Hash Tables

Data Structures for *Map ADT*

	Find	Insert	Delete
Unsorted Array	$\theta(n)$	$\theta(n)$	$\theta(n)$
Unsorted Linked List	$\theta(n)$	$\theta(n)$	$\theta(n)$
Sorted Array	$\theta(\log(n))$	$\theta(n)$	$\theta(n)$
Sorted Linked List	$\theta(n)$	$\theta(n)$	$\theta(n)$
Binary Search Tree	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$
AVL Tree	$\theta(\log(n))$	$\theta(\log(n))$	$\theta(\log(n))$

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Bucket Array			

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Unsorted Array	$\theta(n)$	$\theta(n)$	$\theta(n)$
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AVL Tree	$\theta(\log(n))$	$\theta(\log(n))$	$\theta(\log(n))$
Bucket Array	$\theta(1)$	$\theta(1)$	$\theta(1)$

Data Structures for *Map ADT*

	Find	Insert	Delete	Space
Unsorted Array	$\theta(n)$	$\theta(n)$	$\theta(n)$	
Unsorted Linked List	$\theta(n)$	$\theta(n)$	$\theta(n)$	
Sorted Array	$\theta(\log(n))$	$\theta(n)$	$\theta(n)$	
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Binary Search Tree	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$	
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Binary Search Tree	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$	$\theta(\mathrm{n})$
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Binary Search Tree	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$	$\theta(h), \theta(n)$	$\theta(\mathrm{n})$
AVL Tree	$\theta(\log(n))$	$\theta(\log(n))$	$\theta(\log(n))$	$\theta(\mathrm{n})$
Bucket Array	$\theta(1)$	$\theta(1)$	$\theta(1)$	Could be large relative to n
Hash Table				

Data Structures for *Map ADT*

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Sorted Array	$\theta(\log(n))$	$\theta(n)$	$\theta(n)$	$\theta(n)$
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Bucket Array	$\theta(1)$	$\theta(1)$	$\theta(1)$	Could be large relative to n
Hash Table				$\theta(\mathrm{n})$

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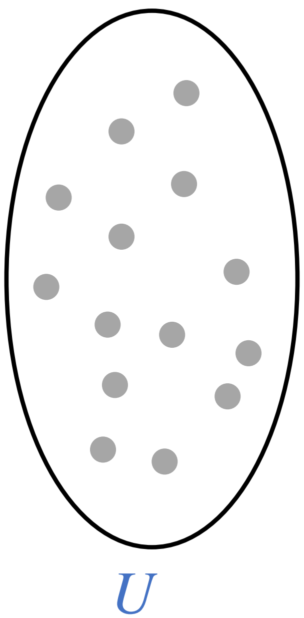
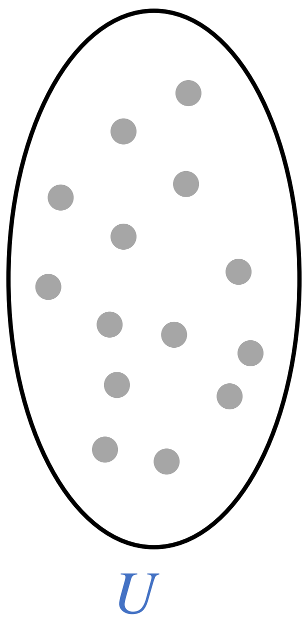
Bucket Array	$\theta(1)$	$\theta(1)$	$\theta(1)$	Could be large relative to n
Hash Table	$\theta(1)$	$\theta(1)$	$\theta(1)$	$\theta(\mathrm{n})$

Hash Tables

Hash Tables

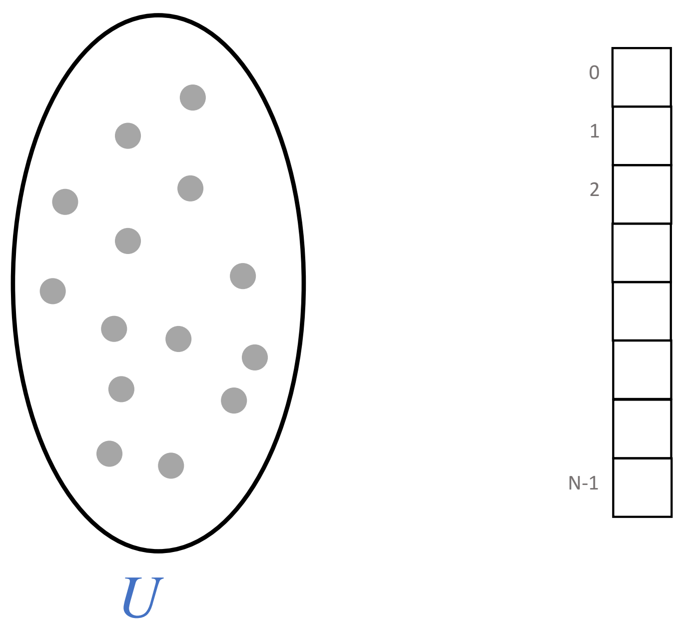


Hash Tables



- U
  Universe from which the keys will be taken

Hash Tables



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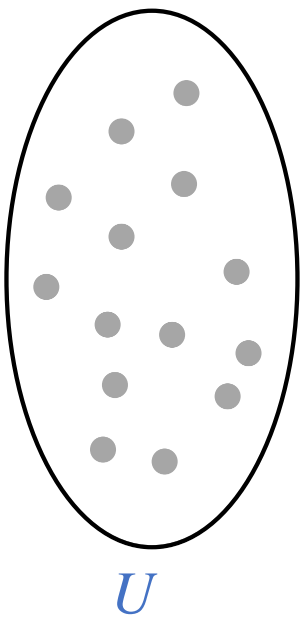

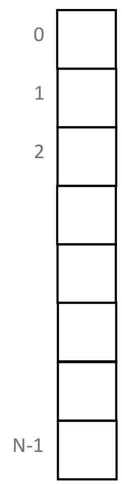

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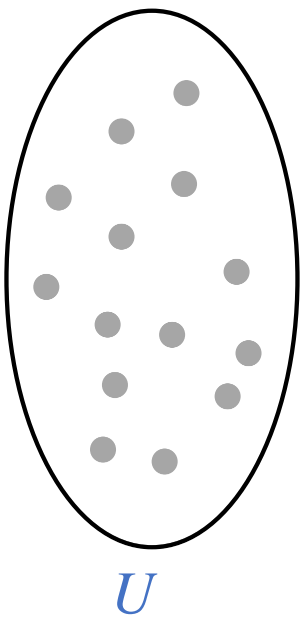
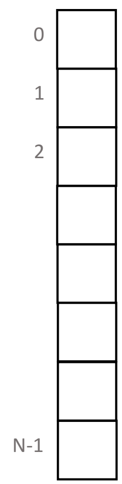
  Universe from which the keys will be taken

- T = [None]*N

Hash Tables





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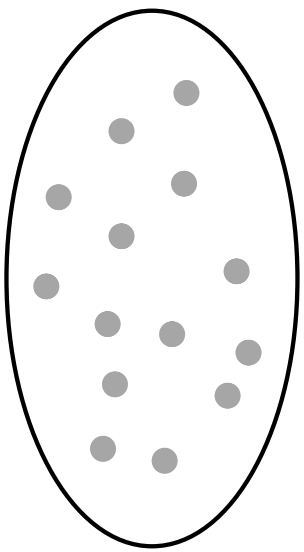
- $T = [None]*N$
  Hash table of N slots, where the entries will be stored

Hash Tables



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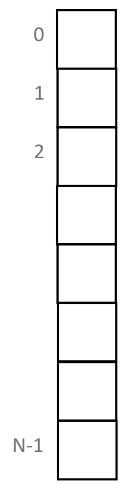

T [0…(N-1)]

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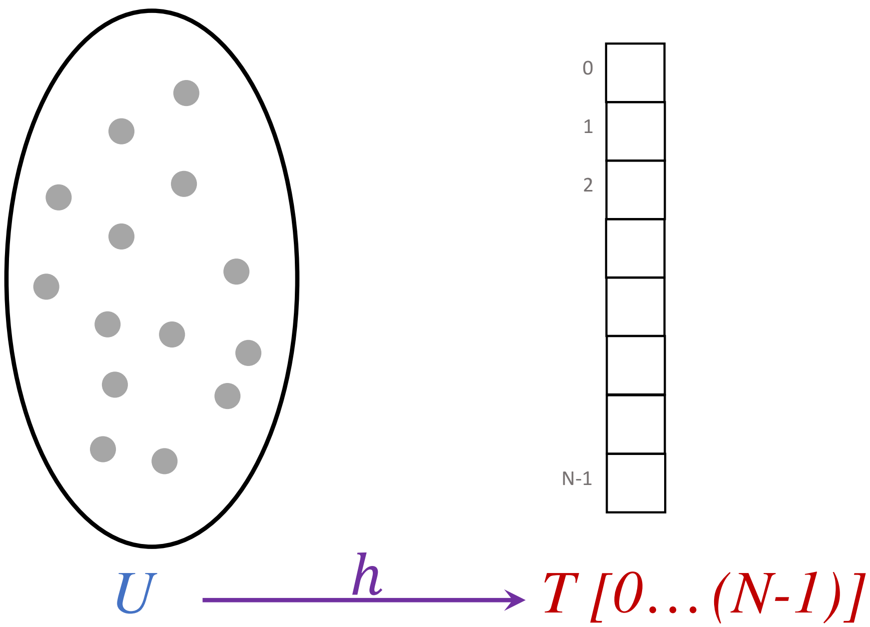

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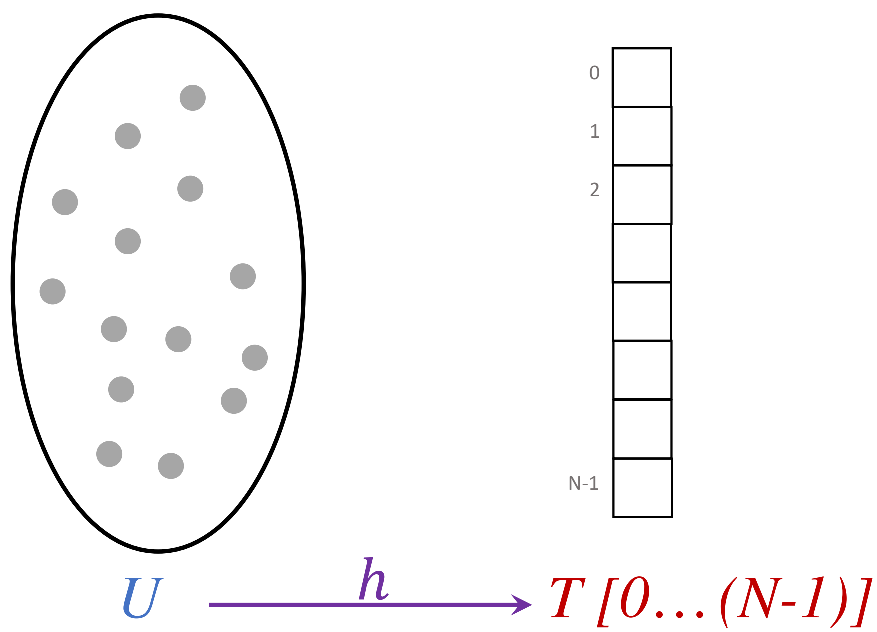

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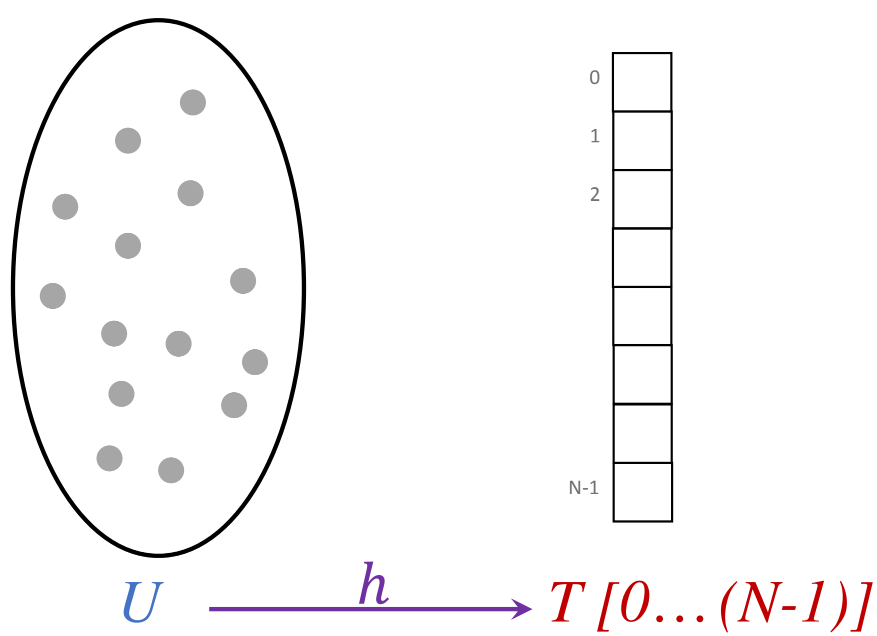
- $h: U \rightarrow \{0, 1, \ \ldots, (N-1)\}$

Hash Tables



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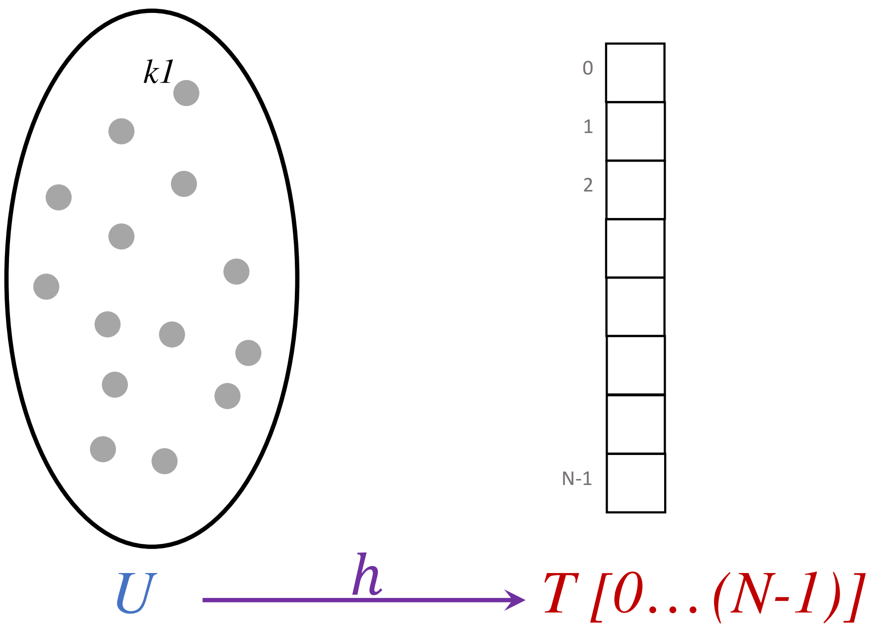
  Hash function that maps keys form the universe to slots in the table

Hash Tables



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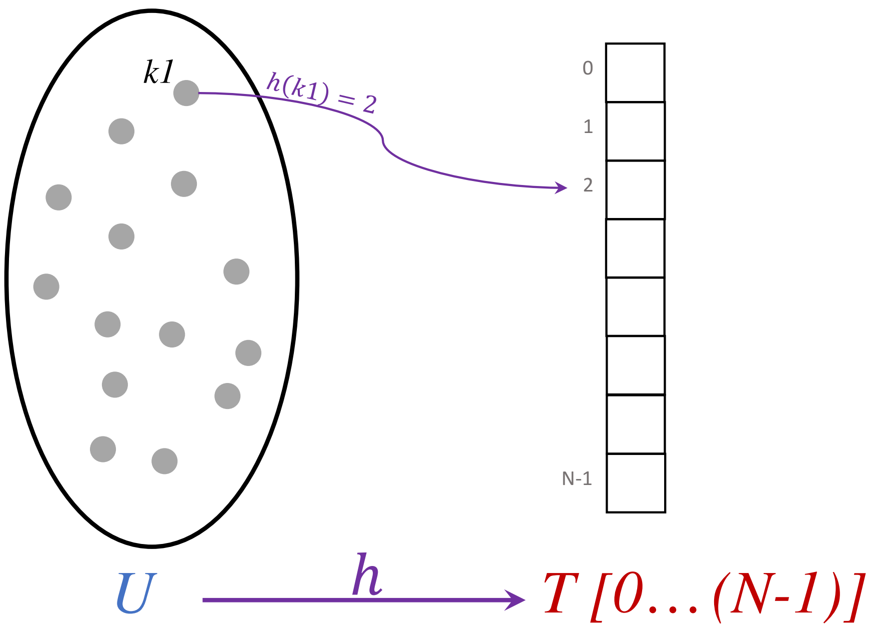

