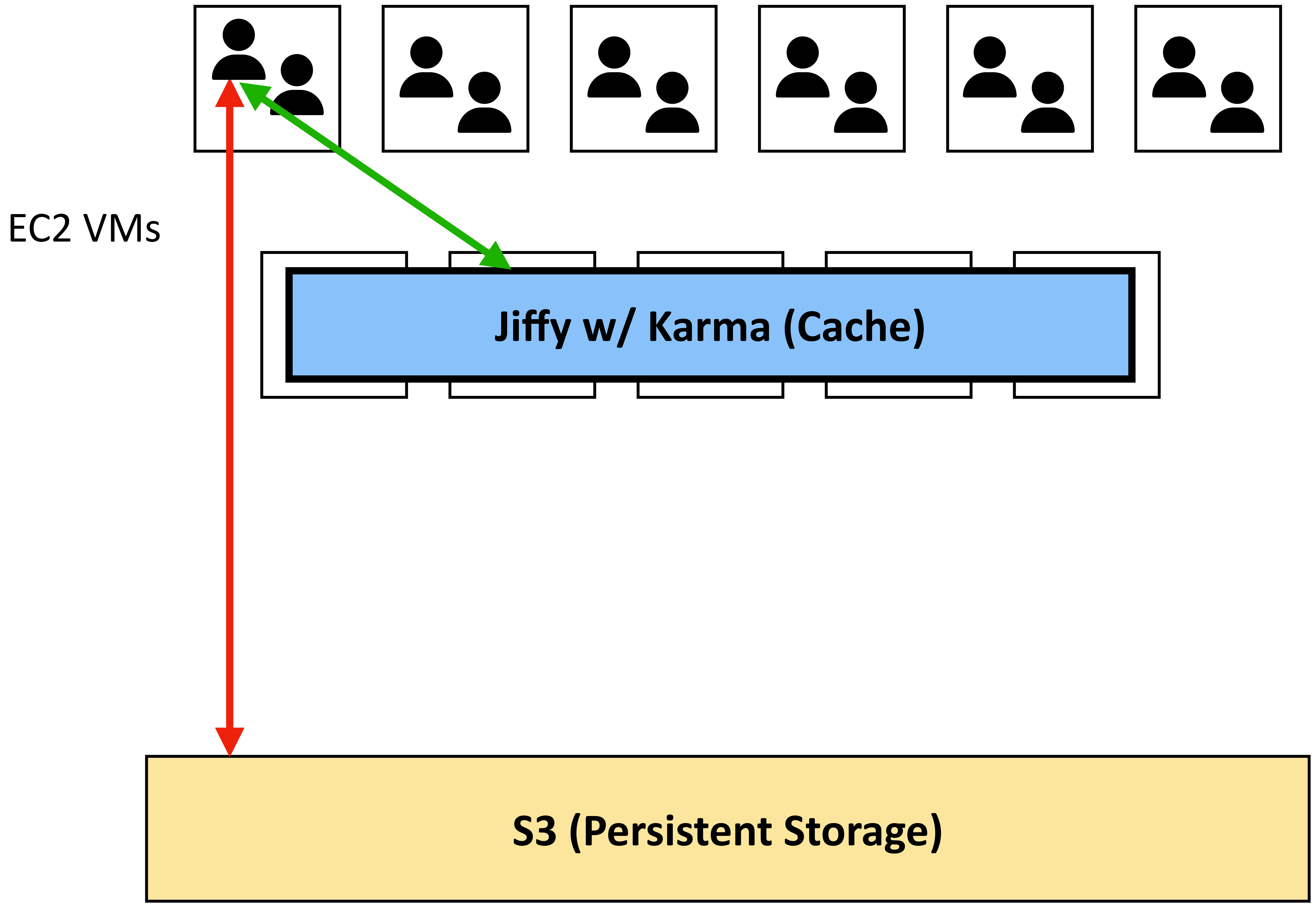

Workload

Dynamic demands -> vary working set size

Demands taken from Snowflake dataset

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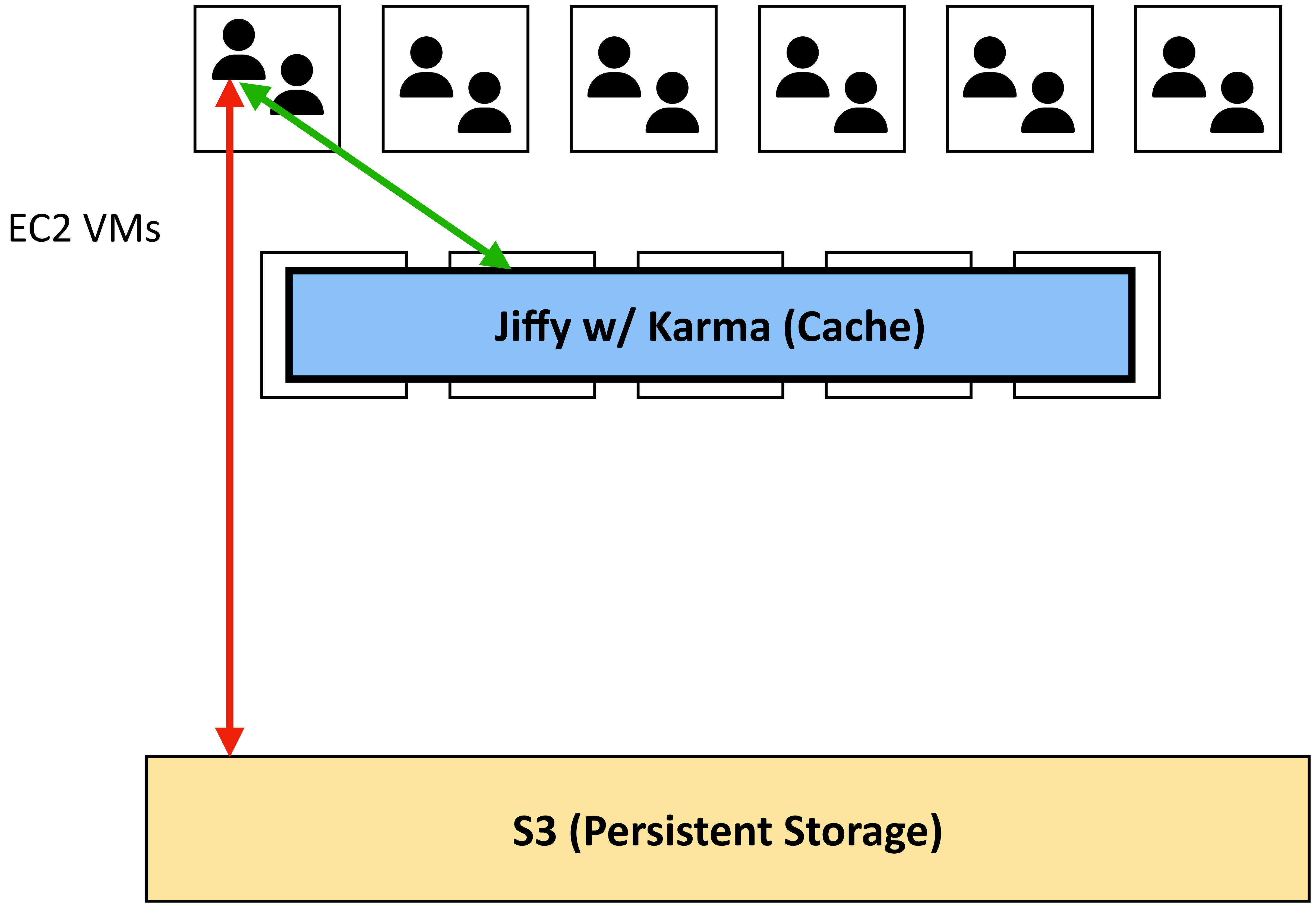

