Hashing in C

CSCI2100a Data Structures Tutorial

Jinwei Liu

jwliu@cse.cuhk.edu.hk

Contents

- **Hash function**
- **Collision resolutions**
  - **Separate Chaining (Open hashing)**
  - **Open addressing (Closed Hashing)**
    - **Linear probing**
    - **Quadratic probing**
    - **Random probing**
    - **Double hashing**

Contents

- **Hash function**

- **Collision resolutions**
  - **Separate Chaining (Open hashing)**
  - **Open addressing (Closed Hashing)**
    - **Linear probing**
    - **Quadratic probing**
    - **Random probing**
    - **Double hashing**

Hashing in C

- One of the biggest drawbacks to a language like C is that there are **no keyed arrays**.

Array

Value
New York
Boston
Mexico
Kansas
Detroit
California

Hash Table

Key	Value
1	New York
2	Boston
3	Mexico
4	Kansas
5	Detroit
6	California

– Can only access *indexed Arrays*, e.g. ***city[5];***

– *Cannot directly* access the values e.g. ***city[“California"];***

Hashing - hash function

- Hash function
  - A mapping function that maps a *key* to an index number in the range *0* to *TableSize -1*

```
/* Hash function for ints */
int hashfunc(int integer_key)
{
    return integer_key % HASHTABLESIZE;
}
```

- However, **collisions** cannot be avoided.

Hashing - hash function Cont.

```
/* hash functions for strings from Sample Code in
Weiss's*/
typedef unsigned int Index;

Index Hash1( const char *Key, int TableSize
)
{
      unsigned int HashVal = 0;
      while( *Key != '\0' )
            HashVal += *Key++;
      return HashVal % TableSize;
}
```

- However, **collisions** cannot be avoided.

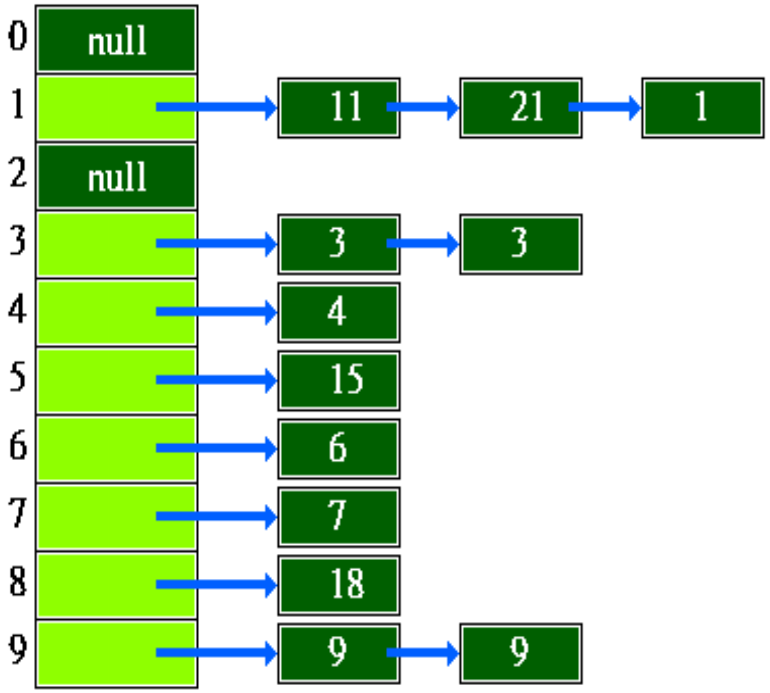
Contents

- Hash function

- **Collision resolutions**
  - **Separate Chaining (Open hashing)**
  - Open addressing (Closed Hashing)
    - Linear probing
    - Quadratic probing
    - Random probing
    - Double hashing

Hashing - separate chaining

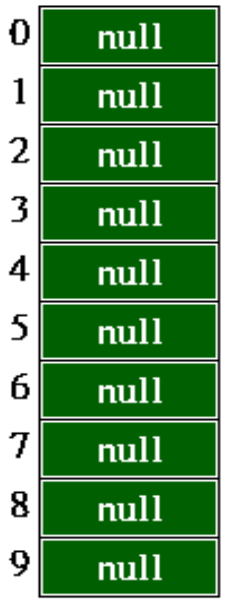
- If two keys map to same value, the elements are chained together by creating a linked list of elements



Hashing - example

- Insert the following four keys 22 84 35 62 into hash table of size 10 using separate chaining.
- The hash function is key % 10

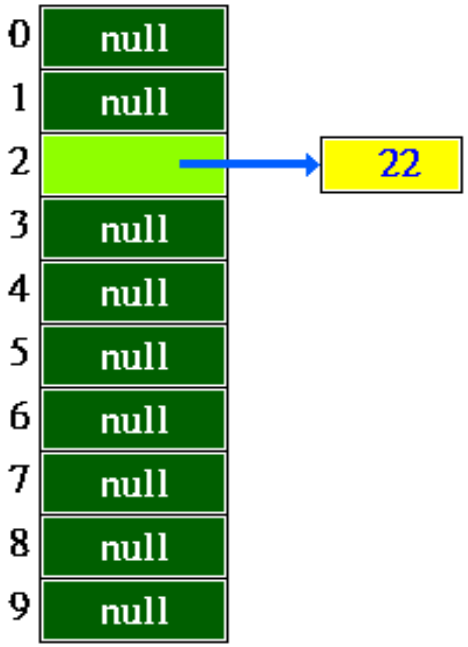
Initial hash table



Hashing - example

- Insert the following four keys 22 84 35 62 into hash table of size 10 using separate chaining.
- The hash function is key % 10

22 % 10 = 2

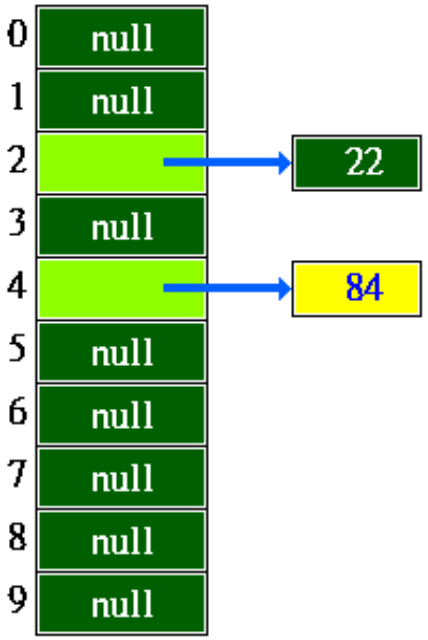


After insert 22

Hashing - example

- Insert the following four keys 22 84 35 62 into hash table of size 10 using separate chaining.
- The hash function is key % 10

84 % 10 = 4

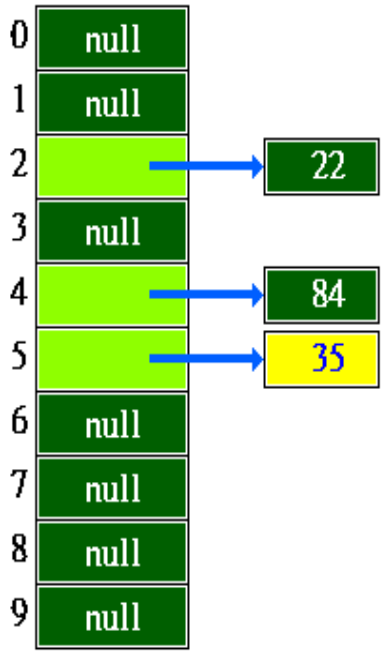


After insert 84

Hashing - example

- Insert the following four keys 22 84 35 62 into hash table of size 10 using separate chaining.
- The hash function is key % 10

