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Lecture 31
Collision Resolution II

FIT 1008
Introduction to Computer Science

MONASH University
Information Technology

https://upload.wikimedia.org/wikipedia/commons/5/50/Japanese_car_accident_blur.jpg

Hash Table operations: Insert

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

http://blog.mlive.com/annarbornews_impact/2008/12/large_wcc_parking_121708.jpg

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 <u>a linked list of items</u>
  - Upon collision, the element is added to the linked list

http://2.bp.blogspot.com/-YA-pB_QYUGI/TnbKKJ-eYxI/AAAAAAAAAFA/34OrD2S6xBc/s1600/cbe9caa5_f433bdd9_ae77_4546_95be_776c36fbea07.jpg

```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
```

Take the thing there and consider the first part as key and the second as value

Open Addressing: Linear Probing

- Search for an item with hash value N:
  - Perform a linear search from array[N] until either the item or an empty space is found
- But careful, you must deal again with:
  - <u>Full table</u> (to avoid going into an infinite loop)
  - Restarting from position 0 if the end of table is reached.

search(key)

- Get the position N using the hash function, N = hash(key)
- If array[N] is empty return None.
- If there is <u>already an item there</u>:
  - If there is already something there, with the same key return the associated data.
  - If there is already something there with a different key, you need to find the key and return data

__setitem__(self, key, data)

insert or update item (key, data)

__getitem__(self, key)

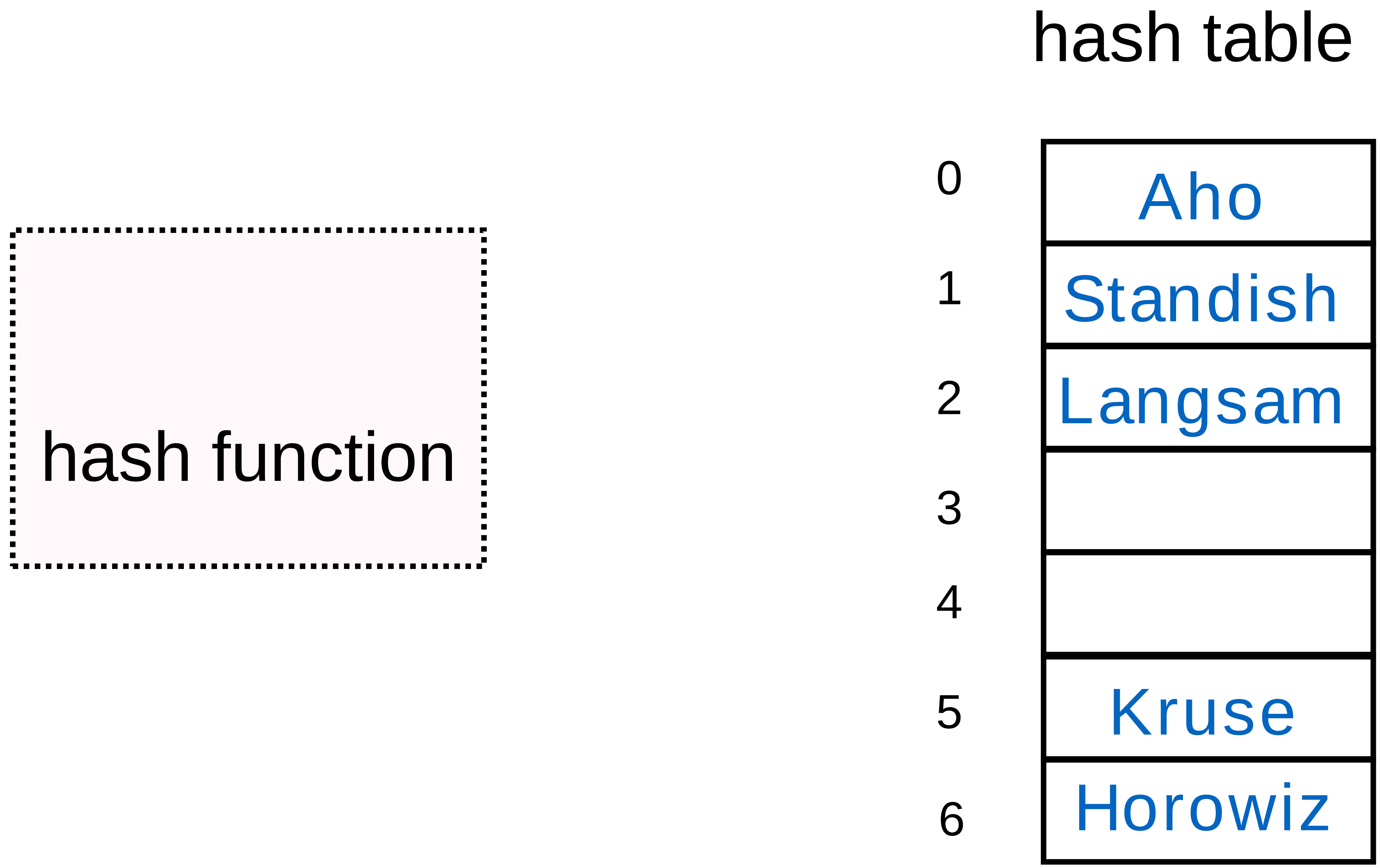
give me the data associated to a key

```python
def __getitem__(self, key):
    position = self.hash(key)
    for i in range(self.table_size):
        if self.array[position] is None:  # found empty slot
            raise KeyError(key)
        elif self.array[position][0] == key:  # found key
            return self.array[position][1]
        else:  # there is something there but different key, try next
            position = (position + 1) % self.table_size
    raise KeyError(key)
```

