

Hash Tables

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Lecture Topics

- Hash Table Basics
 - A Simple Hash Table
- Hash Functions
- Collision Resolution
 - Closed Addressing (Separate Chaining)
 - Open Addressing (Linear Probing)
- Resizing/Rehashing

Hash Tables

- A **hash table** (sometimes called a “dictionary”, “hash map”, or “map”) is a linear data structure consisting of **Key-Value Pairs** (KVPs).
- Keys and Values can be any data type.
 - Usually, all Keys are the same type and all Values are the same type.
- Implemented using an array.
 - This (in ideal circumstances) gives constant time for putting data into and getting data out of the hash table.

Hash Tables

- First, an array is created.

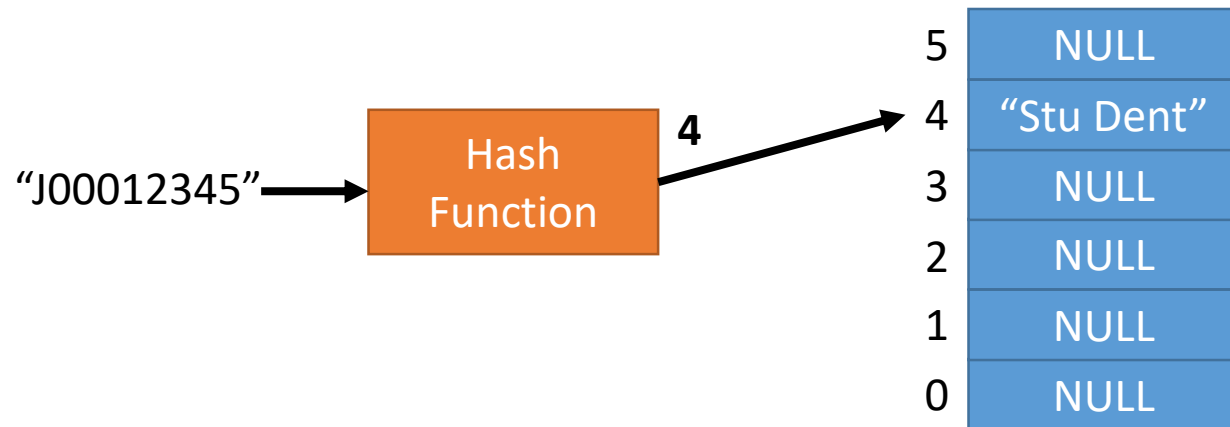
5	NULL
4	NULL
3	NULL
2	NULL
1	NULL
0	NULL

Hash Tables

- Then, a **hash function** converts a KVP's key to an index in the array.

- KVP

- Key = "J00012345"
- Value = "Stu Dent"

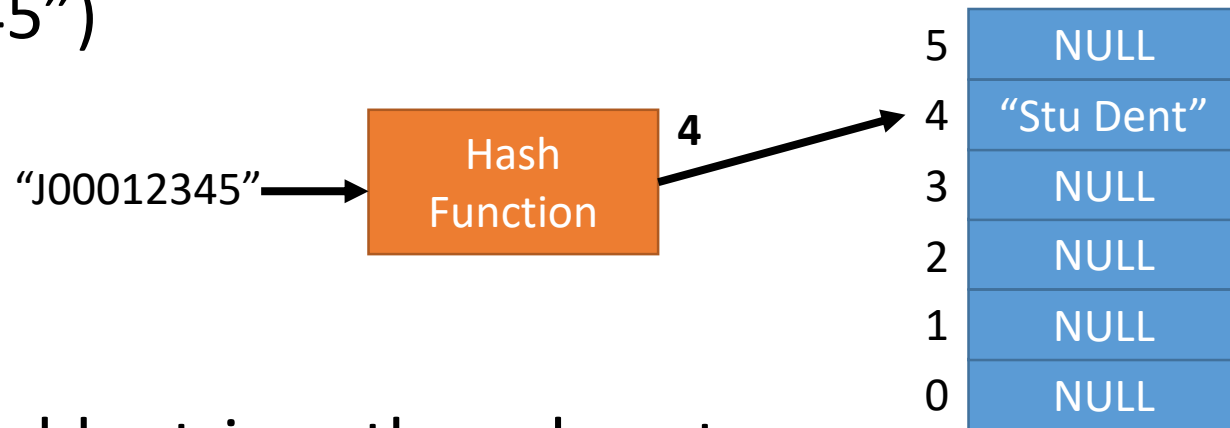


- In this example, the key was hashed to the value 4

Hash Tables

- The same hash function allows us to retrieve the value using the key.