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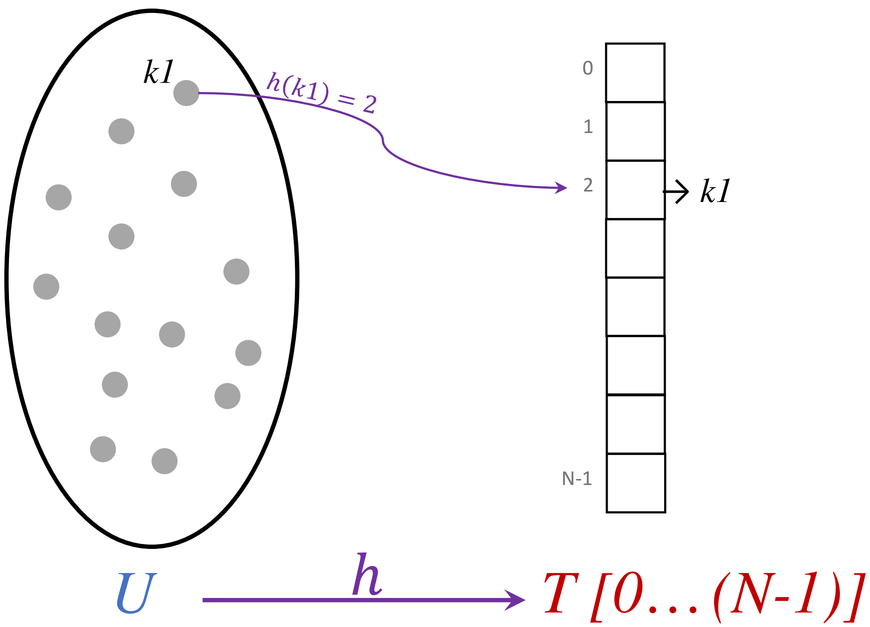

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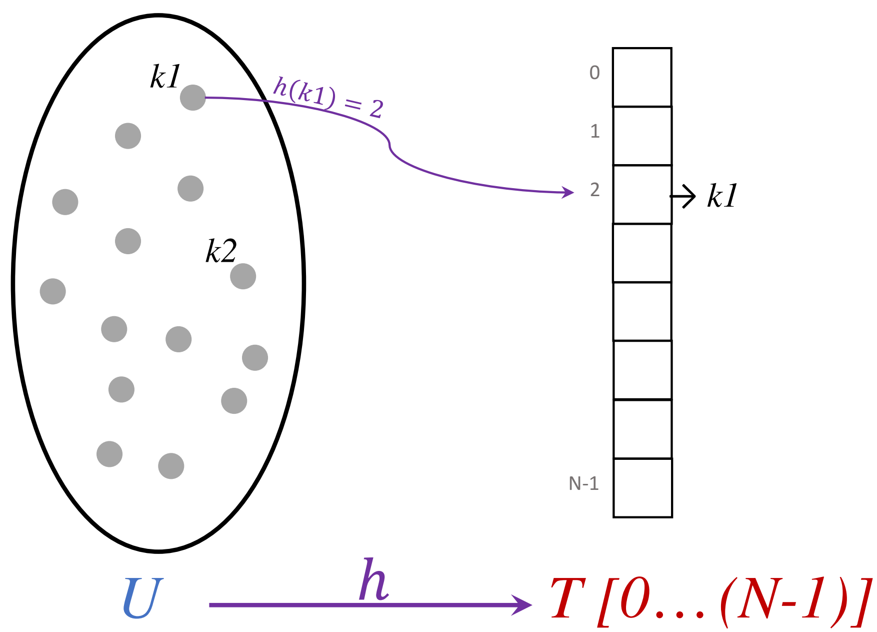

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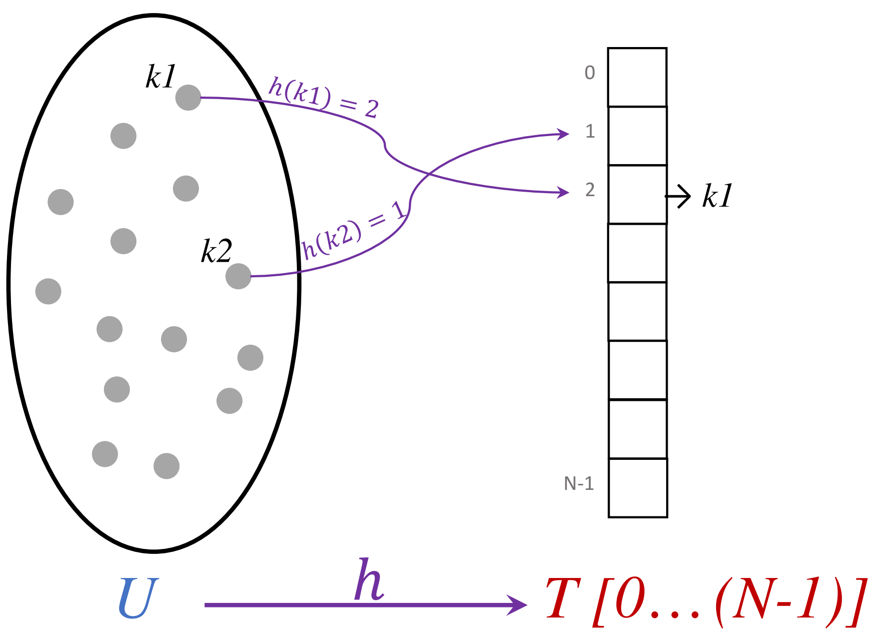

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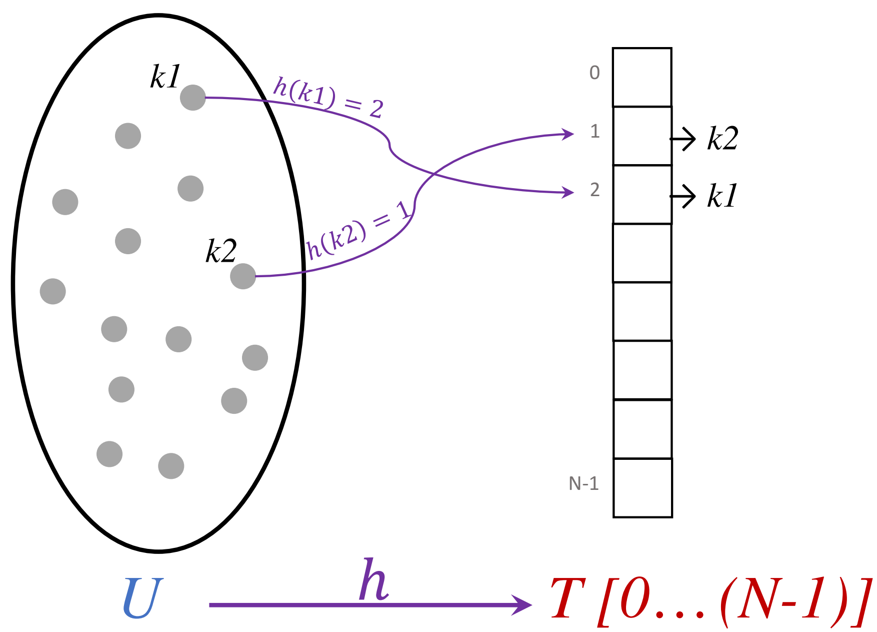

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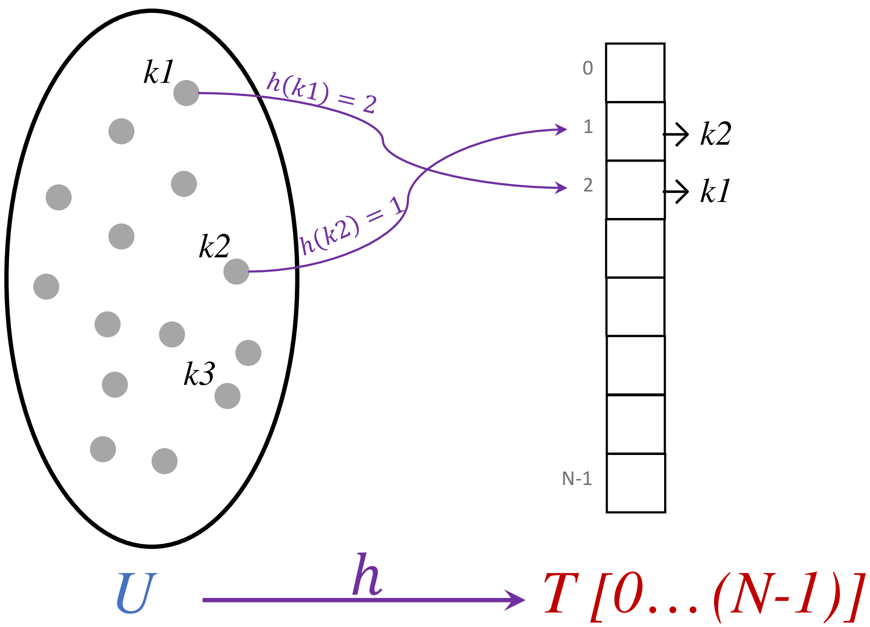

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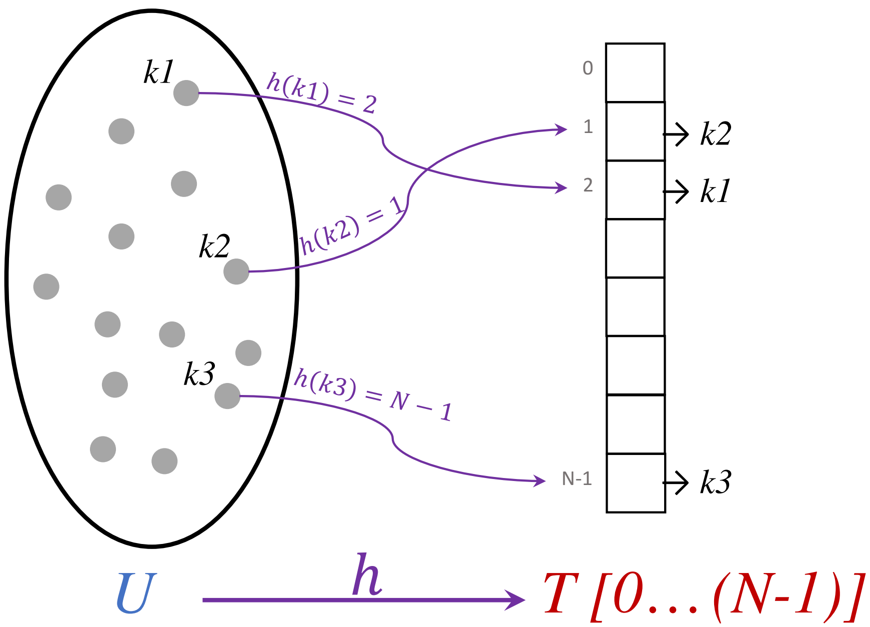

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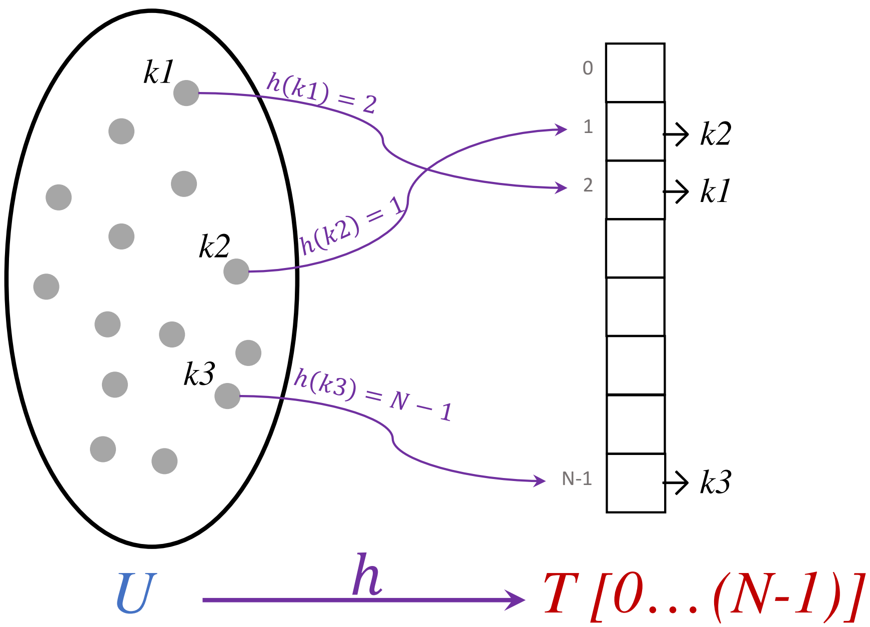

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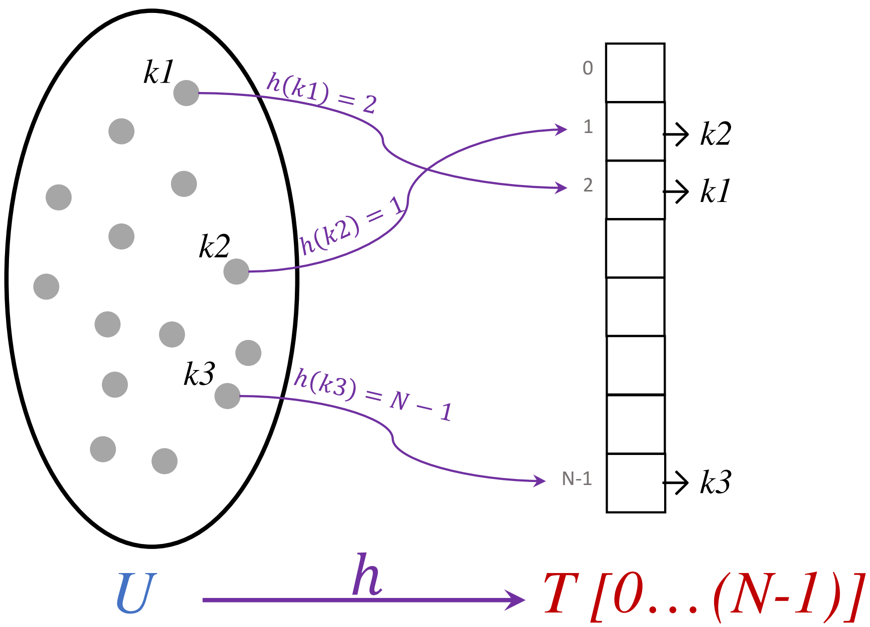
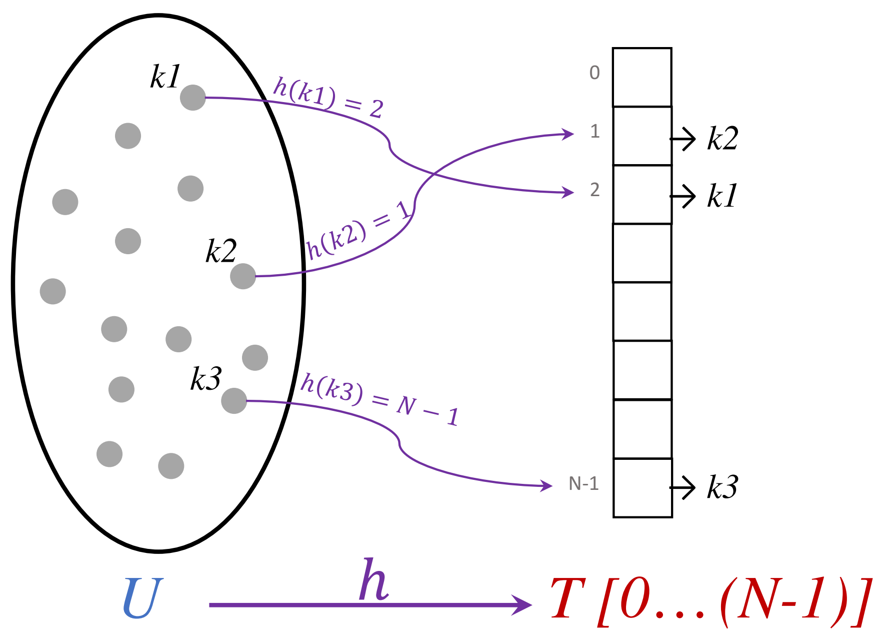


insert(key, value):

