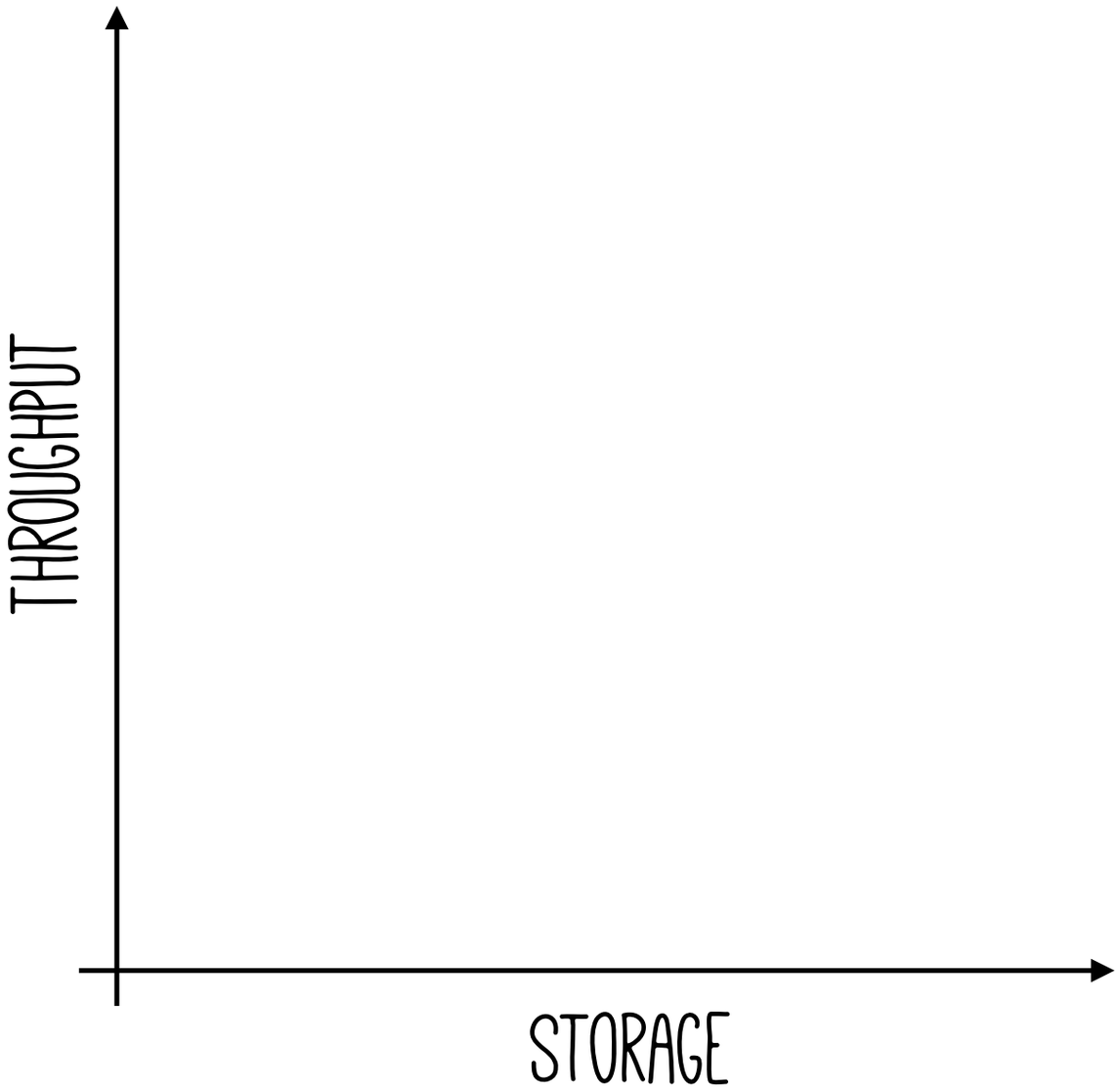
BlowFish:
Dynamic Storage-Performance Tradeoff in Data Stores

Anurag Khandelwal, Rachit Agarwal, Ion Stoica


Existing Data Stores

Existing Data Stores



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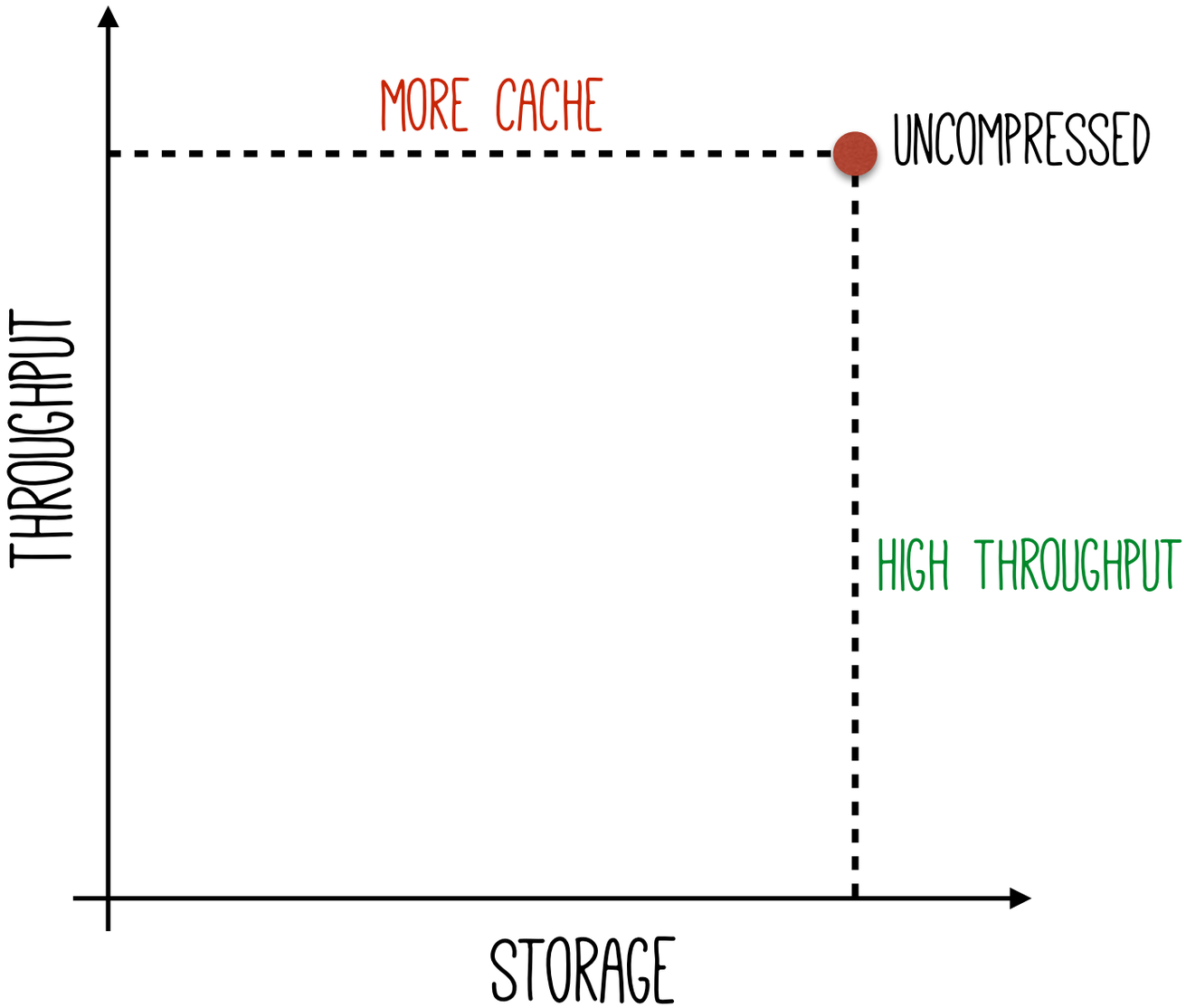

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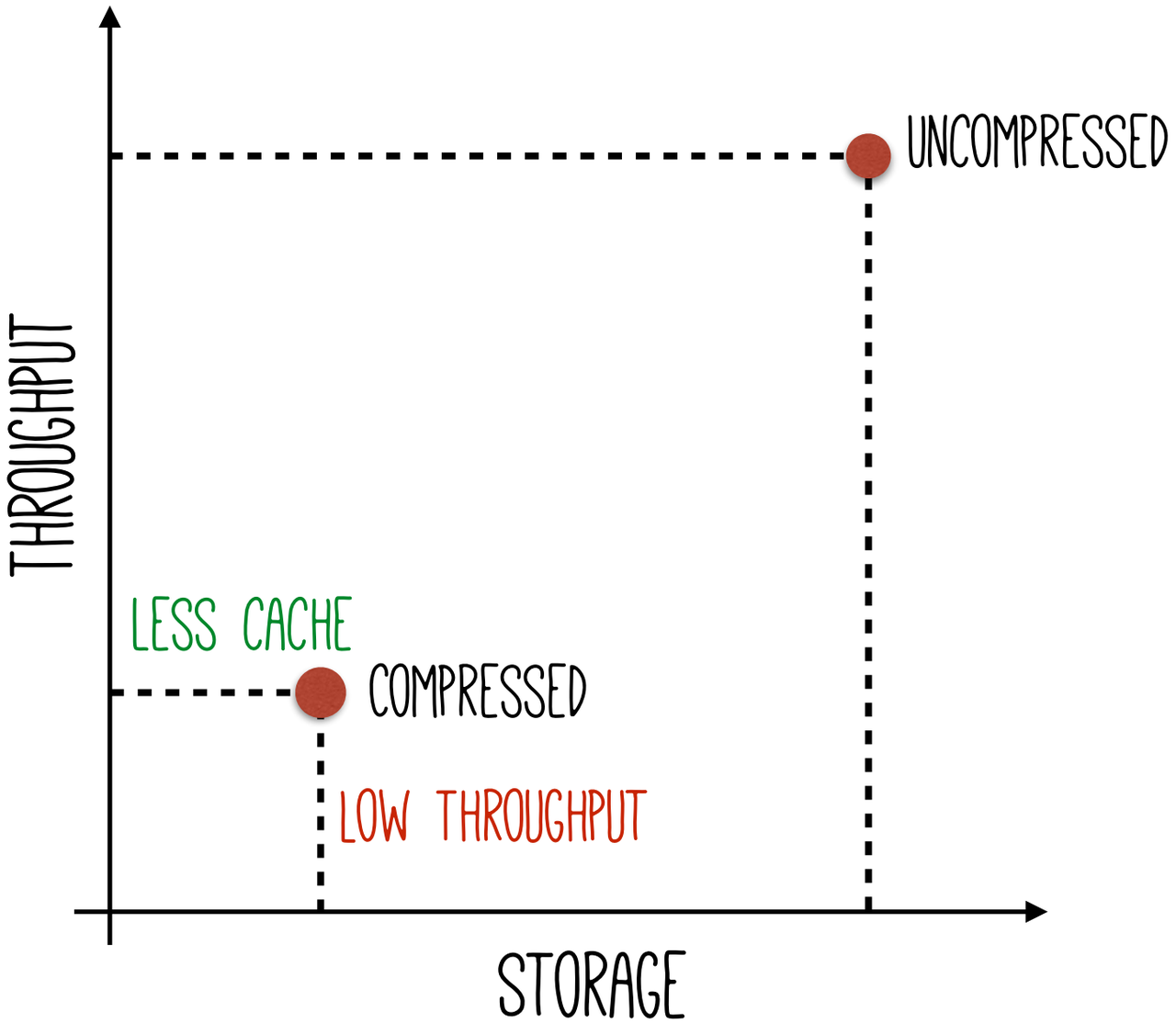

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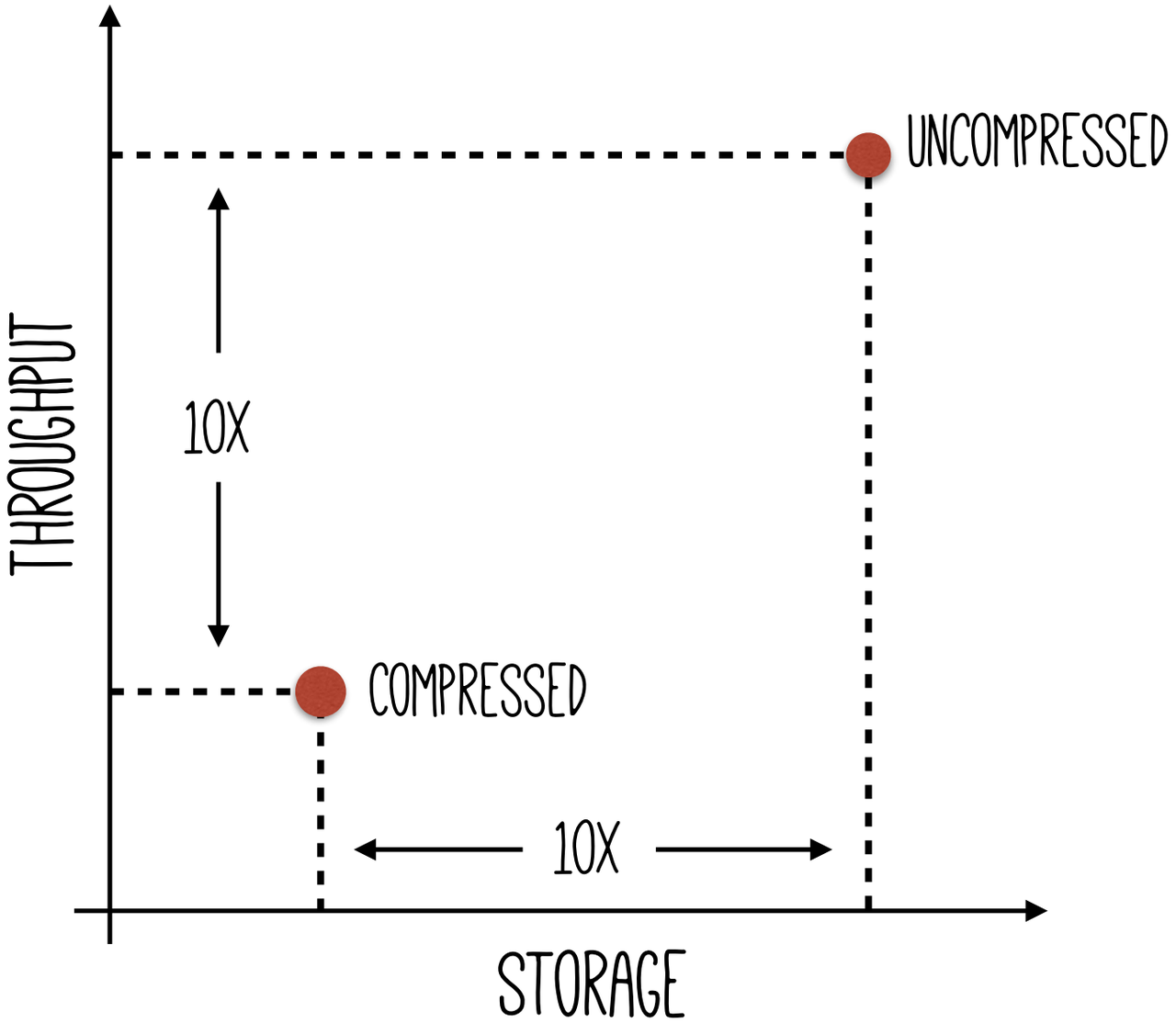

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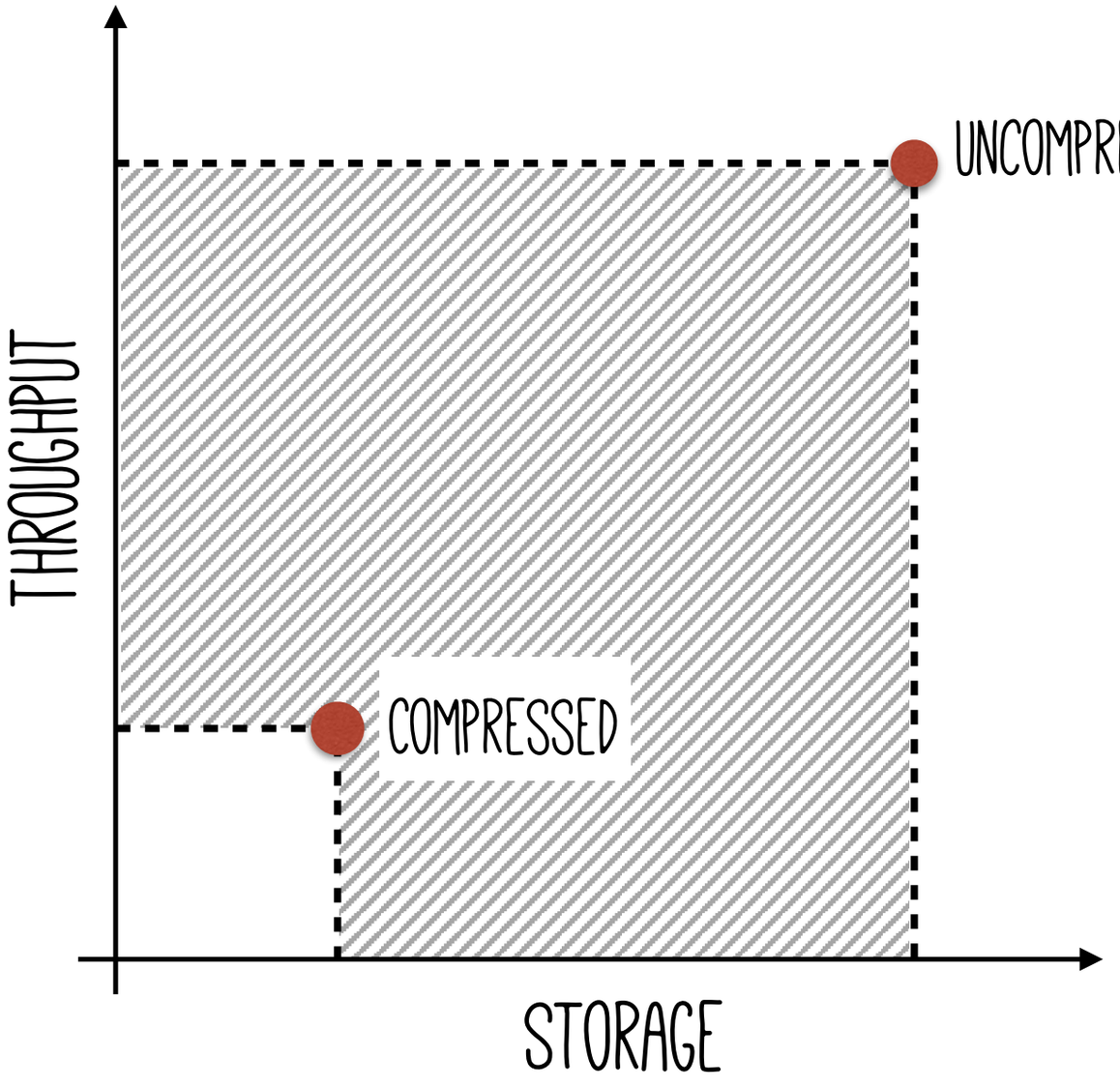
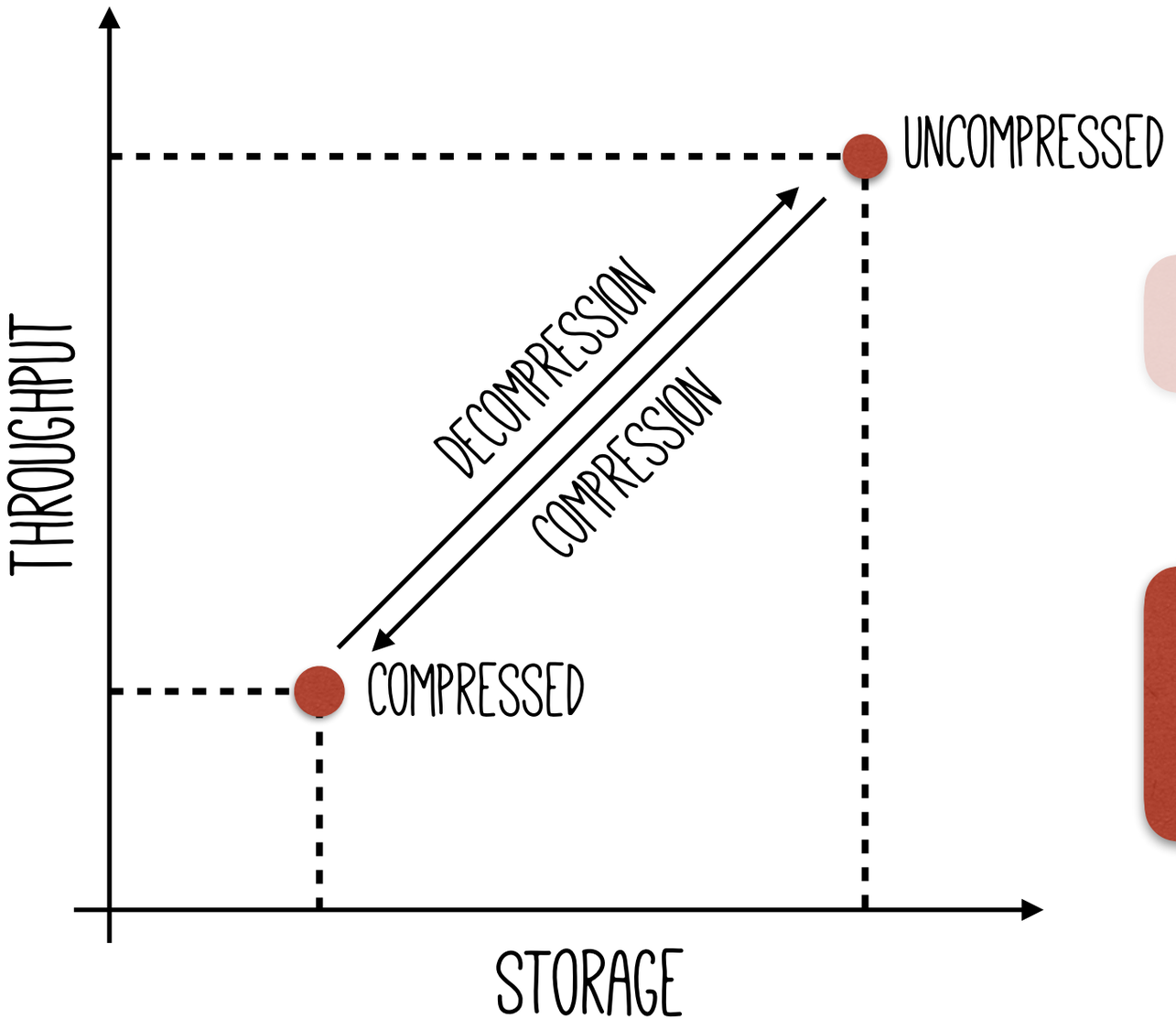


Unachievable points

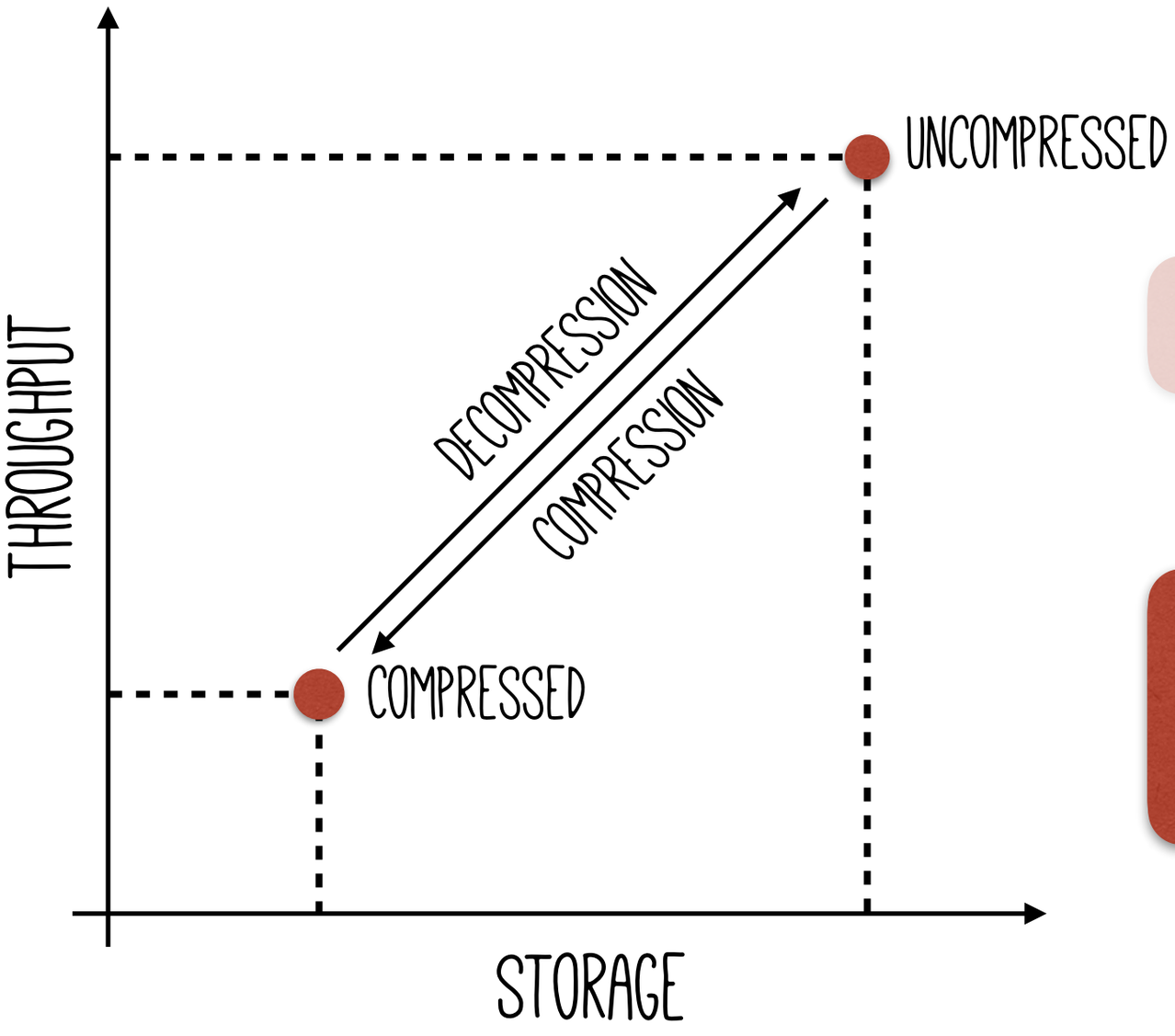
Existing Data Stores



Unachievable points

Switching between the two
incurs high latency & CPU

Existing Data Stores



Unachievable points

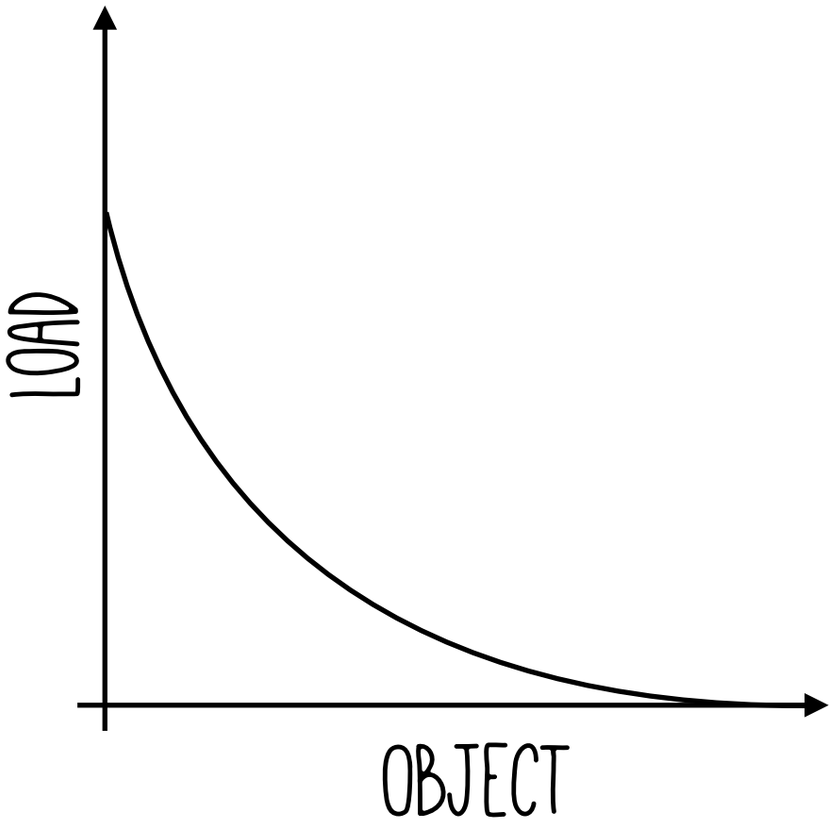
Switching between the two incurs high latency & CPU

Leads to degraded performance when underlying workload or infrastructure changes

A Motivating Example

A Motivating Example

Load across items heavily skewed



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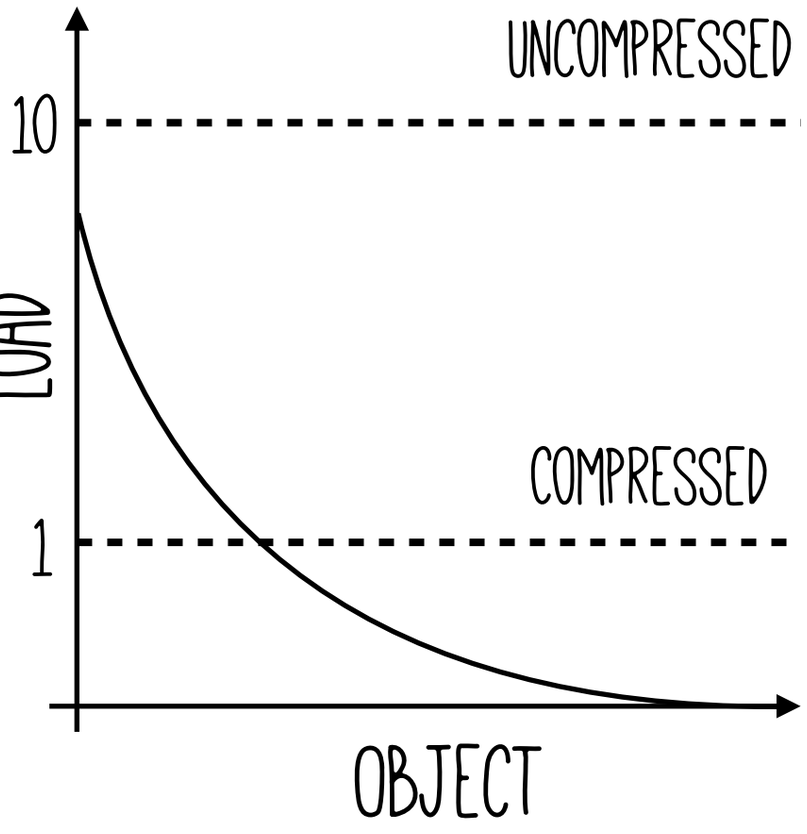

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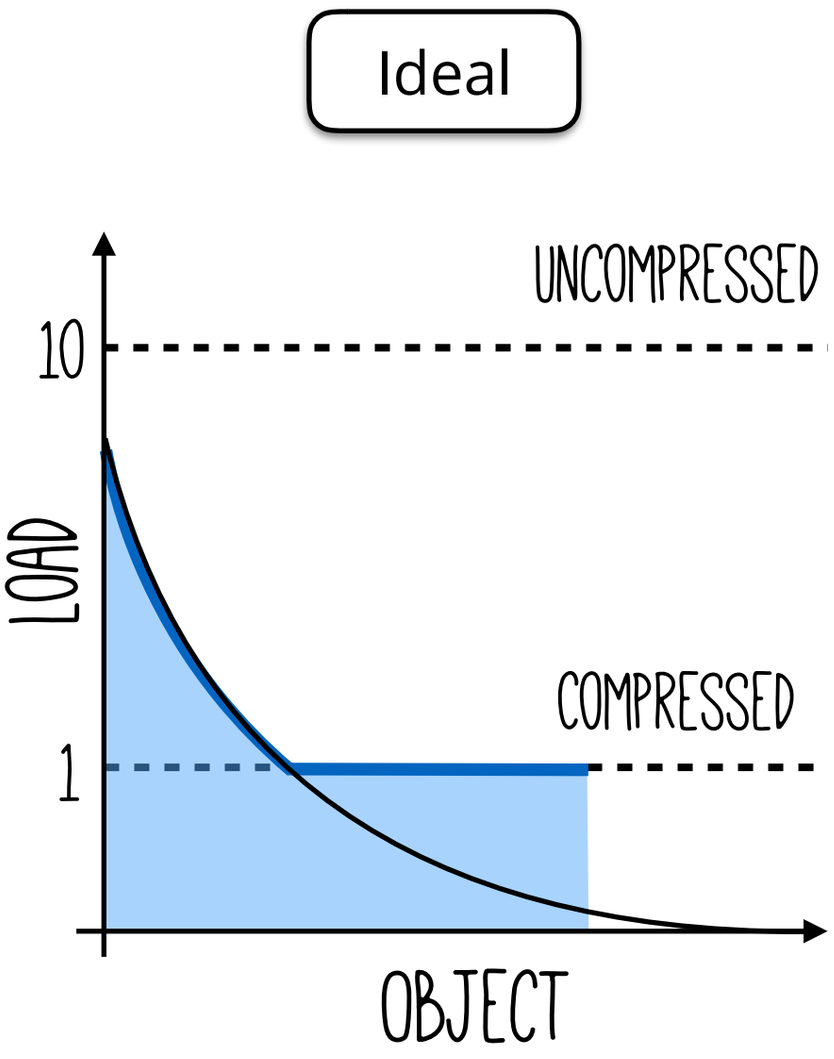

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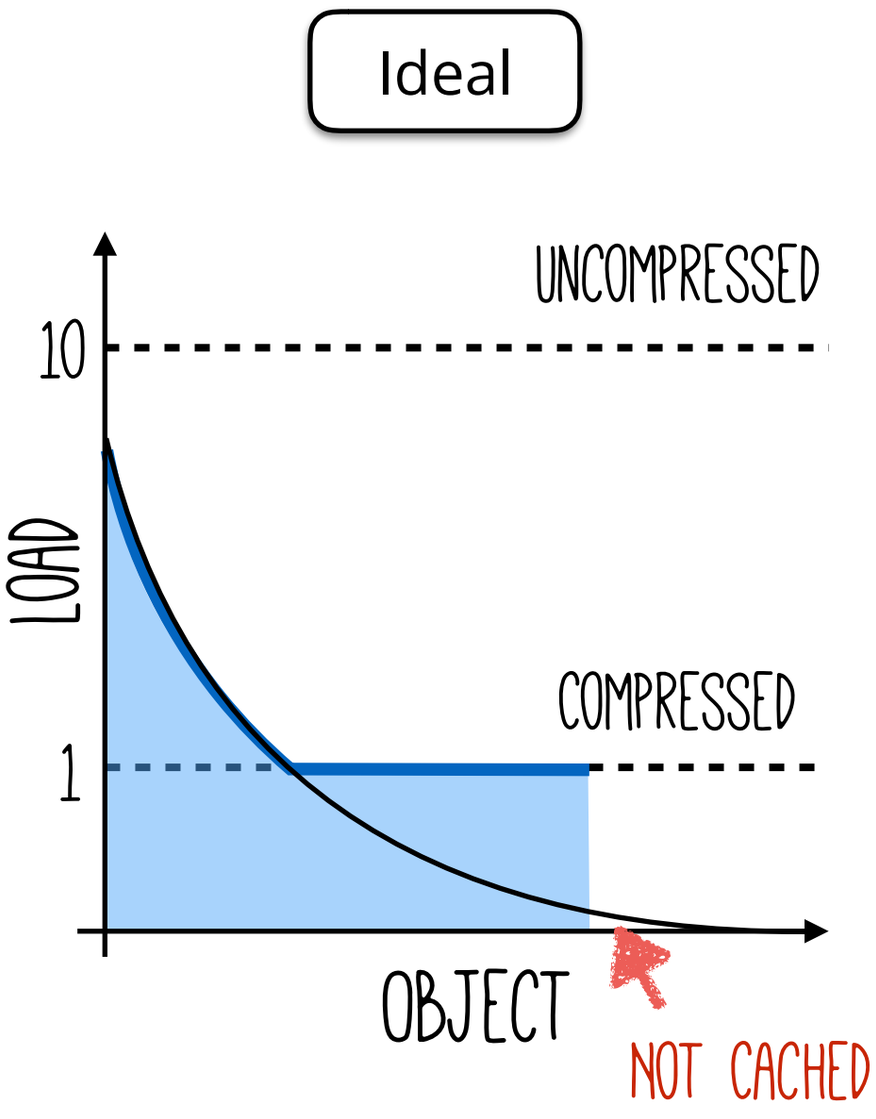
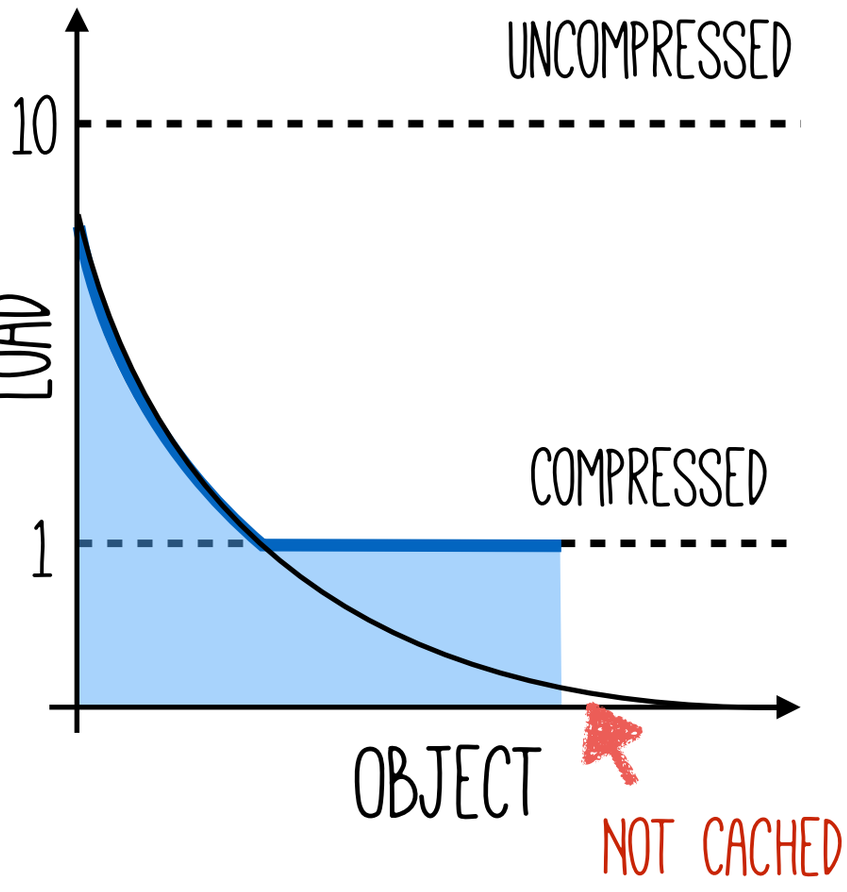