I showed you this last week but we didn’t use Key Errors

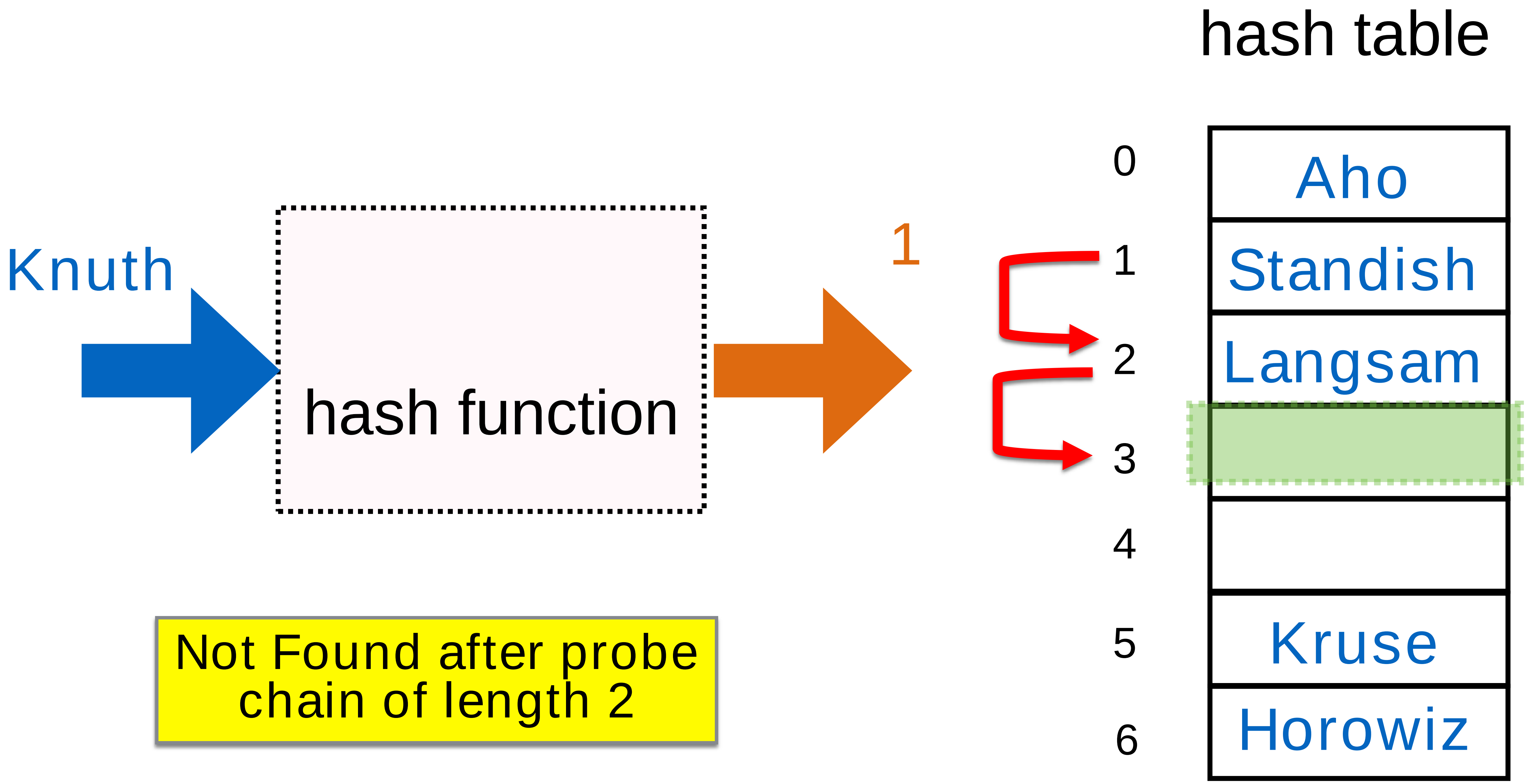
Example: search

key: Langsam



Example: search

key: Knuth



Open Addressing: Linear Probing

- What about delete?
- One possibility:
  - Use the search function to find the item
  - If found at N delete and reinsert every item from N+1 to the first empty position

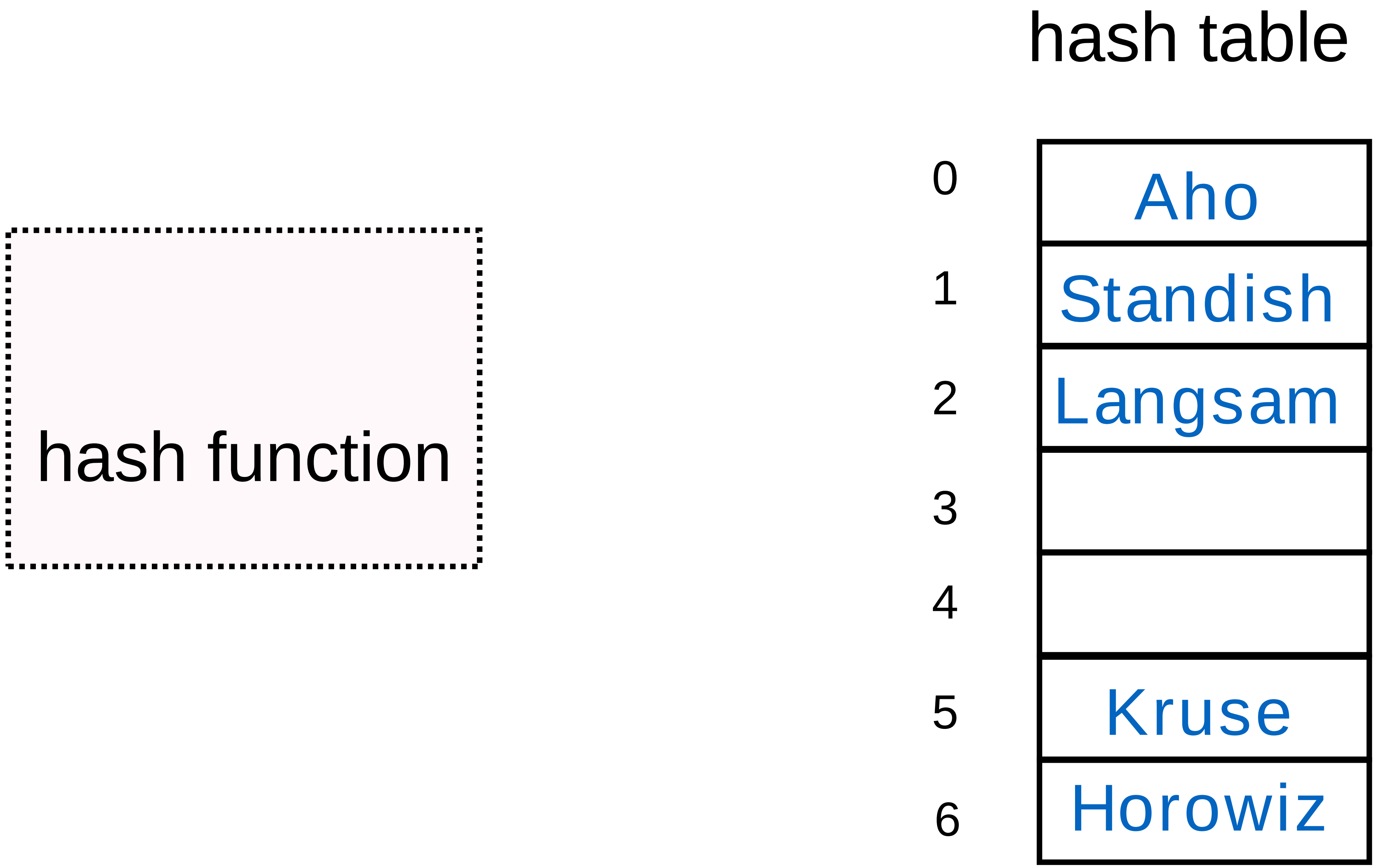
    Time consuming! (though should not be many)

What if I do not reinsert?