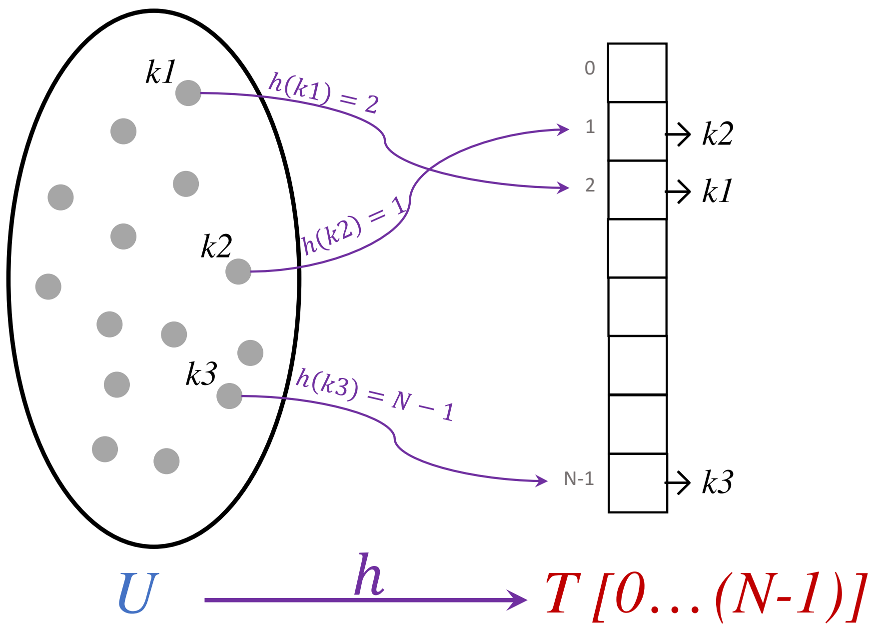
Hash Tables



insert(key, value):

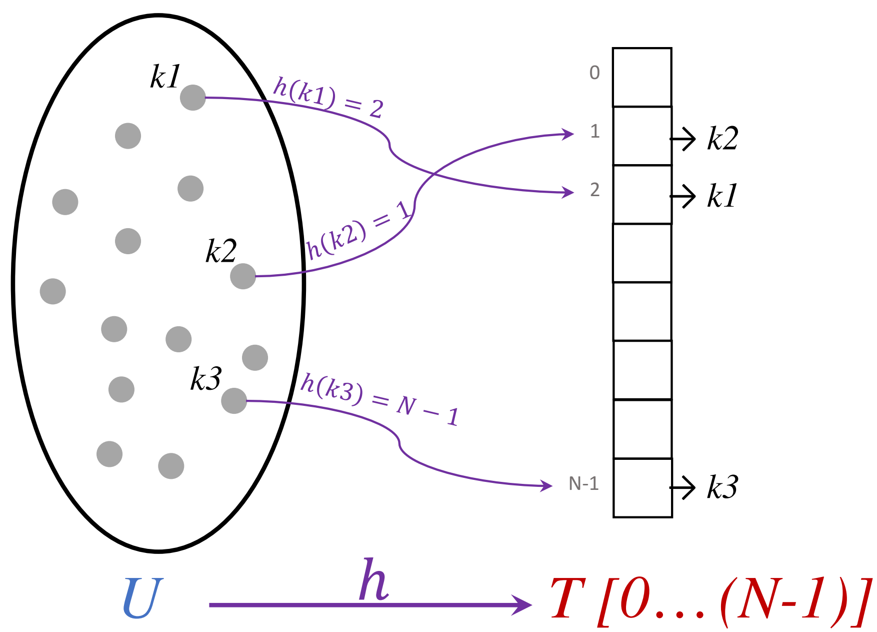
$i = h(key)$

Hash Tables



insert(key, value):
i = h(key)
T[i] = value

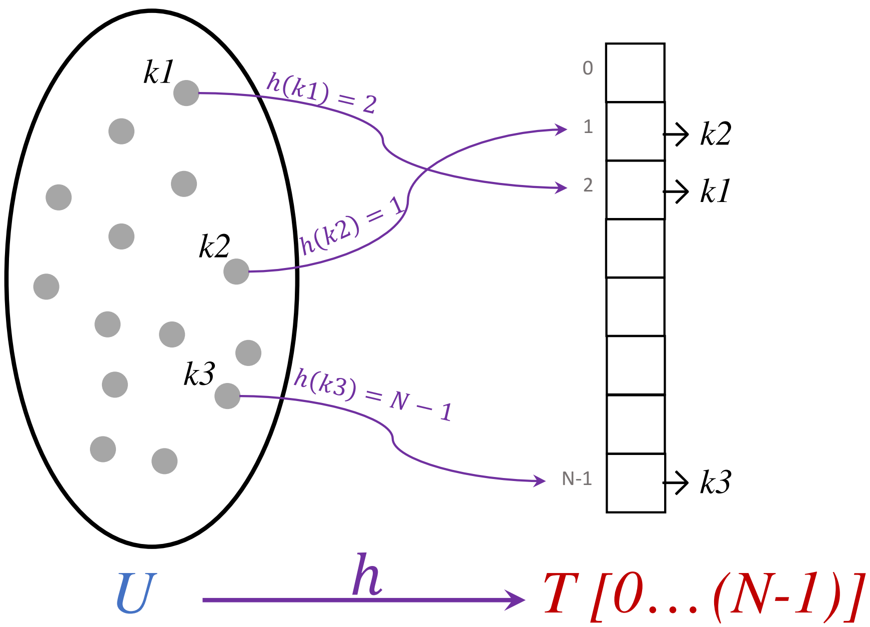
Hash Tables



insert(key, value):
i = h(key)
T[i] = value

find(key):

Hash Tables



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i = h(key)
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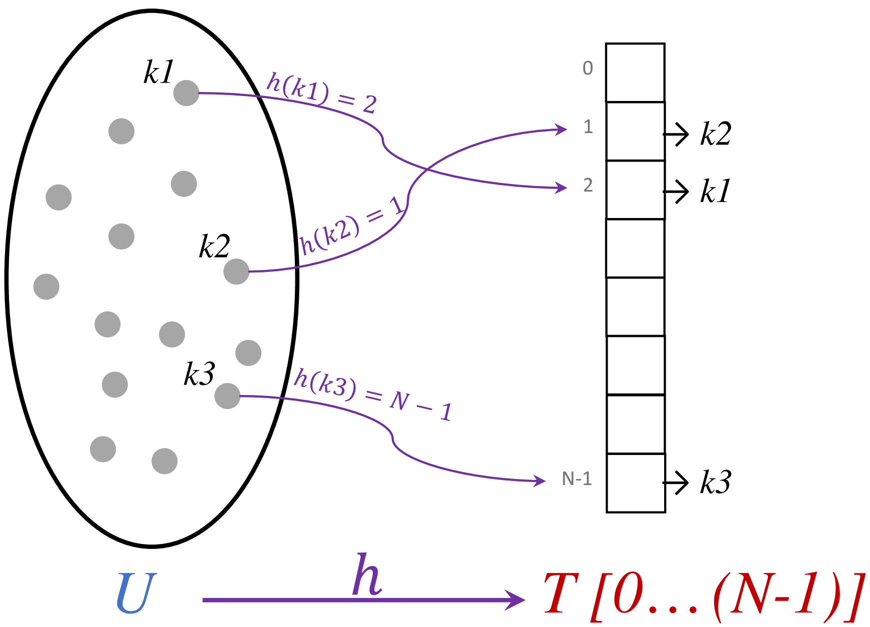
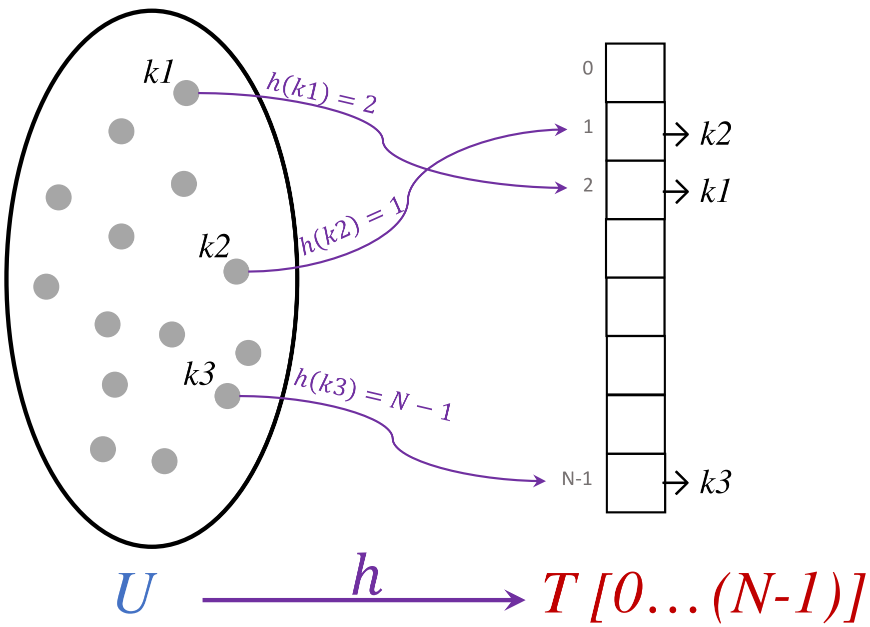
Hash Tables



insert(key, value)
i = h(key)
T[i] = value

find(key)
i = h(key)
return T[i]

Hash Tables



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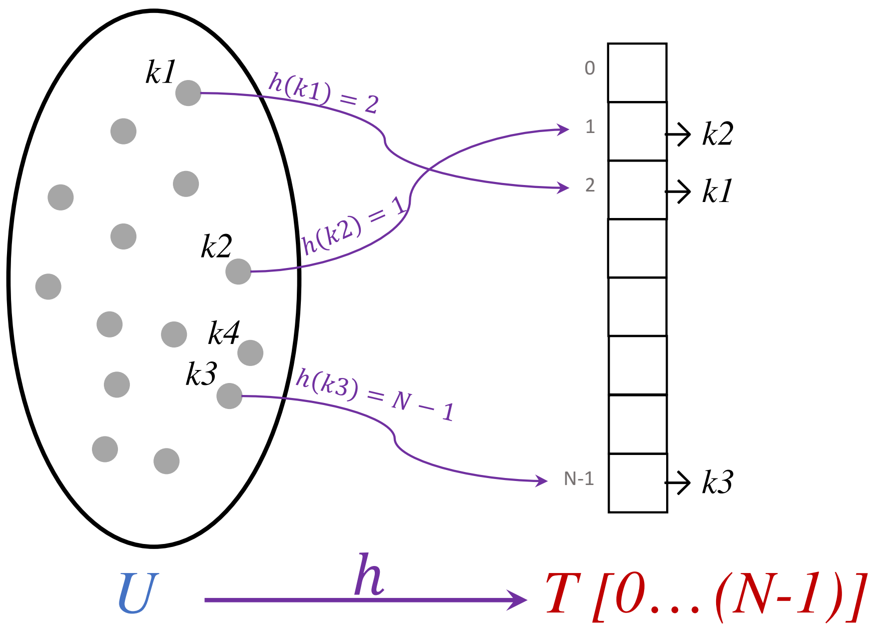

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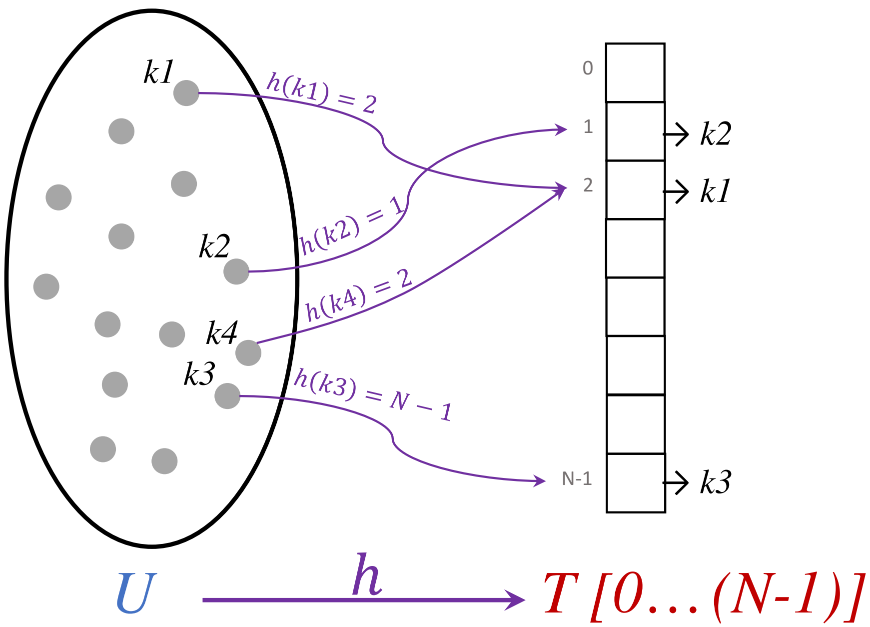

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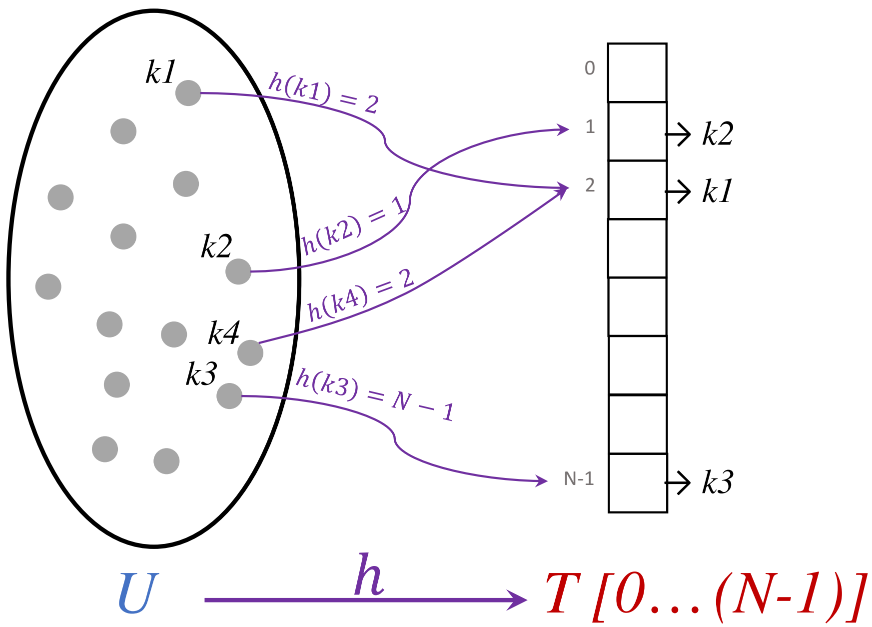
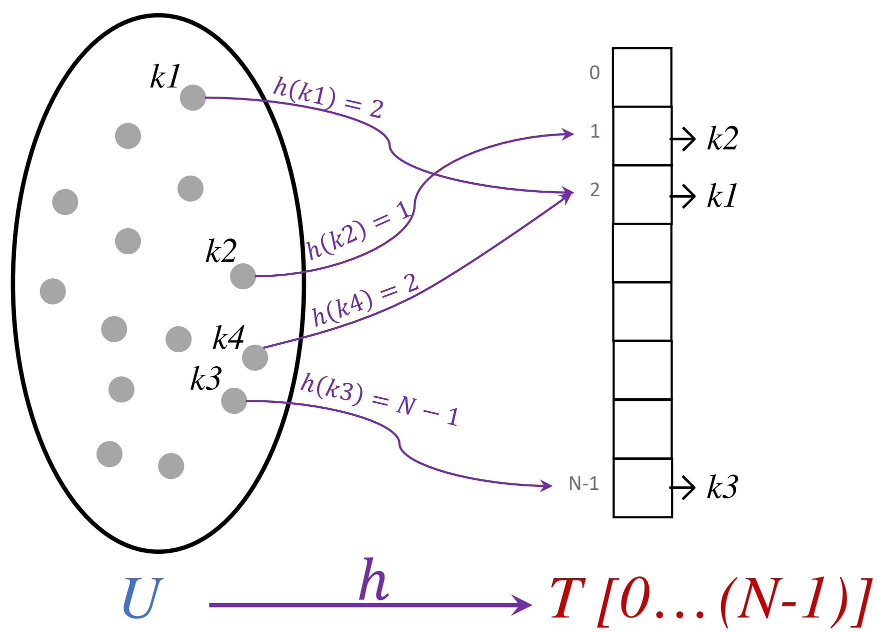