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(See paper for details)

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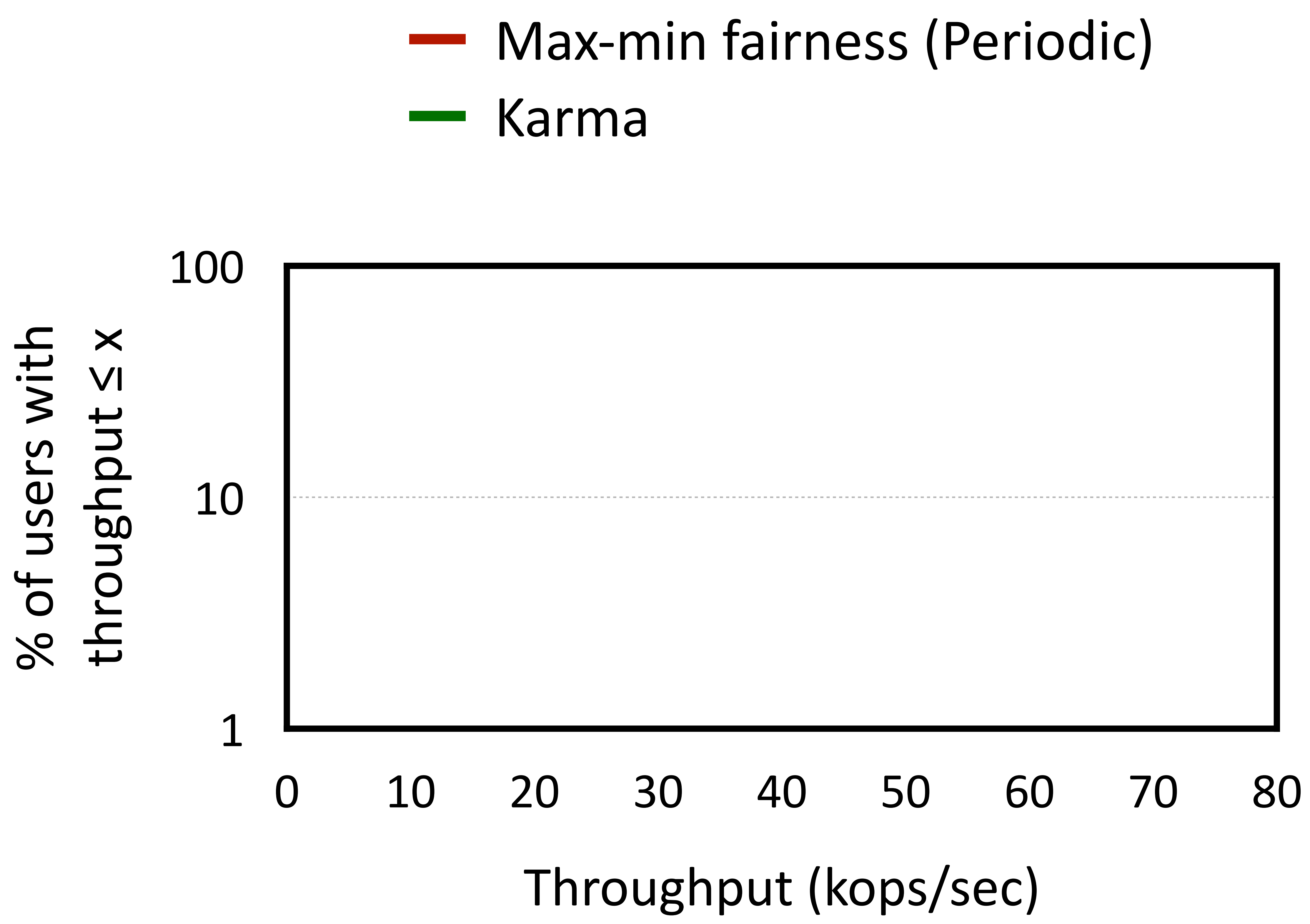

