Prepared by Julian García, based on material by
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Lecture 24
Collision Resolution

FIT 1008
Introduction to Computer Science

MONASH University
Information Technology

Objectives for this lecture

- To understand two of the main methods of conflict resolution:
  - Open addressing:
    - Linear Probing
    - Quadratic probing
    - Double Hashing
  - Separate Chaining
- To understand their advantages and disadvantages
- To be able to implement them

Collisions: two main approaches

- **Open addressing**:
  - Each array position contains a single item
  - Upon collision, use an empty space to store the item (which empty space depends on which technique)

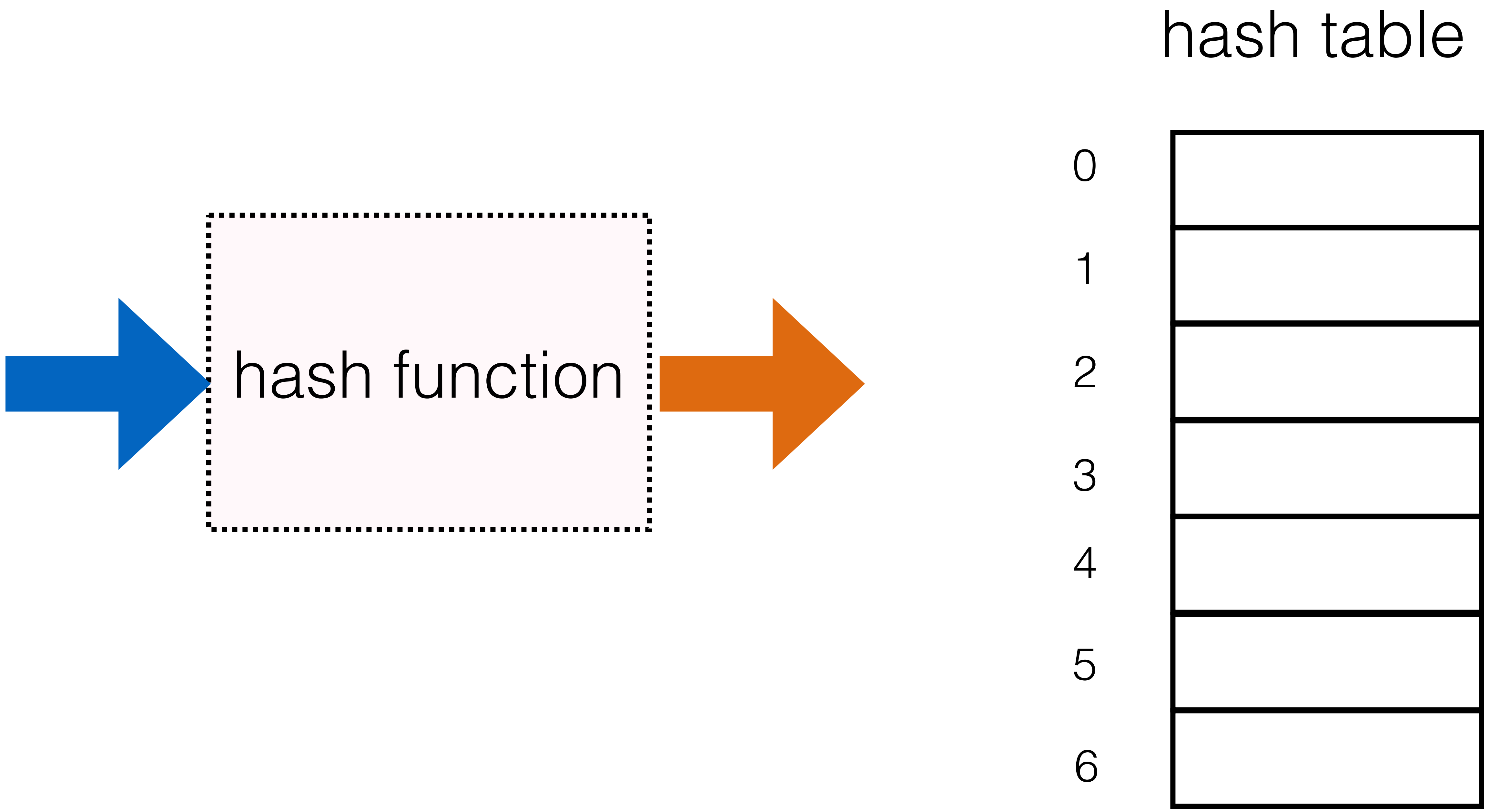
- **Separate chaining**:
  - Each array position contains a linked list of items
  - Upon collision, the element is added to the linked list

Open Addressing: Linear Probing

- **Insert item with hash value N**:
  - ➡ If array[N] is empty just put item there.
  - ➡ If there is already an item there:
    look for the **first empty space in the array** from **N+1** (if any) and add it there
- Linear search from N until an empty slot is found
- **Things to think about**:
  - Full table (to avoid going into an infinite loop)
  - Restarting from position 0 if the end of table is reached
  - Finding an item with the same key.

Example

Aho, Kruse, Standish, Horowitz, Langsam, Sedgewick, Knuth



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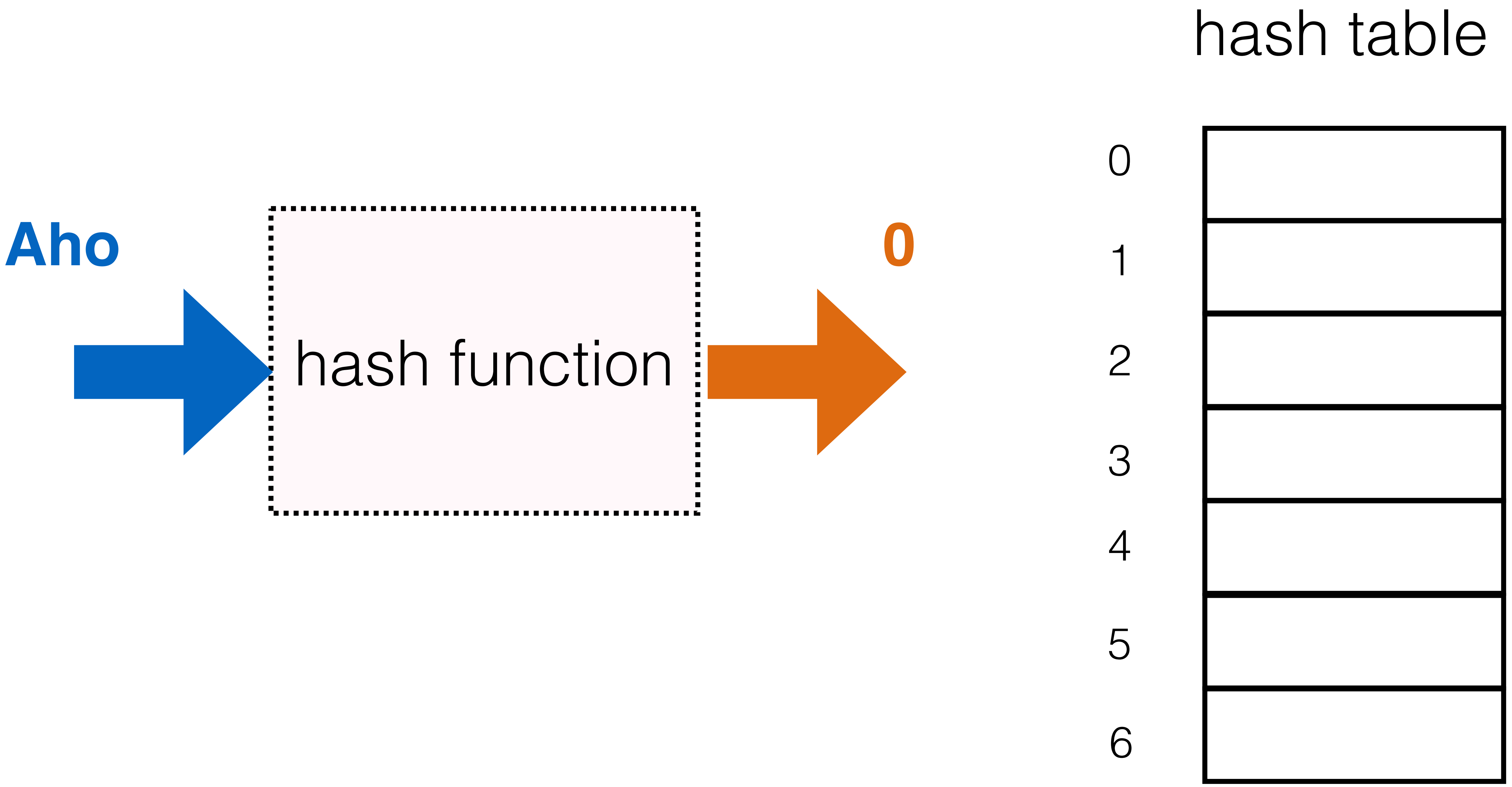