The Collisions Problem:
multiple keys could be mapped to the same slot

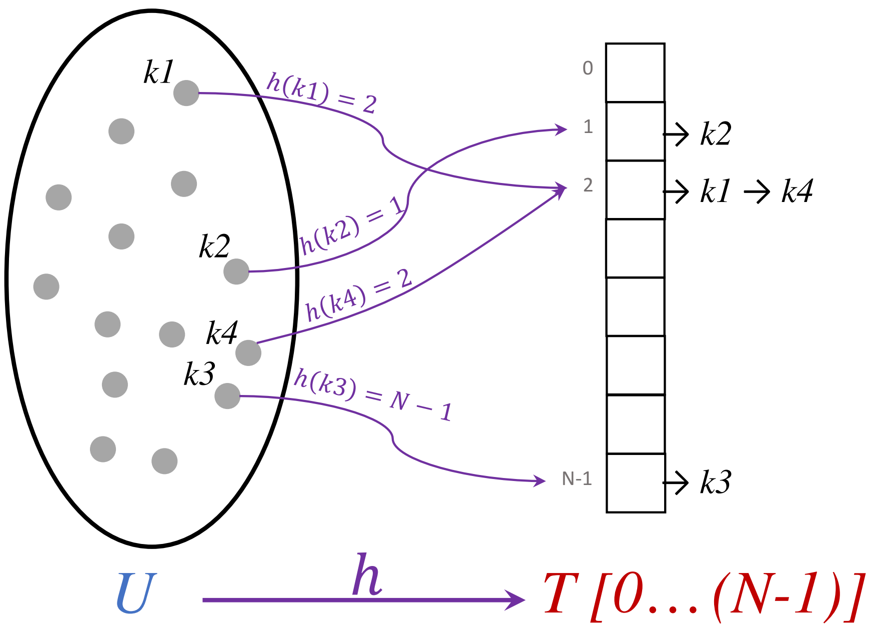
Hash Tables



<u>The Collisions Problem</u>:
multiple keys could be mapped to the same slot

<u>An easy solution</u>:
Chaining – store all entries that are mapped to the same slot, in some secondary collection

Hash Tables



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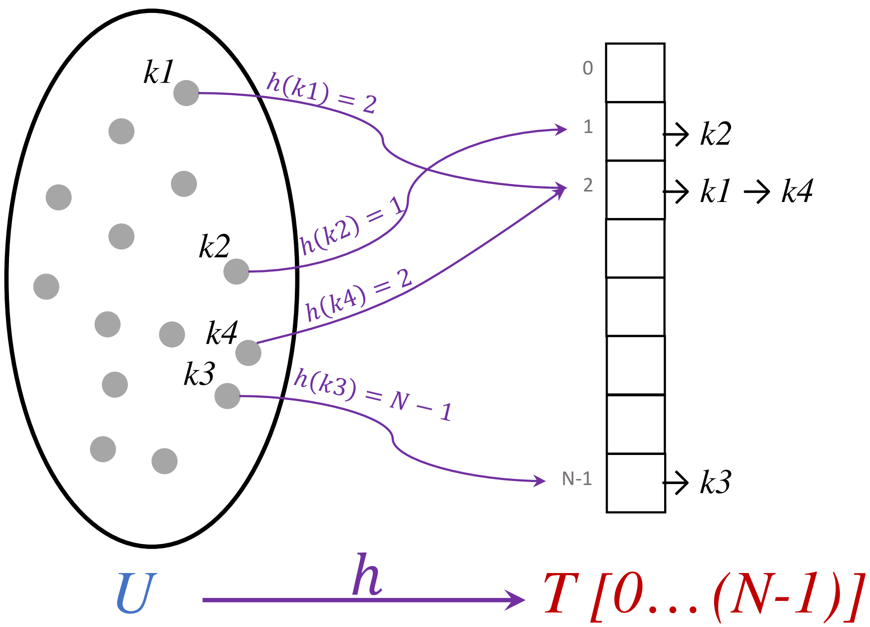

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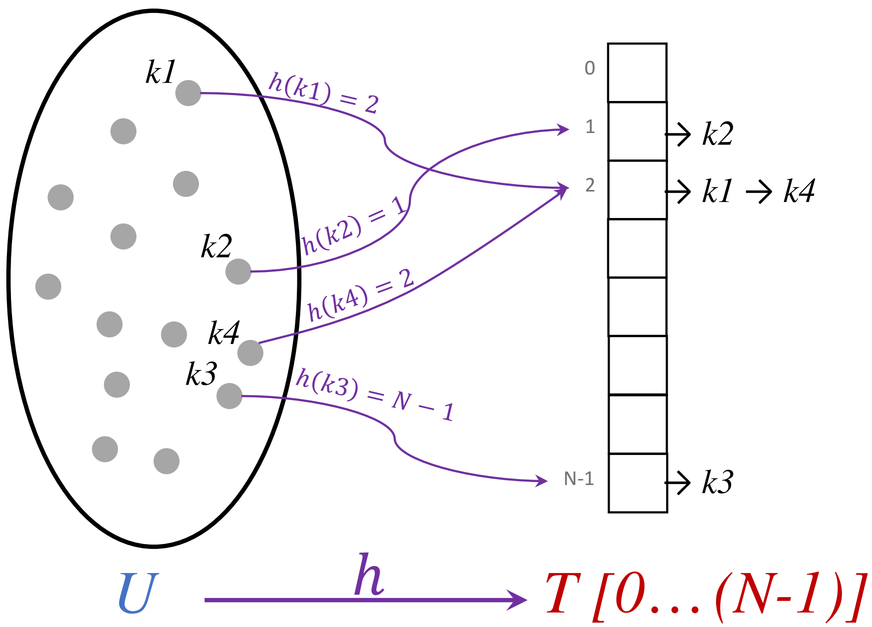
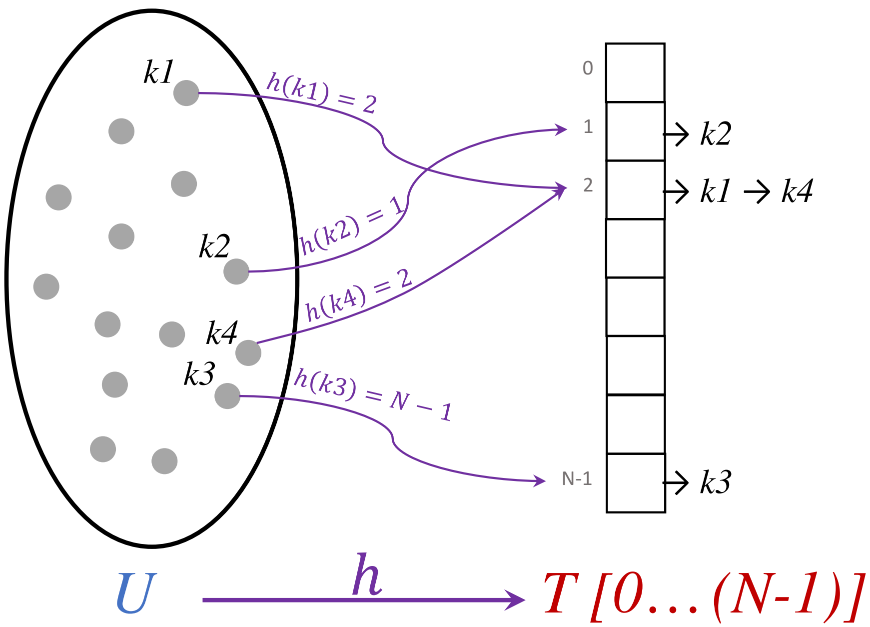


Problem: When using chaining, a lot of keys could end up being stored at the same slot $\Rightarrow$ bad performance

Hash Tables



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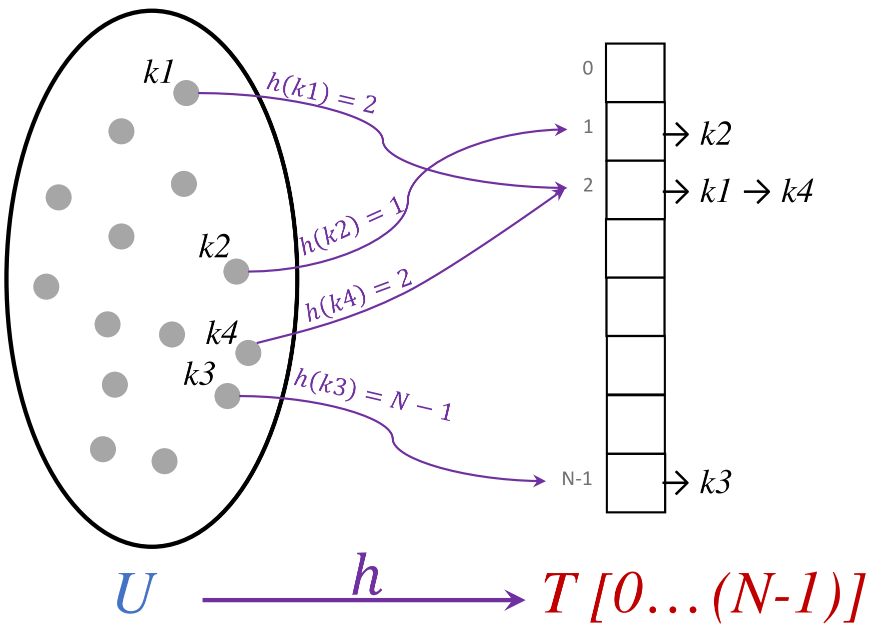
Solution: Use a "good" hash function (a function that evens out the collisions)

Hash Tables



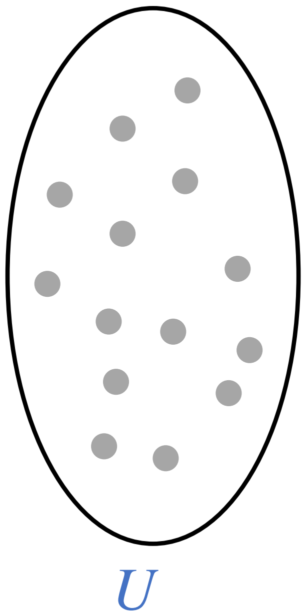
Problem: When using chaining, a lot of keys could end up being stored at the same slot $\Rightarrow$ bad performance

Solution: Use a "good" hash function (a function that evens out the collisions)

Uniform Hashing Function:
A function that when given a randomly chosen key, it will be equally likely mapped to any of the N slots of T, independently of where any other key has hashed to

Hash Functions

Hash Functions



Hash Functions

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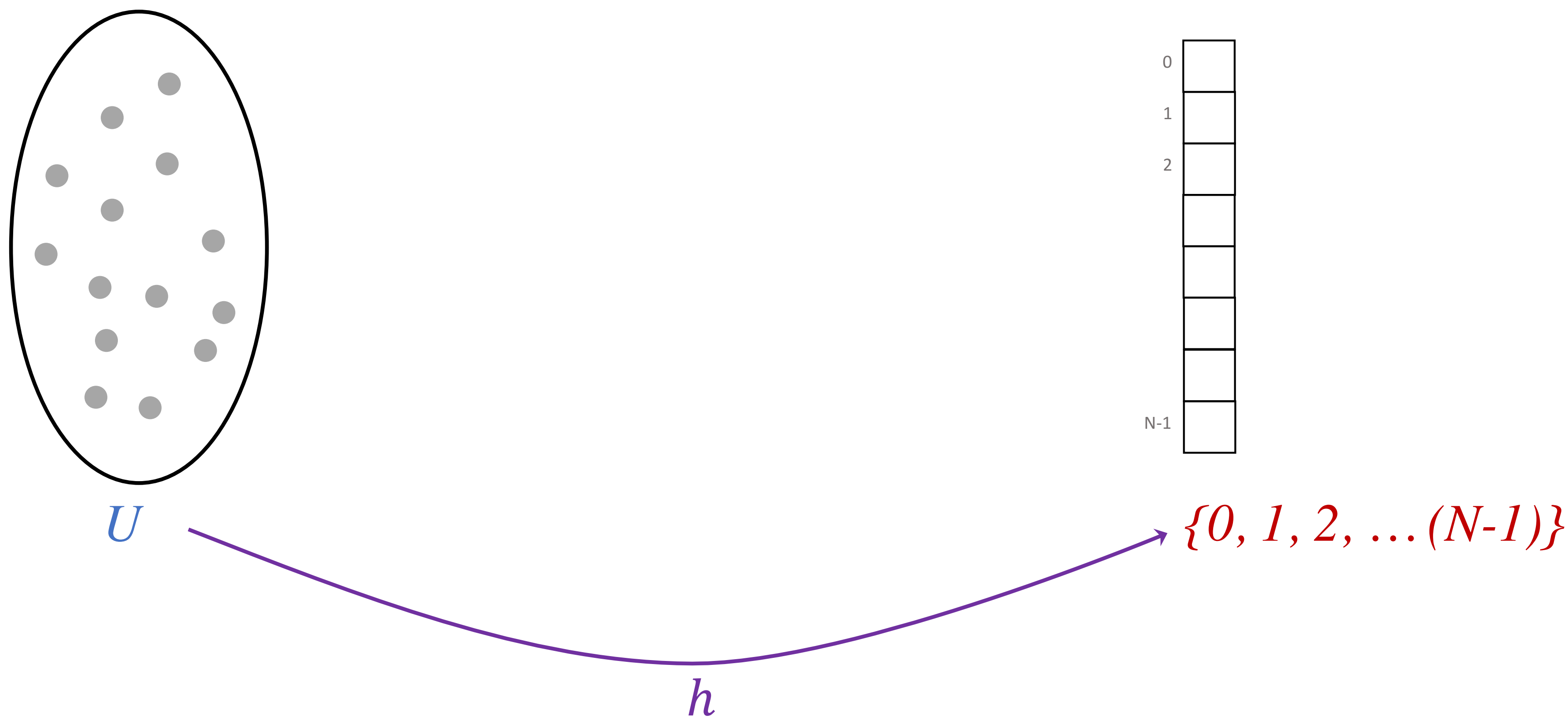