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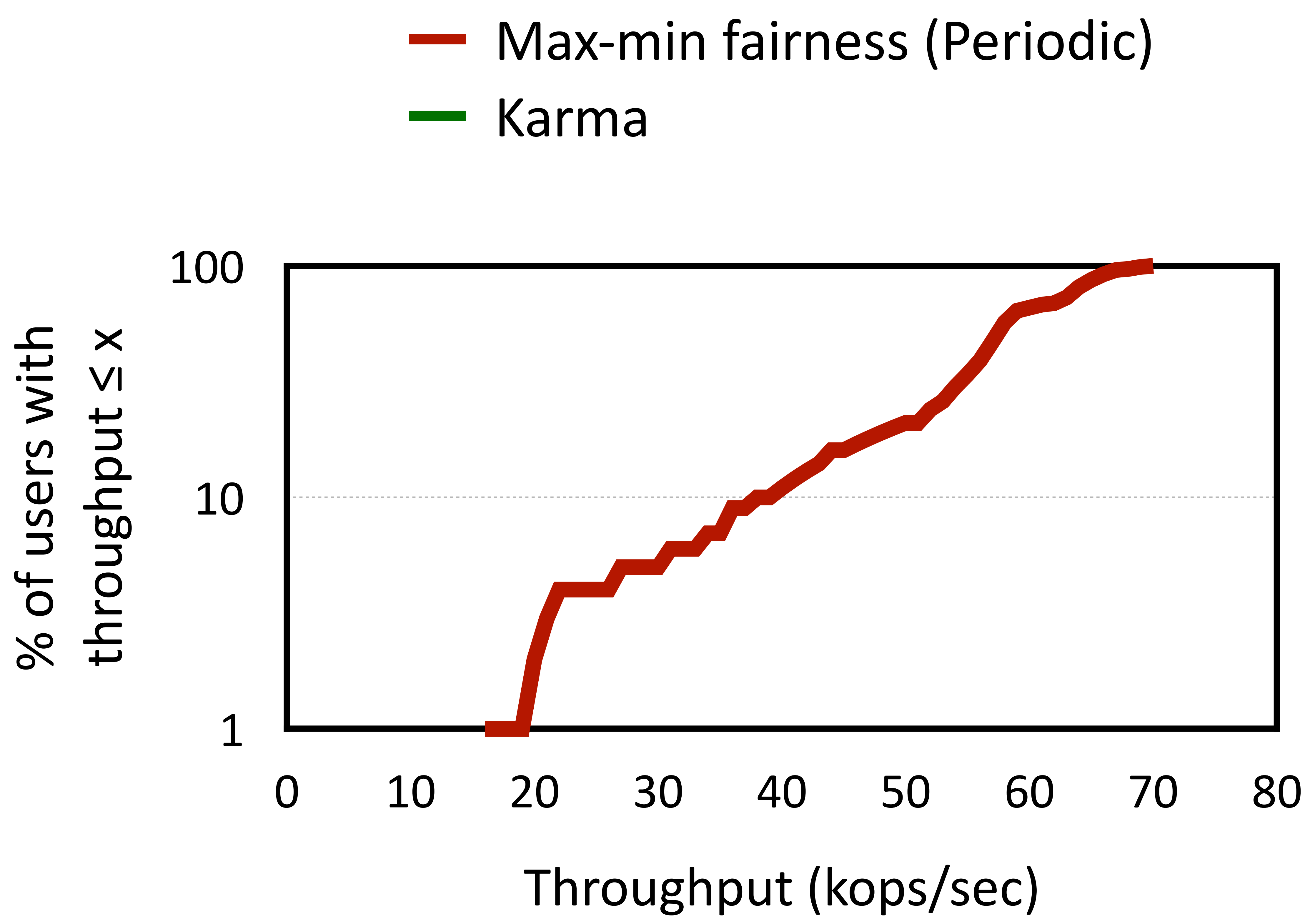

