Hashing

Part Two

Recap from Last Time

Hash Functions

- A **hash function** is a function that converts a large object (a genome, a string, a sequence of elements, etc.) into a smaller object (a shorter string, an integer, etc.)
- A hash function ***must*** be deterministic: given an input, it must always produce the same output.
  - *Why?*
- A hash function ***should*** try to produce different outputs for different inputs.
  - Not always possible if there are only finitely many possible outputs.

Overview of Our Approach

- To store key/value pairs efficiently, we will do the following:
  - Create a lot of **buckets** into which key/value pairs can be distributed.
  - Use a hash function to associate each possible key with a bucket.
  - To look up the value associated with a key:
    - Jump into the bucket containing that key.
    - Look at all the values in the bucket until you find the one associated with the key.

Building a Hash Table

Quick Announcements!

Apply to Section Lead!

http://cs198.stanford.edu

Casual CS Dinner

- Casual dinner for women studying computer science is next **Thursday, May 23** at **5:30PM** at the **Gates Patio**.
- Everyone is welcome!
- RSVP through link sent out Friday, or at

http://bit.ly/cscasualdinners

YEAH Hours

- YEAH Hours (assignment review session) for Assignment 5 is **tomorrow**, May 21st in **Gates B12** from **5:30PM – 6:30PM**.
  - We will post notes on the course website.

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} // End announcements
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Hash Table Performance

- Suppose that we have n elements and b buckets.
- Assuming a good hash function, the expected time to look up an element is **$O(1 + n / b)$**.
- The ratio n / b is called the **load factor**.
- Intuitively, this makes sense – if the elements are distributed evenly, you only need to look, on average, at n / b of them.