- `hashTable.get("J00012345")`



- The statement above would retrieve the value at index 4

Hash Tables

- Quite a bit that needs considering.
 - How to convert the key to a valid index in the array?
 - **Hash Functions**
 - How do we handle what happens when two keys hash to the same index?
 - **Collision Resolution**
 - What happens when the hash table runs out of space?
 - **Resizing/Rehashing**

A Simple Hash Table

- We'll start with a very basic example to get the general idea of what is going on.
- Our simple hash table will use ints for keys and strings for values of each KVP.
 - And use a very simple hash function.
- No collision resolution.

A Simple Hash Table

- A KVP object.
 - This is what will be stored in the array.
- No setter for the key.
 - It should never change.
 - The value can be replaced/updated.

```
class KVP {  
    private:  
        int key;  
        string value;  
    public:  
        KVP(int k, string v) {  
            key = k;  
            value = v;  
        }  
  
        int getKey() {  
            return key;  
        }  
  
        string getValue() {  
            return value;  
        }  
  
        void setValue(string v) {  
            value = v;  
        }  
};
```

A Simple Hash Table

- KVP **map
 - A pointer (array) of KVP pointers.
- Constructor:
 - Sets every index to NULL
- Destructor:
 - Deletes each KVP in the array.
 - Deletes the array.

```
class HashTable {  
    private:  
        KVP **map;  
        const int SIZE = 10;  
    public:  
        HashTable() {  
            map = new KVP*[SIZE];  
            for(int i=0; i<SIZE; i++) {  
                map[i] = NULL;  
            }  
        }  
  
        ~HashTable() {  
            for(int i = 0; i < SIZE; i++) {  
                delete map[i];  
            }  
            delete[] map;  
        }  
};
```

delete vs free()

- The delete operator releases the object's memory AND calls the object's destructor.
 - **delete myObject;**
- The free function releases the object's memory but does NOT call the object's destructor.
 - **free(myObject);**

A Simple Hash Table - Put

- Hash Function:
 - $\text{key} \% \text{size}$.
 - If size is 10, it guarantees a remainder of 0 through 9
- If that index is null:
 - Safe to add the new KVP
- If it's not null, but the keys are equal:
 - Update the value of the KVP
- Otherwise, a collision has occurred.

```
void put(int key, string value) {  
    int hashValue = key % SIZE;  
    if(map[hashValue] == NULL) {  
        KVP *temp = new KVP(key, value);  
        map[hashValue] = temp;  
    }  
    else if(map[hashValue]->getKey() == key) {  
        map[hashValue]->setValue(value);  
    }  
    else {  
        __throw_invalid_argument("Hash Collision");  
    }  
}
```

A Simple Hash Table - Get

- Hash Function:
 - $\text{key} \% \text{size}$.
 - Same thing we did in “put”.
- If that index is not null:
 - Return the value
- Otherwise (it was null) there is no value to return.

```
string get(int key) {  
    int hashValue = key % SIZE;  
    if(map[hashValue] != NULL) {  
        return map[hashValue]->getValue();  
    }  
    else {  
        __throw_invalid_argument("KVP not found");  
    }  
}
```

A Simple Hash Table - Remove

- Hash Function:
 - $\text{key} \% \text{size}$.
 - Same thing we did in “put”.
- If that index is not null:
 - Delete the KVP
 - Set that index to null

```
bool remove(int key) {  
    int hashValue = key % SIZE;  
    if(map[hashValue] != NULL) {  
        delete map[hashValue];  
        map[hashValue] = NULL;  
        return true;  
    }  
    else {  
        return false;  
    }  
}
```

A Simple Hash Table

```
int main() {  
    HashTable ht;  
    ht.put(3456, "ABC Corporation");  
}
```