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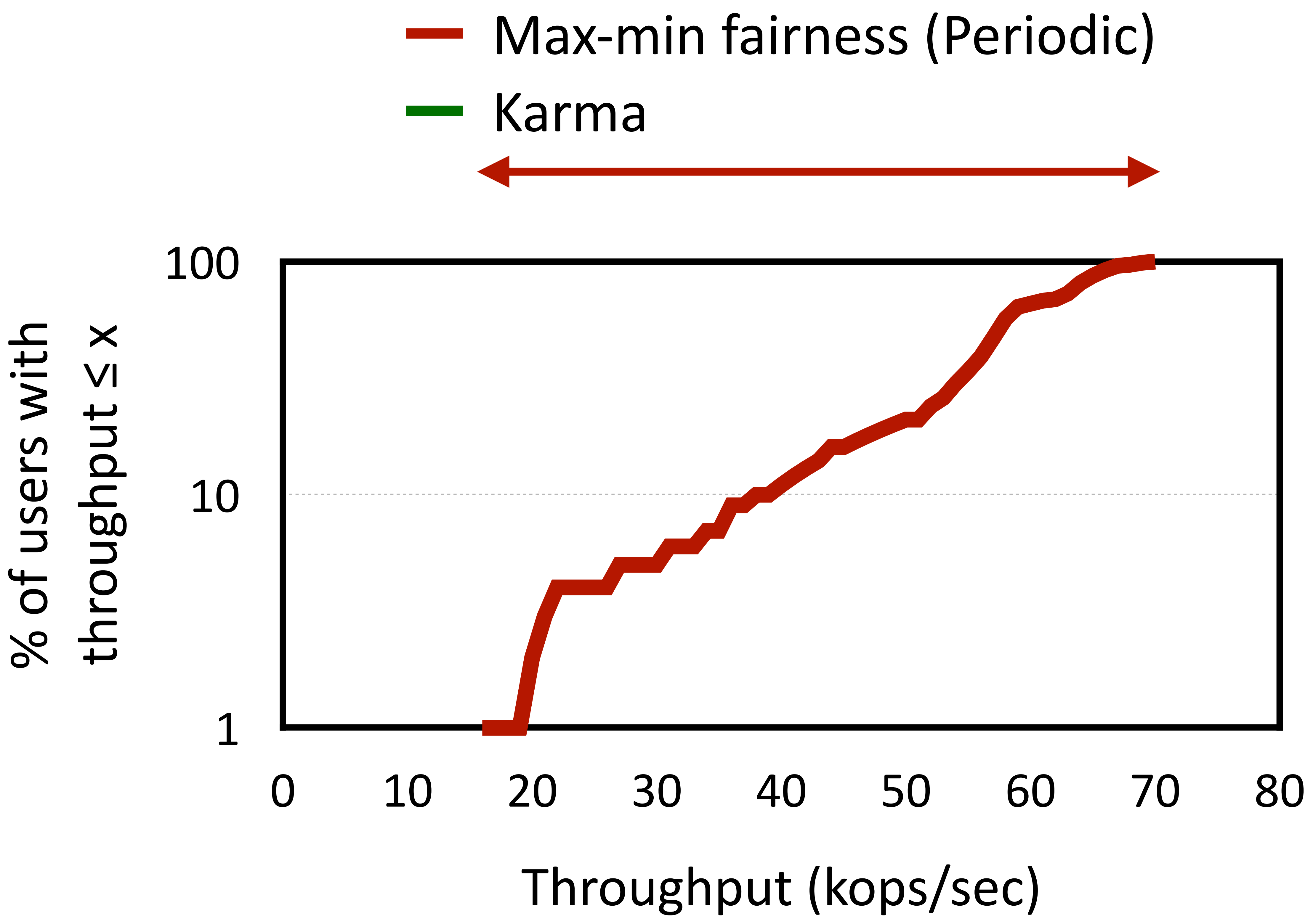

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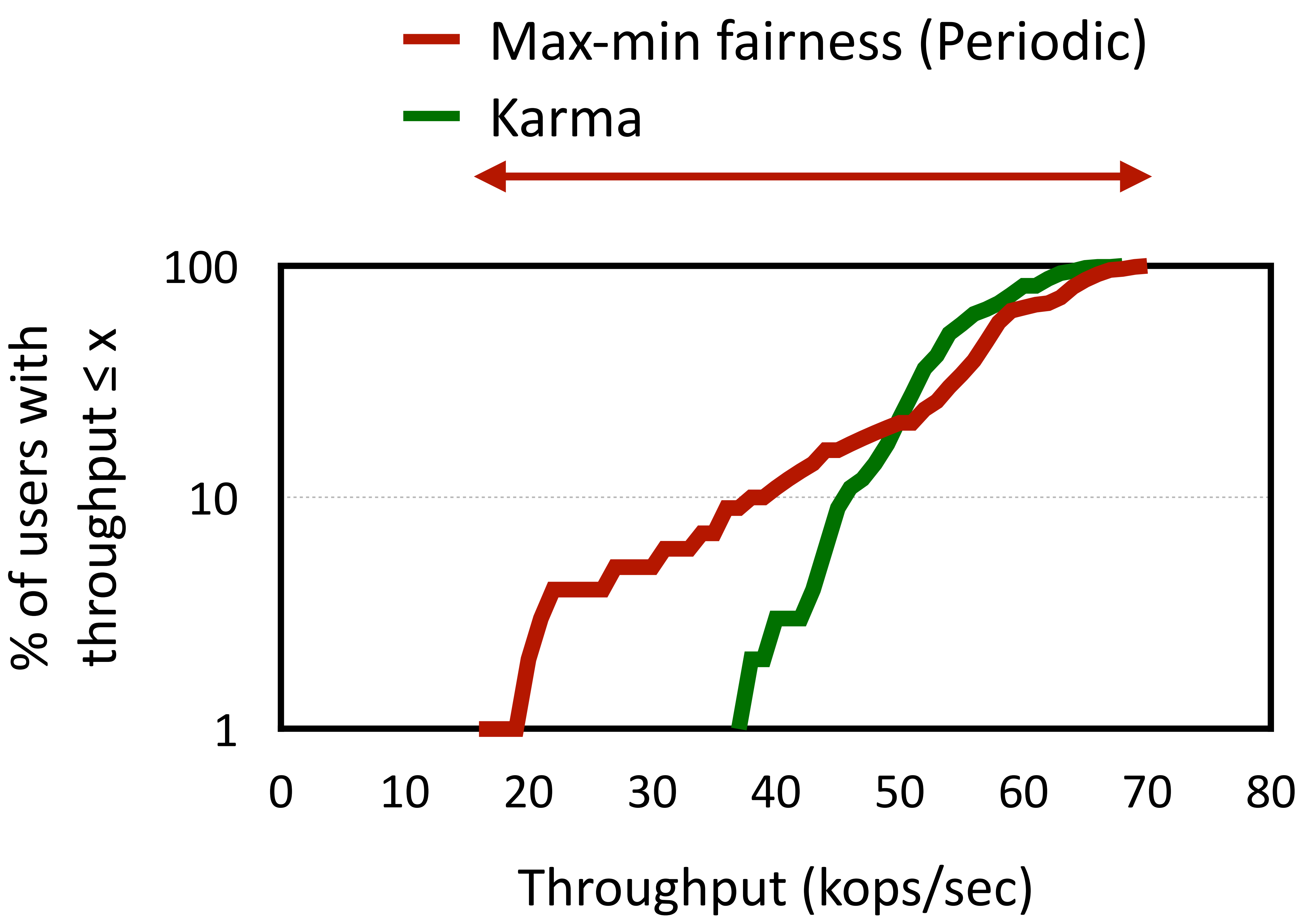

