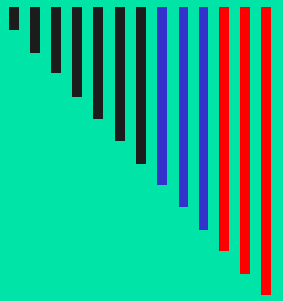


Chapter 13

Searching

Objectives

Upon completion you will be able to:

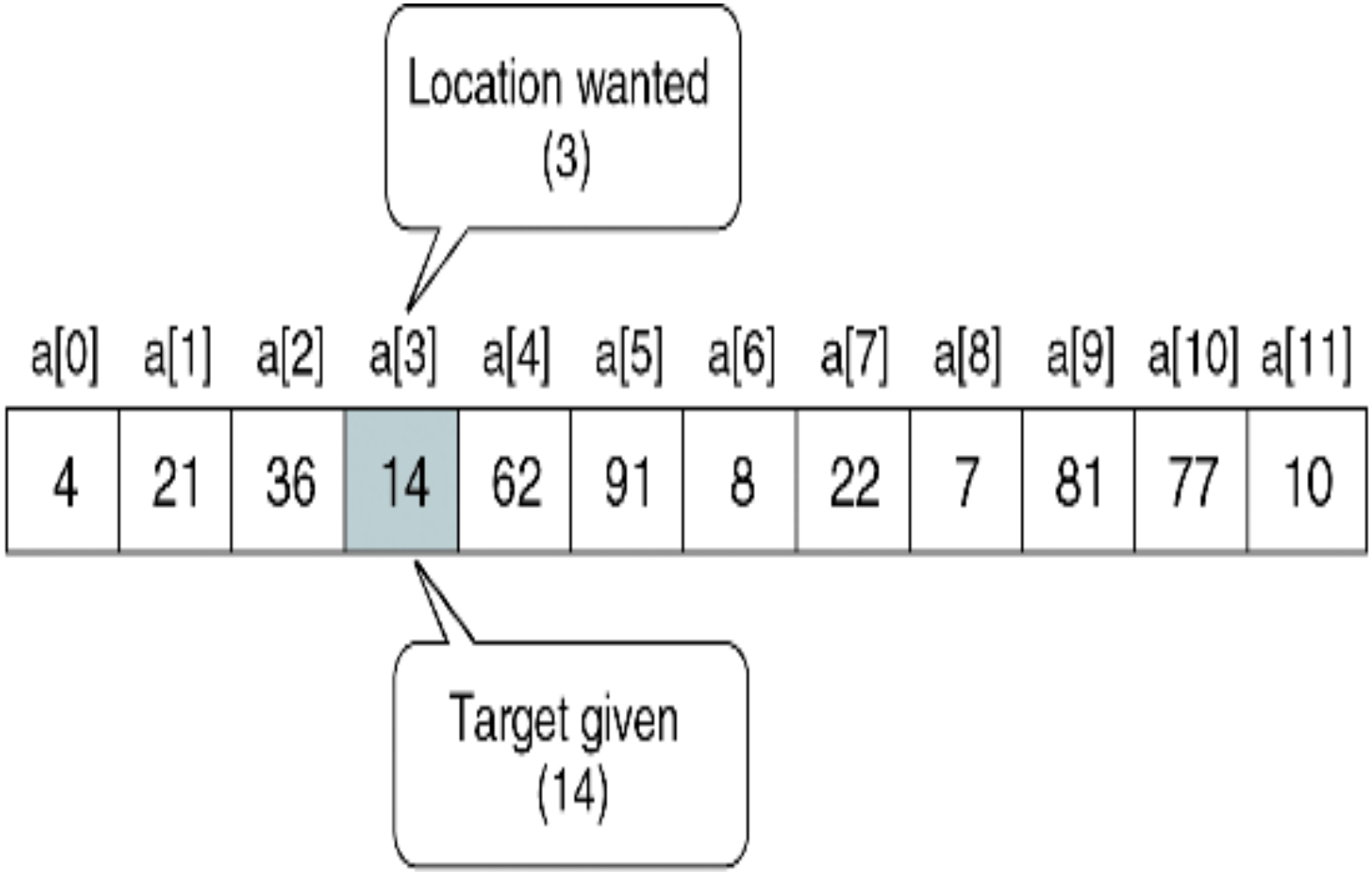
- **Design and implement sequential searches**
- **Discuss the relative merits of different sequential searches**
- **Design and implement binary searches**
- **Design and implement hash-list searches**
- **Discuss the merits of different collision resolution algorithms**

13-1 List Searches

In this section we study searches that work with arrays. The two basic searches for arrays are the sequential search and the binary search.

- **Sequential Search**
- **Variations on Sequential Searches**
- **Binary Search**
- **Analyzing Search Algorithms**

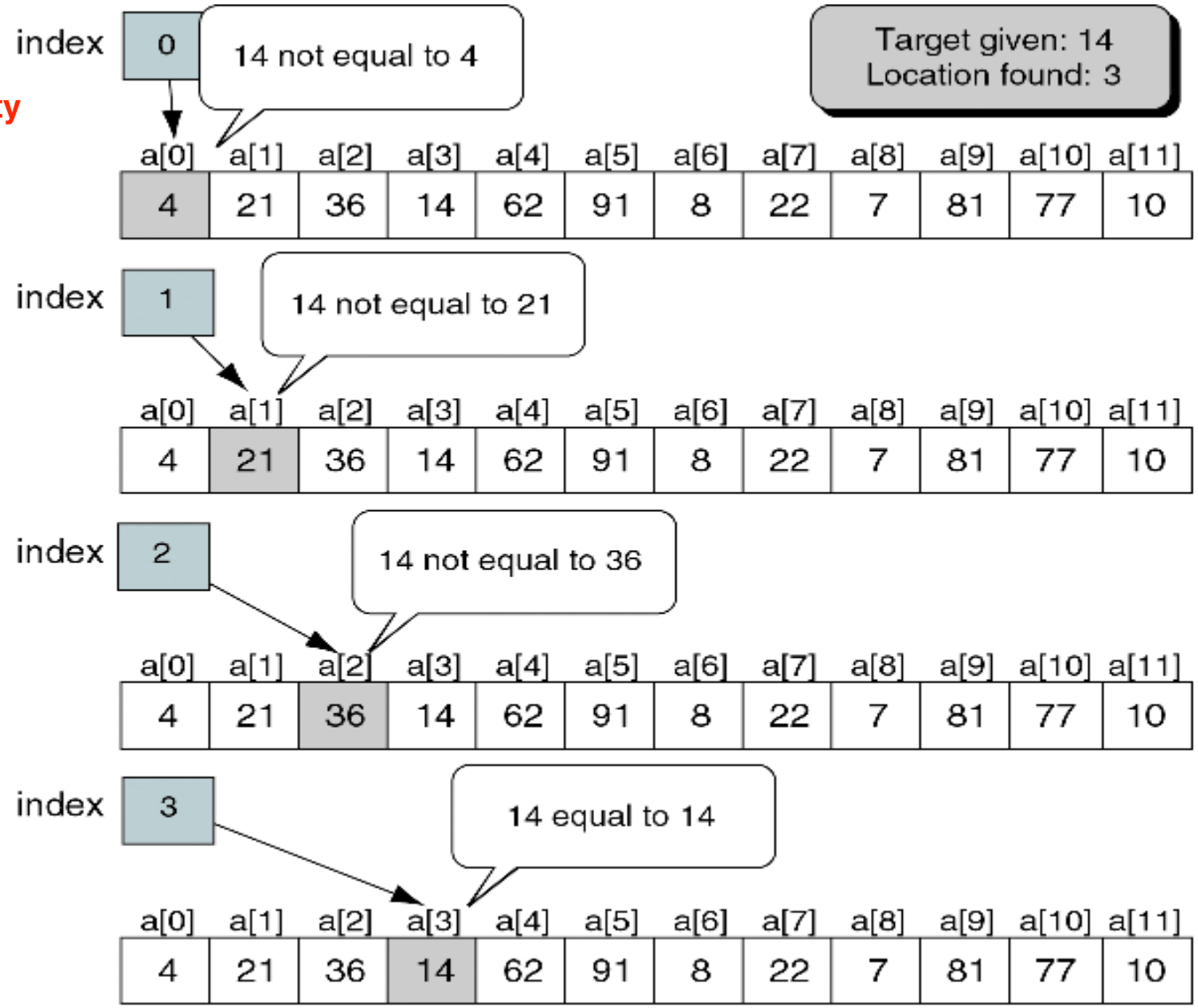
Search Concept



Successful Search of Unordered List

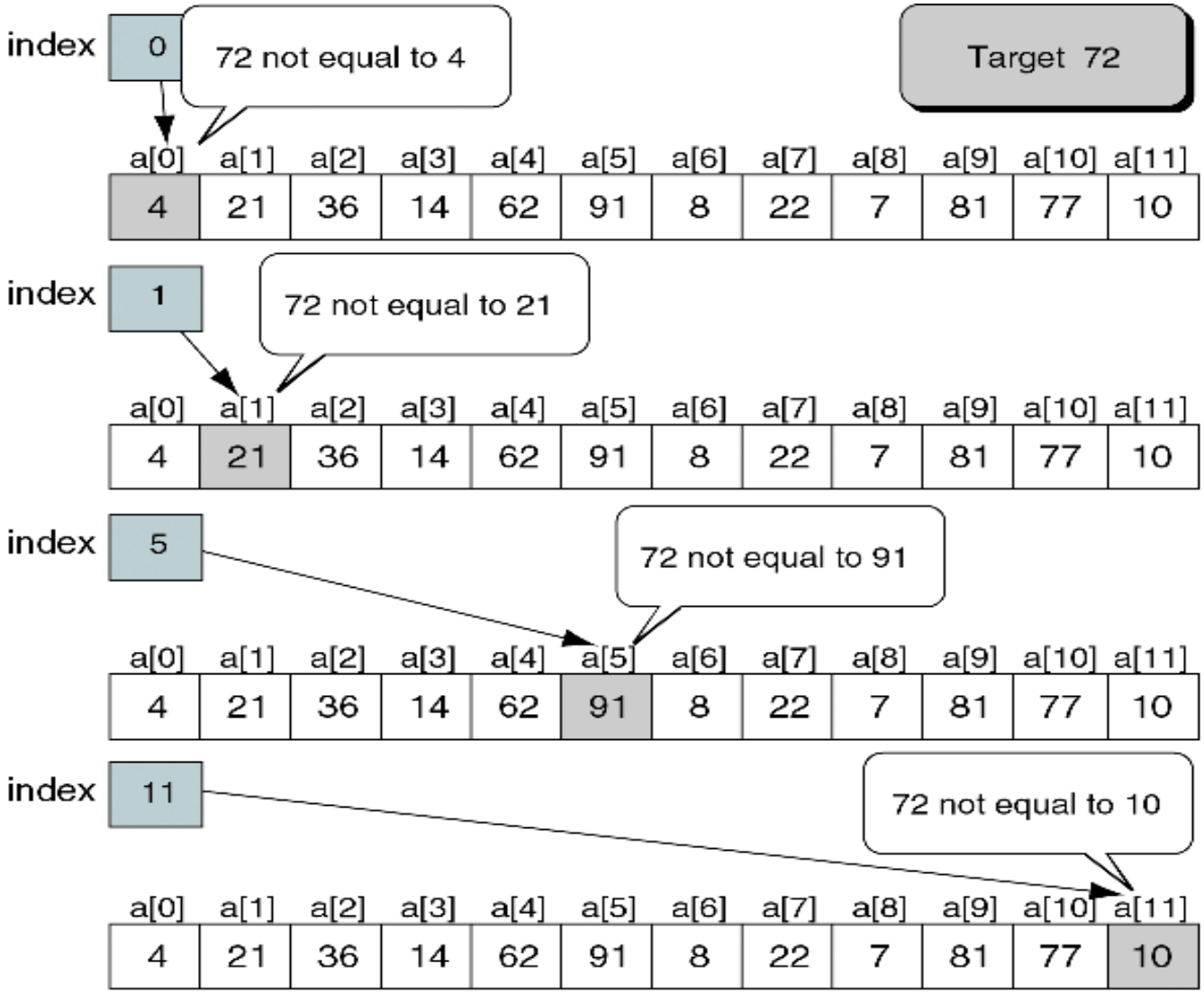
Time complexity

O(n/2) = O(n)



Unsuccessful Search of Unordered List

Worst case



Note: Not all test points are shown.