A Motivating Example

Load across items heavily skewed

Ideal

Compressed + Uncompressed



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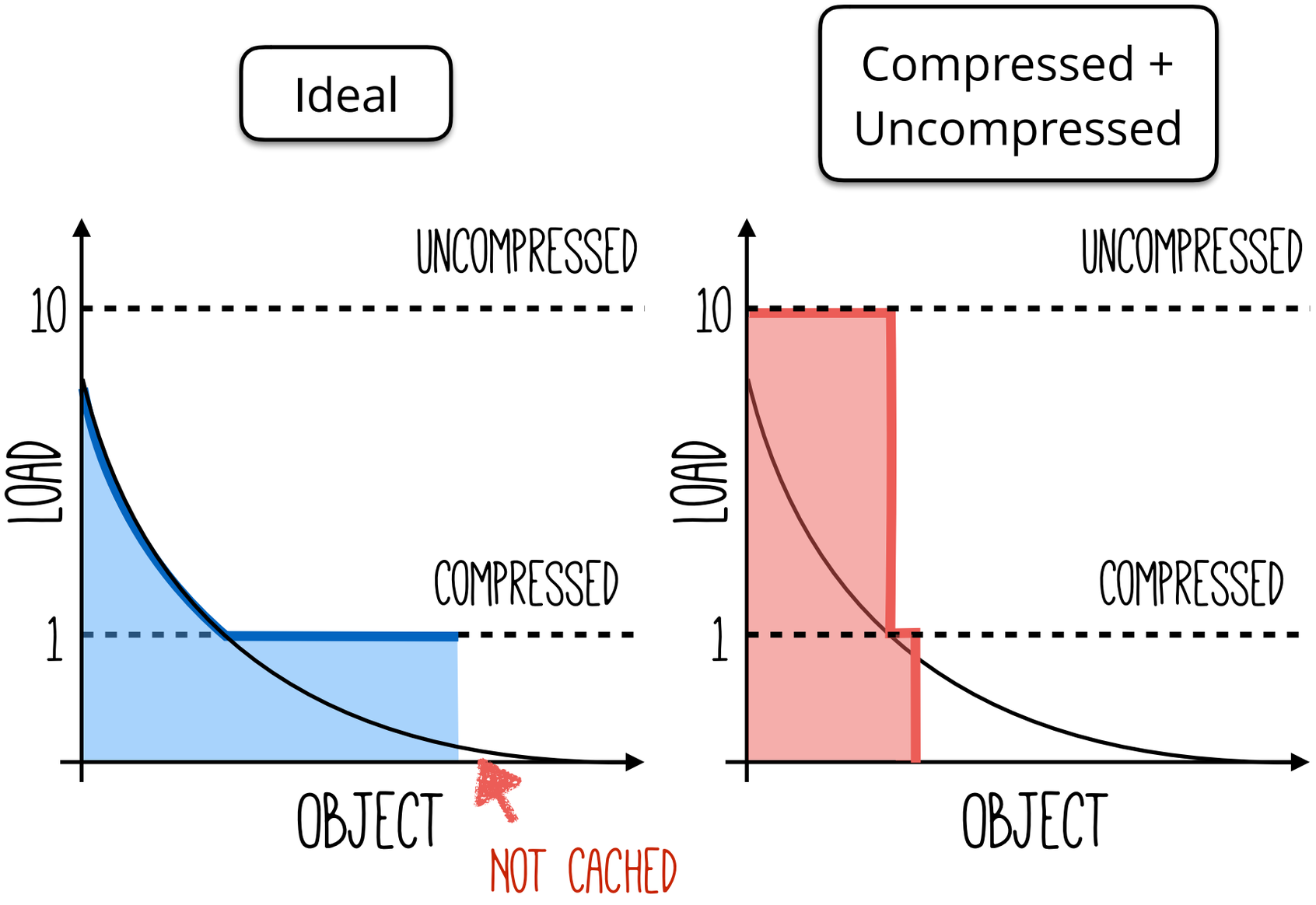

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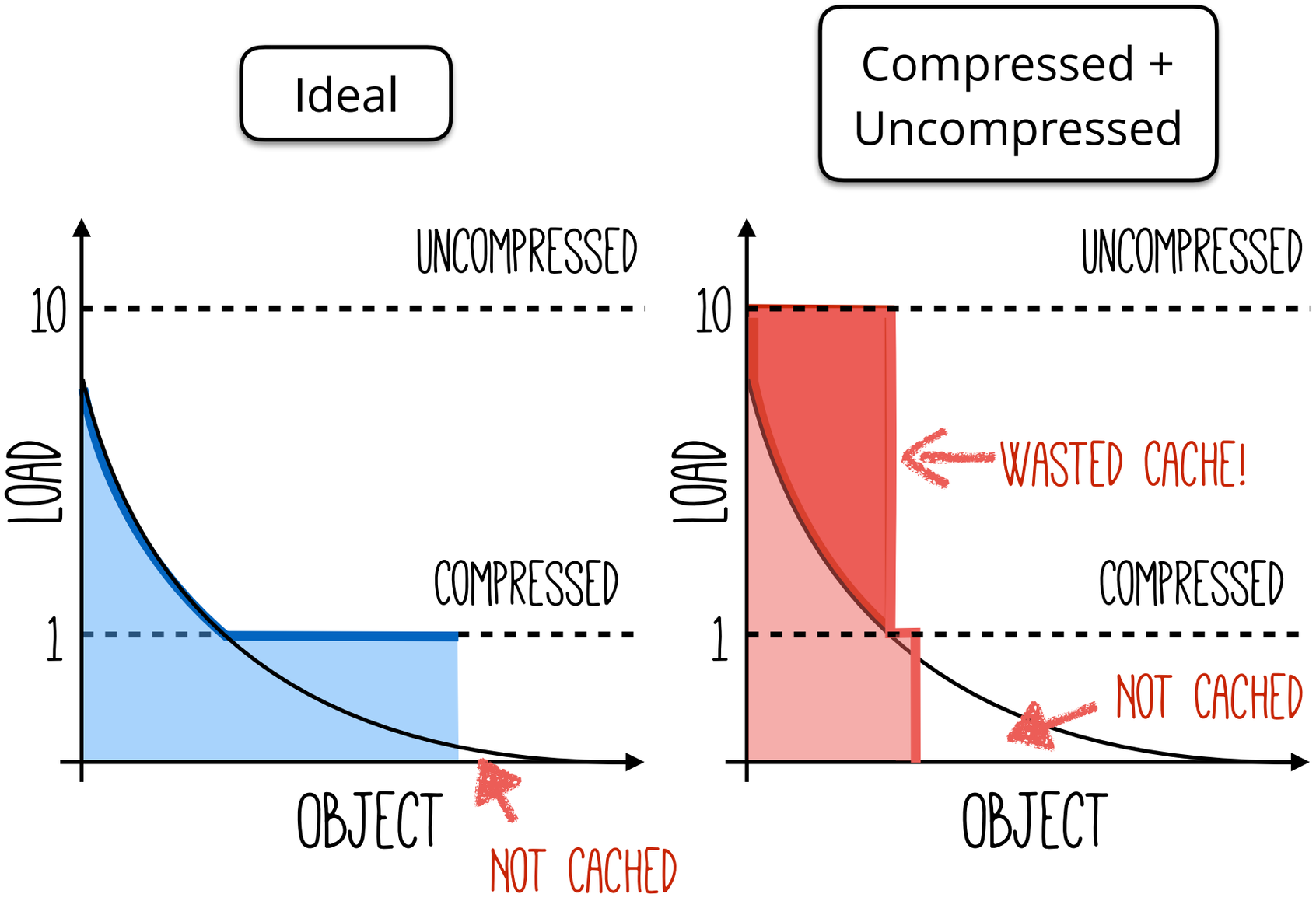

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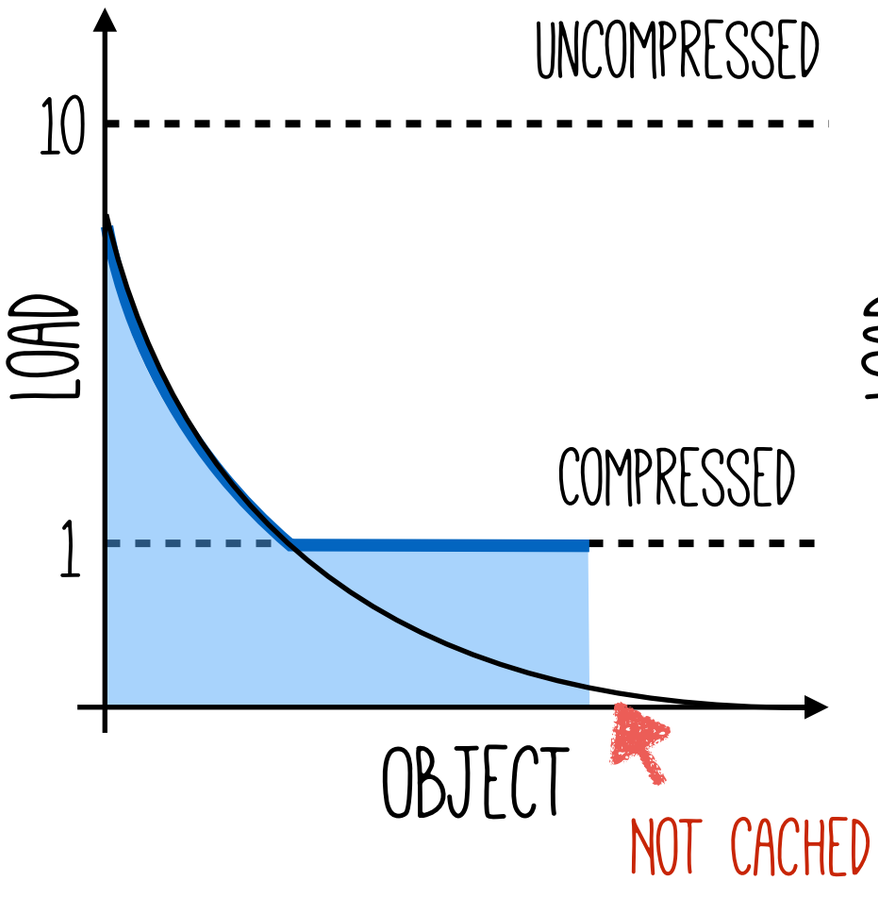

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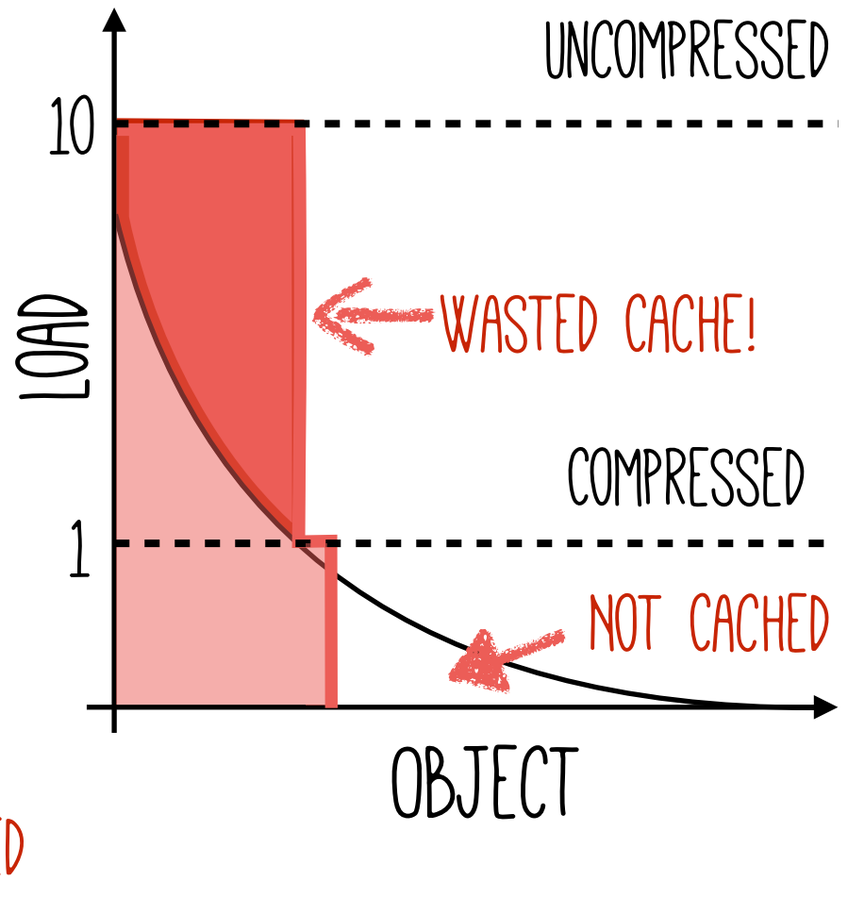

Selective Replication: #Replicas α Load

A Motivating Example

Load across items heavily skewed

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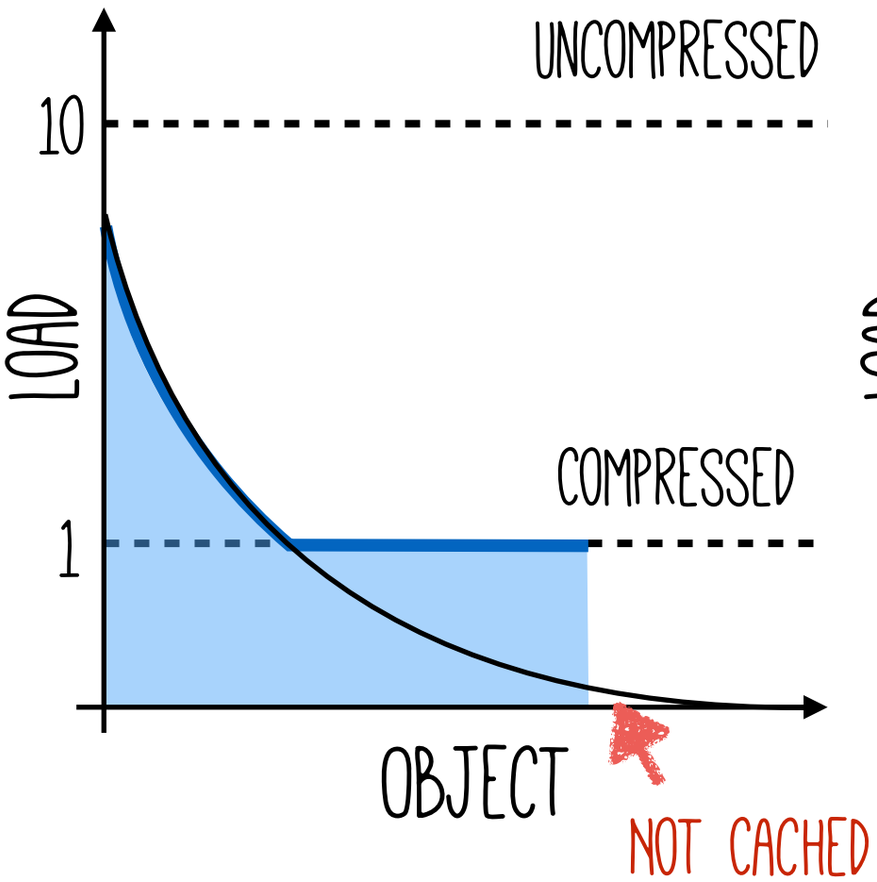

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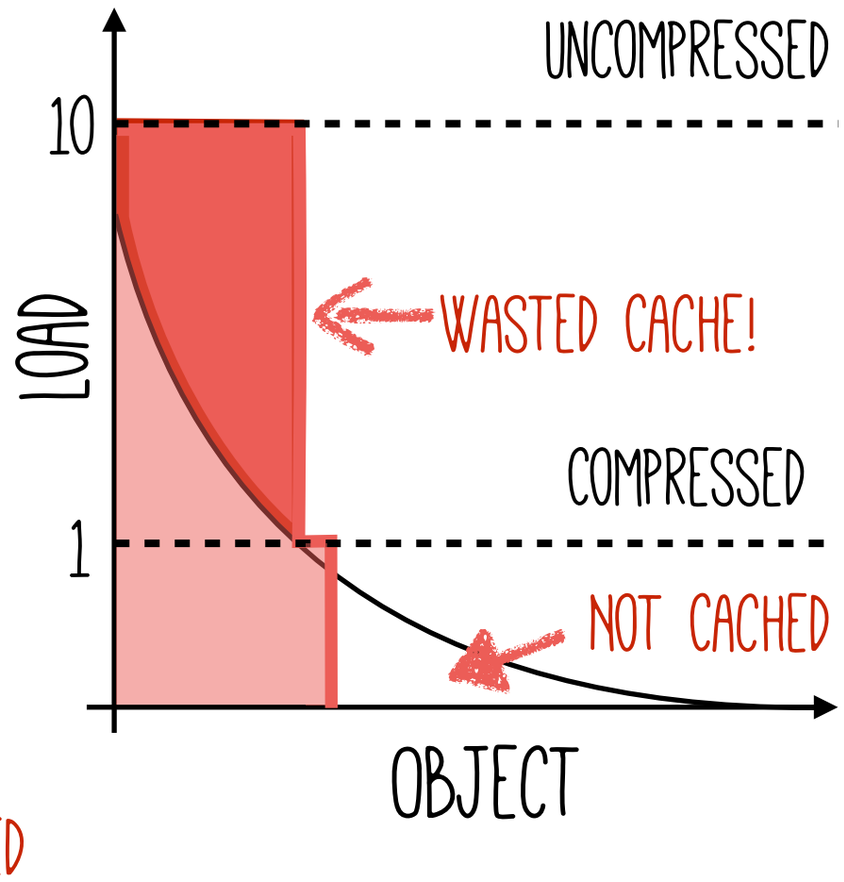

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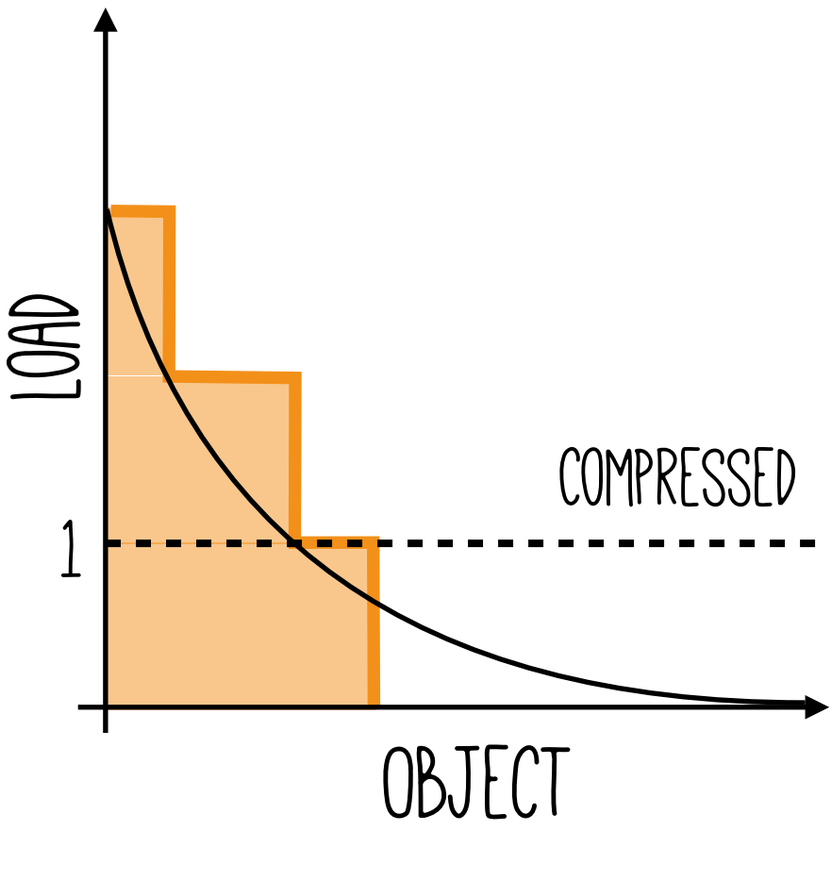

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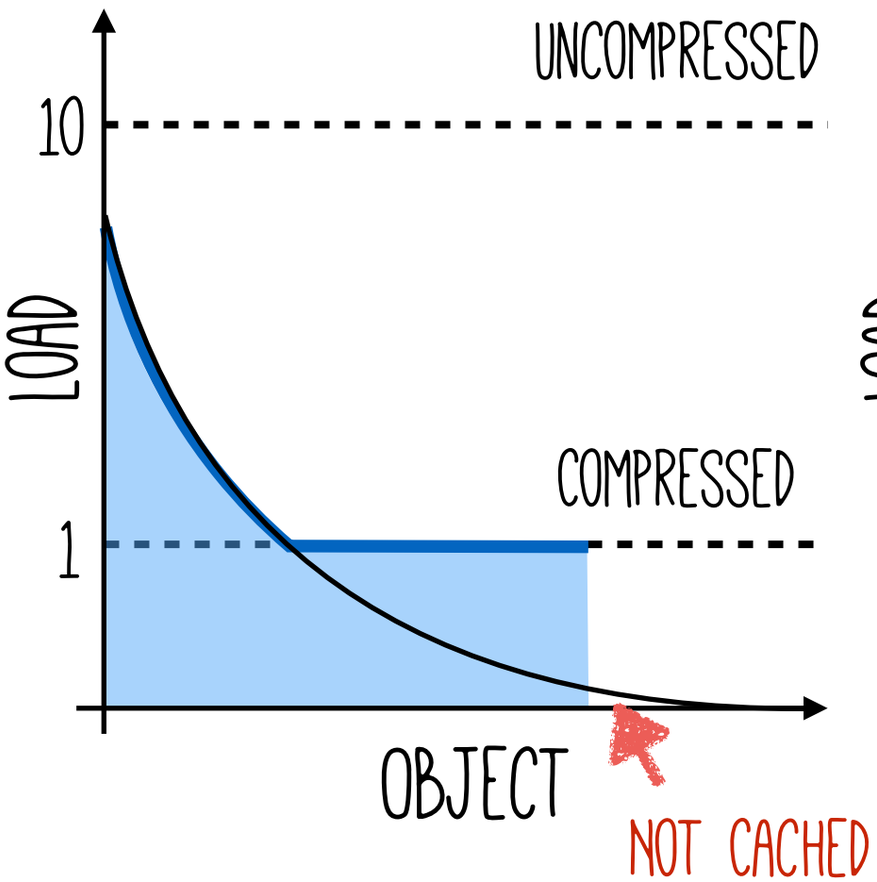

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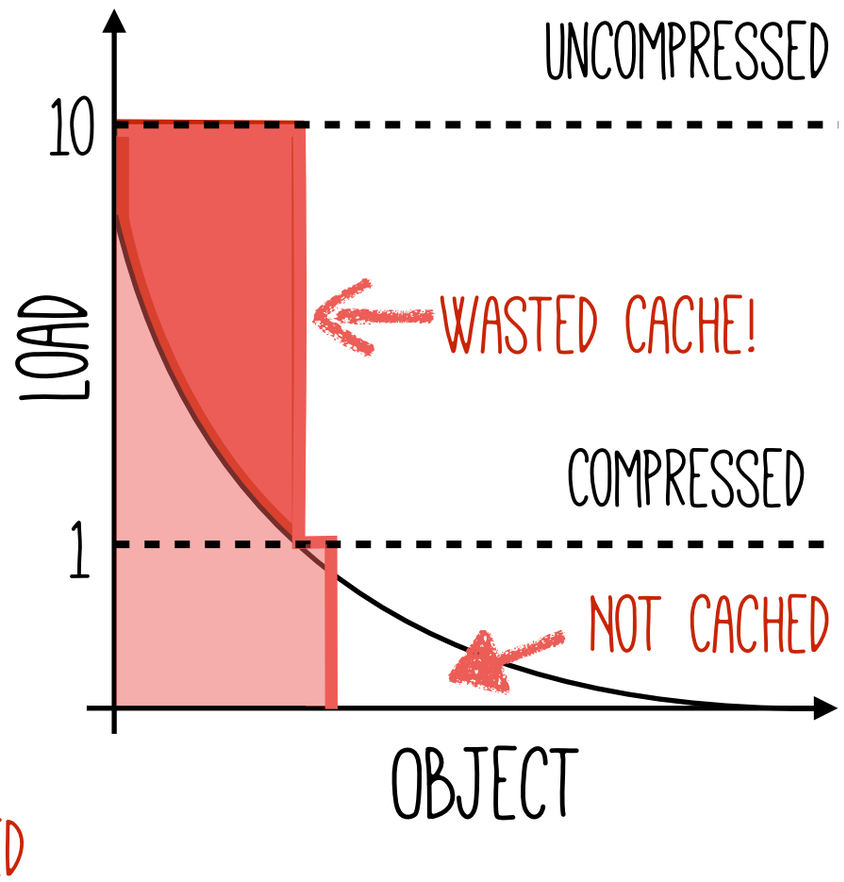

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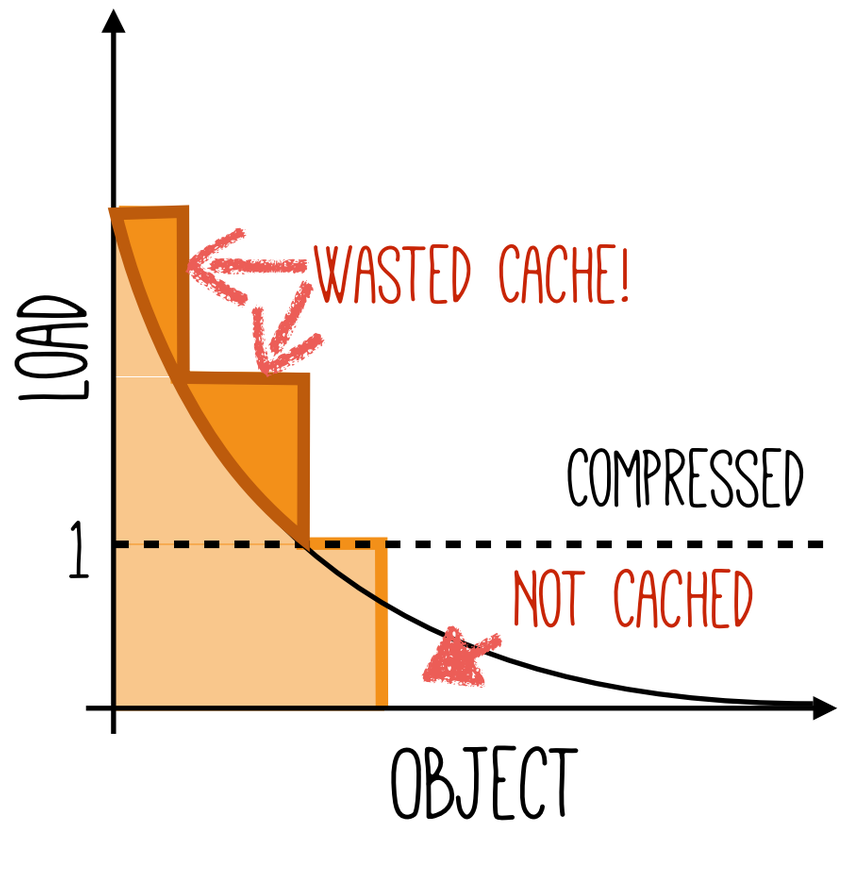

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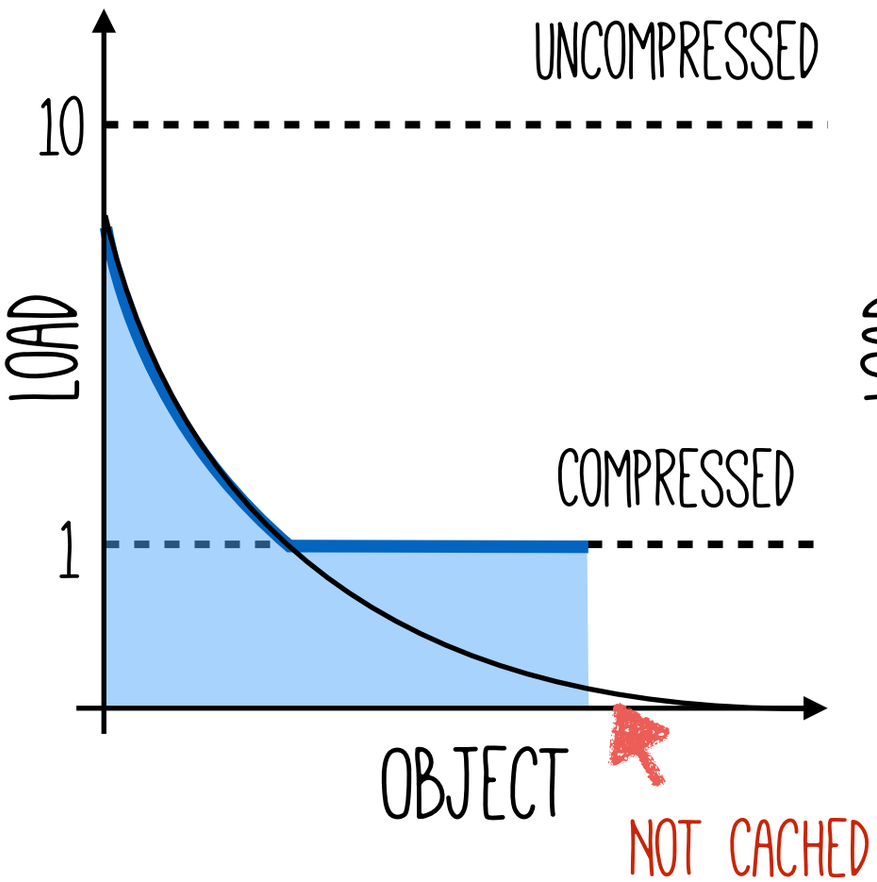

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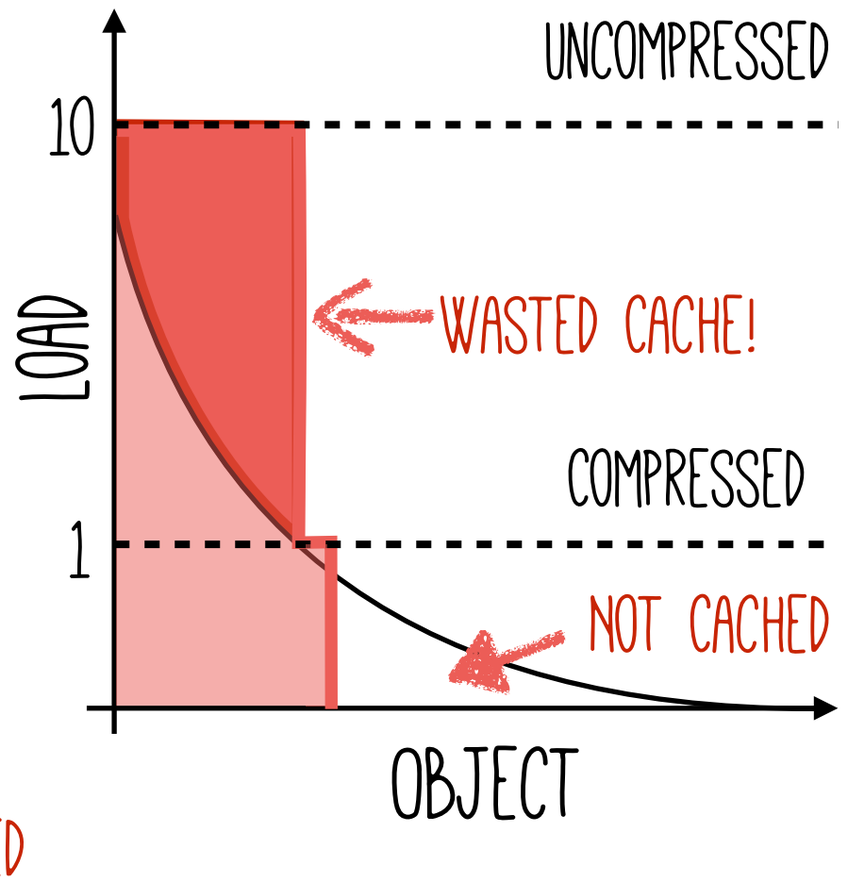

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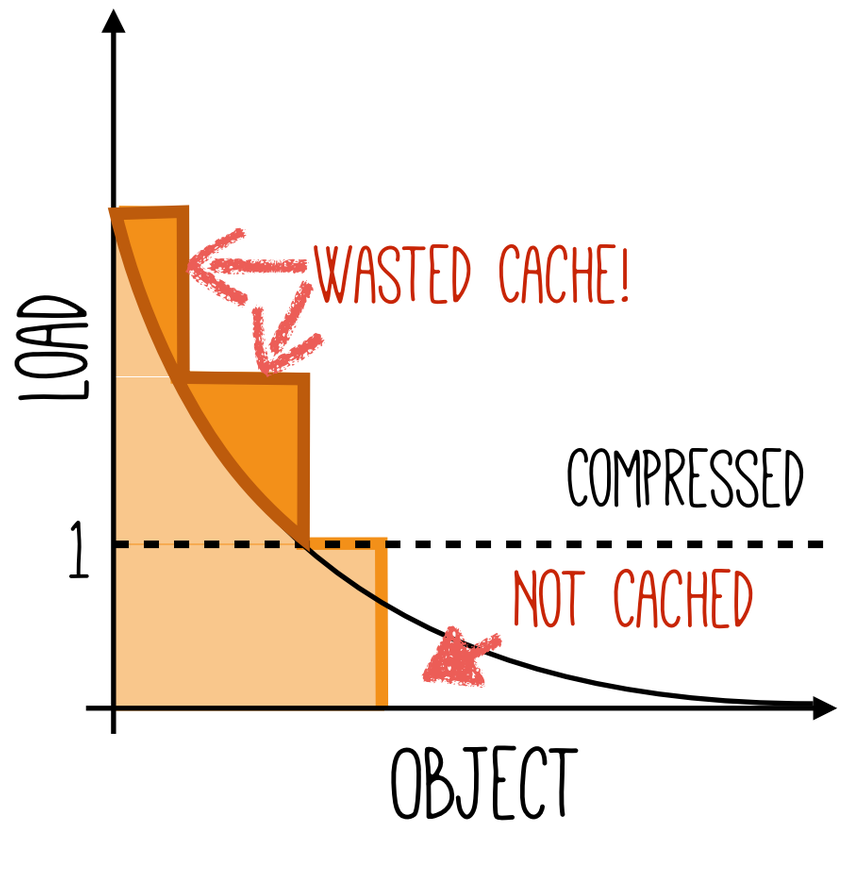
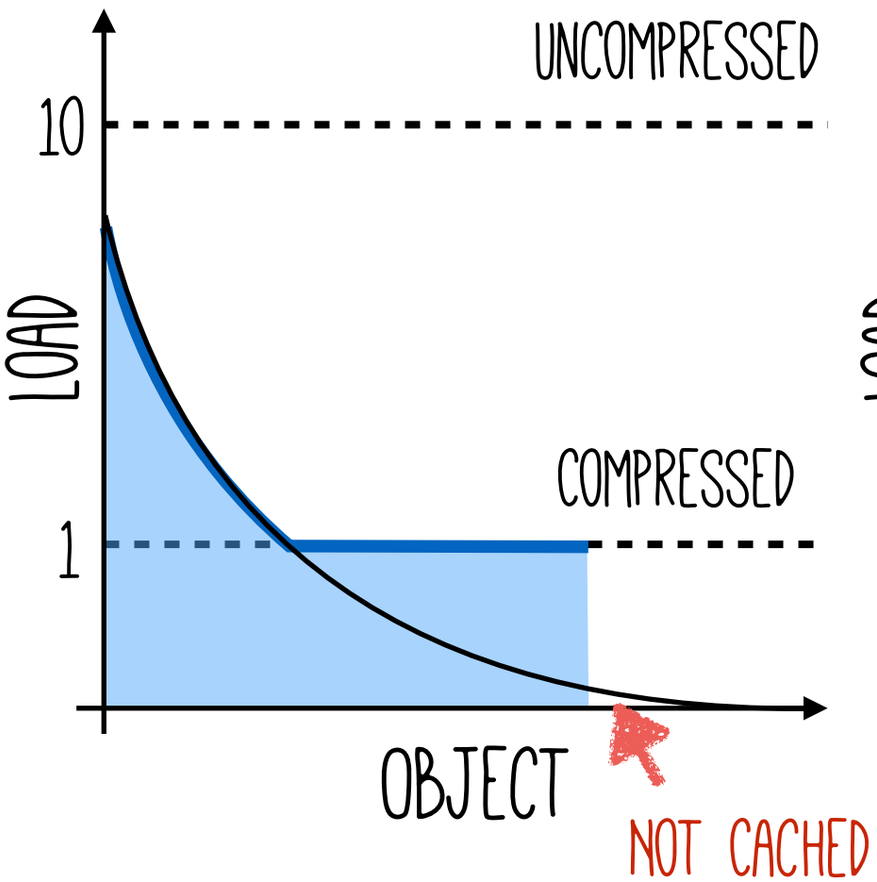


