CS-2001
DATA STRUCTURE

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HASHING

What is a database?

- Structured collection of data.

Student ID	First Name	Last Name	Email	Major	Faculty
200120	Kate	West	kwest@email.com	Music	Arts
200121	Julie	McLain	jmclain@email.com	Finance	Business
200122	Tom	Erlich	terlich@email.com	Sculpture	Arts
200123	Mark	Smith	msmith@email.com	Biology	Science
200124	Jen	Foster	jfoster@email.com	Physics	Science
200125	Matt	Knight	mknight@email.com	Finance	Business
200126	Karen	Weaver	kweaver@email.com	Music	Arts
200127	John	Smith	jsmith@email.com	Sculpture	Arts
200128	Allison	Page	apage@email.com	History	Humanities
200129	Craig	Cambell	ccambell@email.com	Music	Arts
200130	Steve	Edwards	sedwards@email.com	Biology	Science
200131	Mike	Williams	mwilliams@email.com	Linguistics	Humanities
200132	Jane	Reid	jreid@email.com	Music	Arts

The Dictionary ADT

- A dictionary (table) is an abstract model of a database
- A dictionary stores key-element pairs
- The main operation supported by a dictionary is searching by key

Dictionary

- Collection of pairs.
  - (key, value)
  - Each pair has a unique key.
- Operations.
  - Get(theKey)
  - Delete(theKey)
  - Insert(theKey, theValue)

Implementing a Dictionary

- ***Unordered sequence***
  - searching and removing takes O(n) linear time
  - inserting takes O(1) constant time
  - applications to log files (*frequent insertions*, *rare searches, and removals*)
  - **For Example:** 34 14 12 22 18

Implementing a Dictionary

- ***Array-based ordered sequence***

  (assume keys can be ordered)

  - searching takes O(log n) time ***(binary search)***
  - inserting and removing takes O(n) time
  - application to lookup tables

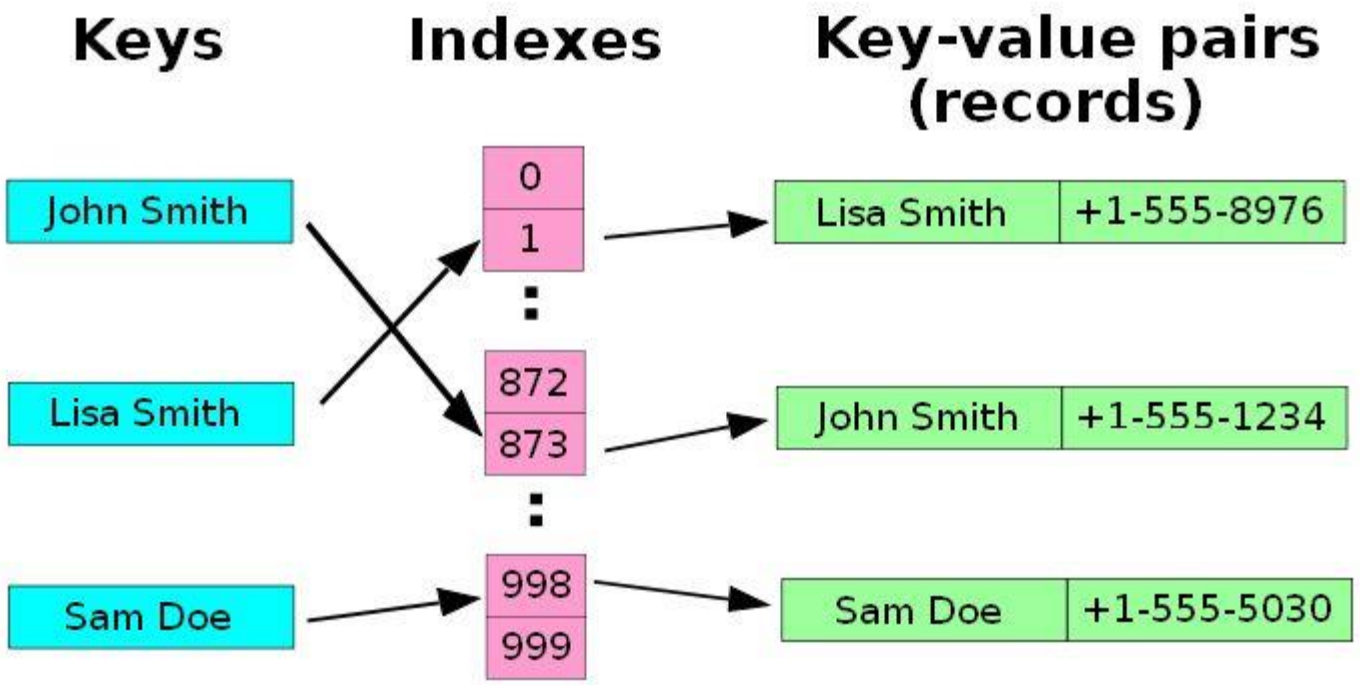
  (frequent searches, rare insertions, and removals)

- **For Example:** 34 14 12 22 18

Concept of Hashing

- A **hash table**, or a **hash map**, is a data structure that associates keys (names) with values (attributes).
  - Look-Up Table
  - Dictionary
  - Cache
  - Extended Array

Example



A small phone book as a hash table.

(Figure is from Wikipedia)

Hash Table

- **Hash table:**
  - Collection of pairs,
  - Lookup function (Hash function)
- Hash tables are often used to implement associative arrays,
  - Worst-case time for Get, Insert, and Delete is O(size).
  - Expected time is O(1).

Origins of the Term

- The term "hash" comes by way of analogy with its standard meaning in the physical world, to "chop and mix." **D. Knuth** notes that **Hans Peter Luhn** of IBM appears to have been the first to use the concept, in a memo dated January 1953; the term hash came into use some ten years later.

Applications

- Keeping track of customer account information at a bank
  - Search through records to check balances and perform transactions
- Keep track of reservations on flights
  - Search to find empty seats, cancel/modify reservations
- Search engine
  - Looks for all documents containing a given word

Search vs. Hashing

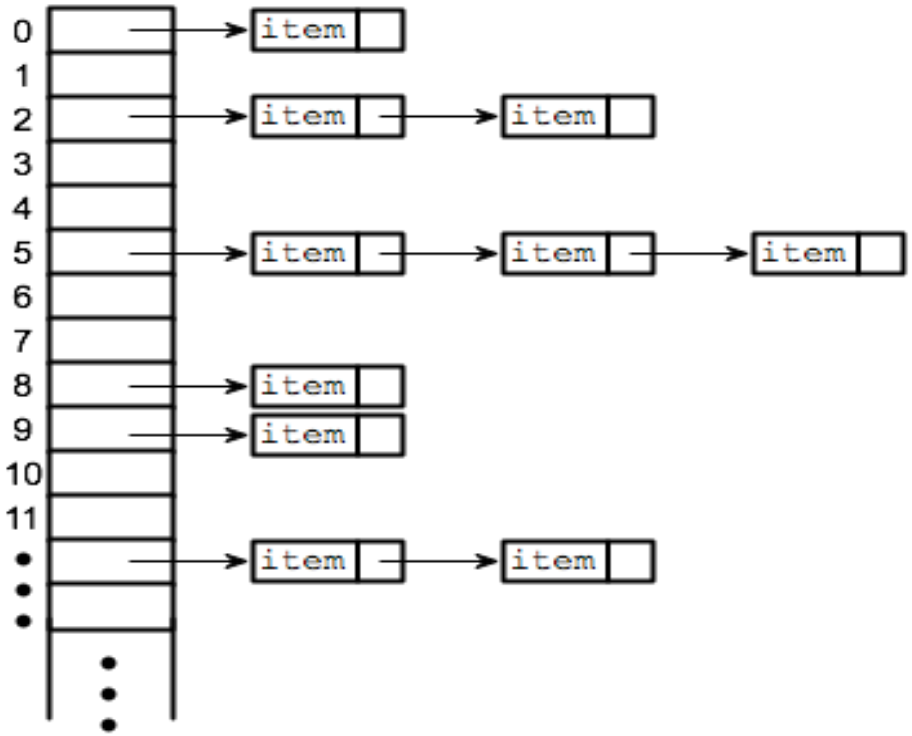
- Search tree methods: key comparisons
  - Time complexity: O(size) or O(log n)
- Hashing methods: hash functions
  - Expected time: O(1)
- Types
  - Static hashing
  - Dynamic hashing

Static Hashing

- Key-value pairs are stored in a fixed size table called a *hash table*.
  - A hash table is partitioned into many ***buckets***.
  - Each bucket has many ***slots***.
  - Each slot holds one record.
- A **hash function $f(x)$** transforms the identifier (key) into an address in the hash table.