Sequential Search

```
Algorithm seqSearch (list, last, target, locn)
Locate the target in an unordered list of elements.
   Pre    list must contain at least one element
          last is index to last element in the list
          target contains the data to be located
          locn is address of index in calling algorithm
   Post   if found: index stored in locn & found true
          if not found: last stored in locn & found false
   Return found true or false
 1 set looker to 0
 2 loop (looker < last AND target not equal list[looker])
   1   increment looker
 3 end loop
 4 set locn to looker
 5 if (target equal list[looker])
   1   set found to true
 6 else
   1   set found to false
 7 end if
 8 return found
end seqSearch
```

Variation 1: Sentinel Search

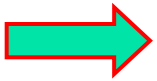
```
Algorithm SentinelSearch (list, last, target, locn)
Locate the target in an unordered list of elements.
   Pre    list must contain element at the end for sentinel
          last is index to last data element in the list
          target contains the data to be located
          locn is address of index in calling algorithm
   Post   if found--matching index stored in locn & found
             set true
          if not found--last stored in locn & found false
   Return found true or false
1  set list[last + 1] to target
2  set looker to 0
3  loop (target not equal list[looker])
   1   increment looker
4  end loop
5  if (looker <= last)
   1   set found to true
   2   set locn  to looker
6  else
   1   set found to false
   2   set locn  to last
7  end if
8  return found
end SentinelSearch
```

Variation 2: Probability Search

```
Algorithm ProbabilitySearch (list, last, target, locn)
Locate the target in a list ordered by the probability of each
element being the target--most probable first, least probable
last.
   Pre    list must contain at least one element
          last is index to last element in the list
          target contains the data to be located
          locn is address of index in calling algorithm
   Post   if found--matching index stored in locn,
             found true, and element moved up in priority.
          if not found--last stored in locn & found false
   Return found true or false
1  find target in list
2  if (target in list)
   1   set found to true
   2   set locn to index of element containing target
   3   if (target after first element)
       1  move element containing target up one location
   4   end if
3  else
   1   set found to false
4  end if
5  return found
end ProbabilitySearch
```

Ordered List Search

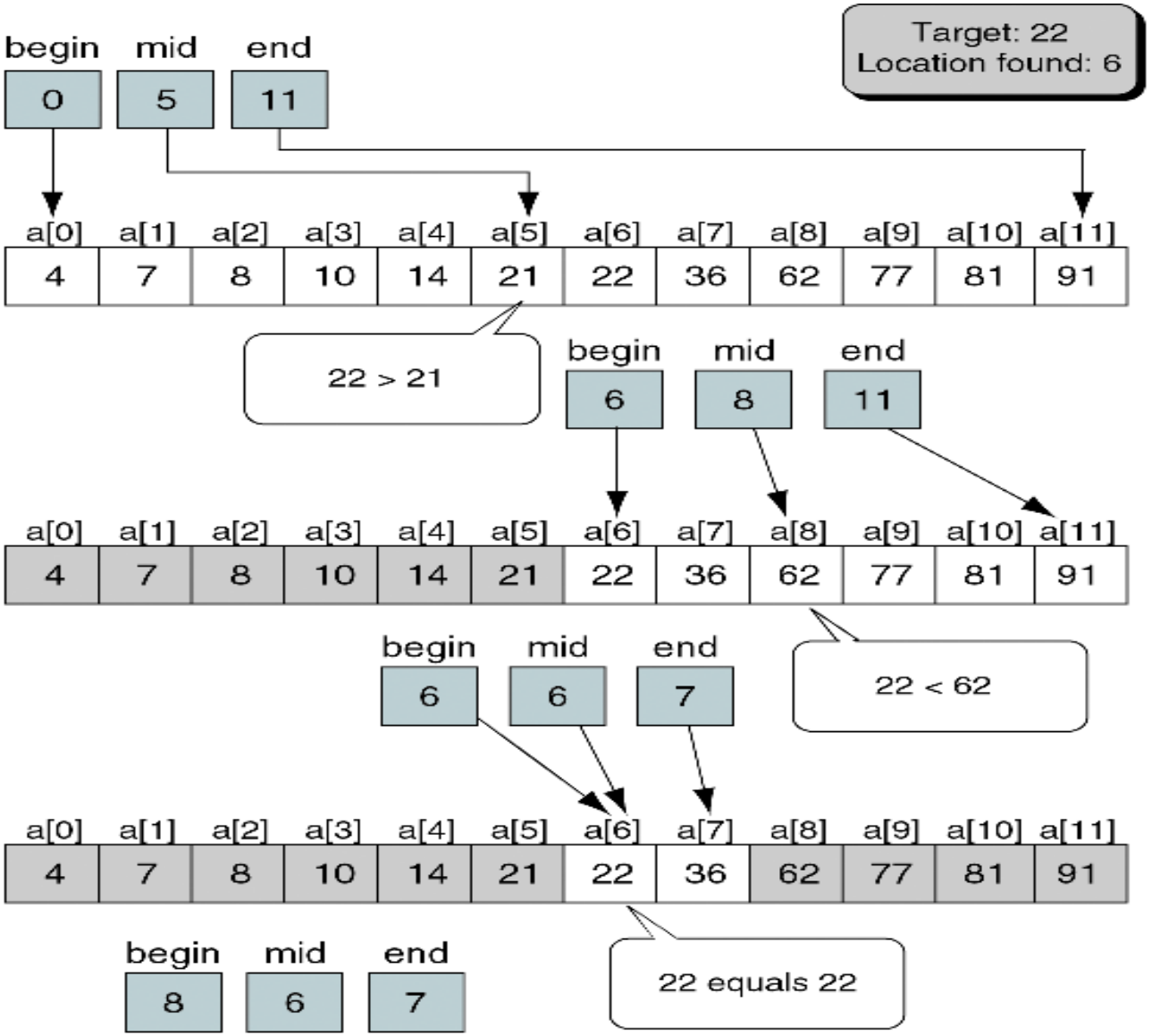
- Pure sequential search: *O(n)* and two conditions in loop
- Sentinel search: *O(n)* and single one condition in loop
- Ordered list search
  - Seq. search with target = list [loc]: *O(n)* with 2 tests
  - Seq. search with target > or <= list[loc]: *O(n/2)* with 2 tests



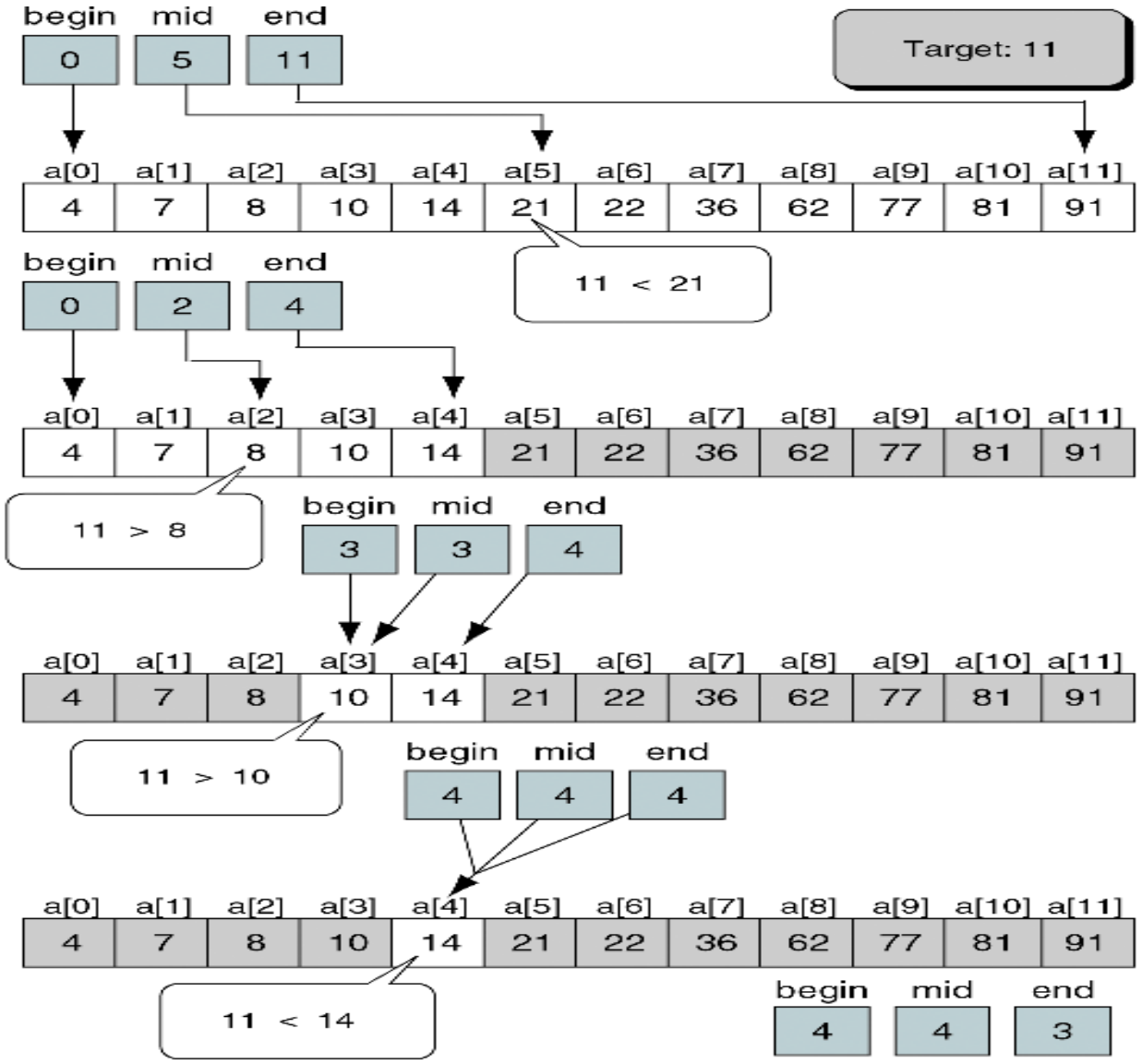
```
1  if (target less than last element in list)
   1   find first element less than or equal to target
   2   set locn to index of element
2  else
   1   set locn to last
3  end if
4  if (target in list)
   1   set found to true
5  else
   1   set found to false
6  end if
7  return found
end OrderedListSearch
```

O(n/2) with one test !