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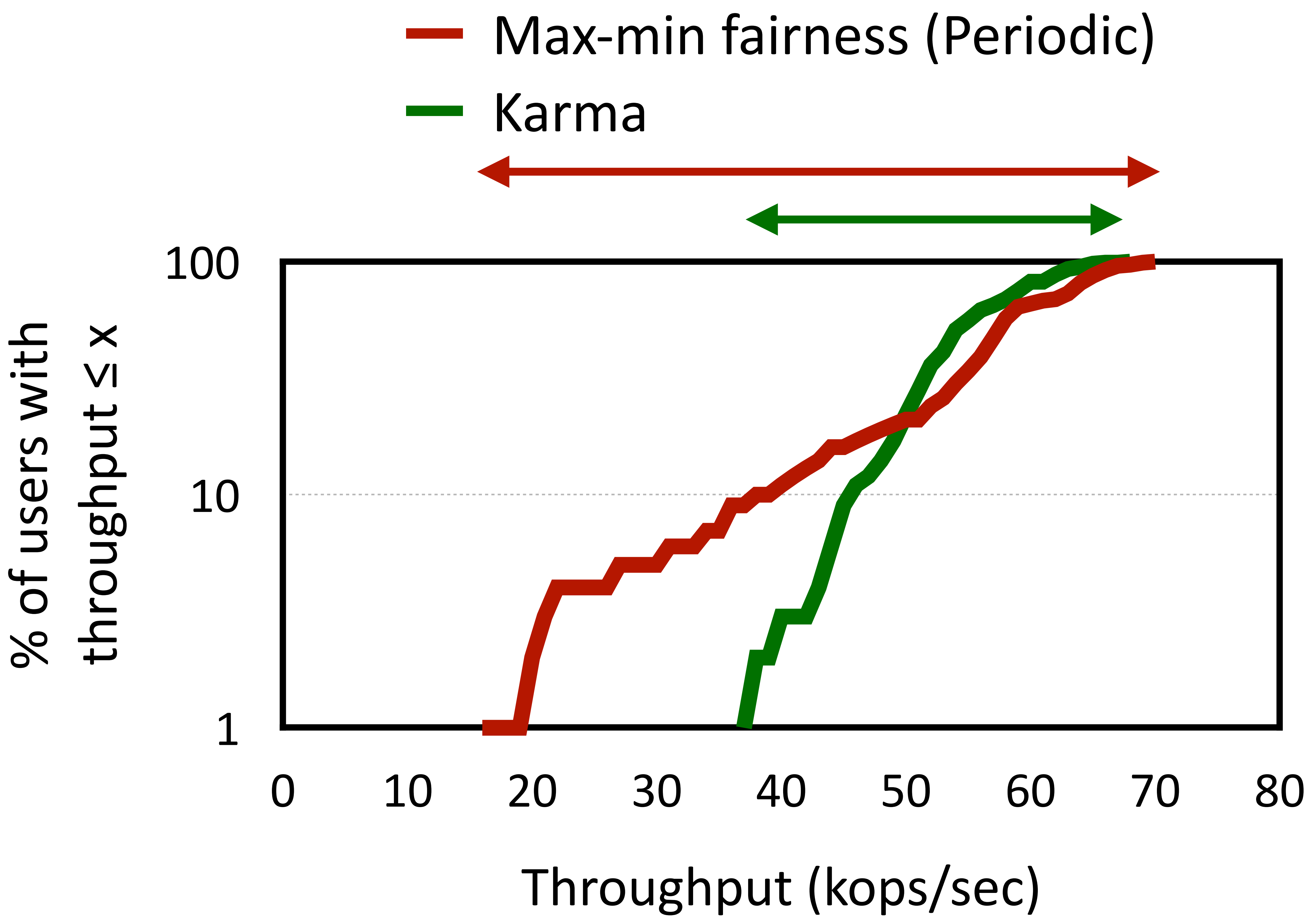