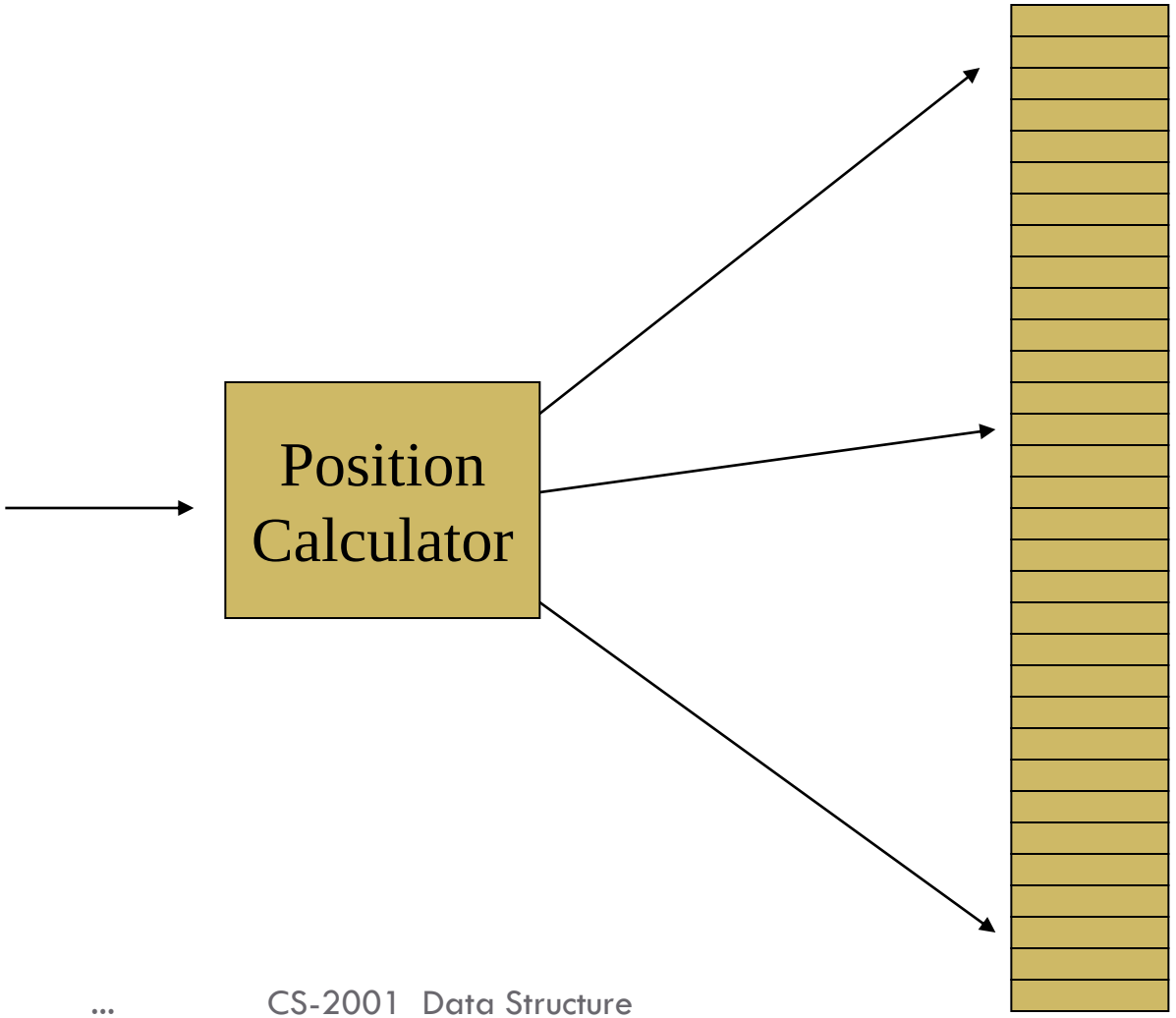
Hash Table

- Tables that can be searched for an item in **O(1)** time using a hash function to form an address from the key.



Hashing Engine

- itemKey



Hashing – A Simple Scenario

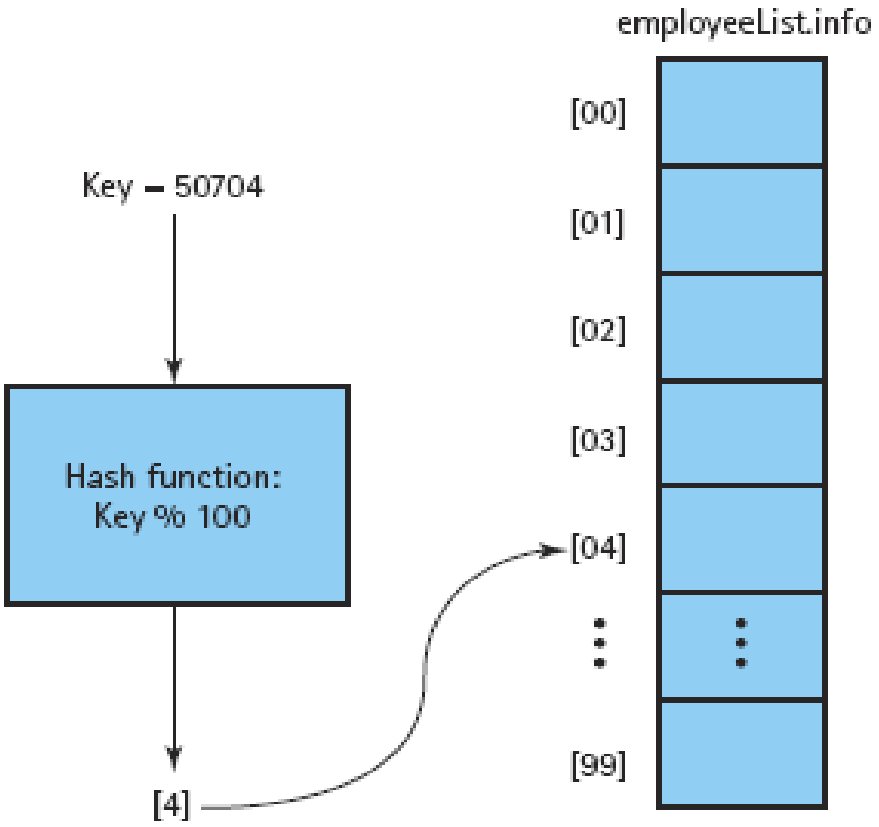
- A list of employees of a fairly small company.
- Each of the 100 employees has an ID number in the range 0 to 99,
- We have to access the employee records using the key *idNum*.