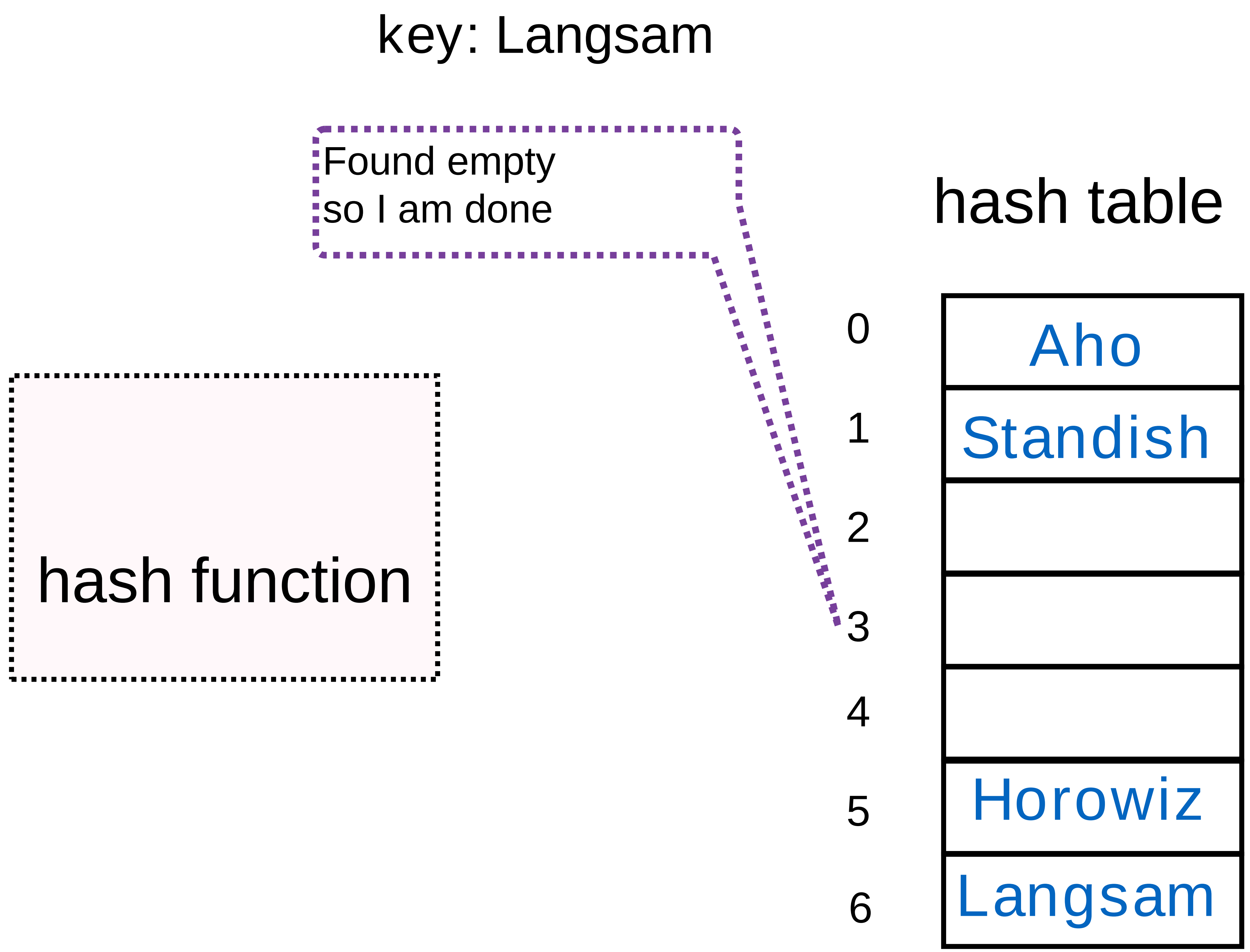
search may incorrectly report some items as not found

Example: delete

key: Kruse



Example: delete



Open Addressing: Linear Probing

- Load factor: total number of items/TABLESIZE

- Cluster: sequence of full hash table slots (i.e., without an empty slot)

- Clusters once formed, tend to grow…
  - Items that hash to a value within the cluster, get inserted at the end making it bigger
  - This might involve more than one hash value

- Cluster can form even when the load is small

Example of cluster

- All 5 elements are part of a cluster
- Langsam, Kruse and Horowiz allhave same hash value (5)
- Aho and Standish have values 0 and 1
- From then on, any element mapped to 0,1,2,5 or 6 will be part of the cluster

hash table

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

Linear Probing: Problems

- Tendency for clustering to occur as the load is > 0.5
- Low speed on clustering. We start under-delivering on the promise of constant time search and insert.
- Deletion of records is difficult
- If implemented in arrays – table may become full fairly quickly, resizing is time and resource consuming

Can we reduce clustering by taking bigger and bigger steps?

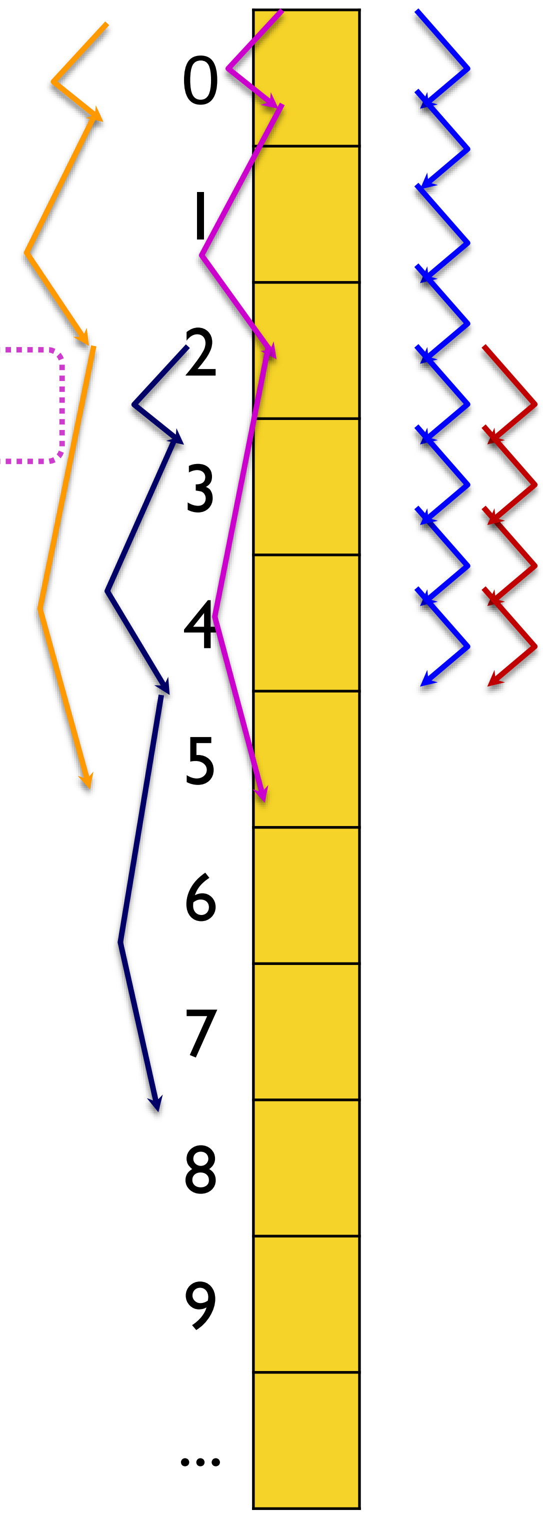
Open Addressing: Quadratic Probing

N+S
S is the step

- Linear probing: search at N+1, N+2, N+3…
- Quadratic probing: search at N+1, N+4, N+9, N+16

$N+S^2$

- primary clustering: keys with different hash values have same probe chains (as in linear probing)
- secondary clustering: keys with same hash values have the same probe chains
- Advantage: Quadratic probing eliminates primary clustering, but can suffer from secondary clustering
- There's a better method: Double Hashing



Open Addressing: Double Hashing

- If a collision occurs, use a second hash function to determine the step.