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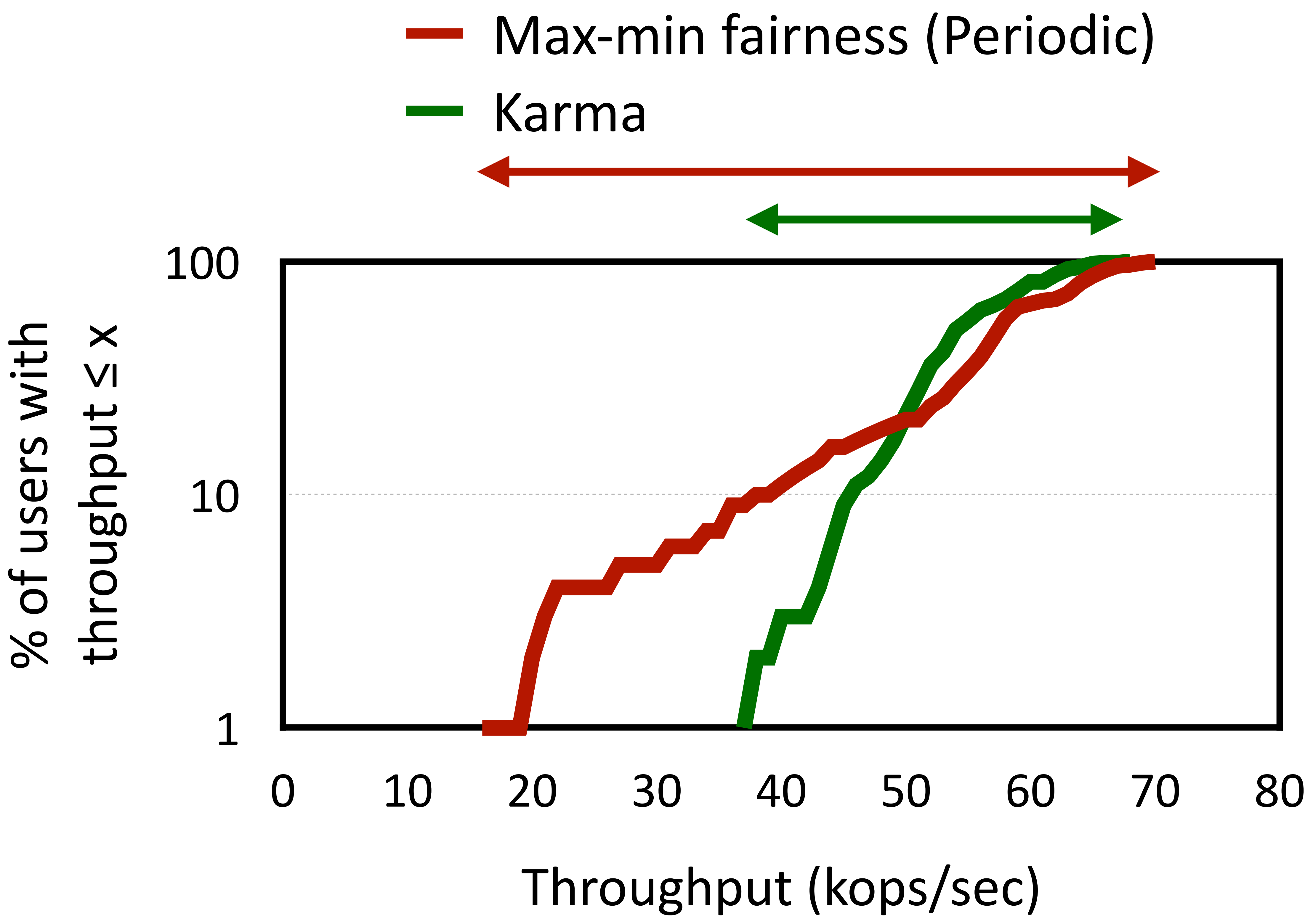