Hashing- A complicated Scenario

- A similar small company that uses its employees five-digit ID number as the primary key,
- Number of employees are still 100.
- Use a hash function to determine the exact location, e.g.,

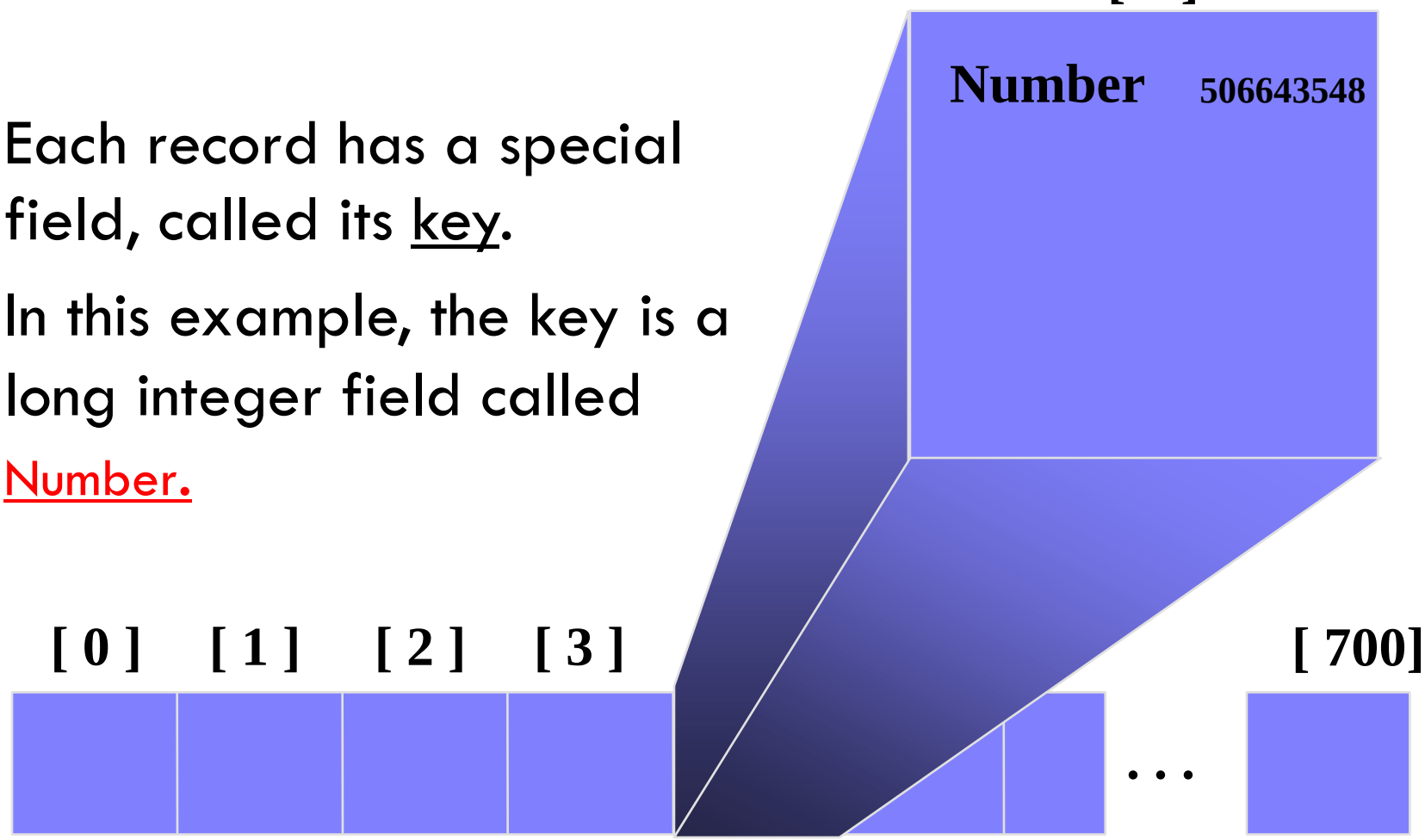
```
Hash(){
return (idNum % MAX_ITEMS);
}
```

Hashing- A complicated Scenario



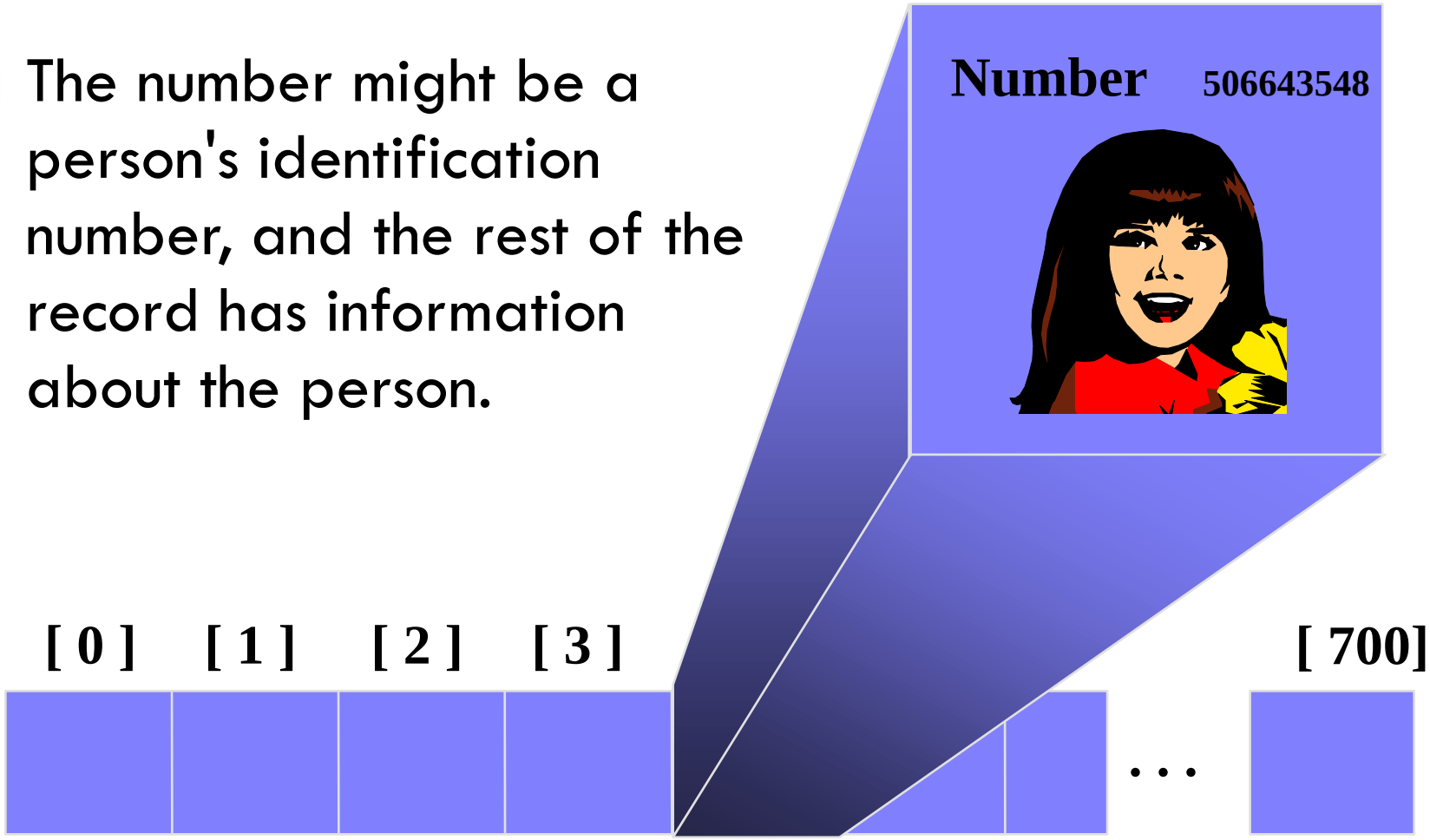
What is a Hash Table ?