Load changes over time

A Motivating Example

Load across items heavily skewed

Ideal



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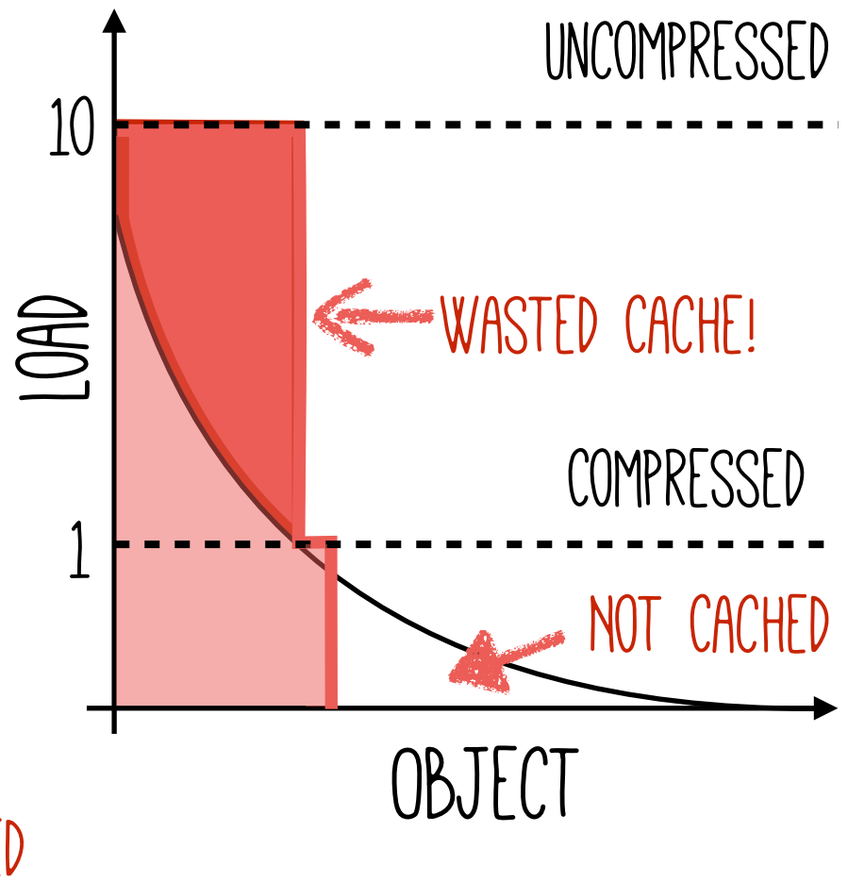

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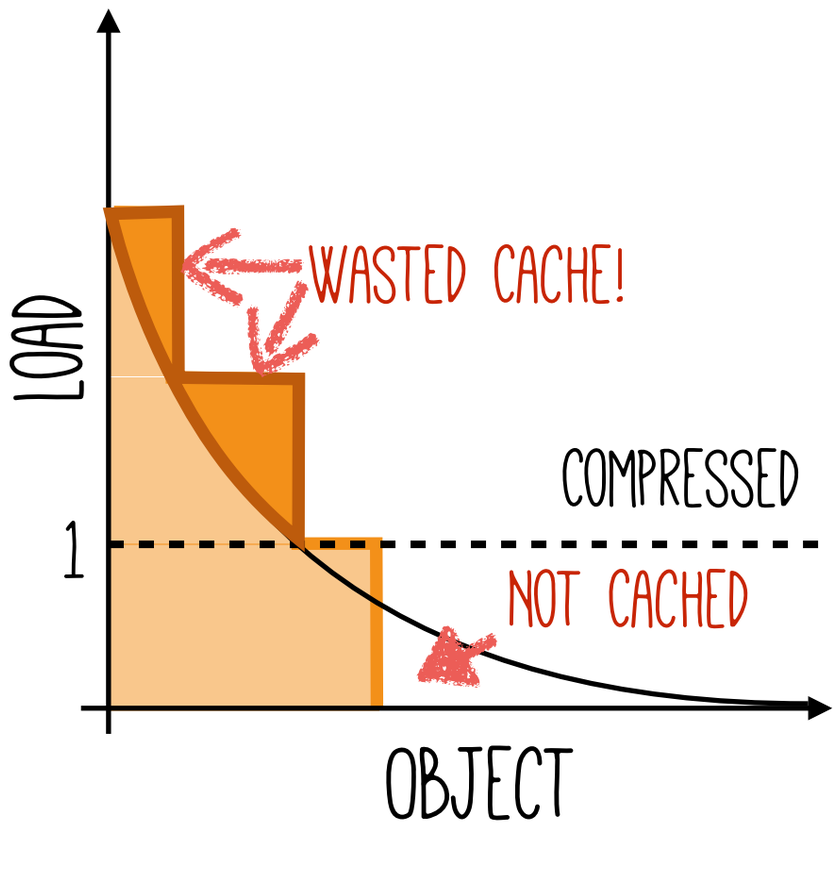
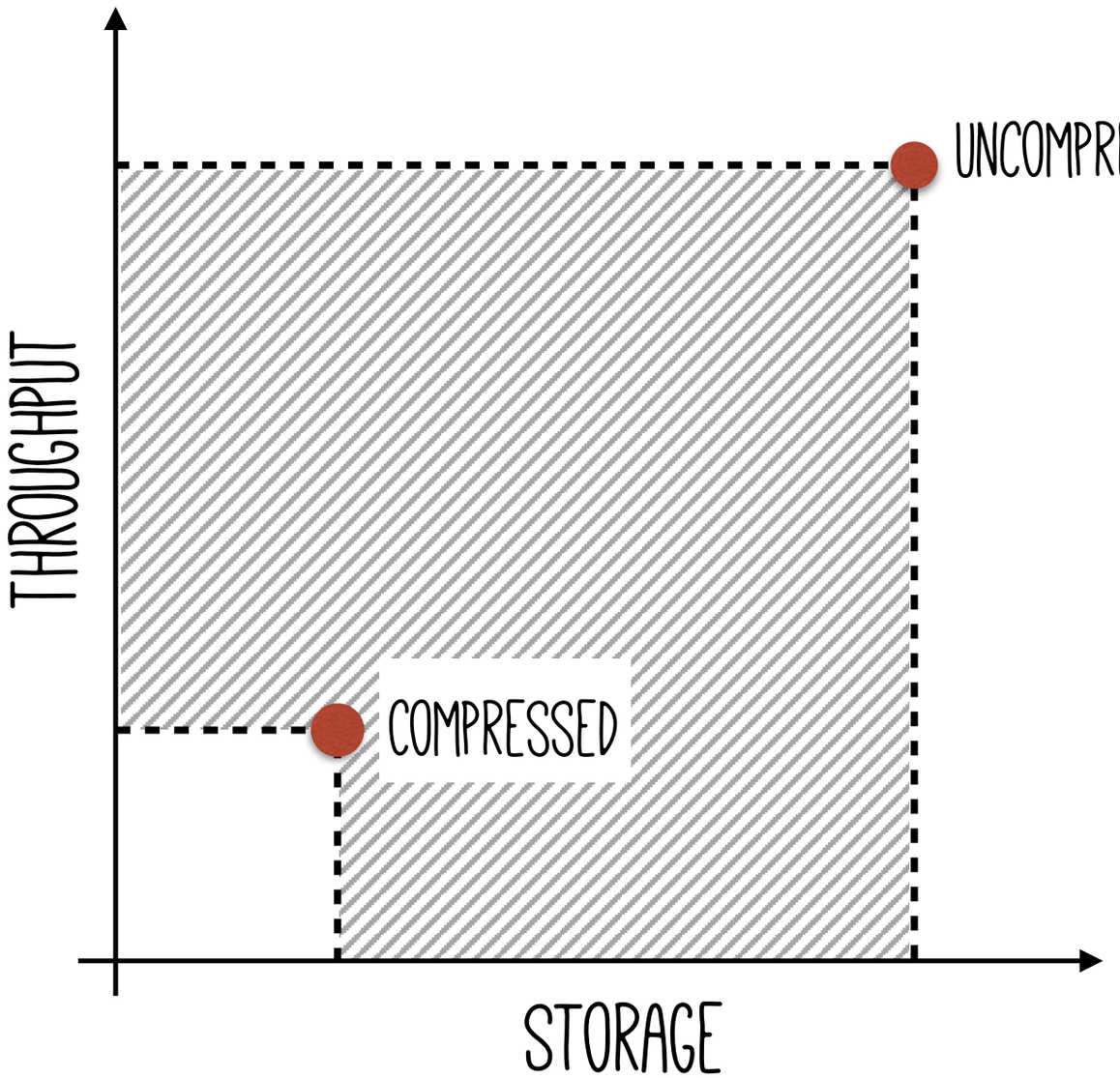
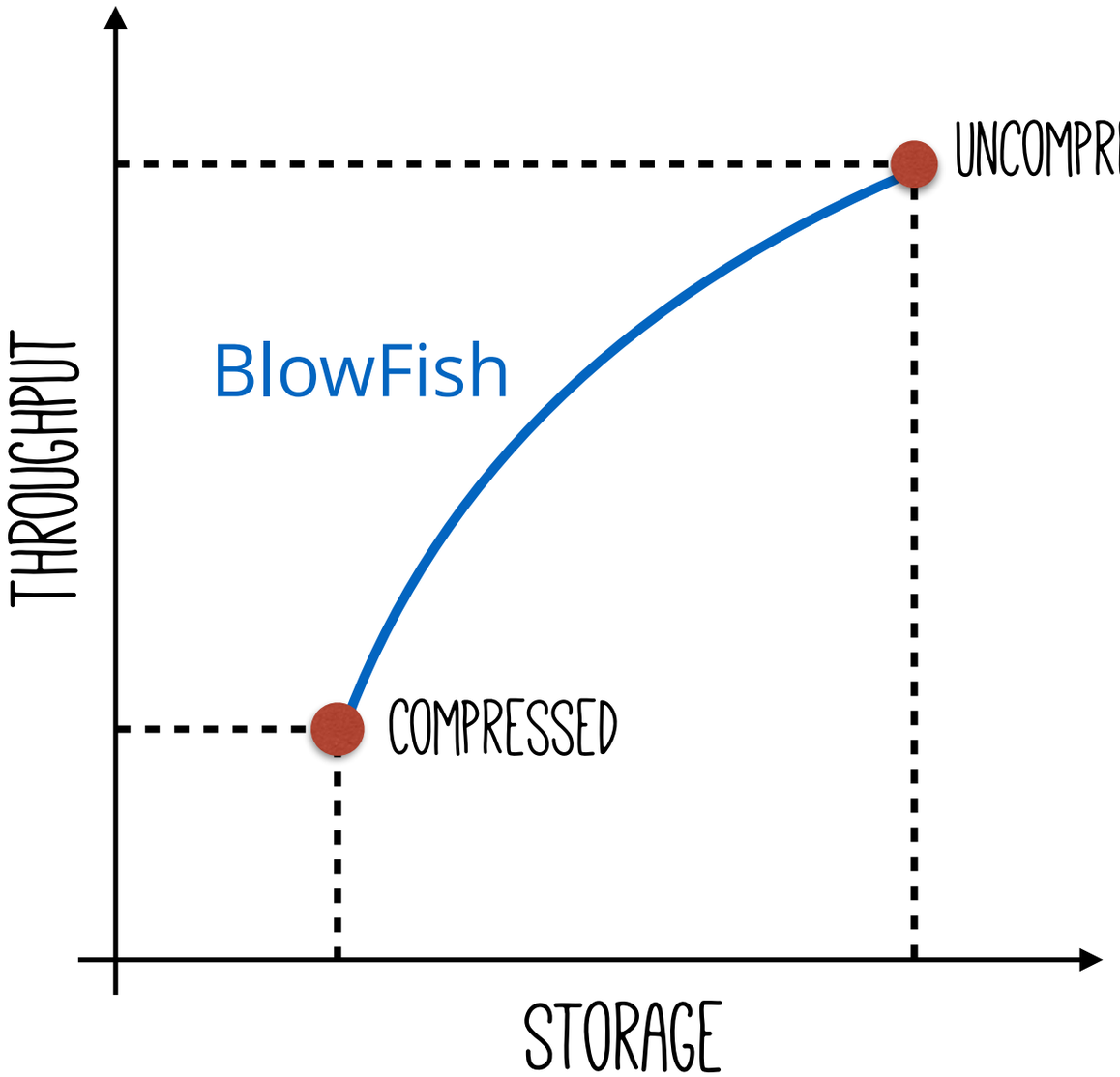


Load changes over time → Degraded performance

BlowFish

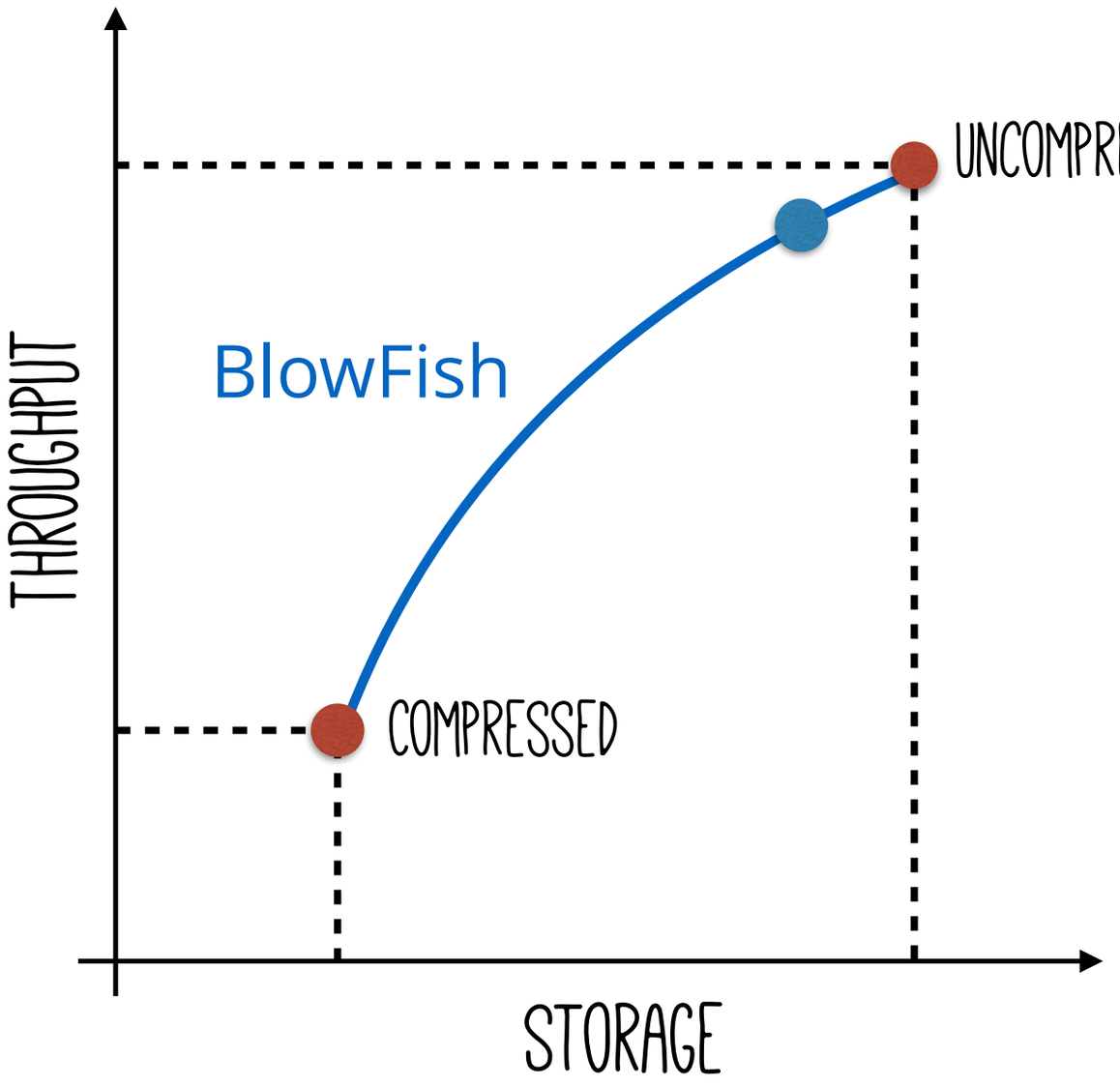


BlowFish



Smooth Tradeoff Curve

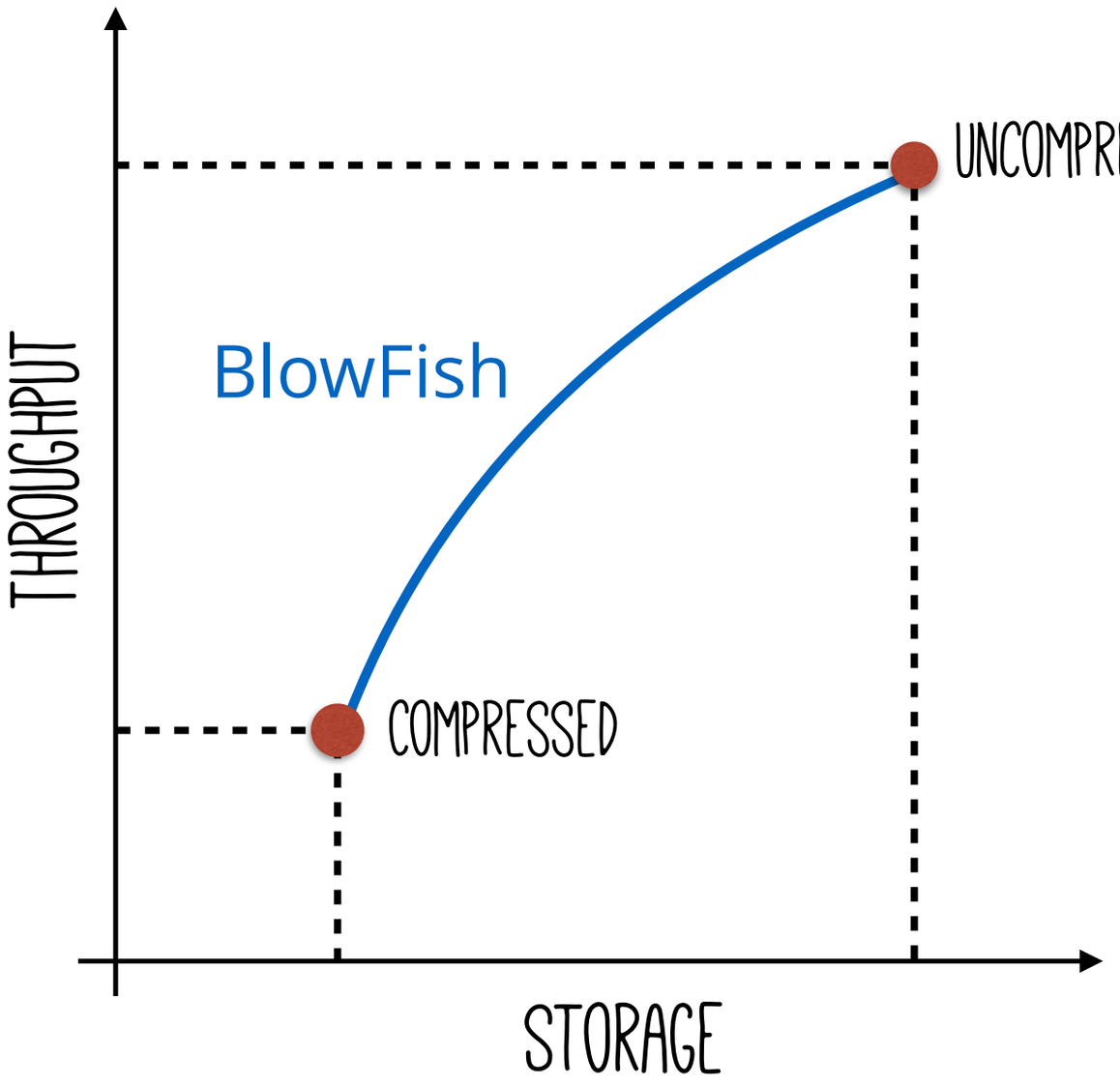
BlowFish



Smooth Tradeoff Curve

Dynamic Navigation

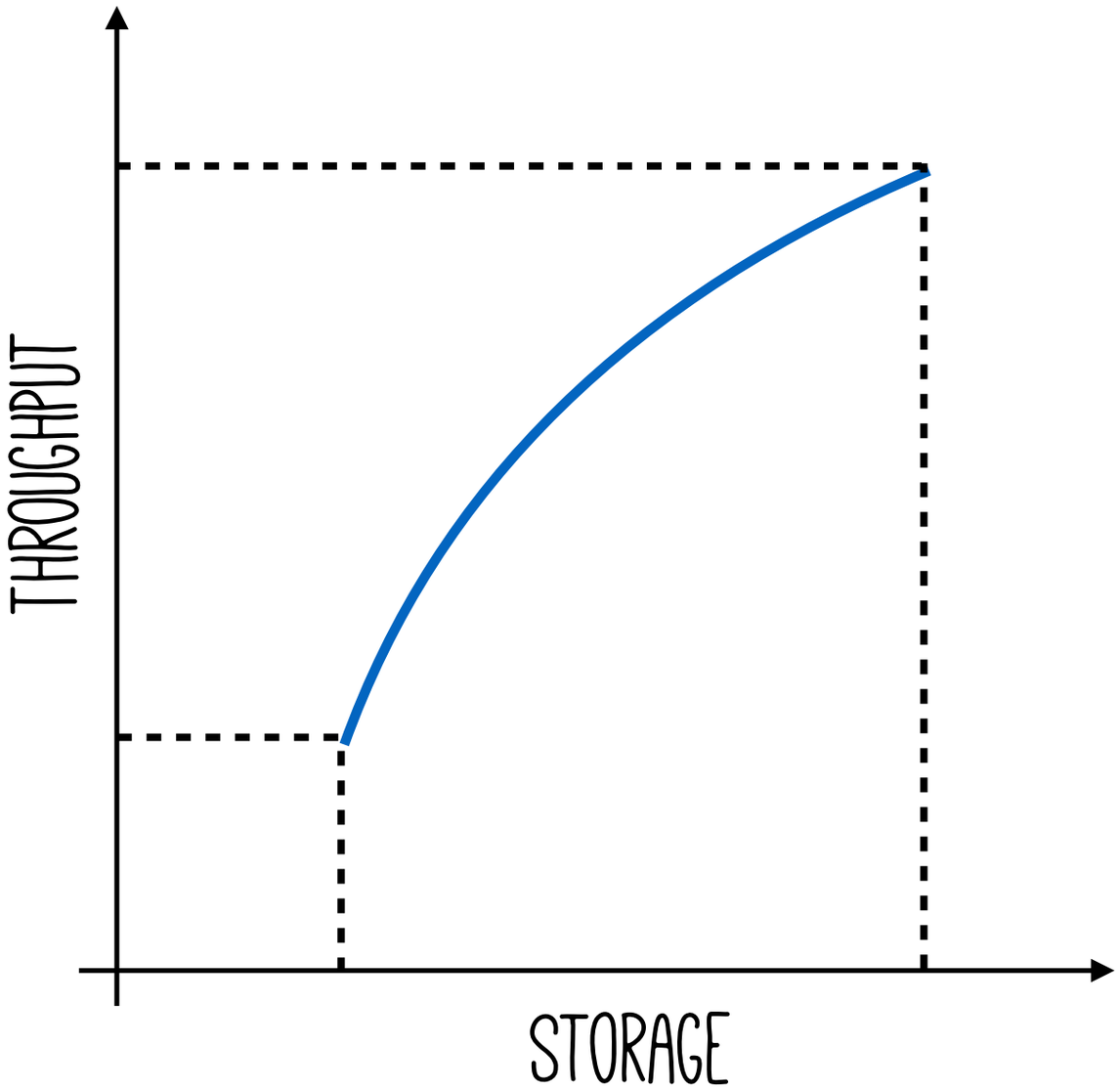
BlowFish

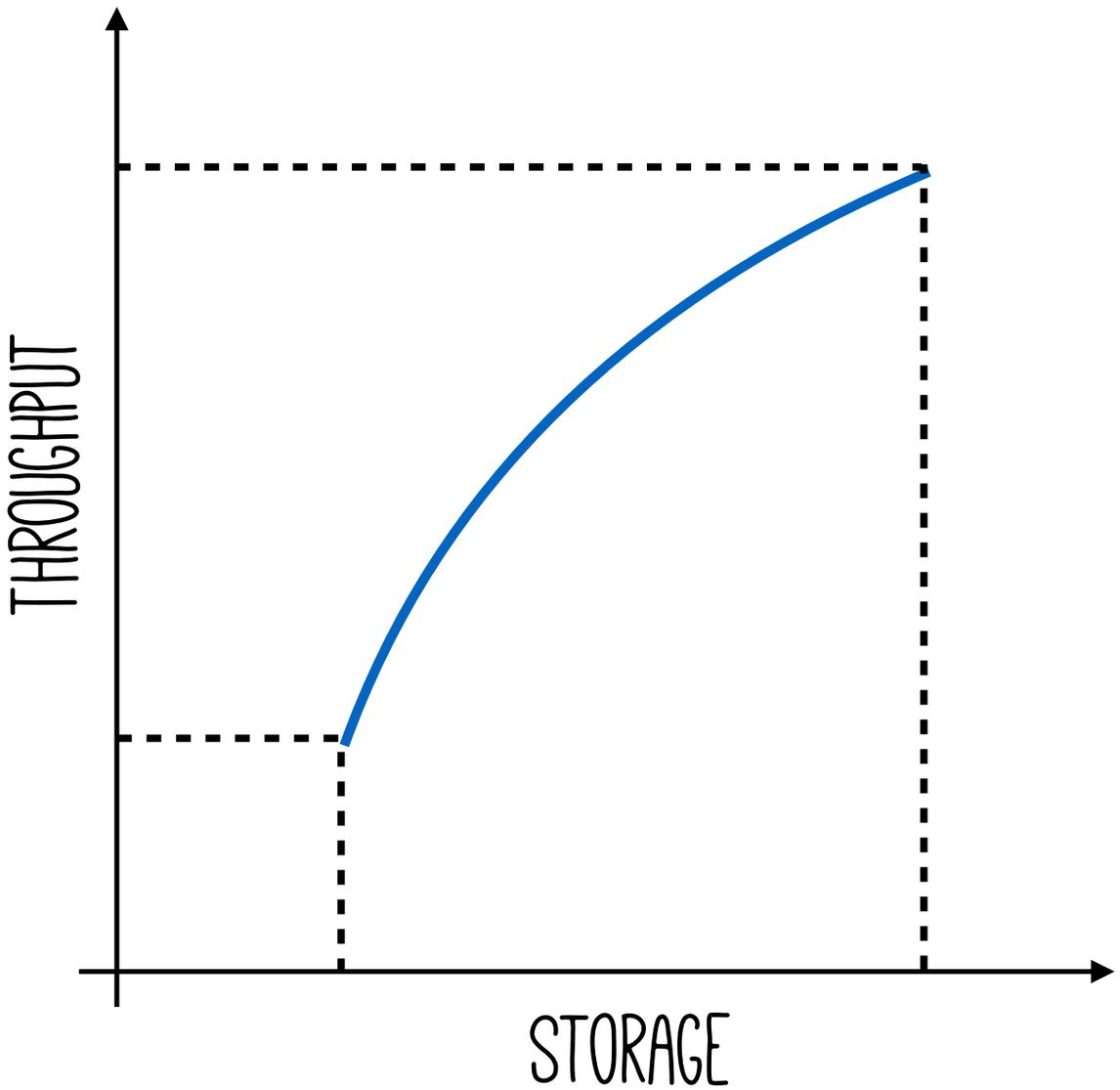


Smooth Tradeoff Curve

Dynamic Navigation

Applications in Several Classical Systems Problems


THROUGHPUT
STORAGE



Storage-Performance Tradeoff

Background

Background

Builds on Succinct [NSDI'15]

Array of suffixes (AoS)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

Array of suffixes (AoS)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

Step 1:
Construct set of suffixes

Array of suffixes (AoS)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

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h	a	p	p	y	p	u	p	p	y

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h	a	p	p	y	p	u	p	p	y

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h	a	p	p	y	p	u	p	p	y

a	p	p	y	p	u	p	p	y

Step 1:
Construct set of suffixes

Array of suffixes (AoS)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

h	a	p	p	y	p	u	p	p	y

a	p	p	y	p	u	p	p	y

p	p	y	p	u	p	p	y

p	y	p	u	p	p	y

y	p	u	p	p	y

p	u	p	p	y

u	p	p	y

p	p	y

p	y

y

Step 1:
Construct set of suffixes

Array of suffixes (AoS)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

h	a	p	p	y	p	u	p	p	y

a	p	p	y	p	u	p	p	y

p	p	y	p	u	p	p	y

p	y	p	u	p	p	y

y	p	u	p	p	y

p	u	p	p	y

u	p	p	y

p	p	y

p	y

y

Step 2:
Sort suffixes (lexicographically)

Array of suffixes (AoS)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

a	p	p	y	p	u	p	p	y

h	a	p	p	y	p	u	p	p	y

p	p	y

Array of suffixes (AoS)

p	p	y	p	u	p	p	y

p	u	p	p	y

p	y

p	y	p	u	p	p	y

u	p	p	y

y

y	p	u	p	p	y

Suffix array (AoS2Input)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

Step 3:
Mark location of each sorted suffix (in input file)

a	p	p	y	p	u	p	p	y

h	a	p	p	y	p	u	p	p	y

p	p	y

p	p	y	p	u	p	p	y

p	u	p	p	y

p	y

p	y	p	u	p	p	y

u	p	p	y

y

y	p	u	p	p	y

Suffix array (AoS2Input)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

Step 3:
Mark location of each sorted suffix (in input file)

a	p	p	y	p	u	p	p	y
h	a	p	p	y	p	u	p	p	y
p	p	y						
p	p	y	p	u	p	p	y	
p	u	p	p	y				
p	y							
p	y	p	u	p	p	y		
u	p	p	y					
y								
y	p	u	p	p	y			

Suffix array (AoS2Input)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1	a p p y p u p p y
	h a p p y p u p p y
	p p y
	p p y p u p p y
	p u p p y
	p y
	p y p u p p y
	u p p y
	y
	y p u p p y

Step 3:
Mark location of each sorted suffix (in input file)

Suffix array (AoS2Input)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1	a	p	p	y	p	u	p	p	y

h	a	p	p	y	p	u	p	p	y

p	p	y

p	p	y	p	u	p	p	y

p	u	p	p	y

p	y

p	y	p	u	p	p	y

u	p	p	y

y

y	p	u	p	p	y

Step 3:
Mark location of each sorted suffix (in input file)

Suffix array (AoS2Input)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1	a p p y p u p p y
0	h a p p y p u p p y
	p p y
	p p y p u p p y
	p u p p y
	p y
	p y p u p p y
	u p p y
	y
	y p u p p y

Step 3:
Mark location of each sorted suffix (in input file)

Suffix array (AoS2Input)

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

AoS2Input

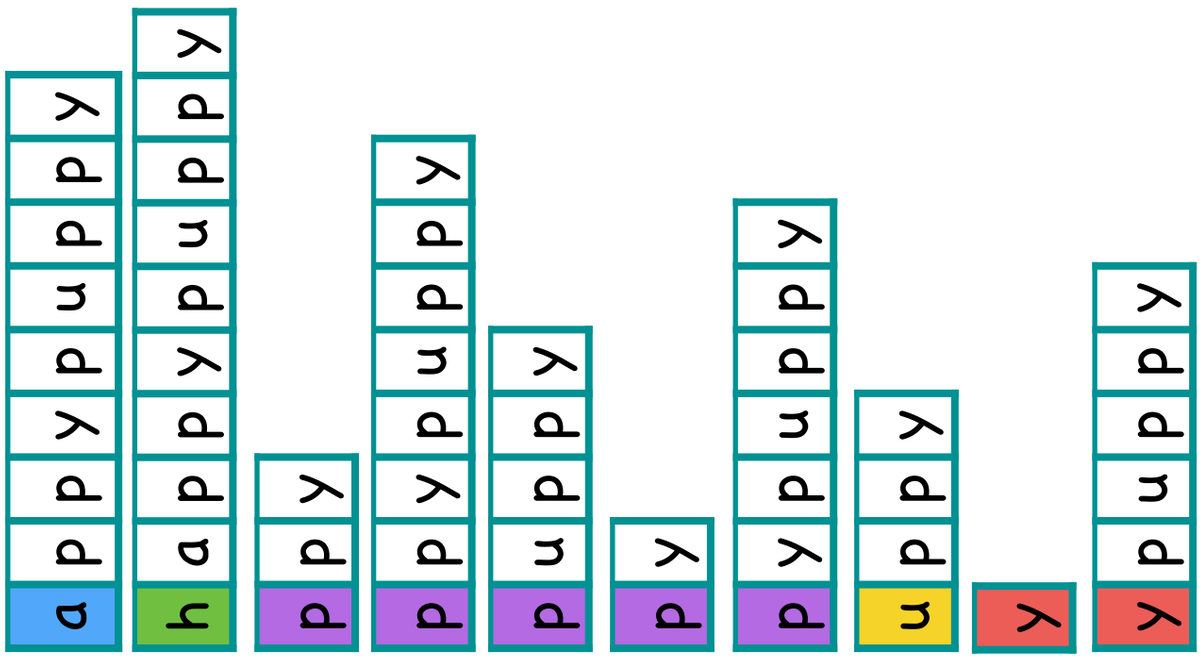
1	a p p y p u p p y
0	h a p p y p u p p y
7	p p y
2	p p y p u p p y
5	p u p p y
8	p y
3	p y p u p p y
6	u p p y
9	y
4	y p u p p y

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

Succinct Data Representation

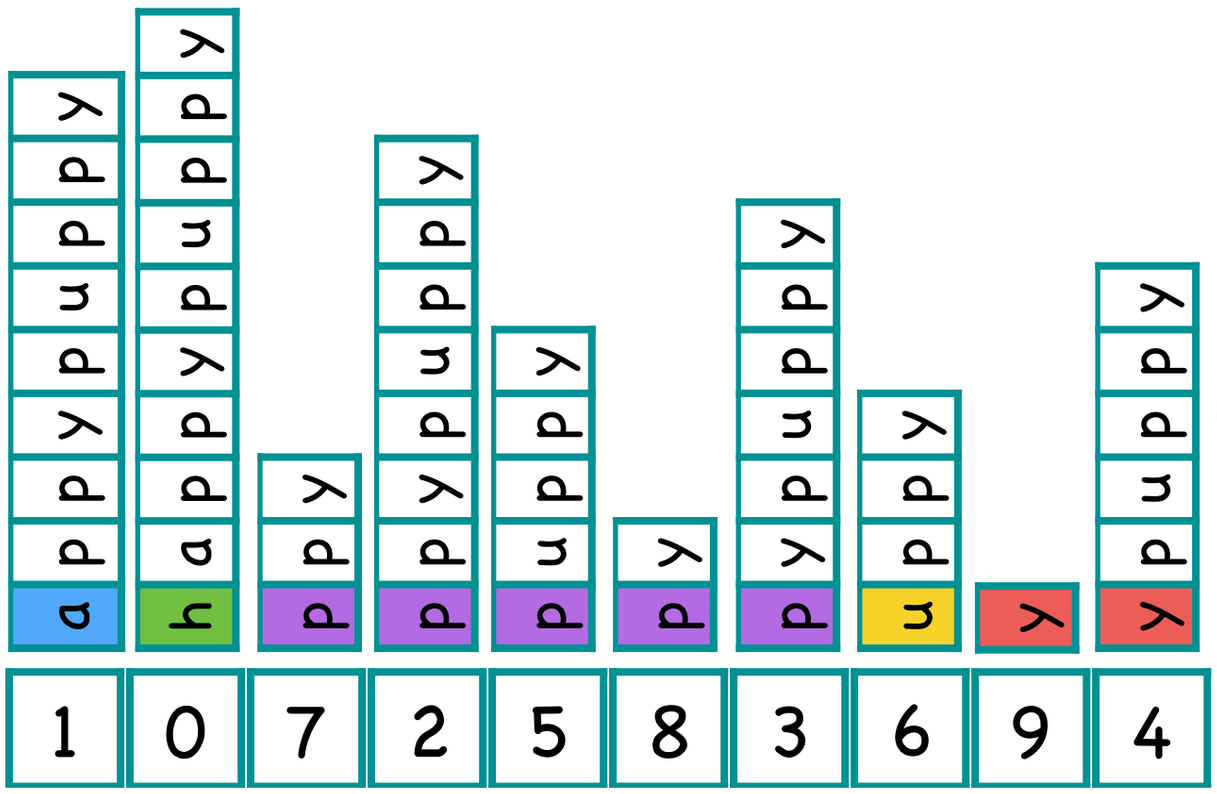
0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