- Second hash function:
  - Cannot hash to 0
  - Use primes: table size & step size are co-primes (avoid revisiting the same positions)

Greatest Common Denominator = 1

- Eliminates both primary and secondary clustering

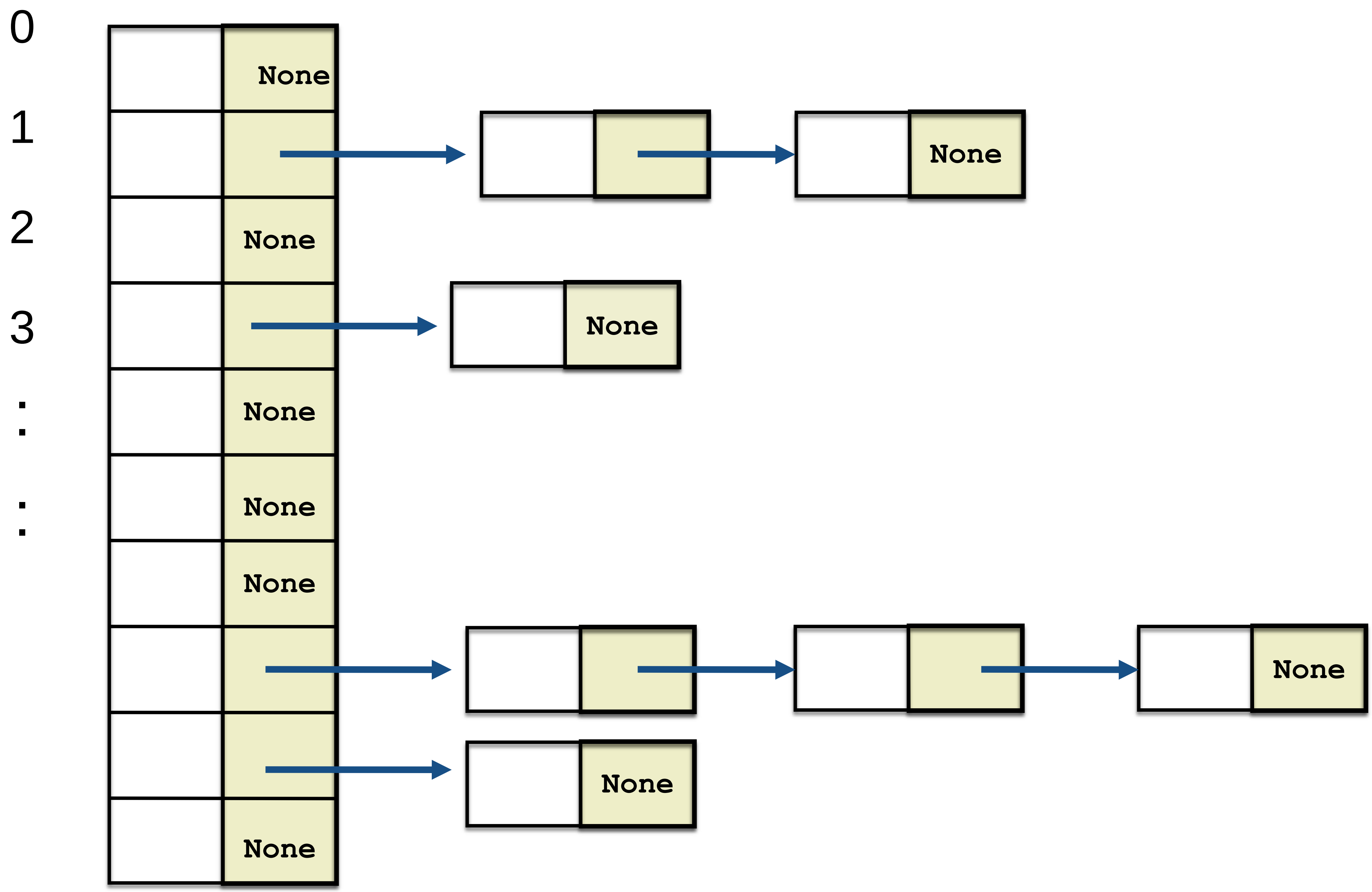
Separate Chaining

Separate Chaining

- Uses a Linked List at each position in the Hash Table.
- Linked list at a position contains all the items that 'hash' to that position.

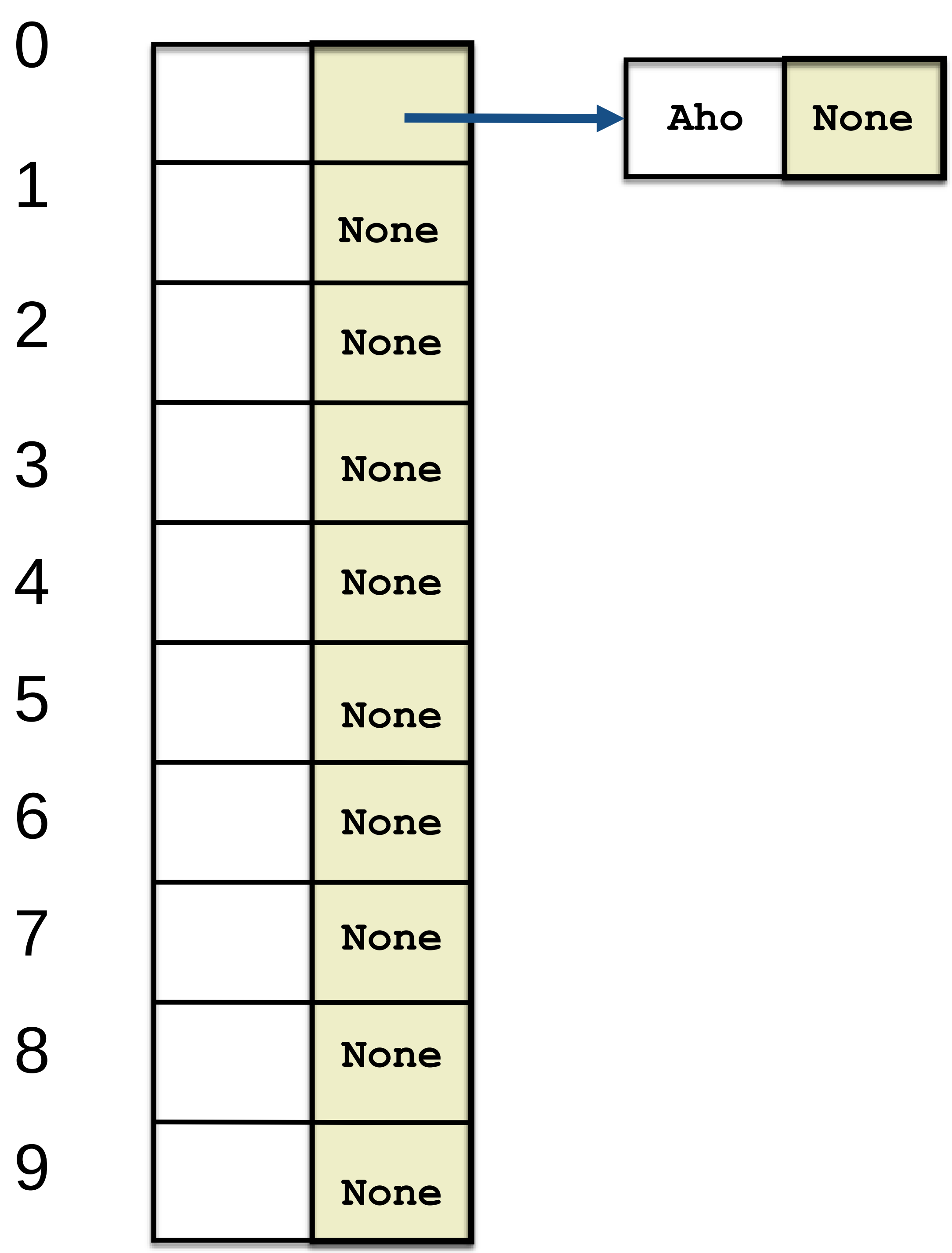
http://2.bp.blogspot.com/-YA-pB_QYUGI/TnbKKJ-eYxI/AAAAAAAAAFA/34QrD2S6xBc/s1600/cbe9caa5_f433bdd9_ae77_4546_95be_776c36fbea07.jpg