35 % 10 = 5

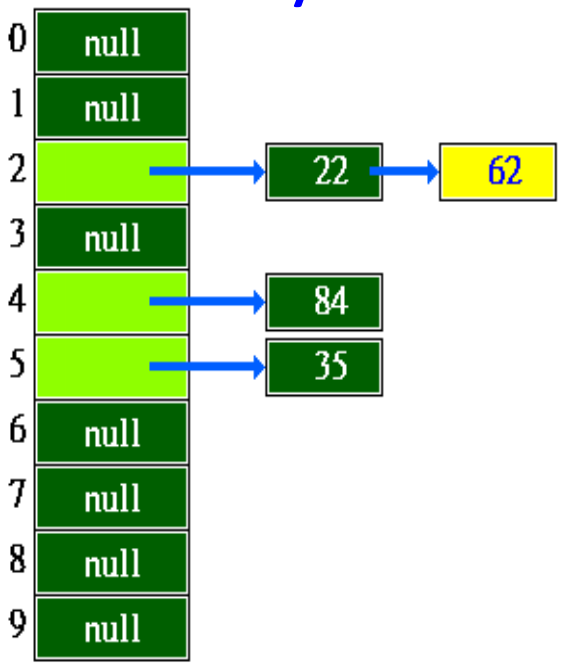


After insert 35

Hashing - example

- Insert the following four keys 22 84 35 62 into hash table of size 10 using separate chaining.
- The hash function is key % 10

62 % 10 = 2



After insert 62

Contents

- Hash function
- Collision resolutions
  - Separate Chaining (Open hashing)
  - **Open addressing (Closed Hashing)**
    - Linear probing
    - Quadratic probing
    - Random probing
    - Double hashing

Hashing

- **Open addressing**
  - Open addressing hash tables store the records directly within the array.
  - A hash collision is resolved by *probing*, or searching through alternate locations in the array.
    - Linear probing
    - Quadratic probing
    - Random probing
    - Double hashing

Hashing - Open addressing

```
#define HASHTABLESIZE 51

typedef struct
{
    int key[HASHTABLESIZE];
    char state[HASHTABLESIZE];
   /* -1=lazy delete, 0=empty, 1=occupied */
} hashtable;

/* The hash function */
int hash(int input)
{
    return input%HASHTABLESIZE;
}
```

Hashing - Open addressing

- Open addressing
  - if collision occurs, *alternative cells* are tried.

$$h_0(X), h_1(X), h_2(X), \ldots, h_k(X)$$

$$= (Hash(X) + F(k)) \bmod TableSize$$

  - Linear probing $F(k) = k$
  - Quadratic probing $F(k) = k^2$
  - Double hashing $F(k) = k * Hash_2(X)$

Hashing - Open addressing

```
void open_addressing_insert(int item, hashtable * ht )
{
   hash_value = hash(item);
   i = hash_value;
   k = 1;
   while (ht->state[i]!= 0) {
            if (ht->key[i] == item) {
                     fprintf(stderr,"Duplicate entry\n");
                     exit(1);
            }
            i = h(k++,item);
            if (i == hash_value) {
                     fprintf(stderr, "The table is full\n");
                     exit(1);
            }
   }
   ht->key[i] = item;
}
```

```
/* -1=lazy delete,
0=empty, 1=occupied
*/
```

```
typedef struct
{
    int key[HASHTABLESIZE];
    char state[HASHTABLESIZE];
   /* -1=lazy delete, 0=empty,
1=occupied */
} hashtable;
```

Contents

- Hash function
- Collision resolutions
  - Separate Chaining (Open hashing)
  - **Open addressing (Closed Hashing)**
    - **Linear probing**
    - Quadratic probing
    - Random probing
    - Double hashing

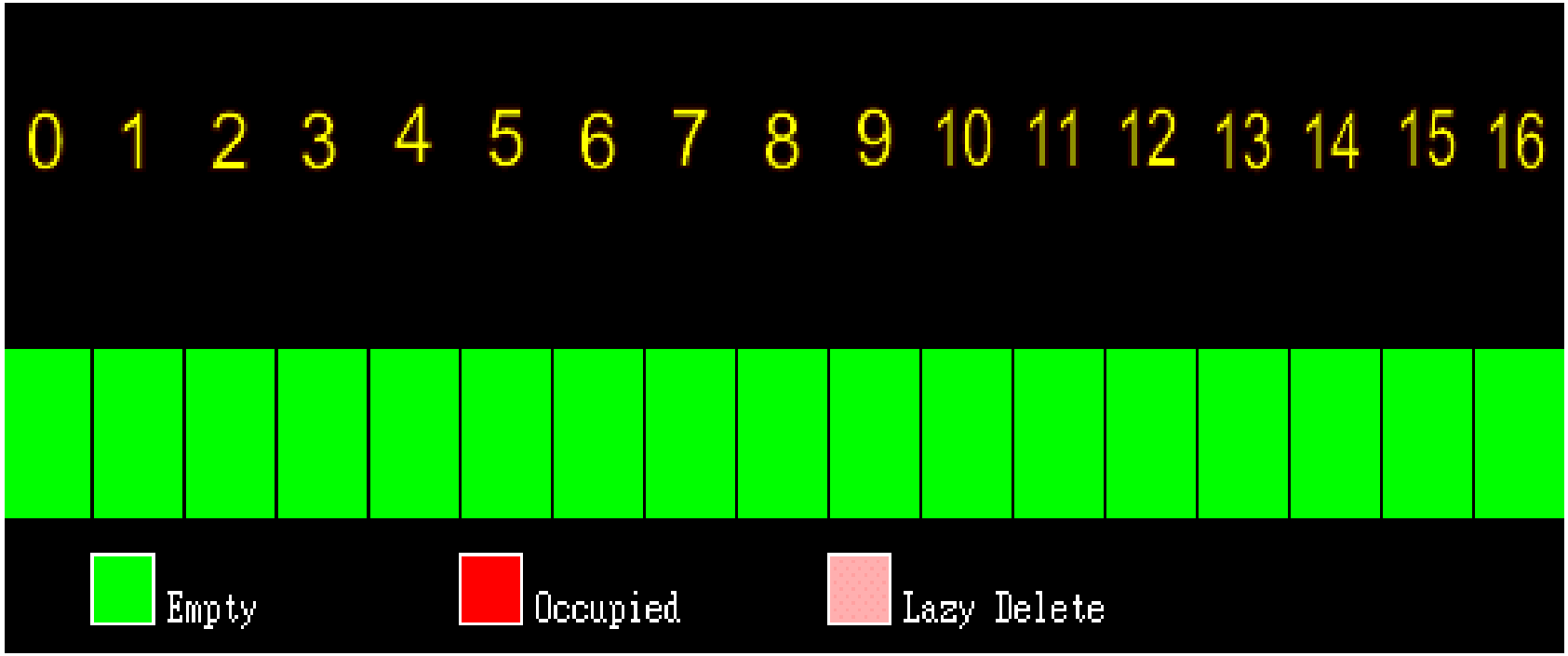
Linear probing

- ***F(k)*** = k

  - $h_k(X)$ = (Hash(X) + k) mod *TableSize*
    - $h_0(X)$ = (Hash(X) + 0) mod *TableSize*,
    - $h_1(X)$ = (Hash(X) + 1) mod *TableSize*,
    - $h_2(X)$ = (Hash(X) + 2) mod *TableSize*,
    - ……