Array of Suffixes (AoS)
(suffixes in sorted order)

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



Array of Suffixes (AoS)

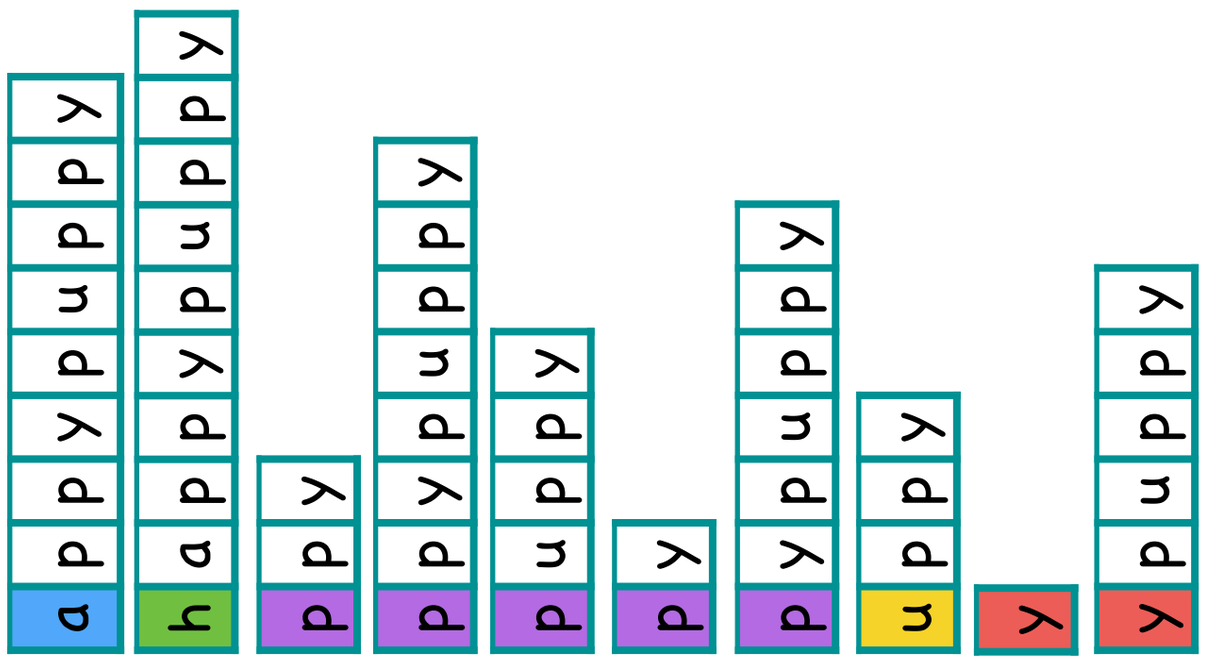
(suffixes in sorted order)

AoS2Input

(location of suffix in file)

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



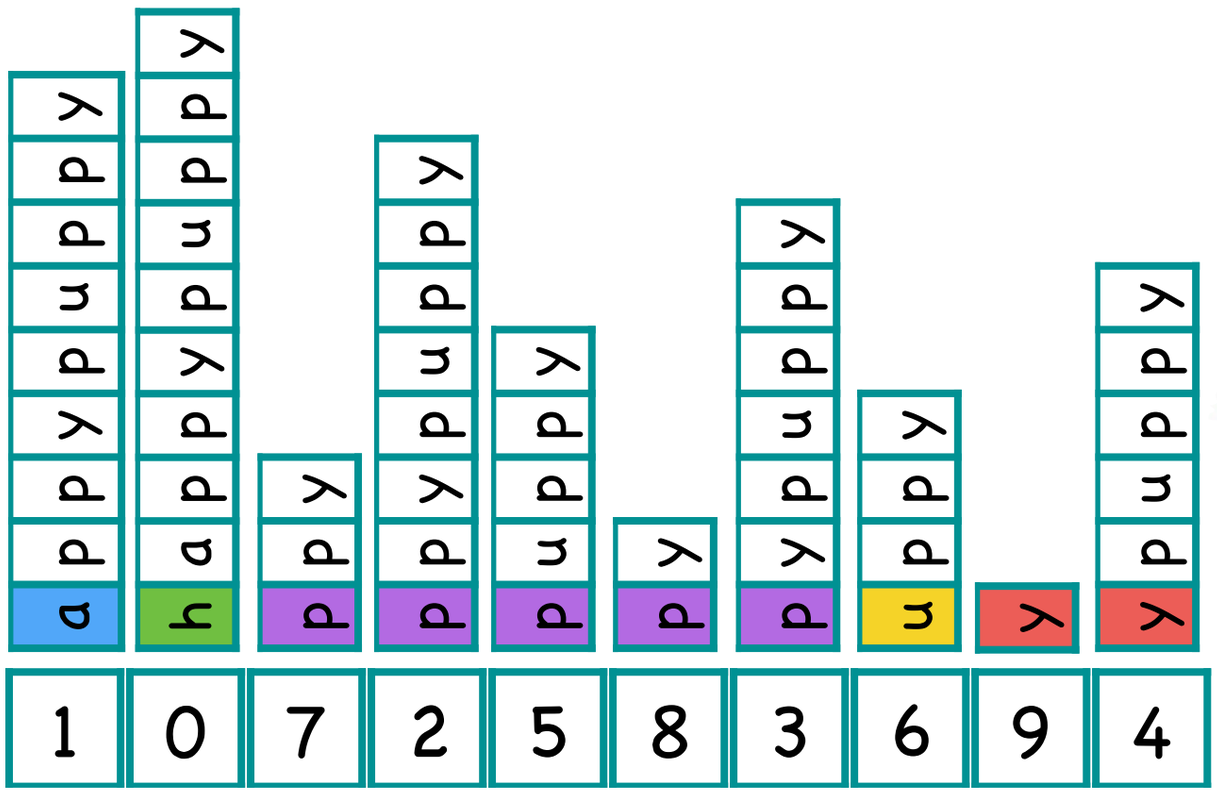
1	0	7	2	5	8	3	6	9	4

Arbitrary substring search

via binary search

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



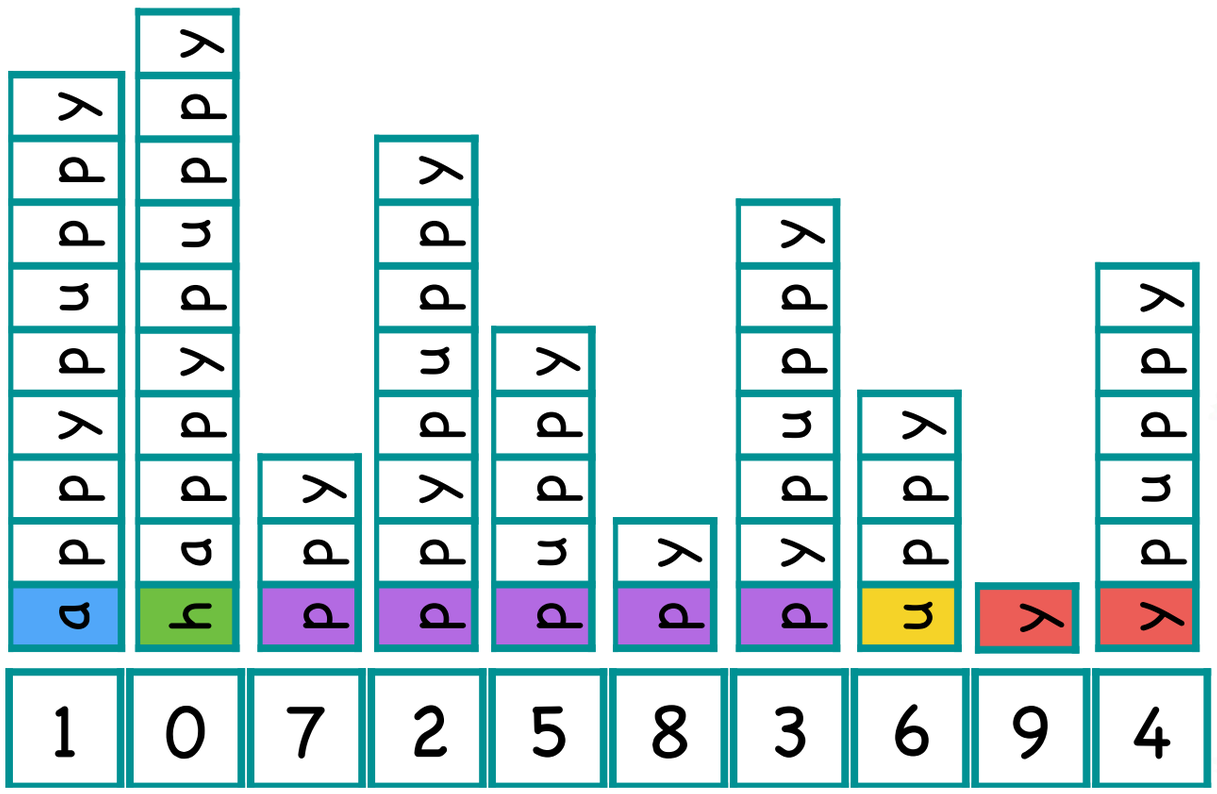
1	0	7	2	5	8	3	6	9	4

Problem1: Size of AoS

O(n*n) bits

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



Problem1: Size of AoS

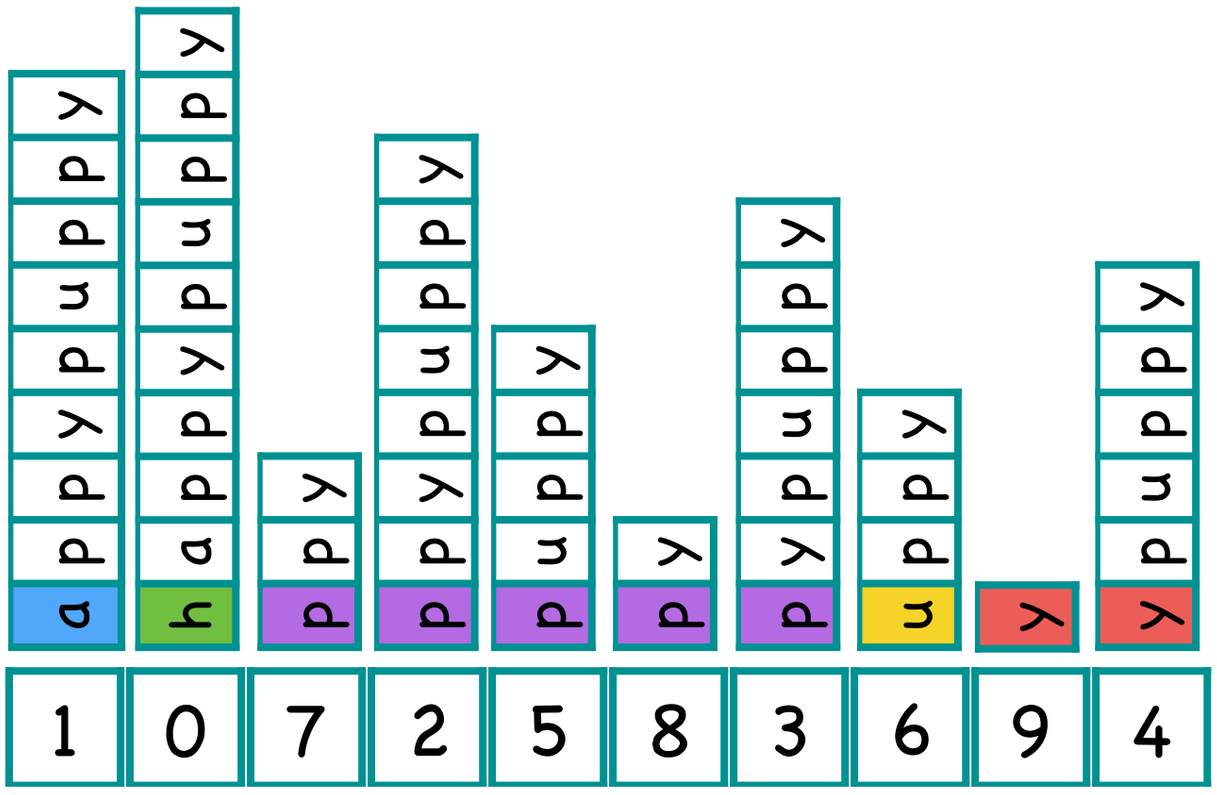
O(n*n) bits

Problem2: Size of AoS2Input

each entry takes log(n) bits

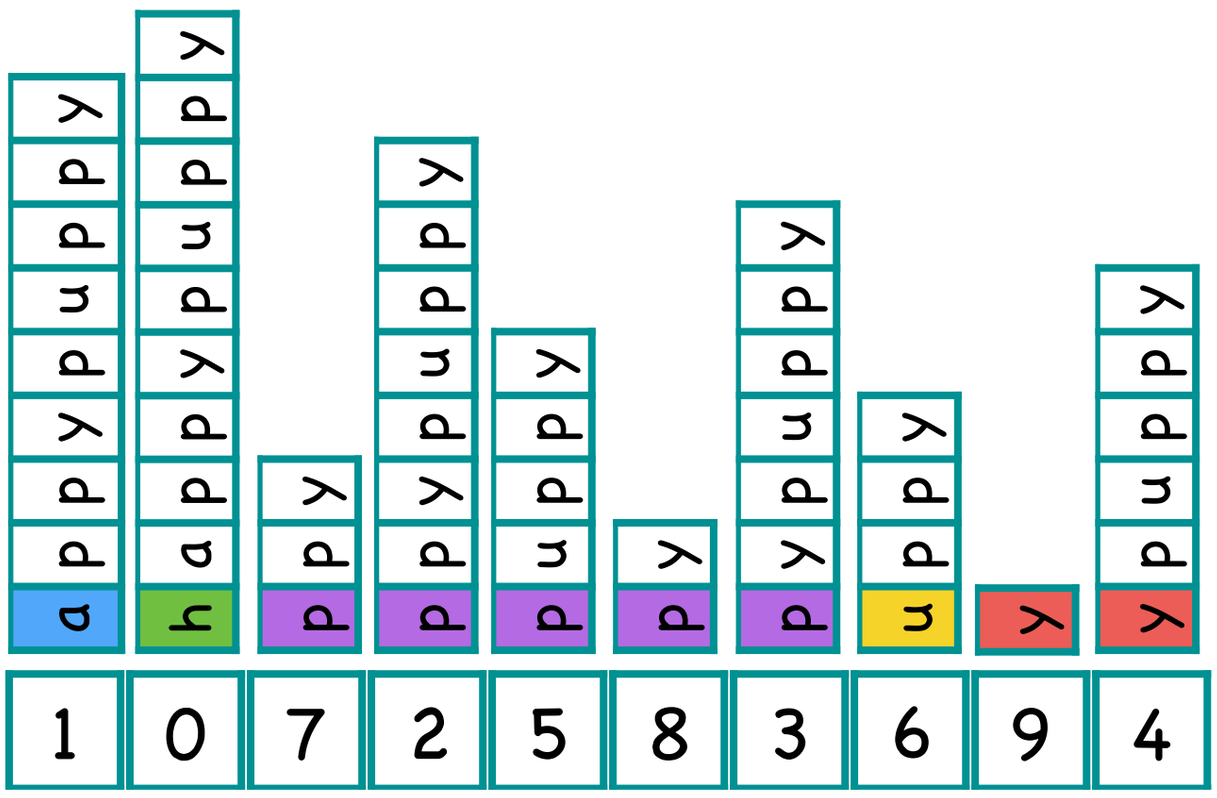
Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



Succinct Data Representation

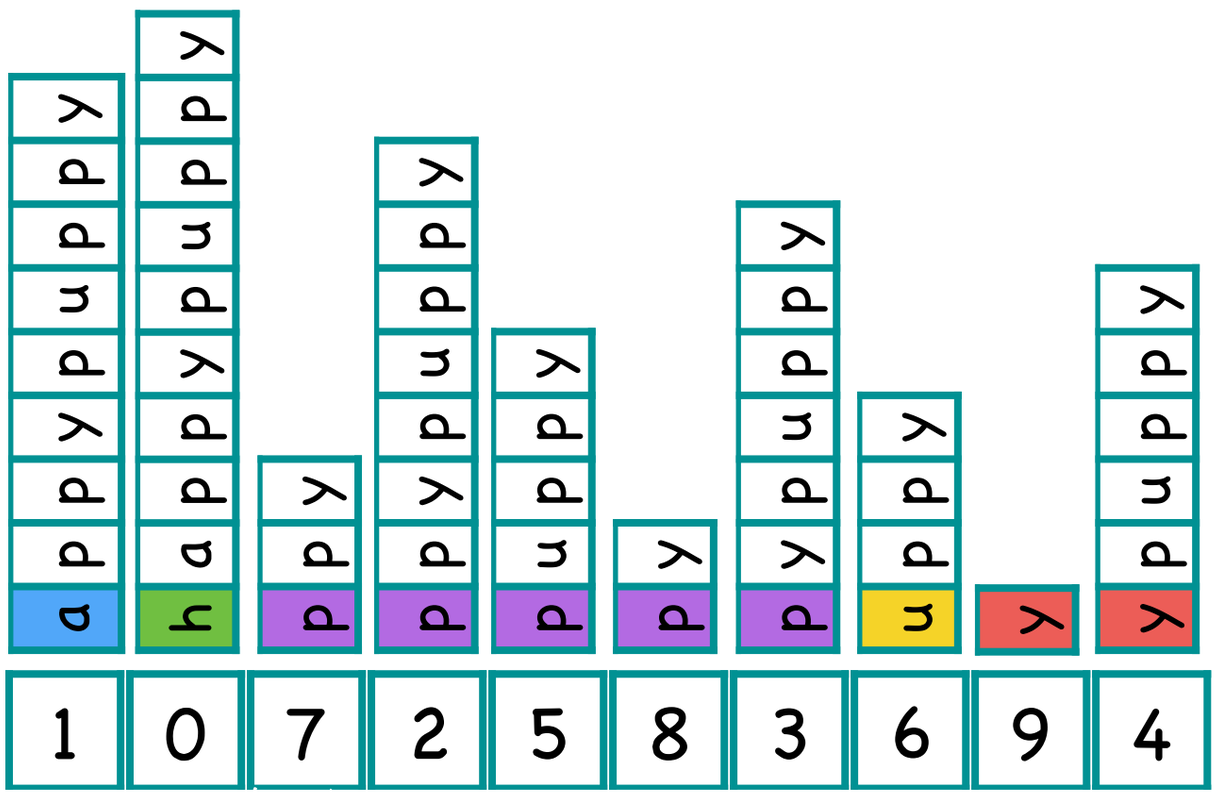
0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



0

Succinct Data Representation

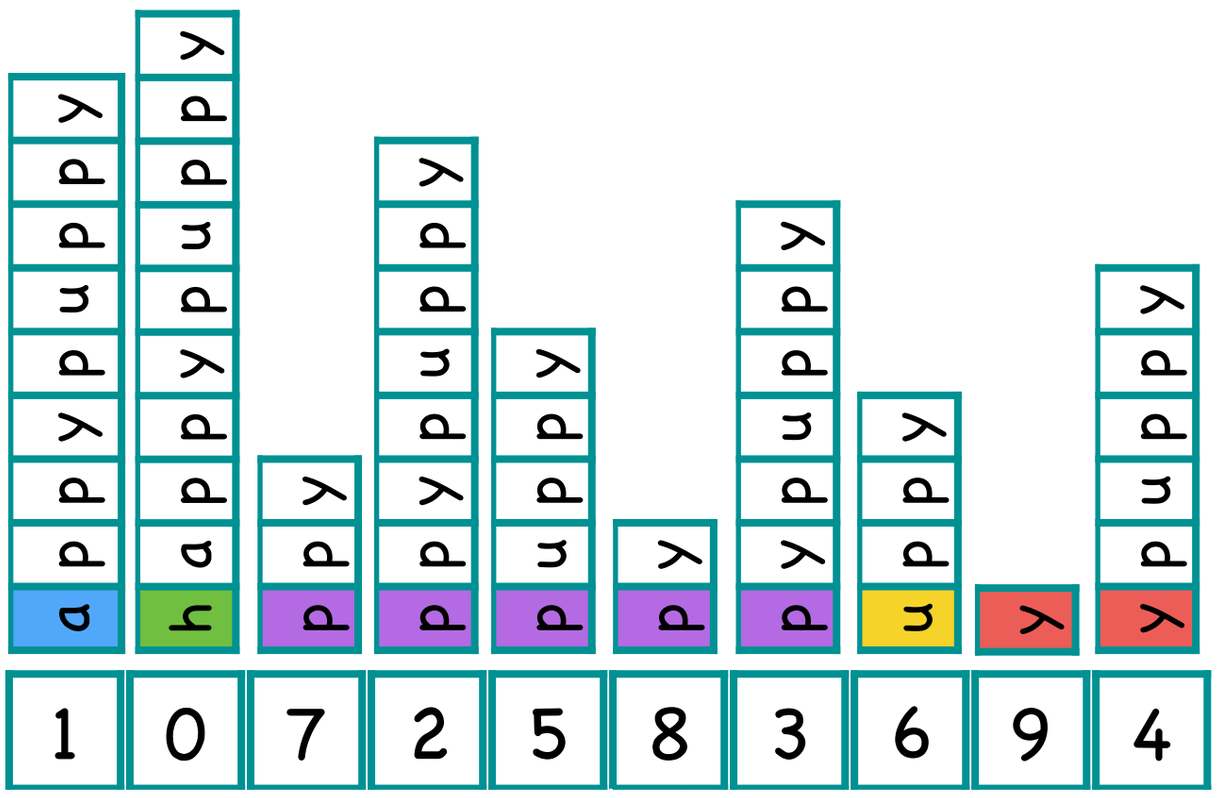
0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



3	0

Succinct Data Representation

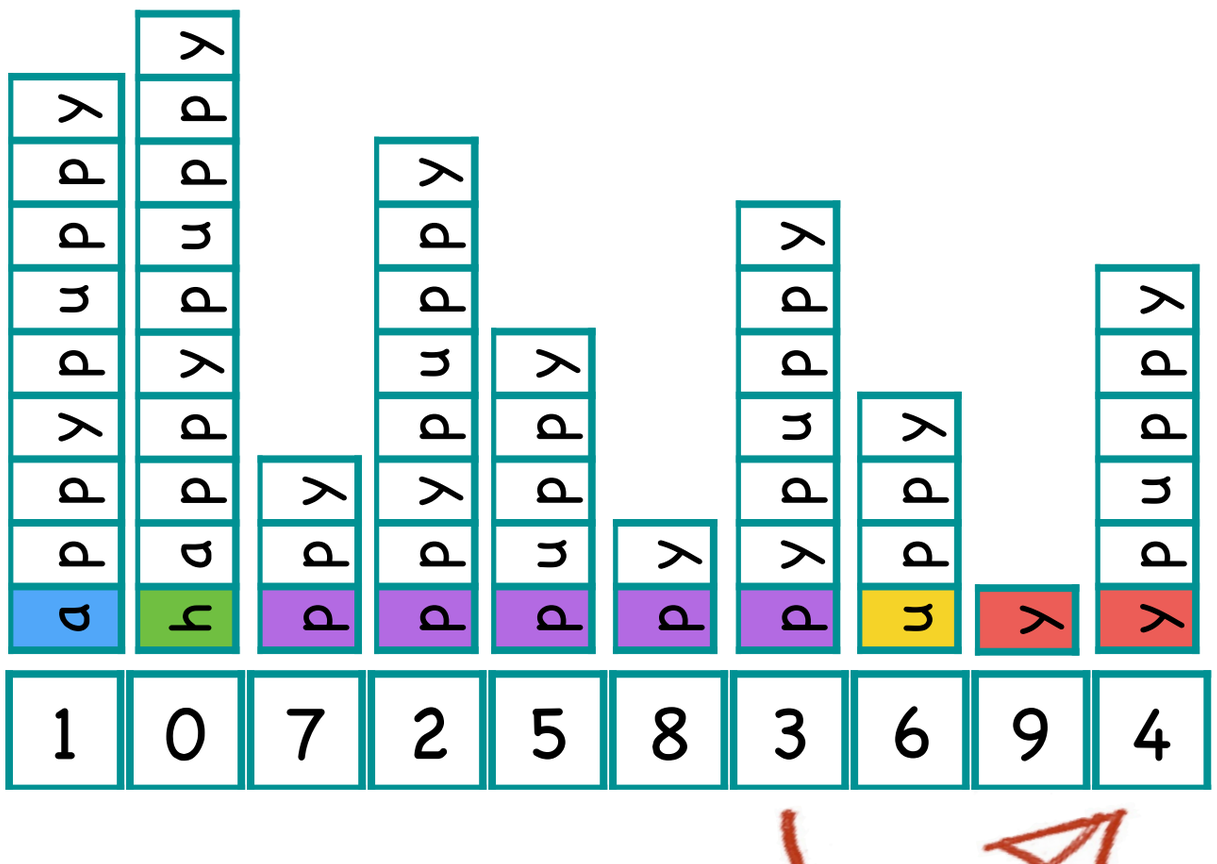
0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



3	0		6

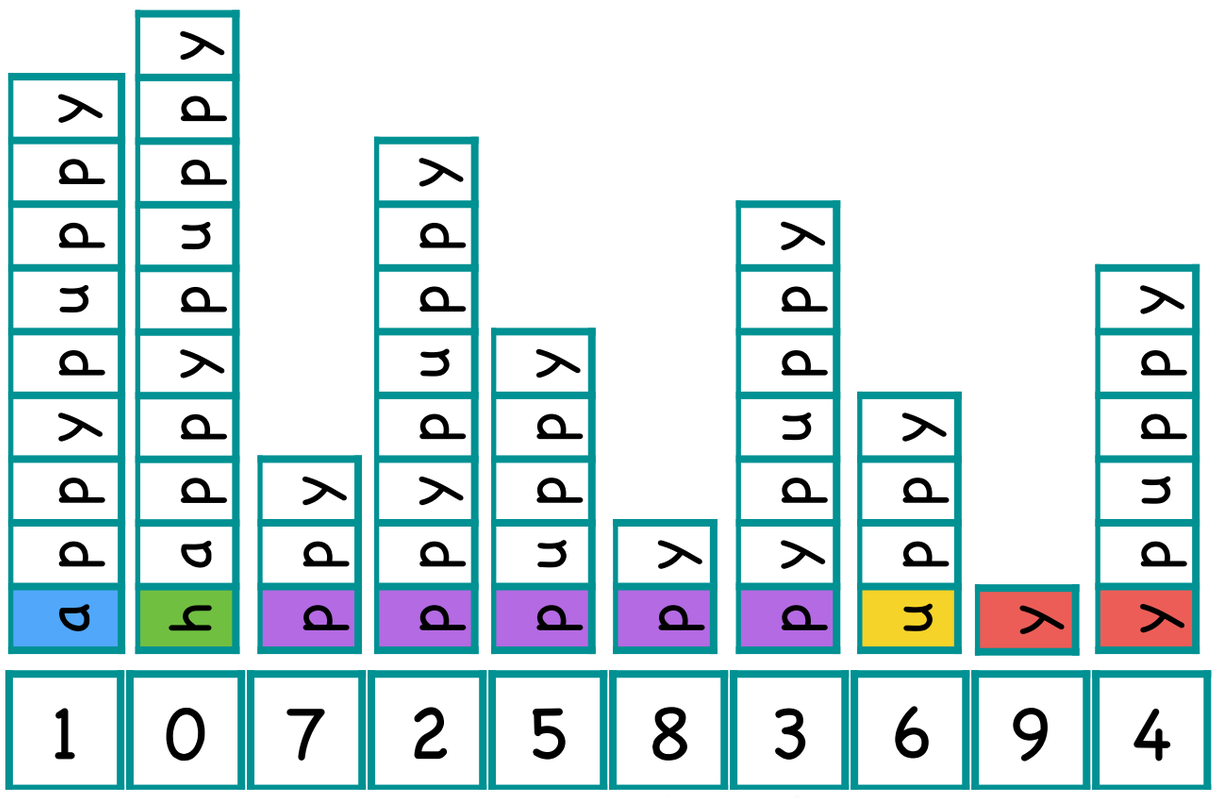
Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



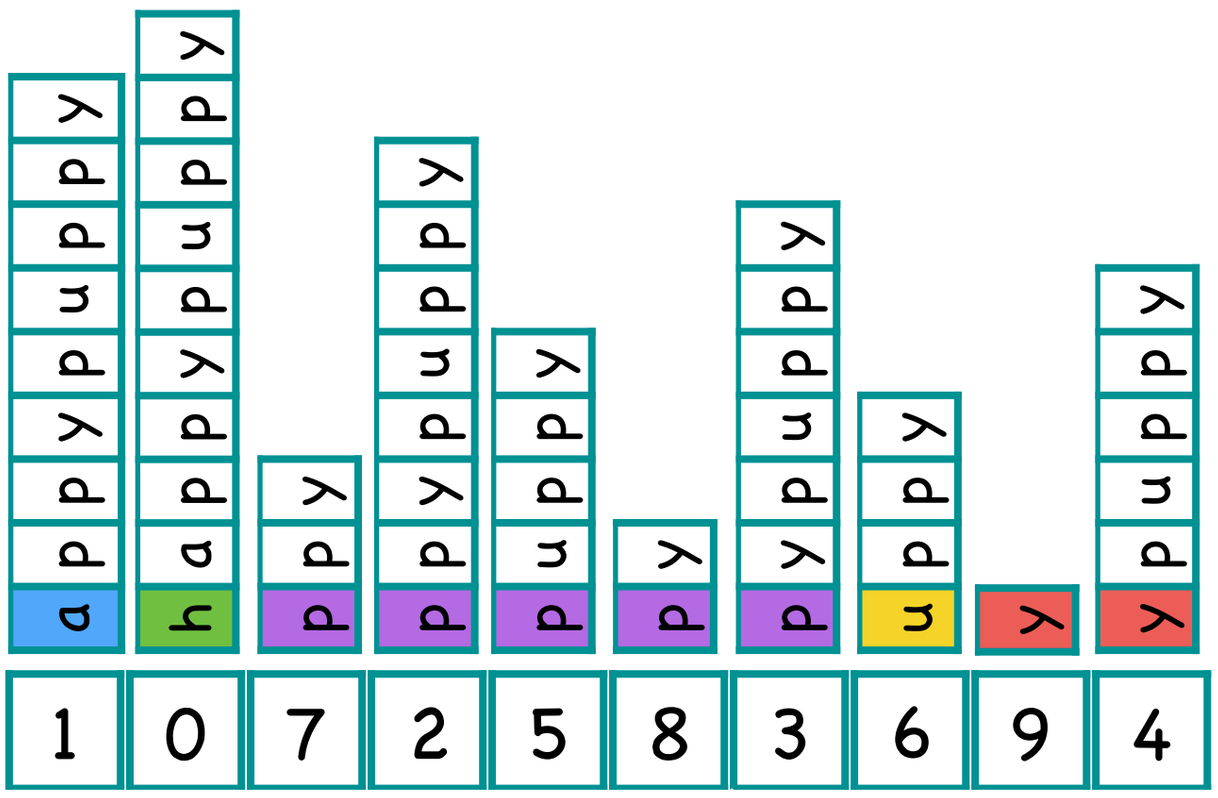
Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



Succinct Data Representation

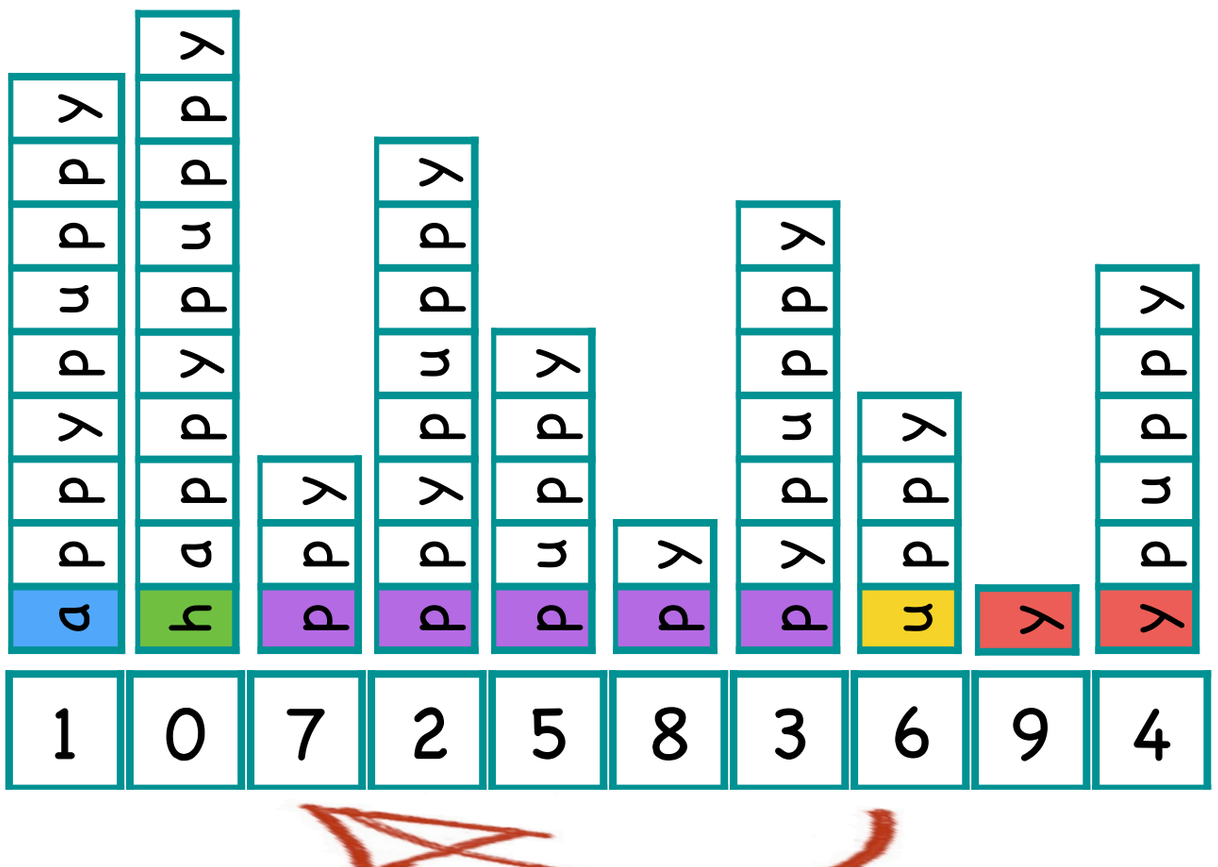
0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