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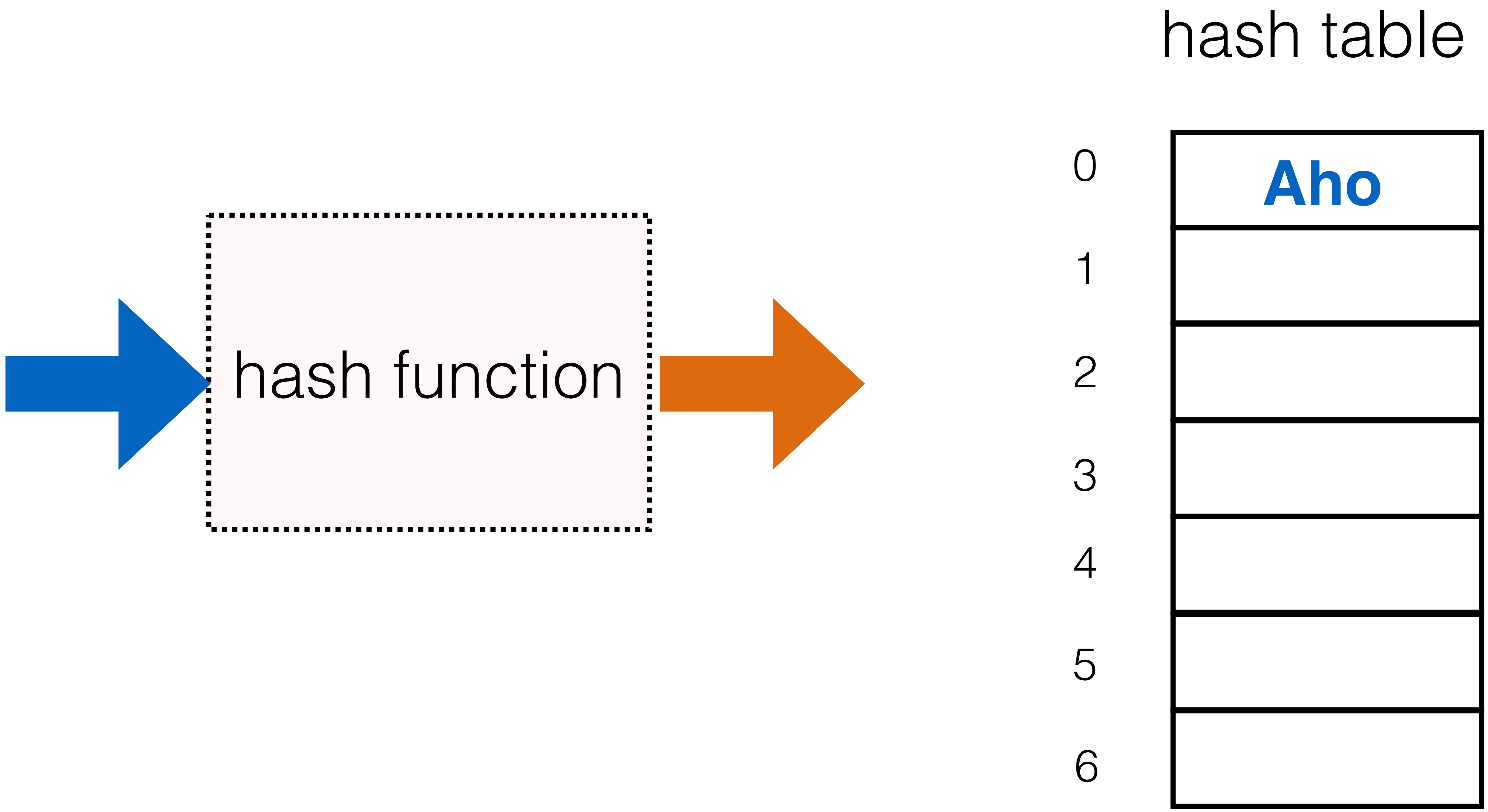

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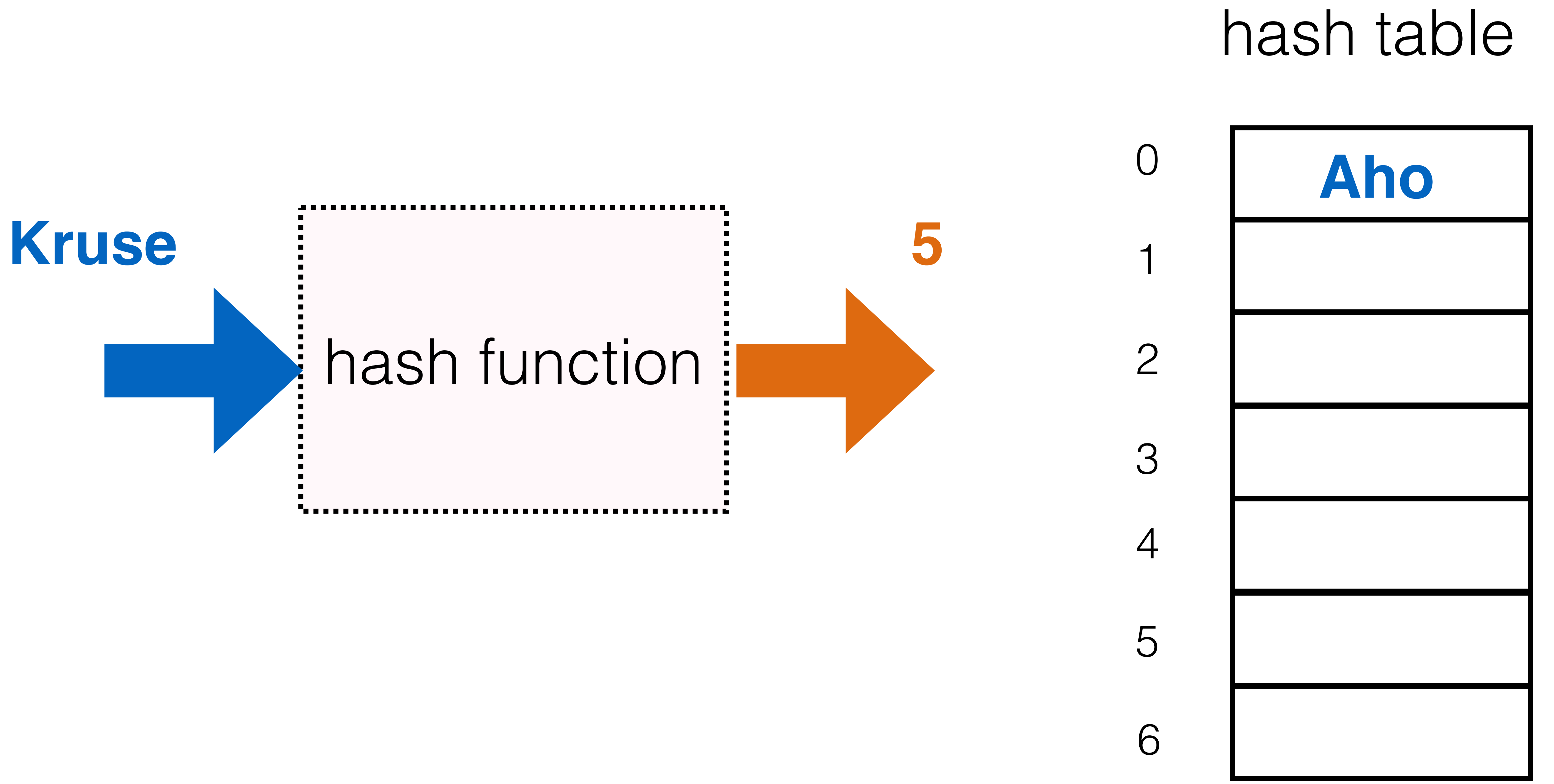

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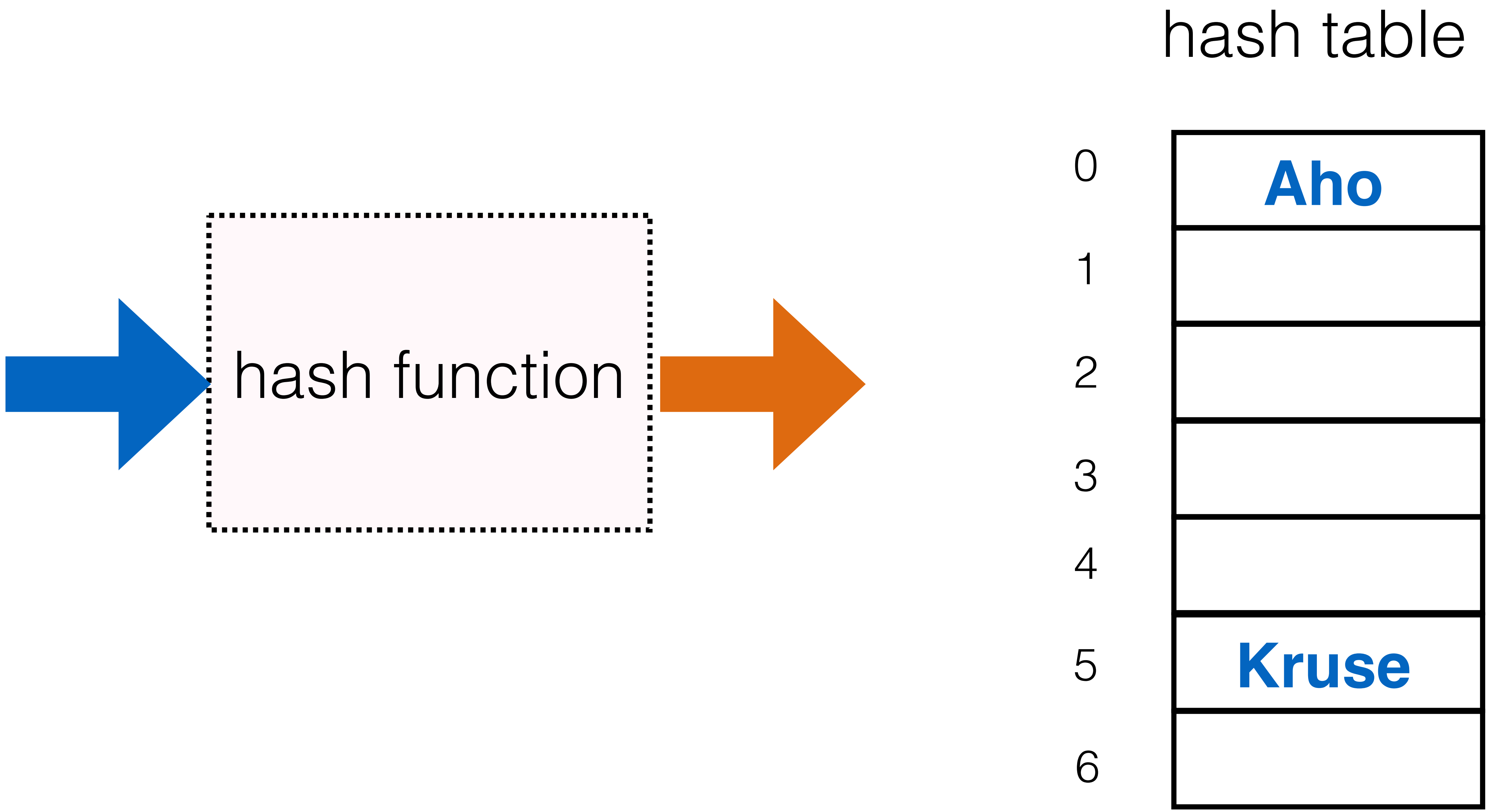