- Each record has a special field, called its key.
- In this example, the key is a long integer field called Number.



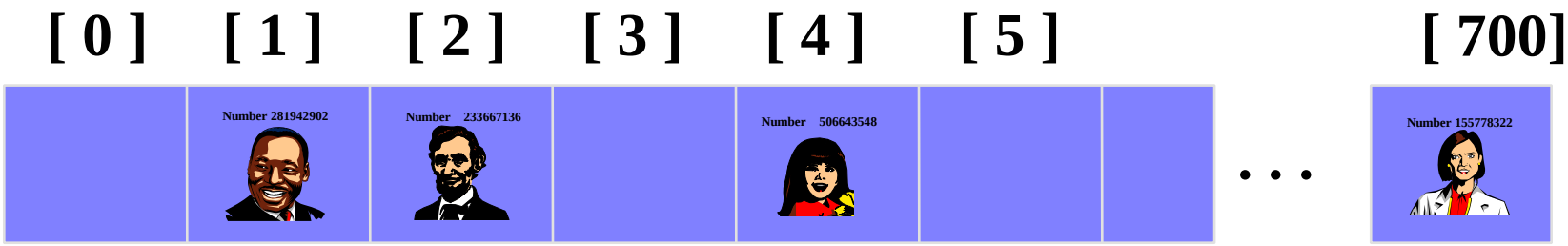
What is a Hash Table ?

- The number might be a person's identification number, and the rest of the record has information about the person.



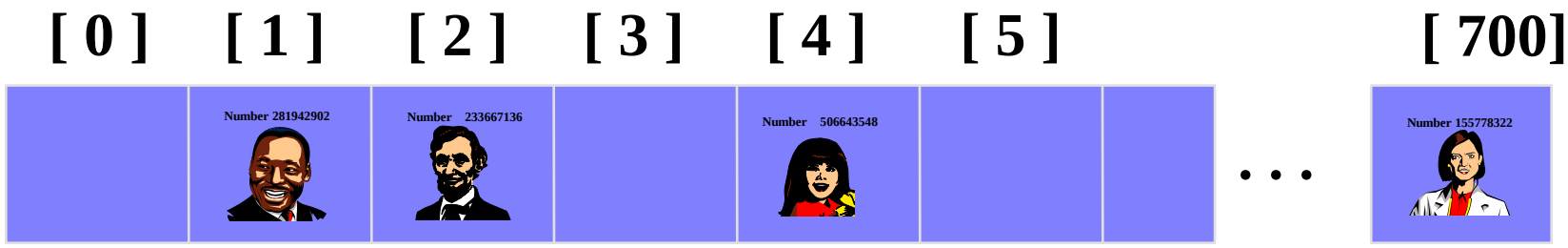
What is a Hash Table ?

- When a hash table is in use, some spots contain valid records, and other spots are "empty".



Inserting a New Record

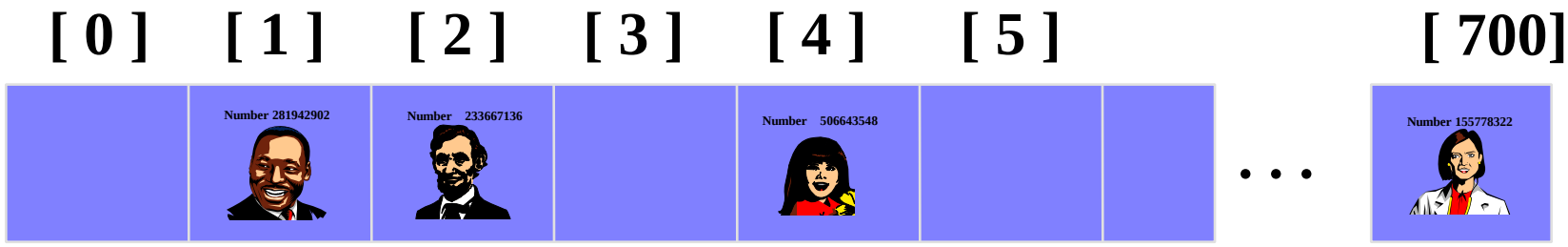
- In order to insert a new record, the **key** must somehow be **converted to** an array **index**.
- The index is called the **hash value** of the key.



Inserting a New Record

- **Typical way to create a hash value:**

What is (580625685 mod 701) ?



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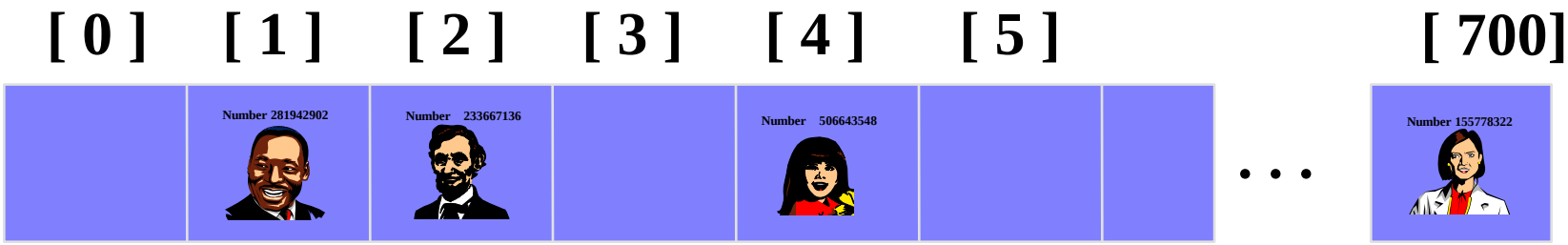
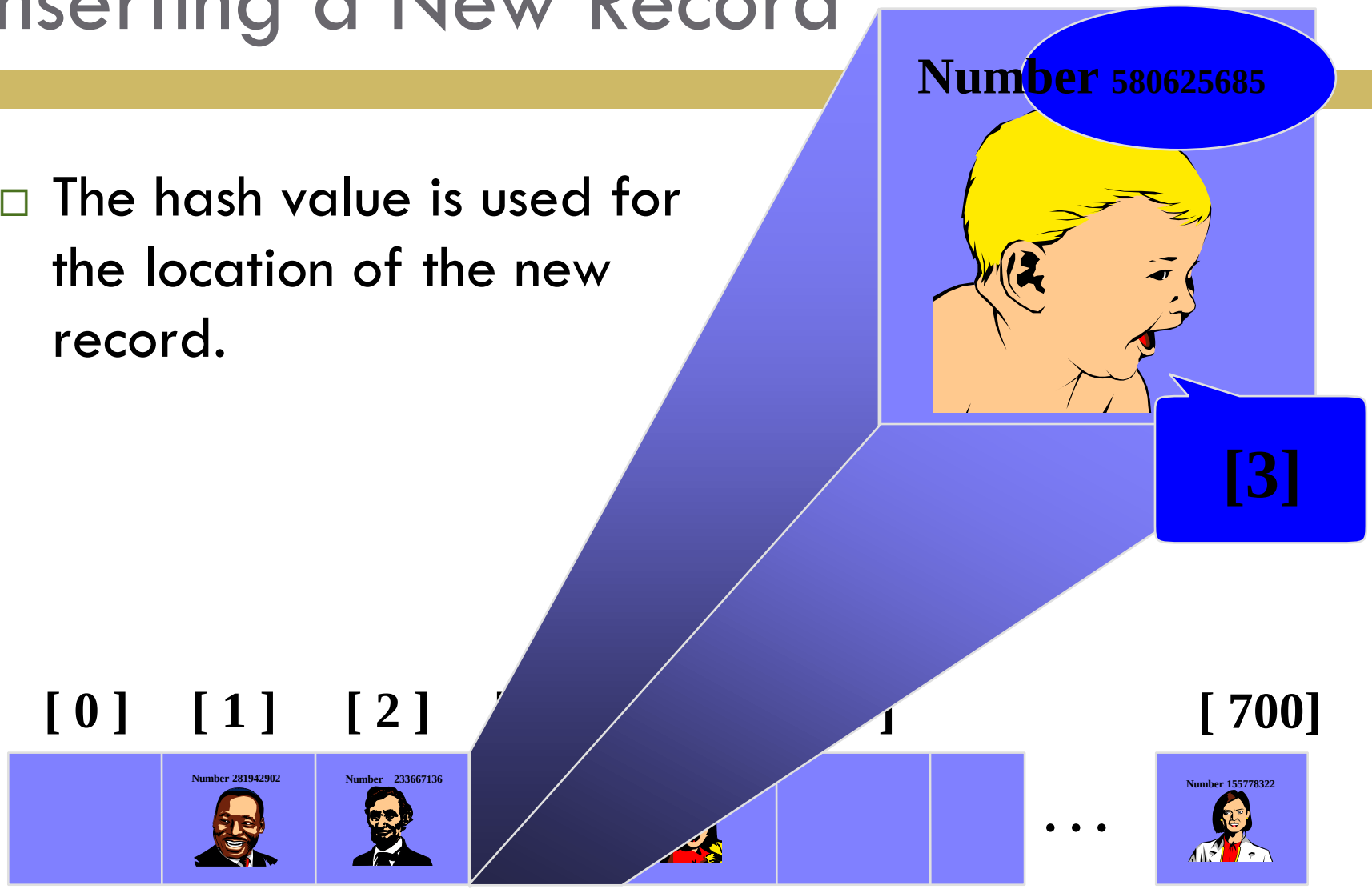