3	0		6	7		9			4

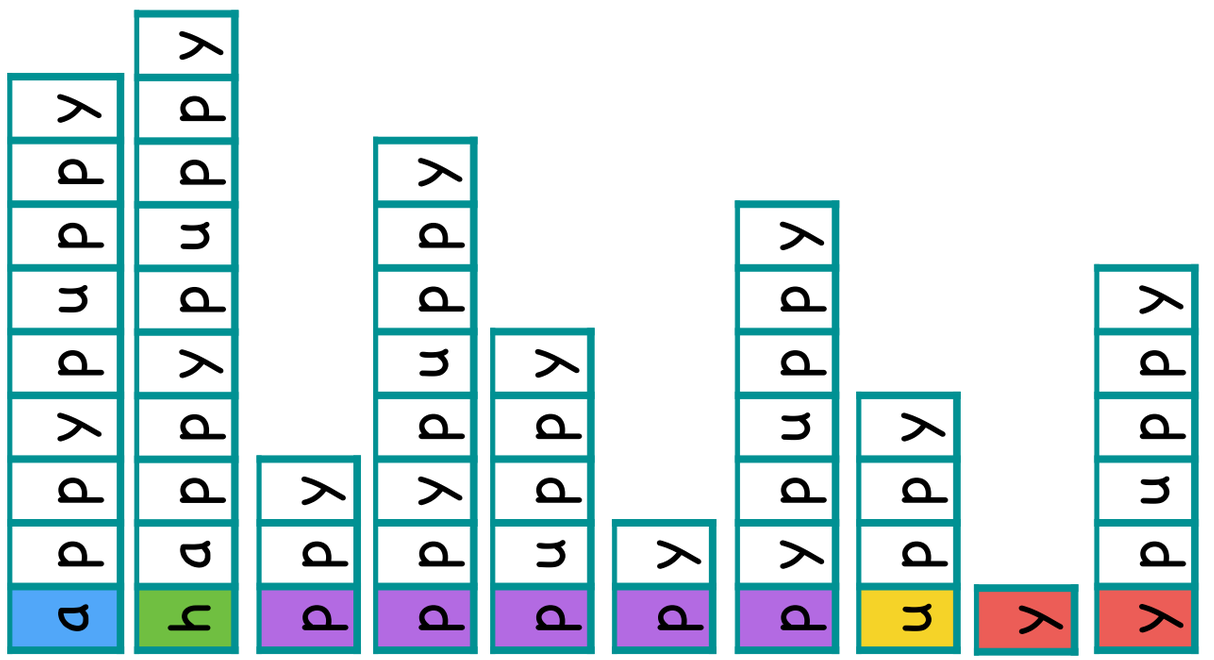
Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

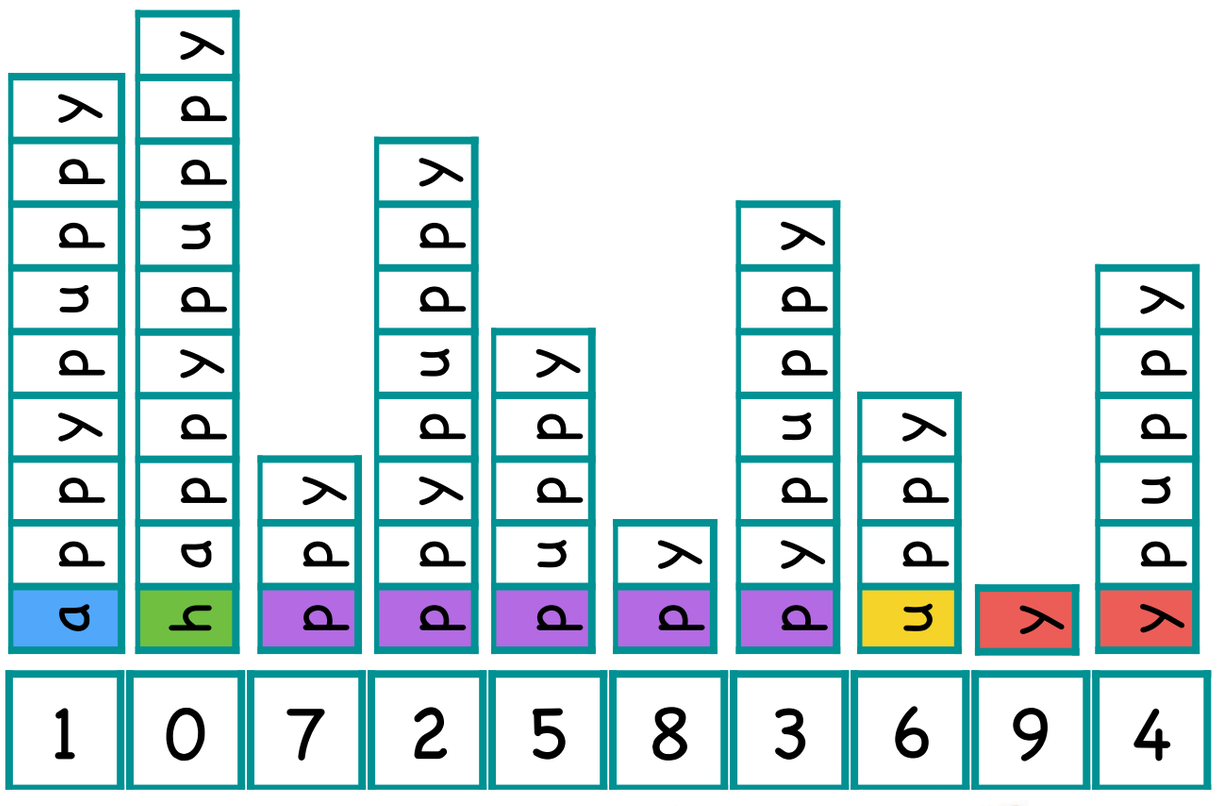


1	0	7	2	5	8	3	6	9	4

3	0	5	6	7	9	2	4

Succinct Data Representation

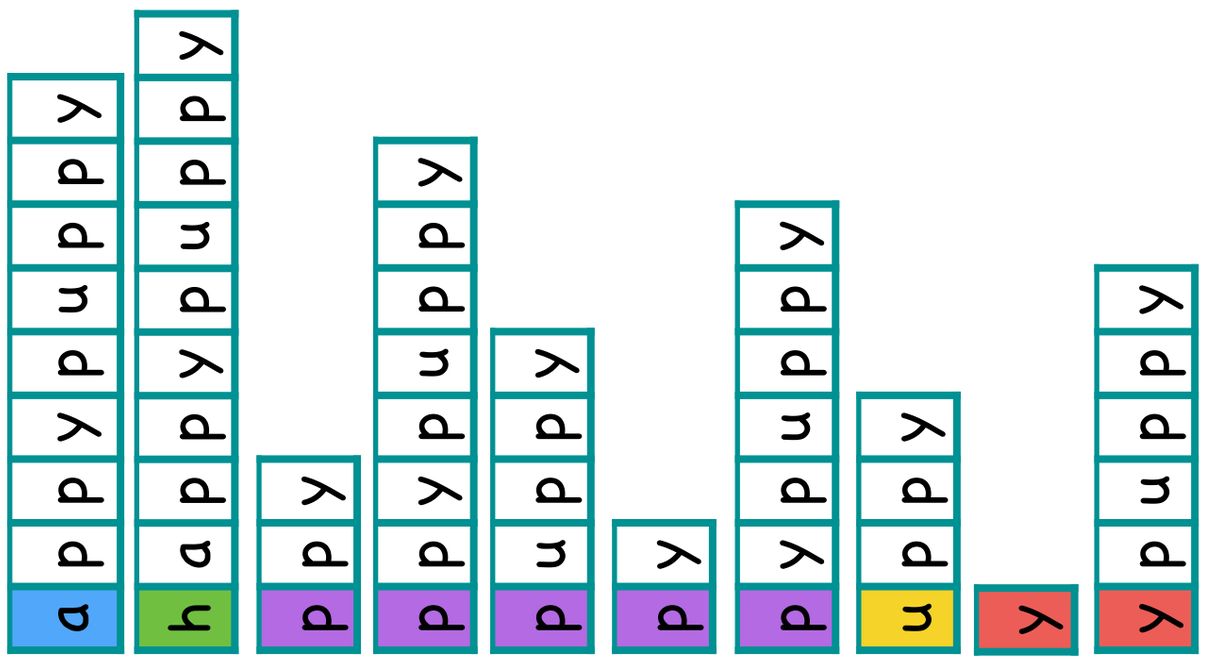
0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



3	0	5	6	7	8	9	2		4

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

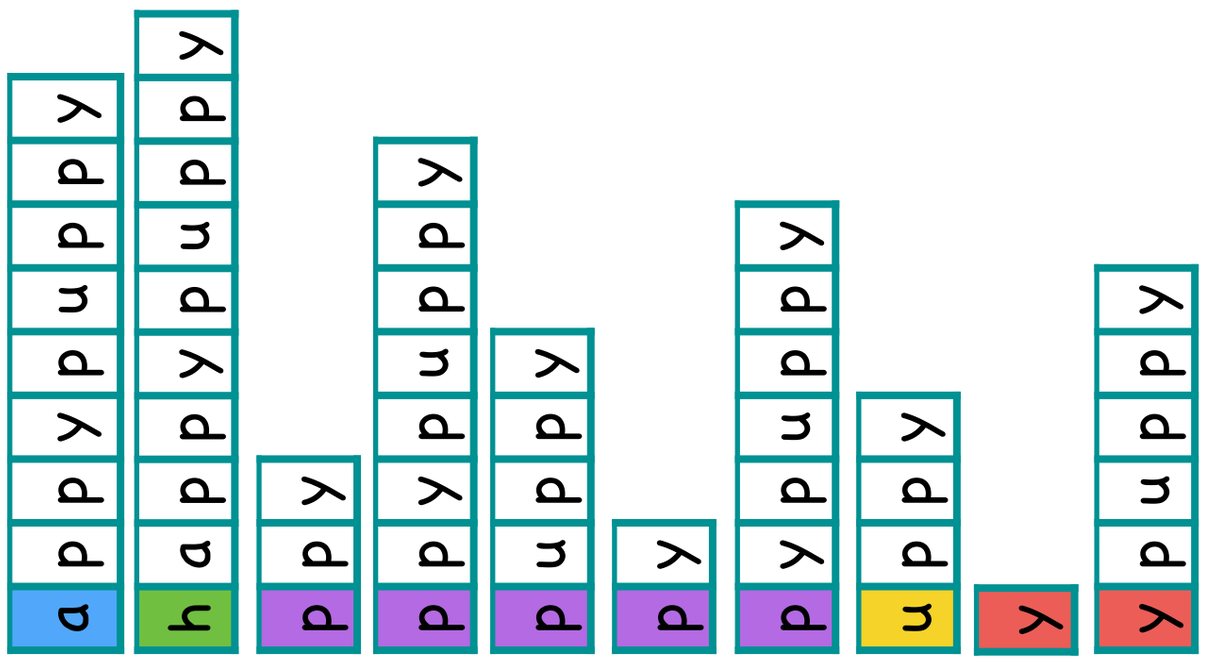


1	0	7	2	5	8	3	6	9	4

3	0	5	6	7	8	9	2	1	4

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

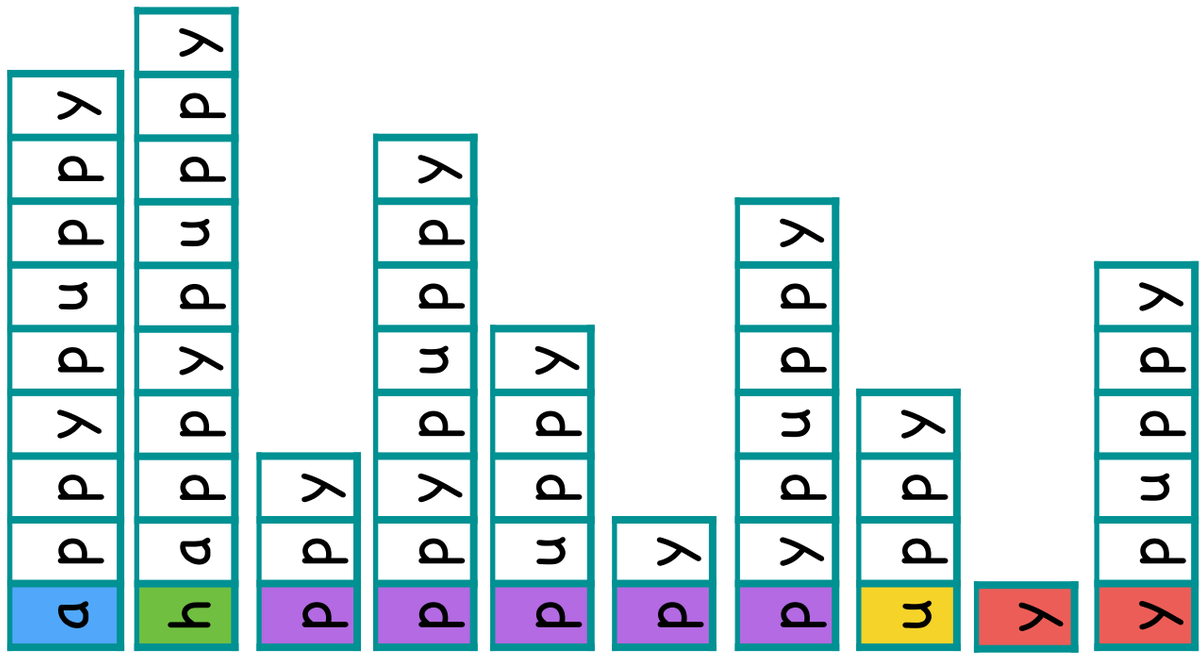


1	0	7	2	5	8	3	6	9	4

3	0	5	6	7	8	9	2	1	4

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



1	0	7	2	5	8	3	6	9	4

NextCharIdx

(index of suffix after removing the first character)

3	0	5	6	7	8	9	2	1	4

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

h	a	p	p	y	p	u	p	p	y
1	0	7	2	5	8	3	6	9	4

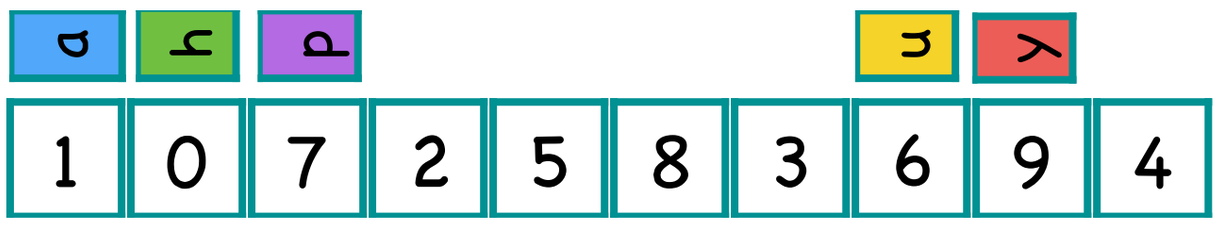
3	0	5	6	7	8	9	2	1	4

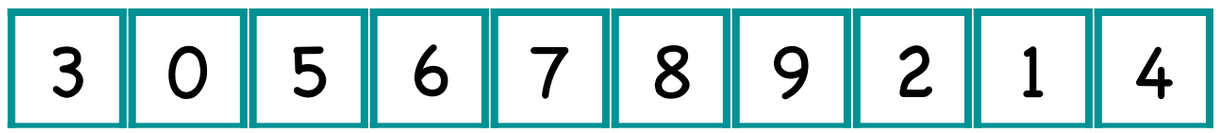
NextCharIdx

(index of suffix after removing the first character)

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y





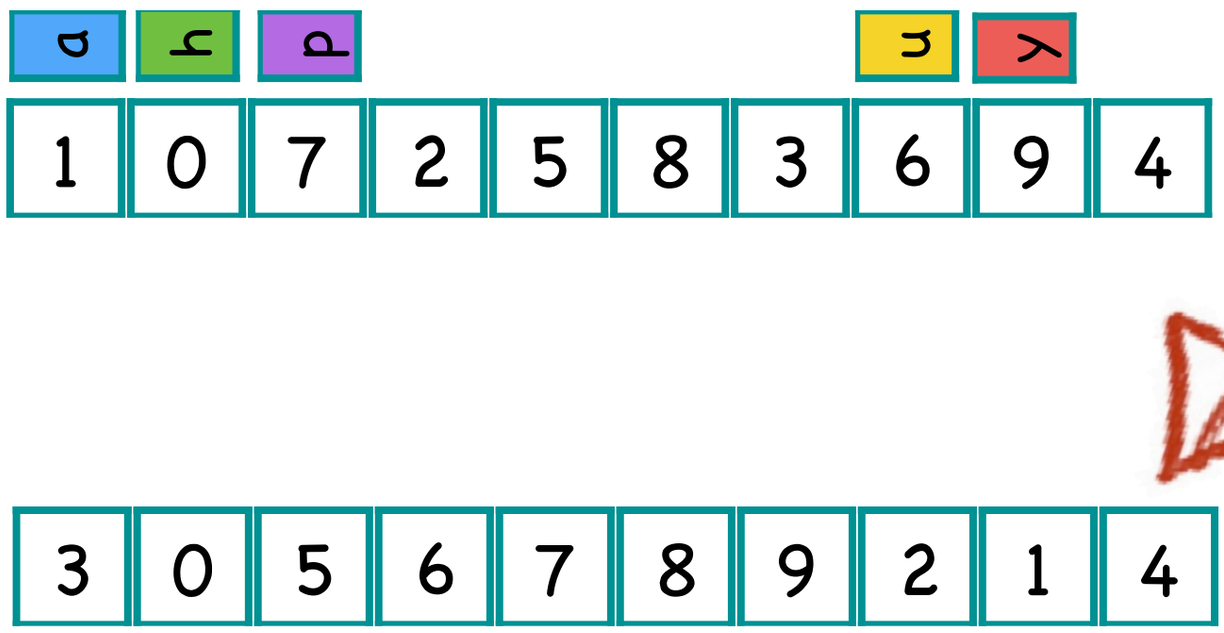
NextCharIdx

(index of suffix after removing the first character)

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

No redundancy in AoS2Input

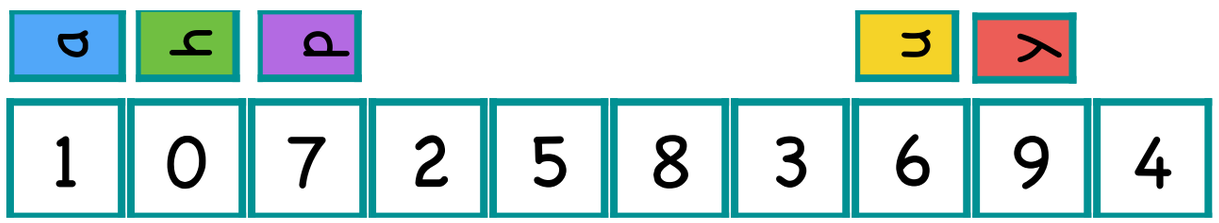


NextCharIdx

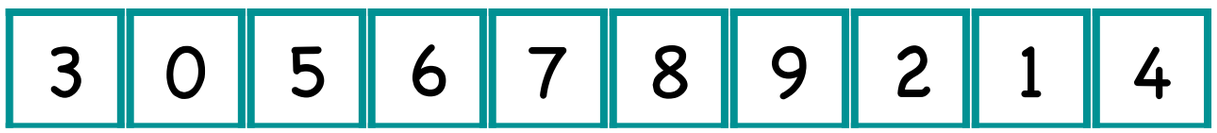
(index of suffix after removing the first character)

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



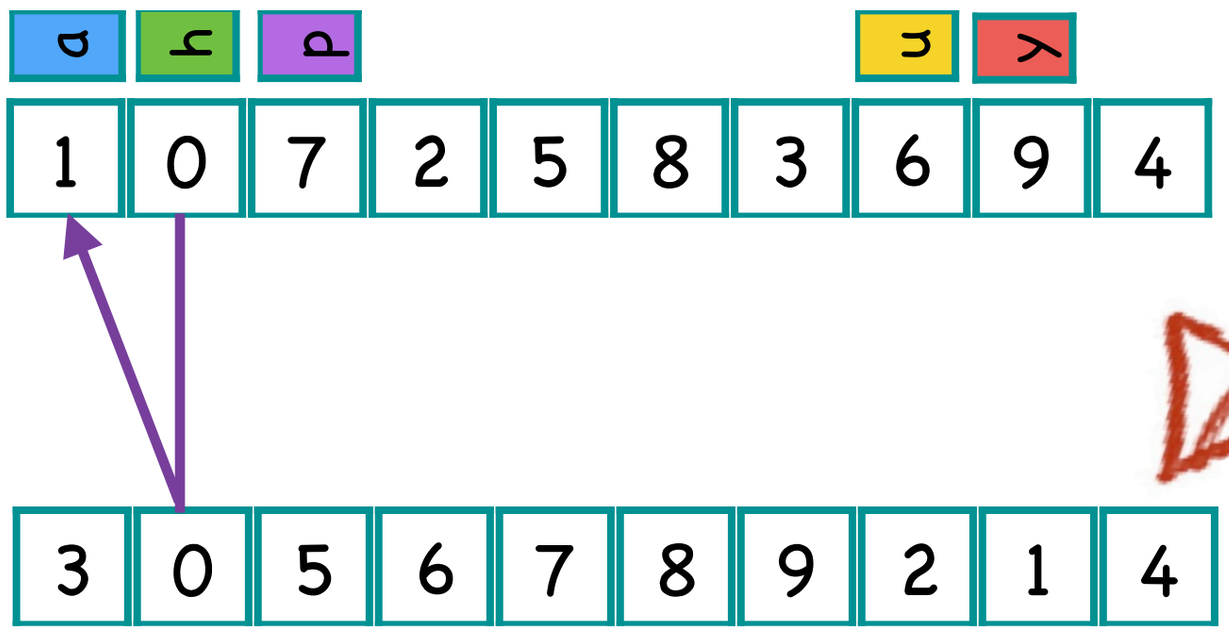
NextCharIdx
(index of next larger value in AoS2Input)



NextCharIdx
(index of suffix after removing the first character)

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

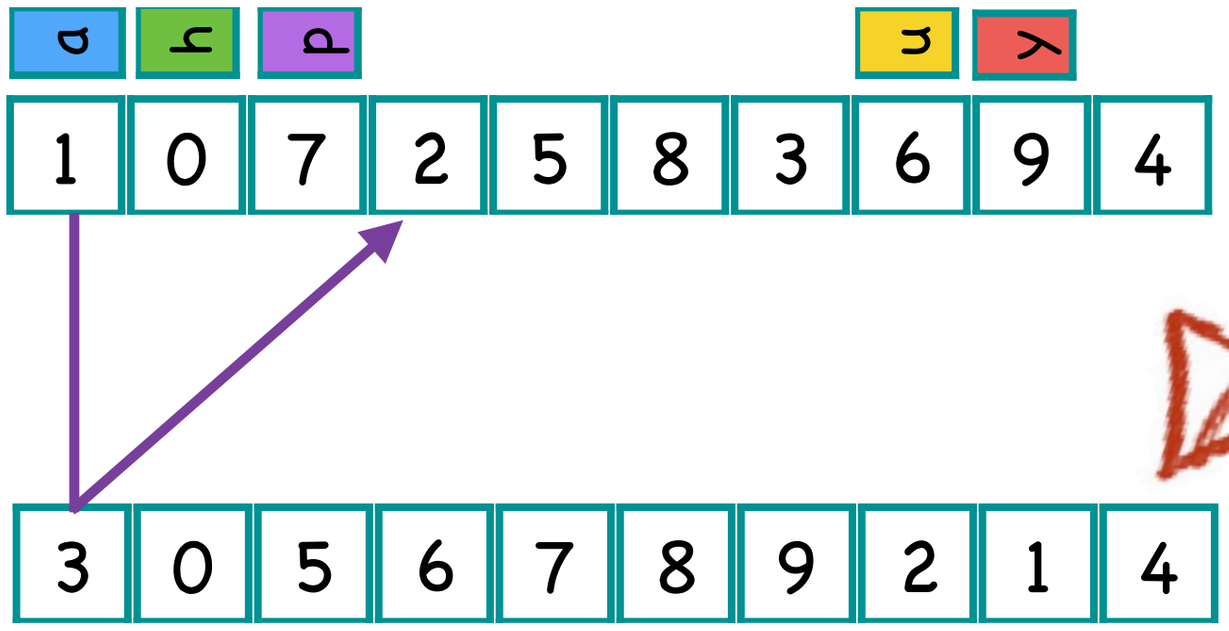


NextCharIdx
(index of next larger value in AoS2Input)

NextCharIdx
(index of suffix after removing the first character)

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y



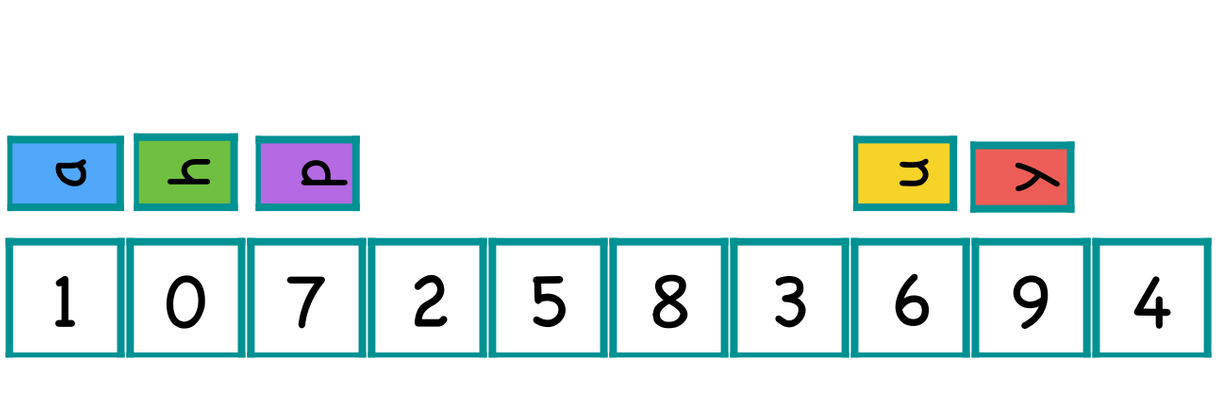
NextCharIdx
(index of next larger value in AoS2Input)

NextCharIdx
(index of suffix after removing the first character)

Succinct Data Representation

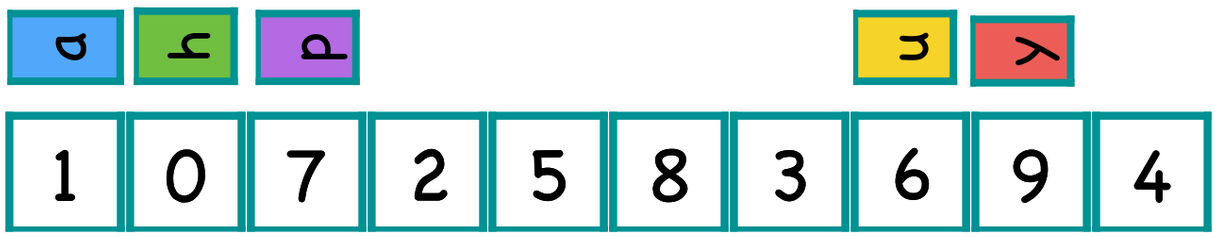
0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

No redundancy in AoS2Input



Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

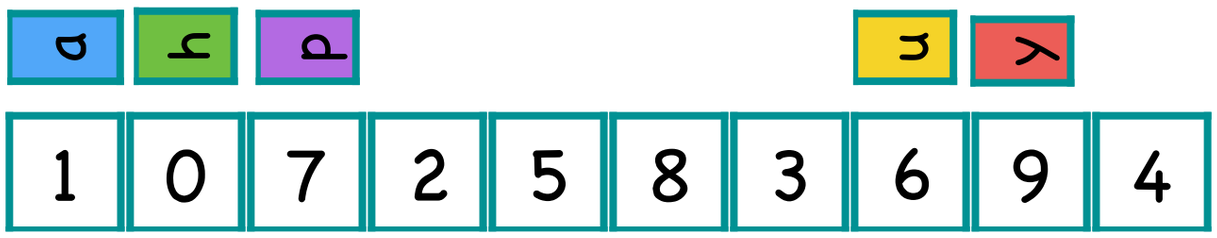


Solution: Sample!

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

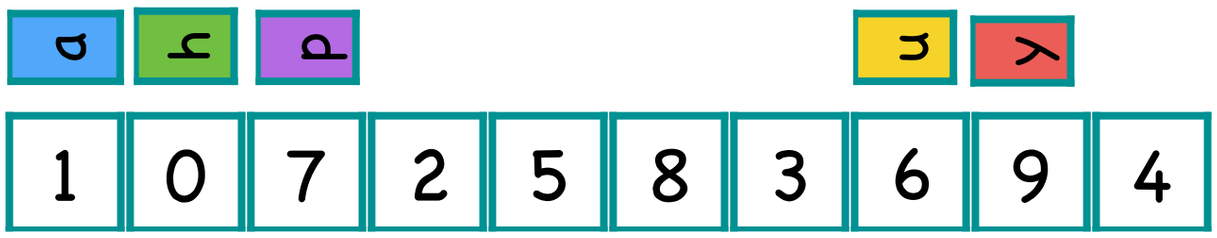
1		7		5		3		9	



Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1		7		5		3		9	



Problem: How to find unsampled values?

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1		7		5		3		9	

a	h	p	y	x

1	0	7	2	5	8	3	6	9	4

Problem: How to find unsampled values?

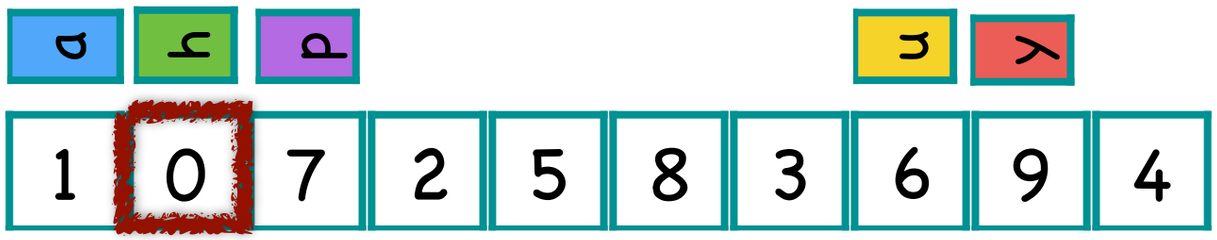
3	0	5	6	7	8	9	2	1	4

Solution:Follow NextCharIdx pointers until you hit a sampled value

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1		7		5		3		9	



Problem: How to find unsampled values?

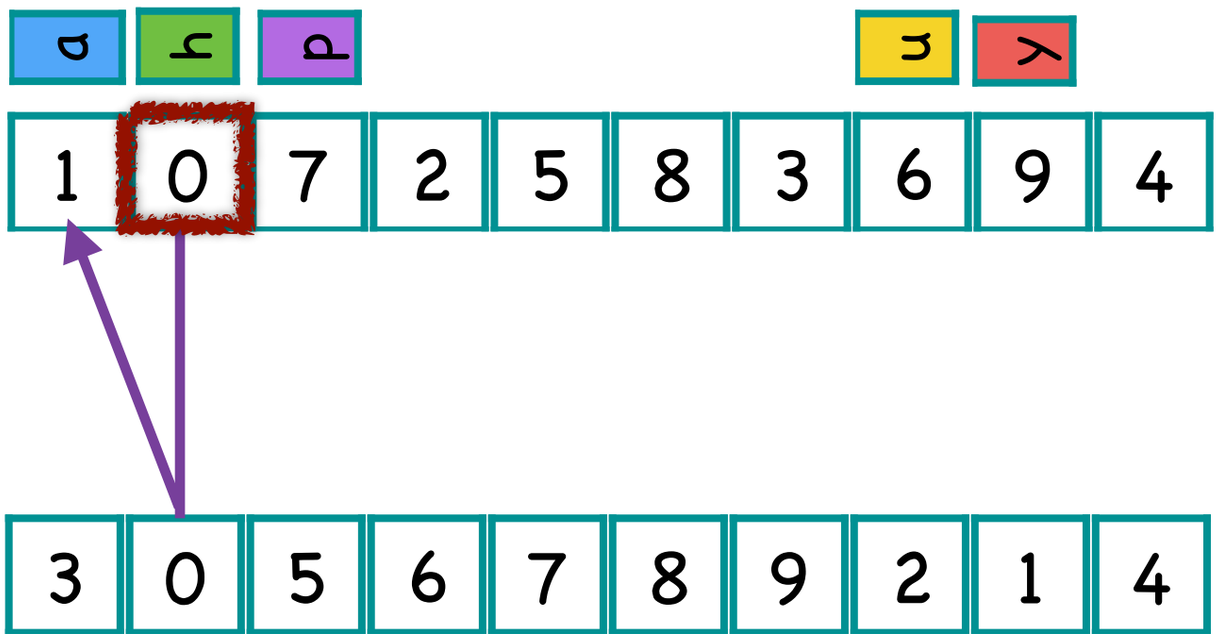
3	0	5	6	7	8	9	2	1	4

Solution:Follow NextCharIdx pointers until you hit a sampled value

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1		7		5		3		9	



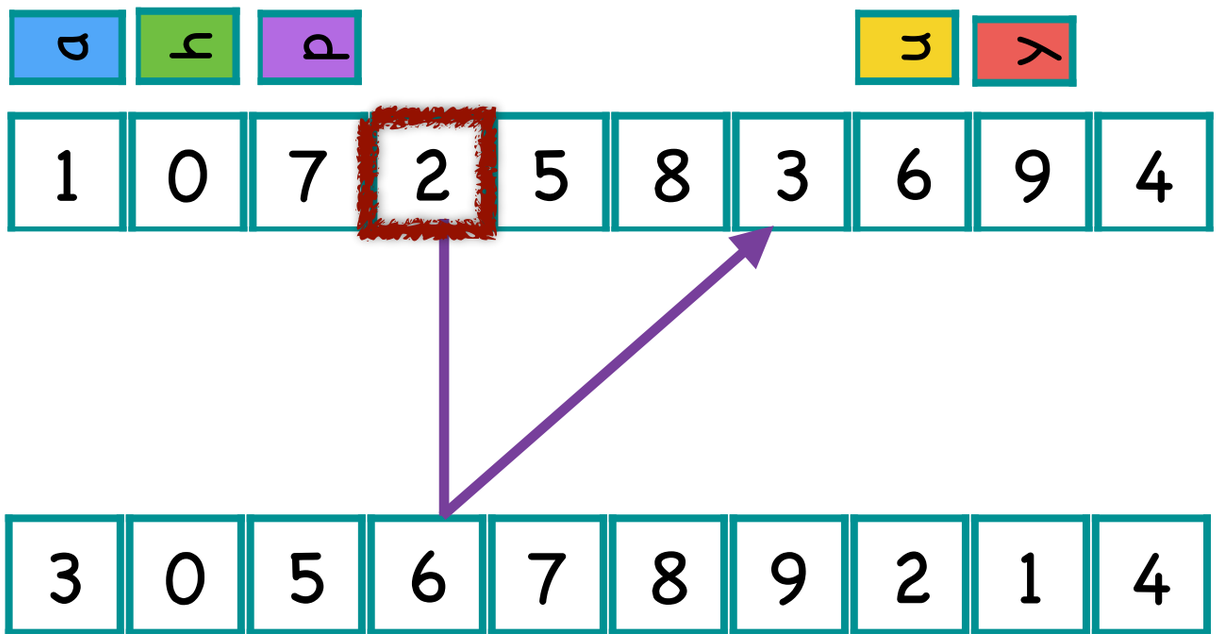
Problem: How to find unsampled values?

Solution:Follow NextCharIdx pointers until you hit a sampled value

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1		7		5		3		9	



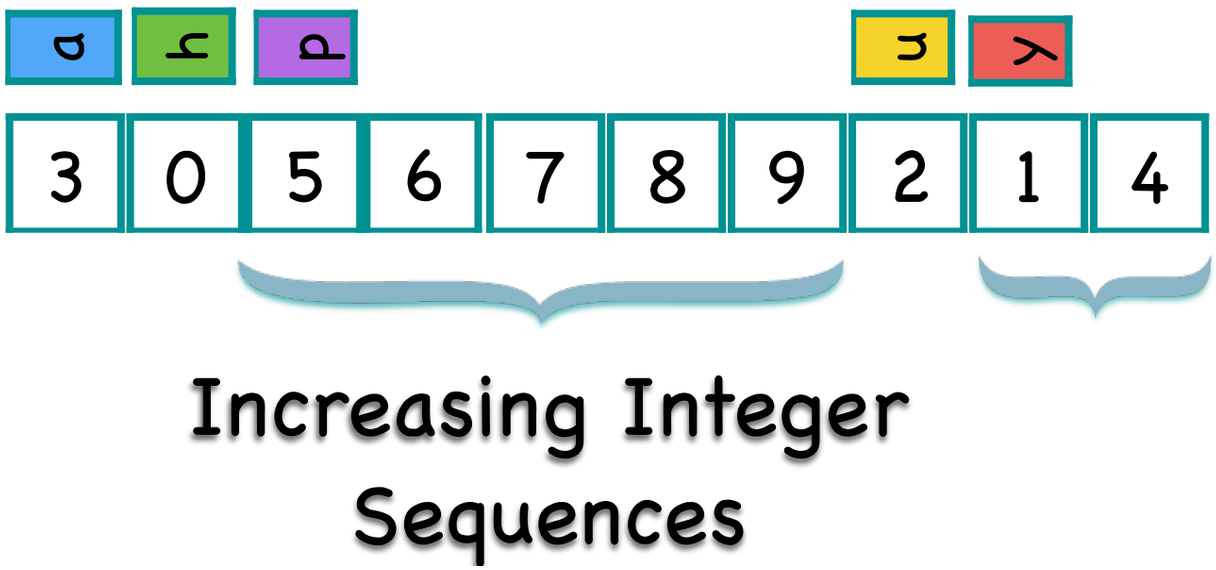
Problem: How to find unsampled values?