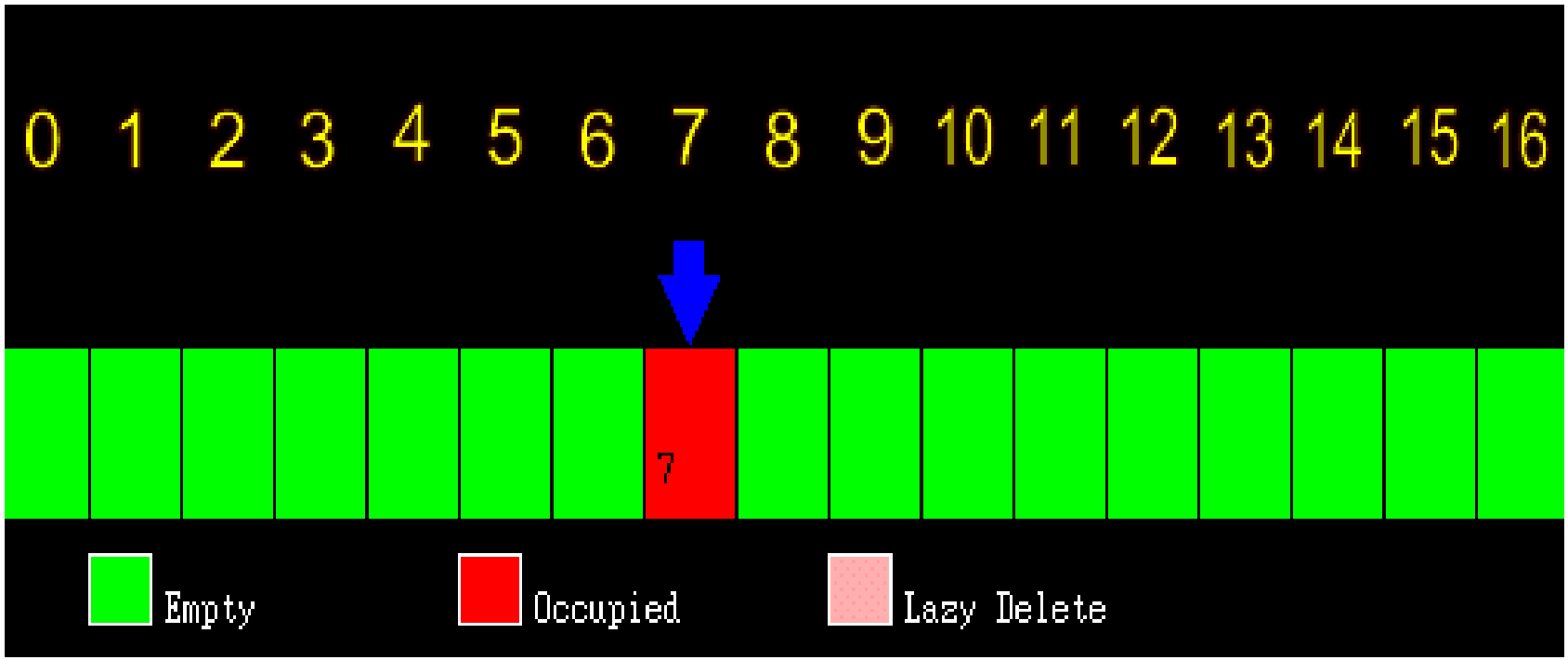
Hashing - Open addressing

- Linear probing example
  - Initial hash table



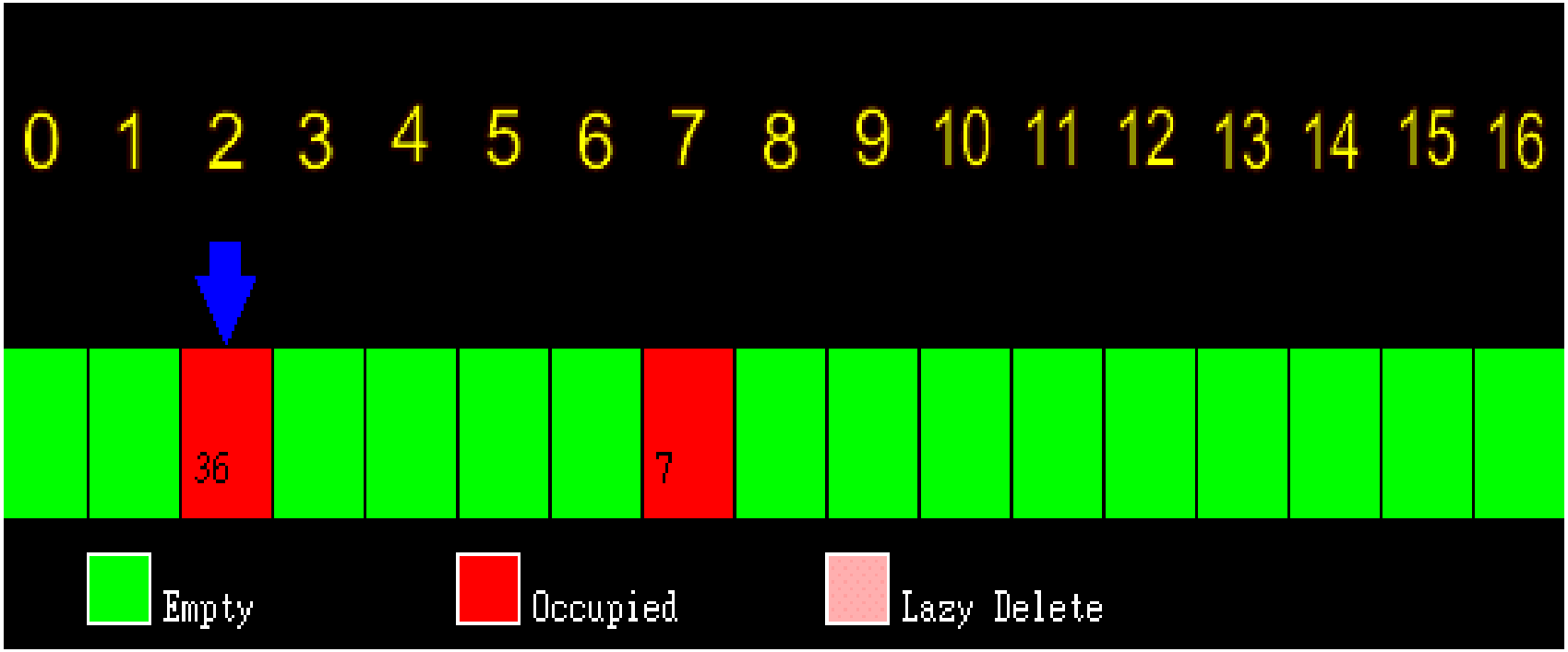
Hashing - Open addressing

- Linear probing example
  - Insert 7 at $h_0(7)$ (7 mod 17) = 7



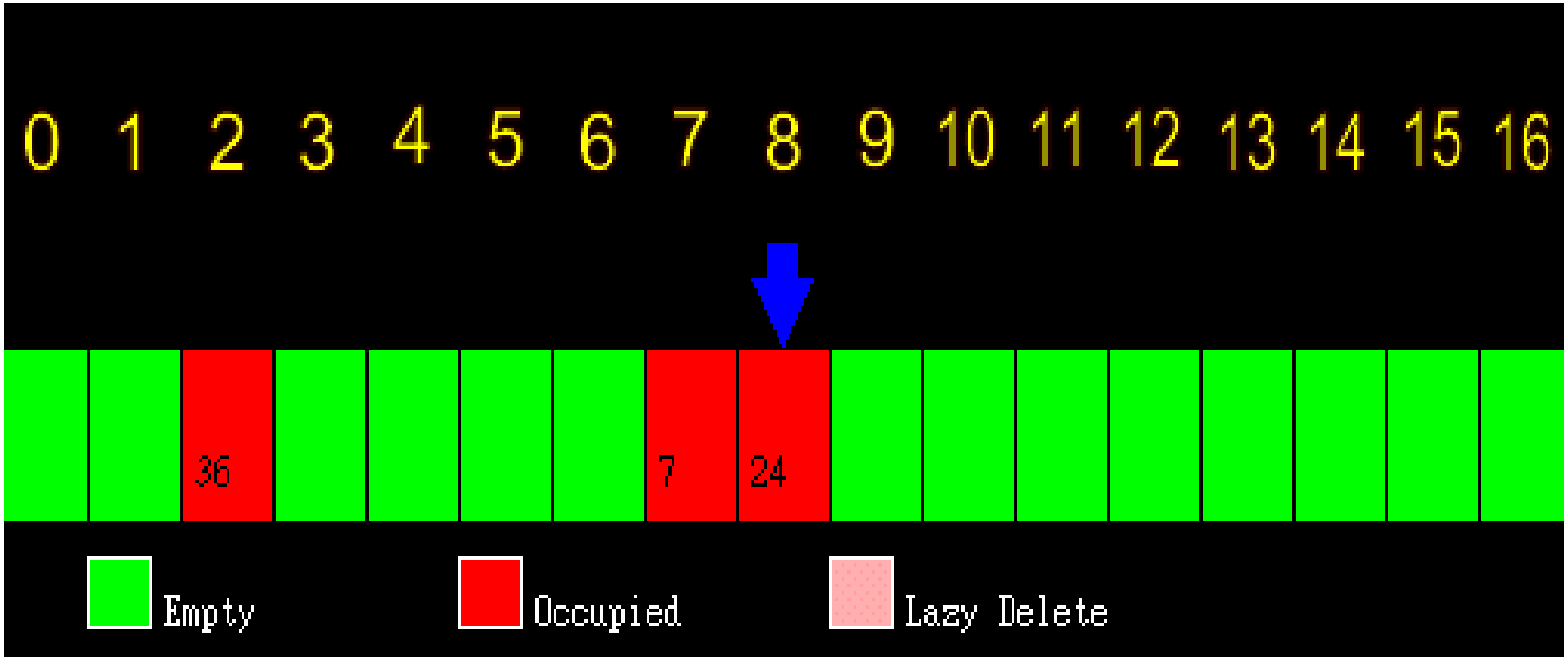
