Karma:
Resource Allocation for Dynamic Demands

Midhul Vuppalapati  Giannis Fikioris  Rachit Agarwal  Asaf Cidon  Anurag Khandelwal  Éva Tardos
Resource allocation is a fundamental problem

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

Resource Pool
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
Resource allocation is a fundamental problem

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

Key Desirable Properties

- **Pareto efficiency**
  Resources should not remain unused if there is demand

- **Strategy-proofness**
  Selfish users cannot increase their allocation by lying
  (selfish ≠ adversarial)
Resource allocation is a fundamental problem
Allocating a resource (e.g. CPU, Memory) with a fixed capacity across multiple users

Key Desirable Properties

- **Pareto efficiency**: Resources should not remain unused if there is demand.
- **Strategy-proofness**: Selfish users cannot increase their allocation by lying (selfish ≠ adversarial).
- **Fairness**: Balanced resource allocations across users.
Resource allocation is a fundamental problem

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

Key Desirable Properties

- **Pareto efficiency**
  Resources should not remain unused if there is demand

- **Strategy-proofness**
  Selfish users cannot increase their allocation by lying (selfish ≠ adversarial)

- **Fairness**
  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**
Strict partitioning

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

Resource Pool

Capacity:
6 slices
Strict partitioning

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

Demands Resource Pool

Capacity: 6 slices
Strict partitioning

Allocating the resource equally across all users ("fair share") independent of their demands
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**Strict partitioning**

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

Demands | Resource Pool
---|---

- **Unsatisfied demand**
- **Wasted resource**
Strict partitioning

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

Demands | Resource Pool
---|---

Unsatisfied demand

Pareto efficiency

Strategy-proofness

Fairness

Wasted resource
Strict partitioning

Allocating the resource equally across all users ("fair share") independent of their demands

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 $\leq$ demand for each user
Max-min Fairness alleviates the limitations of strict partitioning *(under an assumption)*

Maximizing minimum allocation across users while ensuring allocation $\leq$ demand for each user
Max-min Fairness alleviates the limitations of strict partitioning (under an assumption)

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

Demands | Resource Pool
---------|--------------

User 1

User 2

User 3
Max-min Fairness alleviates the limitations of strict partitioning \textit{(under an assumption)}

Maximizing minimum allocation across users while ensuring allocation $\leq$ demand for each user.

Demands | Resource Pool
---|---

- Pareto efficiency
- Strategy-proofness
- Fairness

\textbf{Classical result:} Max-min fairness satisfies Pareto efficiency, strategy-proofness and fairness

\textbf{Underlying assumption:} User demands are static
Dynamic demands are the norm in real world deployments
Dynamic demands are the norm in real world deployments

Shared Analytics Clusters
Dynamic demands are the norm in real world deployments

- Spark
- Hadoop
- Redis
- Memcached

Shared Analytics Clusters
In-memory Key-Value Caches
Dynamic demands are the norm in real world deployments

- Shared Analytics Clusters
- In-memory Key-Value Caches
- Inter-datacenter Network Links
Dynamic demands are the norm in real world deployments

- Analysis of real world workloads
- Shared Analytics Clusters
- In-memory Key-Value Caches
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Dynamic demands are the norm in real world deployments

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Analysis of real world workloads

- CPU Demand
- Memory Demand
Dynamic demands are the norm in real world deployments

- Shared Analytics Clusters
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2-3x variation in demands over 10s of seconds
Dynamic demands are the norm in real world deployments

- **Shared Analytics Clusters**
- **In-memory Key-Value Caches**
- **Inter-datacenter Network Links**

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

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

Analysis of real world workloads

- **CPU Demand**
- **Memory Demand**
Dynamic demands are the norm in real world deployments

- **Shared Analytics Clusters**
- **In-memory Key-Value Caches**
- **Inter-datacenter Network Links**

2-3x variation in demands over 10s of seconds
Dynamic demands are the norm in real world deployments

**Shared Analytics Clusters**
- 2-3x variation in demands over 10s of seconds

**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]
Dynamic demands are the norm in real world deployments

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

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More than 5x variation in demands within an hour
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Inter-datacenter Network Links
35% variation in demands over 5 minute intervals
[Microsoft, Abuzaid et al., NSDI’21]

Significant variation in user demands over time in real workloads
Max-min fairness under dynamic demands: loses one or more of its properties

Pareto efficiency

Strategy-proofness

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

Max-min fairness based on demands at t=0

- Pareto efficiency
- Strategy-proofness
- Fairness
Max-min fairness under dynamic demands: loses one or more of its properties