Solution:Follow NextCharIdx pointers until you hit a sampled value

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1		7		5		3		9	

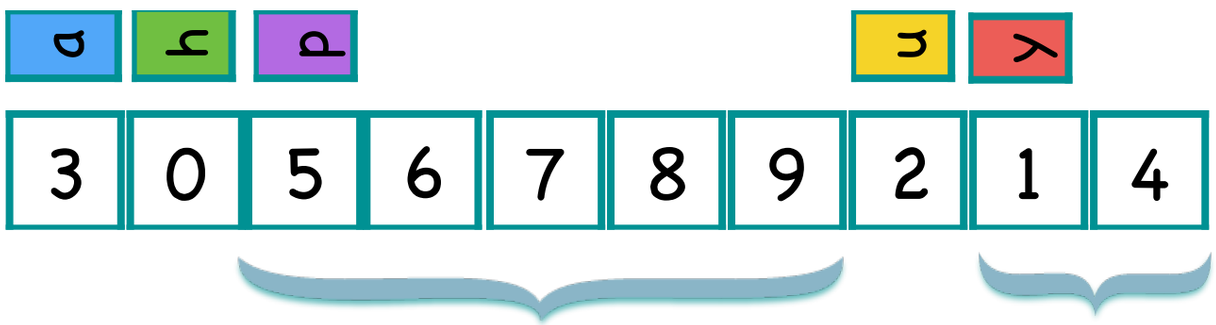


Increasing Integer Sequences

Succinct Data Representation

0	1	2	3	4	5	6	7	8	9
h	a	p	p	y	p	u	p	p	y

1		7		5		3		9	

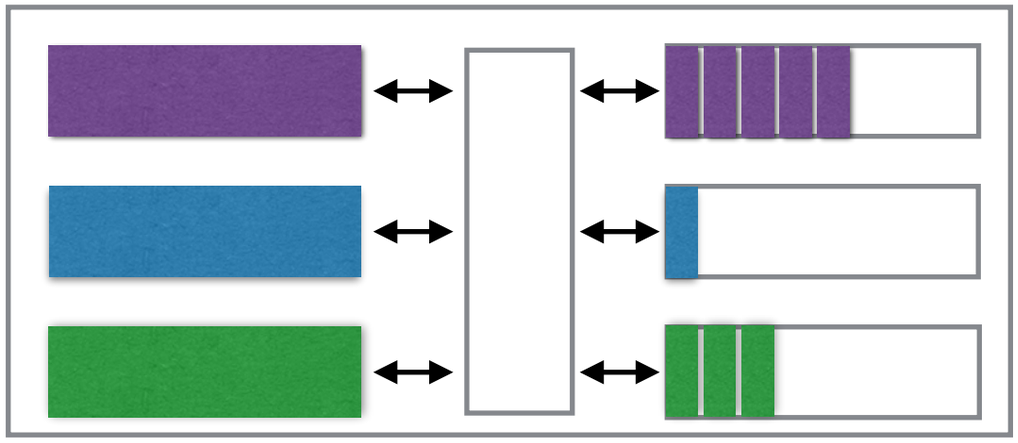


Increasing Integer Sequences

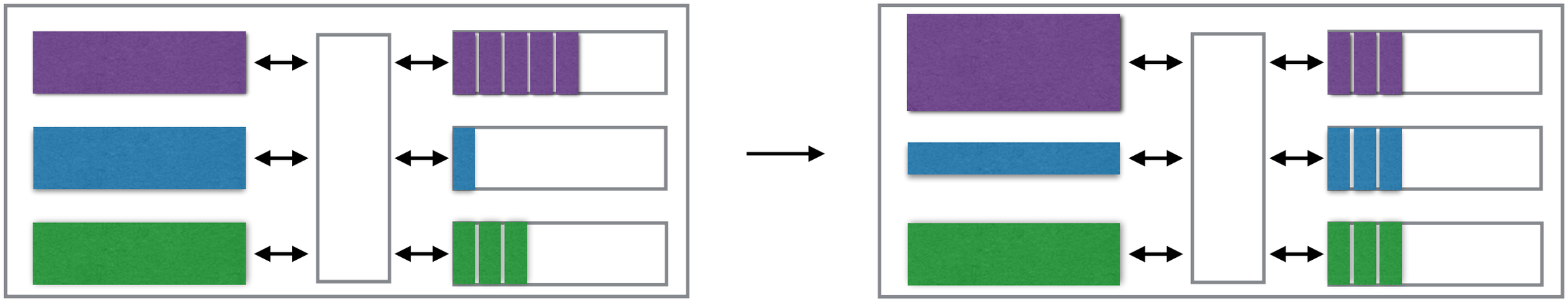
Can be compressed!

Technical **Details**

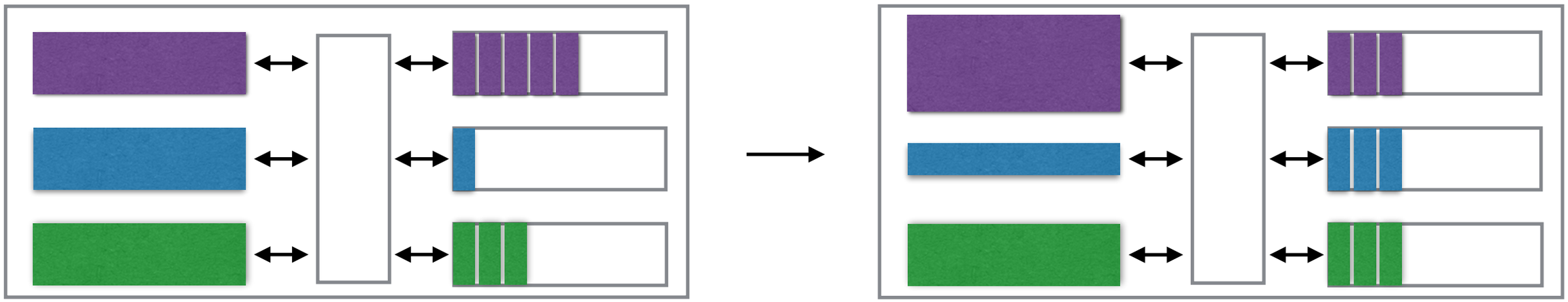
Technical **Details**



Technical **Details**

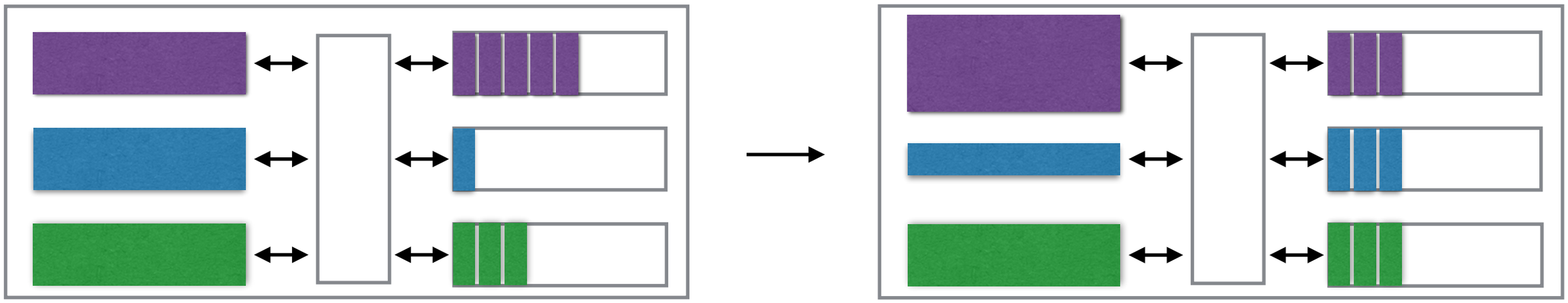


Technical **Details**



- How should partitions share cache on a server?

Technical **Details**



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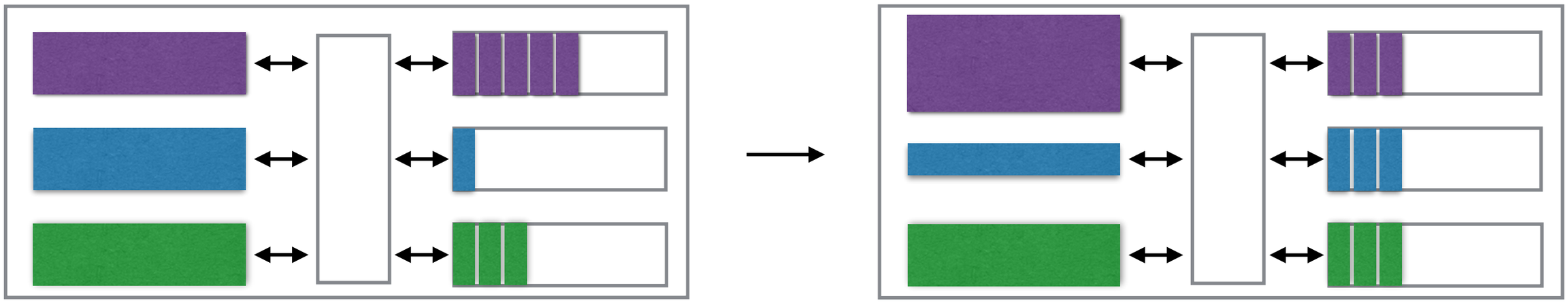

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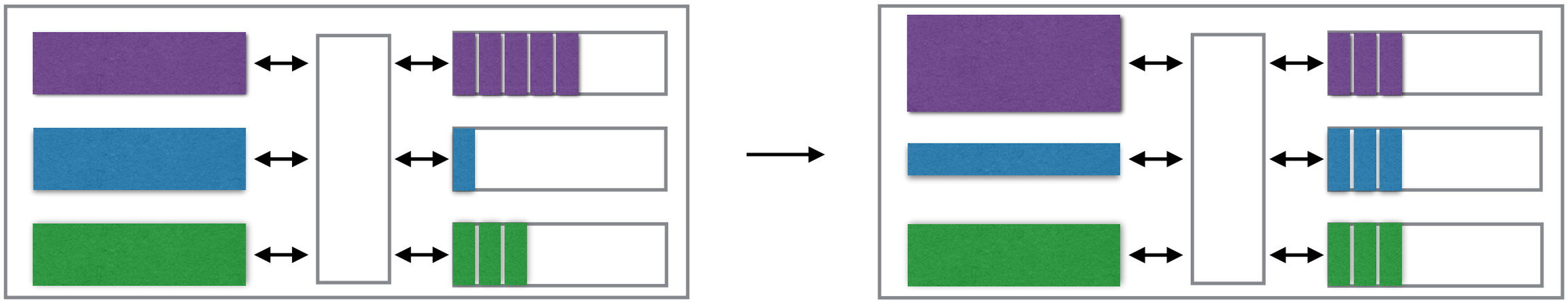

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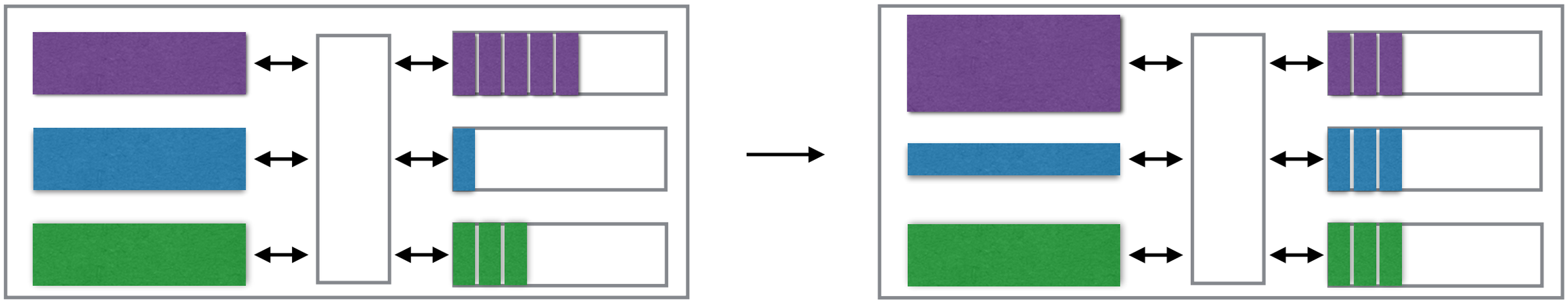

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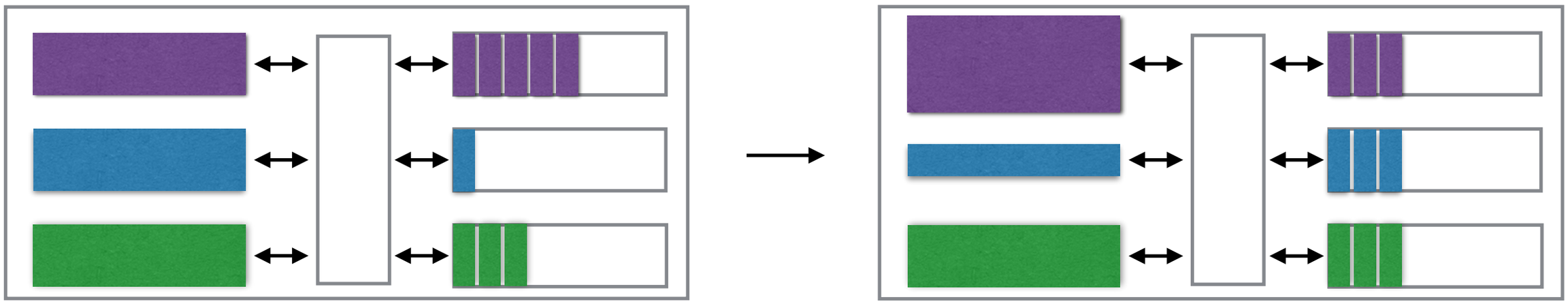

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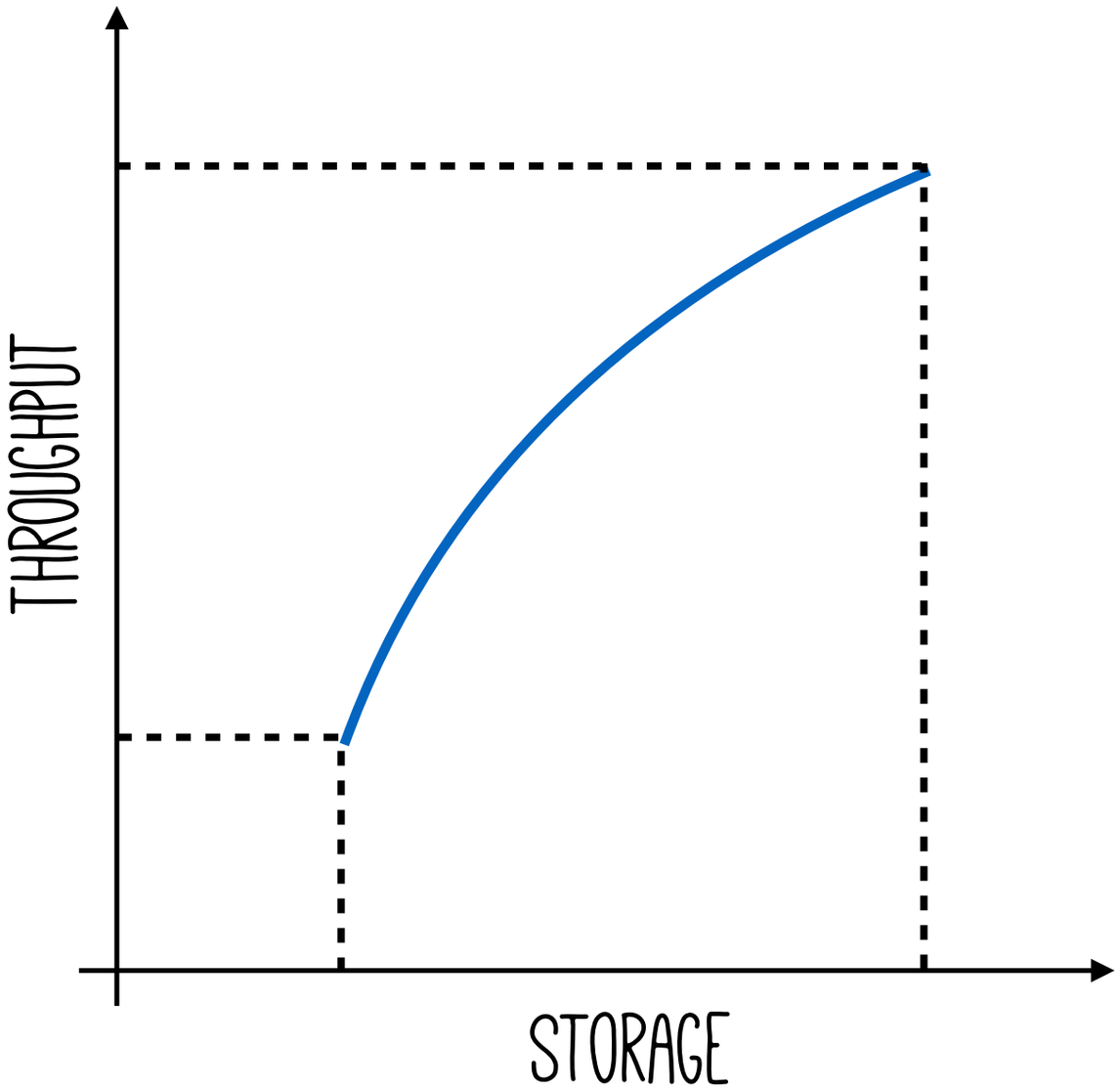
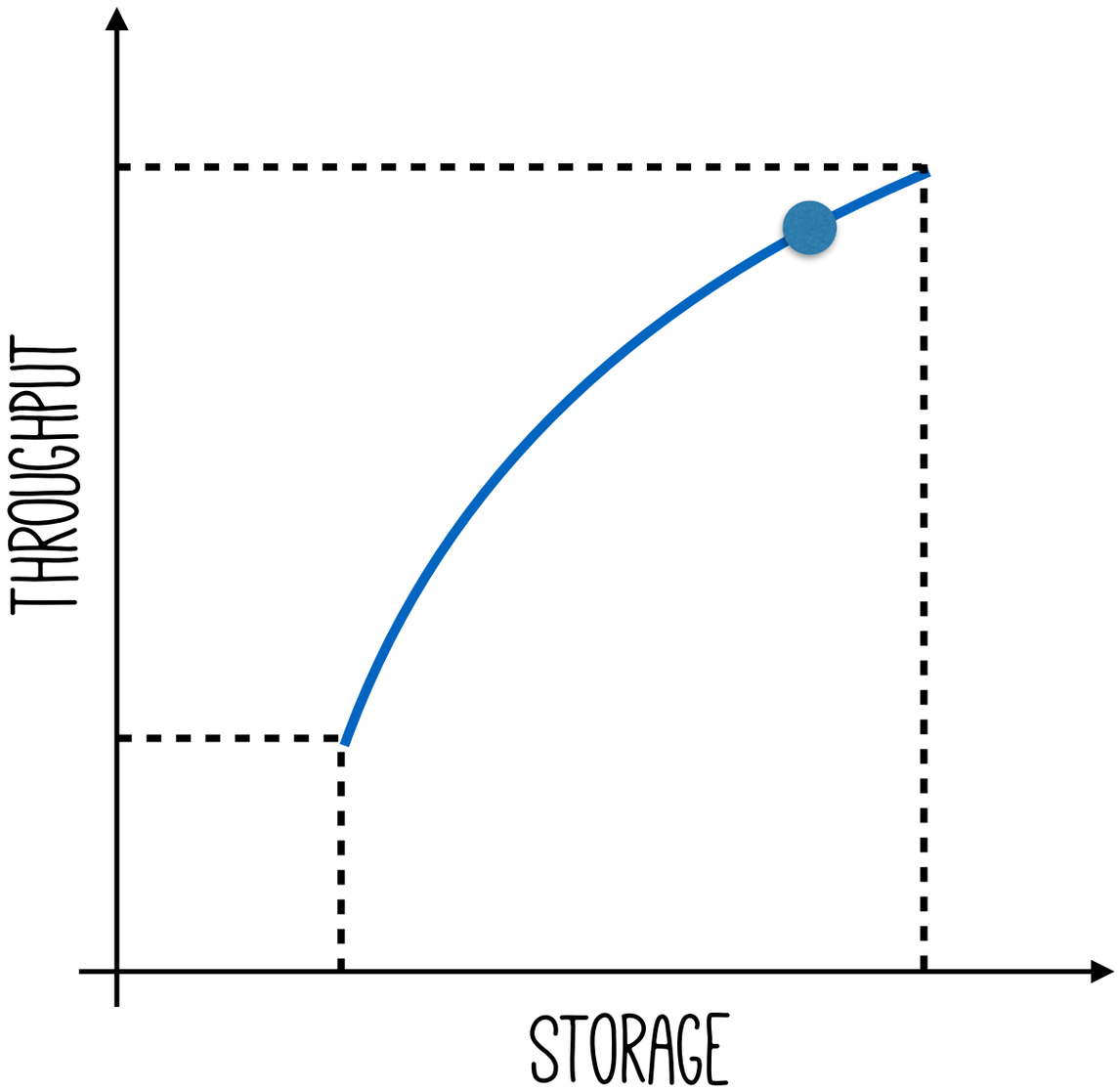
Unified Solution: Back-pressure style scheduling

Cache proportional to load, without explicit coordination


THROUGHPUT
STORAGE



Dynamic Navigation

of tradeoff curve

Assumptions & Limitations

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- Functionality close to state-of-the-art NoSQL stores

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- System is not network-bottlenecked

  [MICA, NSDI'14] → True for most data stores today

Applications

Applications

Look at classical systems problems through a new “lens”

Spatial Skew

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Load distribution across partitions is heavily skewed

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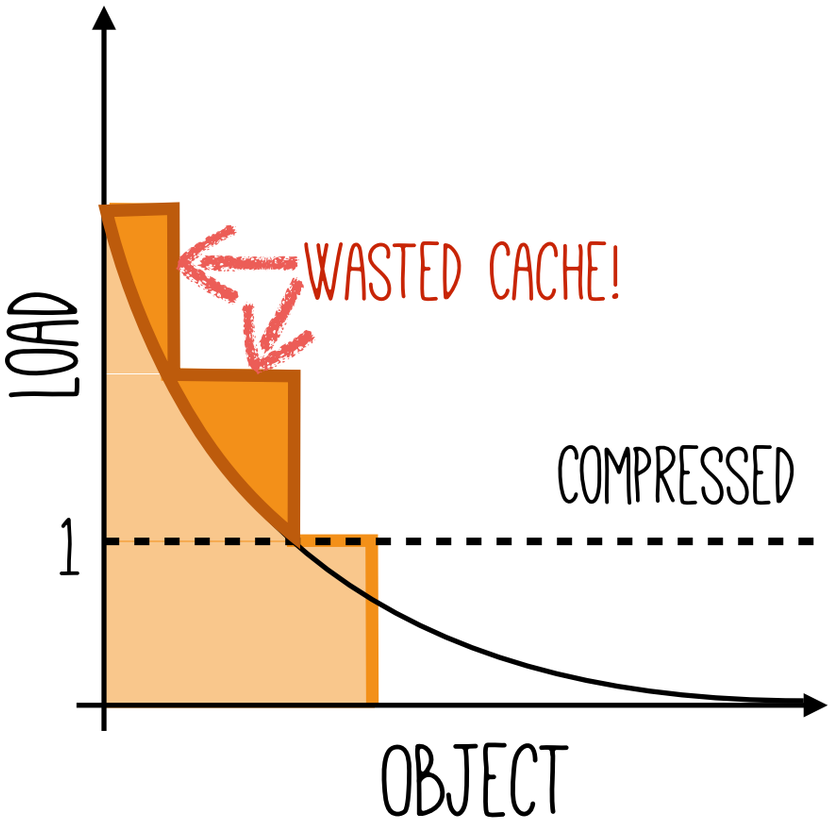
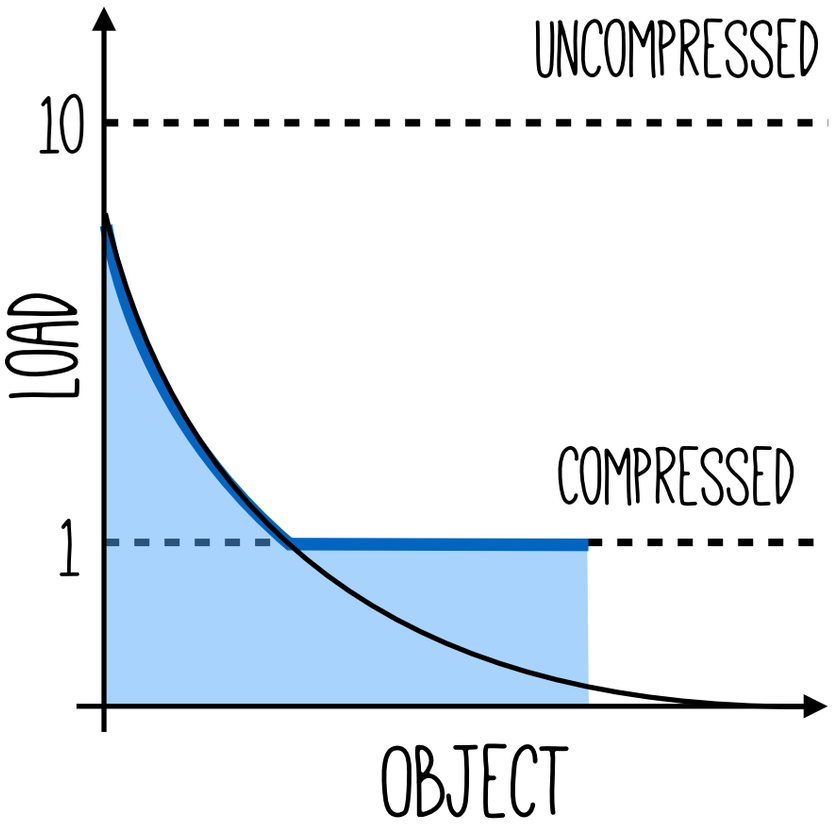


Selective Replication

#Replicas **α** Load

Spatial Skew

Load distribution across partitions is heavily skewed



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Fractionally change storage just enough to meet load

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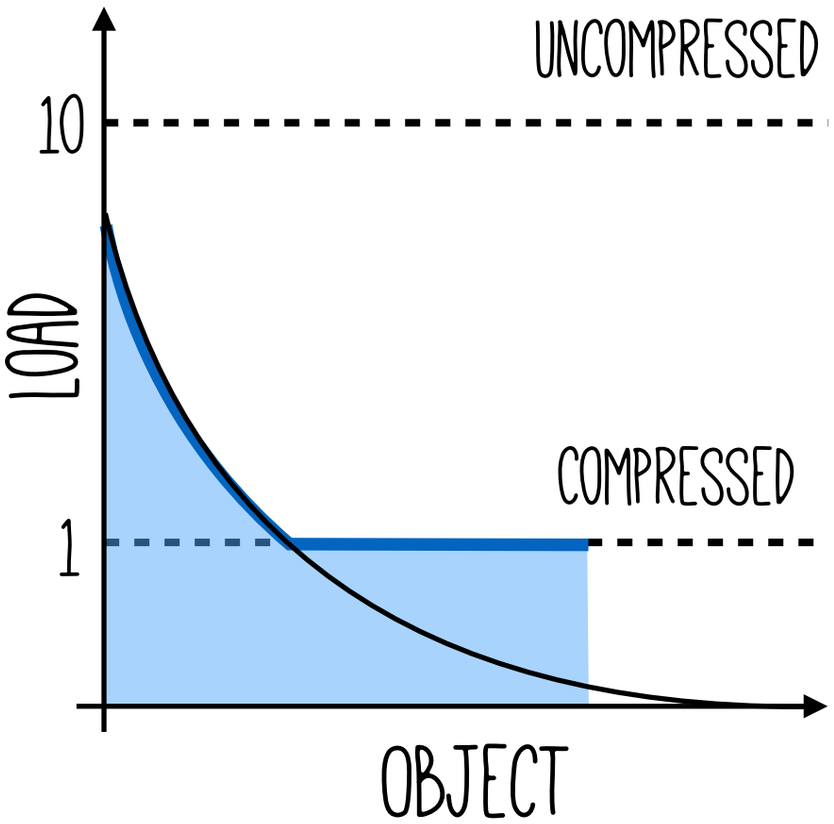

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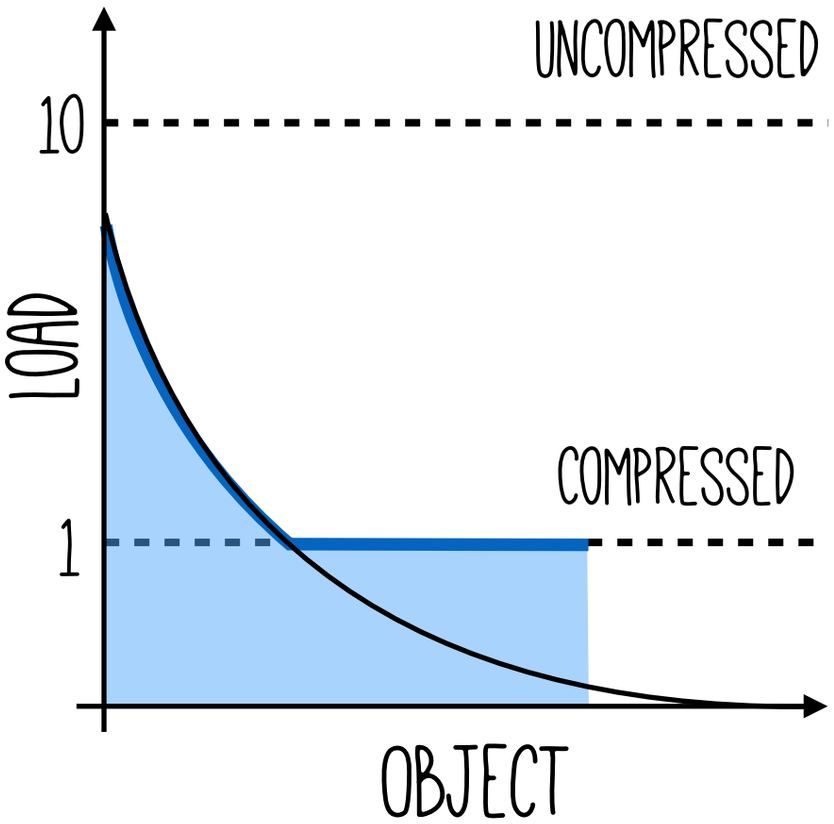

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within 10% of optimal

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Study on Facebook Warehouse Cluster [HotStorage'13]

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Transient failures → 90% of failures

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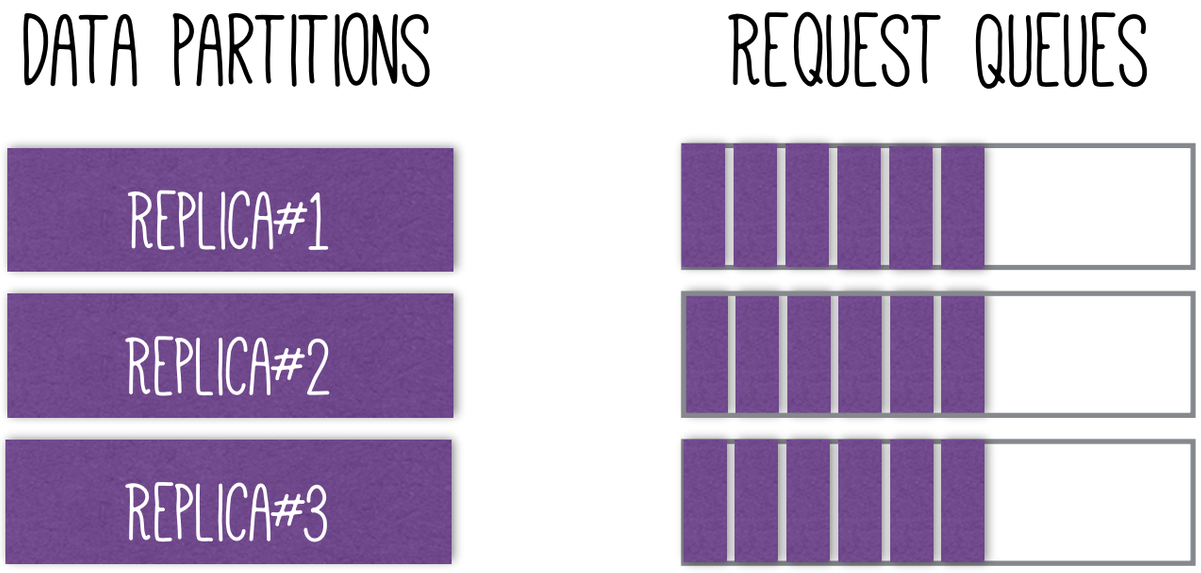

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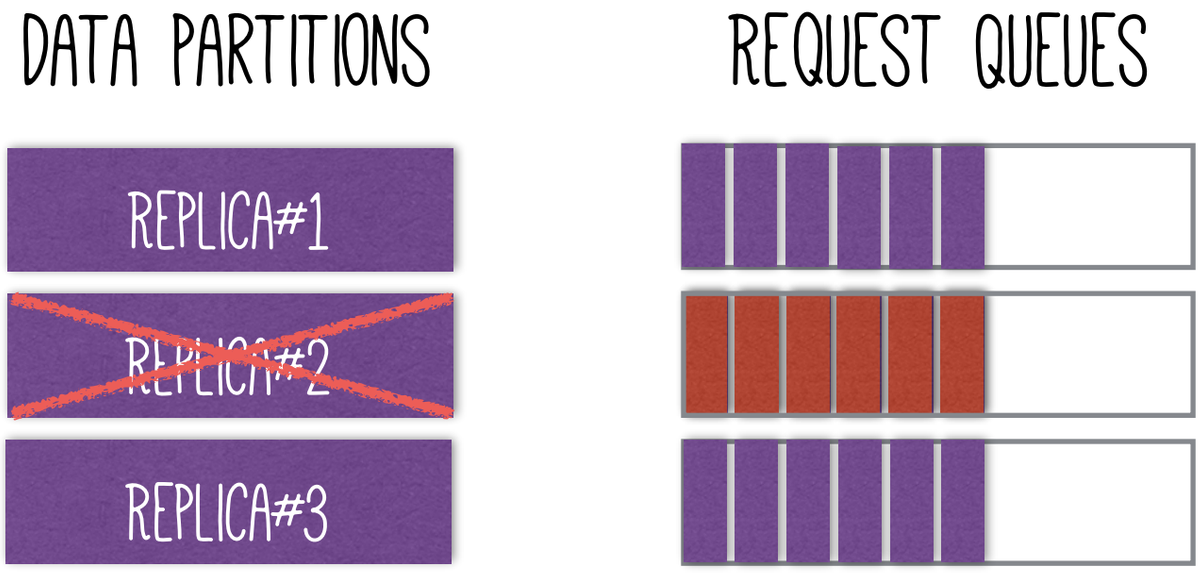

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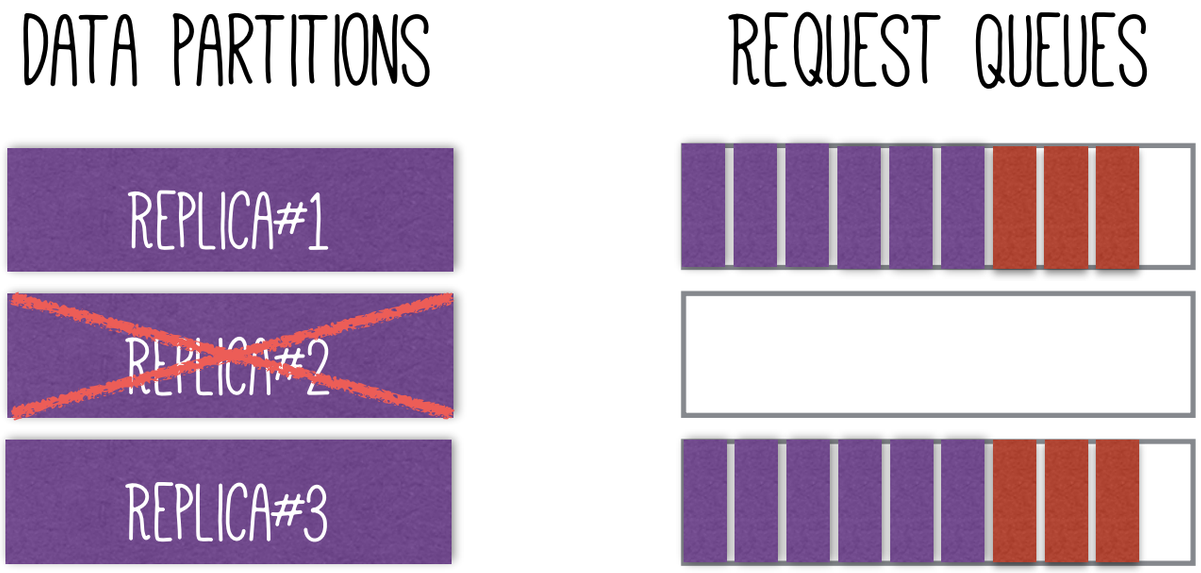