3456

Hash Function:
key % size

$$3456 \% 10 = 6$$

9	NULL
8	NULL
7	NULL
6	3456 : "ABC Corporation"
5	NULL
4	NULL
3	NULL
2	NULL
1	NULL
0	NULL

A Simple Hash Table

```
int main() {  
    HashTable ht;  
    ht.put(3456, "ABC Corporation");  
    ht.put(1313, "XYZ Associates");  
}
```

1313

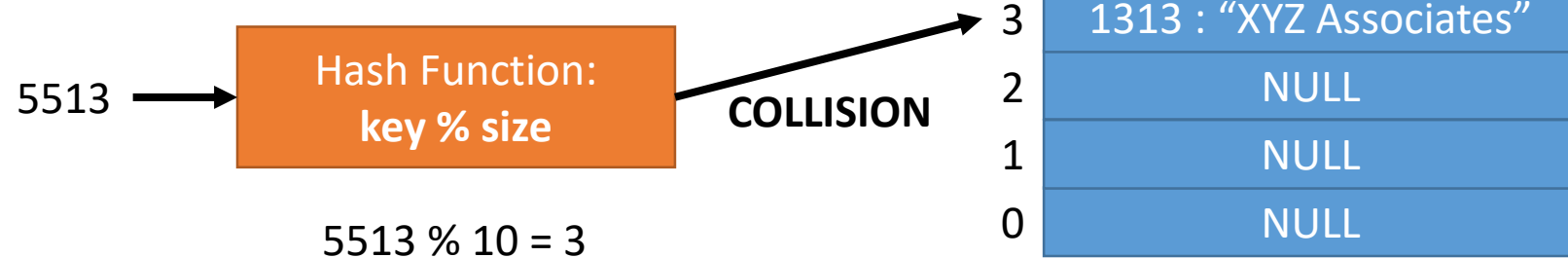
Hash Function:
key % size

$$1313 \% 10 = 3$$

9	NULL
8	NULL
7	NULL
6	3456 : "ABC Corporation"
5	NULL
4	NULL
3	1313 : "XYZ Associates"
2	NULL
1	NULL
0	NULL

A Simple Hash Table

```
int main() {  
    HashTable ht;  
    ht.put(3456, "ABC Corporation");  
    ht.put(1313, "XYZ Associates");  
    ht.put(5513, "FGH Inc.");  
}
```



Hash Functions

- There is no perfect hash function.
- The goals of the hash function are:
 - Distribute keys to indexes the best it can.
 - Minimize collisions.

Hash Functions

- Let's look again at the hash function shown previously:
 - $\text{key} \% \text{size}$
 - The size is 10, so $\text{key} \% 10$
- The last digit of the key decides the index.
 - $345\mathbf{6} \% 10 = \mathbf{6}$
 - $131\mathbf{3} \% 10 = \mathbf{3}$
 - $551\mathbf{3} \% 10 = \mathbf{3}$

Hash Functions

- If keys are sufficiently different, the performance won't be too bad.
 - Might have a collision here and there that could be resolved without wasting too much time.
 - $3456 \% 10 = 6$
 - $1313 \% 10 = 3$
 - $4822 \% 10 = 2$
 - $99999 \% 10 = 9$
- If every key will end with a 3....
 - Always a collision.
 - $3453 \% 10 = 3$
 - $1313 \% 10 = 3$
 - $4823 \% 10 = 3$
 - $99993 \% 10 = 3$

Hash Functions

- One trick is to use array sizes that are prime:
 - $\text{key} \% \text{size}$
 - If the size is 31, then its $\text{key} \% 31$
- It will reduce the number of common factors between the key and the size.
 - $3456 \% 31 = 15$
 - $1313 \% 31 = 11$
 - $5513 \% 31 = 26$

Hash Functions

- Different keys:
 - $3456 \% 31 = 15$
 - $1313 \% 31 = 11$
 - $4822 \% 31 = 17$
 - $99999 \% 31 = 24$
- Every key ends with a 3....
 - $3453 \% 31 = 12$
 - $1313 \% 31 = 11$
 - $4823 \% 31 = 18$
 - $99993 \% 31 = 18$
 - $99983 \% 31 = 8$
- Won't entirely eliminate collisions.
- Distributes indexes better, leading to fewer collisions.