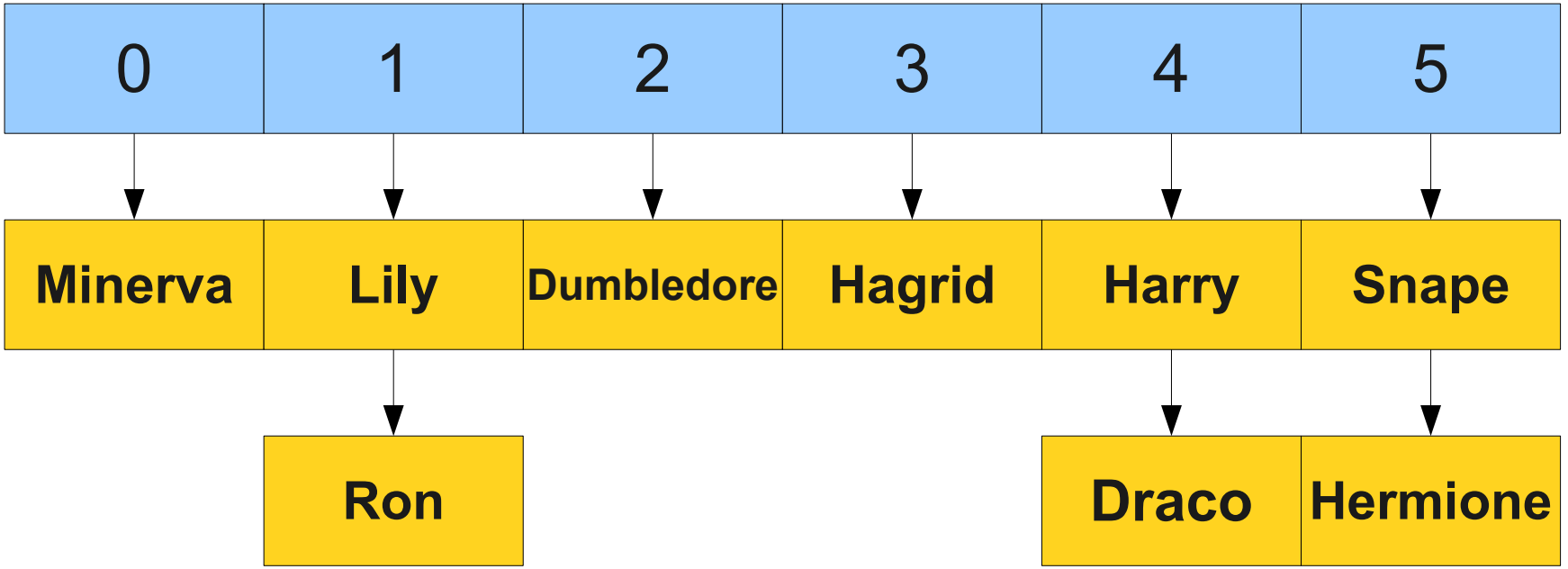
Hashing and Rehashing

Hashing and Rehashing

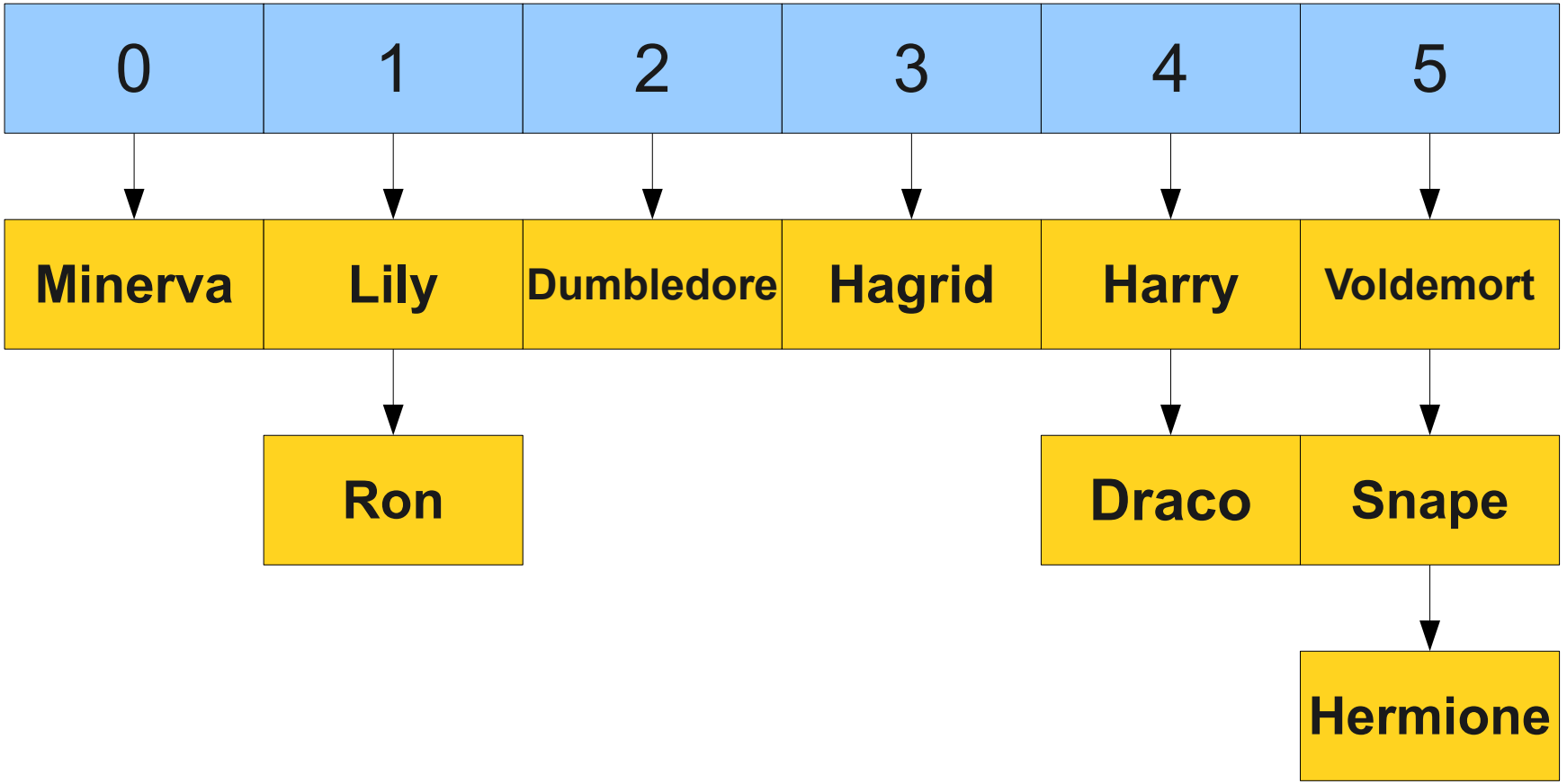
Voldemort

Hashing and Rehashing

Voldemort

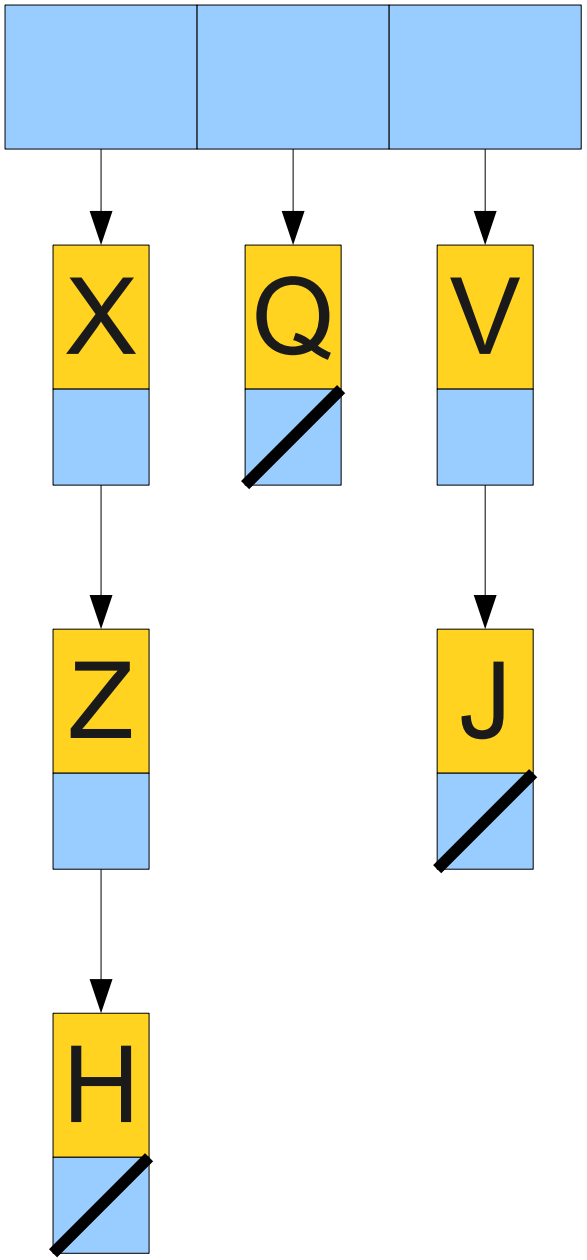


Hashing and Rehashing



Hashing and Rehashing

- Idea: Track the number of buckets b and the number of total elements n.