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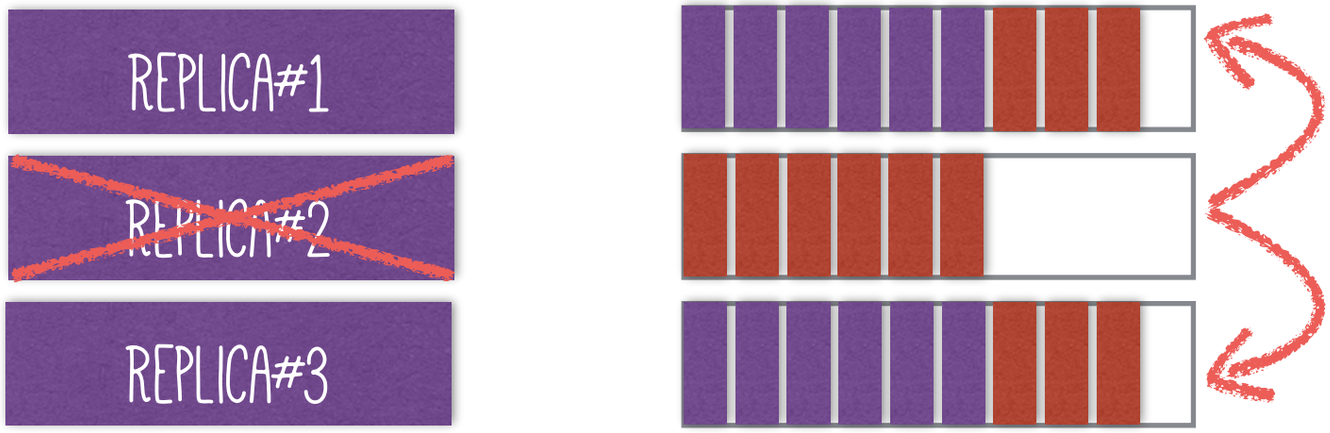

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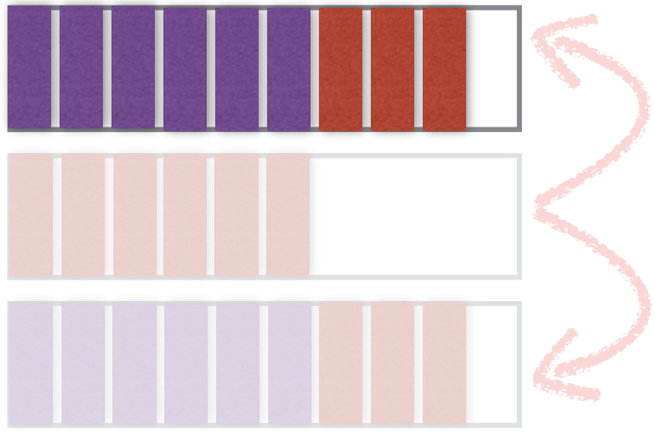

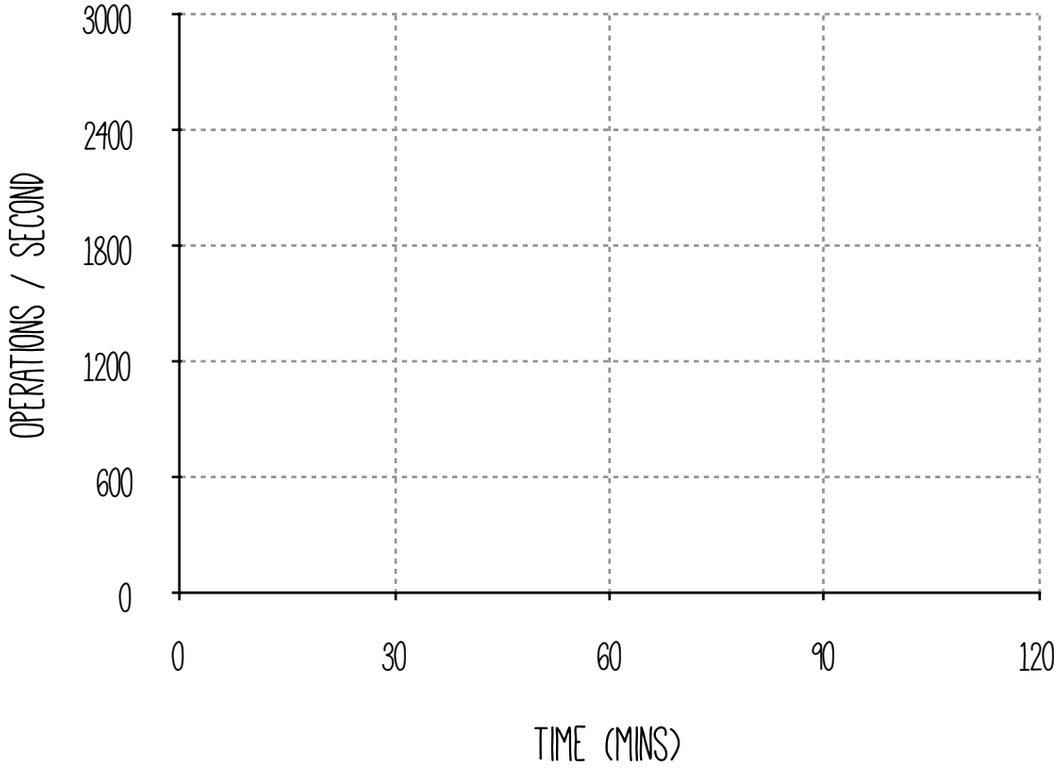

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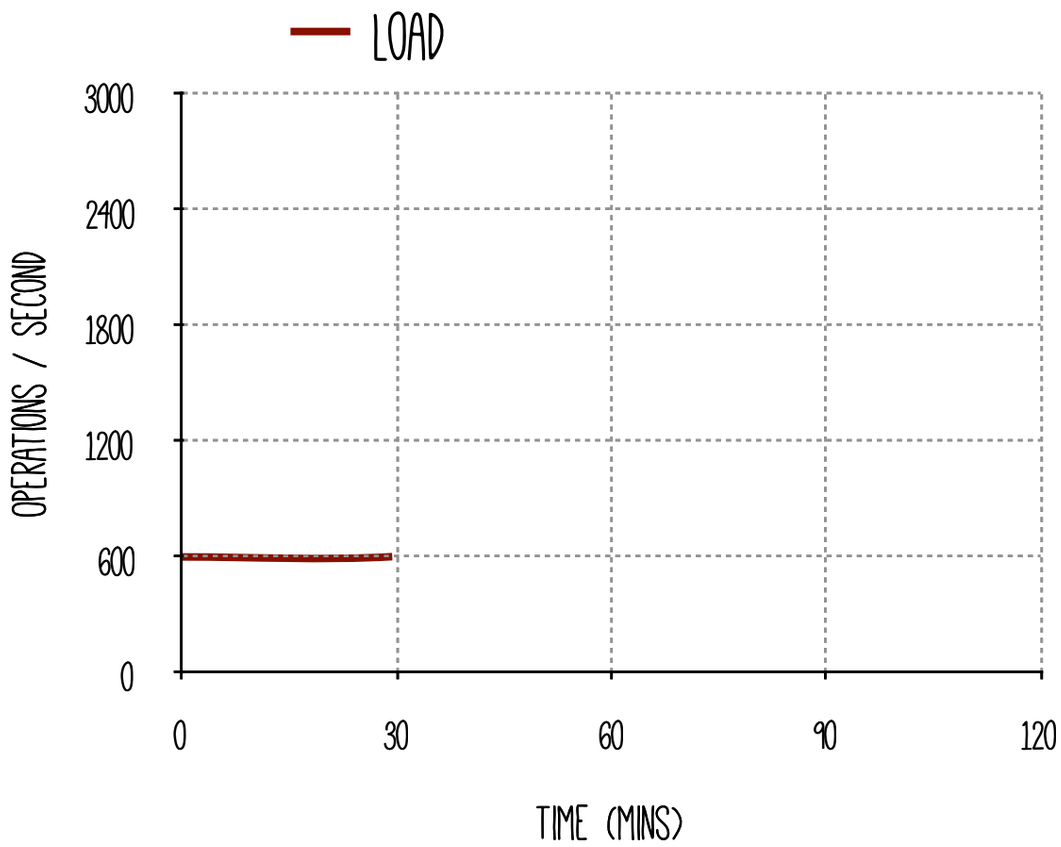

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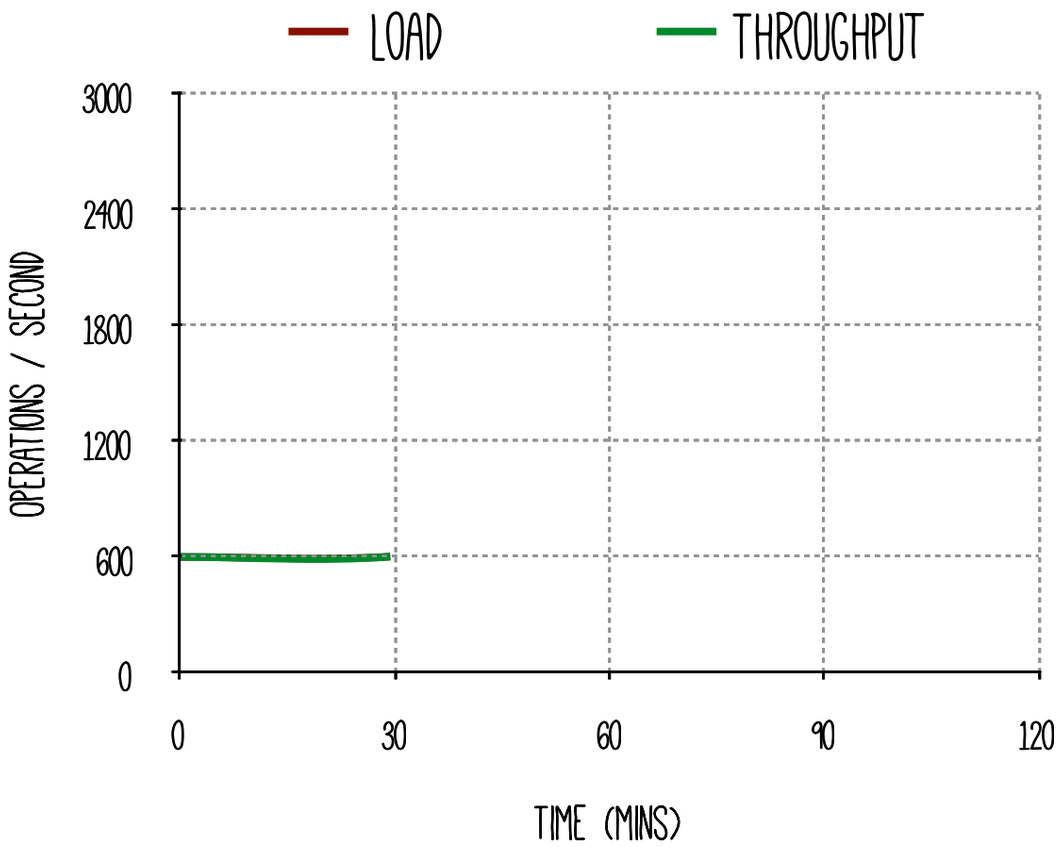

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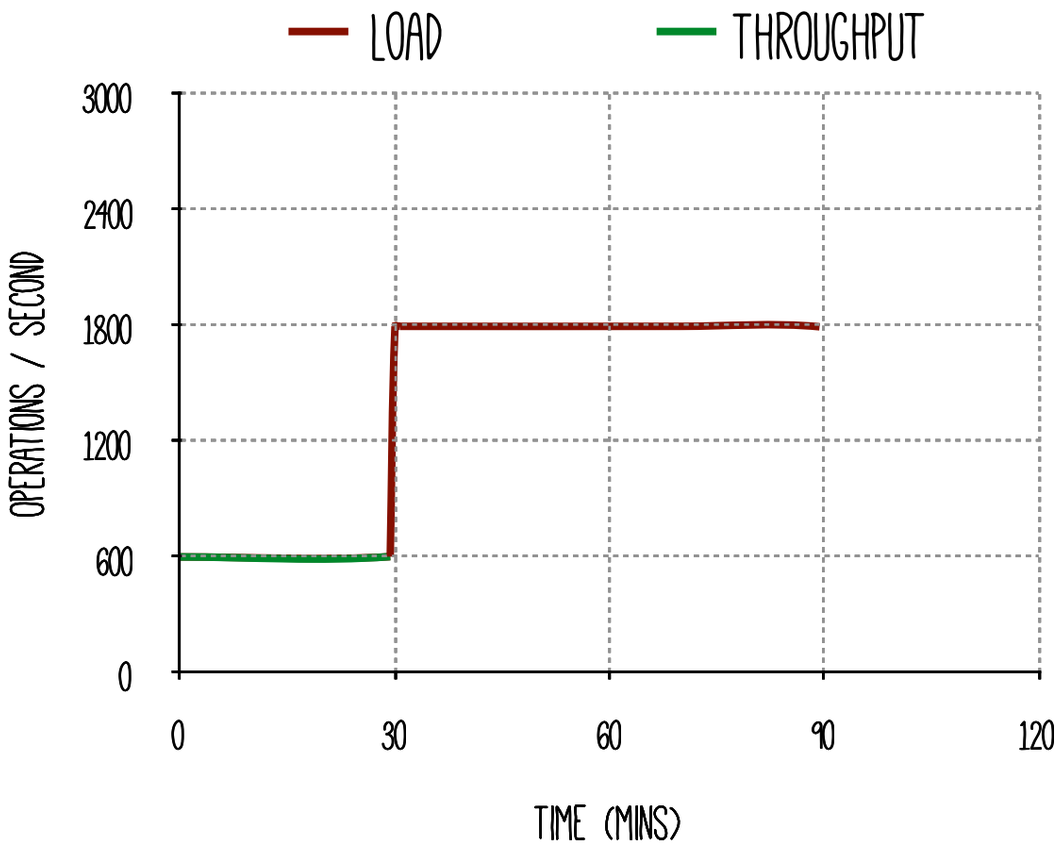

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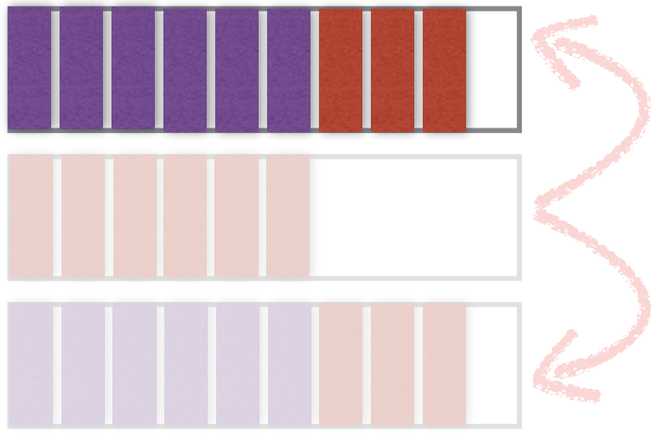

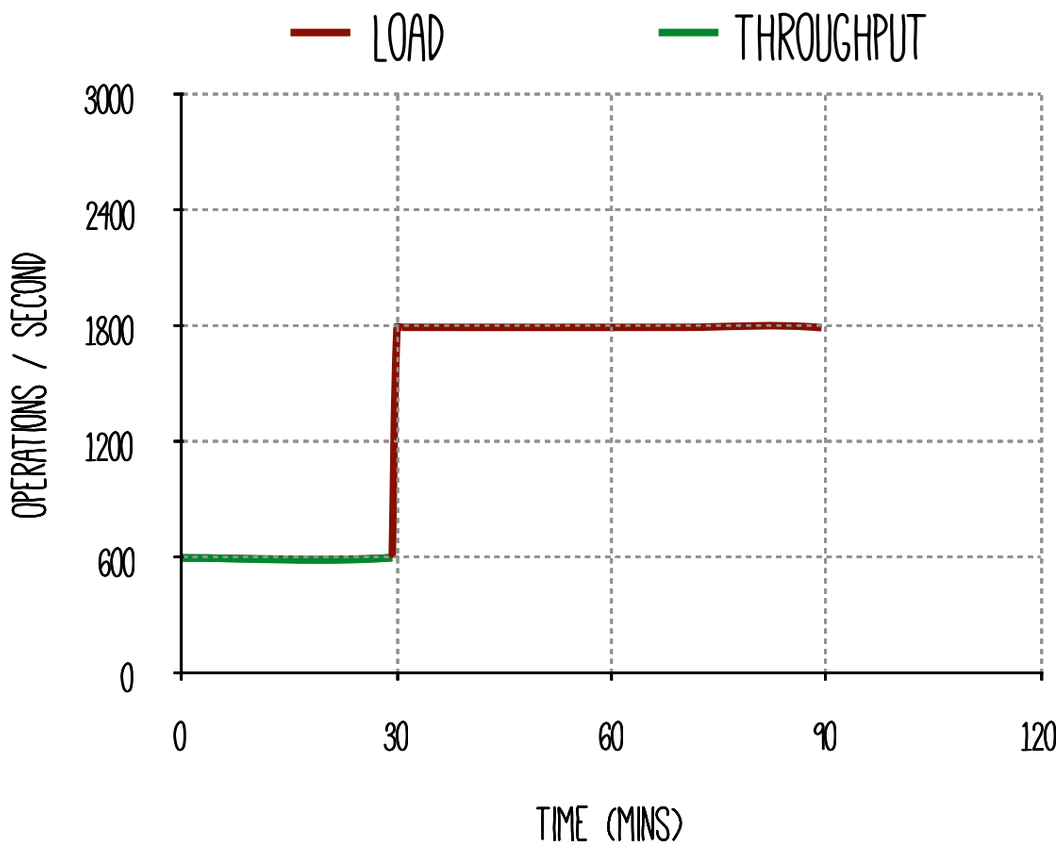

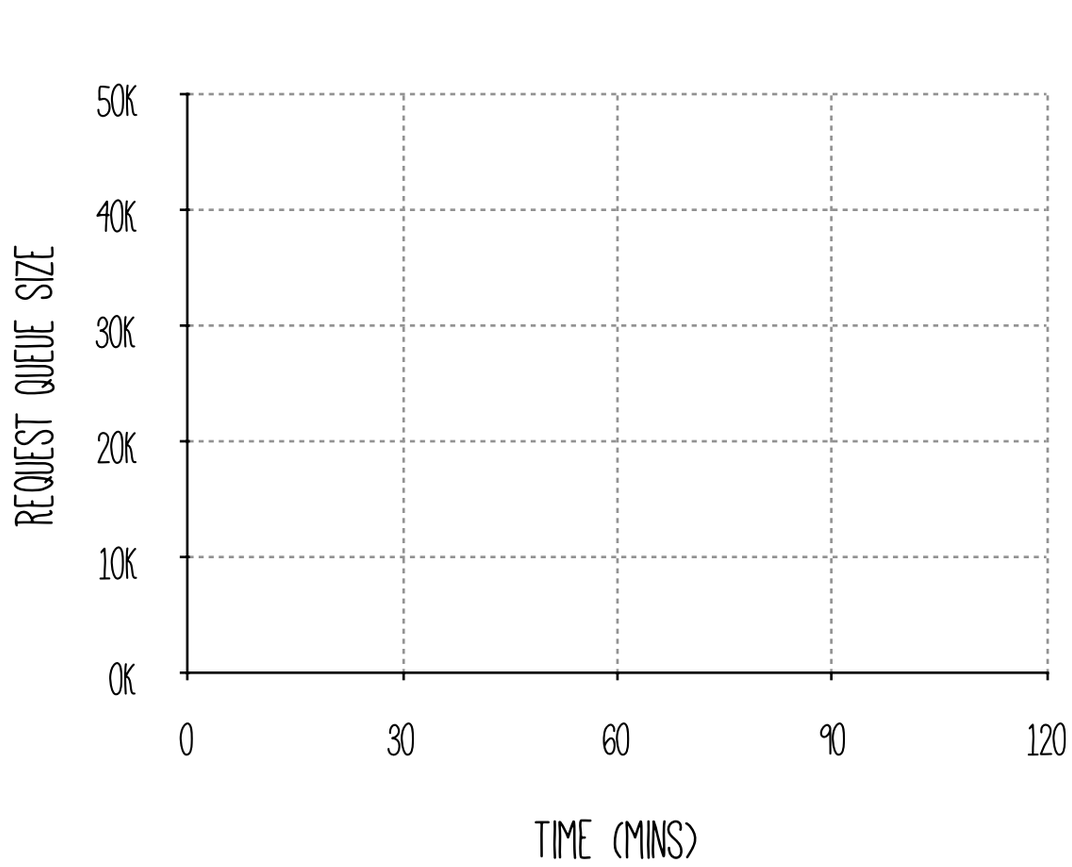

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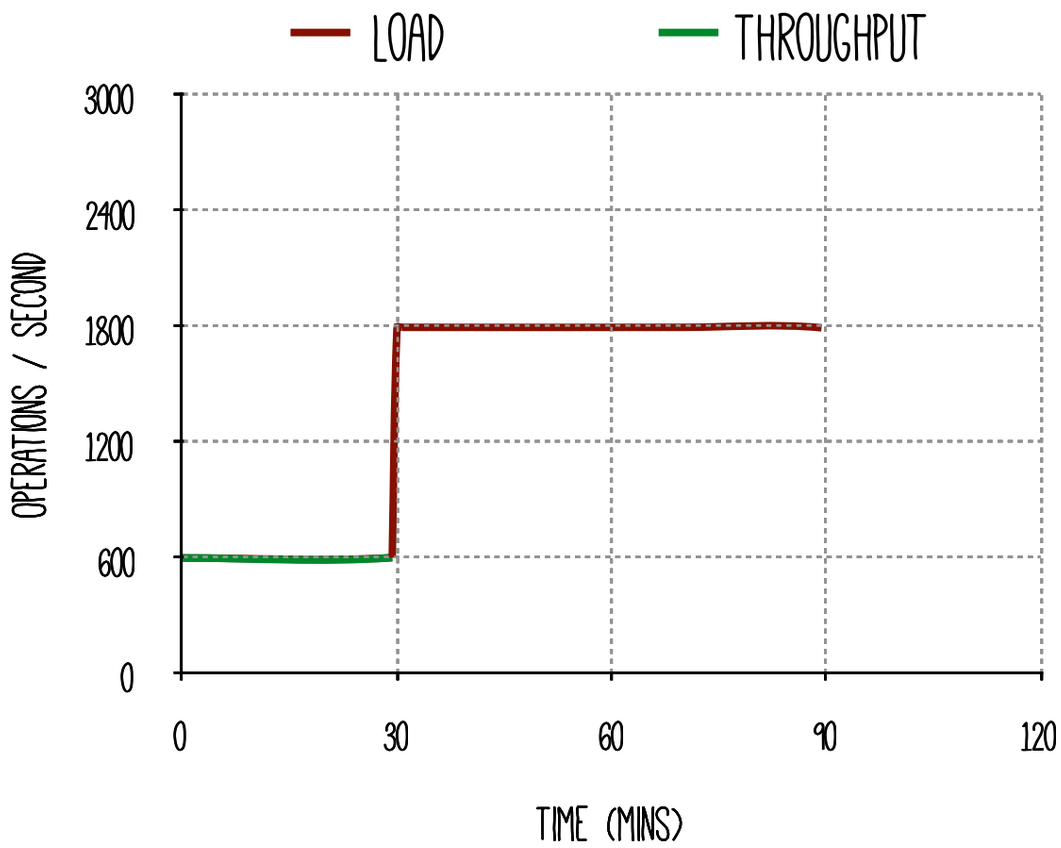

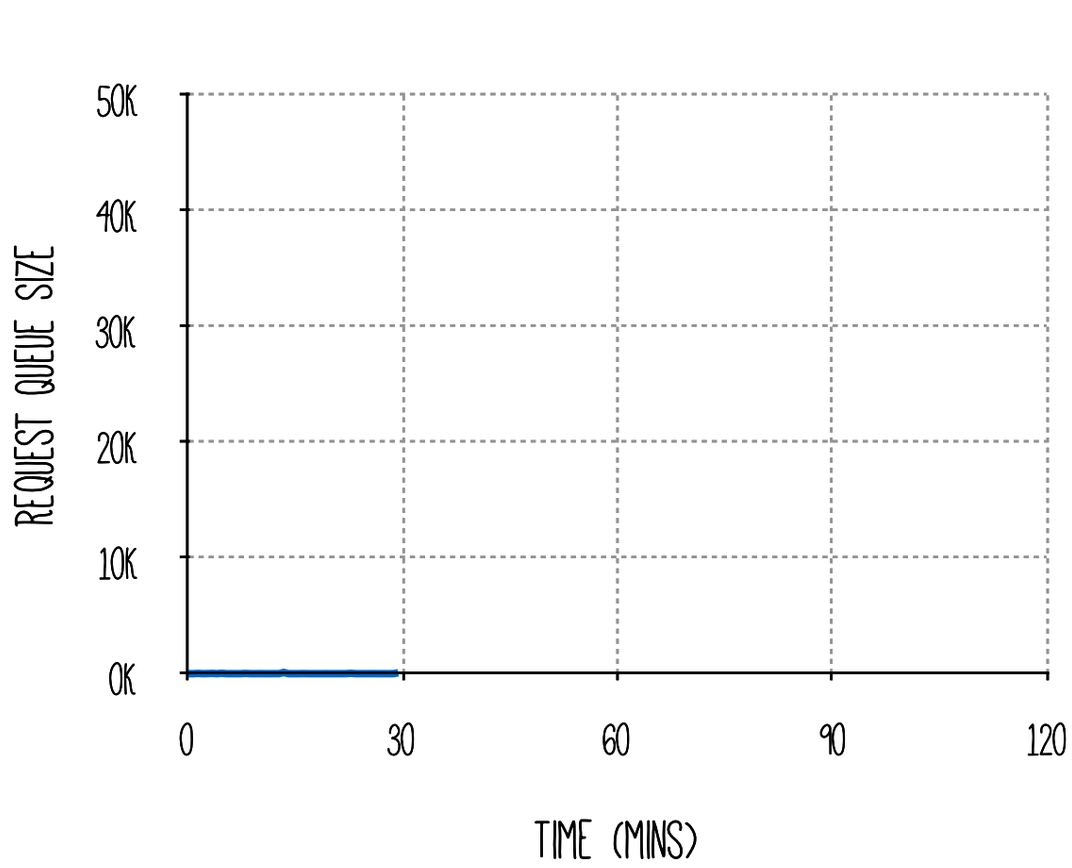

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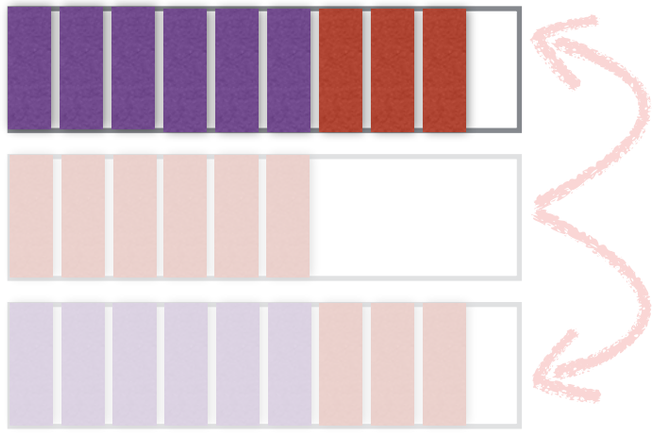

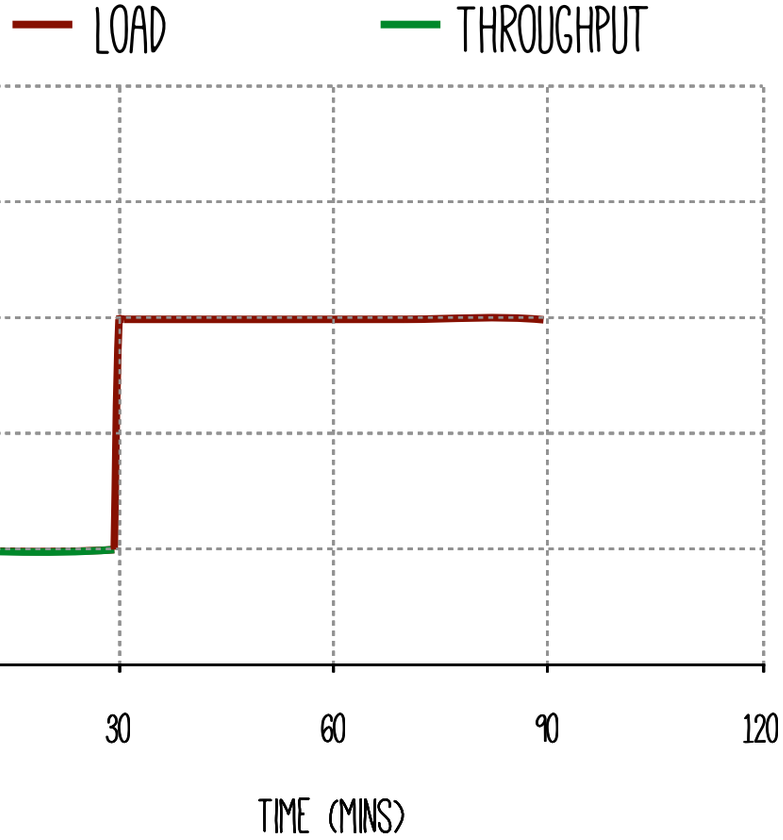

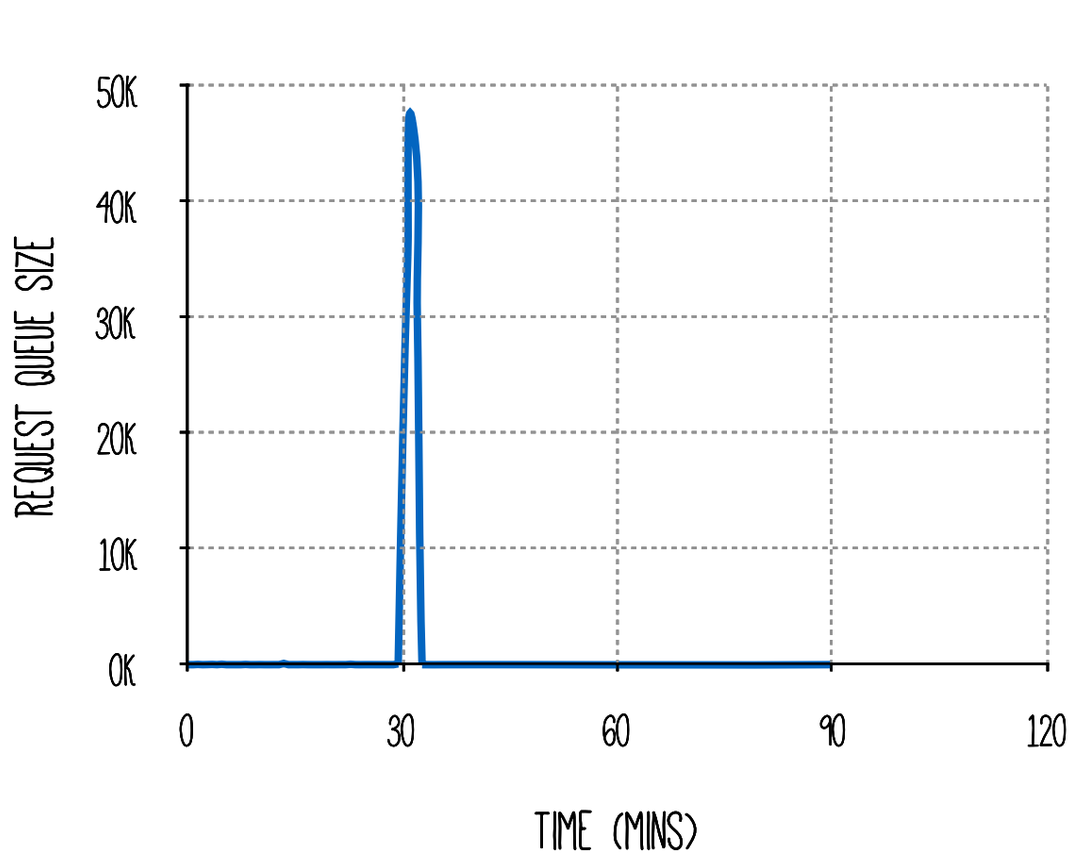

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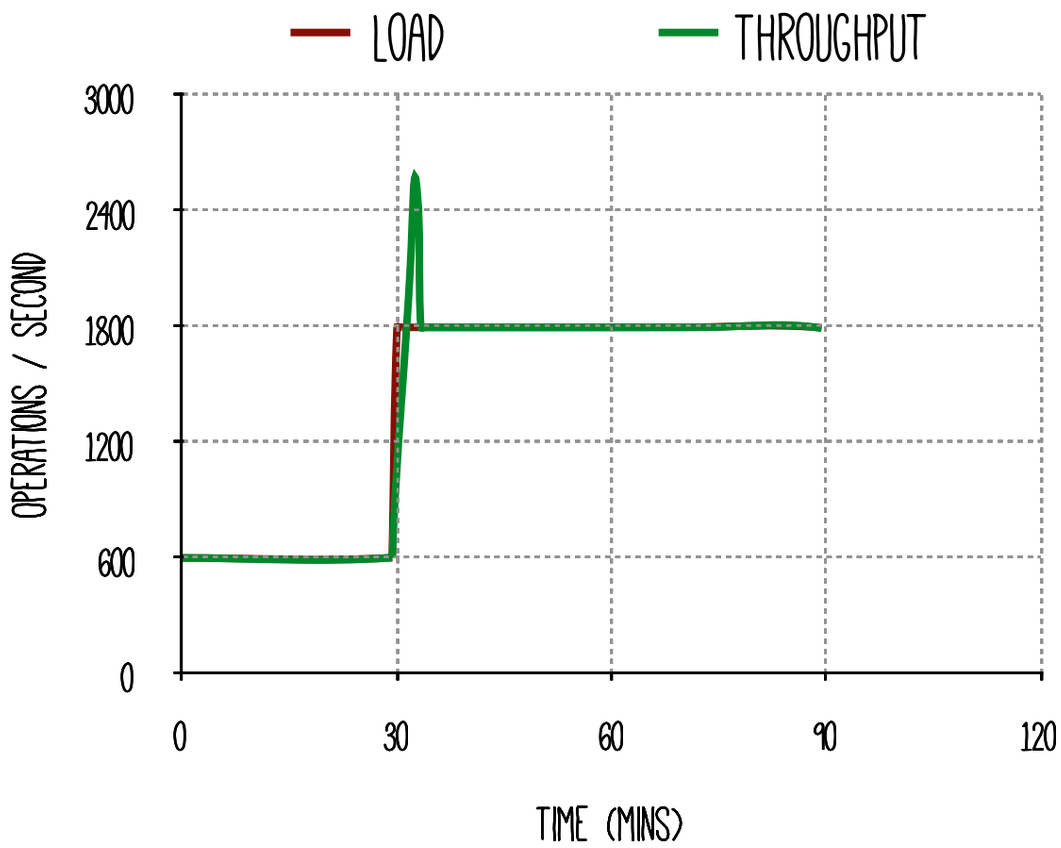