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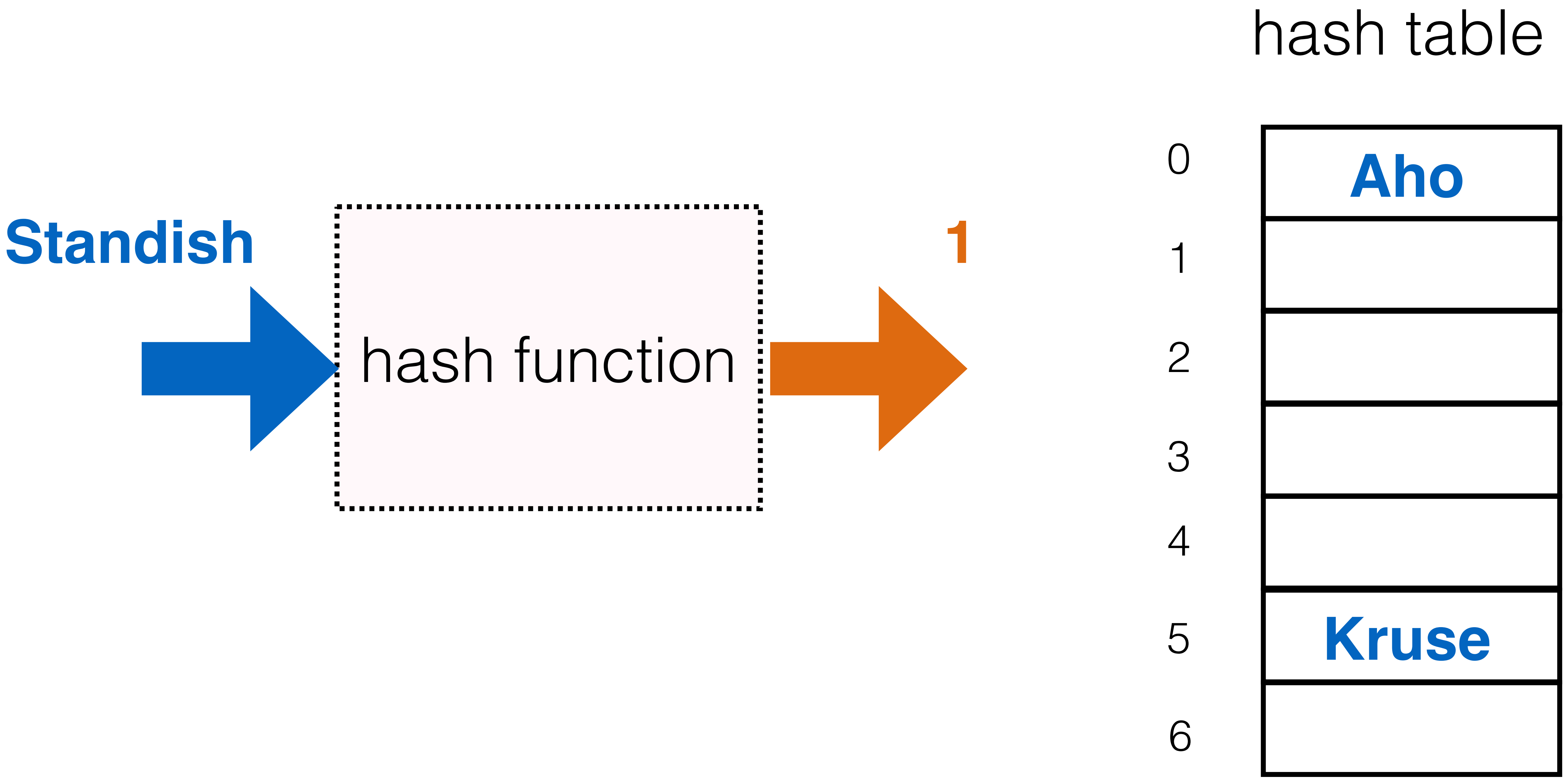

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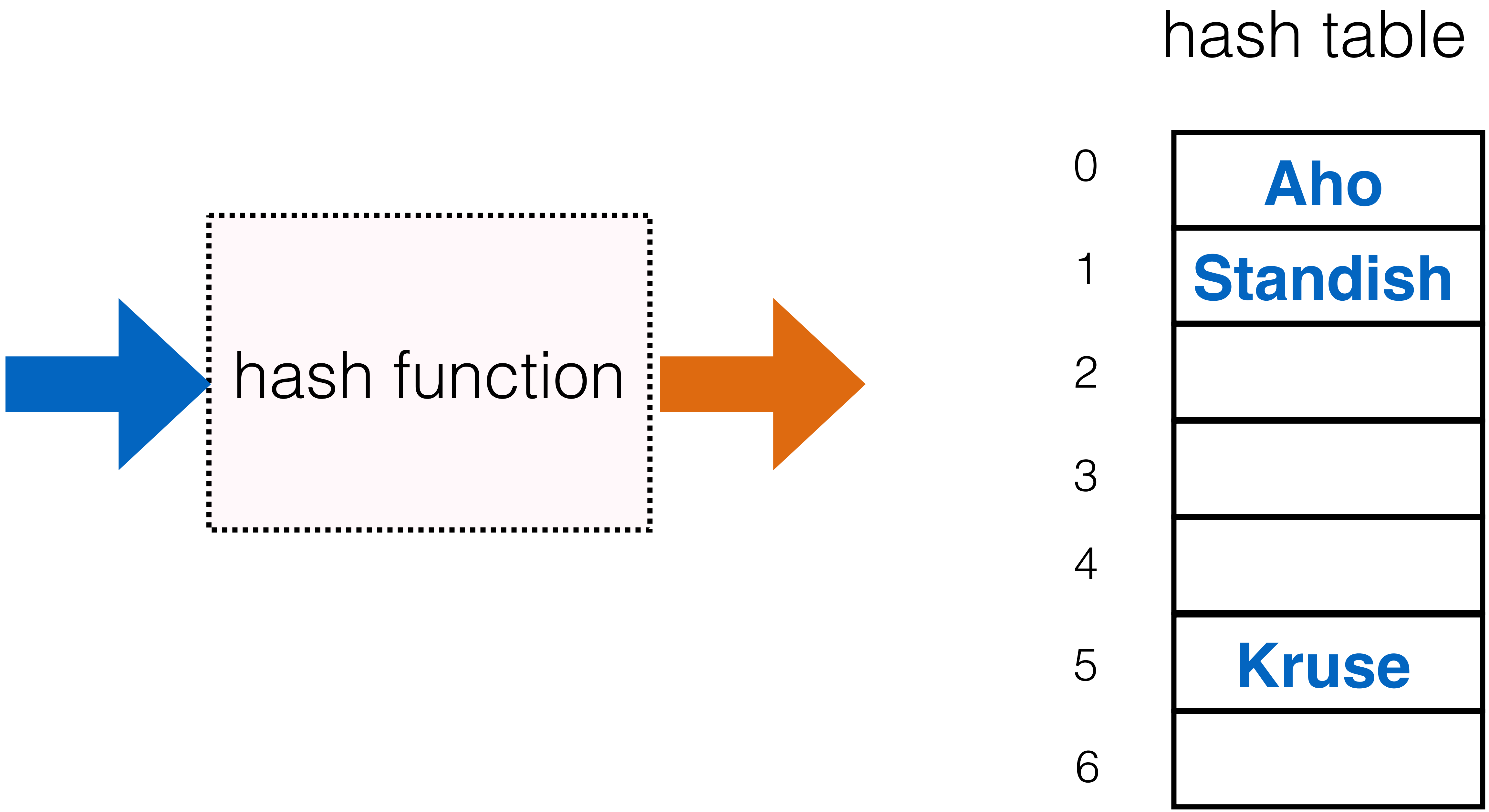

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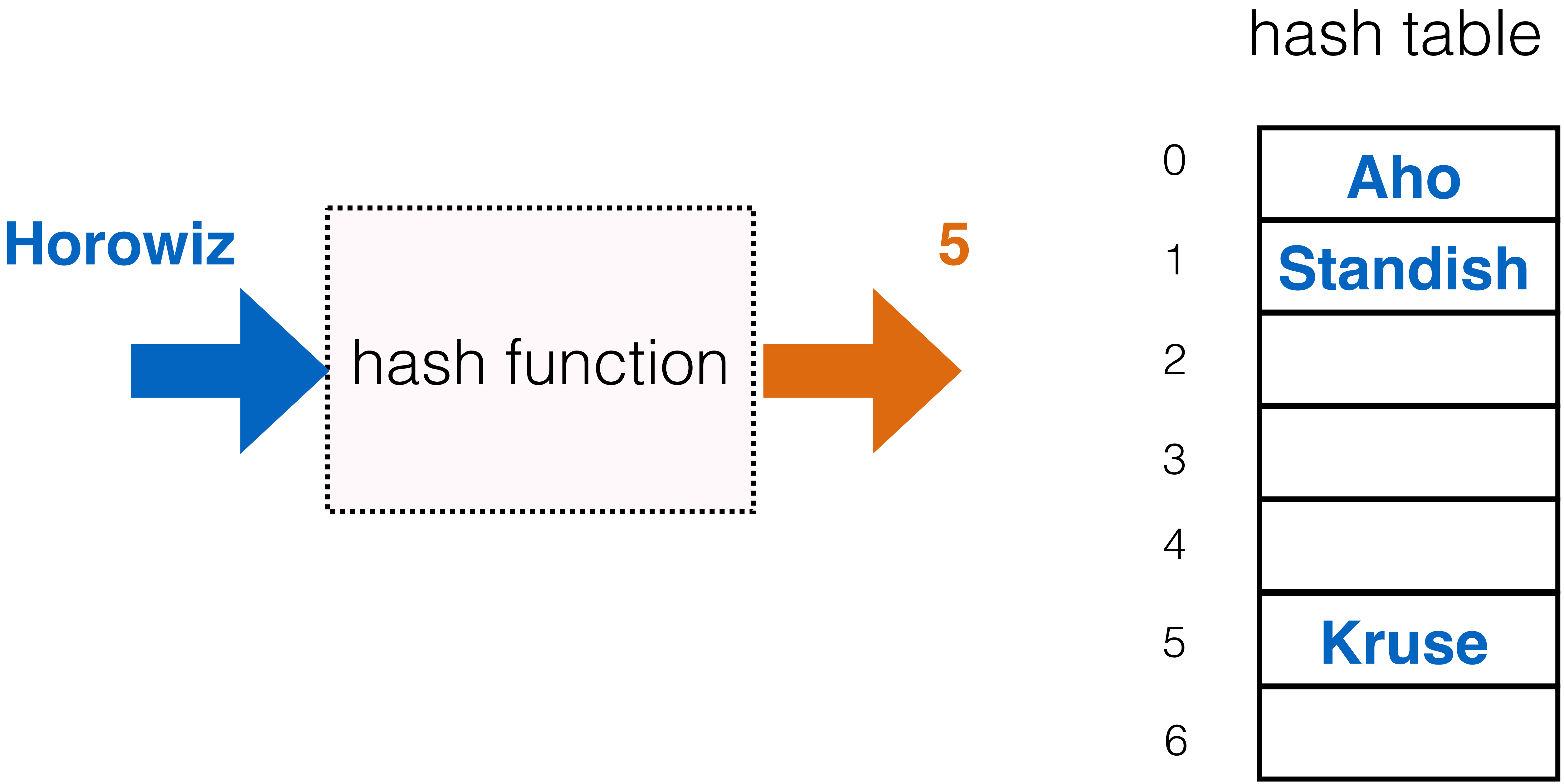