Successful Binary Search Example



Unsuccessful Binary Search Example



Binary Search

```
Algorithm binarySearch (list, last, target, locn)
Search an ordered list using Binary Search
   Pre    list is ordered; it must have at least 1 value
          last is index to the largest element in the list
          target is the value of element being sought
          locn is address of index in calling algorithm
   Post   FOUND: locn assigned index to target element
                 found set true
          NOT FOUND: locn = element below or above target
                     found set false
   Return found true or false
1  set begin to 0
2  set end to last
3  loop (begin <= end)
   1   set mid to (begin + end) / 2
   2   if (target > list[mid])
          Look in upper half
       1   set begin to (mid + 1)
```

Binary Search (cont.)

```
   3   else if (target < list[mid])
          Look in lower half
       1   set end to mid - 1
   4   else
          Found: force exit
       1   set begin to (end + 1)
   5   end if
4  end loop
5  set locn to mid
6  if (target equal list [mid])
   1   set found to true
7  else
   1   set found to false
8  end if
9  return found
end binarySearch
```

Efficiency (time complexity): *O(log n)*

13-2 Search Implementations

Having discussed the basic concepts of array searches, we write C implementations of the two most common.

- **Sequential Search in C**
- **Binary Search In C**

Sequential Search

```
 1  /* Locate target in an unordered list of size elements.
 2        Pre  list must contain at least one item
 3             last is index to last element in list
 4             target contains the data to be located
 5             locn is address of index in calling function
 6        Post FOUND: matching index stored in locn address
 7                    return true (found)
 8             NOT FOUND: last stored in locn address
 9                        return false (not found)
10  */
11  bool seqSearch (int list[ ], int  last,
12                  int target,  int* locn)
13  {
14  // Local Definitions
15     int looker;
```

Sequential Search (cont.)

```
16
17  // Statements
18     looker = 0;
19     while (looker < last && target != list[looker])
20        looker++;
21
22     *locn = looker;
23     return ( target == list[looker] );
24  }  // seqSearch
```

Binary Search

```
1  /* Search an ordered list using Binary Search.
2       Pre  list must contain at least one element
3            last is index to largest element in list
4            target is value of element being sought
5            locn is address of index in calling function
6       Post FOUND: locn = index to target element
7                    return true (found)
8            NOT FOUND: locn = index below/above target
9                       return false (not found)
```

Binary Search (cont.)

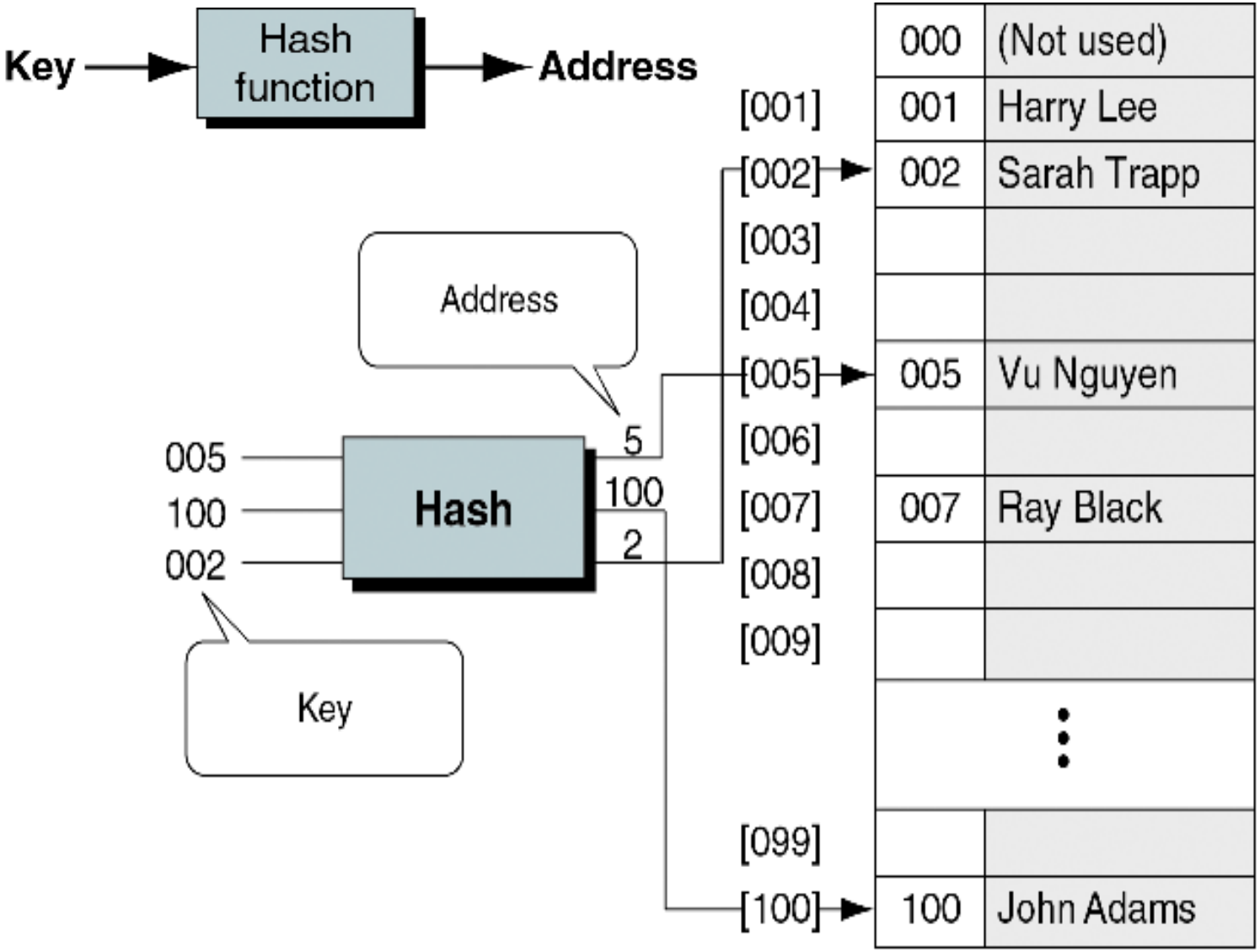
```
10  */
11  bool binarySearch   (int list[ ], int  last,
12                       int target,  int* locn )
13  {
14  // Local Definitions
15     int begin;
16     int mid;
17     int end;
18
19  // Statements
20     begin = 0;
21     end  = last;
22     while (begin <= end)
23        {
24         mid = ( begin + end ) / 2;
25         if ( target > list[ mid ] )
26            // look in upper half
27            begin = mid + 1;
28            else if ( target < list[ mid ] )
29               // look in lower half
30               end = mid - 1;
31         else
32               // found: force exit
33               begin = end + 1;
34        } // end while
35     *locn = mid;
36     return (target == list [mid]);
37  }  // binarySearch
```

13-3 Hashed List Searches

The goal of a hashed search is to find the target data in only one test. After discussing some basic hashed list concepts, we discuss eight hashing methods. At the end of the section, we develop a hashing algorithm that uses several of the methods discussed in the section.

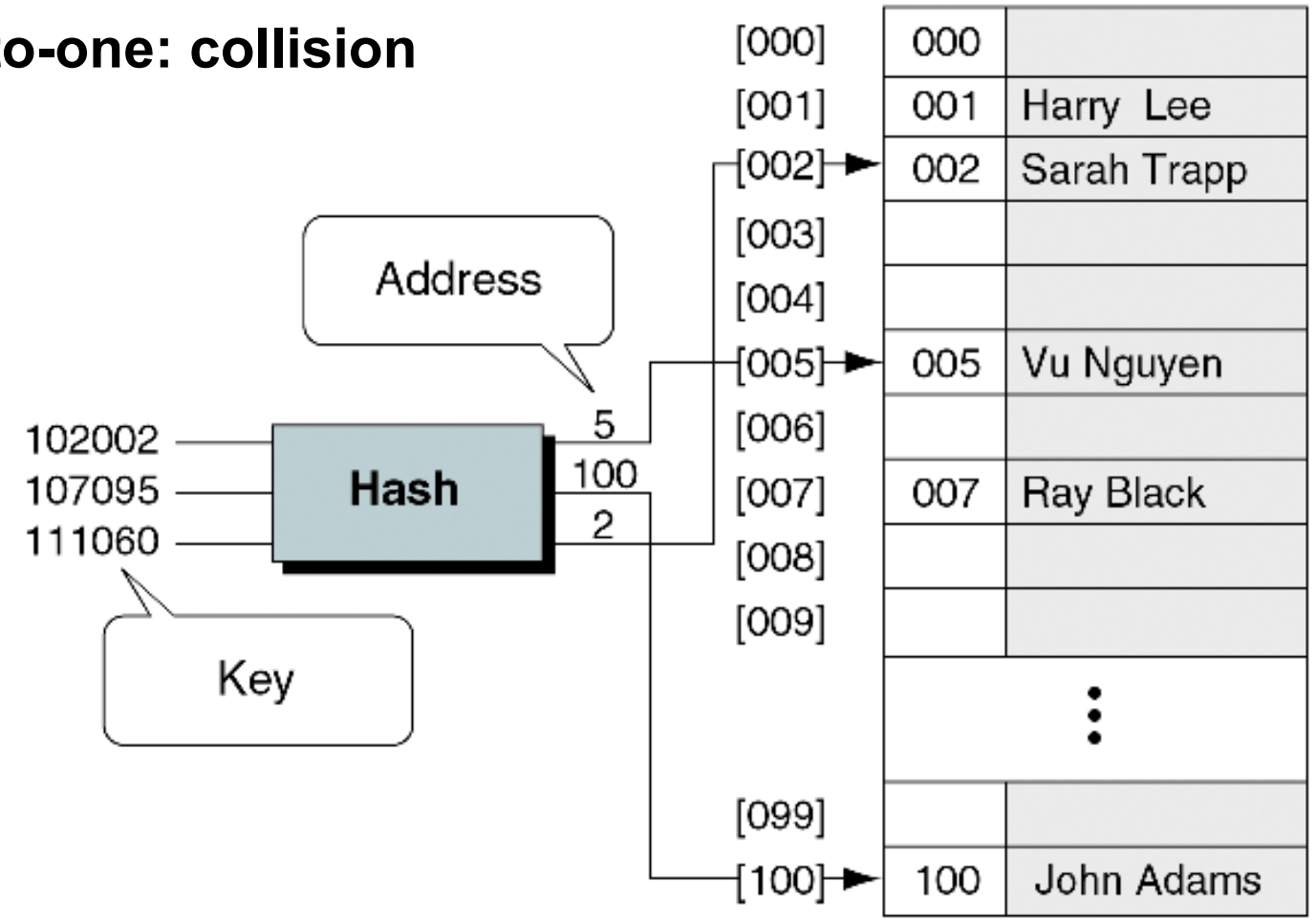
- **Basic Concepts**
- **Hashing Methods**
- **One Hashing Algorithm**