Hash Functions

- Hashing a string is a little different.
- We wouldn't want to use the string's length, because if every key is the same number of characters, we'd always hash to the same index.
- A good way to hash strings is to use each character's decimal value in the hash function.

Hash Functions

- Add up the decimal value of each character in the key.
- Return:
 - The sum % the table size

```
int hashFunction(string key, int size) {  
    int hash = 0;  
    for(int i = 0; i < key.length(); i++) {  
        hash = hash + key[i];  
    }  
    return hash % size;  
}
```


Hash Functions

- This will work well enough for strings with varying characters.
- But, the characters of some strings may add up to the same total.
 - DDD1, DCE1, DEC1 all add up to the same total.
- Multiplying the hash by a prime number can help reduce the number of collisions.

Hash Functions

- Won't eliminate every collision, but it will distribute indexes a little better in situations where the character decimal values add up to the same sum.

```
int hashFunction(string key, int size) {  
    int hash = 0;  
    for(int i = 0; i < key.length(); i++) {  
        hash = (19 * hash) + key[i];  
    }  
    return hash % size;  
}
```

Collision Resolution

- As we've seen, collisions are bound to happen.
- We'll see two techniques to resolve collisions:
 - Closed Addressing (using Separate Chaining)
 - Open Addressing (using Linear Probing)

Closed Addressing

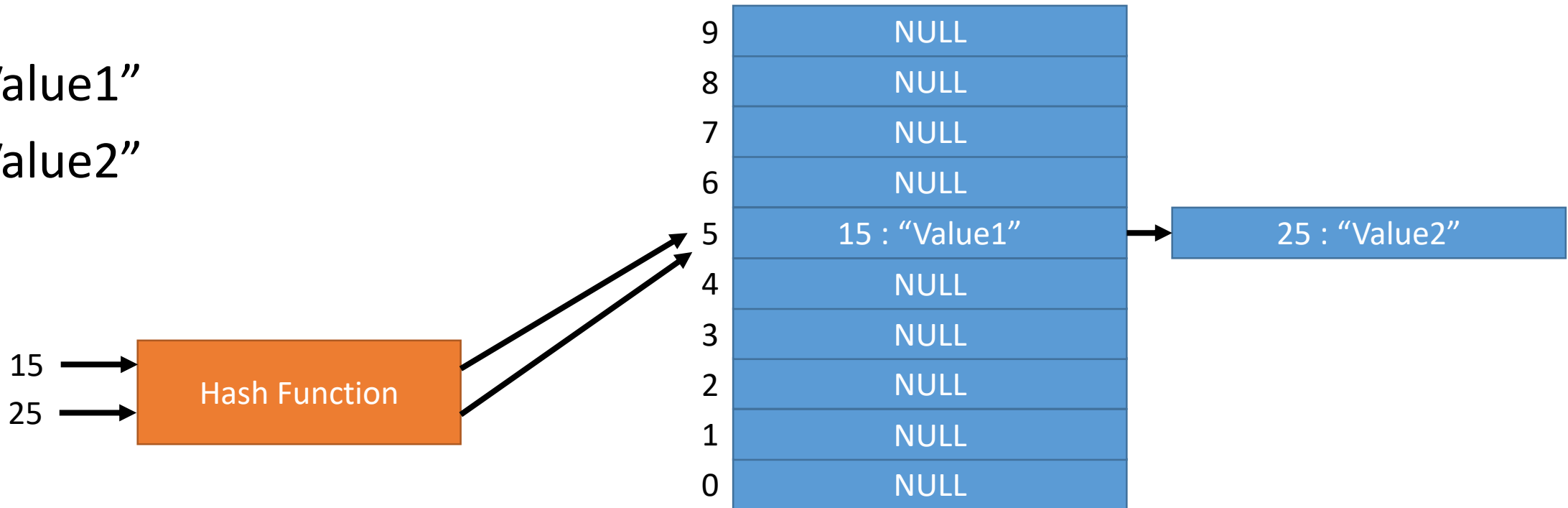
- Closed Addressing means that the key's hash value always corresponds to its index in the array.
- Stored at each index is a linked list, where each node is a KVP.
 - The list can shrink/grow in size dynamically.
 - Sometimes called a “bucket” in this context.
- Basically, we're allowing more than one KVP to be stored at one index.