hash table



Aho, Kruse, Standish, Horowiz, Langsam, Sedgwick, Knuth

0, 5, 1, 5, 5, 2, 1



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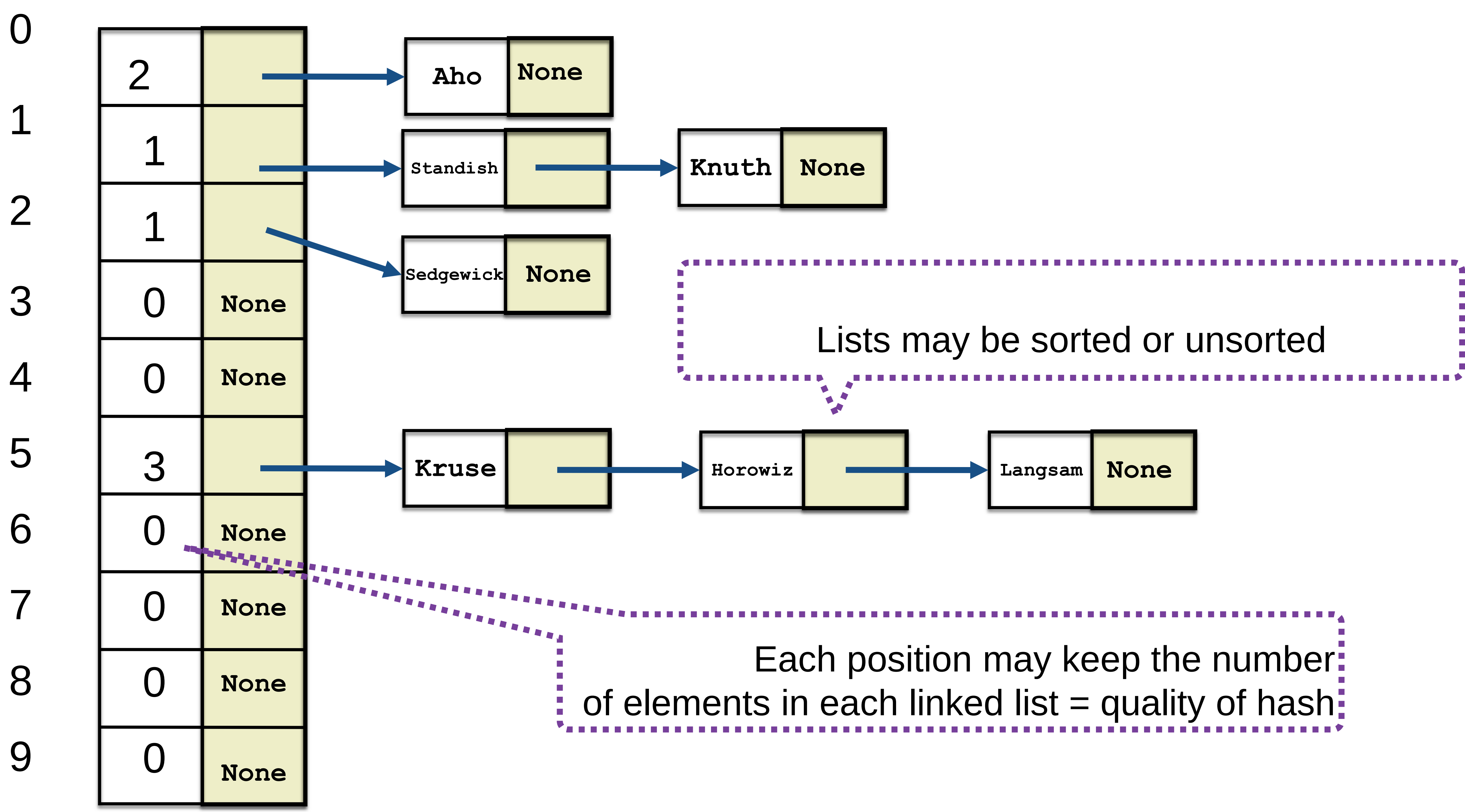


Separate Chaining

- Apply hash function to get a position N in the array
- Insert: Insert key into the Linked List at position N
- Search: Search for key in the Linked List at position N
- Delete: Search for key; delete the node in the Linked List at position N

Separate Chaining

Advantages:

- Conceptually simpler
- Insertions and deletions are easy and quick
- Naturally resizable, allows a varying number of records to be stored