Inserting a New Record

- The hash value is used for the location of the new record.



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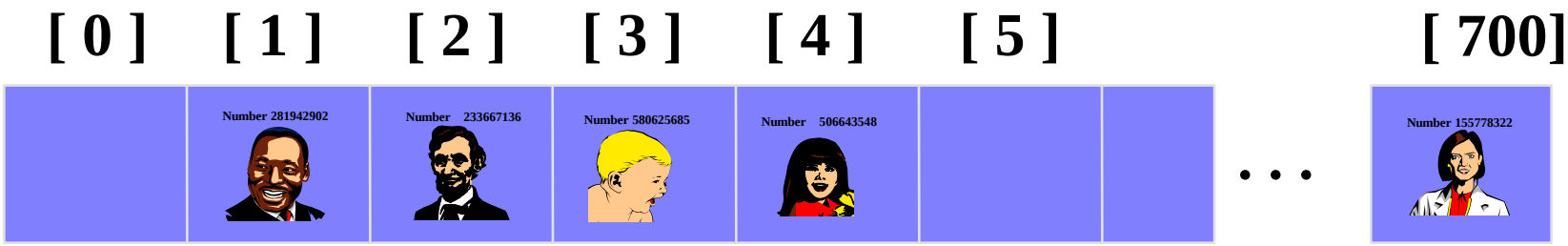
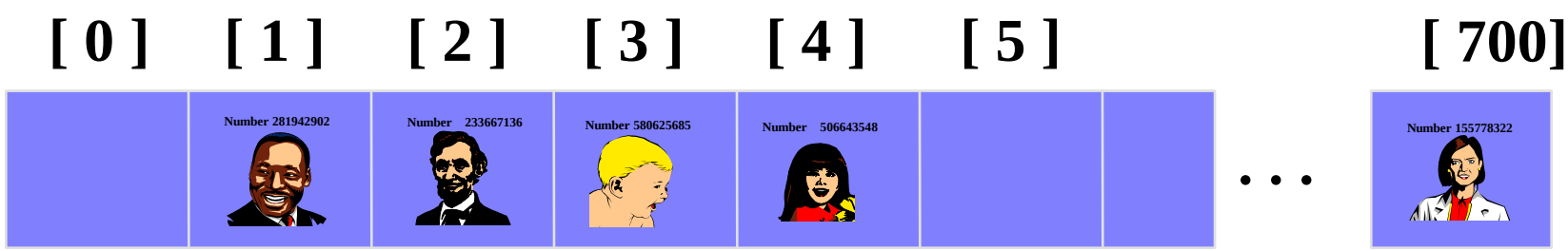


Collisions

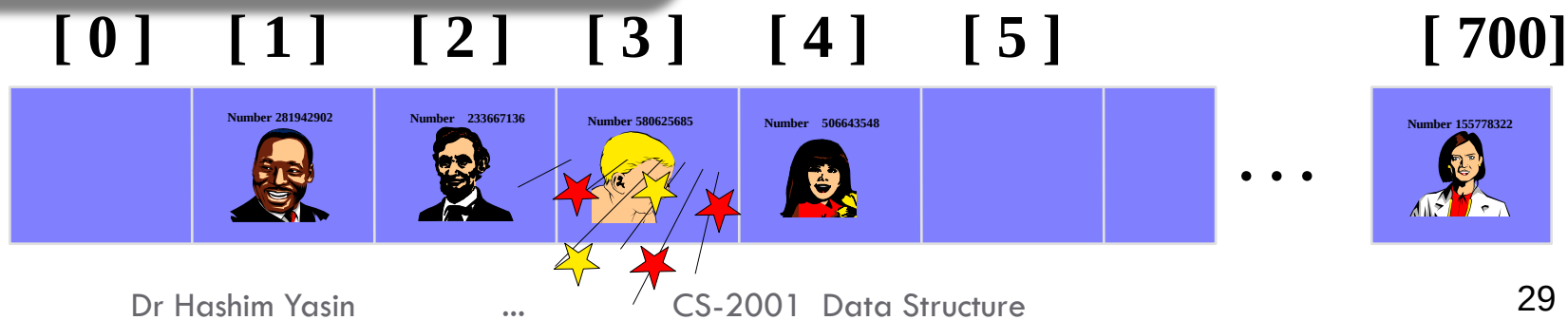
- Here is another new record to insert, with a hash value of 2.



Collisions

- This is called a **collision**, because there is already another valid record at [2].

When a collision occurs, move forward until you find an empty spot.



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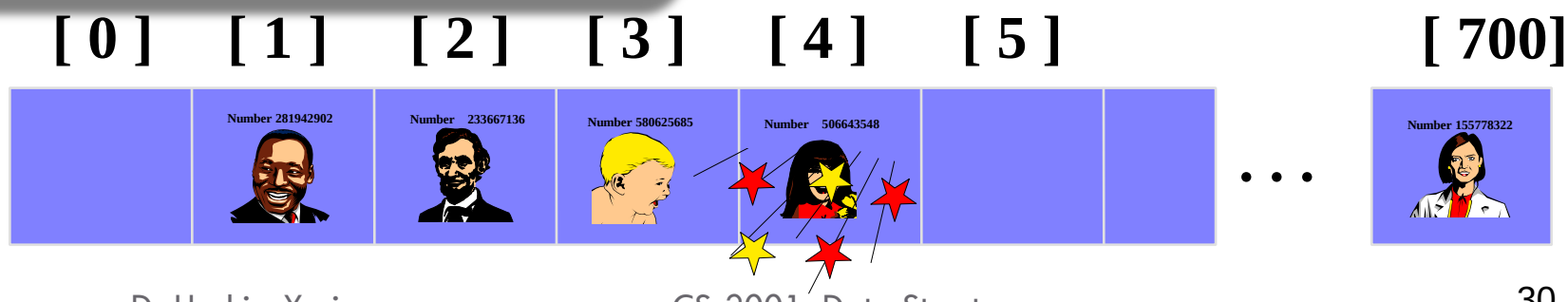