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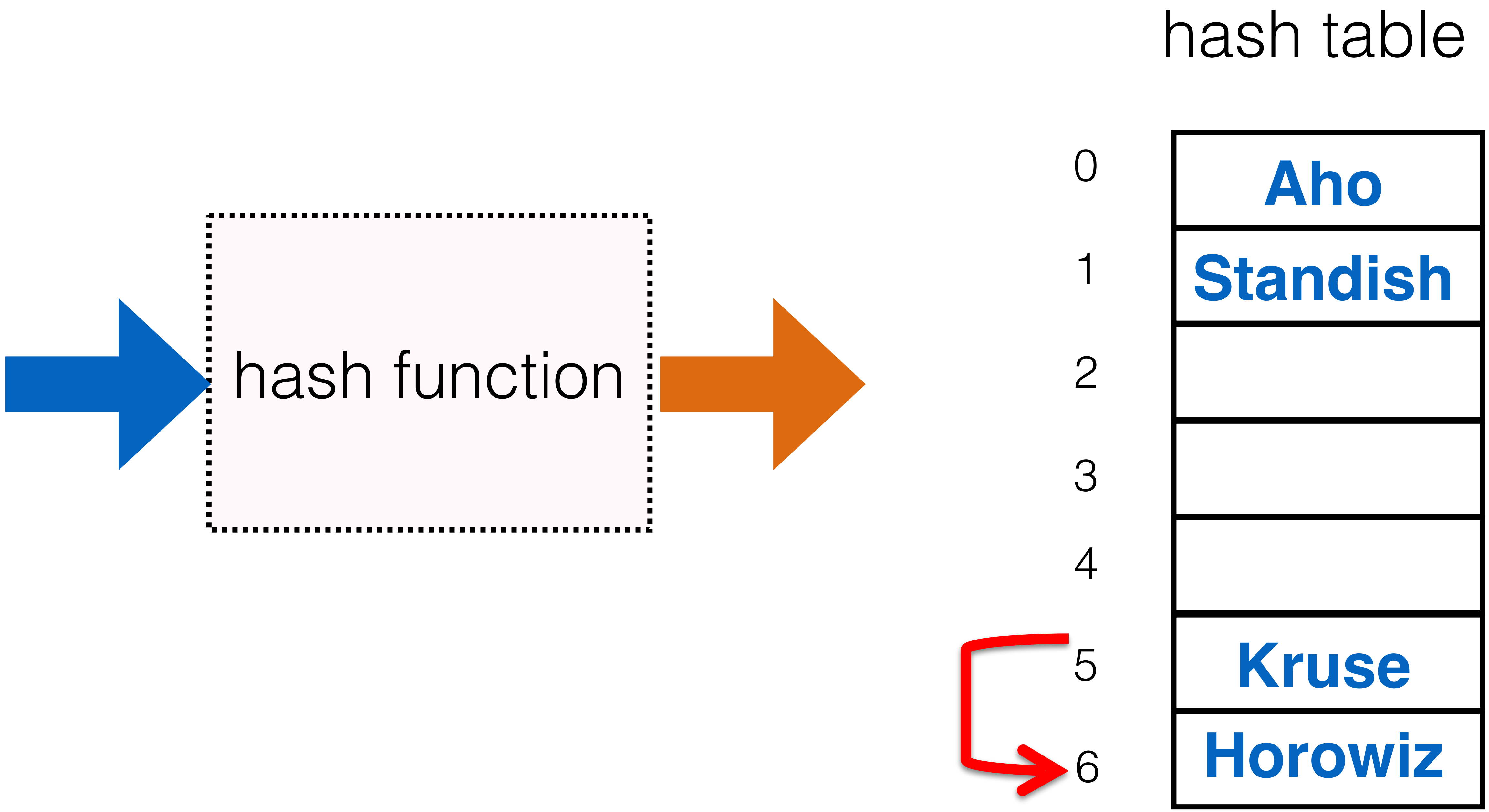

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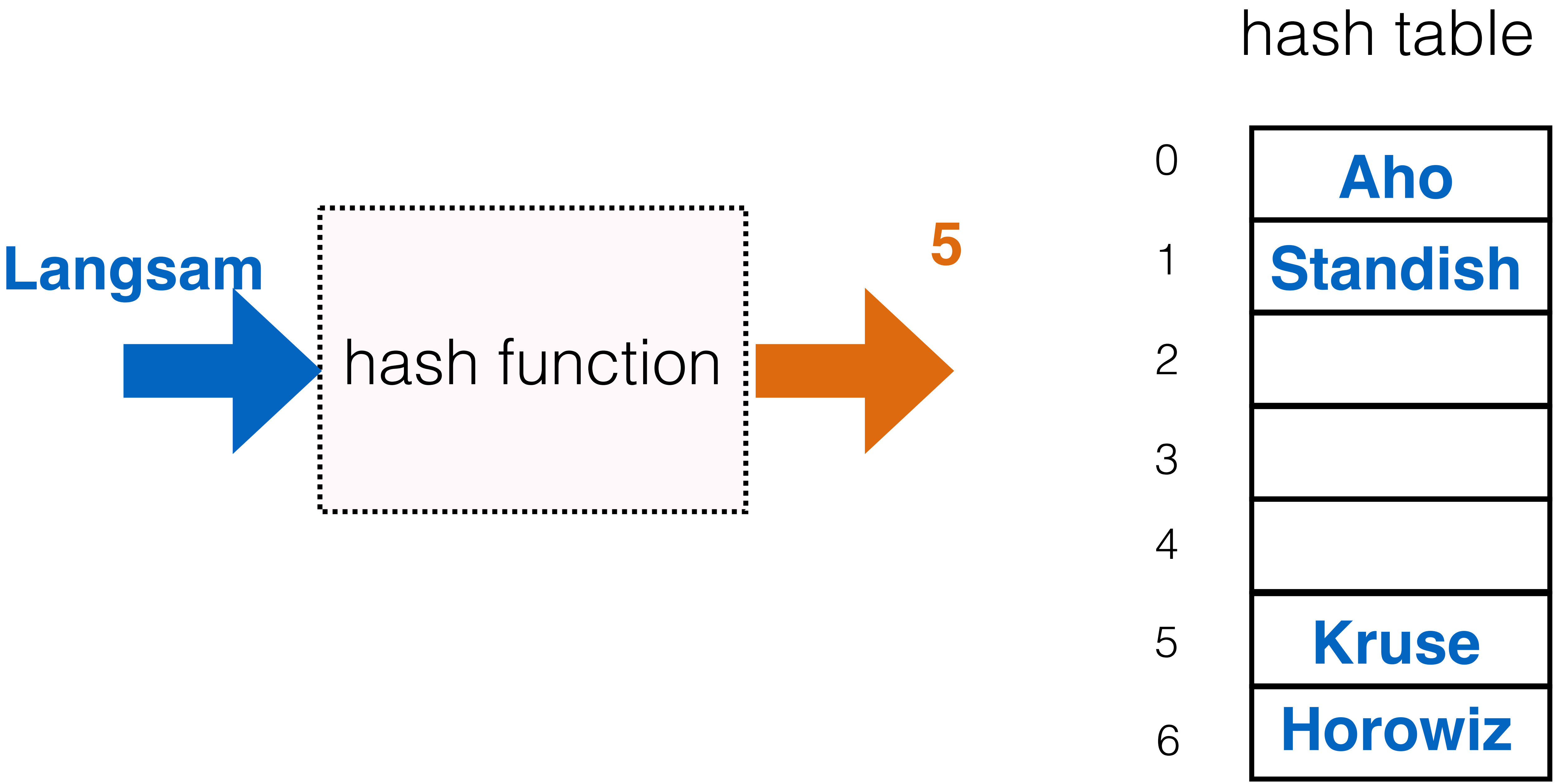

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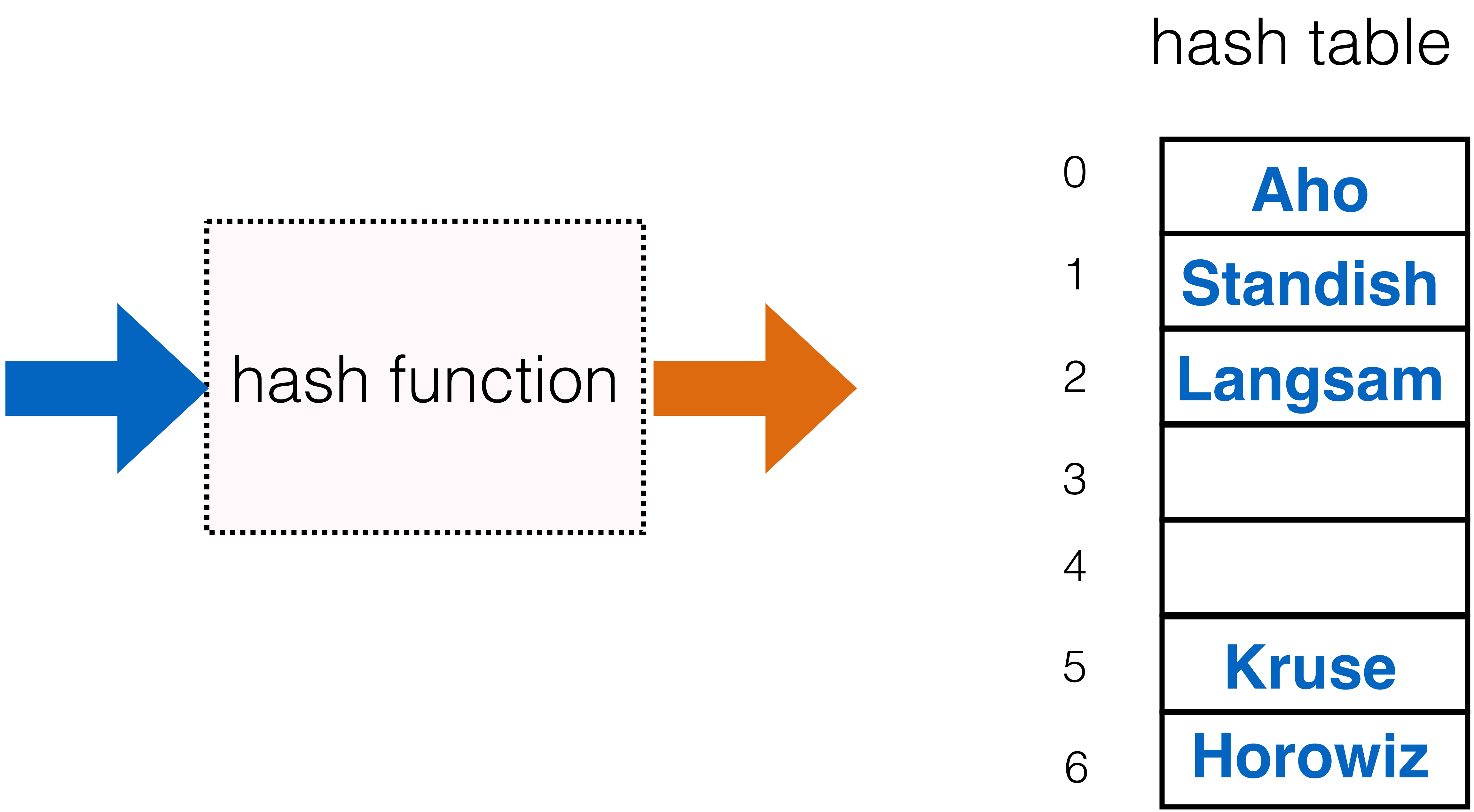