- When inserting, if n/b exceeds some small constant (say, 2), double the number of buckets and redistribute the elements evenly.
- This makes $n/b \leq 2$, so the expected lookup time in a hash table is **O(1)**.
- On average, the lookup time is *independent* of the total number of elements in the table!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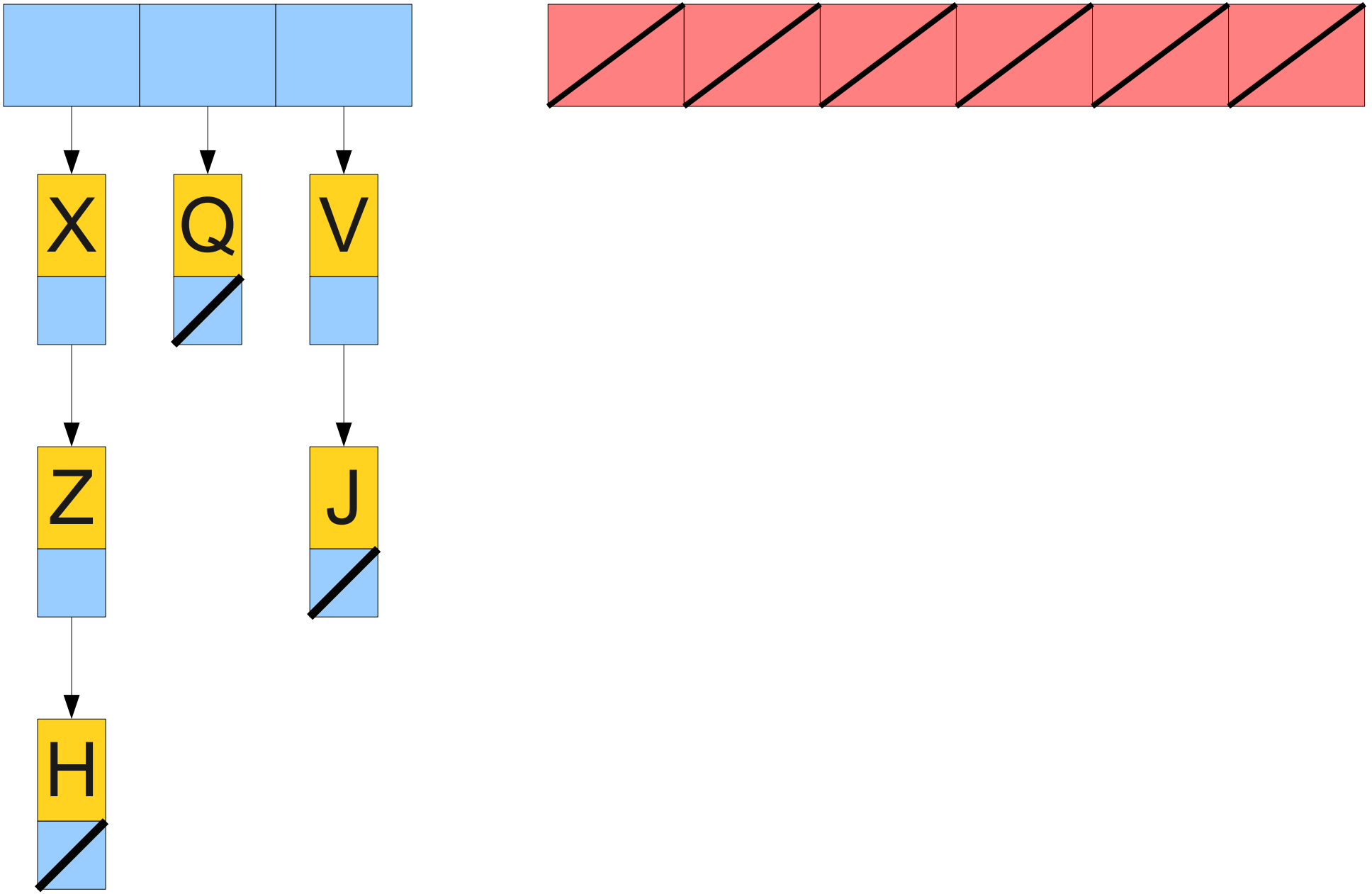
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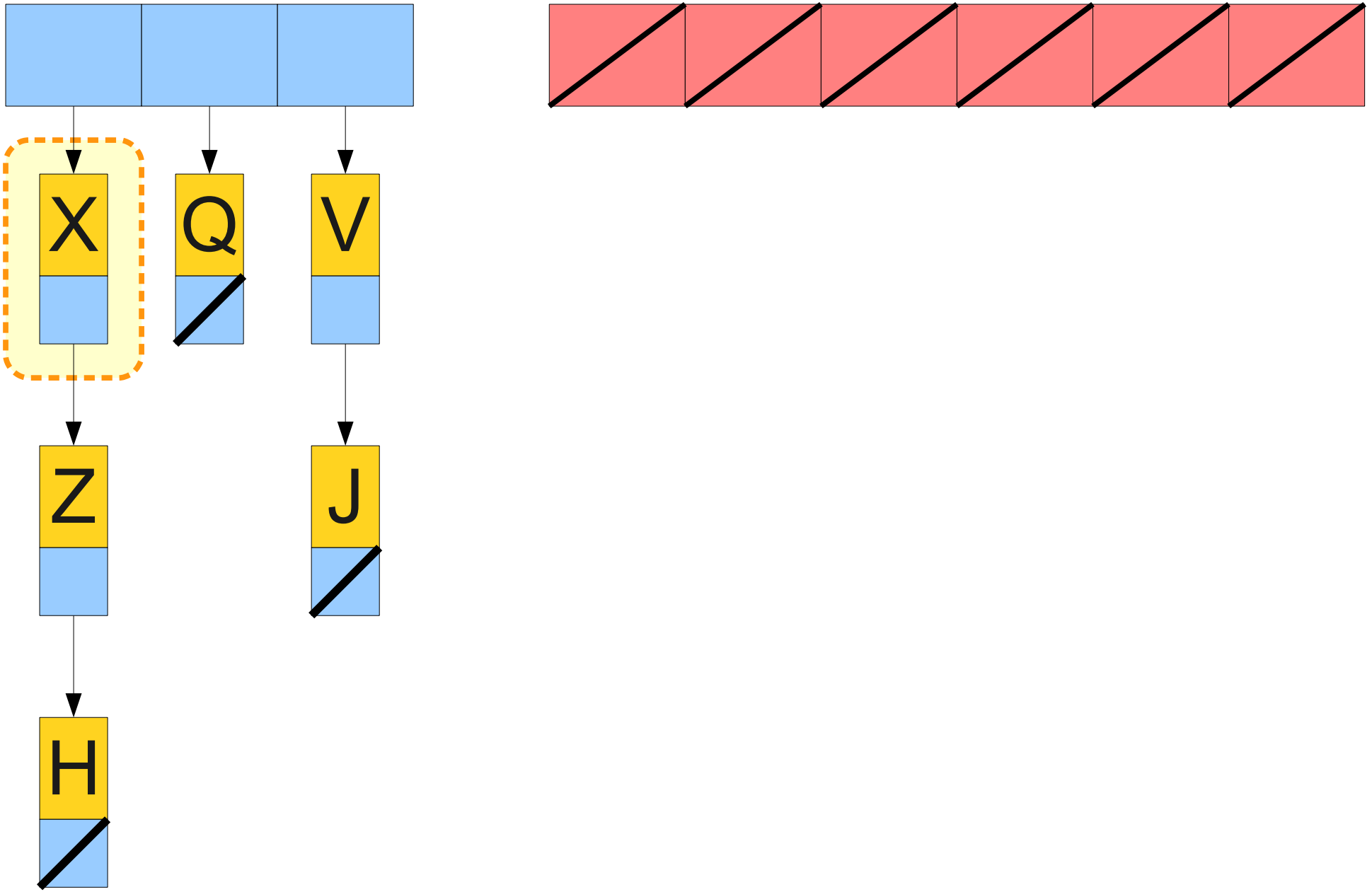
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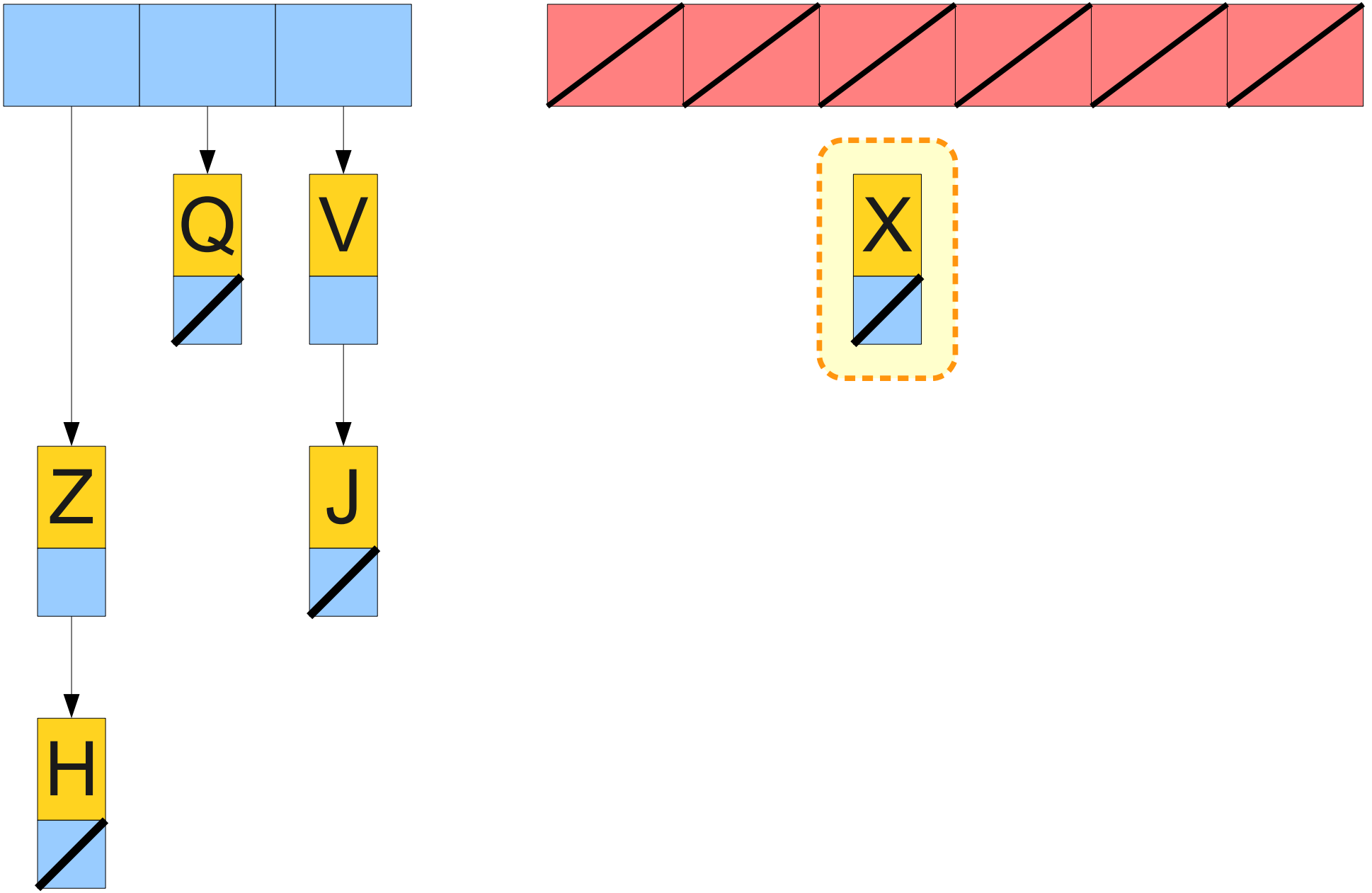