Max-min fairness based on demands at $t=0$

- Pareto efficiency
- Strategy-proofness
- Fairness

(Explained in paper)
Max-min fairness under dynamic demands: looses one or more of its properties

<table>
<thead>
<tr>
<th>Max-min fairness based on demands at ( t=0 )</th>
<th>Max-min fairness applied periodically</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pareto efficiency</td>
<td><strong>X</strong></td>
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<tr>
<td>Strategy-proofness</td>
<td><strong>X</strong></td>
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<tr>
<td>Fairness</td>
<td></td>
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</table>

(Explained in paper)
Max-min fairness under dynamic demands: loses one or more of its properties

Max-min fairness based on demands at $t=0$

- Pareto efficiency: X
- Strategy-proofness: X
- Fairness: X

Max-min fairness applied periodically
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

Demands | Resource Pool

0 1 2
Time

Max-min fairness based on demands at $t=0$ applied periodically

- Pareto efficiency
- Strategy-proofness
- Fairness

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

Running Example

Demands

Resource Pool

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

Running Example

Demands vs 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: loses 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: loses one or more of its properties

Running Example

Demands Resource Pool

Max-min fairness based on demands at t=0

Pareto efficiency

Strategy-proofness

Fairness

Max-min fairness applied periodically
Max-min fairness under dynamic demands: loses 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
Running Example

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

Max-min fairness based on demands at t=0

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Pareto efficiency

Strategy-proofness

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

Running Example

Max-min fairness based on demands at t=0 applied periodically

- Pareto efficiency
- Strategy-proofness
- Fairness
Max-min fairness under dynamic demands: Loses one or more of its properties

Running Example

Demands vs 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: loosens one or more of its properties

Running Example

Demands | Resource Pool
---|---
0 | 1 | 2 | 3 | 4 | 5
0 | 1 | 2 | 3 | 4 | 5
0 | 1 | 2 | 3 | 4 | 5

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

Max-min fairness based on demands at \( t=0 \)

Max-min fairness applied periodically

Pareto efficiency

Strategy-proofness

Fairness
Running Example

Max-min fairness under dynamic demands: loses 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
Max-min fairness under dynamic demands: loses 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

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

Running Example

Demands | Total Allocation

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: loses one or more of its properties.

**Running Example**

<table>
<thead>
<tr>
<th>Demands</th>
<th>Total Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Max-min fairness based on demands at t=0**

- Pareto efficiency: X
- Strategy-proofness: X
- Fairness

Max-min fairness applied periodically

2x Gap
Max-min fairness under dynamic demands: loses one or more of its properties

**Running Example**

<table>
<thead>
<tr>
<th>Demands</th>
<th>Total Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>[ ]</td>
</tr>
<tr>
<td>4</td>
<td>[ ]</td>
</tr>
<tr>
<td>3</td>
<td>[ ]</td>
</tr>
<tr>
<td>2</td>
<td>[ ]</td>
</tr>
<tr>
<td>1</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

**Time**

For n users, a user can get $\Omega(n)$ more allocation than others

Max-min fairness based on demands at $t=0$ applied periodically

- Pareto efficiency
- Strategy-proofness
- Fairness

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

Running Example

For $n$ users, a user can get $\Omega(n)$ more allocation than others
Max-min fairness under dynamic demands: loses one or more of its properties

For n users, a user can get $\Omega(n)$ more allocation than others
Max-min fairness under dynamic demands: loses one or more of its properties

For n users, a user can get \( \Omega(n) \) 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

New resource allocation algorithm for dynamic demands

Theoretical guarantees

- Pareto efficiency
- Strategy-proofness
- Fairness
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: 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 key idea #1: *donated slices* and *shared slices*
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Karma key idea #1: donated slices and shared slices
Karma key idea #2: “credits” for resource allocation
Karma key idea #2: “credits” for resource allocation

-1 credit for borrowing a slice
Karma key idea #2: “credits” for resource allocation

-1 credit for *borrowing* a slice

+1 credit if a *donated* slice is borrowed
Karma key idea #2: “credits” for resource allocation

-1 credit for **borrowing** a slice

+1 credit if a **donated** slice is borrowed

(Every user is given initial credits at t=0)
Karma key idea #2: “credits” for resource allocation

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(Every user is given initial credits at t=0)
Karma allocation algorithm
Karma allocation algorithm