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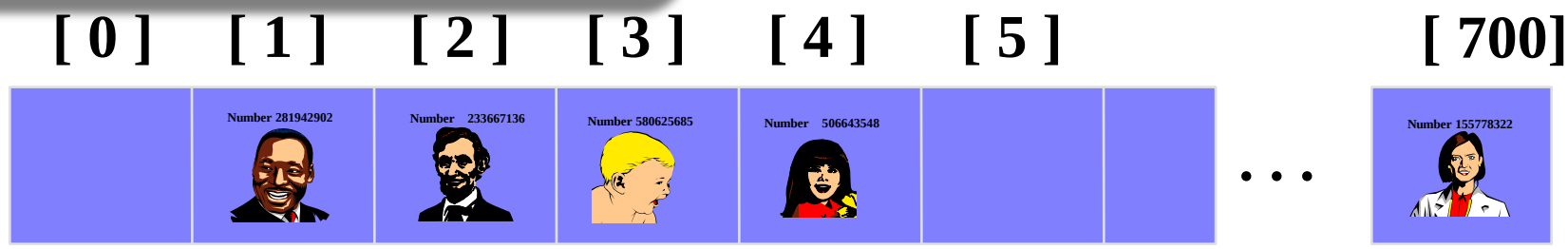

Collisions

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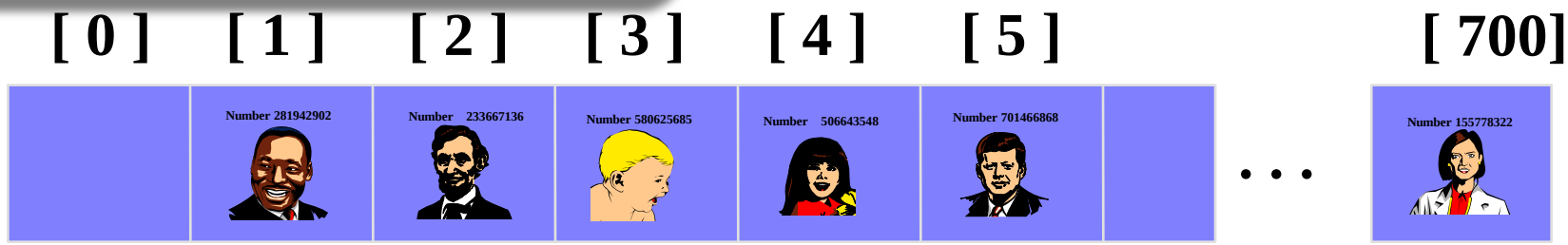
The new record goes in the empty spot.



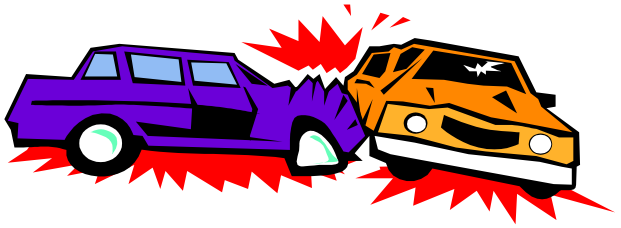
Some Issues

- **Choice of hash function.**
  - ***Really tricky!***
  - To avoid collision (two different pairs are in the same bucket.)
  - Size (number of buckets) of hash table.
- **Overflow handling method.**
  - Overflow: there is no space in the bucket for the new pair.

Choice of Hash Function

- Requirements
  - easy to compute
  - minimal number of collisions
- If a hashing function groups key values together, this is called clustering of the keys.
- A good hashing function distributes the key values uniformly throughout the range.

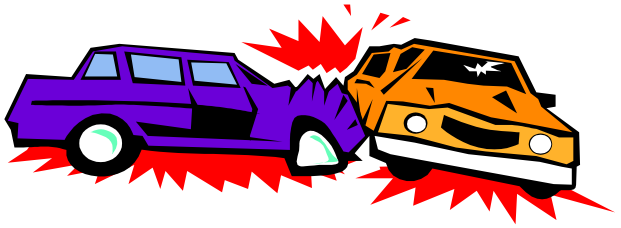
Collision



- The condition resulting when two or more keys produce the same hash location.

- A good hash function minimizes collisions by spreading the elements uniformly throughout the array.

Collision



- Collision handling techniques
  - Linear Probing
  - Rehashing
  - Double Hashing
  - Quadratic Probing
  - Random Probing
  - Buckets
  - Chaining

Collision Resolution Techniques

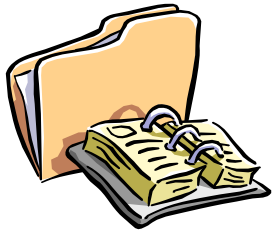
- There are two broad ways of collision resolution:

1. Open Addressing: Array-based implementation.

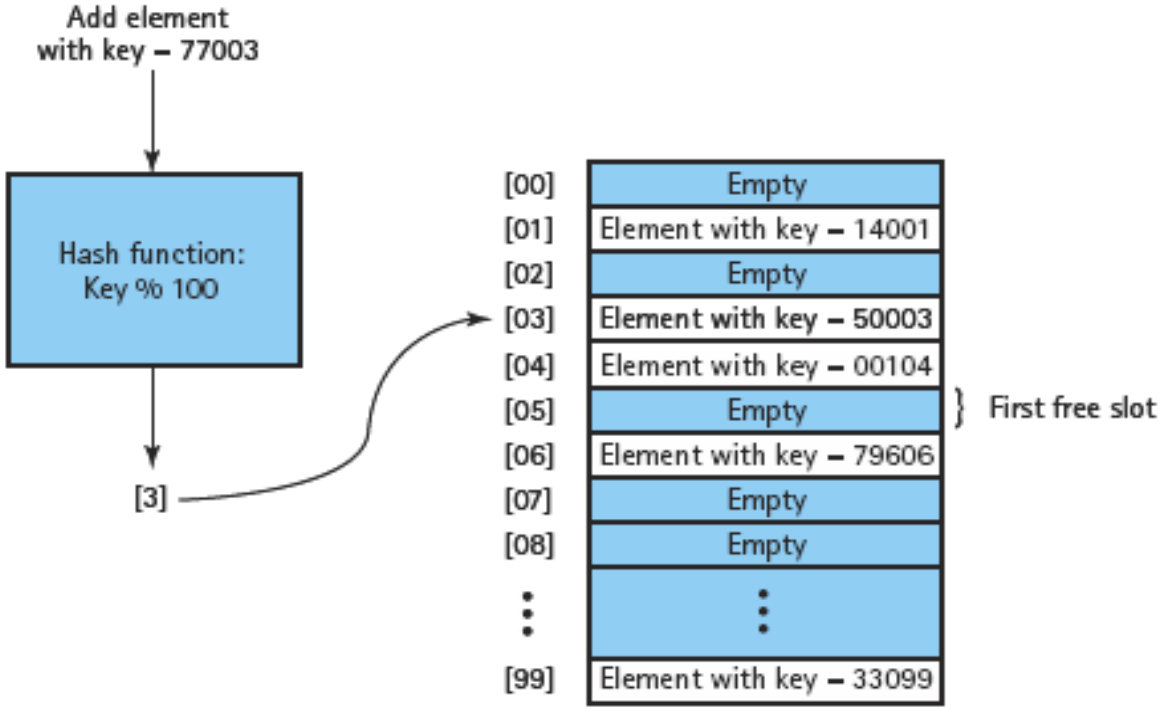
   (i) Linear probing (linear search)
   (ii) Quadratic probing (nonlinear search)
   (iii) Double hashing (uses two hash functions)

2. Separate Chaining: A linked list implementation

Linear Probing



- *Resolving a hash collision by sequentially searching* a hash table beginning at the location return by the hash function.



Linear Probing - Problem

- What happens if the key hashes to the last index in the array and that space is in use?