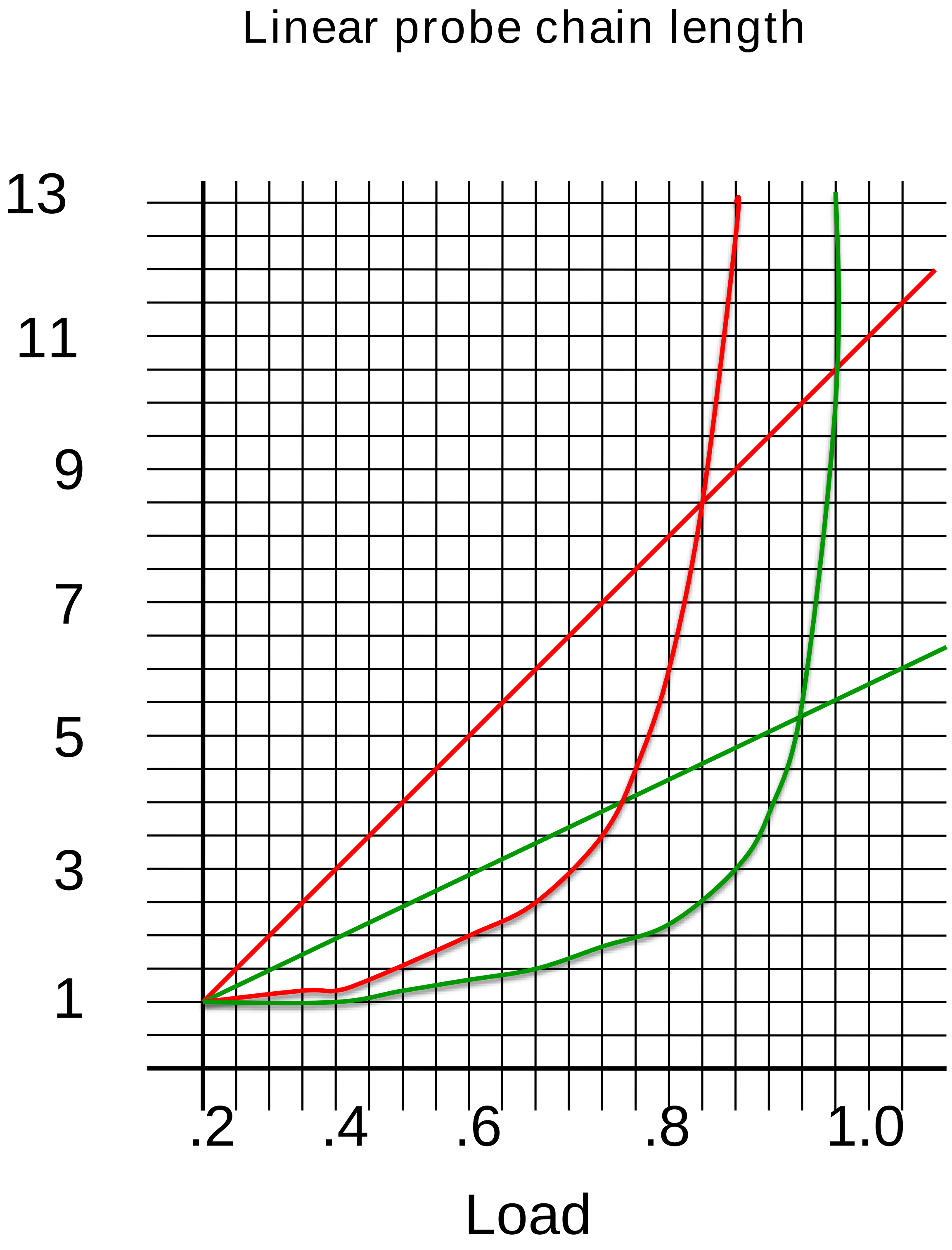
Disadvantages

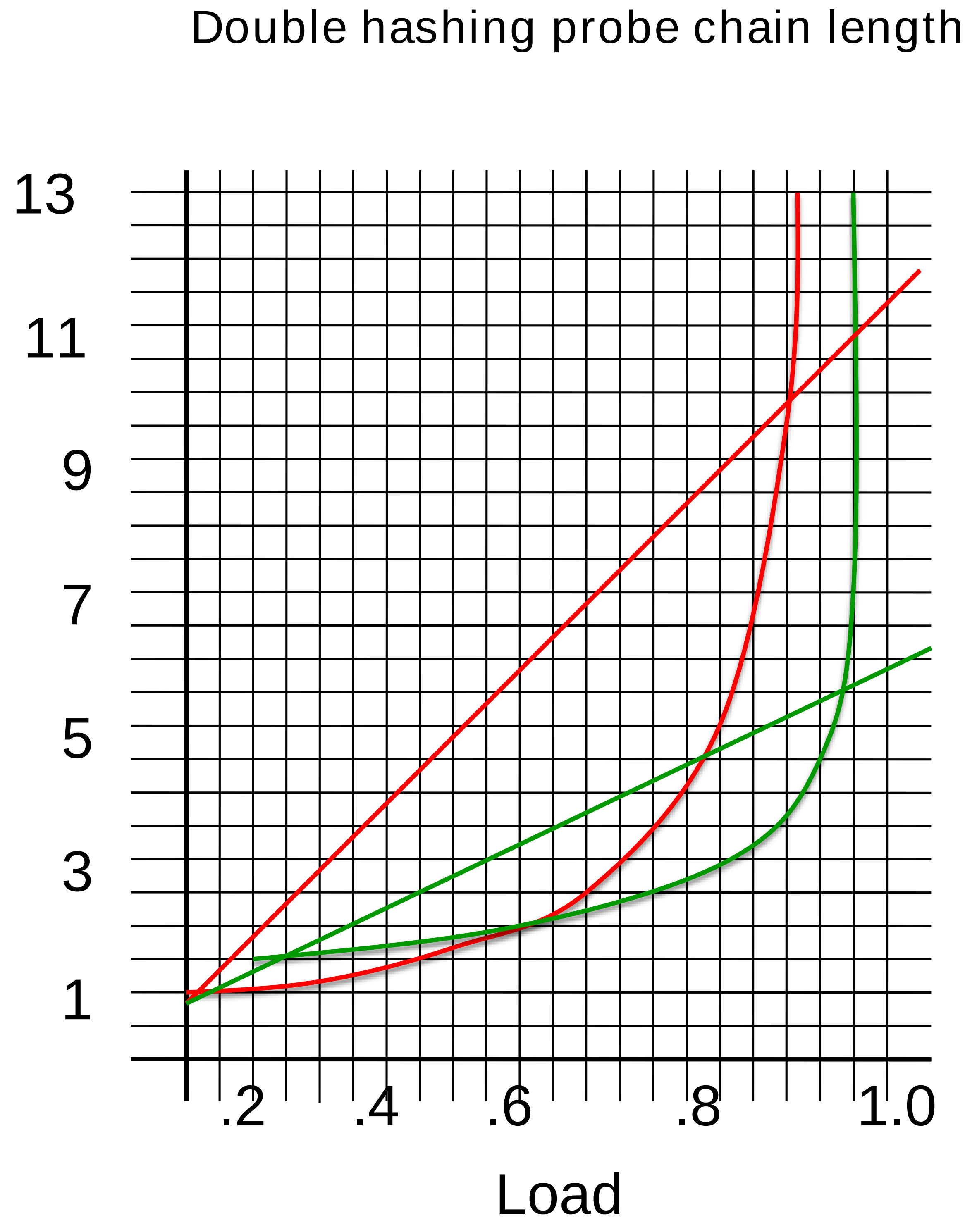
- Requires extra space for the links
- Requires linear search for elements in a list

Comparison: general

- Choice depends on the particular application
  - Linear Probing: fast if memory allows for a large table.
  - Double hashing: efficient use of memory but needs to compute a second hash
  - Separate chaining: simple, extra memory, resizable, fast insert and fast delete
- When the load approaches 1: double hashing far outperforms linear probing
- Open addressing: keep load under 2/3 …. even better 1/2
- Separate chaining: efficiency degrades linearly with load

Superimposing Separate Chaining





found/not found

Dynamic Hashing

- Each time the load in an open address method gets greater than desirable
  - 1/2 for linear probing
  - 2/3 for double hashing