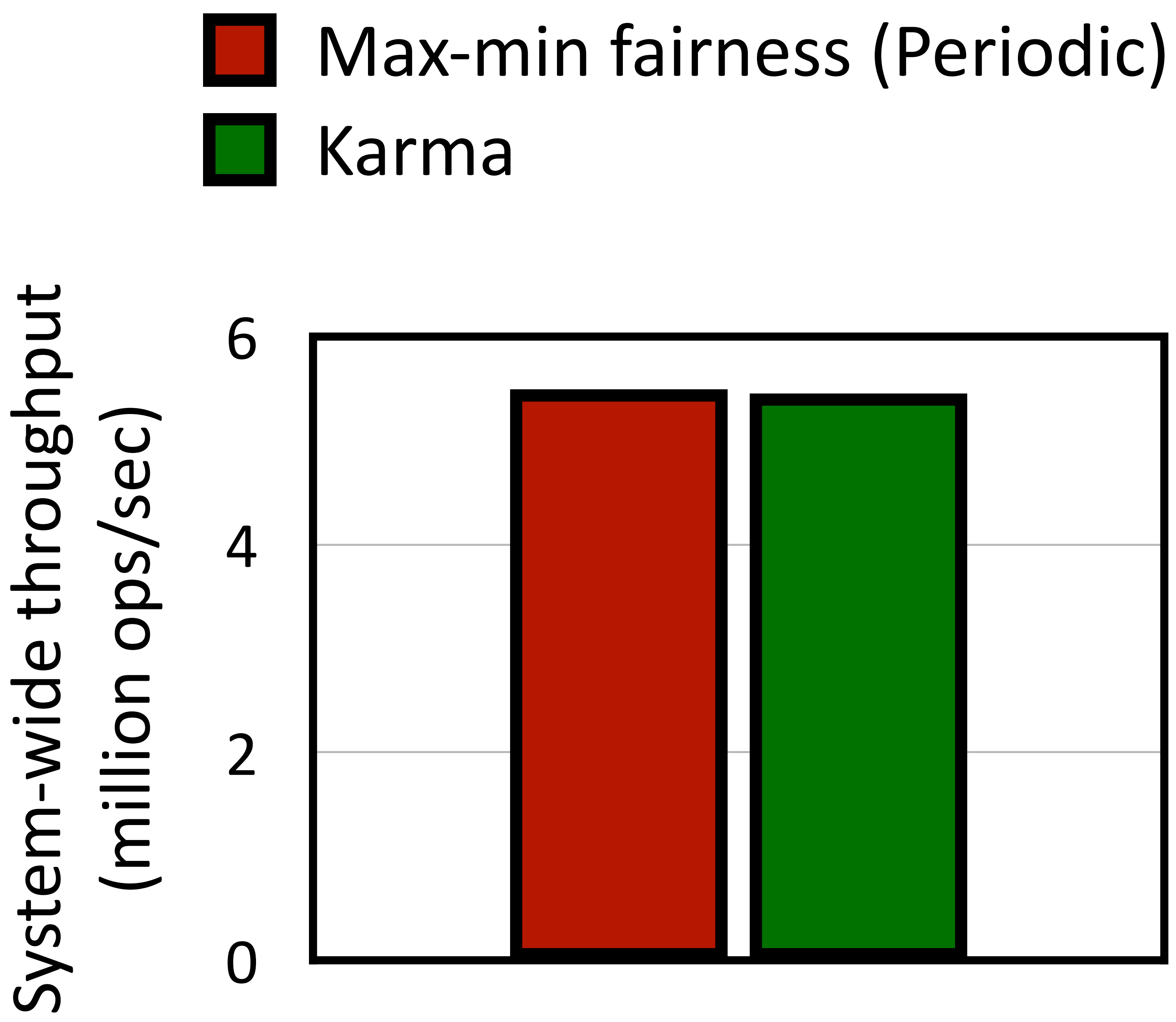

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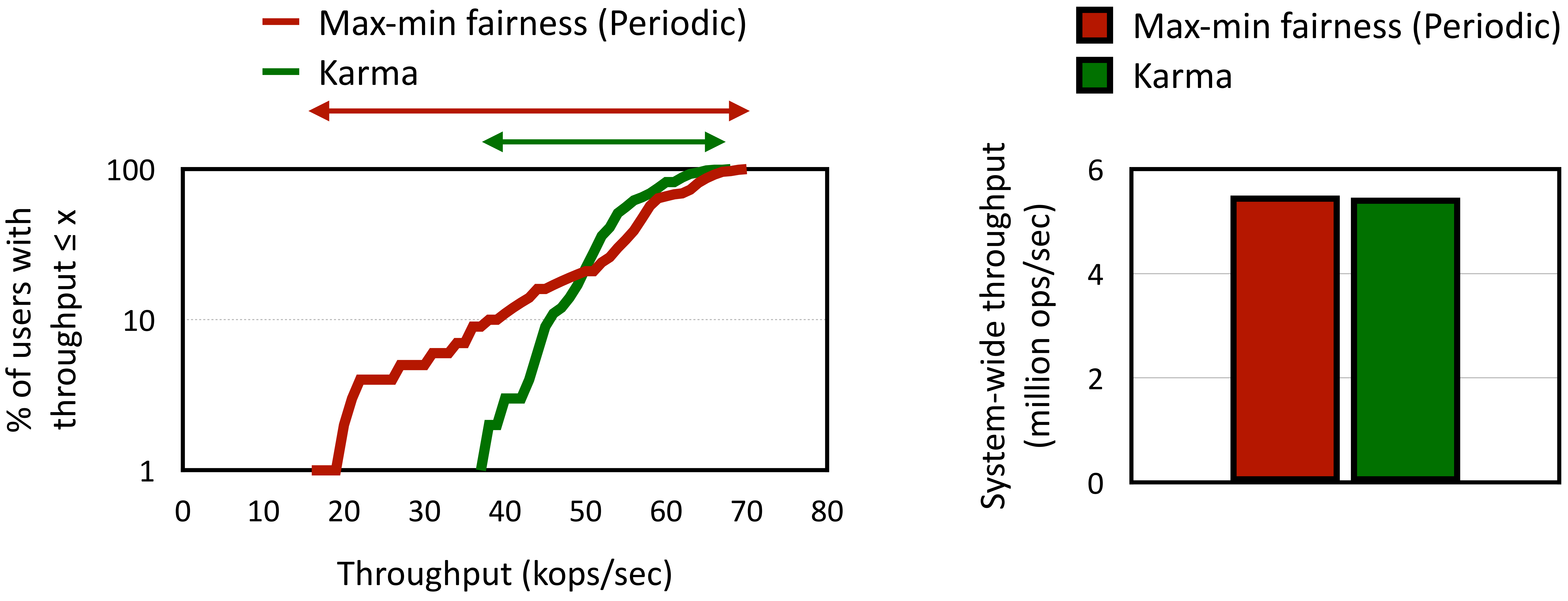
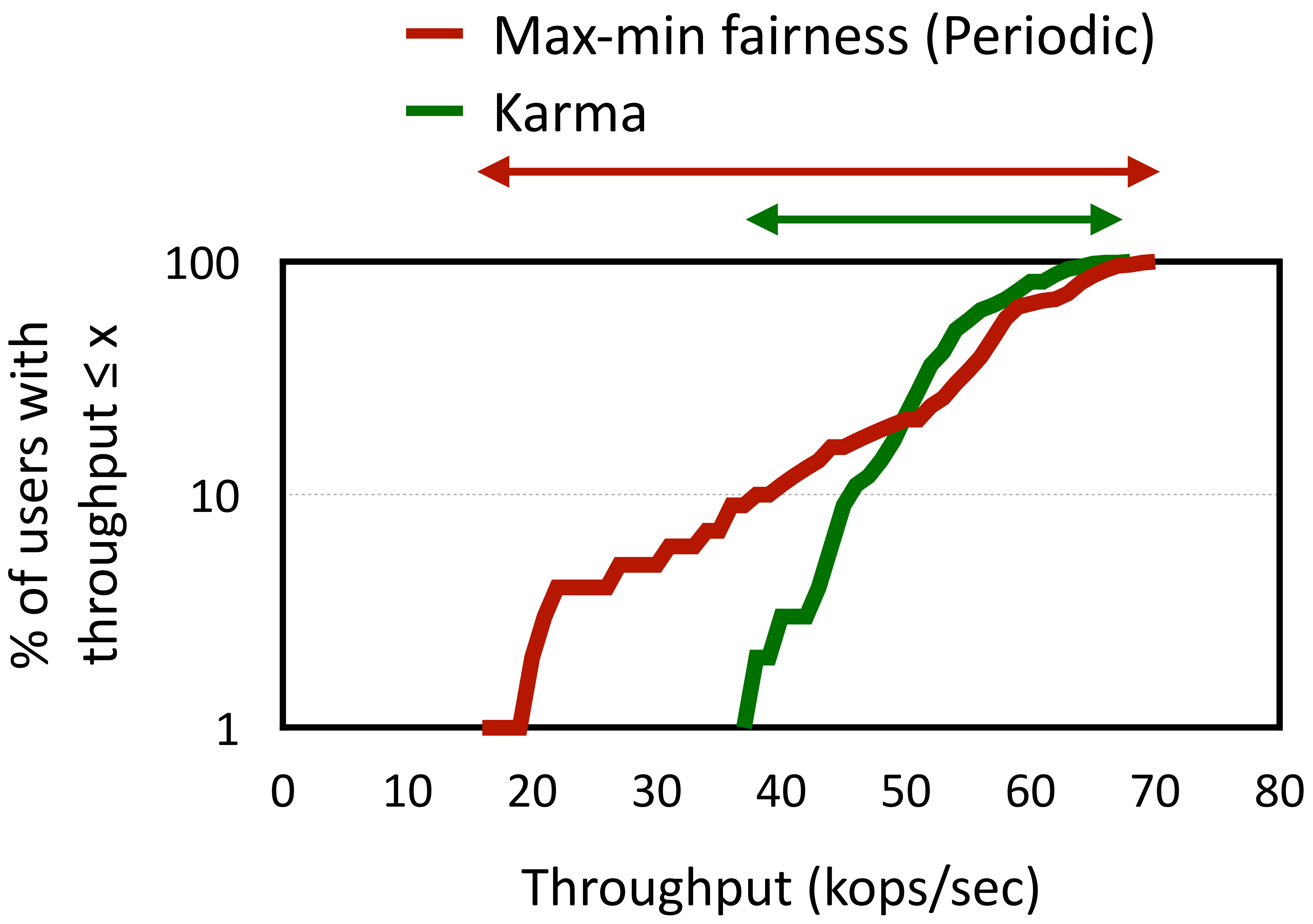
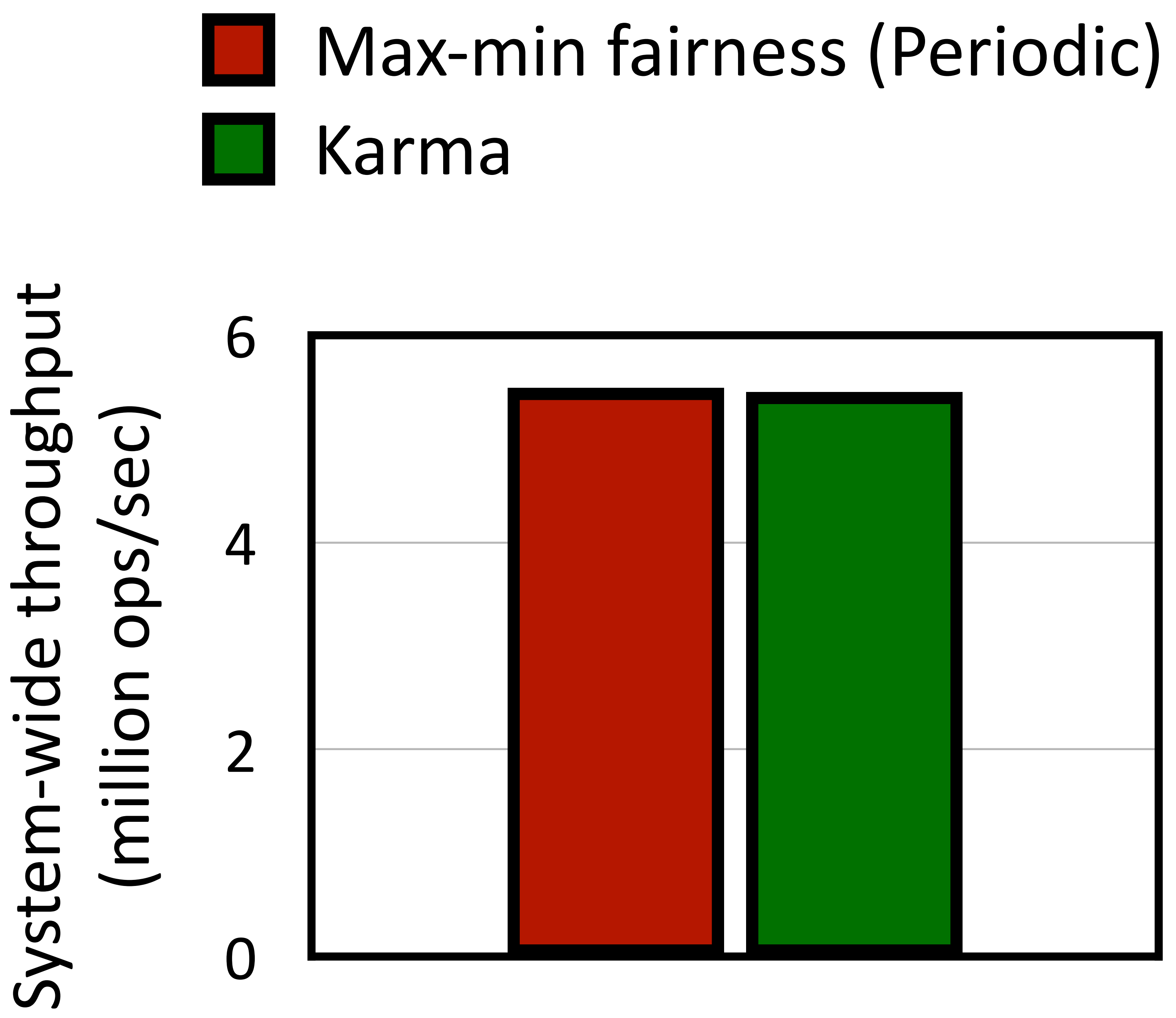


Karma minimizes disparity across users
(while maintaining high average performance)

Glimpse of Karma evaluation results





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

Midhul Vuppalapati (midhul@cs.cornell.edu)