Closed Addressing

KVPs

15:“Value1”

25:“Value2”



Closed Addressing - Put

```
void put(int key, string value) {  
    int hashValue = key % SIZE;  
    KVP *newEntry = new KVP(key, value);  
    if(map[hashValue] == NULL) {  
        Bucket *newList = new Bucket;  
        map[hashValue] = newList;  
    }  
    map[hashValue]->add(newEntry);  
}
```

Closed Addressing – Adding to Bucket

```
void add(KVP* newKVP) {
    if(head == NULL) {
        head = newKVP;
        tail = newKVP;
    }
    else {
        KVP *temp = head;
        while(temp != NULL && (temp->getKey() != newKVP->getKey())) {
            temp = temp->getNext();
        }
        if(temp == NULL) {
            tail->setNext(newKVP);
            tail = tail->getNext();
        }
        else {
            temp->setValue(newKVP->getValue());
        }
    }
}
```

Closed Addressing - Get

```
string get(int key) {  
    int hashValue = key % SIZE;  
    if(map[hashValue] == NULL) {  
        __throw_invalid_argument("Key not found");  
    }  
    KVP *e = map[hashValue]->get(key);  
    if(e == NULL) {  
        __throw_invalid_argument("Key not found");  
    }  
    else {  
        return e->getValue();  
    }  
}
```


Closed Addressing – Getting from Bucket

```
KVP* get(int key) {  
    KVP *current = head;  
    while(current != NULL && current->getKey() != key) {  
        current = current->getNext();  
    }  
    return current;  
}
```