- Solution
  - We can consider the array to be a circular structure and continue looking for an empty slot at the beginning of the array

Linear Probing - Searching

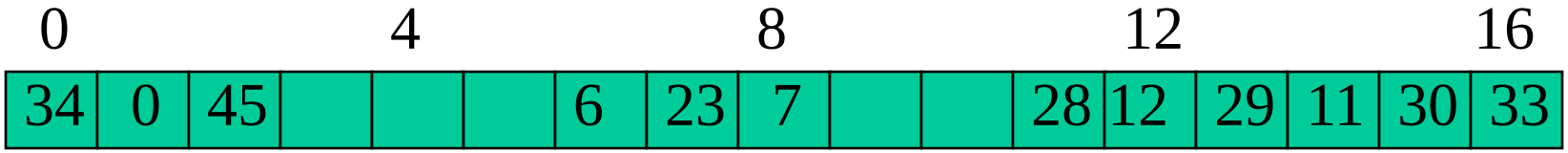
To search for an element using Linear probing

- Perform the hash function on the key
- Compare the desired key to the actual key in the element at the designated location
- If the keys do not match use linear probing beginning at the next slot in array
- If key is found return true
- If not found return false

Linear Probing - Example

- divisor = b (number of buckets) = 17.
- Home bucket = key % 17.

- Insert pairs whose keys are 6, 12, 34, 29, 28, 11, 23, 7, 0, 33, 30, 45



Linear Probing - Example

- h(k) = *k* mod 13
- Insert keys:
  - 18 41 22 44 59 32 31 73

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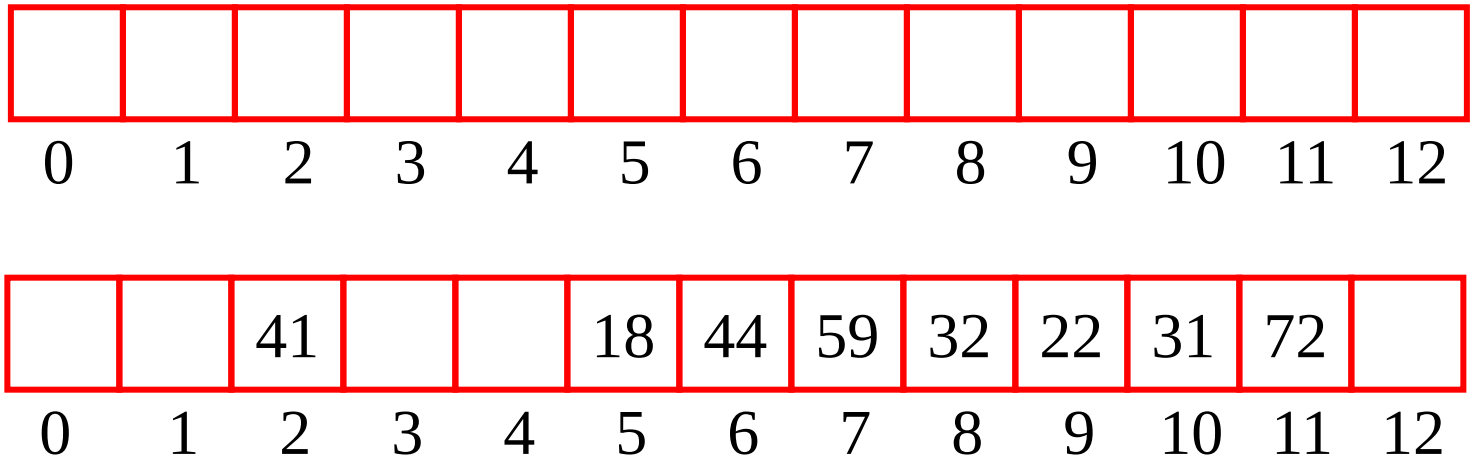


Linear Probing - Deletion

To delete an element using Linear probing

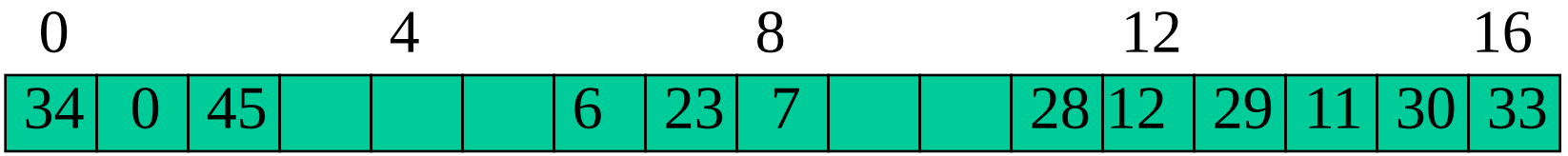
- Find the element with same search approach
- Replace the element with a constant to identify the place was previously occupied
- It will help pre-mature termination of the loop for searching.

Linear Probing - Deletion

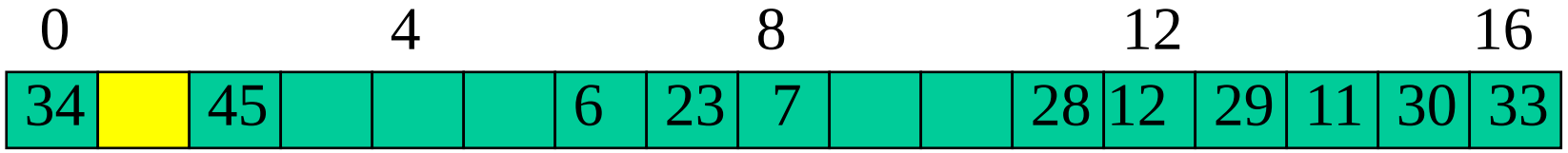
- What if there are many deletions?
  - Reduced searching efficiency

- Conclusion
  - Hash Tables are not efficient where there are many deletions

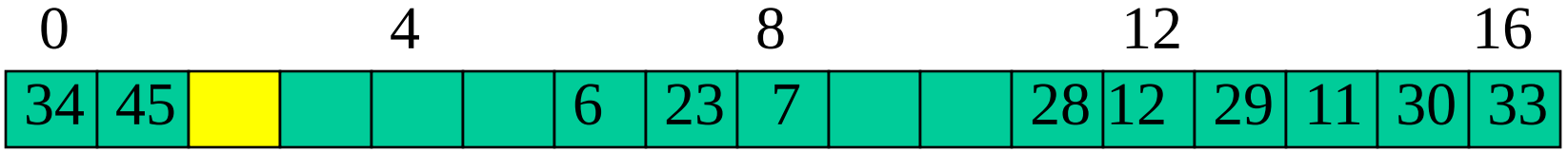
Linear Probing - Deletion



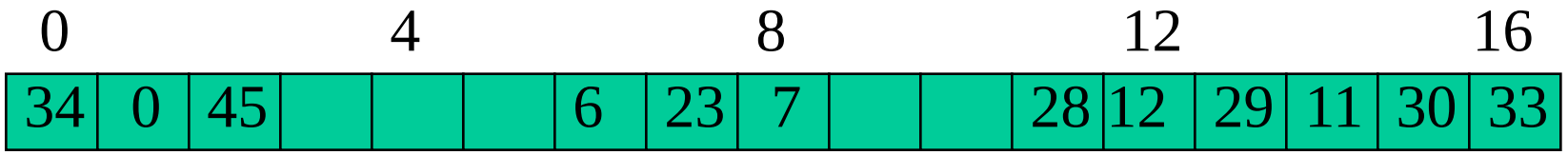
- **Delete(0)**



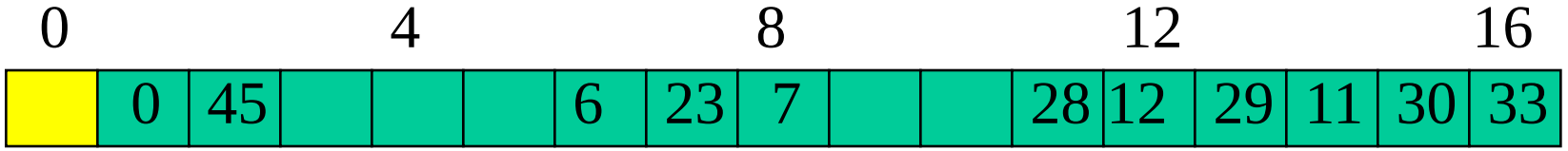
- Search cluster for pair (if any) to fill the vacated bucket.