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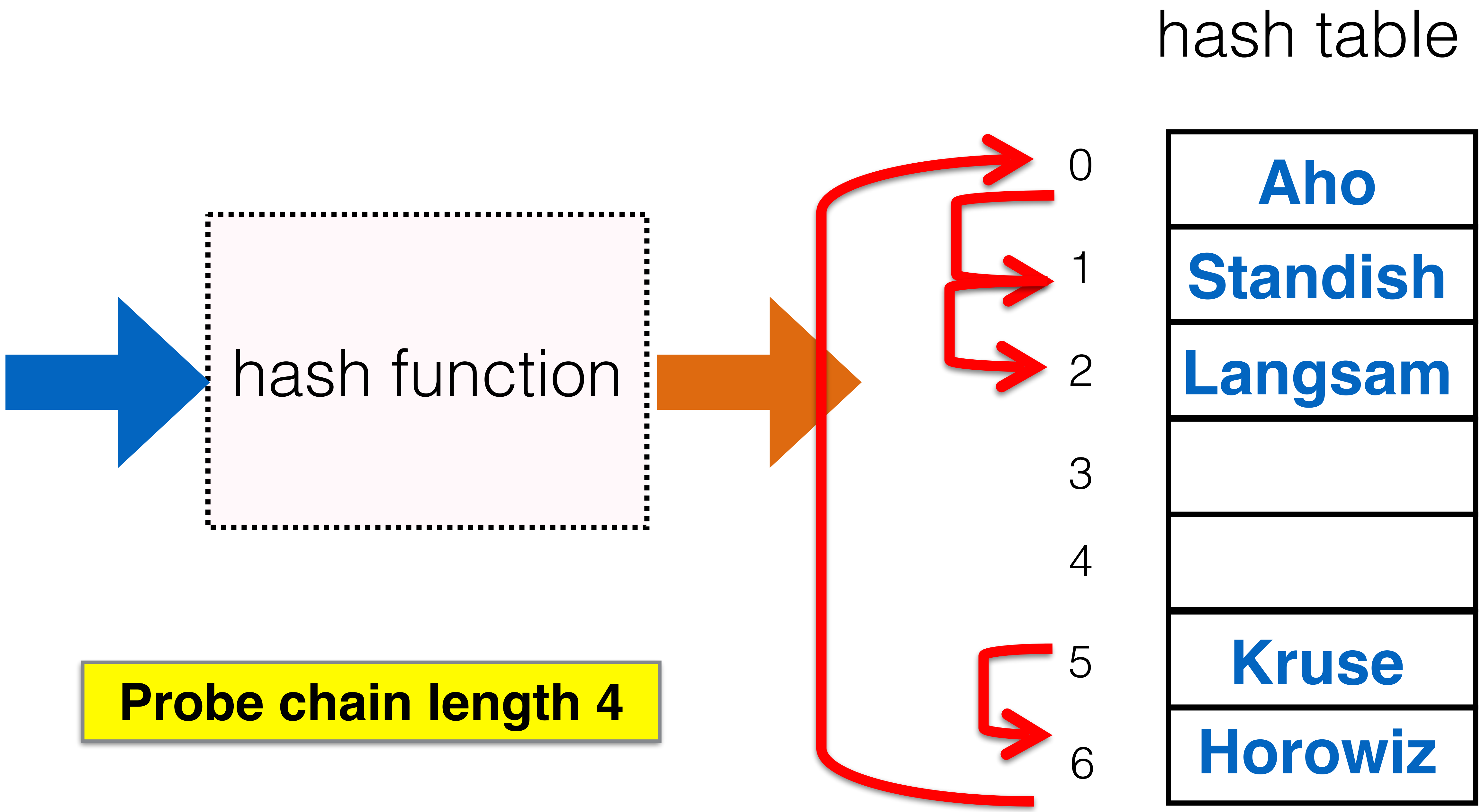

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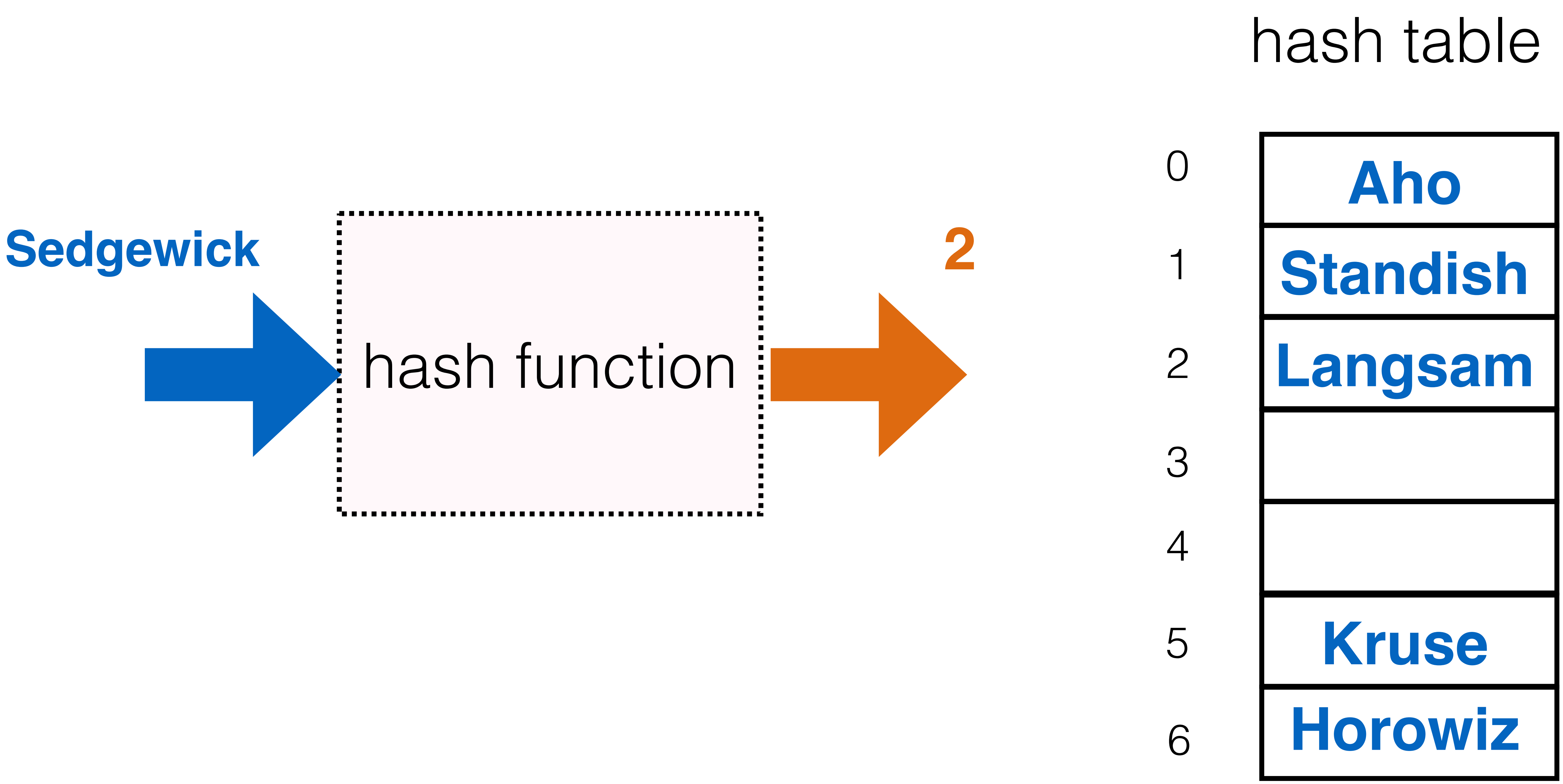