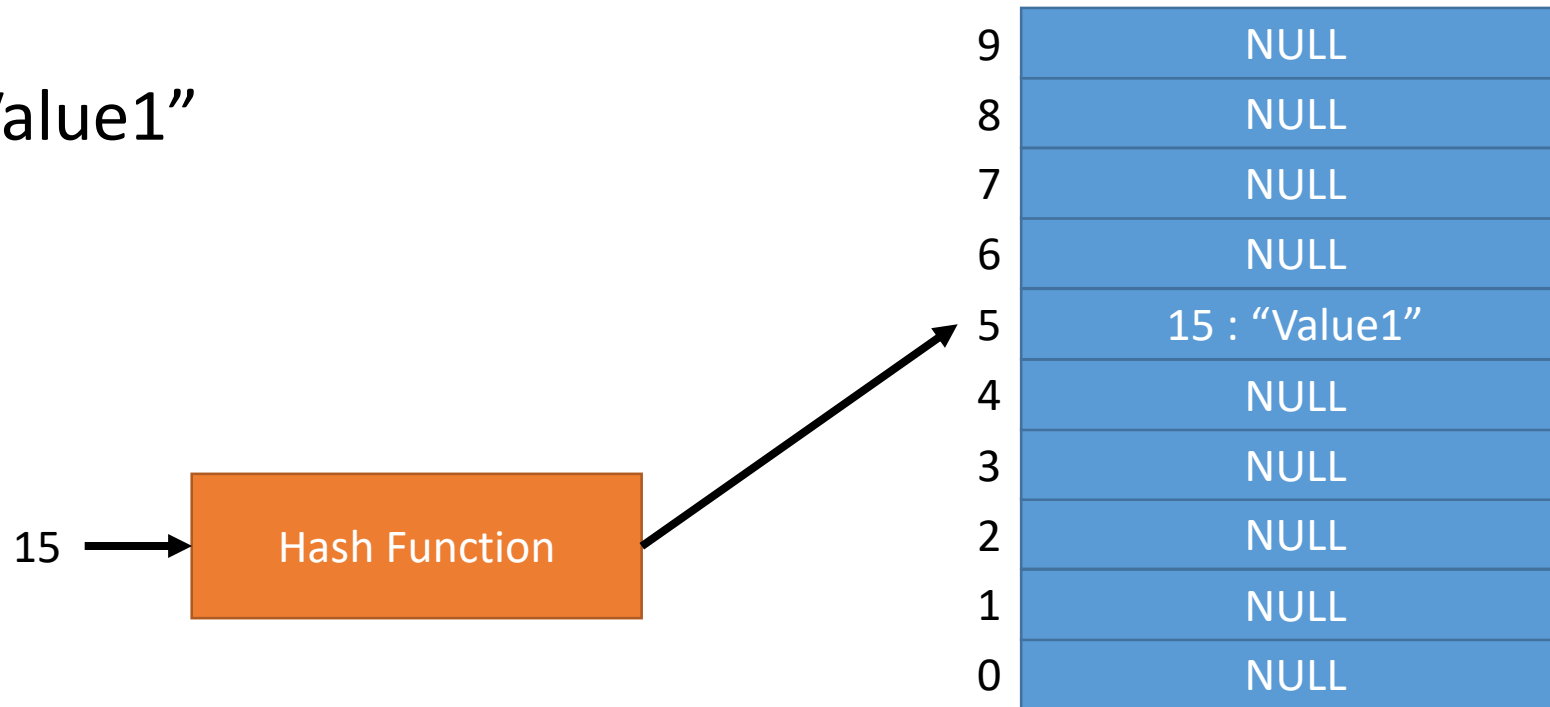
Open Addressing

- Open Addressing means that the key's hash value *may not* directly correspond to an index in the array.
- If that index is already in use, it checks the next index to see if it is empty, then checks the next index, and so on.
 - **Linear Probing**

Open Addressing

KVP

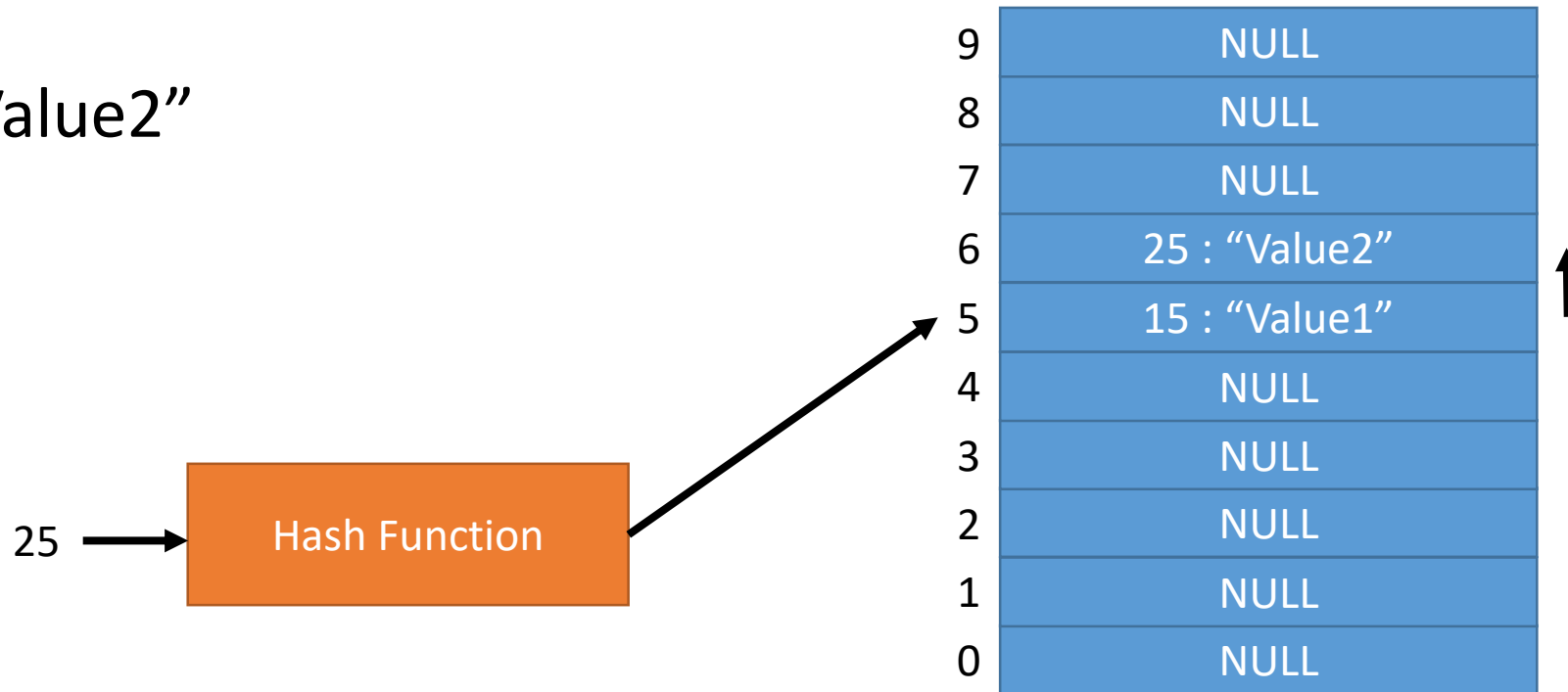
15:“Value1”