Pick borrower with maximum credits
Karma allocation algorithm

- Pick **borrower** with **maximum** credits
- Pick **donor** with **minimum** credits
Karma allocation algorithm

Pick **borrower** with **maximum** credits

Pick **donor** with **minimum** credits
    If no donors, then use a shared slice
Karma allocation algorithm

- Pick **borrower** with **maximum** credits
- Pick **donor** with **minimum** credits
  - If no donors, then use a shared slice

  Allocate slice to borrower
Karma allocation algorithm

- Pick **borrower** with **maximum** credits
- Pick **donor** with **minimum** credits
  - If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor
Karma allocation algorithm

Pick **borrower** with *maximum* credits

Pick **donor** with *minimum* credits
   If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Credits

<table>
<thead>
<tr>
<th>Credits</th>
<th>Donated Slices</th>
<th>Shared Slices</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Demands

<table>
<thead>
<tr>
<th>Time</th>
<th>Demands</th>
<th>Donated Slices</th>
<th>Shared Slices</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>3</td>
<td></td>
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</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pick **borrower** with **maximum** credits

Pick **donor** with **minimum** credits

If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick **borrower** with **maximum** credits

Pick **donor** with **minimum** credits
If no donors, then use a shared slice

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(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick borrower with maximum credits
Pick donor with minimum credits
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Running Example

Karma allocation algorithm

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Karma allocation algorithm

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- (Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

- Pick borrower with maximum credits
- Pick donor with minimum credits
  If no donors, then use a shared slice
  Allocate slice to borrower
  -1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

### Running Example

- **Credits**
  - Borrower with maximum credits
  - Donor with minimum credits

- **Demands**

- **Donated Slices**

- **Shared Slices**

- **Time**

- **Donated Slices**

- **Shared Slices**

- **Karma allocation algorithm**
  - Pick **borrower** with **maximum** credits
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Karma allocation algorithm

Running Example

Pick borrower with maximum credits
Pick donor with minimum credits
If no donors, then use a shared slice
Allocate slice to borrower
-1 credit for borrower, +1 credit for donor
(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick **borrower** with *maximum* credits

Pick **donor** with *minimum* credits

If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

1. Pick borrower with maximum credits
2. Pick donor with minimum credits
   - If no donors, then use a shared slice
   - Allocate slice to borrower
   - -1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

- If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

- Pick **borrower** with *maximum* credits
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  - If no donors, then use a shared slice
  - Allocate slice to borrower
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  - (Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick **borrower** with **maximum** credits

Pick **donor** with **minimum** credits

If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick borrower with **maximum** credits

Pick donor with **minimum** credits

If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Running Example

**Karma allocation algorithm**

- Pick *borrower* with **maximum** credits
- Pick *donor* with **minimum** credits
- If no donors, then use a shared slice
- Allocate slice to borrower
- -1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick borrower with maximum credits
Pick donor with minimum credits
If no donors, then use a shared slice
Allocate slice to borrower
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Karma allocation algorithm

Running Example

- Pick borrower with **maximum** credits
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  If no donors, then use a shared slice
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Karma allocation algorithm

Running Example

Pick borrower with maximum credits

Pick donor with minimum credits
If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor
(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick **borrower** with *maximum* credits

Pick **donor** with *minimum* credits

If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

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(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

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(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick borrower with maximum credits
Pick donor with minimum credits
If no donors, then use a shared slice
Allocate slice to borrower
-1 credit for borrower, +1 credit for donor
(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick borrower with maximum credits

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Karma allocation algorithm

Running Example

- **Pick borrower** with maximum credits
- **Pick donor** with minimum credits
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Karma allocation algorithm

**Running Example**

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Karma allocation algorithm

Running Example

Pick borrower with maximum credits
Pick donor with minimum credits
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Karma allocation algorithm

Running Example

Pick borrower with maximum credits

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Karma allocation algorithm

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(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

- Pick borrower with maximum credits
- Pick donor with minimum credits
  - If no donors, then use a shared slice
  - Allocate slice to borrower
  - -1 credit for borrower, +1 credit for donor
  - (Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

1. Pick borrower with **maximum** credits
2. Pick donor with **minimum** credits
3. If no donors, then use a shared slice
4. Allocate slice to borrower
5. -1 credit for borrower, +1 credit for donor
6. (Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

Pick **borrower** with **maximum** credits

Pick **donor** with **minimum** credits

If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

Running Example

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Pick **borrower** with **maximum** credits

Pick **donor** with **minimum** credits

If no donors, then use a shared slice

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-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma allocation algorithm