Hash Concept

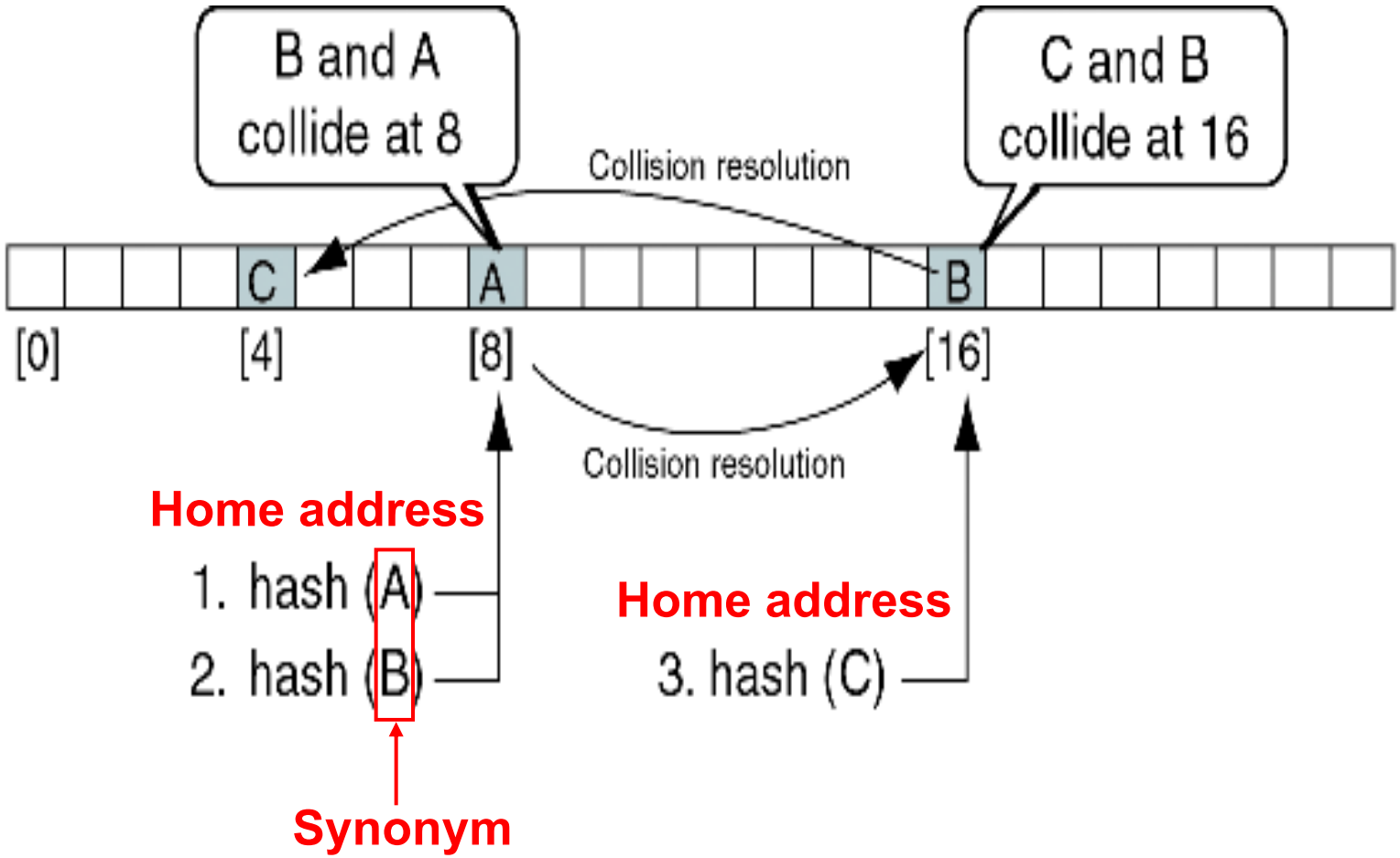


Hash Concept (cont.)

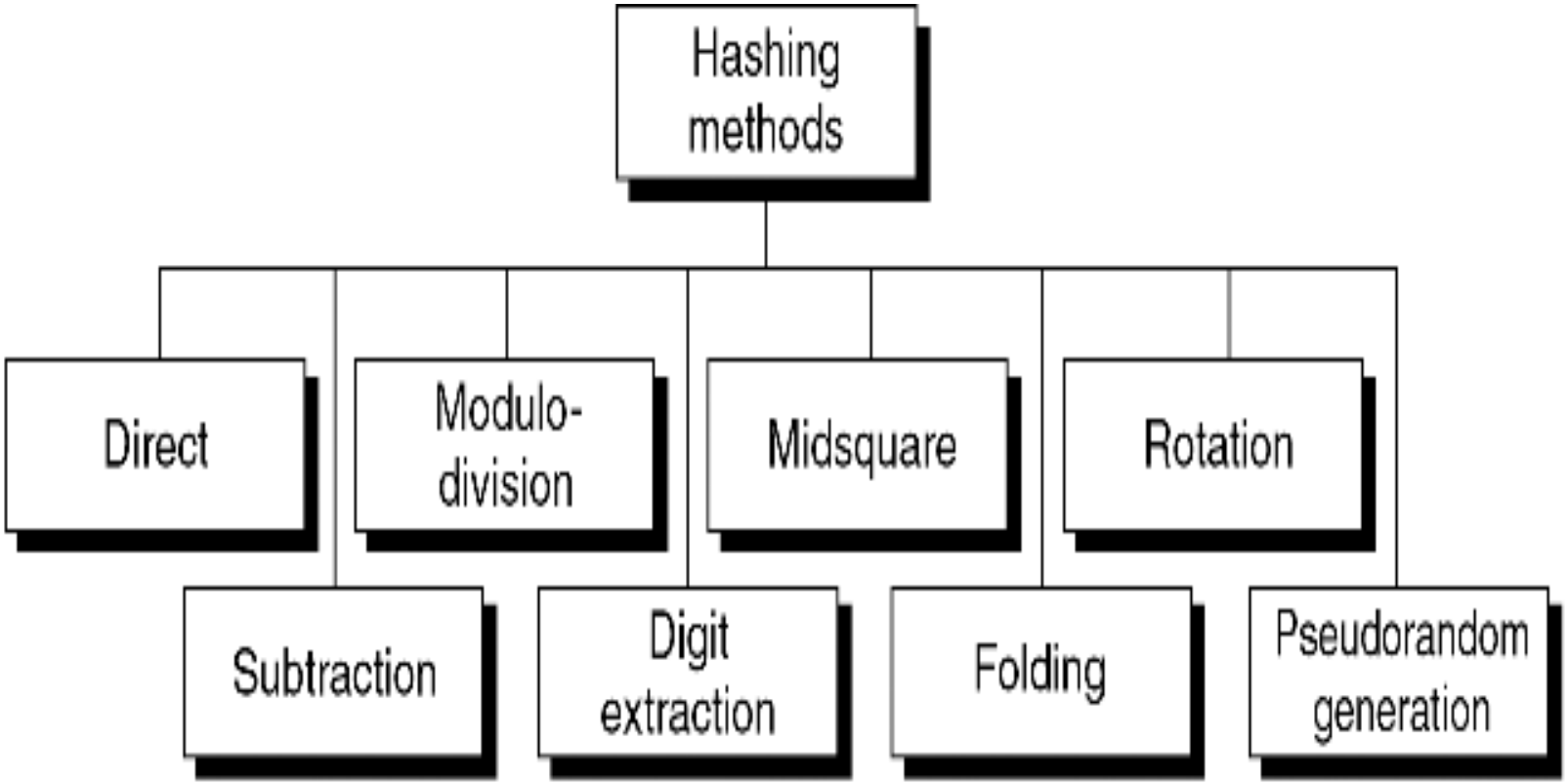
- What about number of key (e.g. employee ID) >> number of address (employee) ?
  - One-to-one: waste memory space
  - Many-to-one: collision