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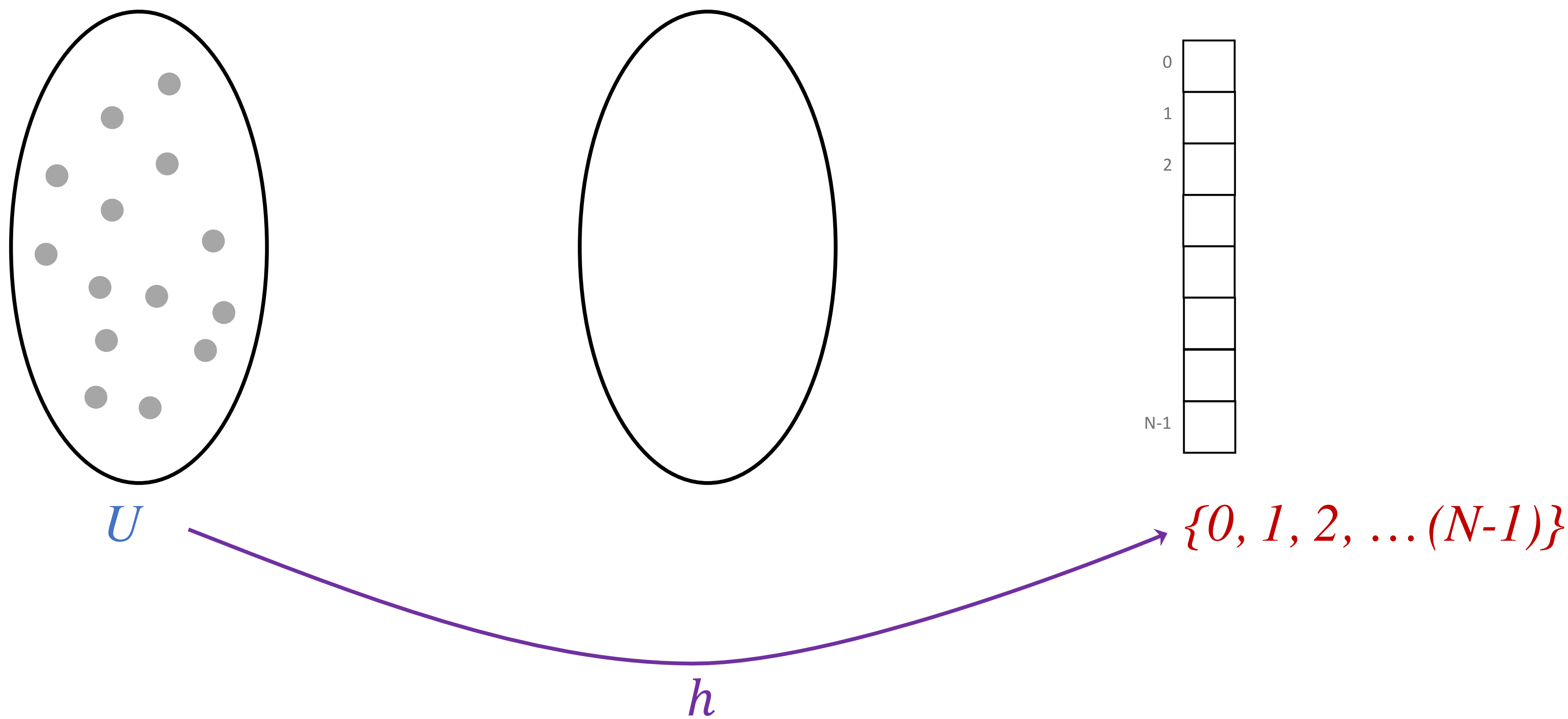

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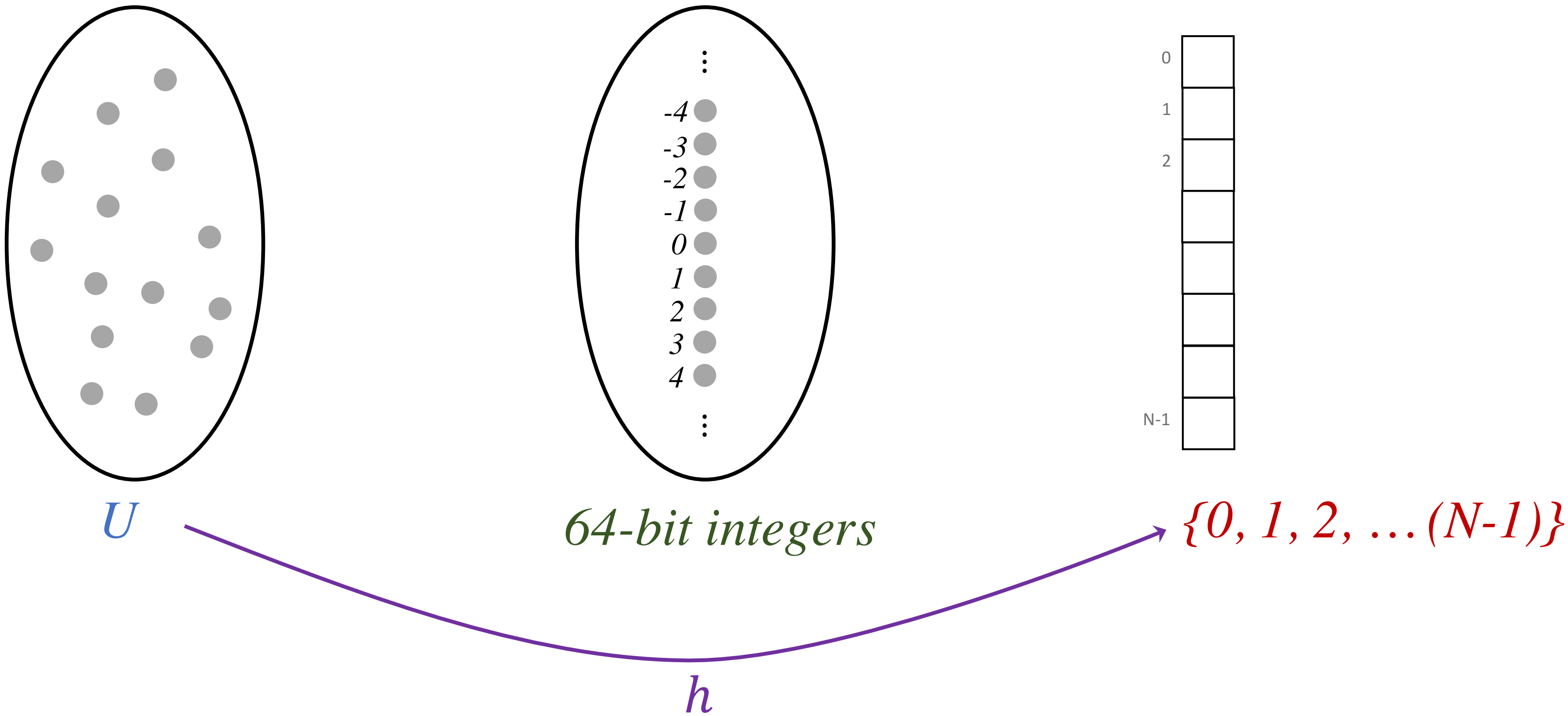

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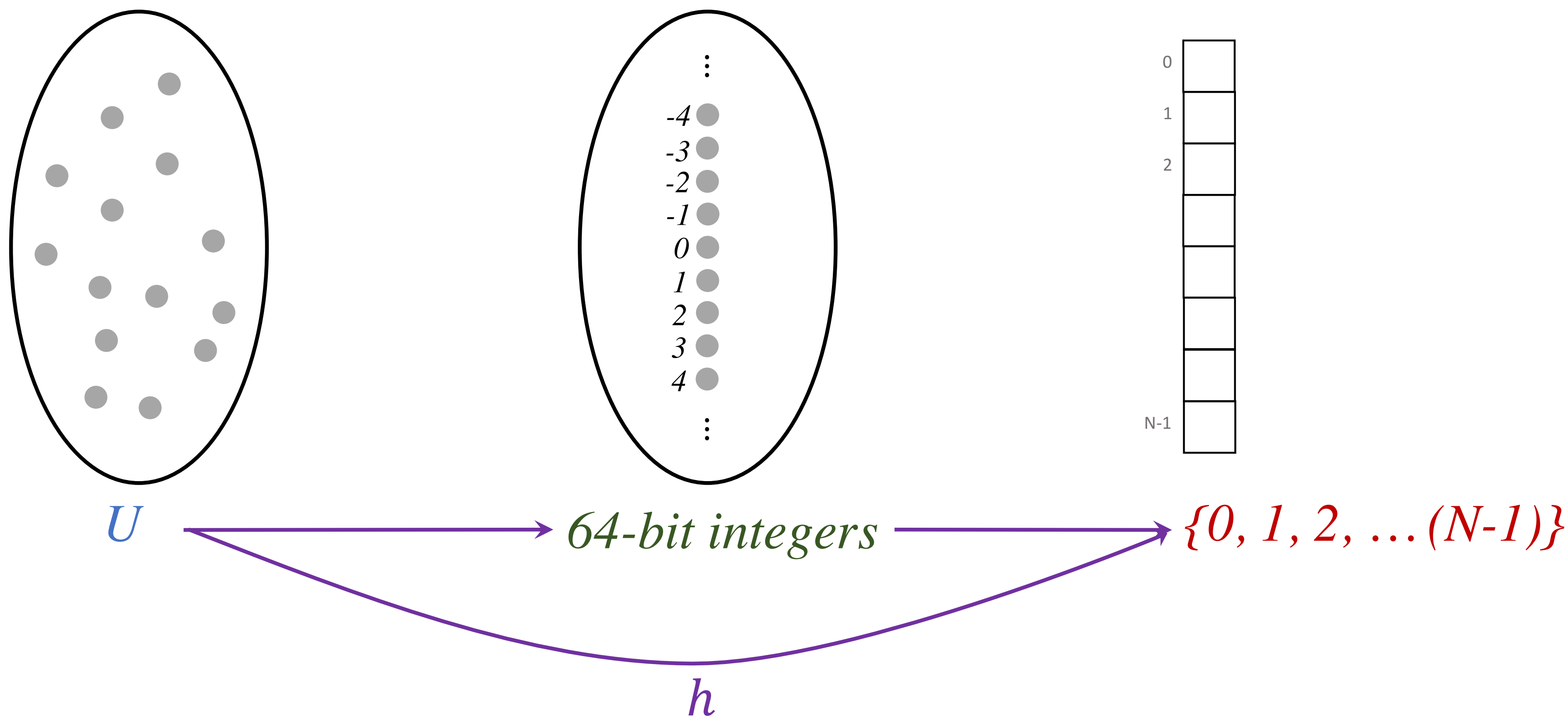

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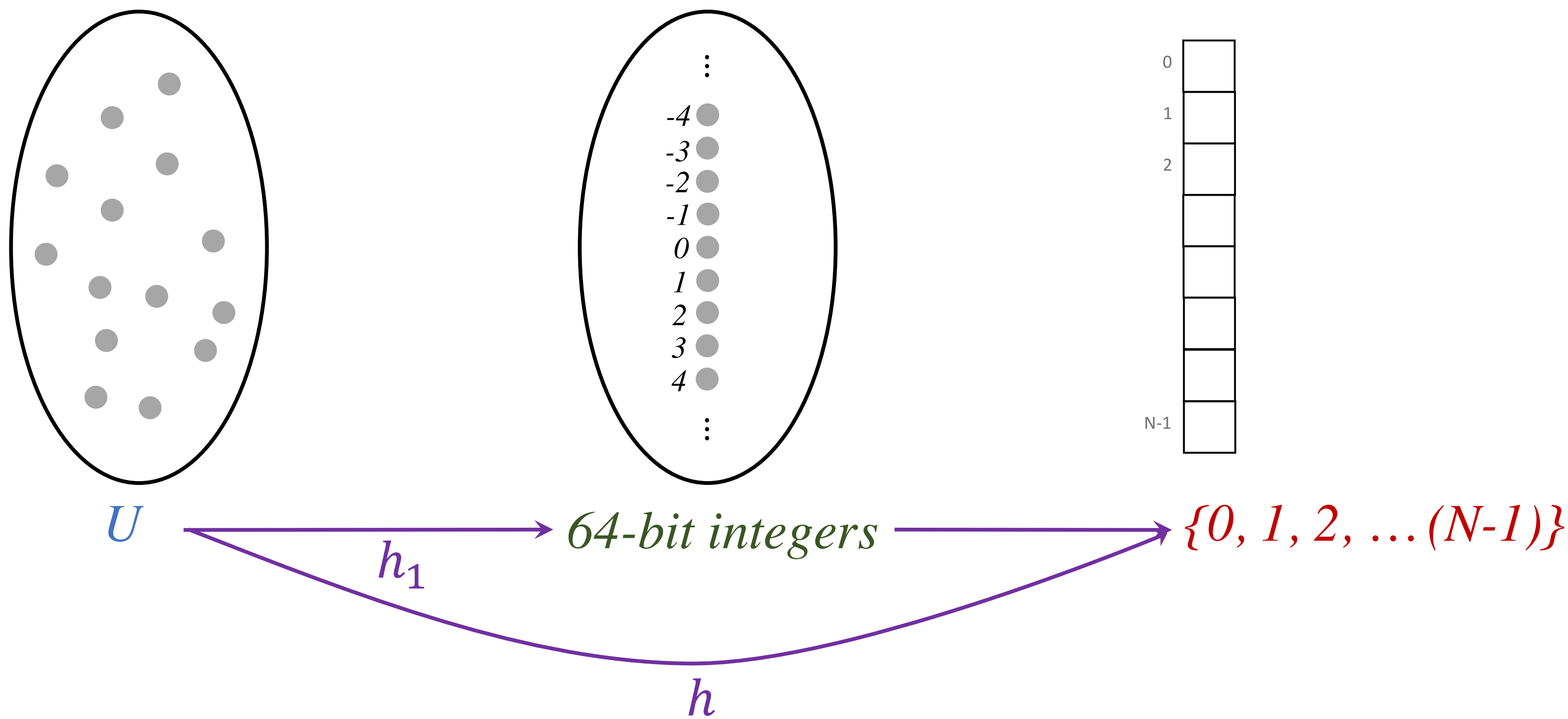
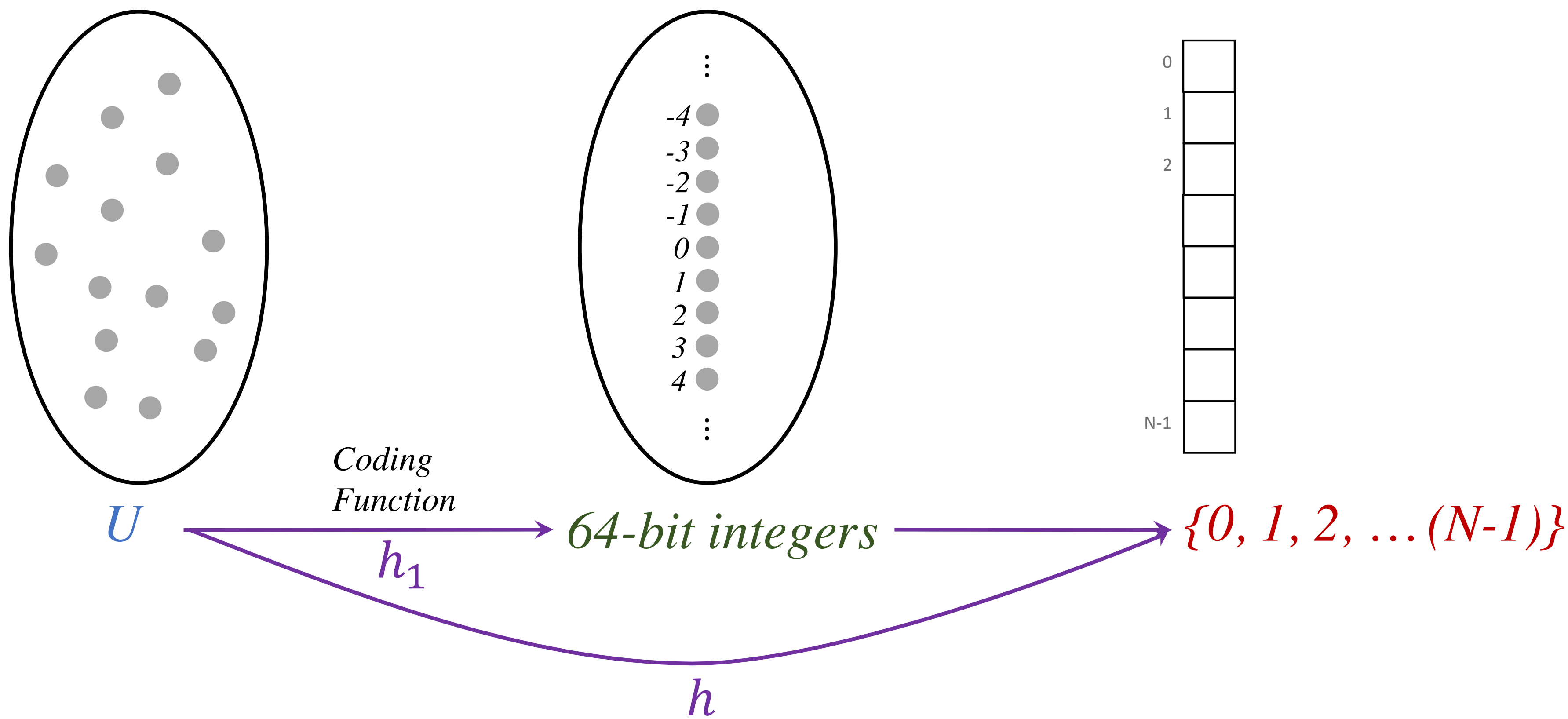