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<th>Credits</th>
<th>Demands</th>
<th>Total Allocation</th>
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Karma allocation algorithm

Running Example

Credits | Demands | Total Allocation

Equal total allocations!
Karma parameterizes the trade-off between instantaneous and long-term fairness.
Karma parameterizes the trade-off between instantaneous and long-term fairness.
Karma parameterizes the trade-off between instantaneous and long-term fairness.
Karma parameterizes the trade-off between instantaneous and long-term fairness.

\[(\text{See paper for more details})\]
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

Karma Allocation Algorithm

Pick **borrower** with **maximum** credits

Pick **donor** with **minimum** credits
If no donors, then use a shared slice

Allocate slice to borrower

-1 credit for borrower, +1 credit for donor

(Repeat until demands satisfied or resources exhausted)
Karma is Pareto efficient

Pareto efficiency
Resources should not remain unused when there is demand

Karma Allocation Algorithm

- Pick borrower with maximum credits
- Pick donor with minimum credits
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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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![Diagram showing strategy-proofness](image)

- Perfect knowledge of
- future demands of all users

Not possible to increase allocation
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**Strategy-proofness**
Selfish users cannot increase their allocation by lying
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Not possible to increase allocation

Perfect knowledge of future demands of all users

No more than 1.5x increase in allocation
Karma provides powerful strategy-proofness properties

**Strategy-proofness**
Selfish users cannot increase their allocation by lying  
(selfish ≠ adversarial)

- **Not possible to increase allocation**
- **Perfect knowledge of**
  - **future demands of all users**
- **No more than 1.5x increase in allocation**

Far from realistic
Karma provides powerful strategy-proofness properties

**Strategy-proofness**
Selfish users cannot increase their allocation by lying
(selfish ≠ adversarial)

- Not possible to increase allocation

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

- No more than 1.5x increase in allocation

Any imprecision in knowledge of future demands of any user
Karma provides powerful strategy-proofness properties

**Strategy-proofness**
Selfish users cannot increase their allocation by lying
(selfish ≠ adversarial)

![Illustration of strategy-proofness](image)

- **Perfect knowledge of future demands of all users**
  - Not possible to increase allocation
  - No more than 1.5x increase in allocation

- **Any imprecision in knowledge of future demands of any user**
  - As much as \( \Omega(n) \) factor decrease in allocation
Karma maximizes the minimum total allocation (given past allocations)

**Fairness**
Balanced resource allocations across users
Karma maximizes the minimum total allocation (given past allocations)

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**Fairness**
Balanced resource allocations across users

![Diagram showing fixed past allocations and total allocation (from 0 to t-1) for three users over time.](image-url)
Karma maximizes the minimum total allocation (given past allocations)

Fairness
Balanced resource allocations across users

Fixed past allocations

Total Allocation (from 0 to t-1)

Credits
Karma: Resource Allocation for Dynamic Demands

New credit-based resource allocation algorithm

Strong theoretical guarantees

Prototype implementation and evaluation
Karma implementation & evaluation
Karma implementation & evaluation

Implemented in distributed elastic memory system (Jiffy [Eurosys’22])
Karma implementation & evaluation

Implemented in distributed elastic memory system (Jiffy [Eurosys’22])
 Evaluated in-memory key-value cache scenario
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Experimental Setup

EC2 VMs

S3 (Persistent Storage)
Karma implementation & evaluation

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Dynamic demands -> vary working set size
Demands taken from Snowflake dataset
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Evaluated in-memory key-value cache scenario

Experimental Setup

Workload

Dynamic demands -> vary working set size
Demands taken from Snowflake dataset

(See paper for details)
Glimpse of Karma evaluation results
Glimpse of Karma evaluation results

- Max-min fairness (Periodic)
- Karma

Throughput (kops/sec)

% of users with throughput ≤ x

56% of users with throughput ≤ x
Glimpse of Karma evaluation results

Max-min fairness (Periodic)
Karma

Throughput (kops/sec)

% of users with throughput ≤ x
Glimpse of Karma evaluation results

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Max-min fairness (Periodic)
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Glimpse of Karma evaluation results

- Max-min fairness (Periodic)
- Karma

Throughput (kops/sec)

System-wide throughput (million ops/sec)
Glimpse of Karma evaluation results

Karma minimizes disparity across users (while maintaining high average performance)
Glimpse of Karma evaluation results

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

(See paper for more detailed evaluation results)
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Prototype implementation and evaluation

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

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

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