Collision Resolution Concept

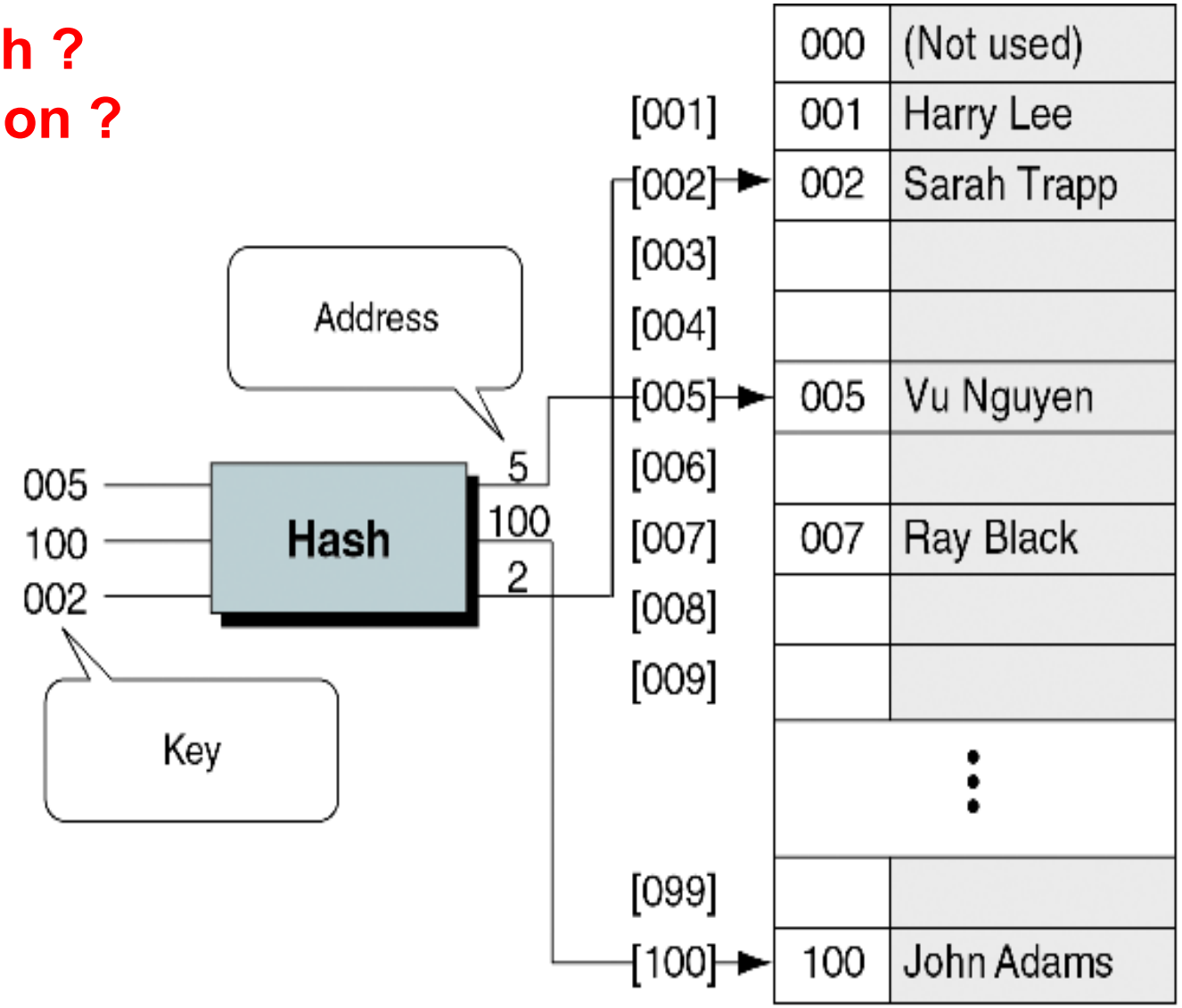


Basic Hash Techniques



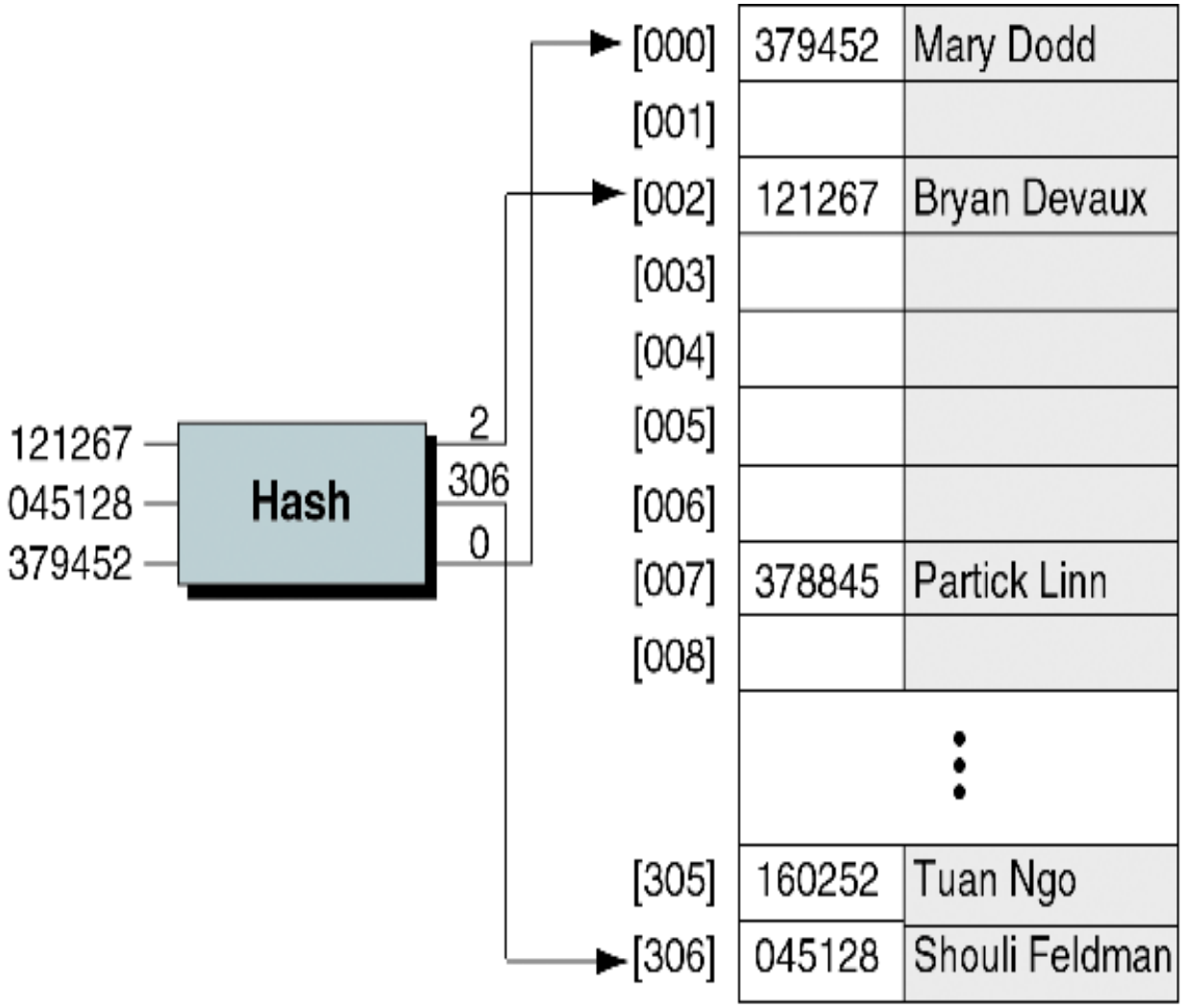
Direct Hashing

Strength ?
Limitation ?



Modulo-division Hashing

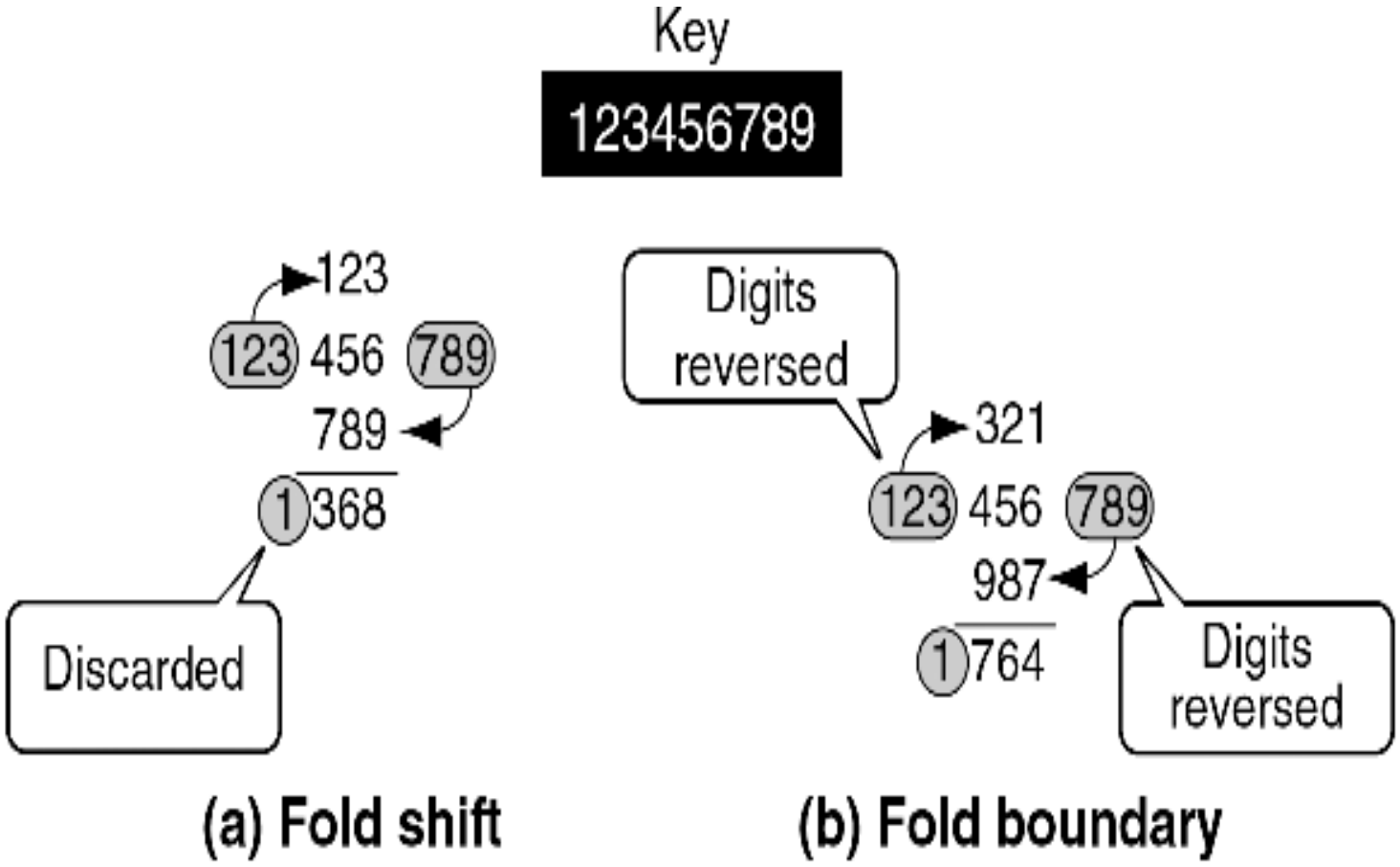
- Address = key *mod* listsize e.g., 2 = 121267 mod 307
- A listsize that is prime number produces fewer collisions



Digit-extraction and Midsquare Hashing

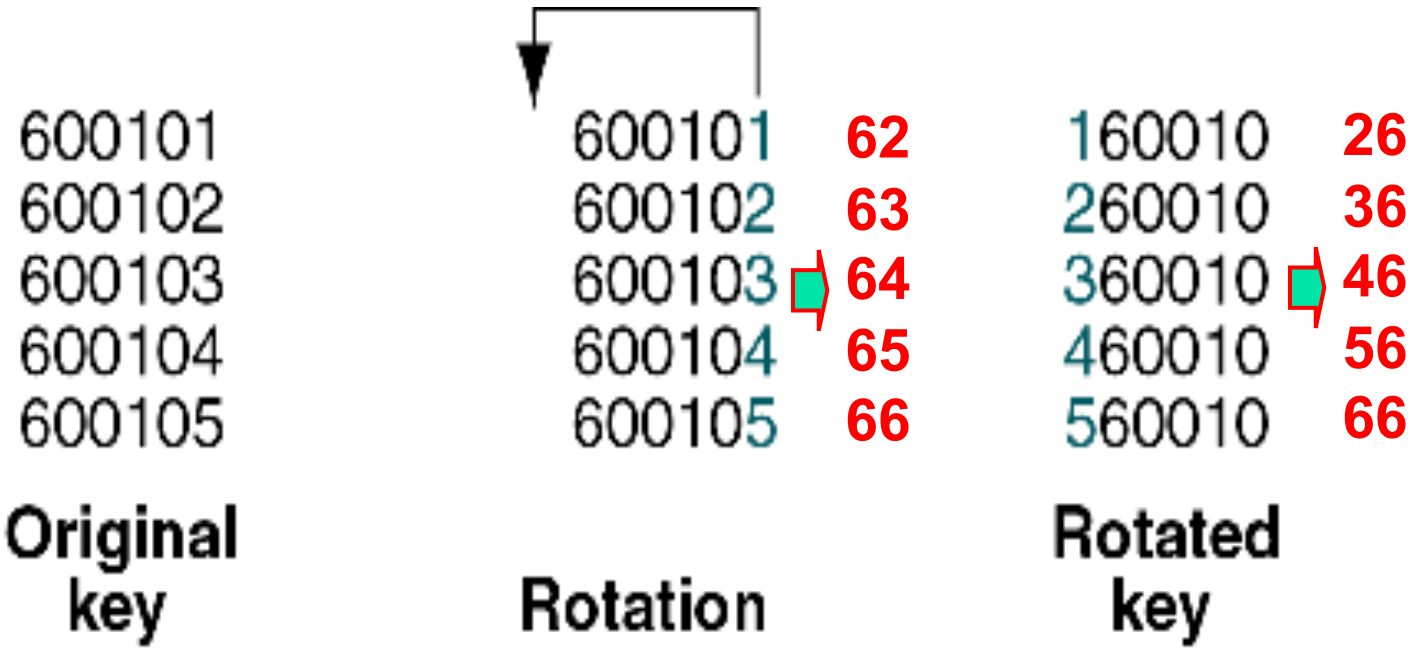
- Digit – extraction (address space 1 ~ 999)
  - 379452 → 394
  - 121267 → 112
  - 378845 → 388
- Midsquare (address space 1 ~ 999)
  - Sqr(9452) = 89340304 → address: 3403
  - 379452 → sqr(379) = 143641 → address: 364