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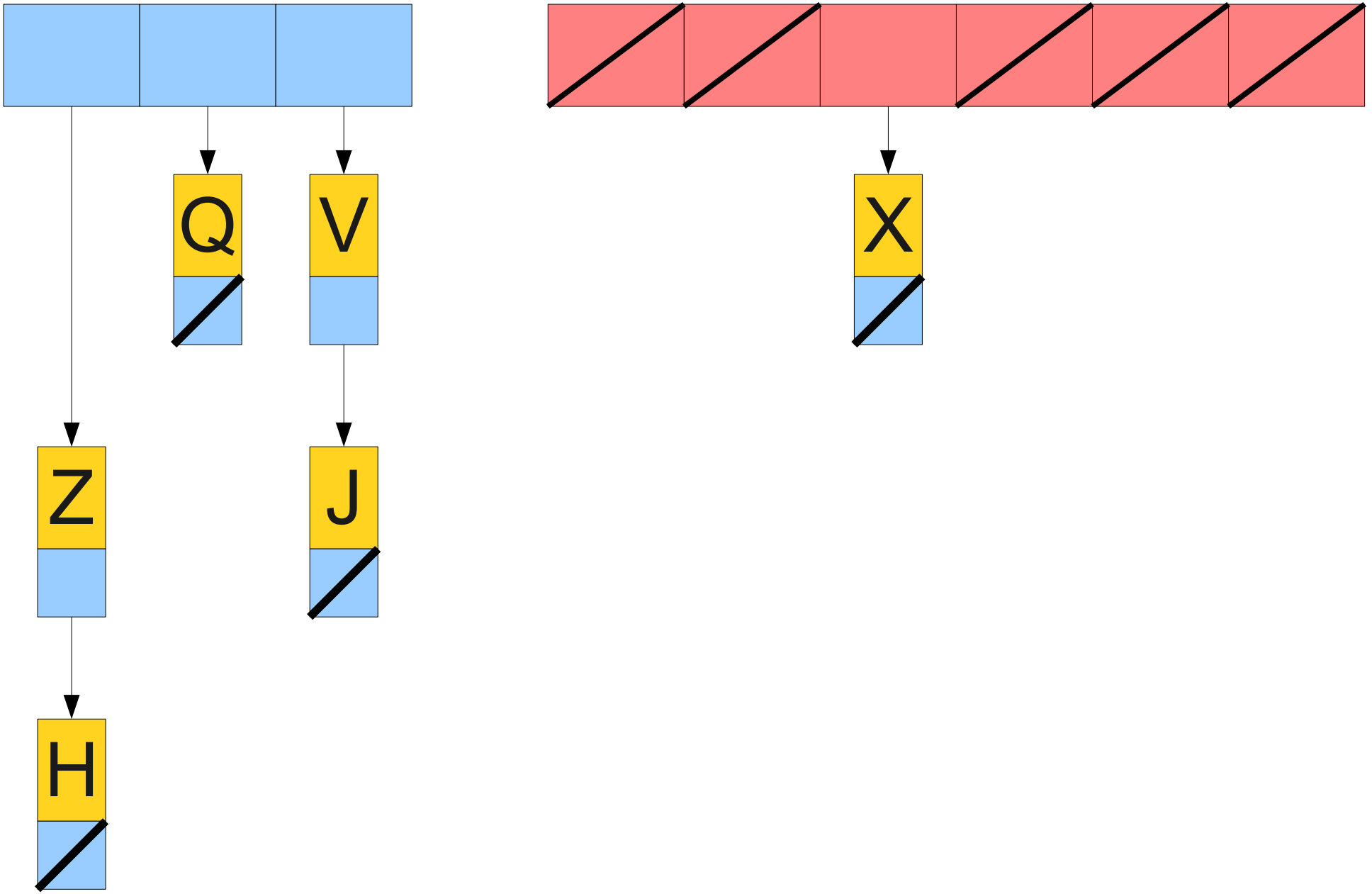
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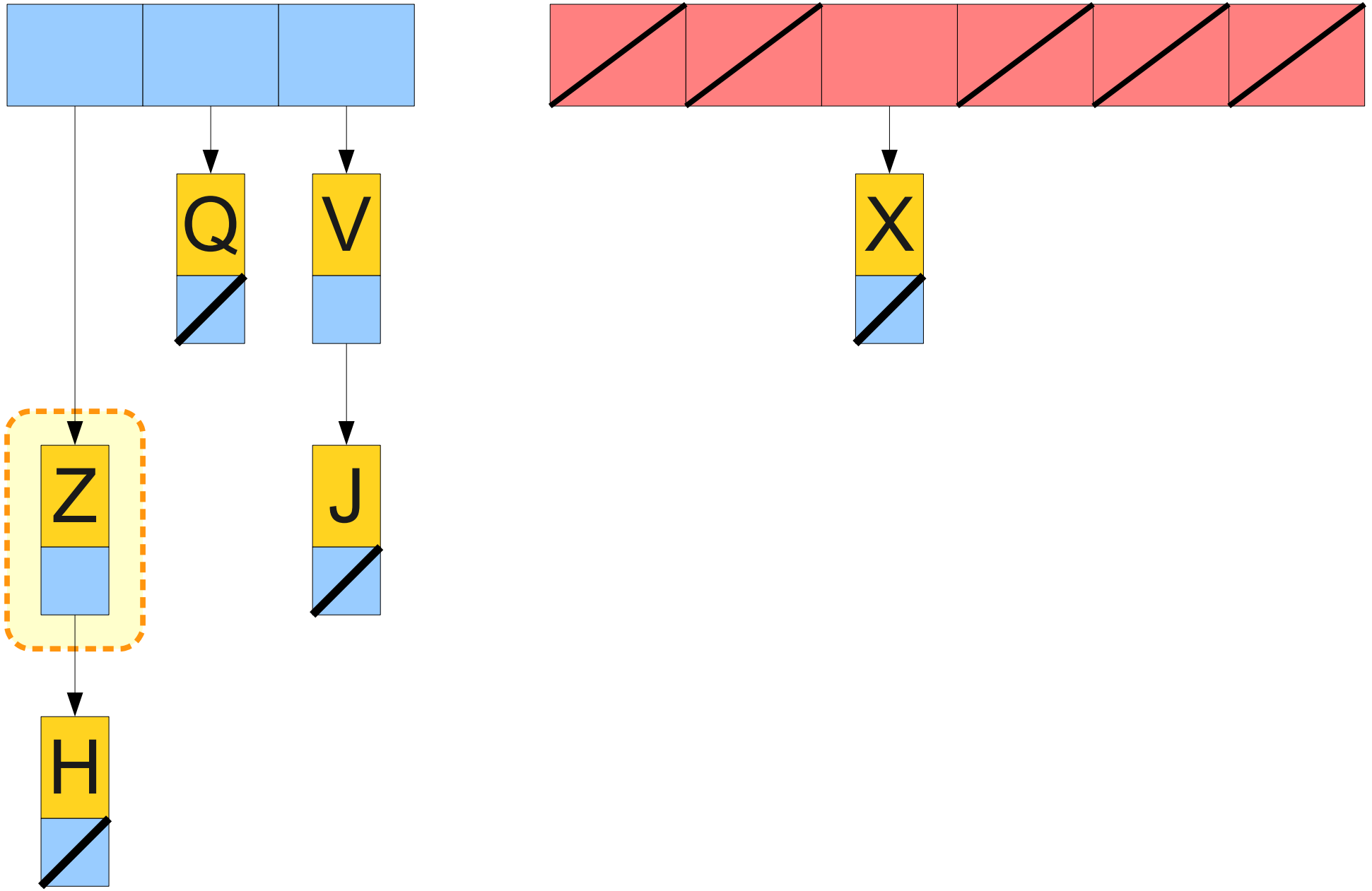
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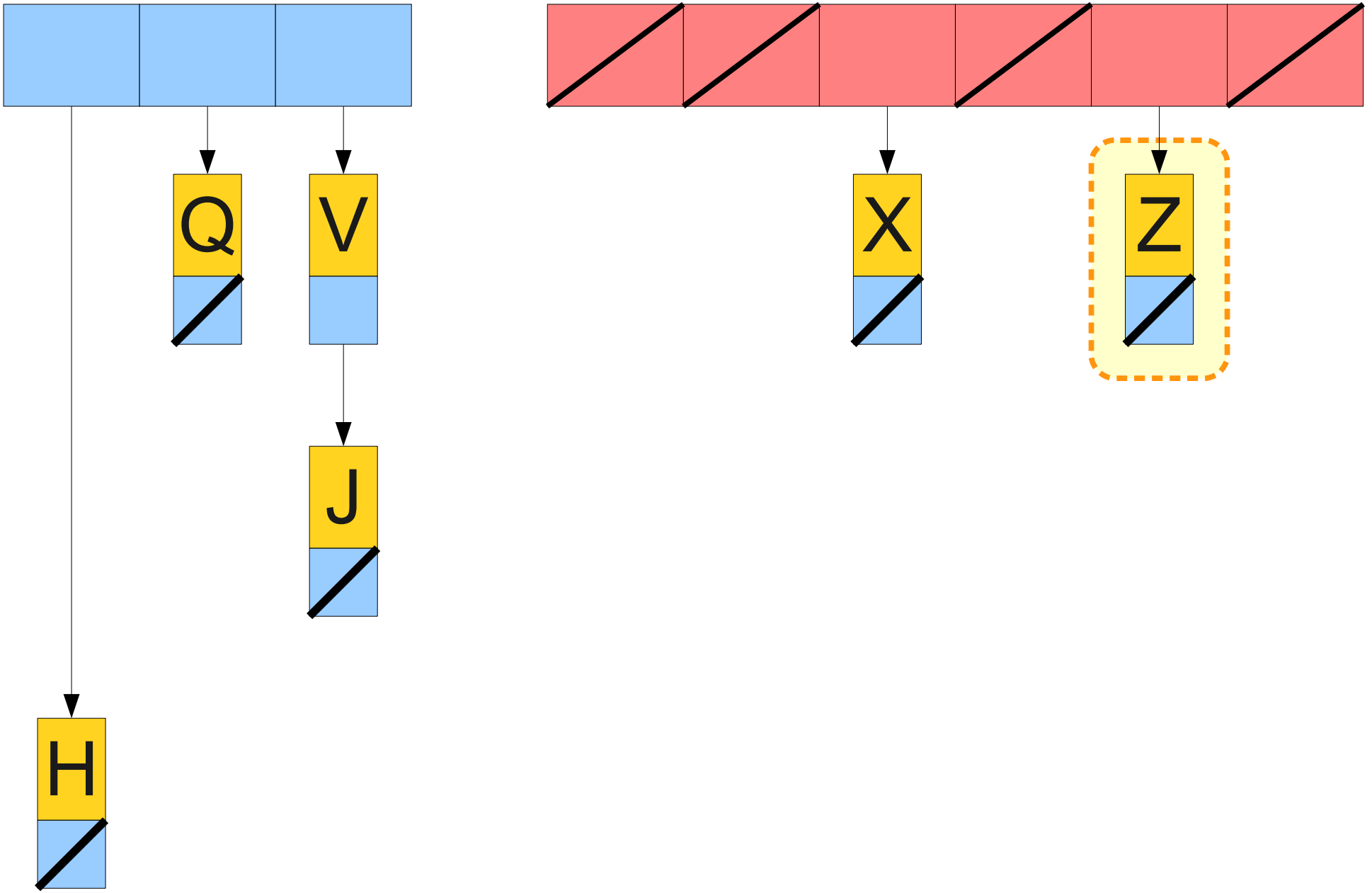