Linear Probing - Deletion



- **Delete(34)**



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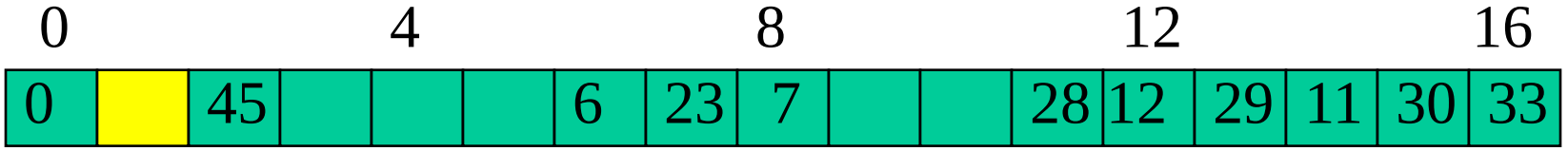

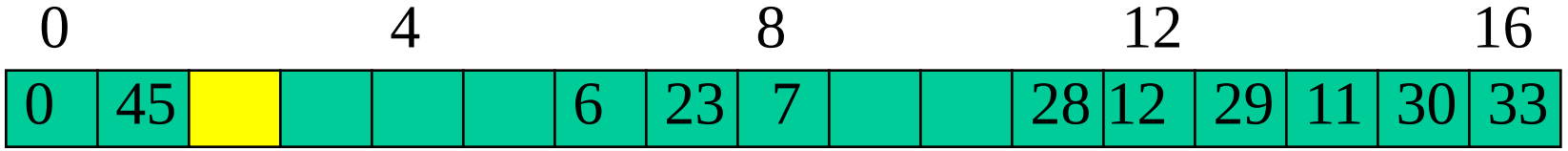

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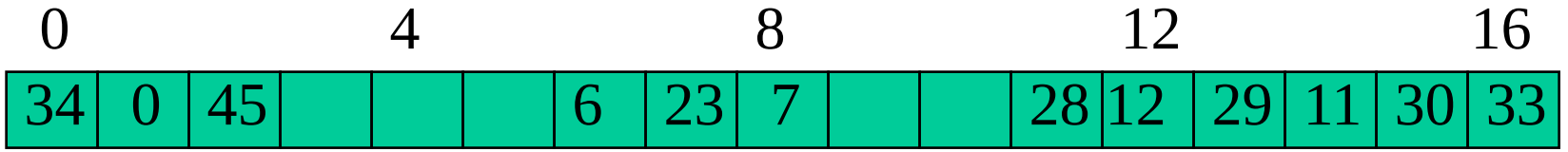
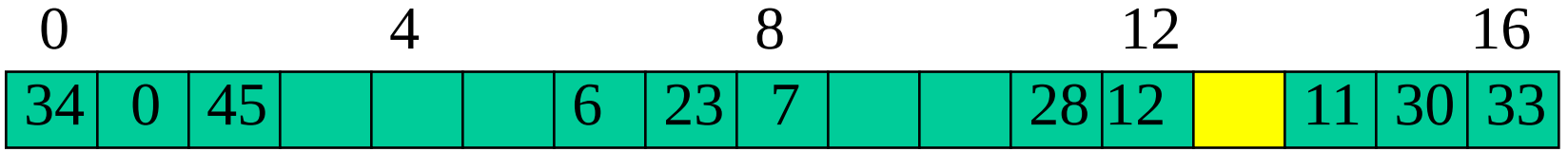


- **Delete(29)**



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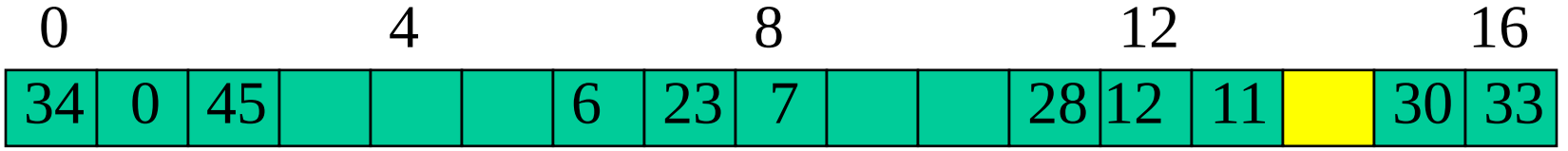

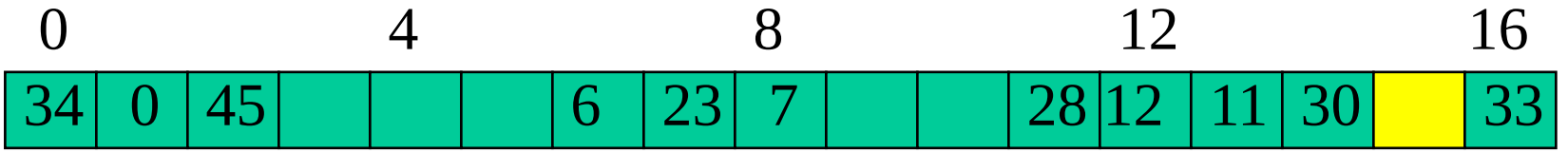

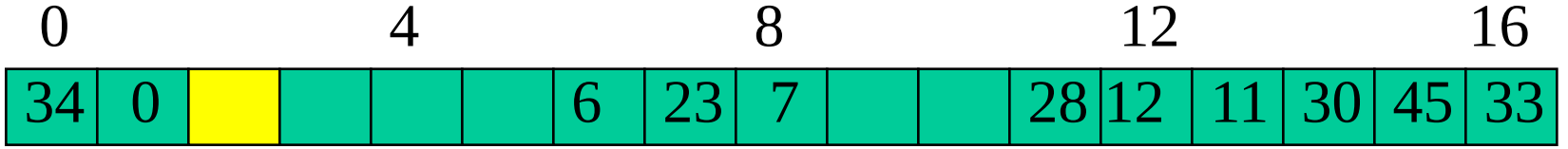

Implementation of Linear Probing

- **Search operation** for locating index:

```
private int findIndex(long key) {
 // return -1 if the item with key 'key' was not found
 int index = h(key);
   int probe = index;
   int k = 1; // probe number
   do {
     if (table[probe]==null) {
       // probe sequence has ended
       break;
     }
     if (table[probe].getKey()==key)
       return probe;
     probe = (index + step(k)) % table.length; // check next slot
     k++;
   } while (probe!=index);
   return -1; // not found
 }
```

Implementation of Linear Probing

- **Find and Deleting the item:**

```
public T find(long key)  {
   int index = findIndex(key);
   if (index>=0)
     return (T) table[index];
   else
     return null; // not found
 }

 public T delete(long key)  {
   int index = findIndex(key);
   if (index>=0) {
     T item = (T) table[index];
     table[index] = AVAILABLE; // mark available
     return item;
   } else
     return null; // not found
 }
```

References

- Nell Dale – Chapter 10.
- http://www.cplusplus.com/doc/tutorial/templates/
- Robert Lafore, Chapter 14, Page 681