Folding Hashing



Rotation Hashing

- Rotation hashing is usually incorporated in combination with other hashing methods, especially when keys are assigned serially
- In the example, it does not work well with *mod* method
- It works well with simple fold shift (two digit address)

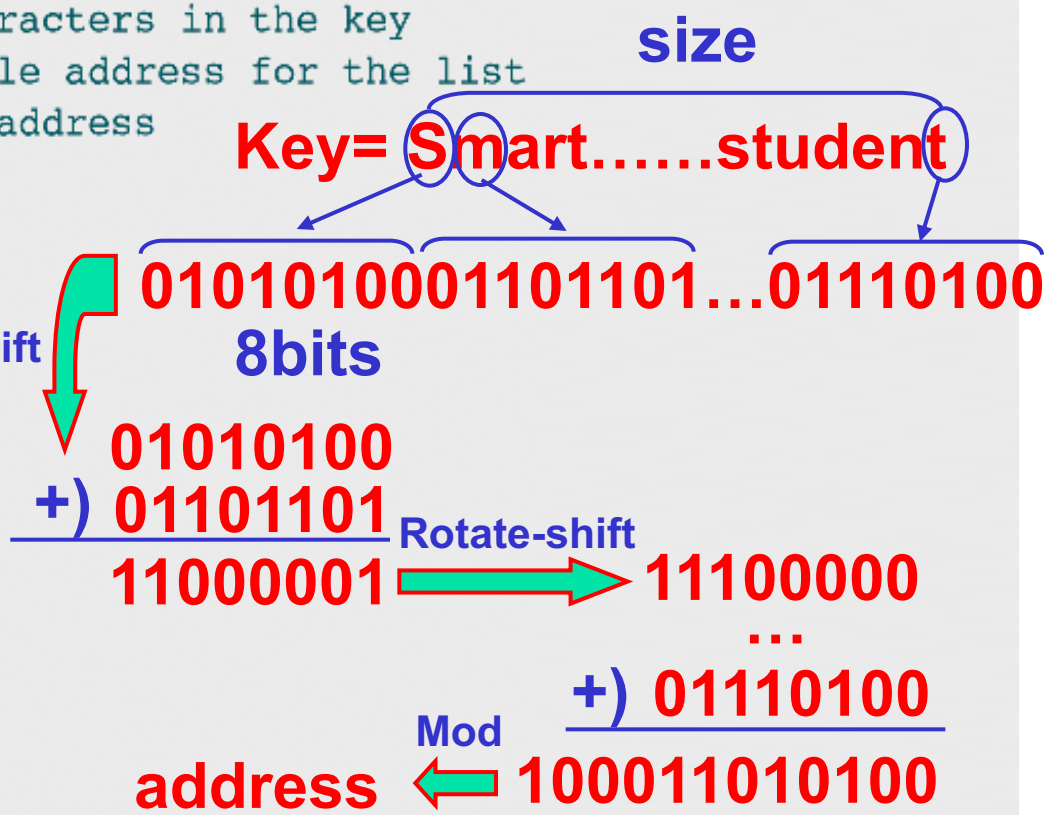


Pseudorandom Hashing

- In pseudorandom hashing the key is used as the seed in a pseudorandom-number generator
- A common random-number generator
  - $y = ax + c$, where x is key, a and c are predifinded constant
- For example (a = 17, c = 7)
  - 121267 → y = ((17 x 121267) + 7) mod 307 = 41

Hashing Algorithm Example

```
Algorithm hash (key, size, maxAddr, addr)
This algorithm converts an alphanumeric key of size
characters into an integral address.
   Pre   key is a key to be hashed
         size is the number of characters in the key
         maxAddr is maximum possible address for the list
   Post  addr contains the hashed address
 1 set looper to 0
 2 set addr to 0
   Hash key
 3 for each character in key
   1   if (character not space)
       1   add character to address
       2   rotate addr 12 bits right
   2   end if
 4 end loop
   Test for negative address
 5 if (addr < 0)
   1   addr = absolute(addr)
 6 end if
 7 addr = addr modulo maxAddr
end hash
```

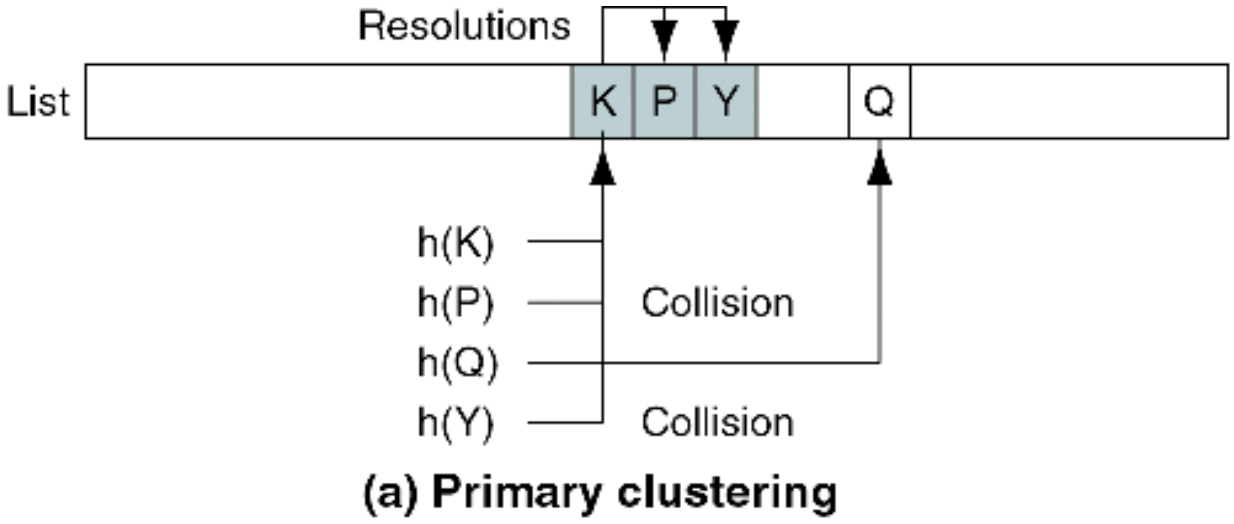


13-4 Collision Resolution

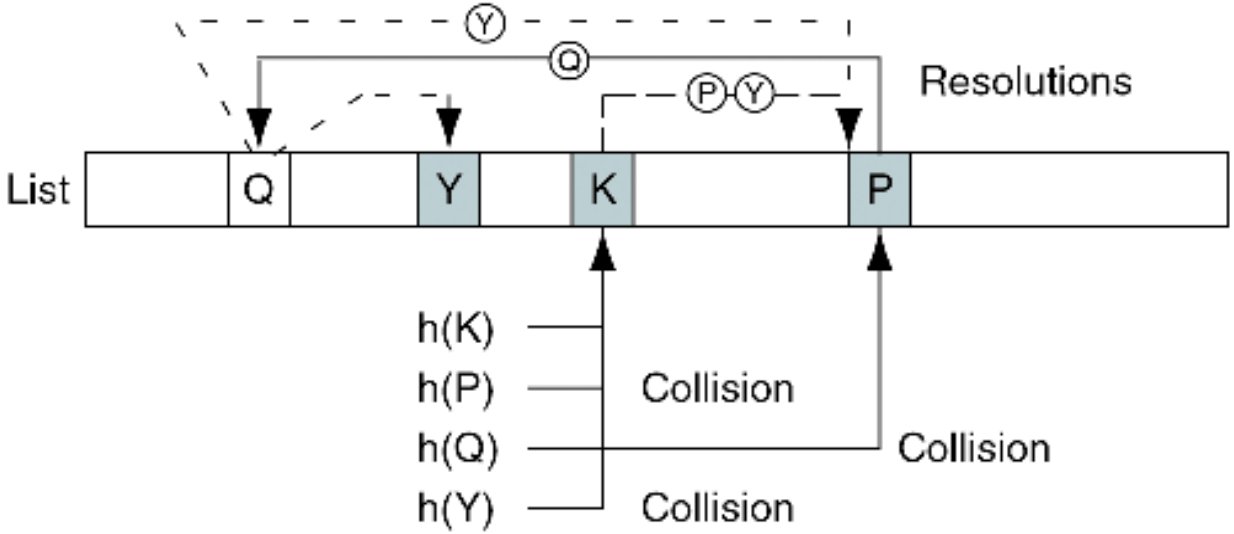
We discuss three structural approaches and four specific collision resolution algorithms. At the end of the section, we develop a C program that builds and searches a hashed list.

- Open Addressing
- Linked List Collision Resolution
- Bucket Hashing
- Combination Approaches
- Hashed List Example