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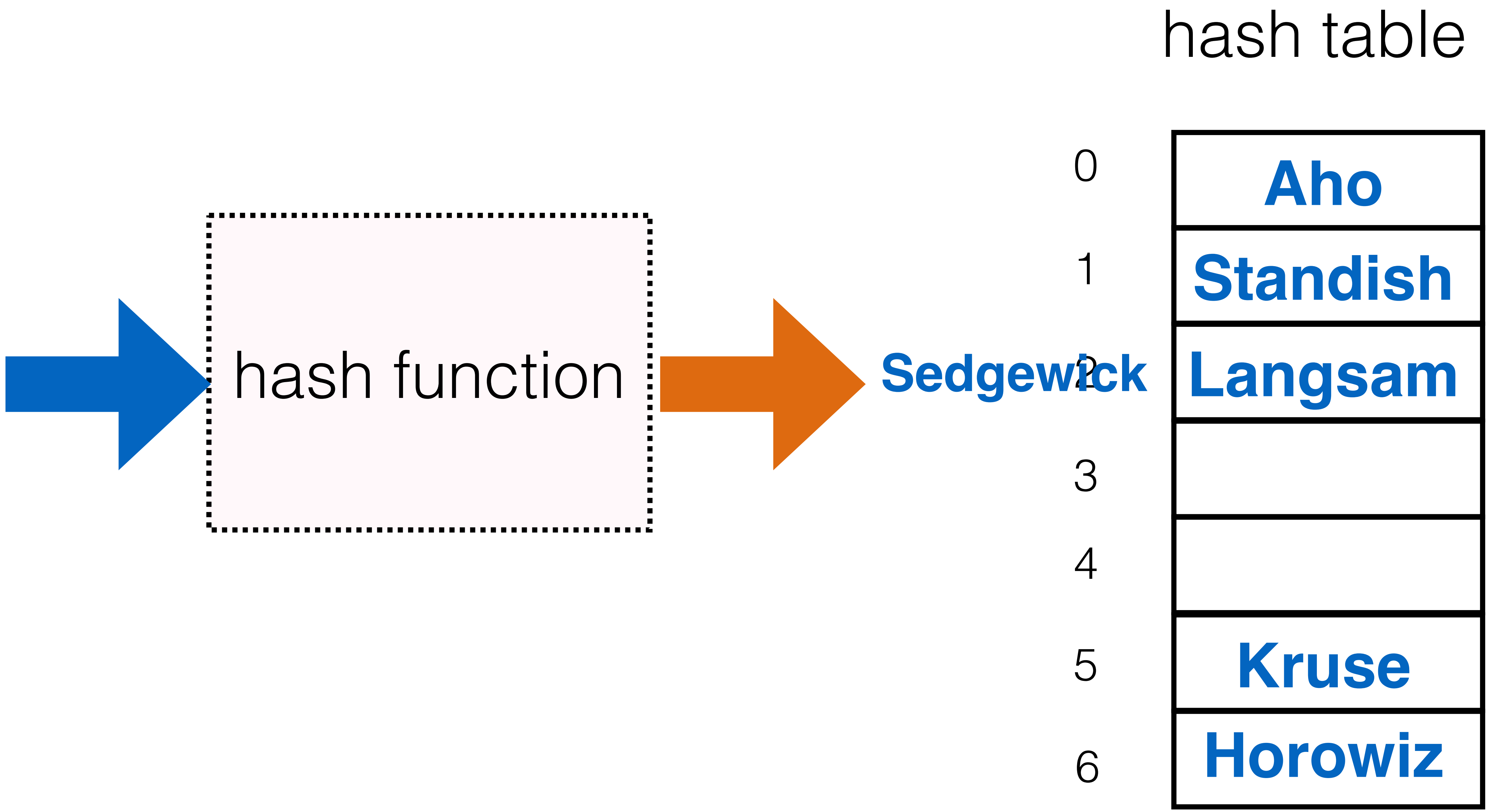

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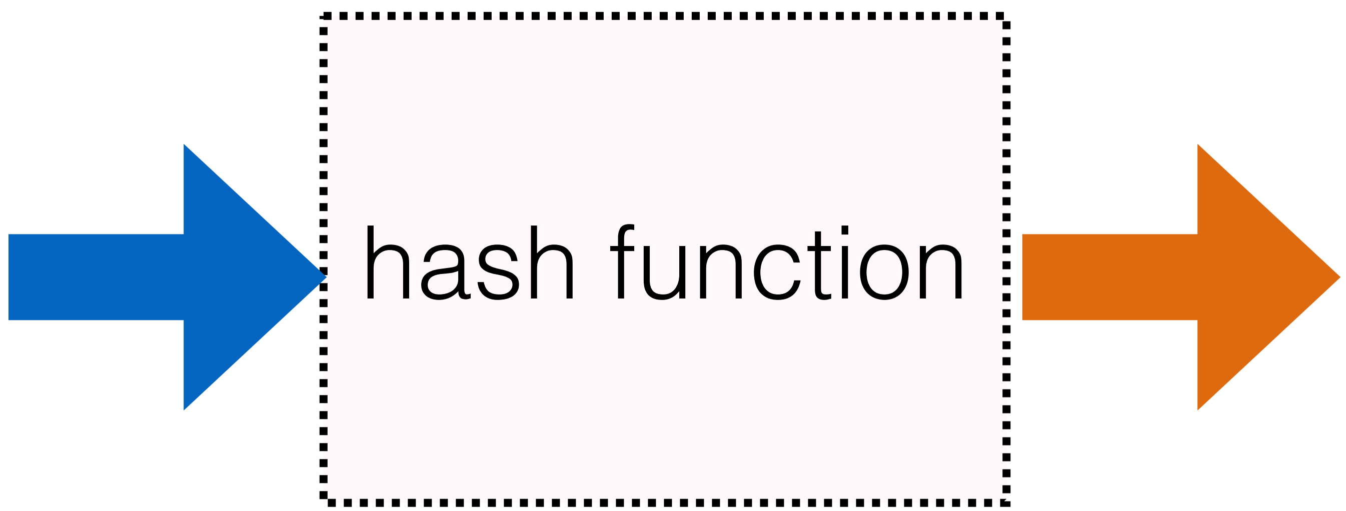
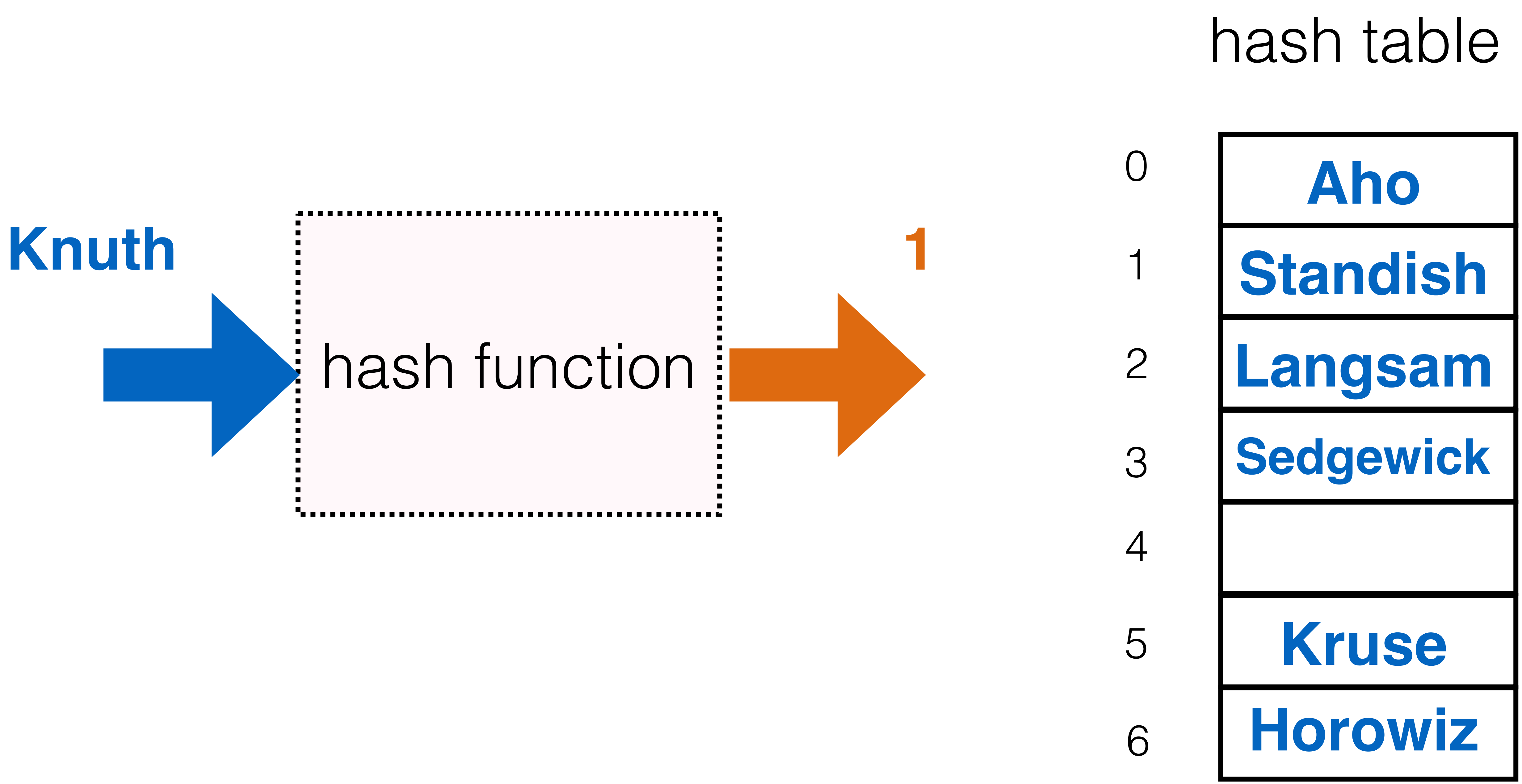


hash table

0	**Aho**
1	**Standish**
2	**Langsam**
3	**Sedgewick**
4	
5	**Kruse**
6	**Horowiz**