  we expand the table by doubling its size

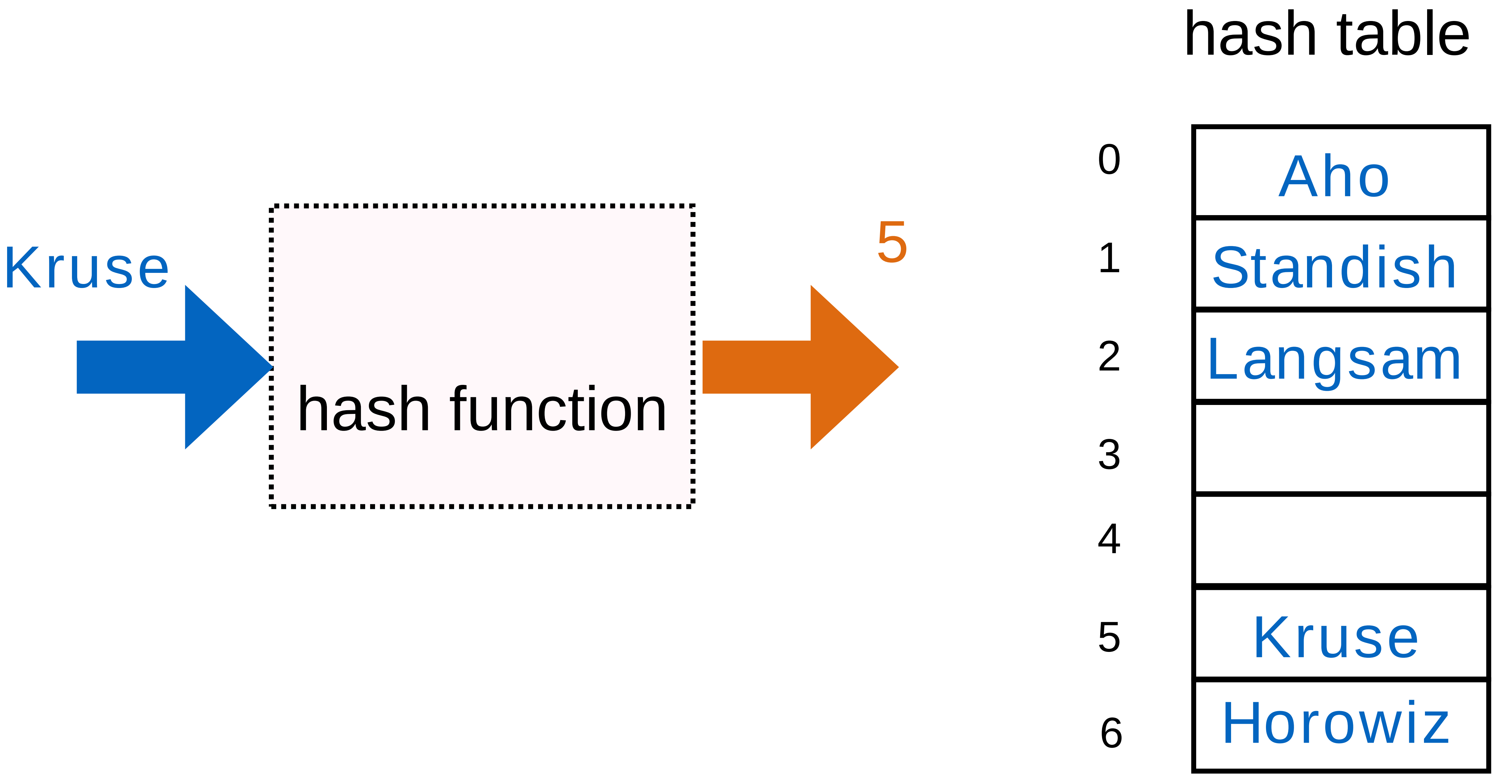
- This requires
  - Creating the new array
  - Rehashing every item in the old table into the new one (due to the use of TABLESIZE in the hash function)

Other ways to delete

- Lazy deletion
- When you remove something, mark it as gone
- Treat these as empty for insertion, and wrong key for search

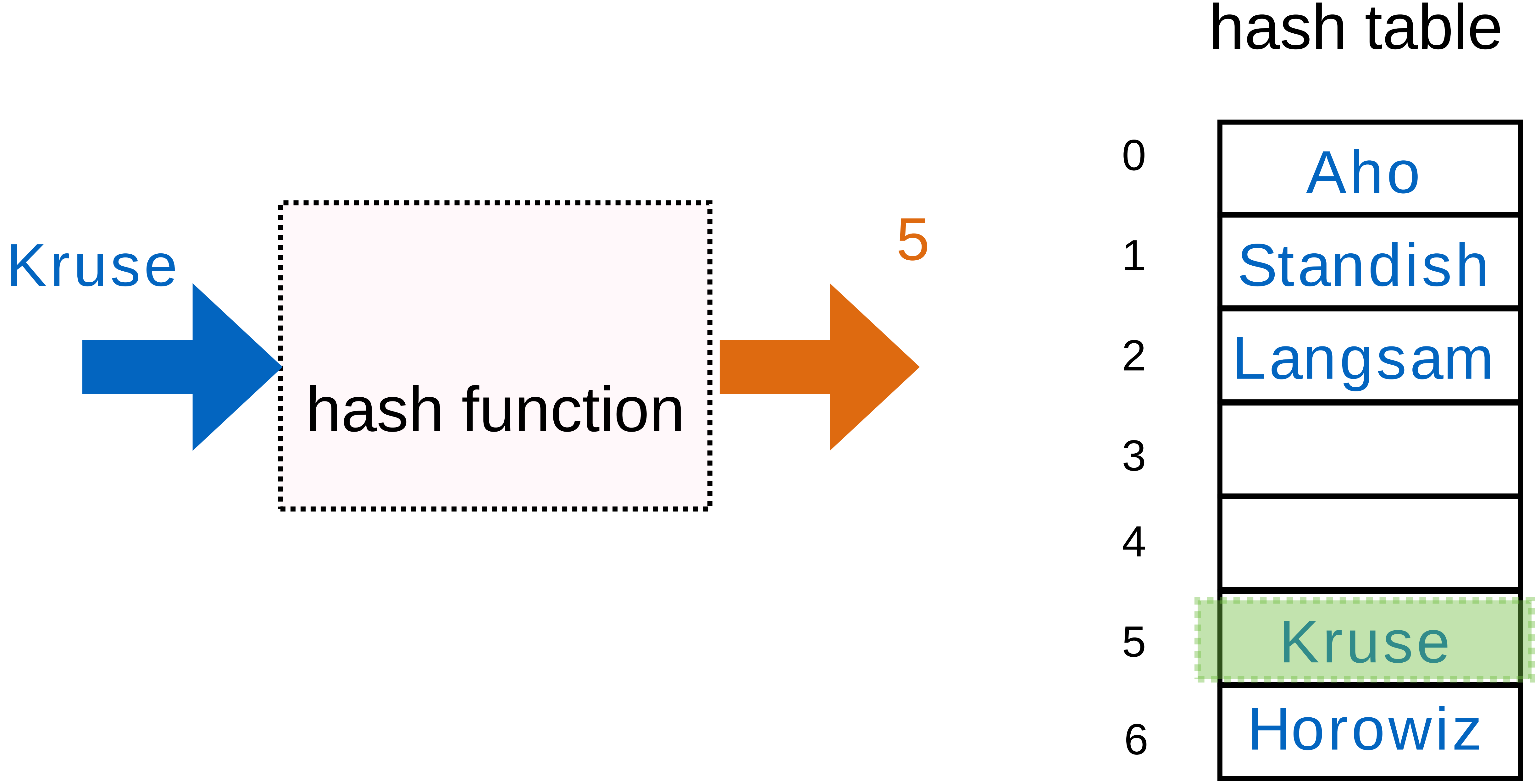
Example: delete (lazy)