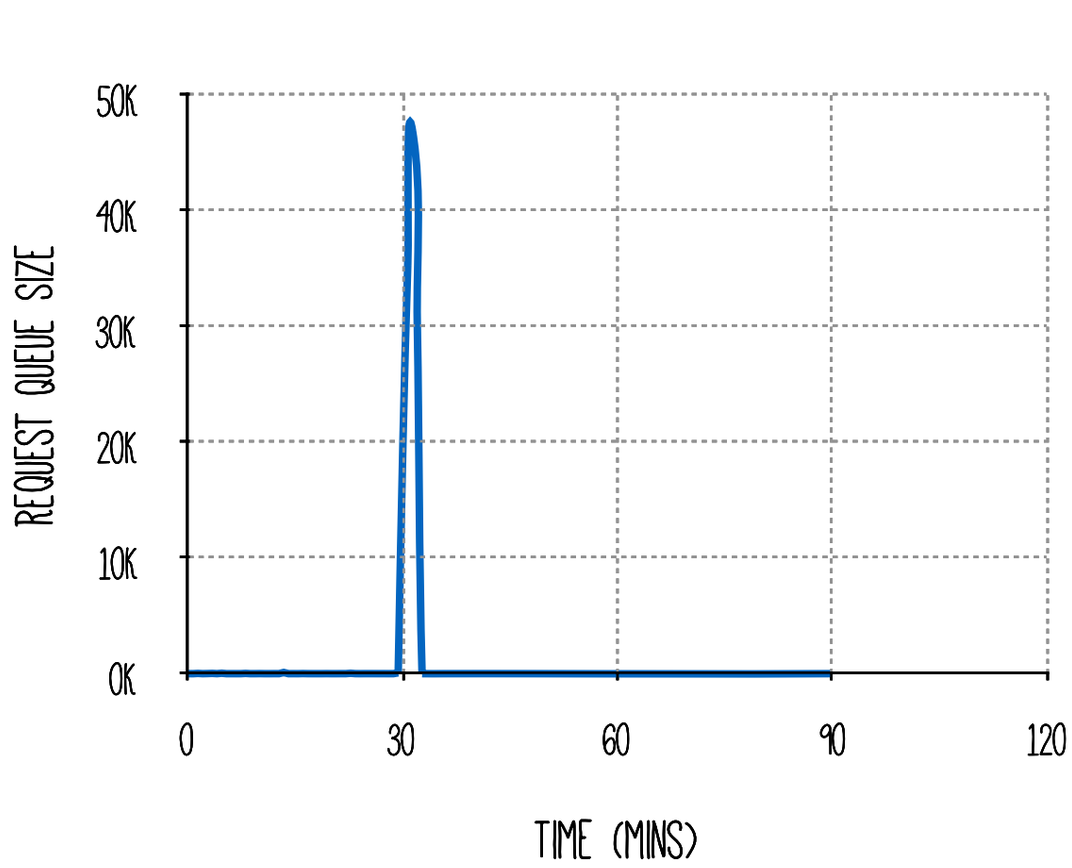

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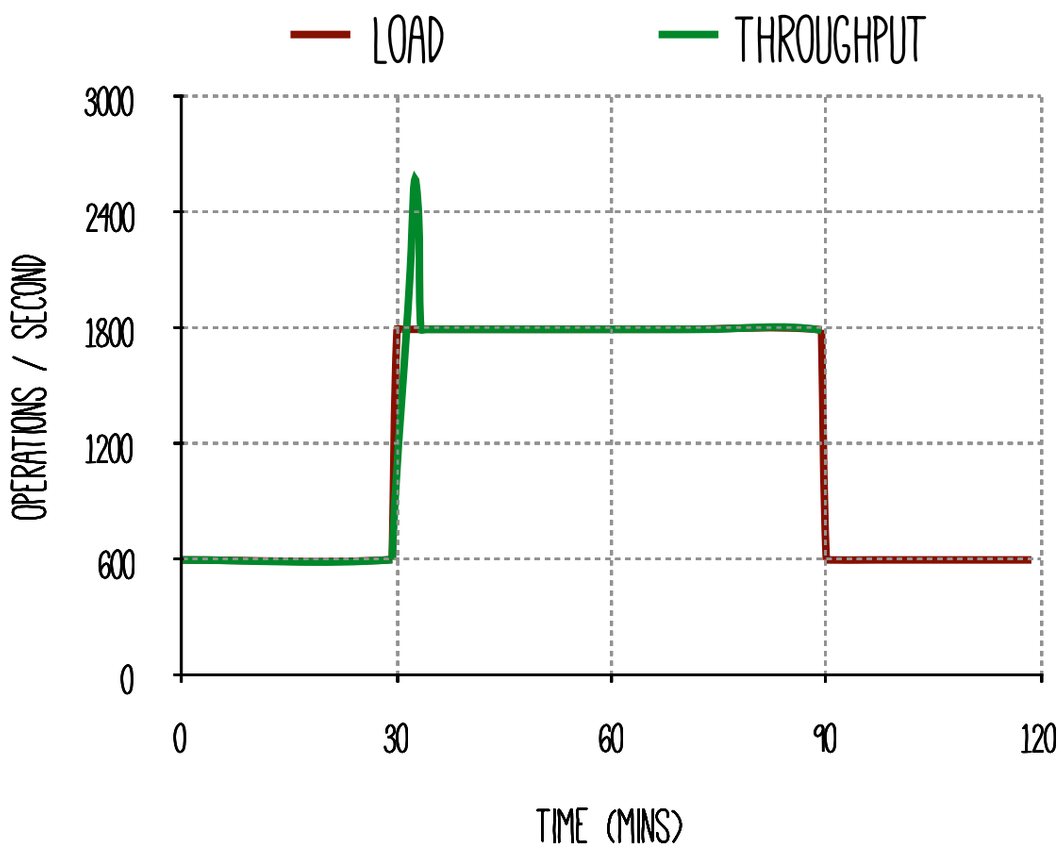

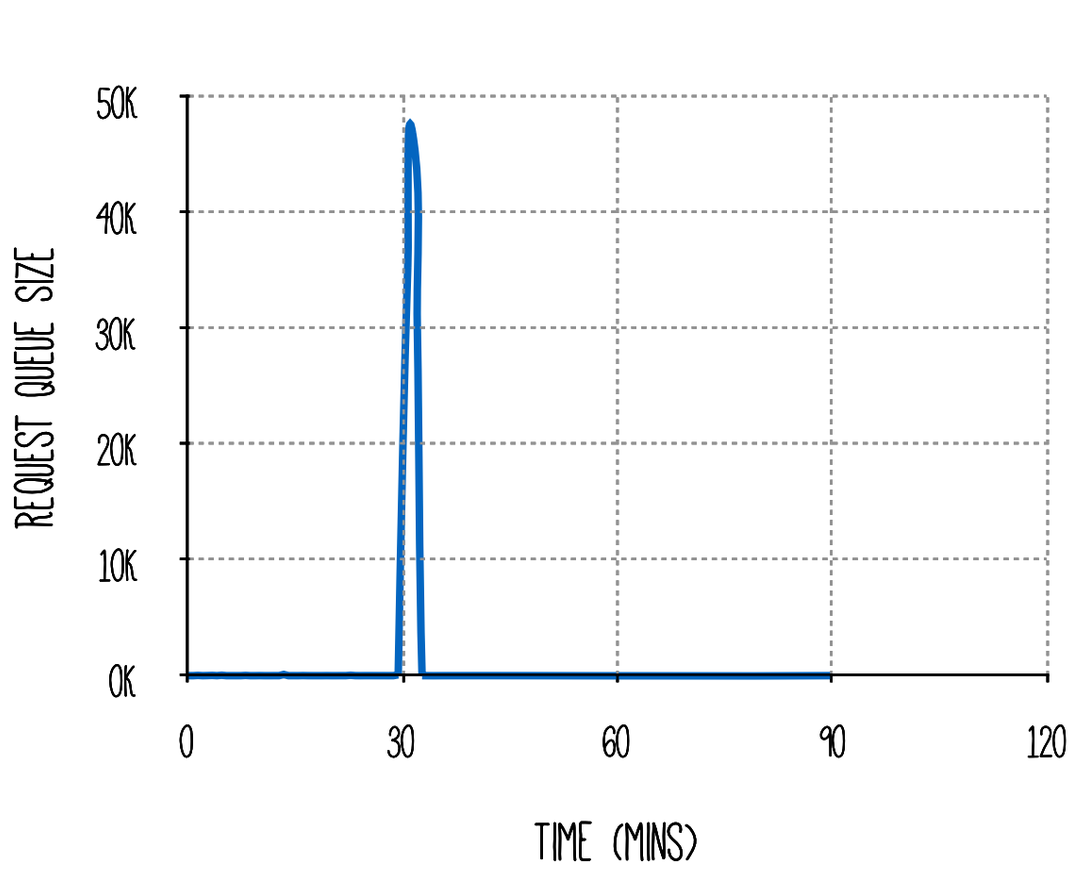

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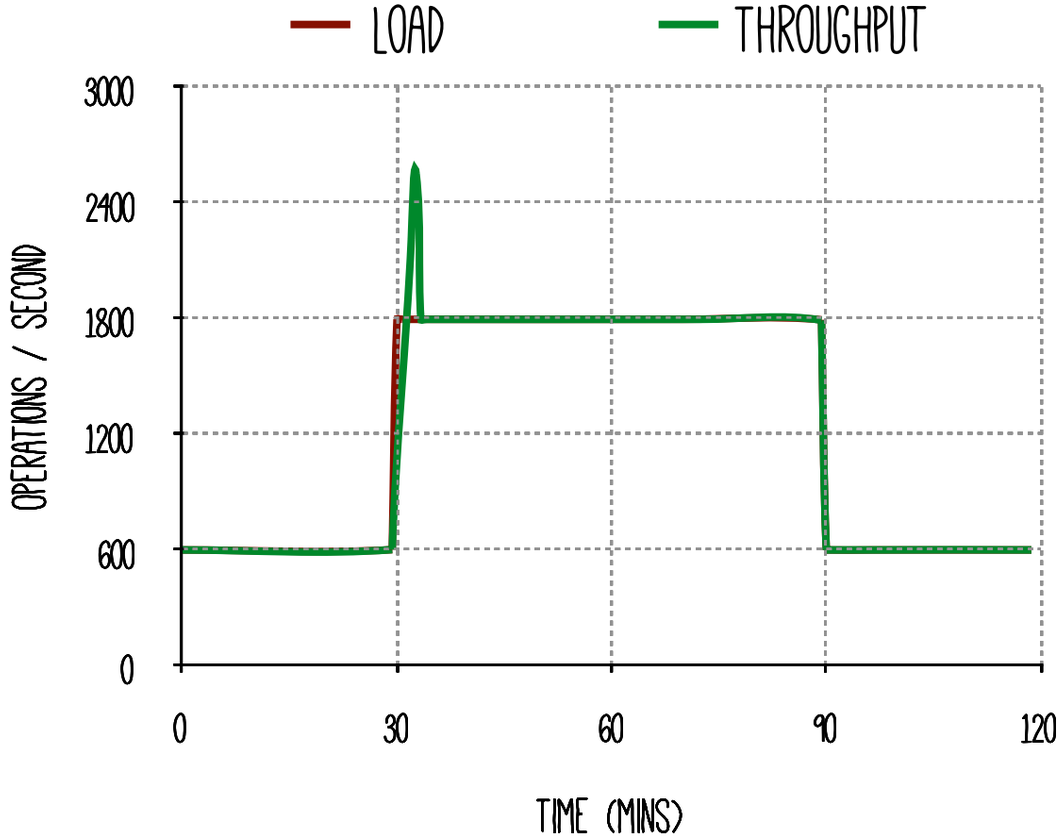

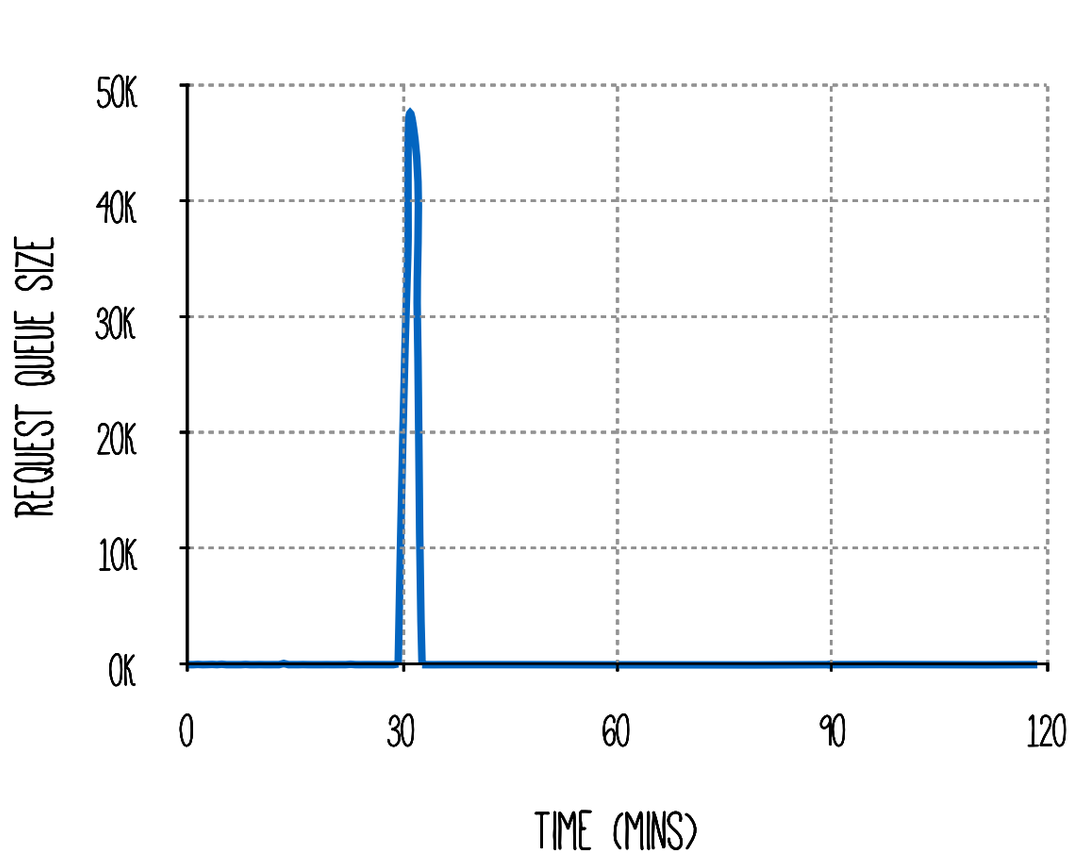

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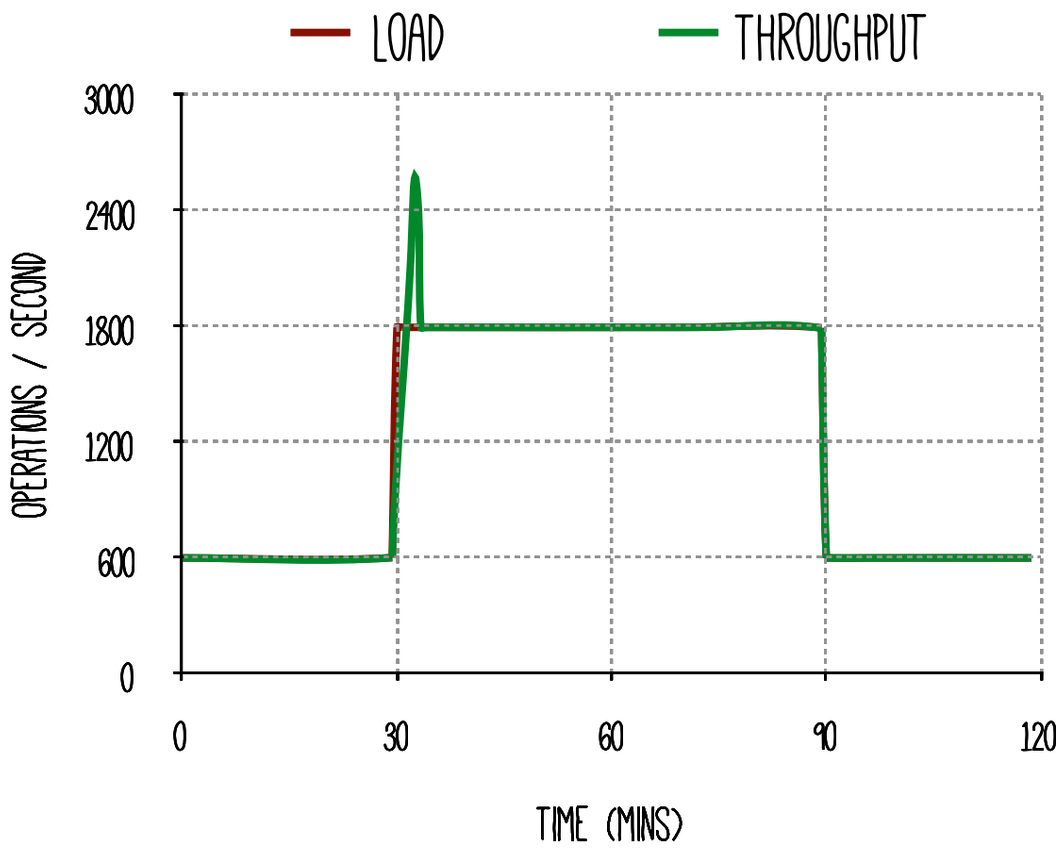
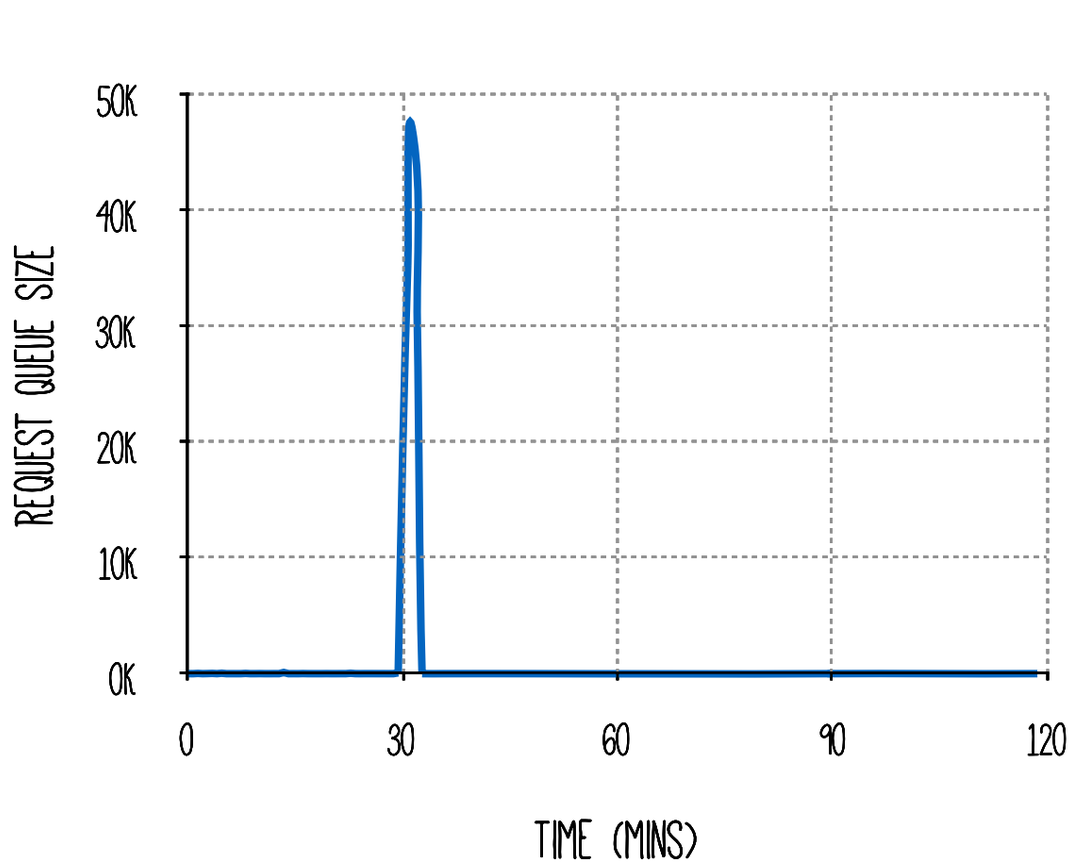
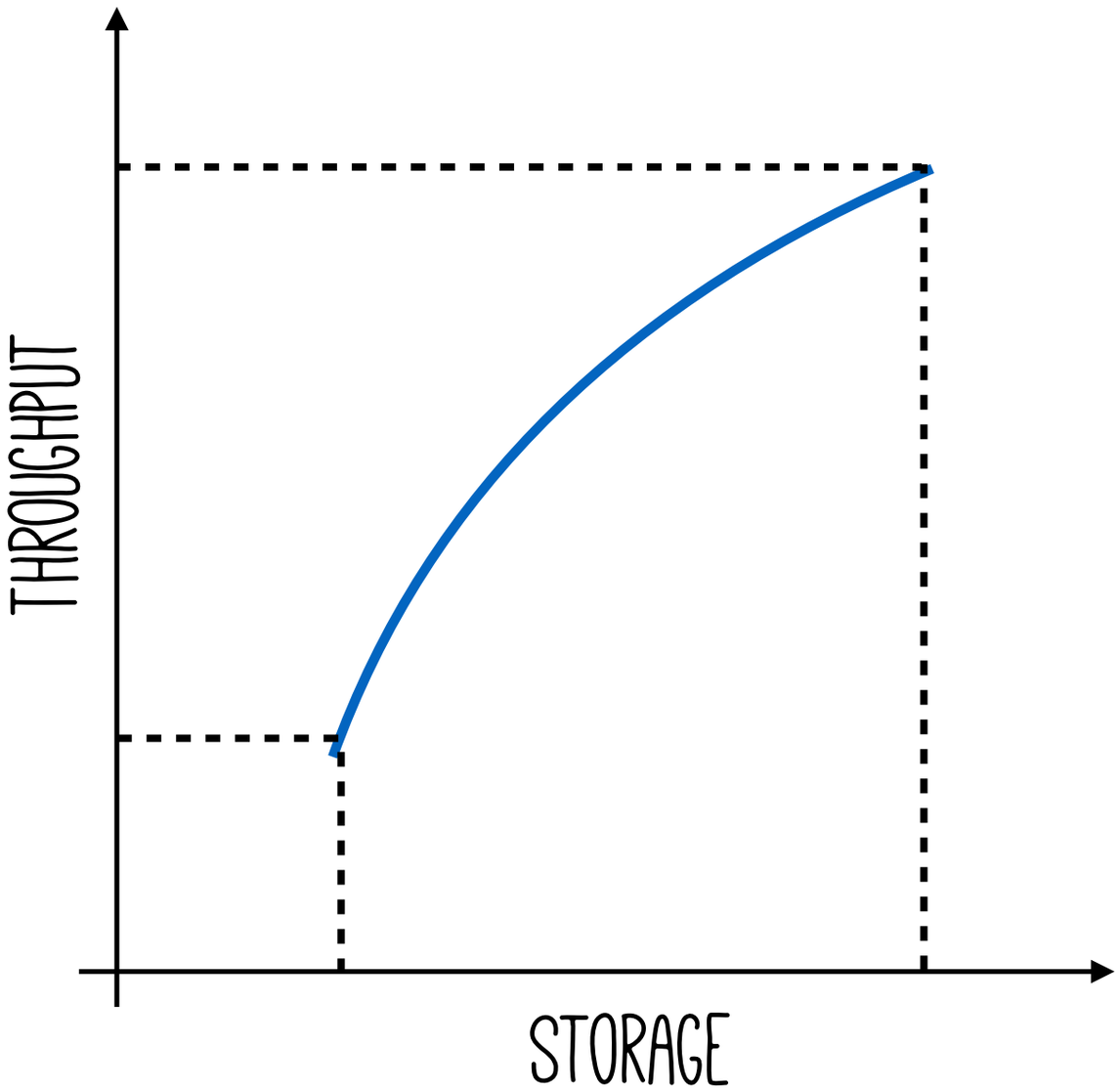




Adapts to 3x higher load in < 5 mins

Summary



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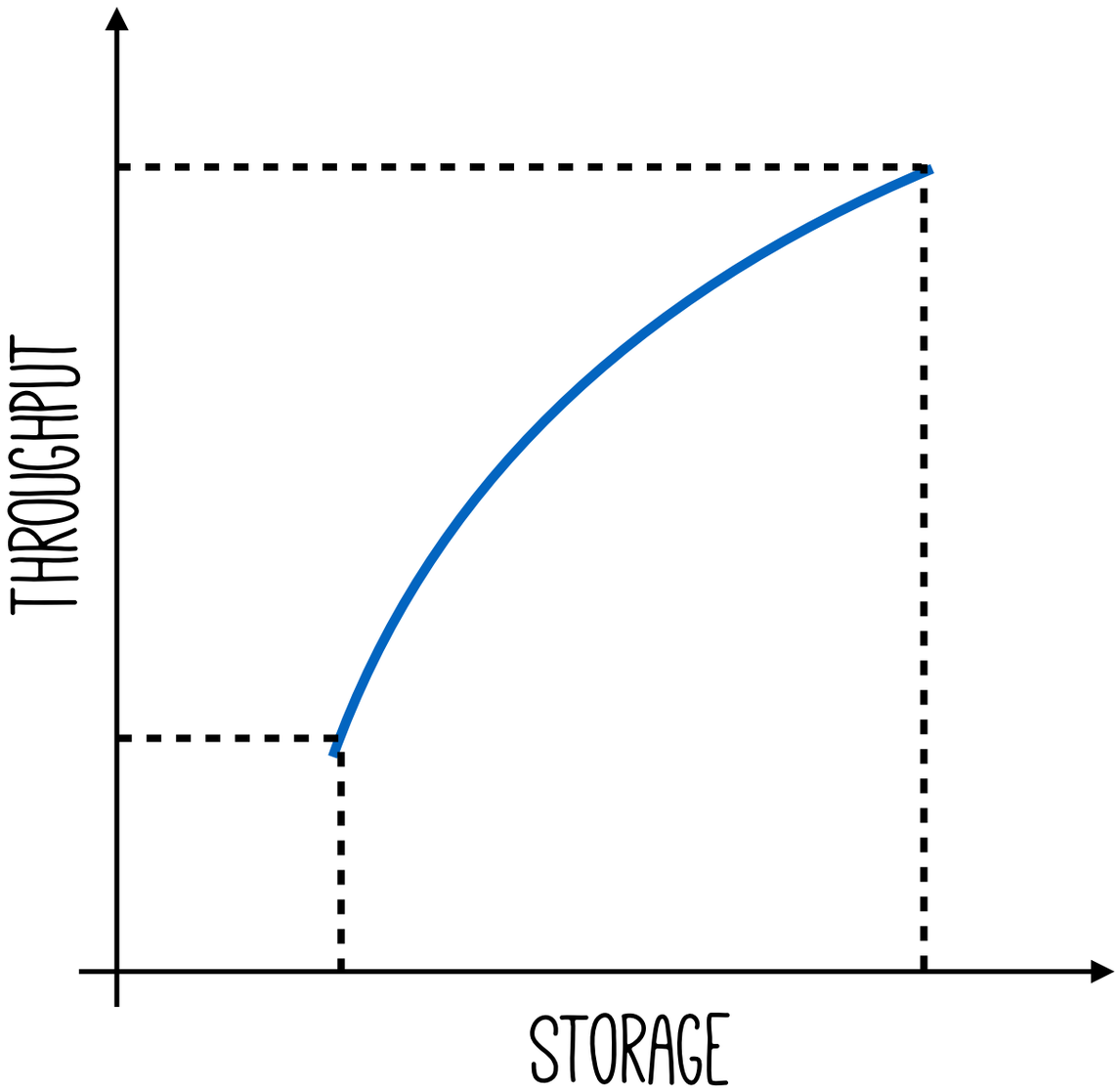
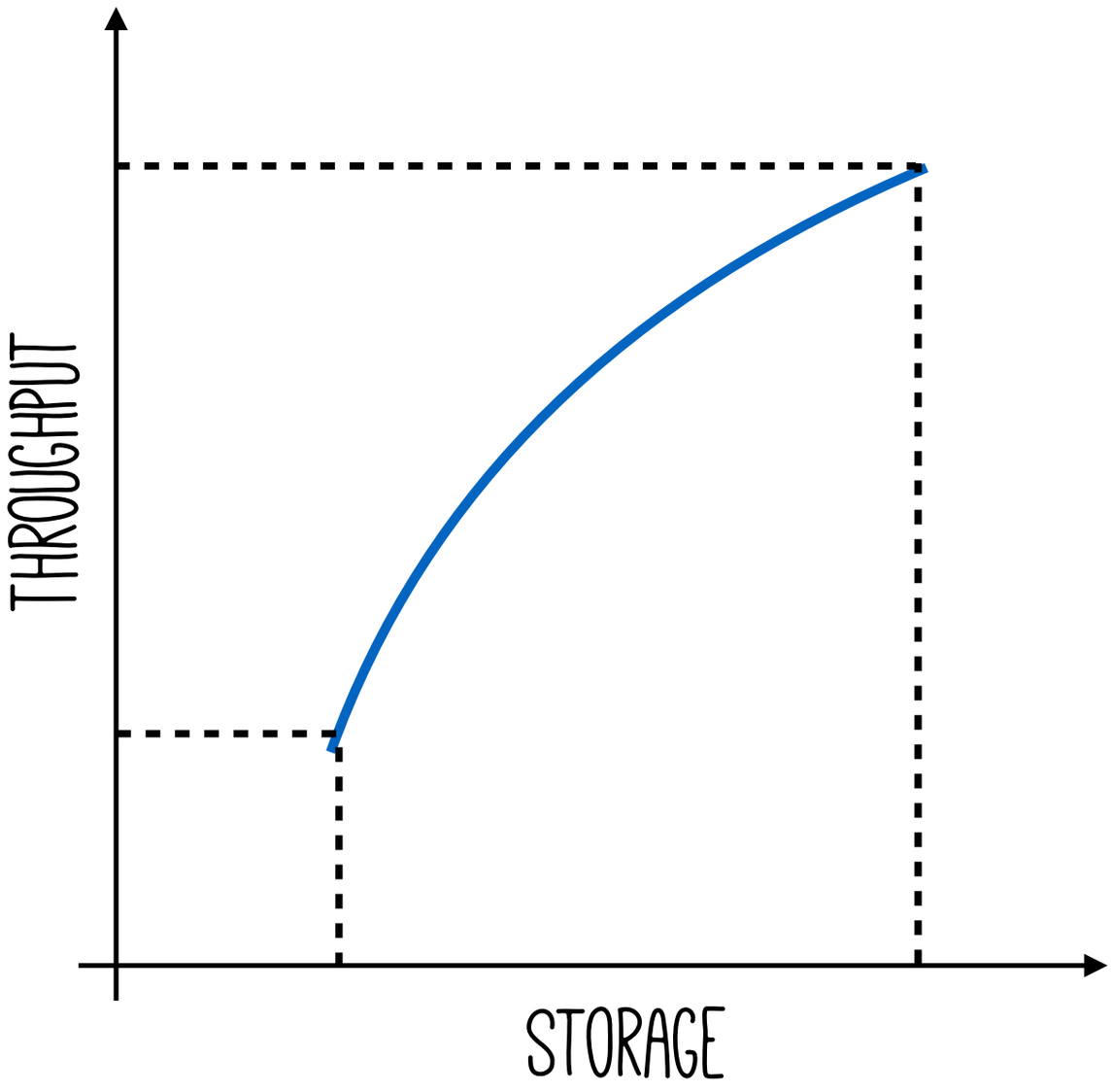


Smooth Tradeoff Curve

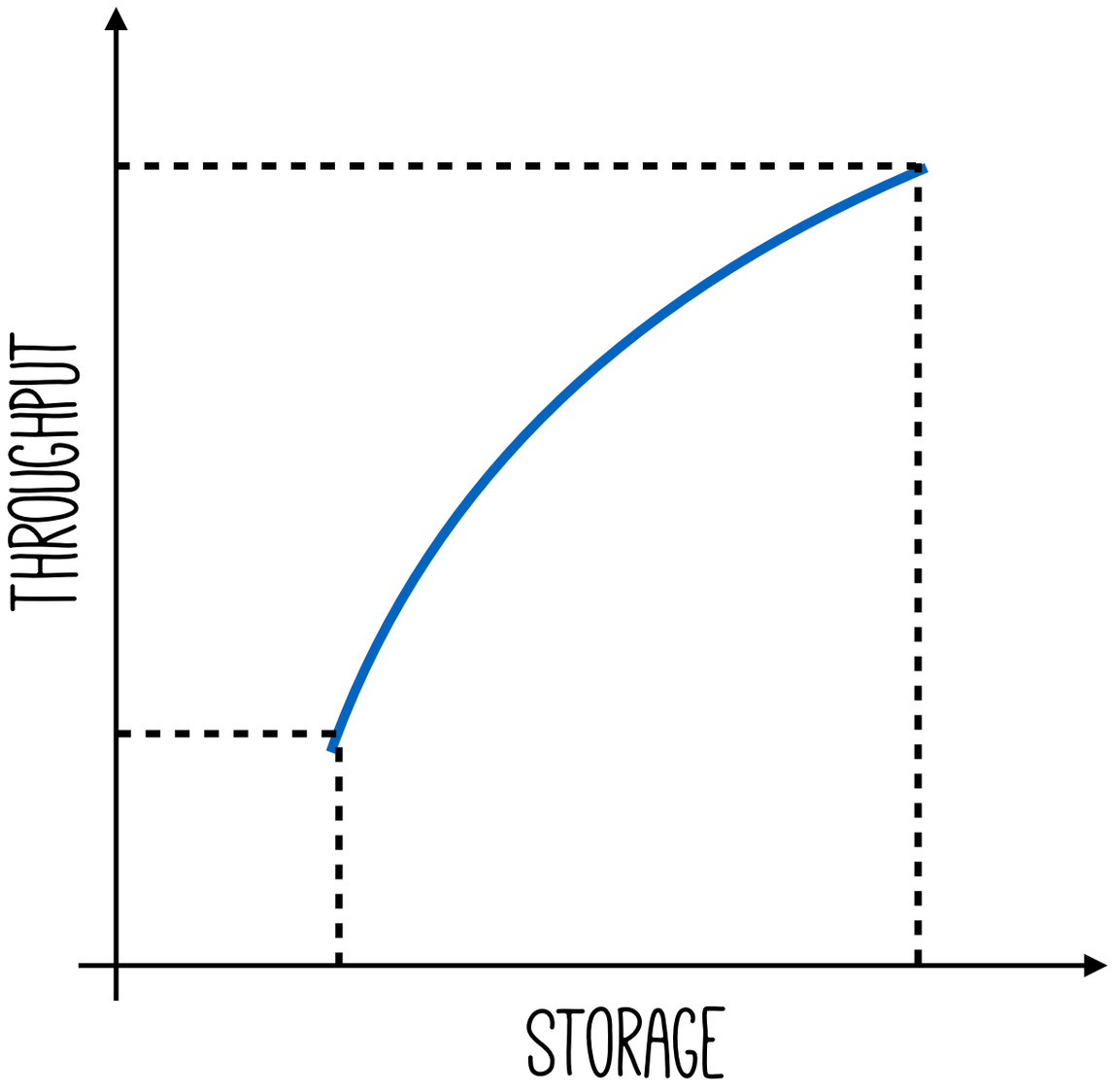
Summary



Smooth Tradeoff Curve

Dynamic Navigation

Summary



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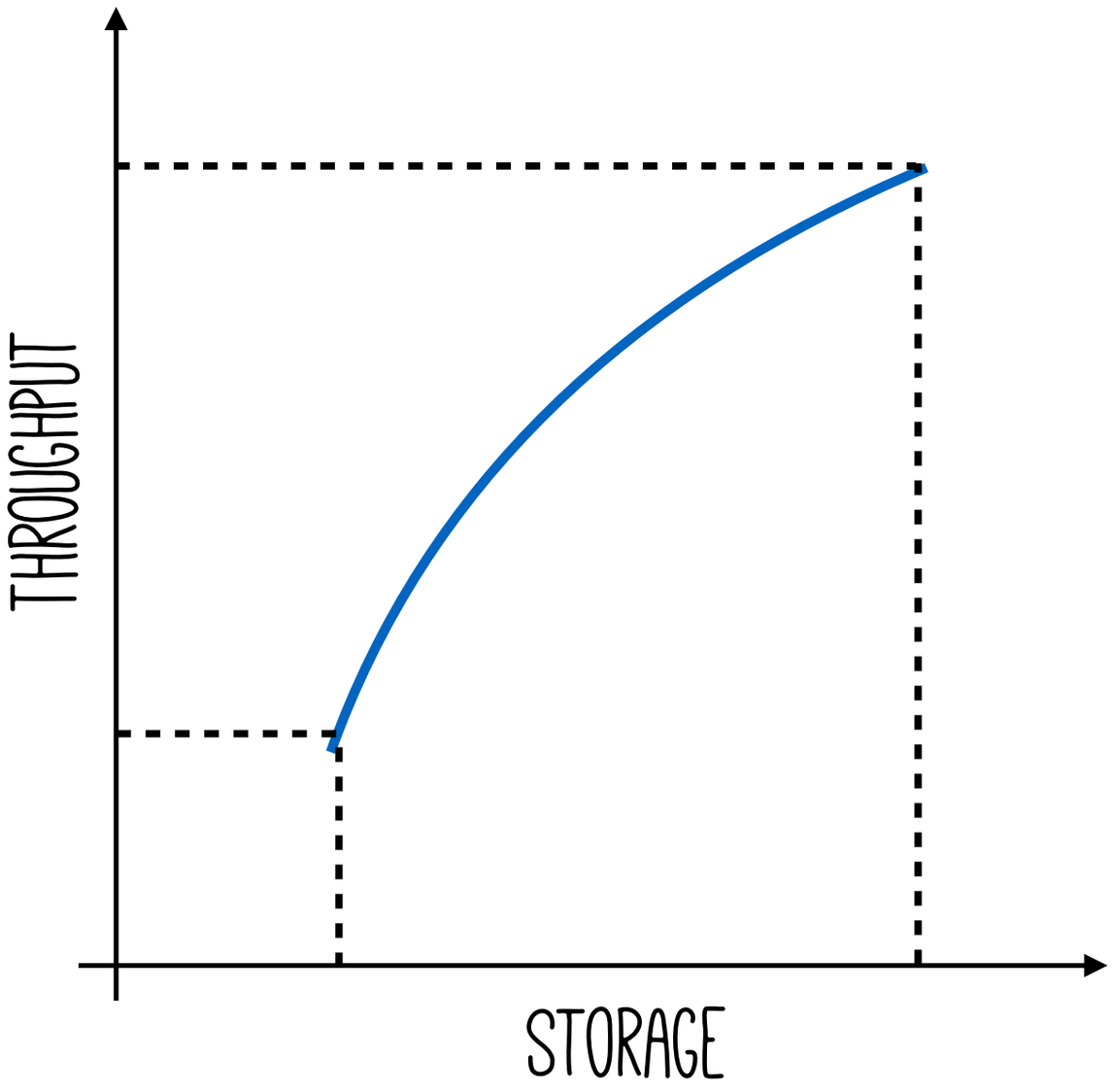
Dynamic Navigation

Applications in Several Classical Systems Problems

Summary



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Thank You! Questions?

Backup Slides