Example

Aho, Kruse, Standish, Horowiz, Langsam, Sedgewick, Knuth



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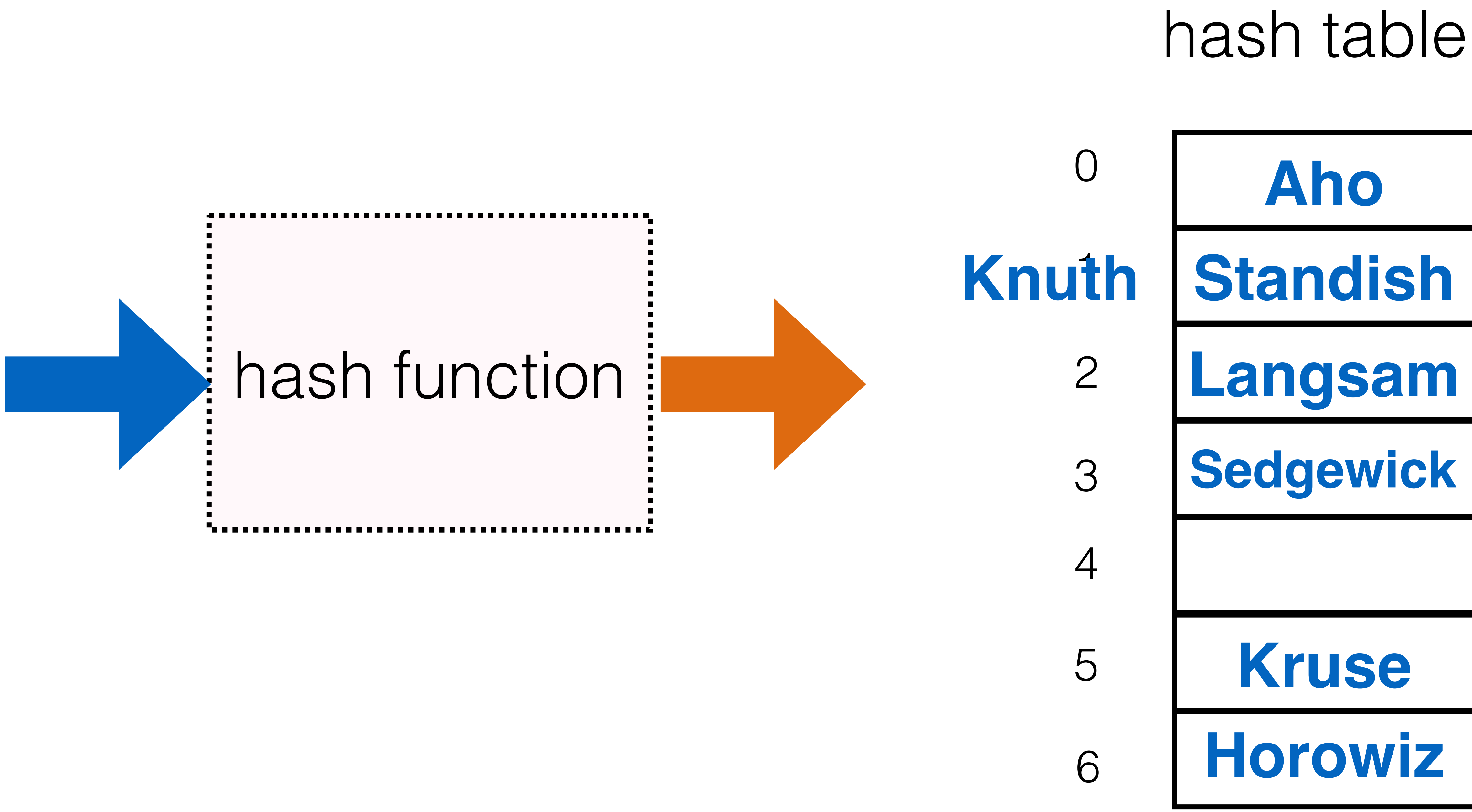

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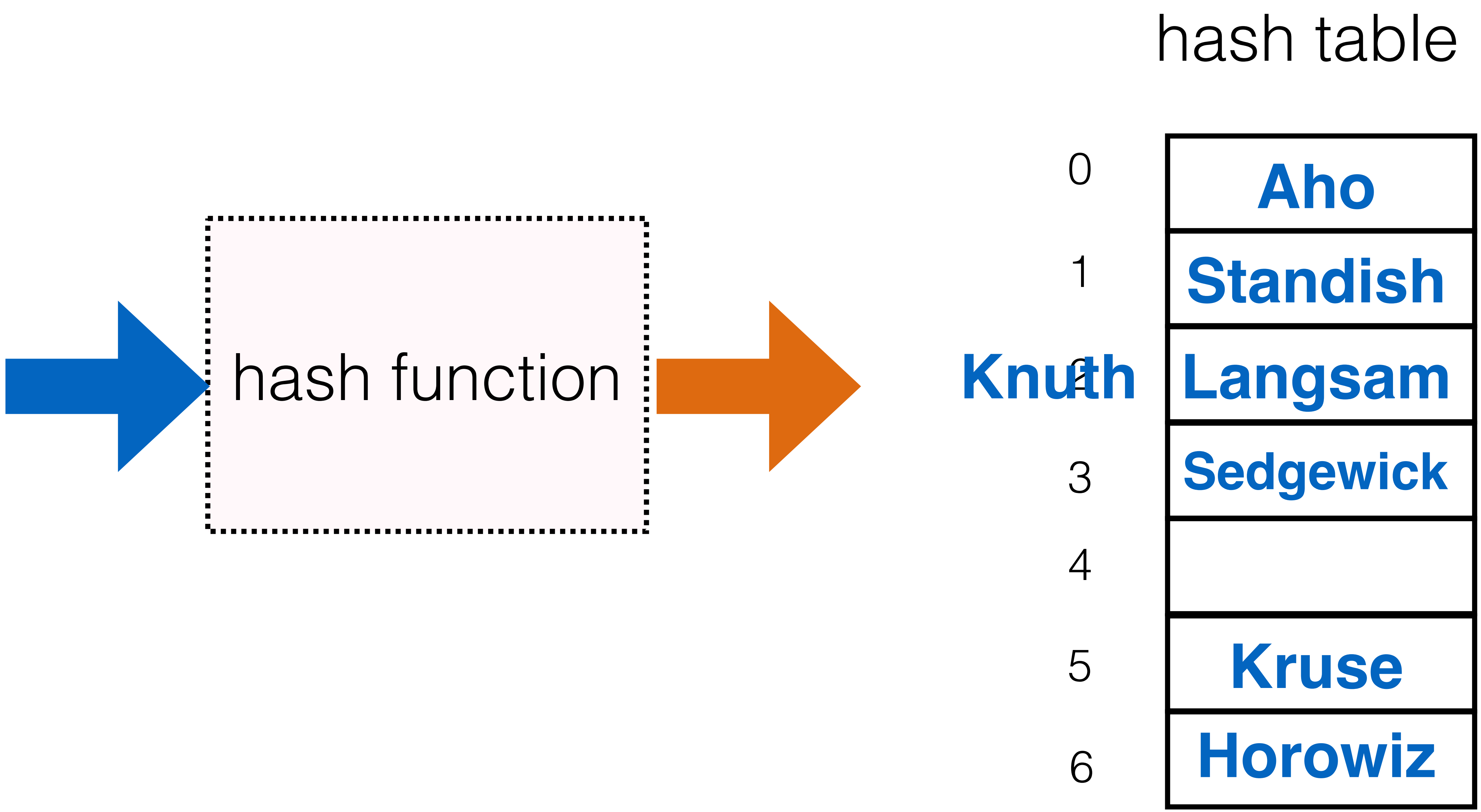

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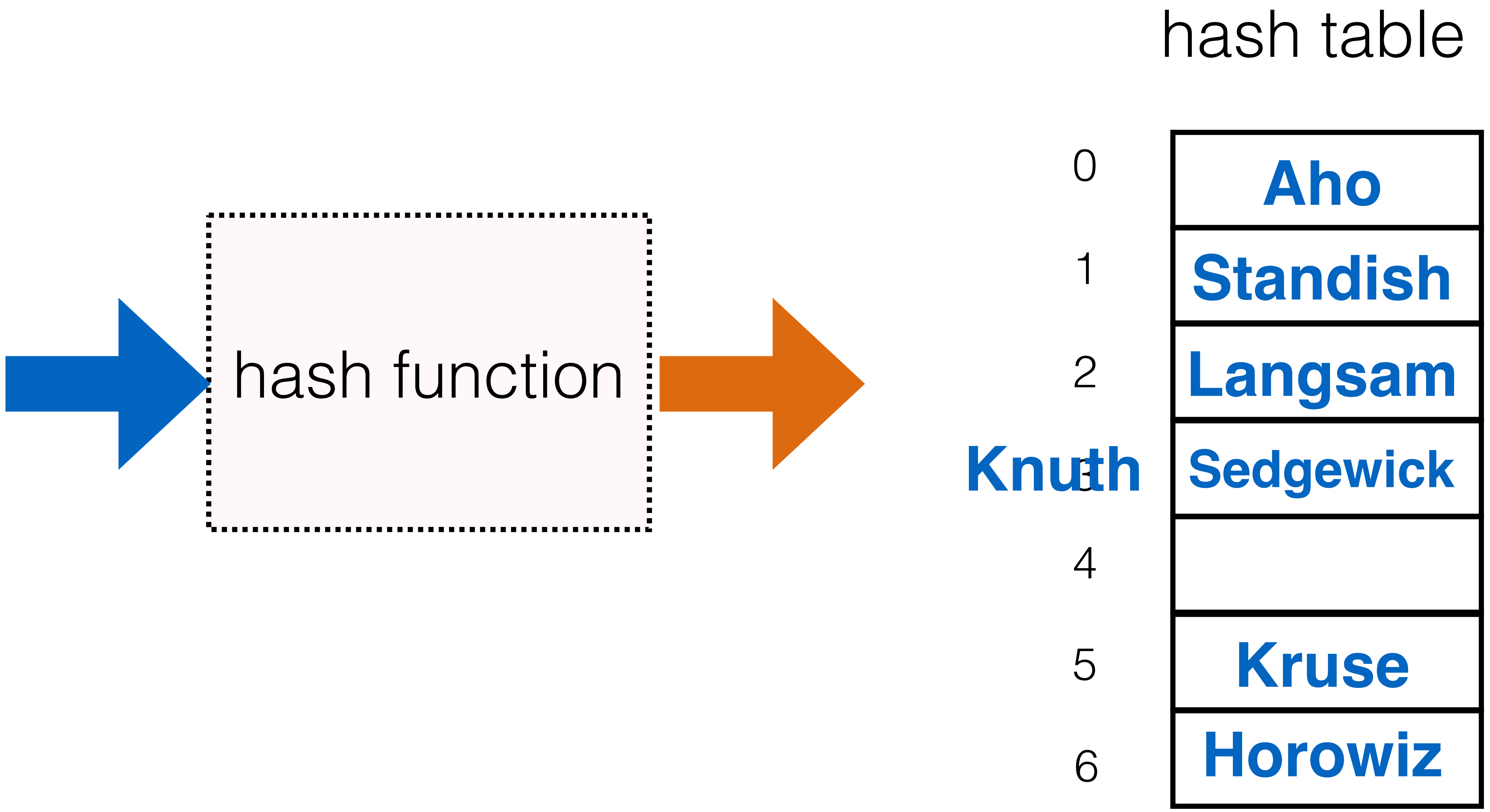