Hash Functions



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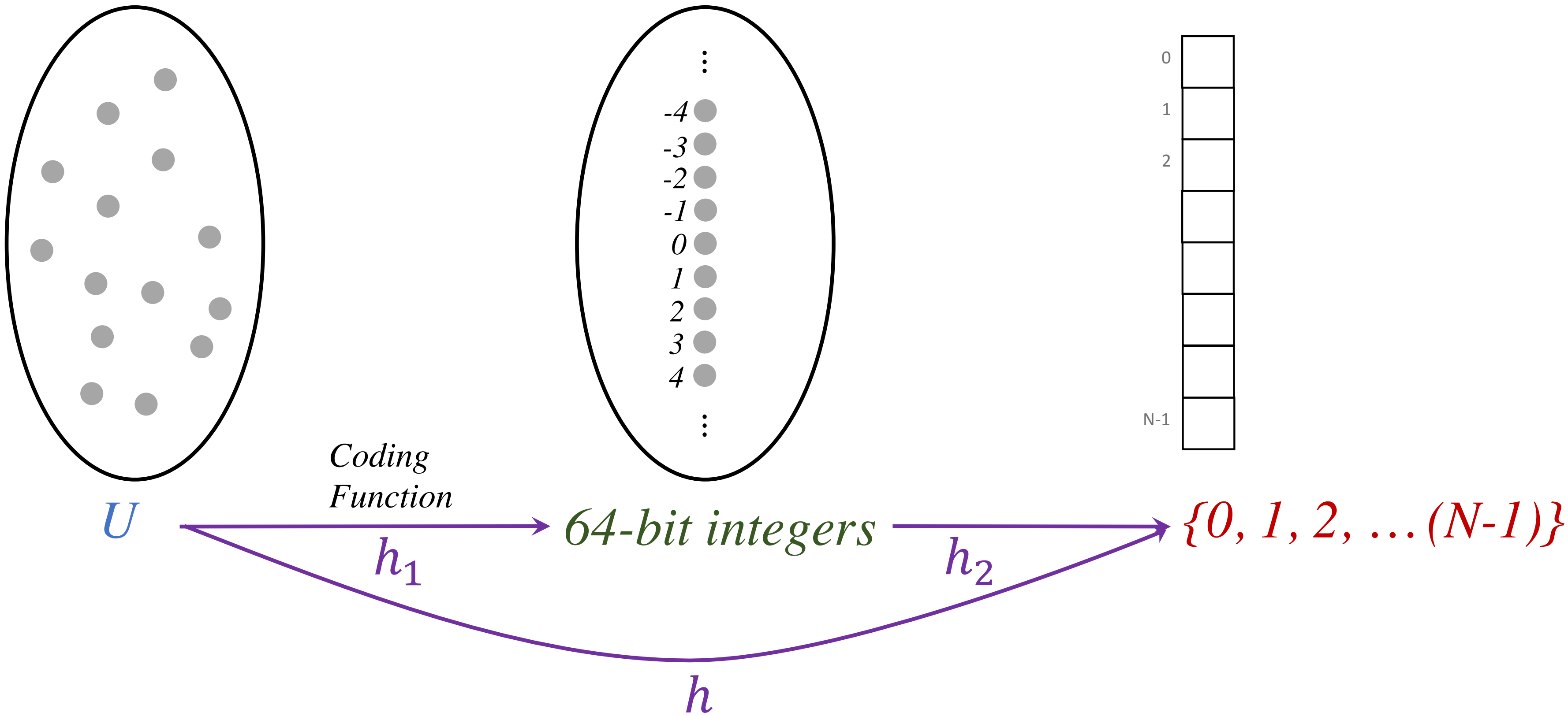

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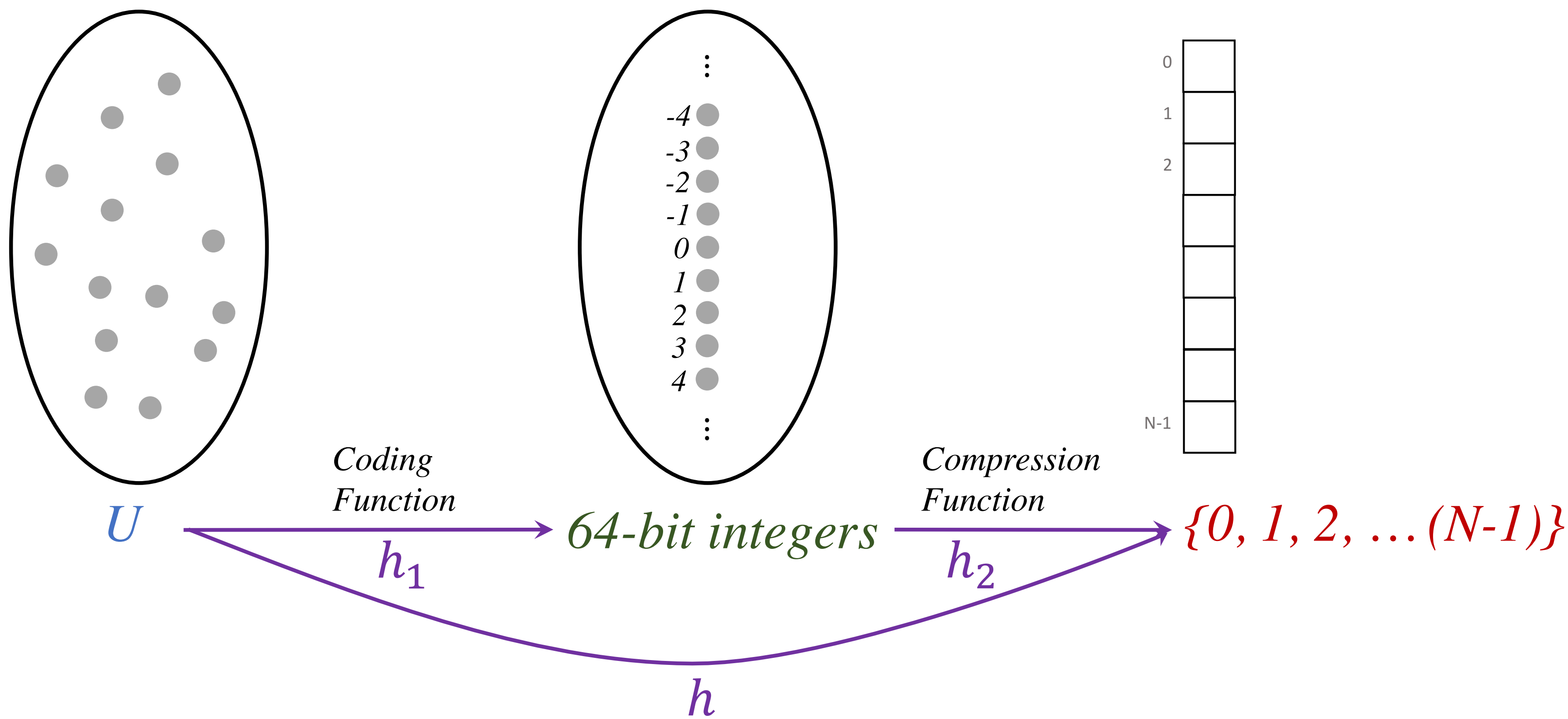

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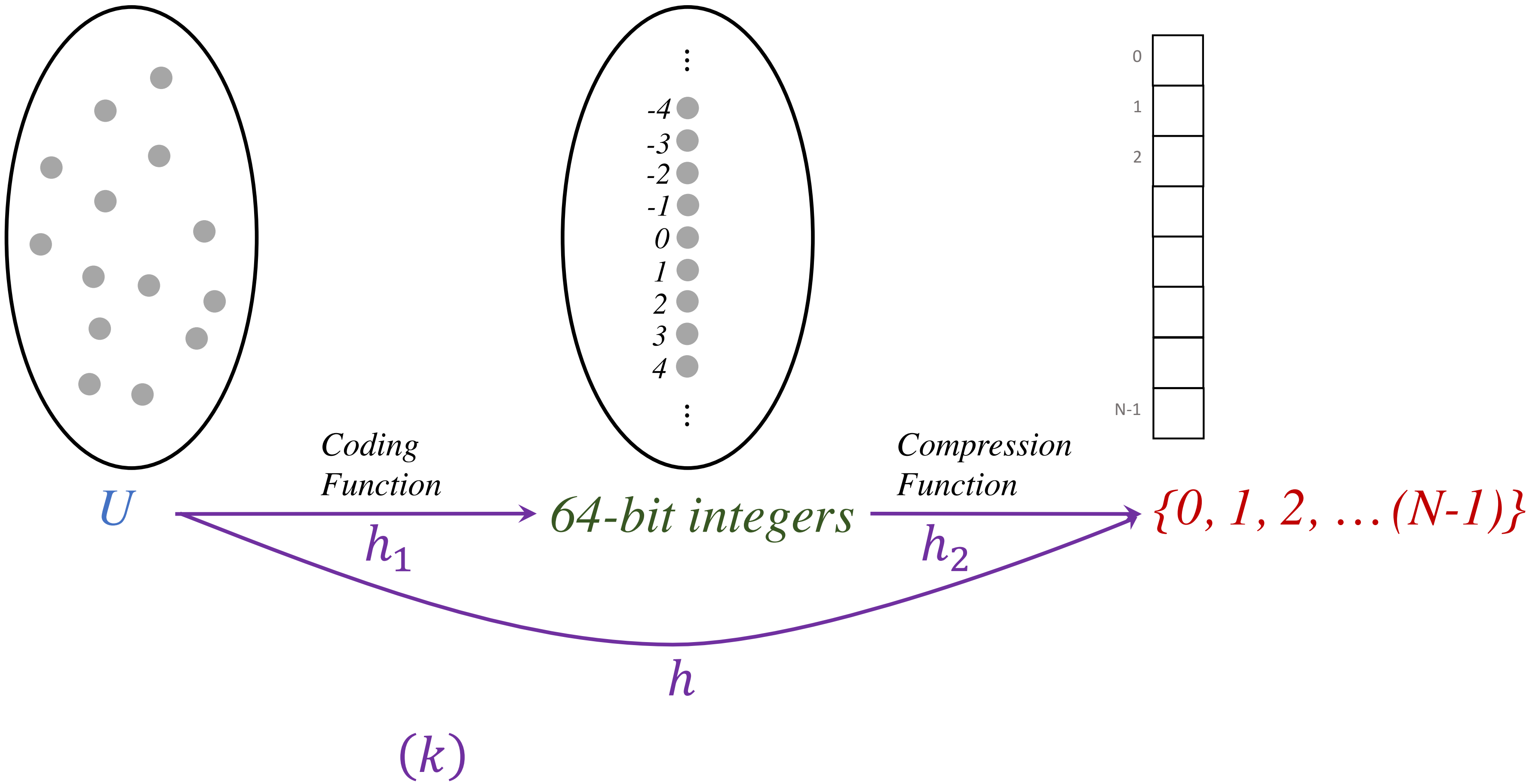

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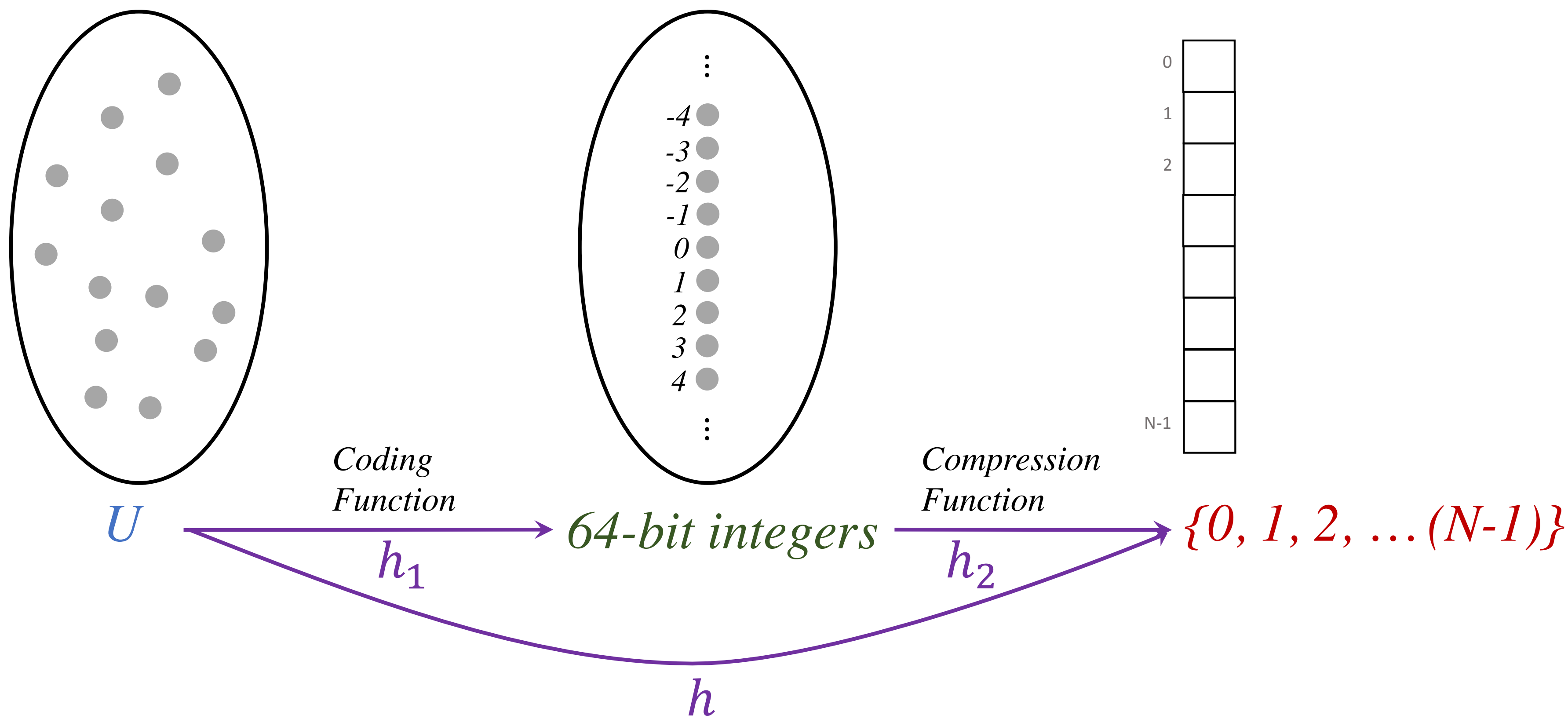
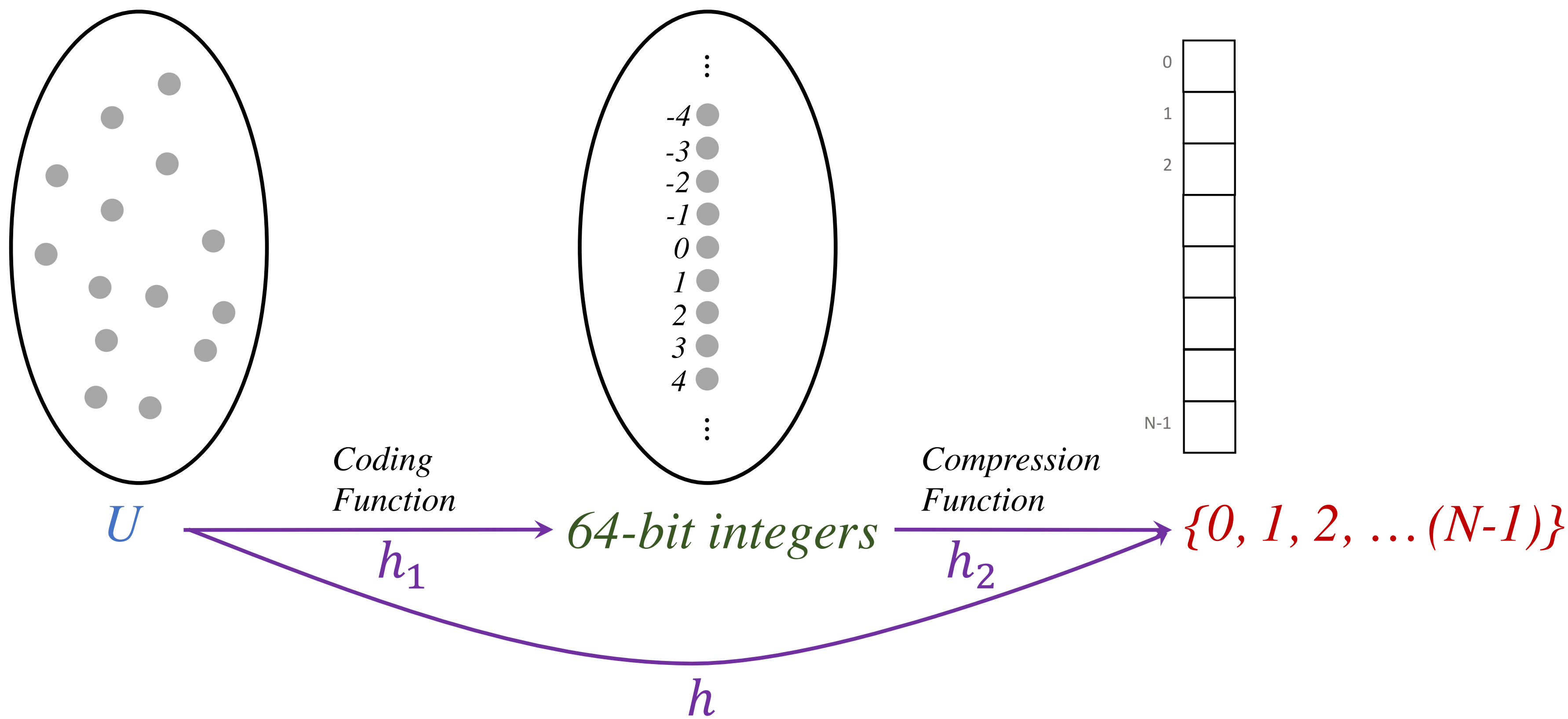