key: Kruse



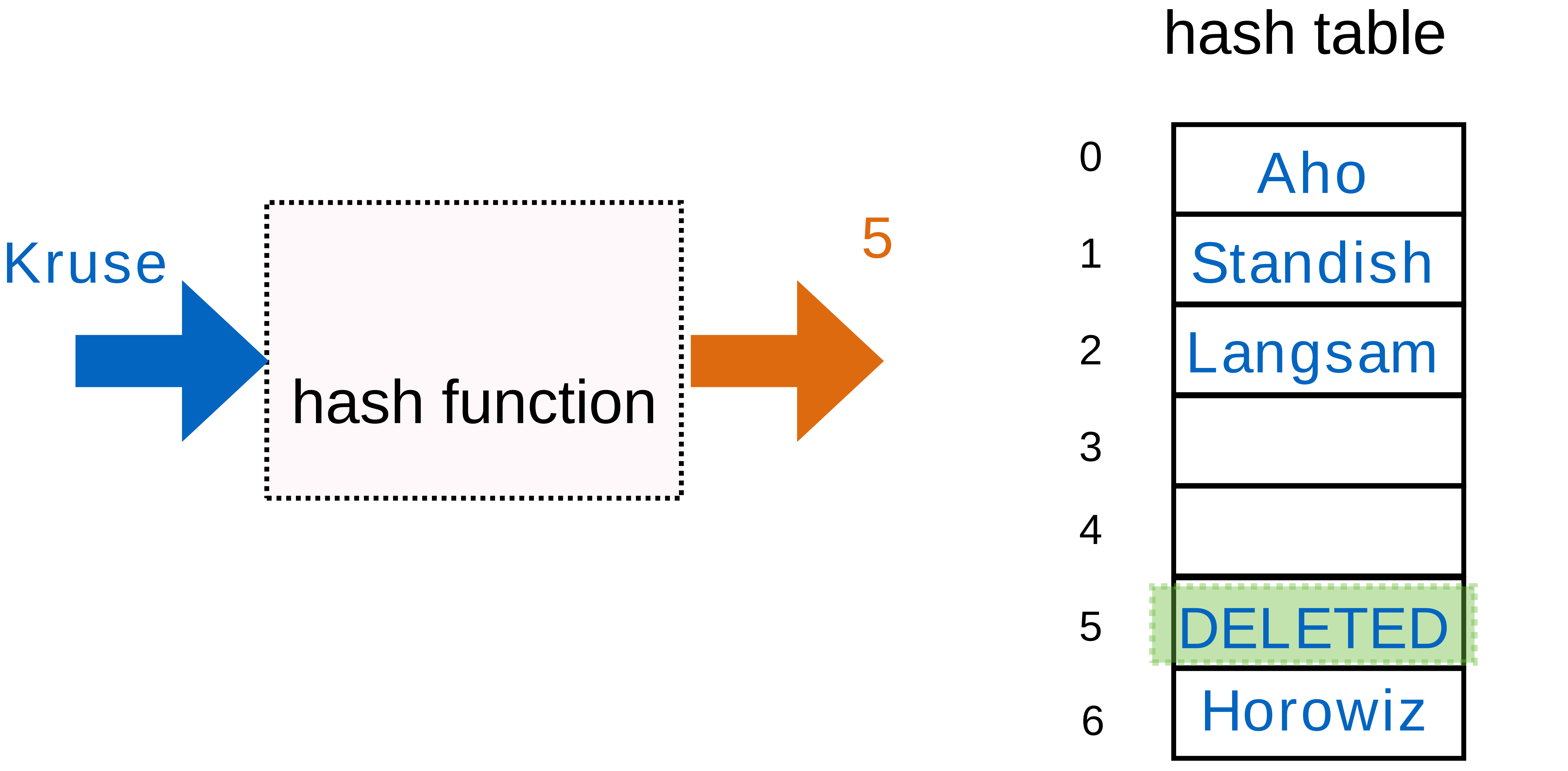
Example: delete (lazy)

key: Kruse



Example: delete (lazy)

key: Kruse

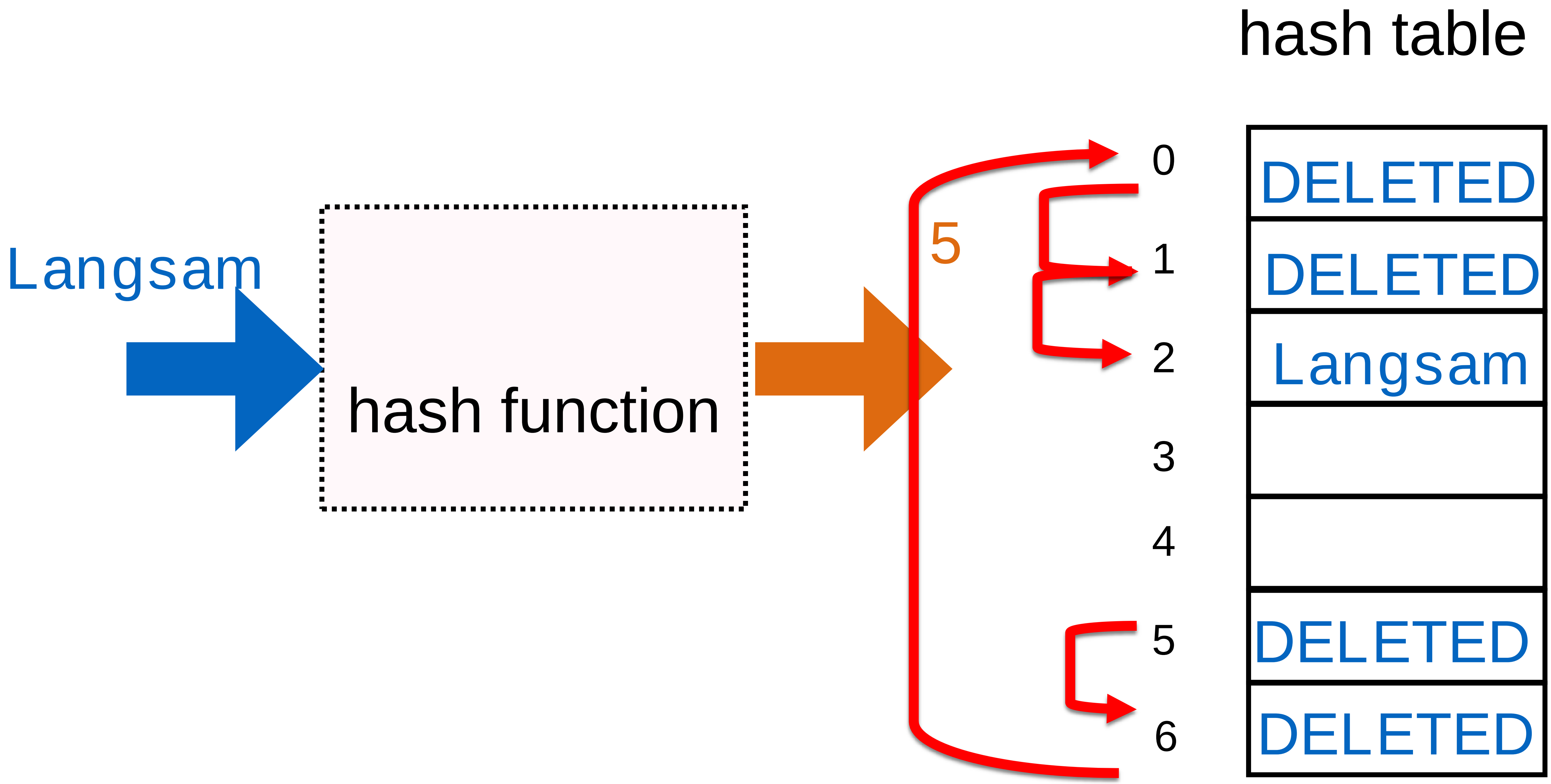


Consequences of lazy deletion

- When inserting, I need to search to the end of the probe chain to confirm it isn’t there
- But I get to insert at the first deleted if it’s not
- Searching in general means quite long chains if I do many deletions

searching after lazy deletion

key: Langsam



Conclusion

- Hash Tables are one of the most used data types
- You have a very good chance of using them in your career
- Choice of hash function, collision handling and load factor are crucial to maintaining an efficient hash table
- They are very simple conceptually:
  - A significant amount of experimental evaluation is usually needed to fine tune the hash function and the TABLESIZE