Clustering and Collisions



(a) Primary clustering

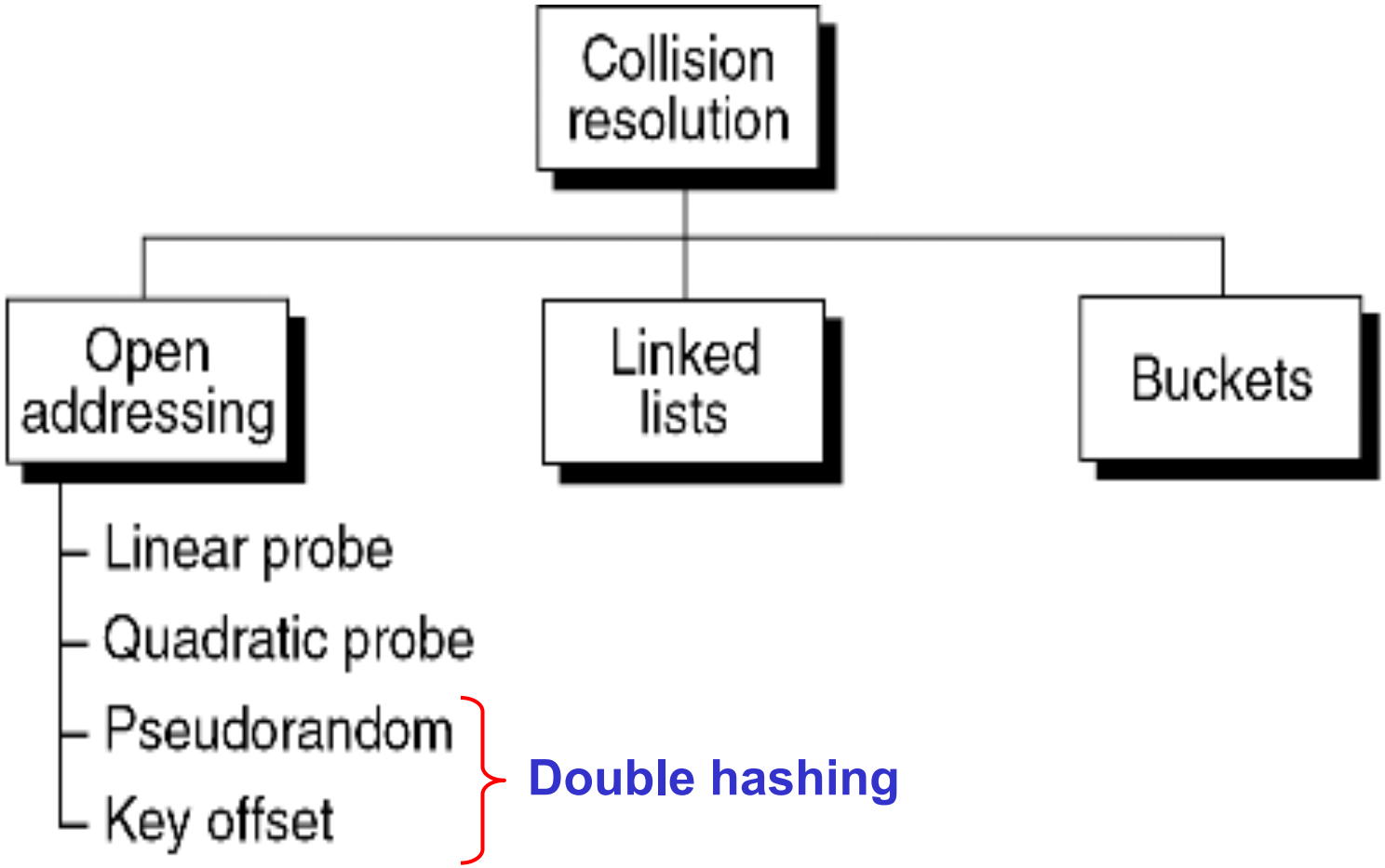


(b) Secondary clustering

Hashing Design Principles

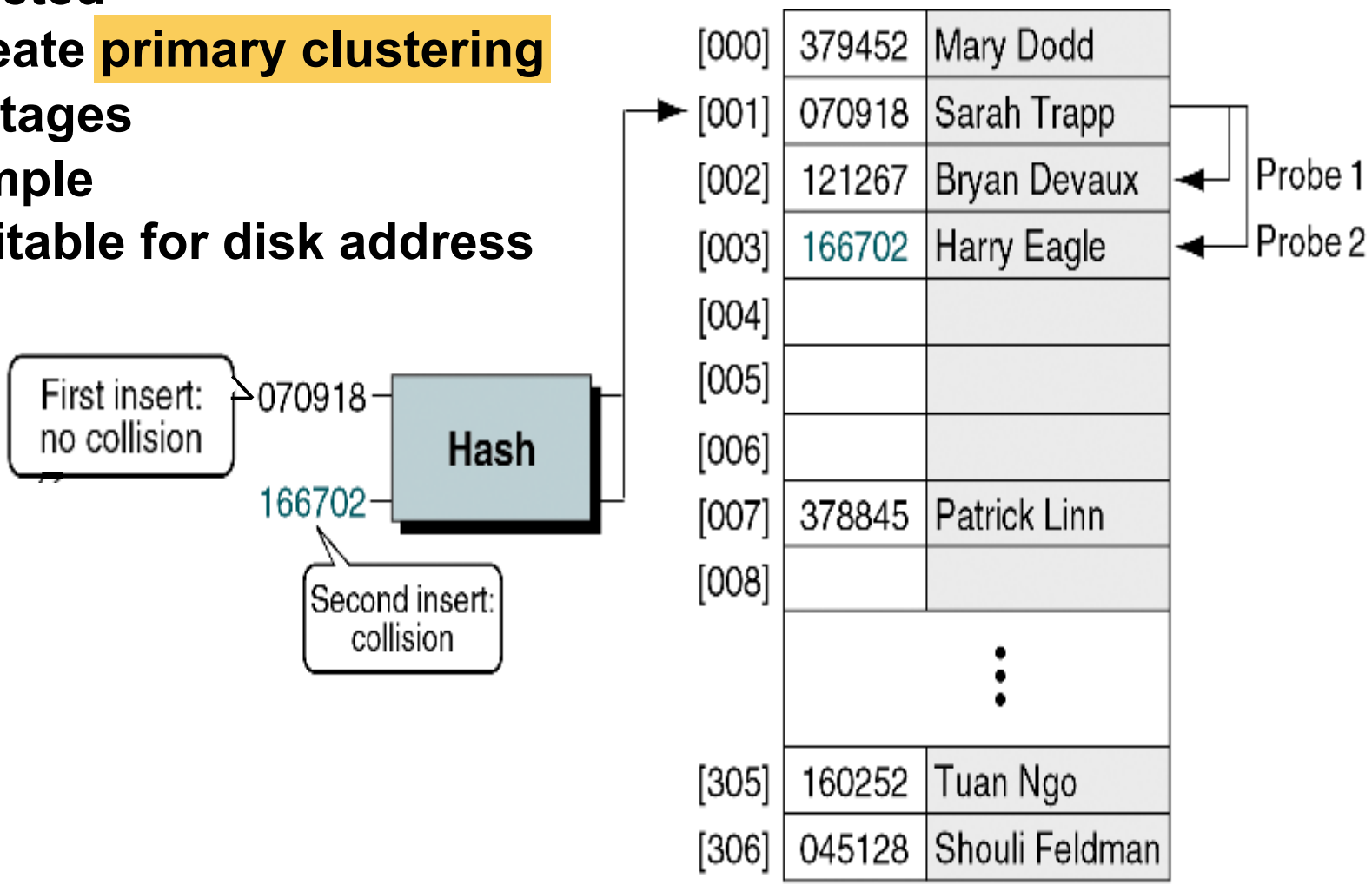
- The *load factor* (# of elements divided by the # of physical elements allocated for the list) no more than 75% full
- Minimize the clustering (primary and secondary clustering)
- Maximize the number of elements to be inserted into a list before a collision occures
- Number of elements examined in the search must be limited
- Traditional limit difficulties
  - Finding the ends doesn't mean that every element has been tested
  - Examining every element would be extensive time-consuming
  - Some of the collision resolution techniques cannot physically examine all of the elements

Collision Resolution Methods



Linear Probe 探針 Collision Resolution

- Disadvantages
  - Not suitable for search, especially after data have been deleted
  - Create primary clustering
- Advantages
  - Simple
  - Suitable for disk address



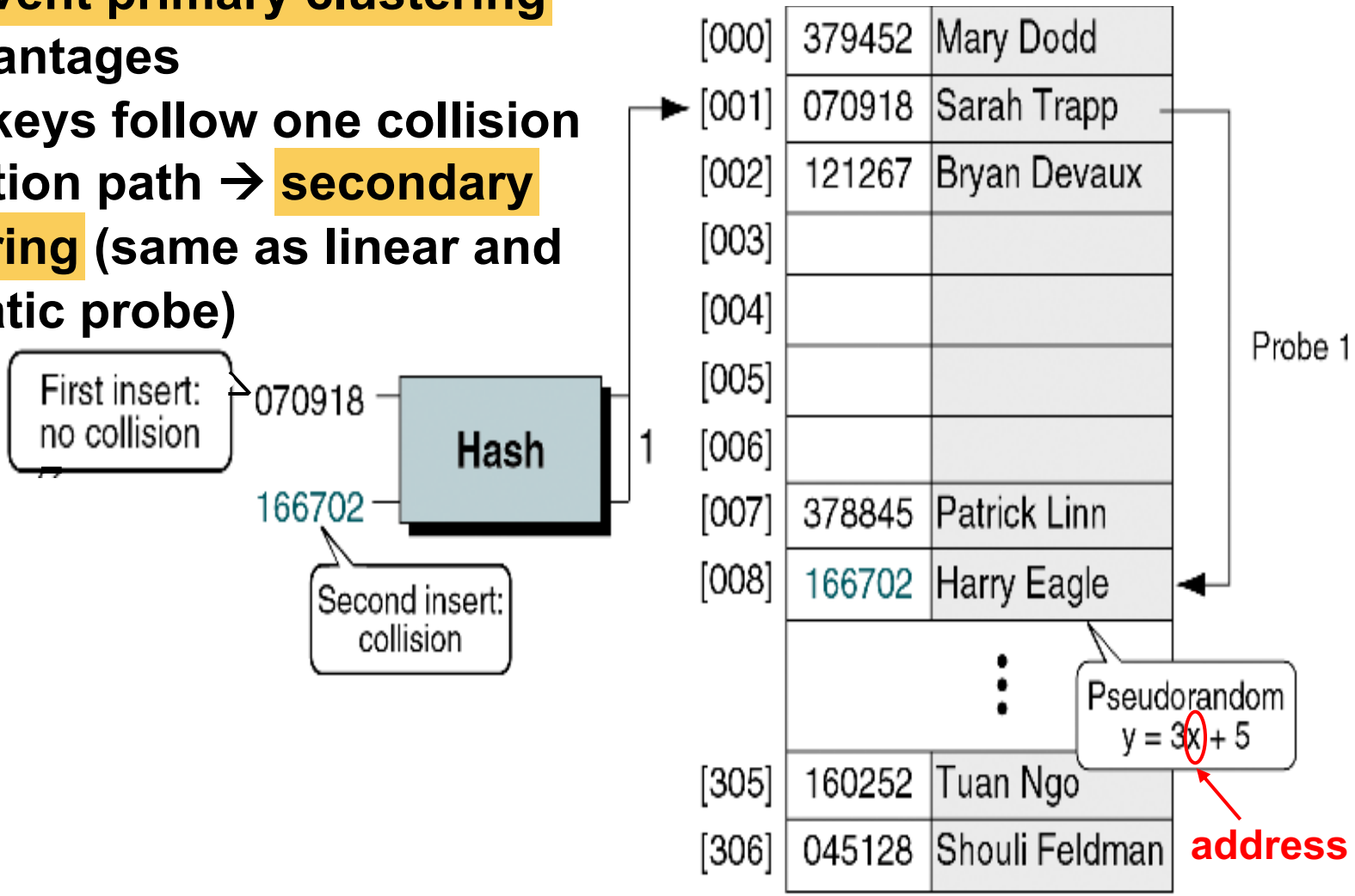
Quadratic Collision Resolution

- Advantage: prevents primary clustering
- Disadvantages
  - Squaring the number is time-consuming → use "add"
  - Impossible to generate a new address for every element → make list size prime number

Probe number	Collision location	Probe^2 and increment	New address
1	1	$1^2 = 1$	1 + 1 ⇨ 02
2	2	$2^2 = 4$	2 + 4 ⇨ 06
3	6	$3^2 = 9$	6 + 9 ⇨ 15
4	15	$4^2 = 16$	15 + 16 ⇨ 31
5	31	$5^2 = 25$	31 + 25 ⇨ 56
6	56	$6^2 = 36$	56 + 36 ⇨ 92
7	92	$7^2 = 49$	92 + 49 ⇨ 41
8	41	$8^2 = 64$	41 + 64 ⇨ 05
9	5	$9^2 = 81$	5 + 81 ⇨ 86
10	86	$10^2 = 100$	86 + 100 ⇨ 86