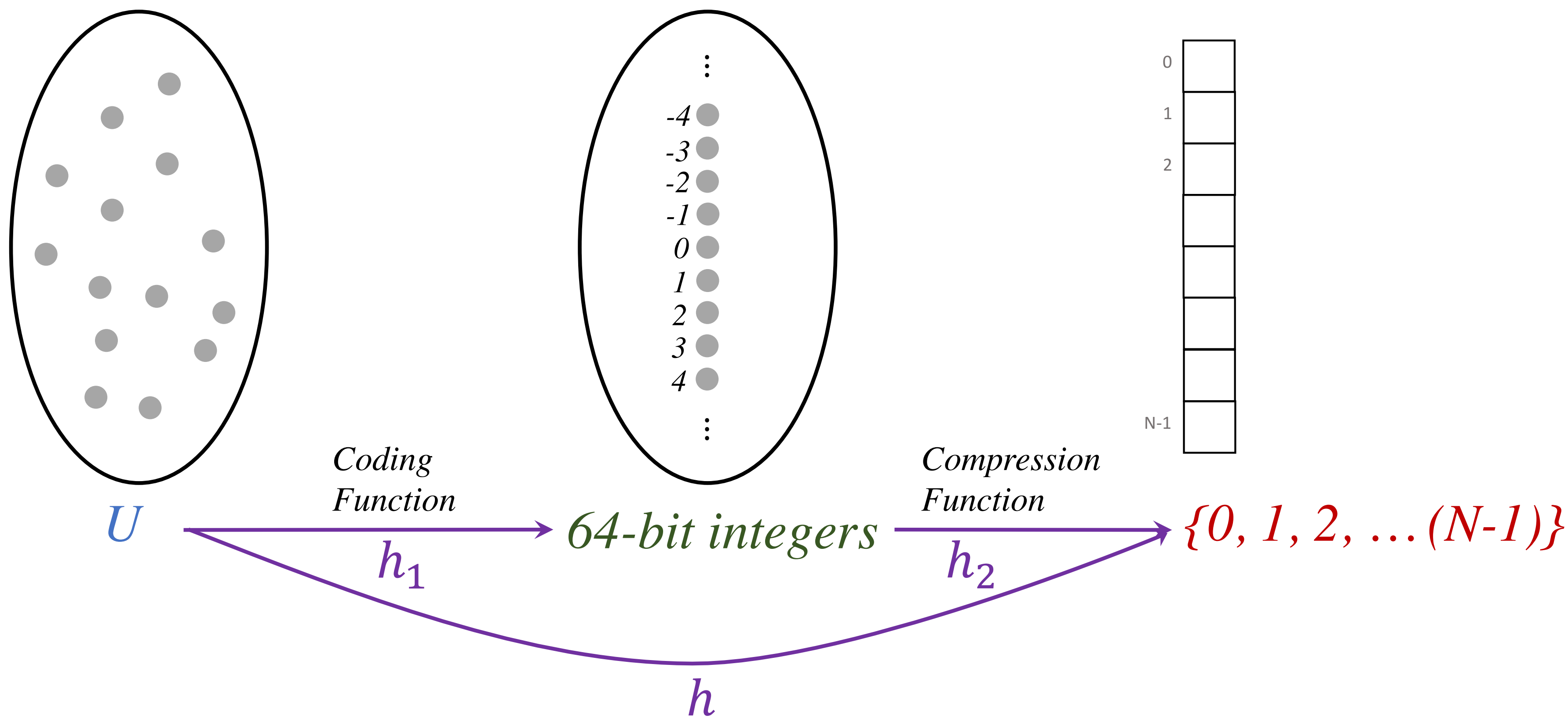
$h_1(k)$

Hash Functions



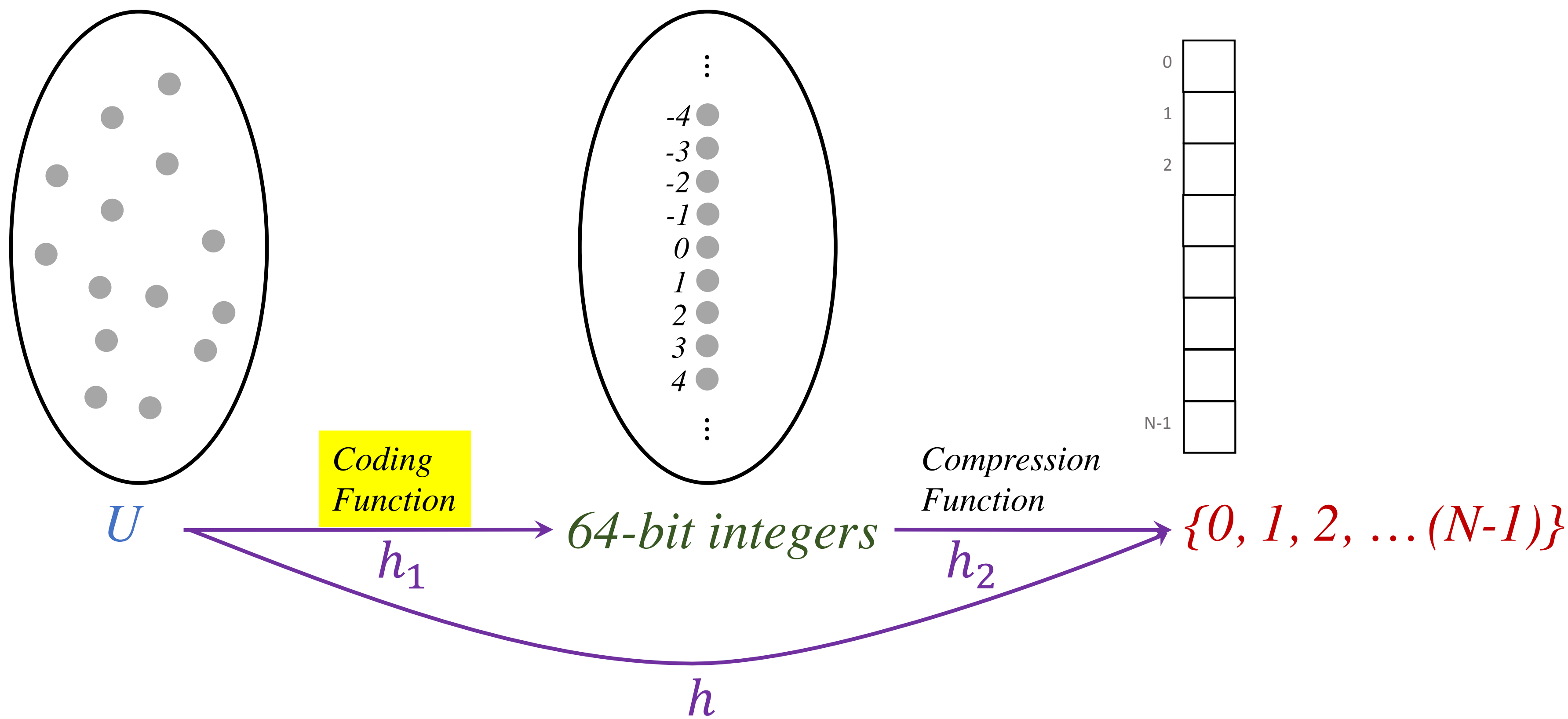
$$h_2(h_1(k))$$

Hash Functions



$$h(k) = h_2(h_1(k))$$

Hash Functions



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Coding Functions

$h_1 : U \rightarrow (64\text{–}bit\ integers)$

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i. <u>Common Approaches</u>:

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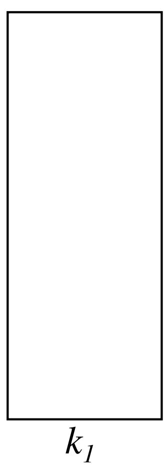

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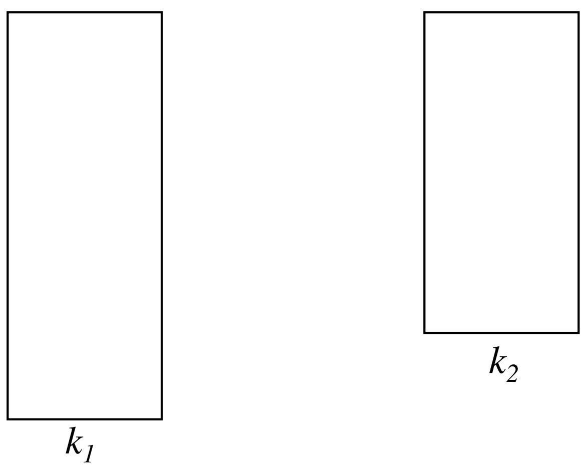

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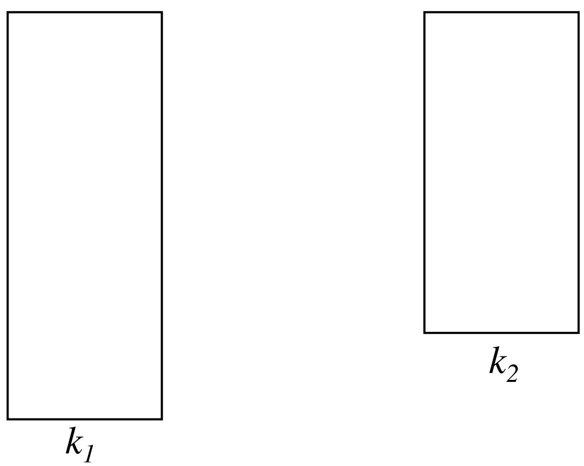

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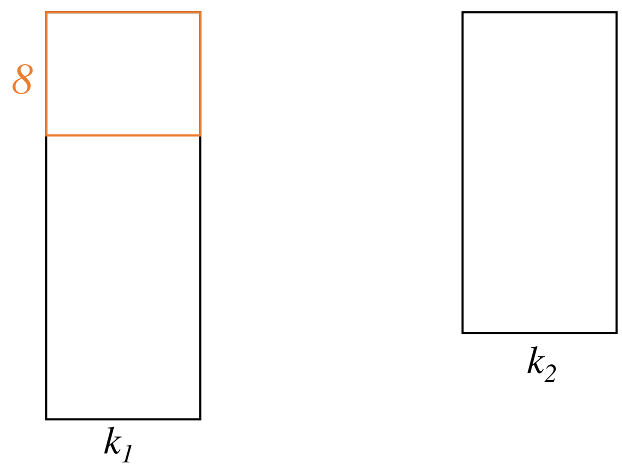

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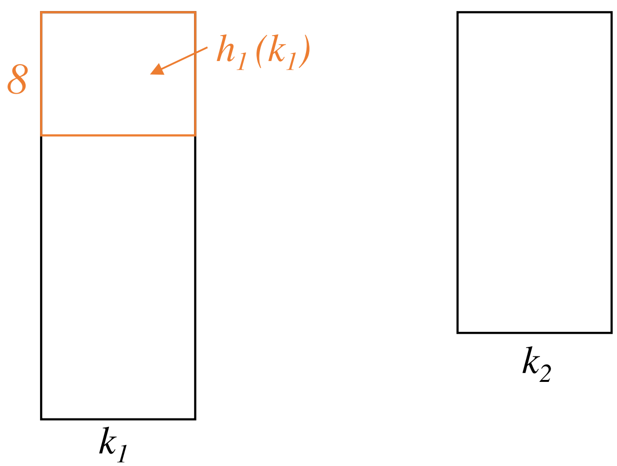

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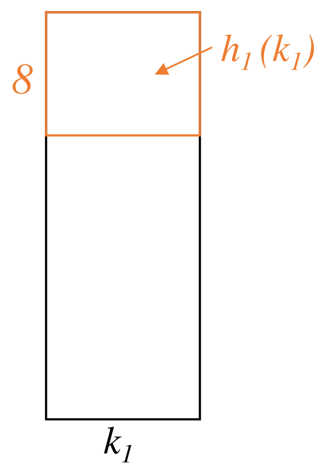

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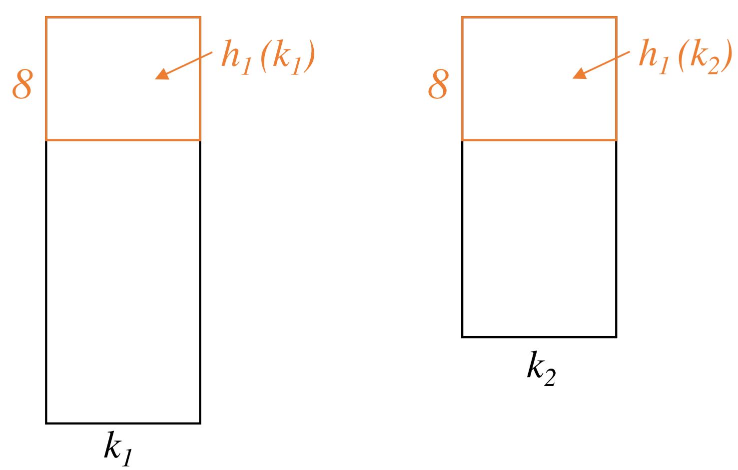

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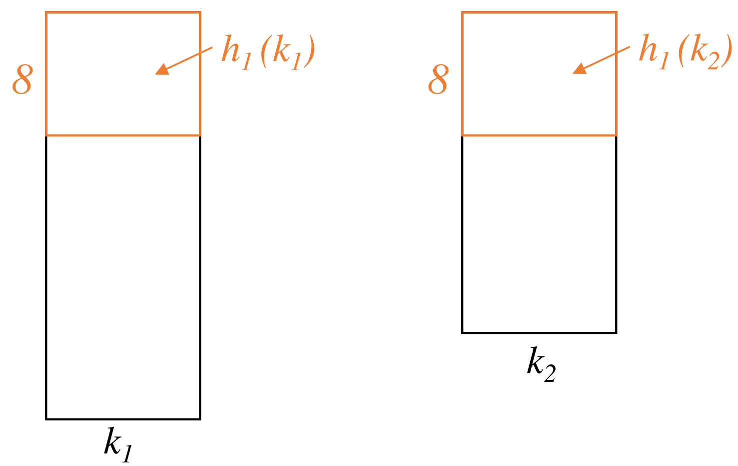

<u>Problem</u>:
This approach ignores part of the data.
In a biased set of keys, these parts could be where the keys differ

Coding Functions

$h_1 : U \rightarrow (64\text{–}bit\ integers)$

i. Common Approaches:
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Coding Functions

$h_1 : U \rightarrow (64\text{−}bit\ integers)$

i. <u>Common Approaches</u>:
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Coding Functions

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  Break key to its components: $key = (k_0, k_1, k_2, \ldots, k_{m-1})$.