Hashing - Open addressing

- Linear probing example
  - Insert 36 at $h_0(36)$ (36 mod 17) = 2



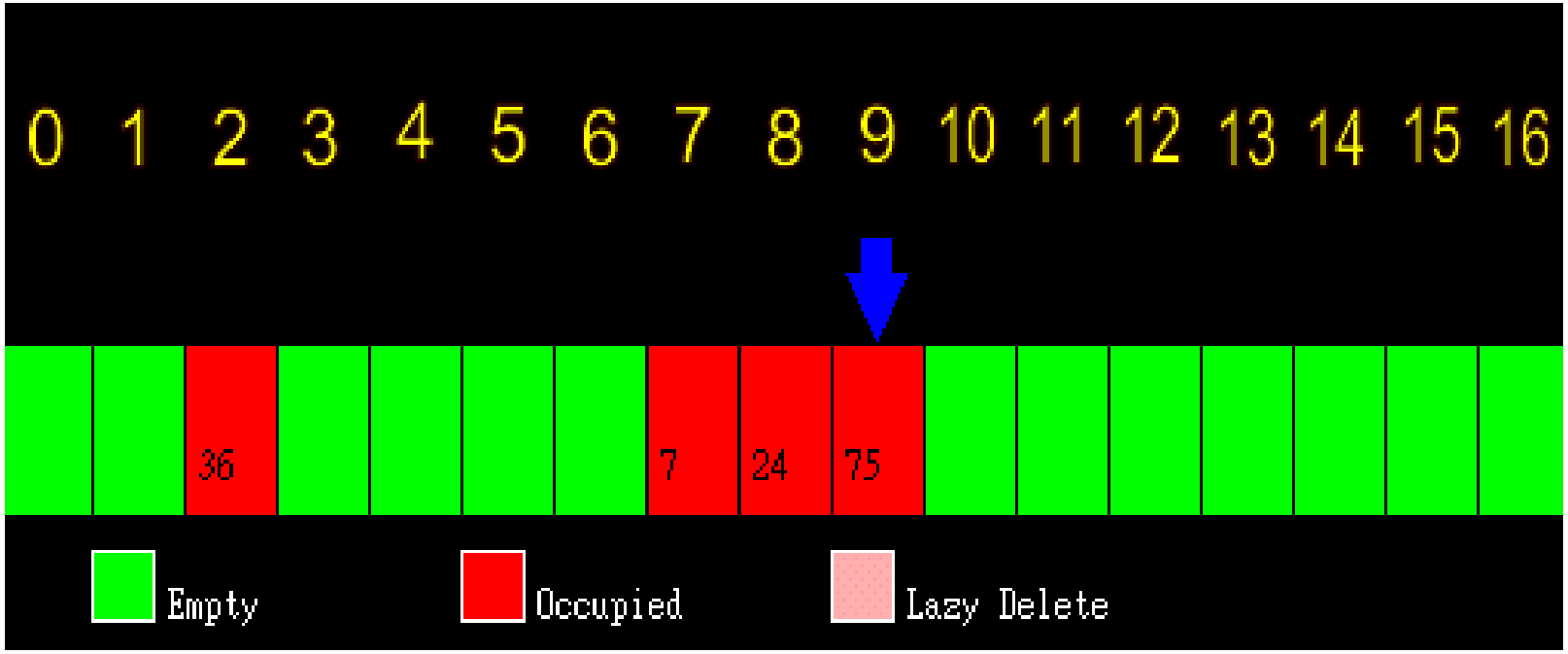
Hashing - Open addressing

- Linear probing example
  - Insert 24 at $h_0(24)=(24 \bmod 17) = 7$, so we call $h_1(24)=((24 + 1) \bmod 17) = 8$