Open Addressing

KVP

25:“Value2”



(Since index 5 was in use, it tries index 6)

Open Addressing - Put

```
void put(string key, string value) {  
    int hashValue = hashFunction(key);  
    int start = hashValue;  
    while(map[hashValue] != NULL && map[hashValue]->getKey().compare(key) != 0) {  
        hashValue = (hashValue + 1) % SIZE;  
        if(start == hashValue) {  
            __throw_overflow_error("Table is full.");  
        }  
    }  
    if(map[hashValue] != NULL) {  
        delete map[hashValue];  
    }  
    map[hashValue] = new KVP(key, value);  
}
```

Open Addressing - Get

```
string get(string key) {  
    int hashValue = hashFunction(key);  
    int start = hashValue;  
    while(map[hashValue] != NULL && map[hashValue]->getKey().compare(key) != 0) {  
        hashValue = (hashValue + 1) % SIZE;  
        if(start == hashValue) {  
            __throw_overflow_error("Key not found.");  
        }  
    }  
    if(map[hashValue] == NULL) {  
        __throw_invalid_argument("Key not found.");  
    }  
    return map[hashValue]->getValue();  
}
```

Resizing

- The greater the **load** (utilization) of the hash table, the greater the chance for a collision.
- Making an oversized hash table would waste space, but perhaps reduce the number of collisions.
- Resizing a hash table would be more efficient.
 - Make the table larger when free space starts running low.
 - Make the table smaller when the load has sufficiently decreased.

Resizing

- Create a (temporary) pointer to the current map

KVP **temp = map;

Resizing

- Decide if shrinking or growing the table

```
if(shrink) {  
    SIZE -= (int)(SIZE * .25); //Decrease 25%  
    if(SIZE < MINSIZE) {  
        SIZE = MINSIZE;  
    }  
}  
else {  
    SIZE = SIZE * 2; //Double the size  
}
```

Resizing

- Create a new map and set all values to null
 - Reset the total count of KVPs

```
map = new KVP*[SIZE];  
  
for(int i=0; i<SIZE; i++) {  
    map[i] = NULL;  
}  
  
count = 0;
```

Resizing

- Rehash each KVP from the old map into the new map.
 - Delete the KVP from the old map
 - Delete the old map

```
for(int i=0; i < oldSize; i++) {  
    if(temp[i] != NULL) {  
        put(temp[i]->getKey(), temp[i]->getValue());  
        delete temp[i];  
    }  
}  
delete[] temp;
```

Resizing

```
void rehash(bool shrink) {
    int oldSize = SIZE;
    KVP **temp = map;
    if(shrink) {
        SIZE -= (int)(SIZE * .25); //Decrease 25%
        if(SIZE < MINSIZE) {
            SIZE = MINSIZE;
        }
    }
    else {
        SIZE = SIZE * 2; //Double the size
    }

    map = new KVP*[SIZE];
    for(int i=0; i<SIZE; i++) {
        map[i] = NULL;
    }

    count = 0;

    for(int i=0; i < oldSize; i++) {
        if(temp[i] != NULL) {
            put(temp[i]->getKey(), temp[i]->getValue());
            delete temp[i];
        }
    }
    delete[] temp;
}
```