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  Break key to its components: $key = (k_0, k_1, k_2, \dots, k_{m-1})$.
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"stop"

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all coded to the same value

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Problem:
This approach doesn't take the positions of the components into account

Coding Functions

$h_1 : U \rightarrow (64\text{−}bit\ integers)$

i. <u>Common Approaches</u>:
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Coding Functions

$h_1 : U \rightarrow (64\text{−}bit\ integers)$

i. <u>Common Approaches</u>:

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Coding Functions

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     Let z be an integer ≥ 2
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     We define: $h_1(key) =$

Coding Functions

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  Fun Fact:

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  Fun Fact: If we take $z = 33$, When coding 50,000 English words, have at most 6 collisions

Coding Functions

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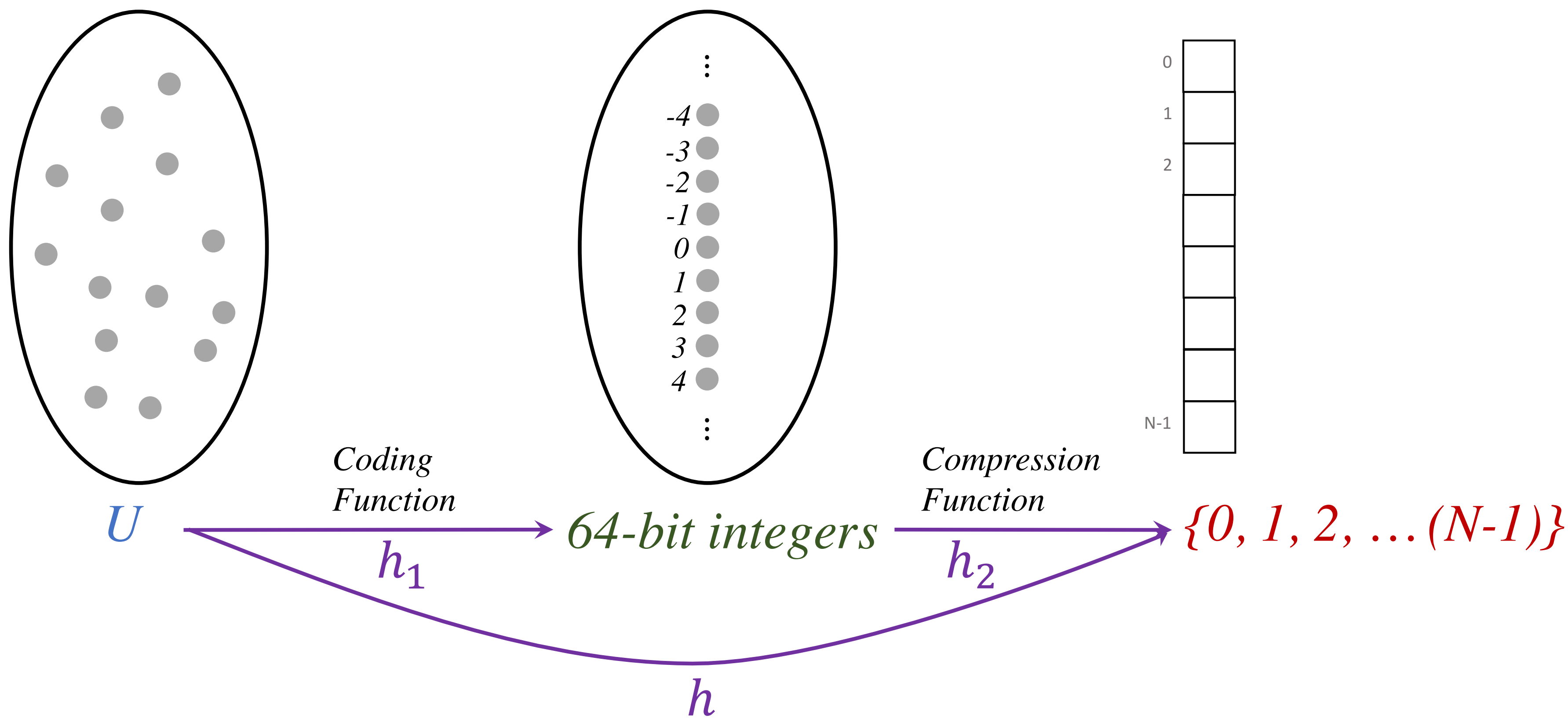
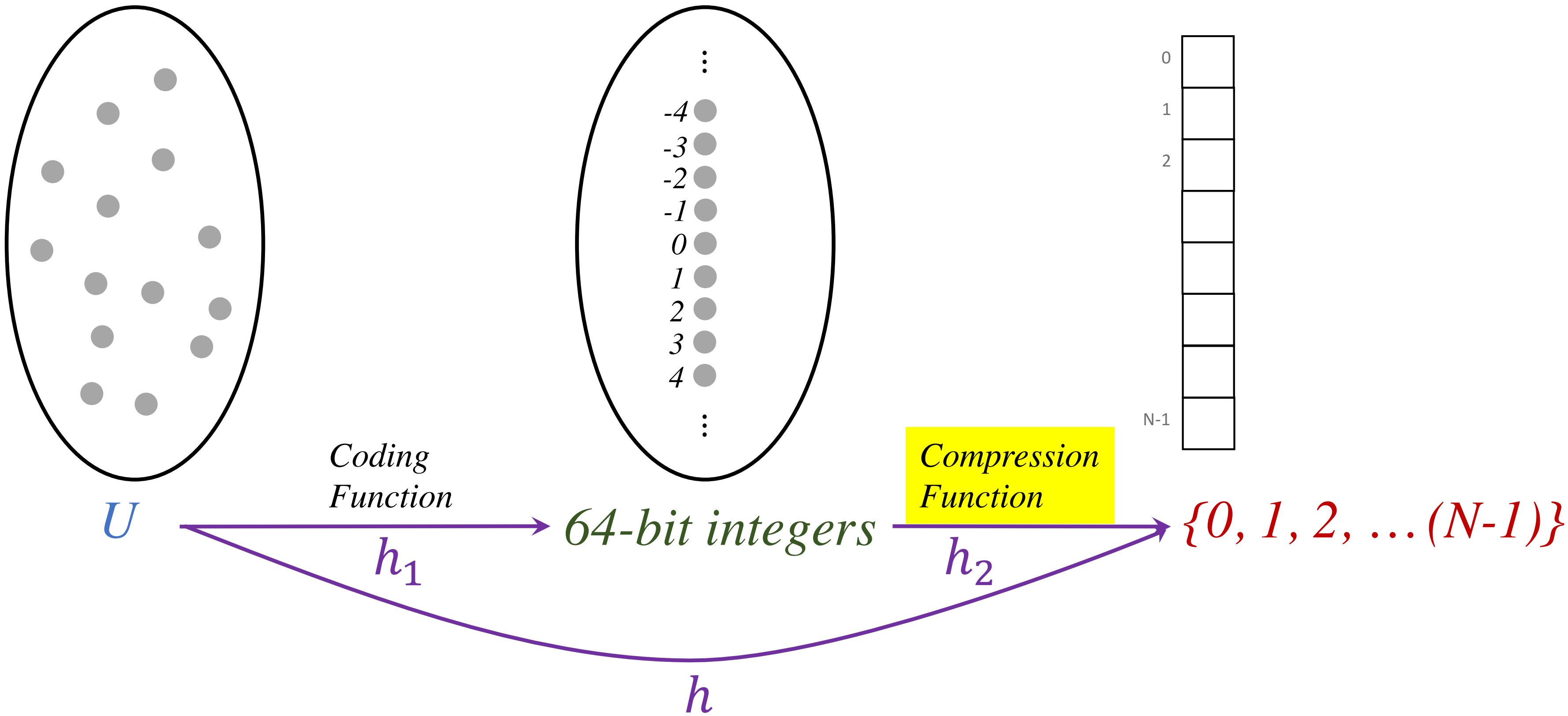
- Make sure that $(x = y) \rightarrow hash(x) = hash(y)$

Hash Functions



$$h(k) = h_2\big(h_1(k)\big)$$

Hash Functions



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Compression Functions

h_2: $(64\text{−}bit\ integers) \rightarrow \{0, 1, \ldots, N - 1\}$

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  Example: if our keys are: {0, 5, 10, 15, 20, 30, 35, 40, 45, 50, 55}:

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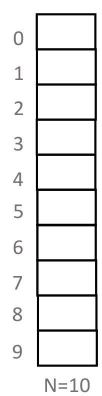

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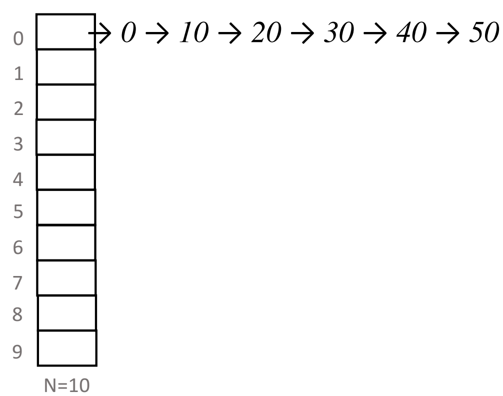

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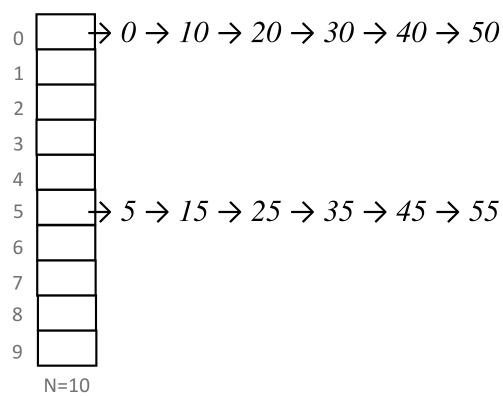

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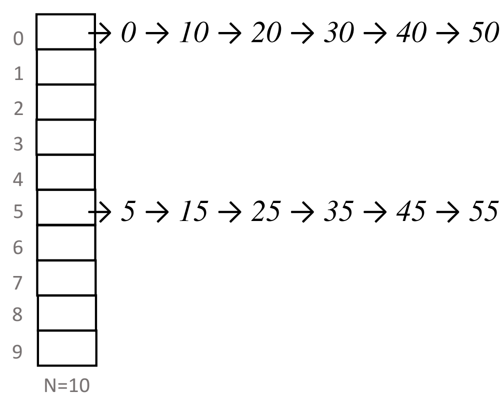

A common heuristic is to choose N to be prime.

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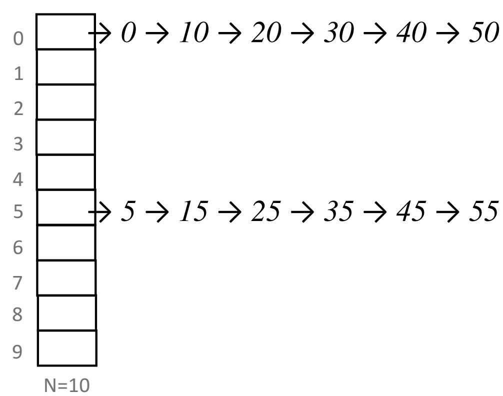

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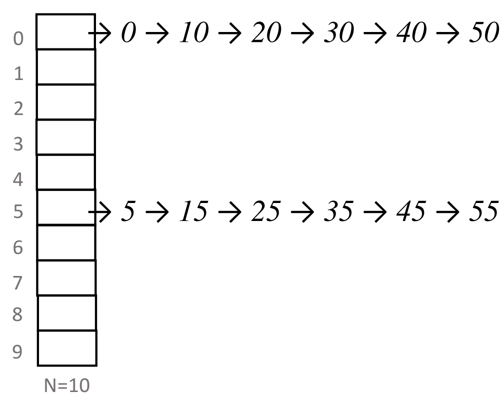
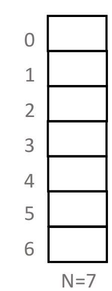
Example: if our keys are: {0, 5, 10, 15, 20, 30, 35, 40, 45, 50, 55}:

For N=10:



A common heuristic is to choose N to be prime.

For N=7:



Compression Functions

h_2: $(64\text{−}bit\ integers) \rightarrow \{0, 1, \ldots, N-1\}$

<u>Common Approaches</u>:

- The Division Method

  We define: $h_2(k) = k \bmod N$

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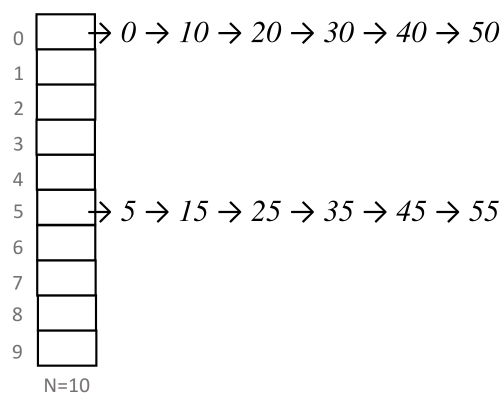

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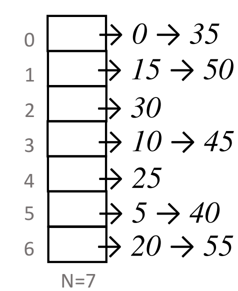

Compression Functions

h_2: $(64\text{-}bit\ integers) \rightarrow \{0, 1, \ldots, N-1\}$

Common Approaches:

- The Division Method

Compression Functions

h_2: $(64\text{–}bit\ integers) \to \{0, 1, \dots, N-1\}$

Common Approaches:

- The Division Method
- The Multiply-Add-and-Divide (MAD) Method

Compression Functions

h_2: $(64\text{−}bit\ integers) \rightarrow \{0, 1, \ldots, N-1\}$

Common Approaches:

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  Let p be a prime number, $p > |U|$

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Example: if $|U|=60$

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the keys are:

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we choose: $p=101$ $a=30$ $b=6$

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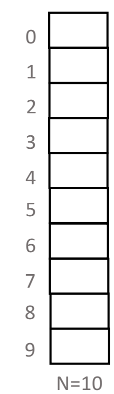

Compression Functions

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Example: if $|U| = 60$

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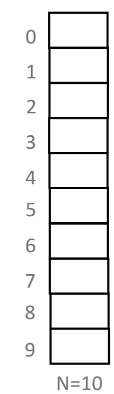
we choose: $p=101 \quad a=30 \quad b=6$

For a table of size N=10: $h_2(k) = [(30k + 6) \; mod \; 101] \; mod \; 10$



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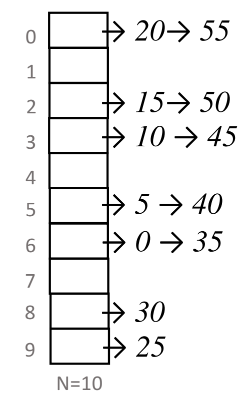

Time Analysis of *Find*

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Worst-Case:

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Worst-Case: all keys are mapped to the same slot, it takes $\theta(n)$ to scan that chain

Time Analysis of $\boldsymbol{Find}$

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Expected-Time:

Time Analysis of $Find$

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II. Let $\propto$ be the load-factor of the table

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That is: $\propto = \frac{n}{N}$

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$\Downarrow$

$\propto =$

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Expected time for $Find$ =

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Expected time for $Find$ = $\theta(1 + \propto)$

Time Analysis of $Find$

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Calculate the hash function and Access slot

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Scan the chain

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If **we always maintain $\boldsymbol{n \leq N}$**

Time Analysis of $\boldsymbol{Find}$

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If **we always maintain** $\boldsymbol{n} \leq \boldsymbol{N}$ $\Rightarrow$ $\propto \leq 1$ $\Rightarrow$ Expected time for $Find$ = $\theta(1)$

Implementation Points

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-

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- Collision resolution:
-
-

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-
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- Performance: always keep $n<N$