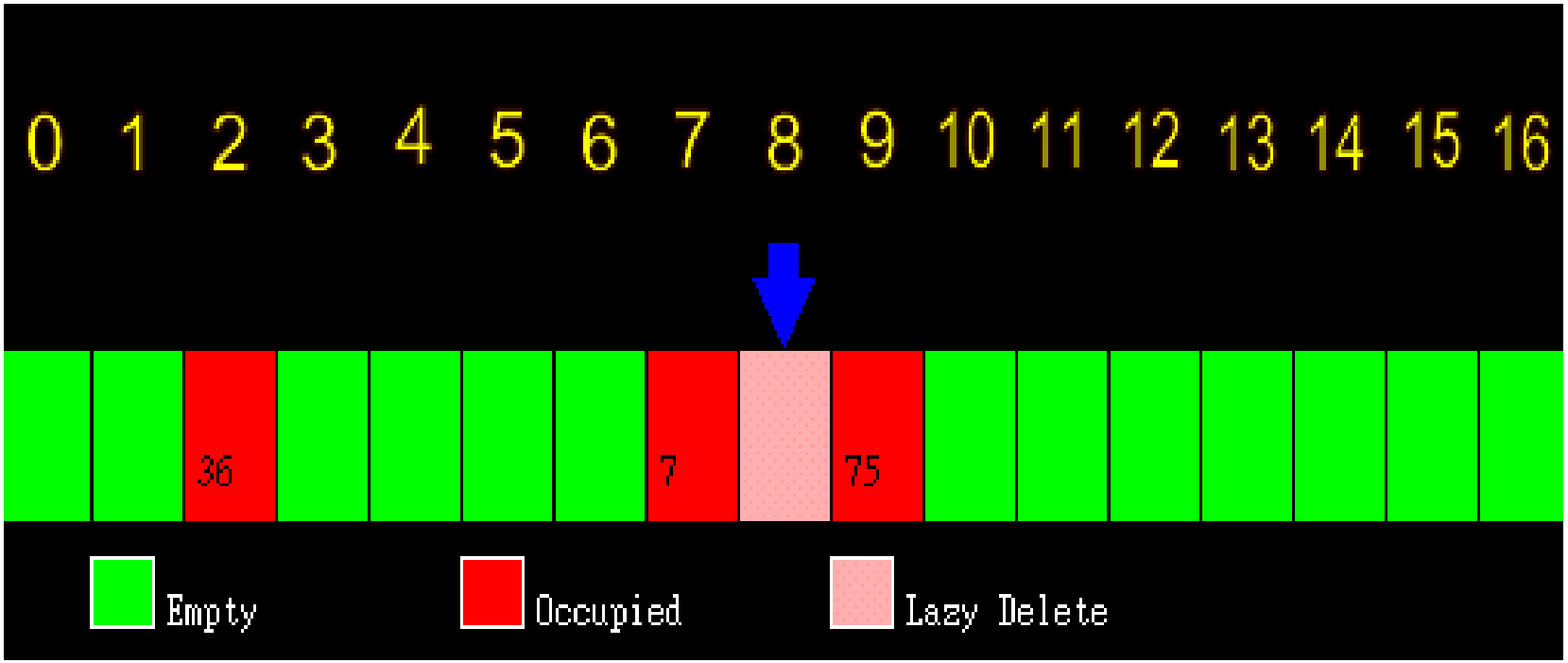
Hashing - Open addressing

- Linear probing example
  - Insert 75 at $h_0(75)=(75 \bmod 17) = 7$, $h_1(75)=((75+1) \bmod 17) = 8$, $h_2(75)=((75+2) \bmod 17) = 9$,



Hashing - Open addressing

- Linear probing example
  - **Delete 24 -> lazy deletion technique**

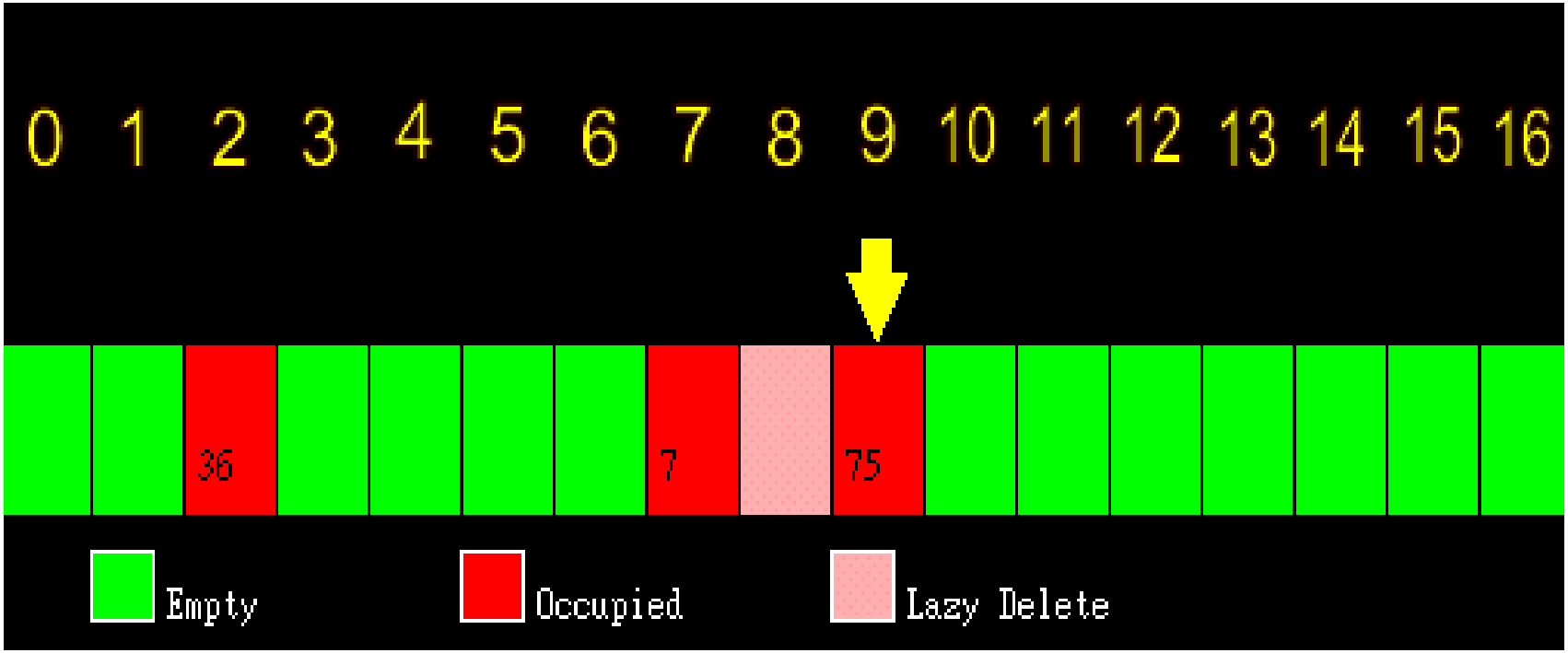


Lazy Deletion

- We need to be careful about removing elements from the table as it may leave holes in the table.
- Lazy Deletion:
  - not to delete the element, but place a marker in the place to indicate that an element that was there is now removed.
  - So when we are looking for things, we jump over the "dead bodies" until we find the element or we run into a null cell.
- Drawback
  - Space cost

Hashing - Open addressing

- Linear probing example
  - Find 75 $h_0(75)$=(75 mod 17) = 7(occupied), 8(lazy delete), 9(Get it!)