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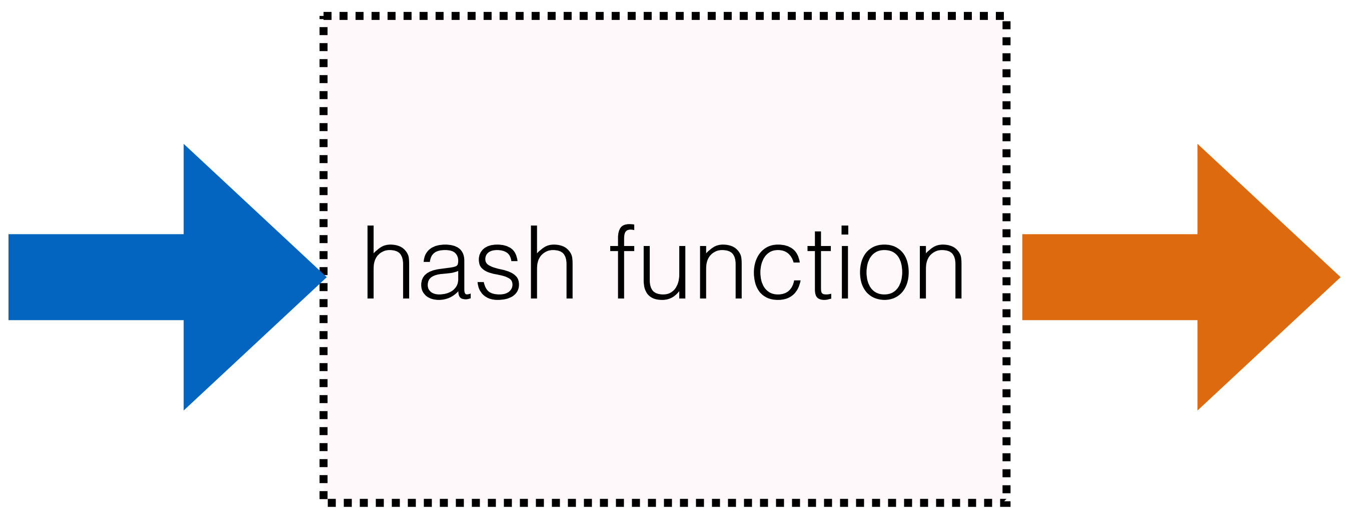
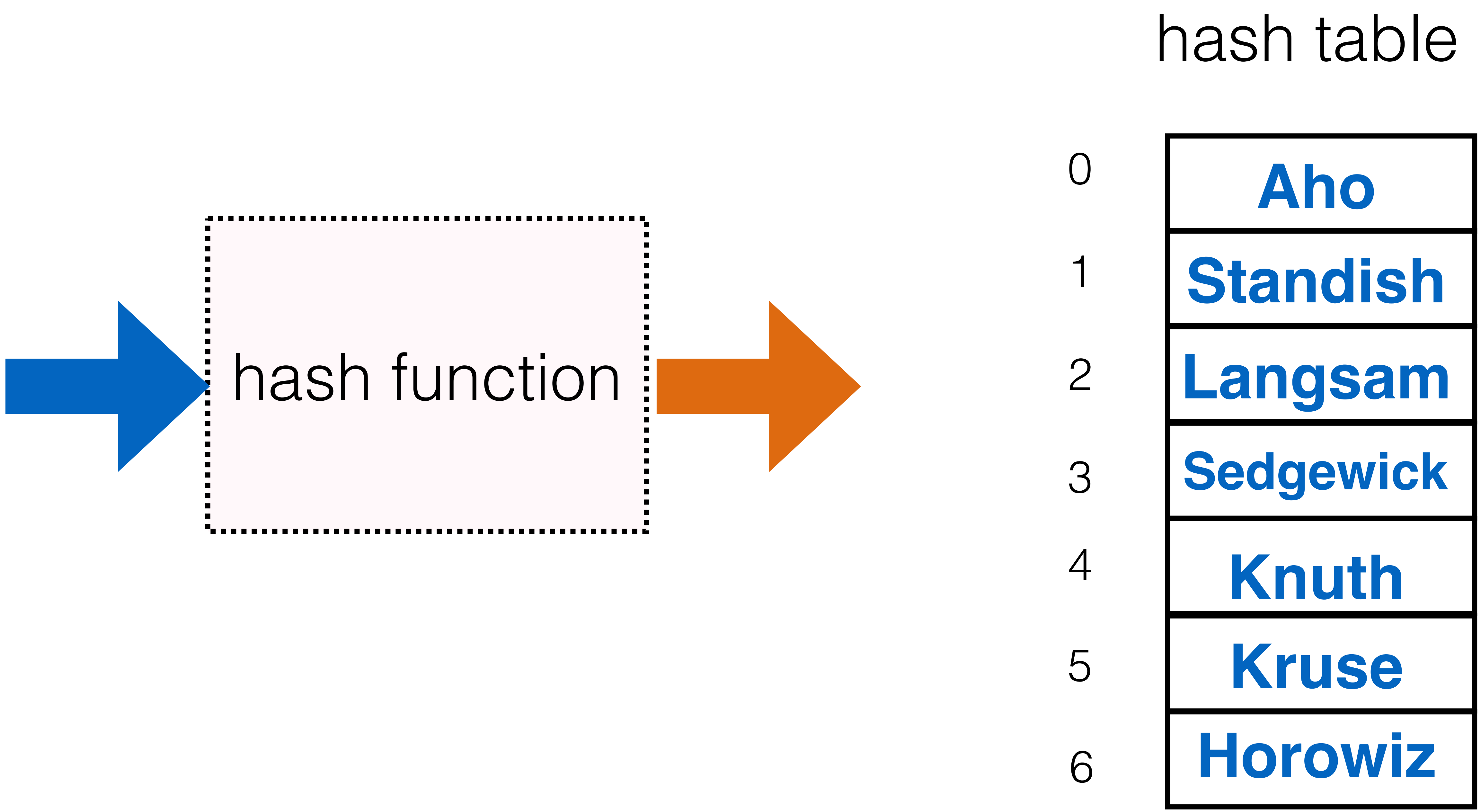


hash table

0	Aho
1	Standish
2	Langsam
3	Sedgewick
4	Knuth
5	Kruse
6	Horowiz

Example

Aho, Kruse, Standish, Horowiz, Langsam, Sedgewick, Knuth



```python
from referential_array import build_array


class HashTableLinear:

    def __init__(self, size=7919):
        self.count = 0
        self.table_size = size
        self.array = build_array(self.table_size)

    def __len__(self):
        return self.count

    def hash_value(self, key):
        h = 0
        a = 31415
        for i in range(len(key)):
            h = (h * a + ord(key[i])) % self.table_size
        return h
```

Hash function with appropriately chosen constants

Open Addressing: Linear Probing

- **Insert item with hash value N**:
  - ➡ If array[N] is empty just put **item** there.
  - ➡ If there is already an item there:
    look for the first empty space in the array from N+1 (if any) and add it there

- Linear search from N until an empty slot is found

- **Things to think about**:
  - Full table (to avoid going into an infinite loop)
  - Restarting from position 0 if the end of table is reached
  - Finding an item with the same key.

Key	Hash value
Aho	0
Kruse	5
Standish	1
Horowitz	5
Langsam	5
Sedgewick	2
Knuth	1

hash table

0	**Aho**
1	**Standish**
2	**Langsam**
3	**Sedgewick**
4	**Knuth**
5	**Kruse**
6	**Horowiz**

We are storing the key only.

In practice you want to store also some data that you associate to each key.

Key	Data	Hash value
Aho	Data structures and algorithms	0
Kruse	Data structures and program design in C++	5
Standish	Data structures in Java	1
Horowitz	Fundamentals of Data Structures	5
Langsam	Data structures using C and C++	5
Sedgewick	Algorithms in C++	2
Knuth	The art of computer programming	1

hash table

0	**Aho**
1	**Standish**
2	**Langsam**
3	**Sedgewick**
4	**Knuth**
5	**Kruse**
6	**Horowiz**

We are storing the key only.

In practice you want to store also some data that you associate to each key.

hash table

	key	data
0	(Aho ,	Data structures and algorithms)
1	(Standish ,	Data structures in Java)
2	(Langsam ,	Data structures using C and C++)
3	(Sedgewick ,	Algorithms in C++)
4	(Knuth ,	The art of computer programming)
5	(Kruse ,	Data structures and program design)
6	(Horowiz ,	Fundamentals of Data Structures)

my_tuple = (key , data)

Python tuple

my_tuple[0] = key
my_tuple[1] = data

Open Addressing: Linear Probing

(key , data)

- **Insert item with hash value N**:
  - ➡ If array[N] is empty just put **item** there.
  - ➡ If there is <u>already an item there</u>:
    look for the first empty space in the array from N+1 (if any) and add it there

- Linear search from N until an empty slot is found

- **Things to think about**:
  - Full table (to avoid going into an infinite loop)
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  - Finding an item with the same key.

insert(key, data)

- Get the position N using the hash function, **N = hash(key)**
- If **array[N] is empty** just put the item **(key, data)** there.
- If there is <u>already an item there</u>:
  - If there is already something there, with the **same key** the user is **updating** the data
  - If there is already something there with a **different key**, you need to **find an empty spot**

What if the Table is full?

```python
def insert(self, key, data):
    position = self.hash(key)
    for _ in range(self.table_size):
        if self.array[position] is None:  # found empty slot
            self.array[position] = (key, data)
            self.count += 1
            return
        elif self.array[position][0] == key:  # found key
            self.array[position] = (key, data)
            return
        else:  # not found, try next
            position = (position + 1) % self.table_size
    self.rehash()
    self.insert(key, data)
```

```python
def __setitem__(self, key, data):
    position = self.hash(key)
    for _ in range(self.table_size):
        if self.array[position] is None:  # found empty slot
            self.array[position] = (key, data)
            self.count += 1
            return
        elif self.array[position][0] == key:  # found key
            self.array[position] = (key, data)
            return
        else:  # not found, try next
            position = (position + 1) % self.table_size
    self.rehash()
    self.__setitem__(key, data)
```

```python
def __str__(self):
    result = ""
    for item in self.array:
        if item is not None:
            (key, value) = item
            result += "(" + str(key) + "," + str(value) + ")"
    return result
```

Conclusion

- Hash Tables are one of the most used data type: You have a very good chance of using them in your career.
- They are very simple conceptually and very powerful in practice.
- A significant amount of **experimental evaluation** is usually needed to fine **tune the hash function** and the TABLESIZE