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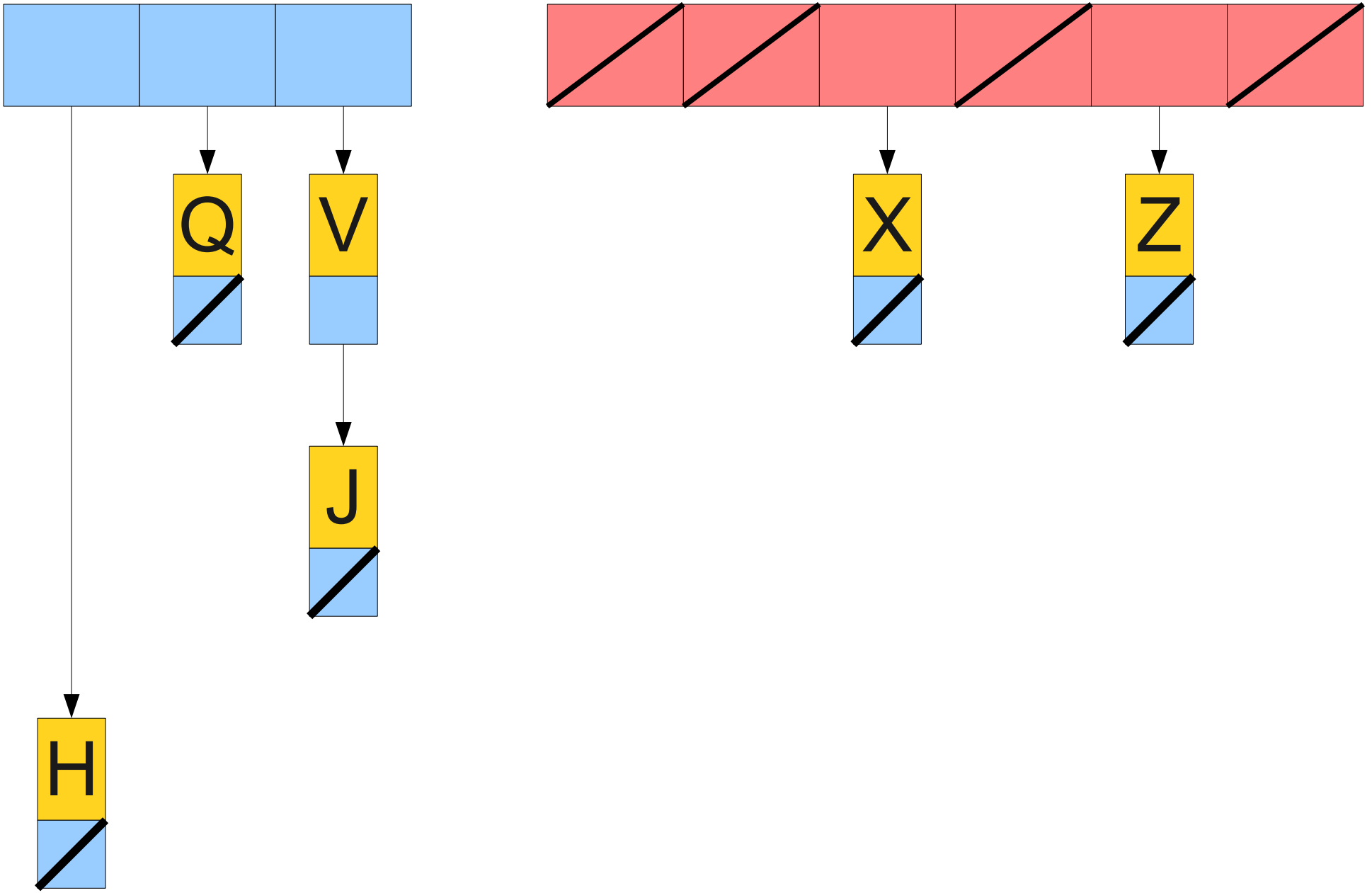
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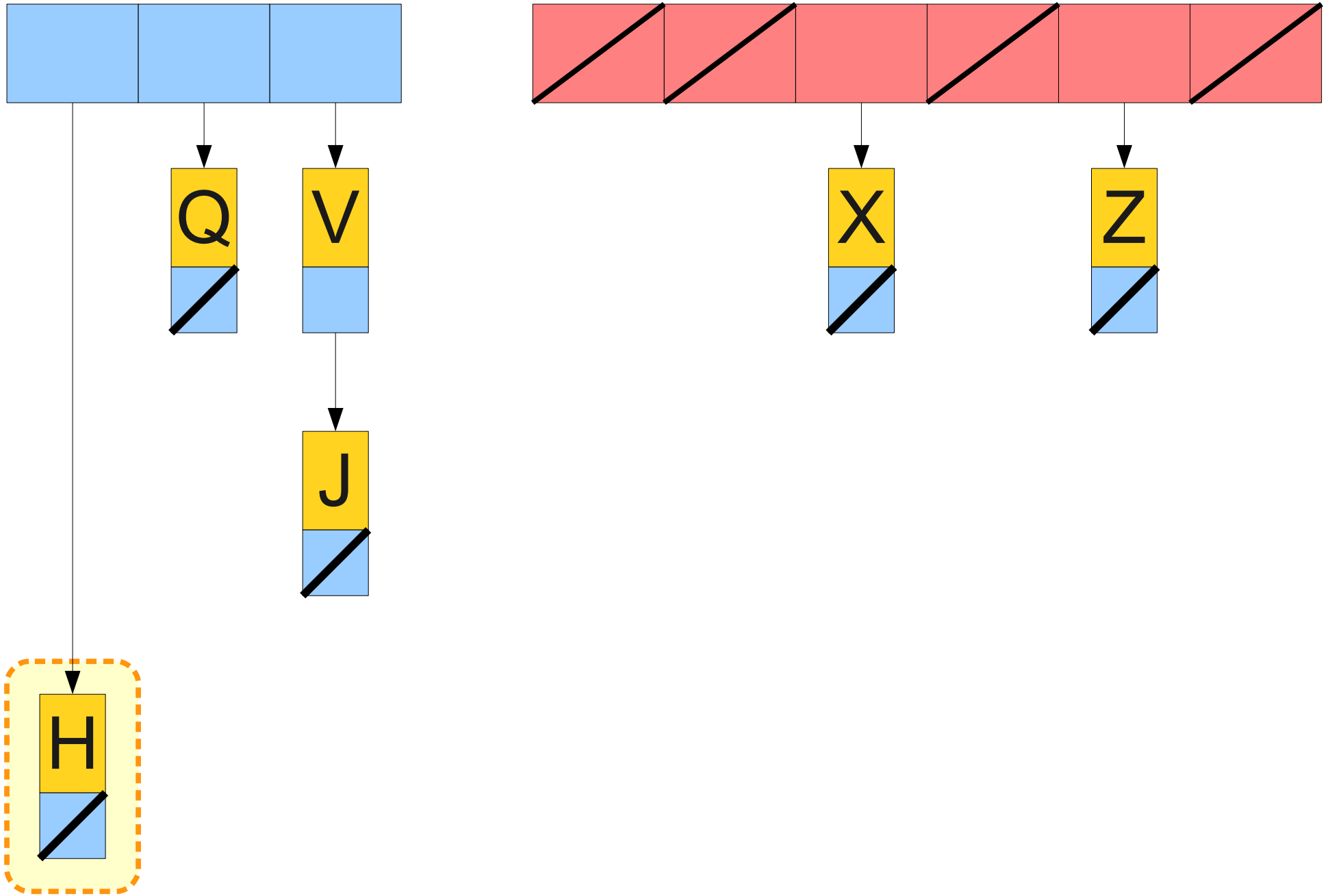
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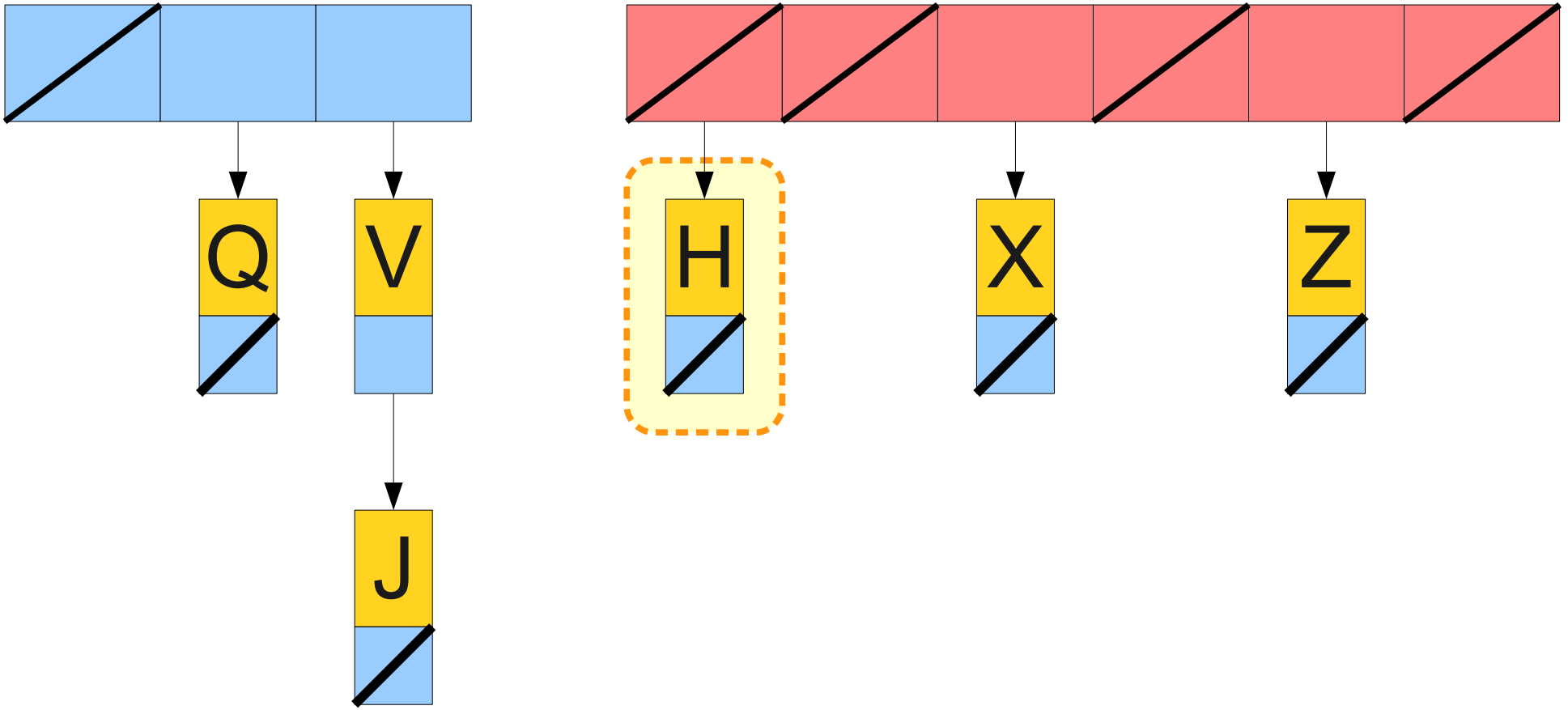