Hashing - Open addressing

- Linear probing

```
/* The h function */
int h(int k, int input)
{
  return (hash(input) + k)% HASHTABLESIZE;
}
```

```
while (ht->state[i]!= 0) {
    if (ht->key[i] == item) {
        fprintf(stderr,"Duplicate entry\n");
        exit(1);
    }
    i = h(k++,item);
    //call the function
    if (i == hash_value) {
        fprintf(stderr, "The table is full\n");
        exit(1);
    }
}
```

Contents

- Hash function
- Collision resolutions
  - Separate Chaining (Open hashing)
  - **Open addressing (Closed Hashing)**
    - Linear probing
    - **Quadratic probing**
    - Random probing
    - Double hashing

Hashing - Open addressing

- Quadratic probing
  - ***F(k)*** = k^2

$h_k(X) = (\text{Hash}(X) + k^2) \bmod \textit{TableSize}$

$h_0(X) = (\text{Hash}(X) + 0^2) \bmod \textit{TableSize}$,
$h_1(X) = (\text{Hash}(X) + 1^2) \bmod \textit{TableSize}$,
$h_2(X) = (\text{Hash}(X) + 2^2) \bmod \textit{TableSize}$, ...

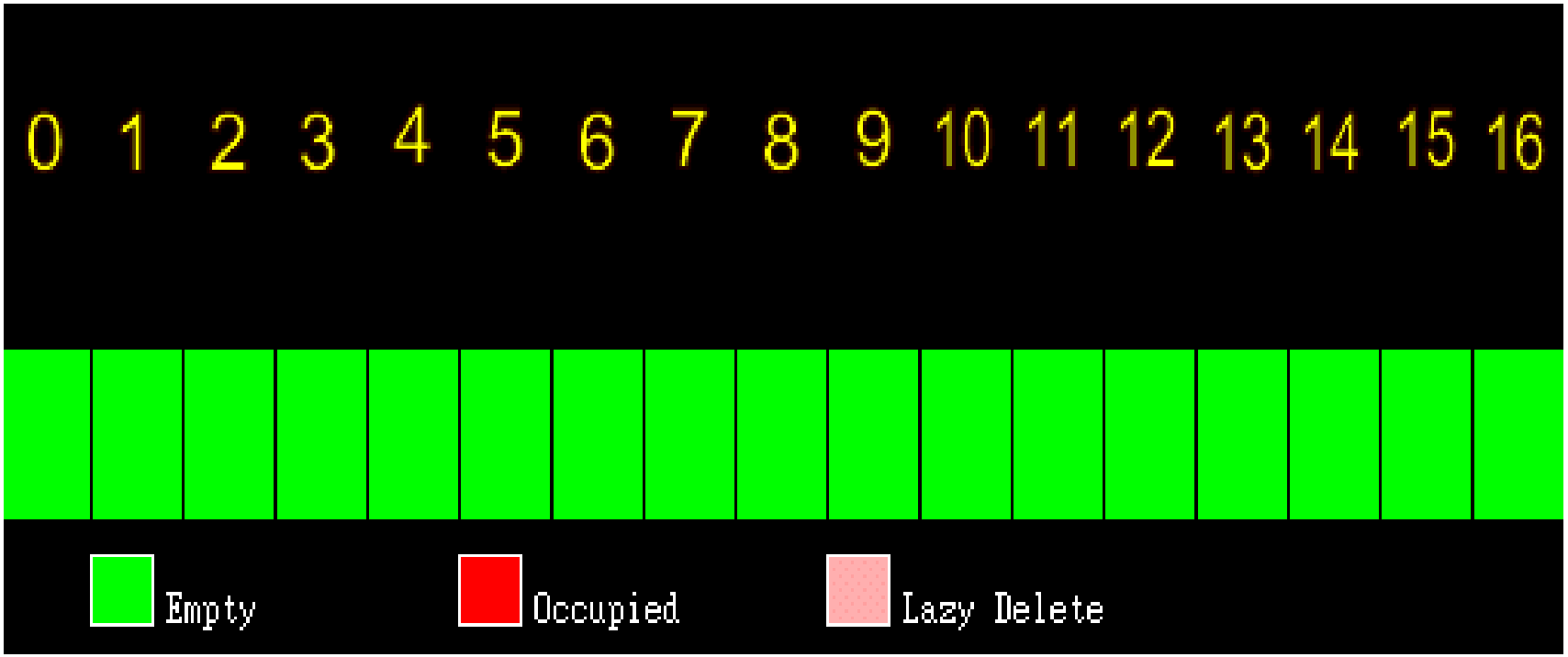
Hashing - Open addressing

- Quadratic probing

```
/* The h function */
int h(int k, int input)
{
    return (hash(input) + k * k) % HASHTABLESIZE;
}
```

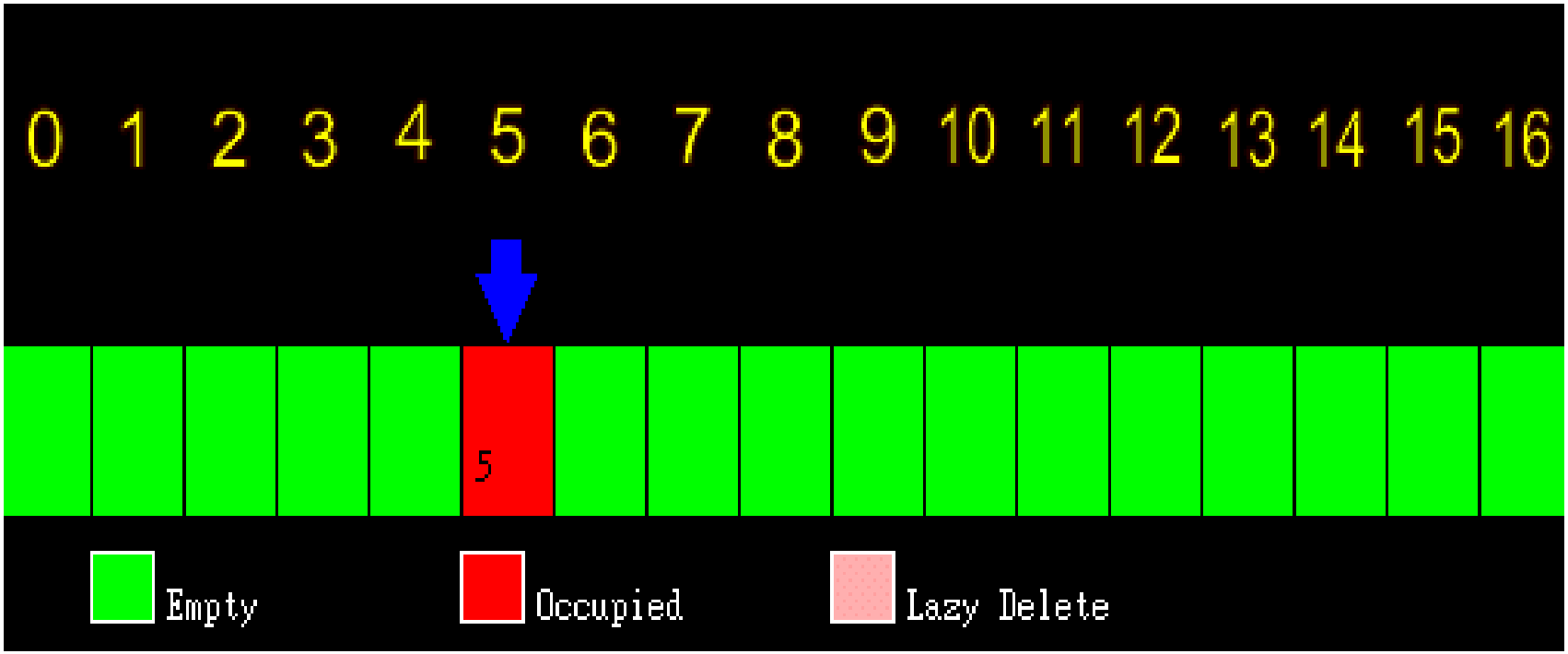
Hashing - Open addressing

- Quadratic probing example
  - Initial hash table



Hashing - Open addressing

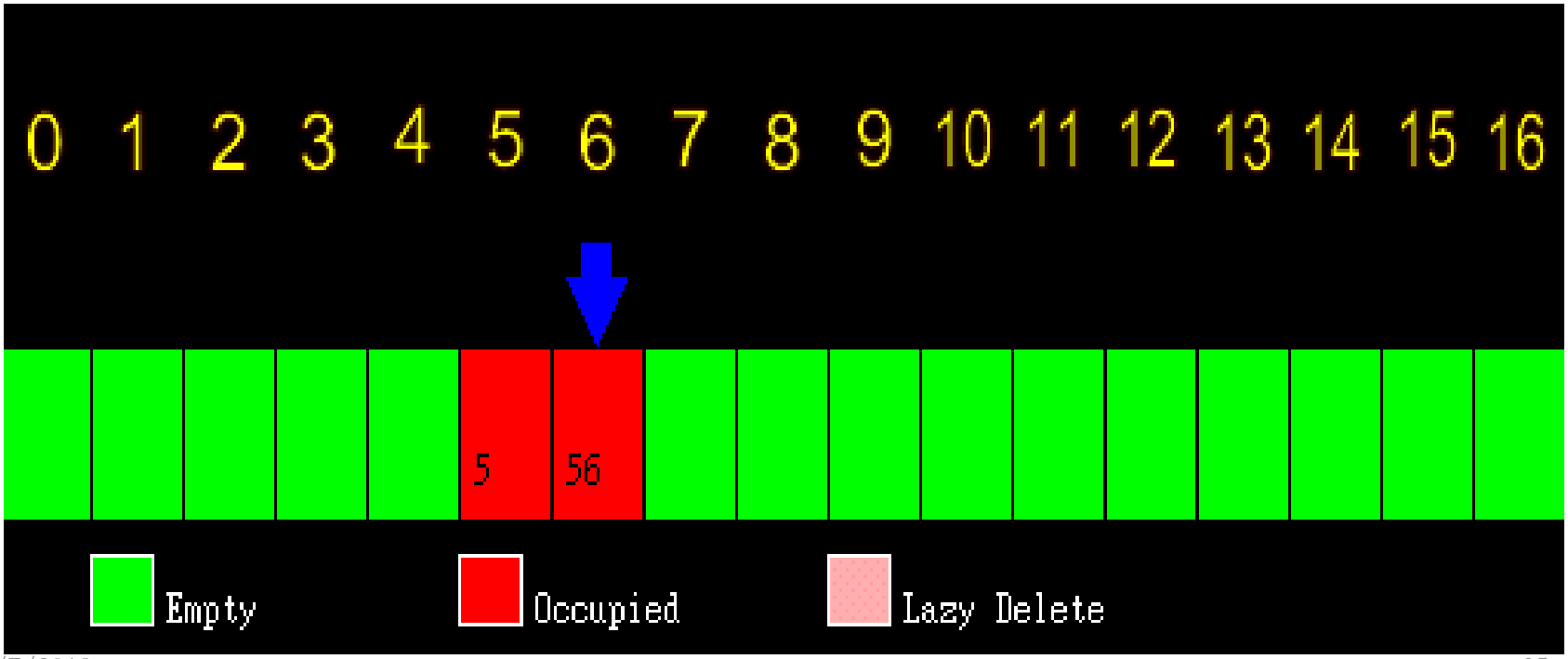
- Quadratic probing example
  - Insert 5 at $h_0(5)=(5 \bmod 17) = 5$



Hashing - Open addressing

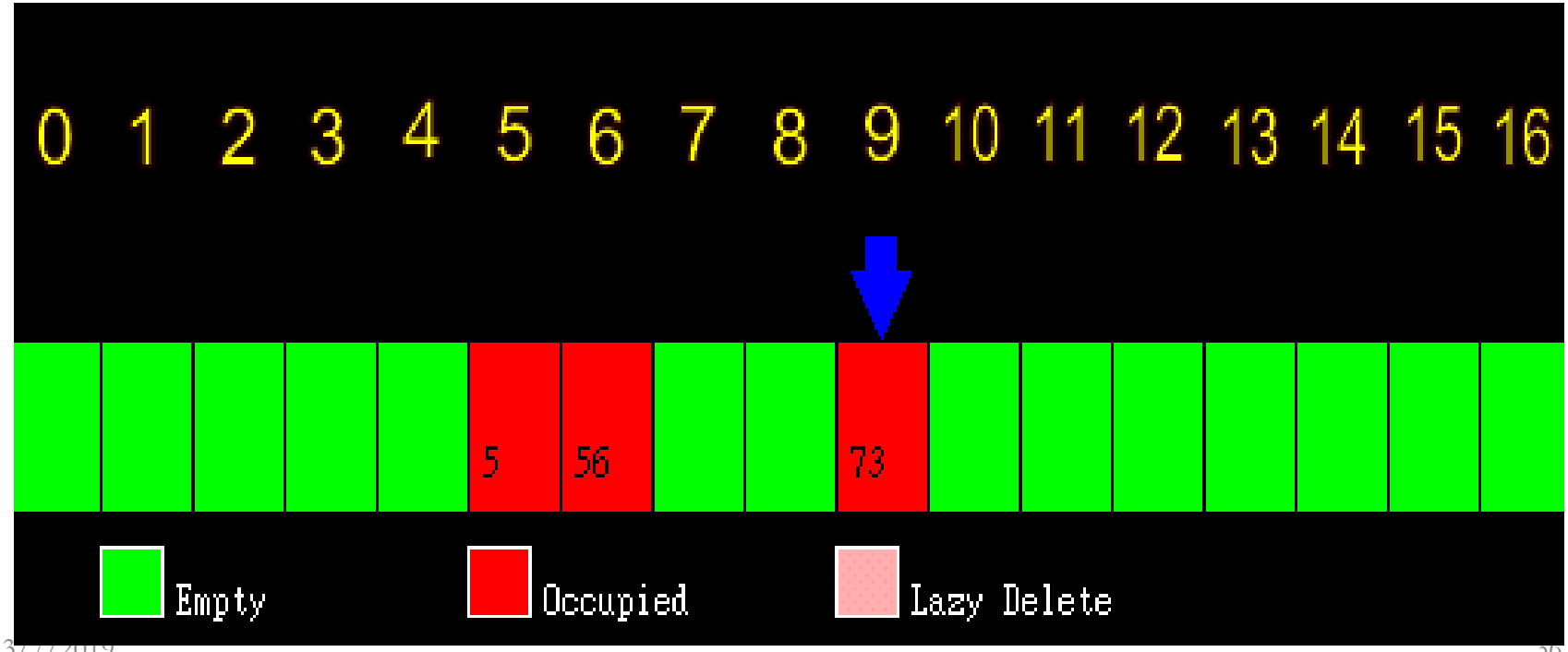
- Quadratic probing example
  - Insert 56 at $h_0(56)=(56 \bmod 17) = 5$