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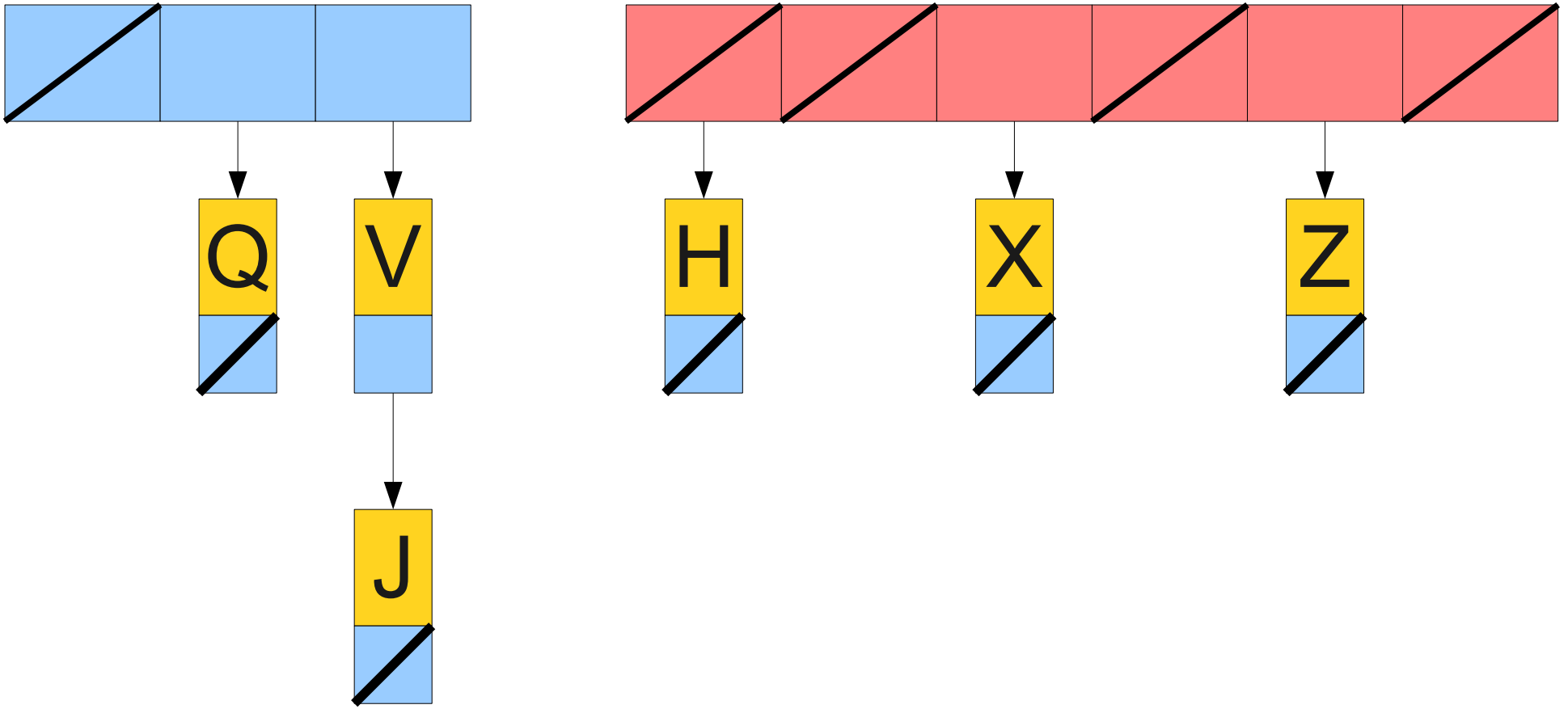
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Coding it Up

The Final Analysis

- Expected time to do a lookup: **O(1)**.
- Expected time to do an insertion:
  - Every n elements, must double the table size and rehash. Does O(n) work, but only every n iterations.
  - Then does O(1) expected work to do the insertion.
  - **Amortized expected O(1) insertion!**

Next Time

- **Binary Search Trees**
  - How else might you store a large number of key/value pairs?
  - And why are our **`Map`** and **`Set`** stored in sorted order?