    $h_1(56)=((56 + 1*1) \bmod 17) = 6$



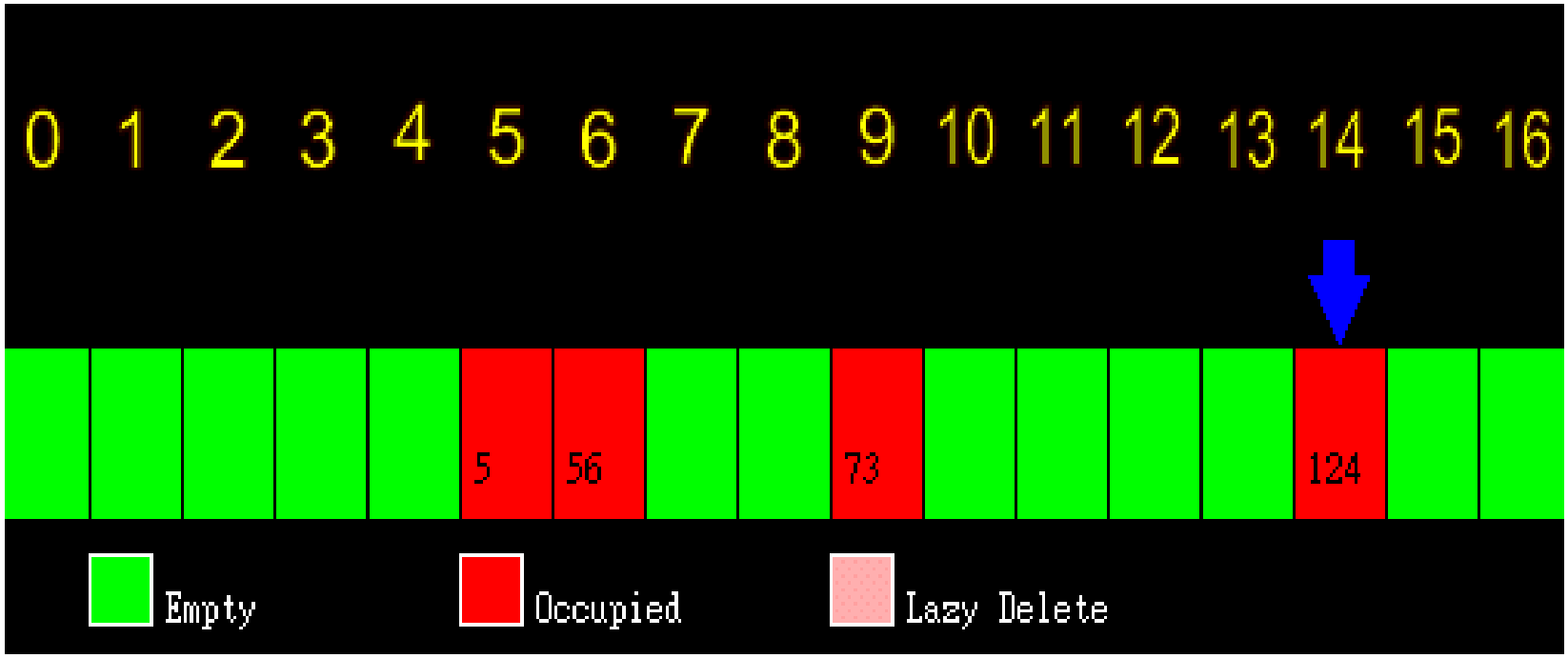
Hashing - Open addressing

- Quadratic probing example
  - Insert 73 at $h_0(56)=(73 \bmod 17) = 5$, $h_1(56)=((73 + 1*1) \bmod 17) = 6$, $h_2(56)=((73 + 2*2) \bmod 17) = 9$



Hashing - Open addressing

- Quadratic probing example
  - Insert 124 at $h_0(124)=(124 \bmod 17) = 5$, $h_1(124)=(124+1*1 \bmod 17) = 6$, $h_0(124)=(124+2*2 \bmod 17) = 9$, $h_3(124)=((124 + 3*3) \bmod 17) = 14$



Contents

- Hash function
- Collision resolutions
  - Separate Chaining (Open hashing)
  - **Open addressing (Closed Hashing)**
    - Linear probing
    - Quadratic probing
    - **Random probing**
    - Double hashing

Hashing - Open addressing

- Random probing
  - ***Randomize(X)***
    - $h_0(X)$ = Hash(X),
    - $h_1(X)$ = ($h_0(X)$ + RandomGen()) mod TableSize,
    - $h_2(X)$ = ($h_1(X)$ + RandomGen()) mod TableSize,

      ……
  - Use ***Randomize(X)*** to 'seed' the random number generator using X
  - Each call of RandomGen() will return the next random number in the random sequence for seed X

Hashing - Open addressing

- Implement random probing using random number generator in C
  - pseudo-random number generator: `rand()`
  - returns an integer between `0` and `RAND_MAX`
  - 'Seed' the randomizer
    - `srand(unsigned int);`
  - Use time as a 'seed'
    - `time(time_t *);`
    - `time(NULL);`

Random number generation in C

```
#include <stdlib.h>
#include <time.h>
int main(){
    int i;
    srand(time(NULL));
    for (i = 0; i < 10; i++){
      printf("%d\n", rand());
    }
    return 0;
}
```

1518815302
1738152472
908546763
1336715571
1352170530
1258145156
1521648530
2111575234
2077691163
1671276321

```
#include <stdlib.h>
#include <time.h>
int main(){
    int i;
    for (i = 0; i < 10; i++){
      srand(time(NULL));
      printf("%d\n", rand());
    }
    return 0;
}
```

1518395127
1518395127
1518395127
1518395127
1518395127
1518395127
1518395127
1518395127
1518395127
1518395127

Contents

- Hash function
- Collision resolutions
  - Separate Chaining (Open hashing)
  - **Open addressing (Closed Hashing)**
    - Linear probing
    - Quadratic probing
    - Random probing
    - **Double hashing**

Hashing - Open addressing

- Double hashing : $F(k) = k * Hash_2(X)$

$h_k(X) = (Hash(X) + k * Hash_2(X)) \bmod TableSize$

$h_0(X) = (Hash(X) + 0 * Hash_2(X)) \bmod TableSize,$
$h_1(X) = (Hash(X) + 1 * Hash_2(X)) \bmod TableSize,$
$h_2(X) = (Hash(X) + 2 * Hash_2(X)) \bmod TableSize, \ldots$

Review

- **Hash function**

- **Collision resolutions**
  - **Separate Chaining (Open hashing)**
  - **Open addressing (Closed Hashing)**
    - **Linear probing**
    - **Quadratic probing**
    - **Random probing**
    - **Double hashing**

Thank you !