Pseudorandom Collision Resolution

- Advantages (double hashing)
  - Prevent primary clustering
- Disadvantages
  - All keys follow one collision resolution path → secondary clustering (same as linear and quadratic probe)



Key-offset Collision Resolution

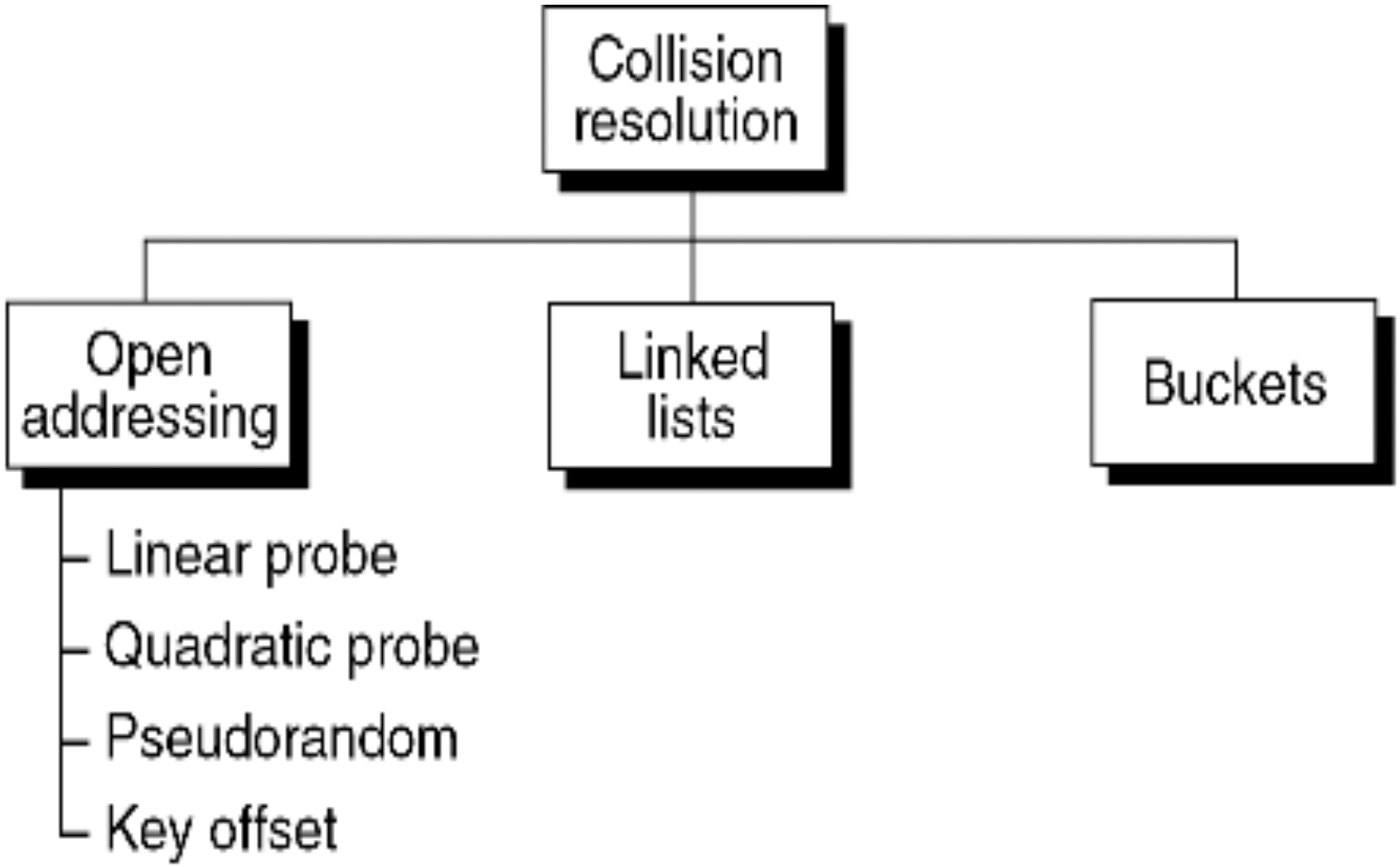
- Calculates the new address as a function of the old address and the key
- Advantages
  - Double hashing that produces different collision paths for different keys
- offset = key/listsize, addr. = ((offset + old addr.) mod listsize
- For example: key = 166702 →offset = 166702/307 = 543

  addr. = ((543+001)*mod* 307) = 237

  If 237 were collision → addr. = ((543+237) *mod* 307) = 166

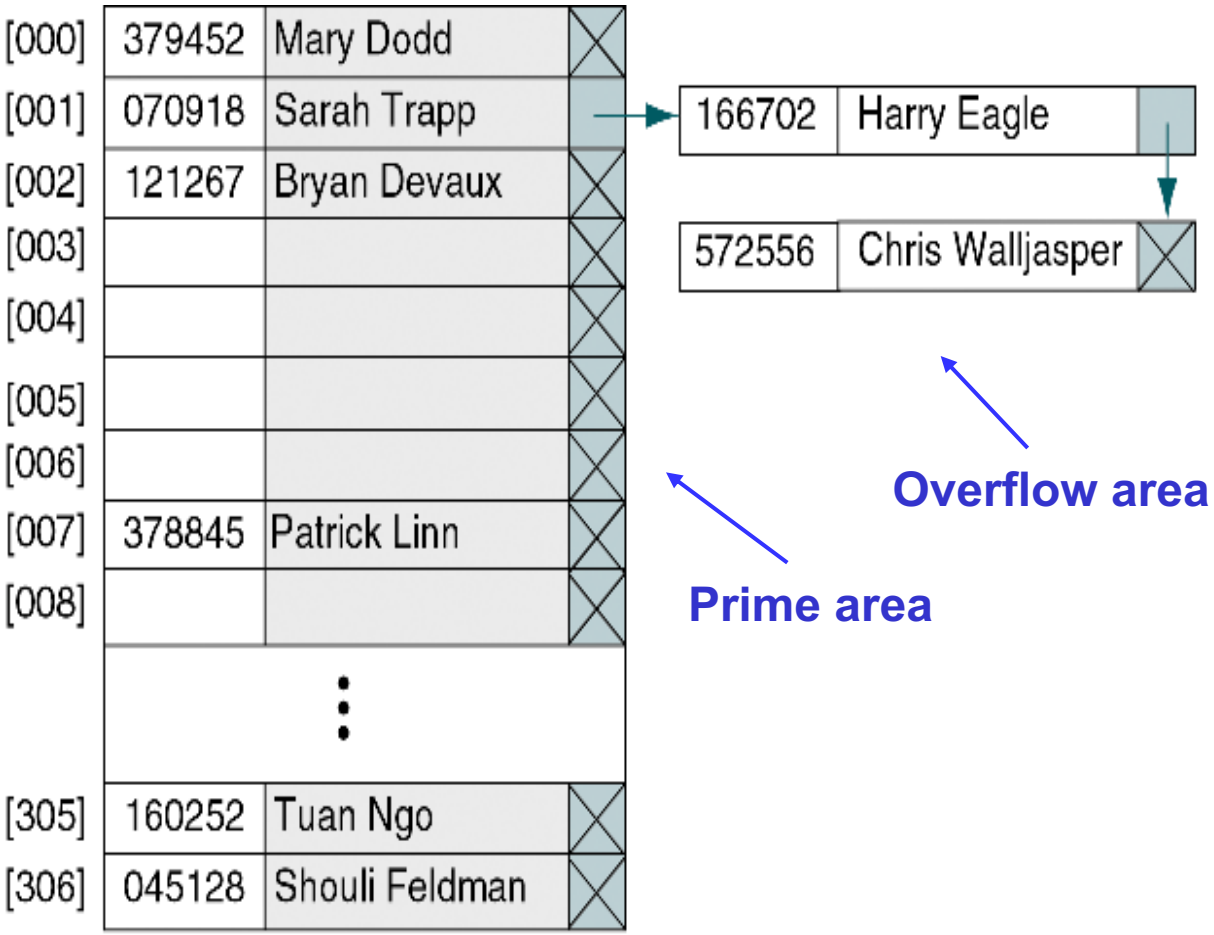
Key	Home address	Key offset	Probe 1	Probe 2
166702	1	543	237	166
572556	1	1865	024	047
067234	1	219	220	132

Collision Resolution Methods



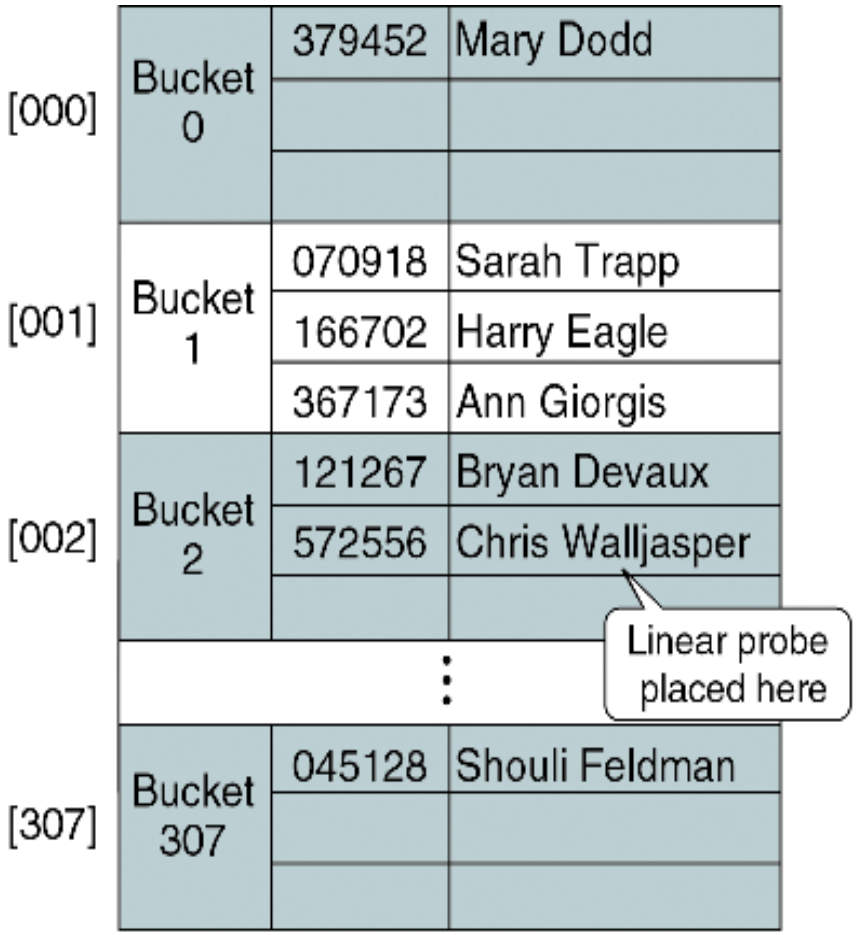
Linked List Collision Resolution

- **Advantage: eliminate the drawback of open addressing method in which each collision resolution increase the probability of future collisions**



Bucket Collision Resolution

- **Disadvantage:**
  - **Uses significant more space when the buckets are partially empty at given time**
  - **Does not completely resolve the collision problem**



Hashed List Search Example

```
1  /* The telephone lookup program using hashing.
2     The input is a file of names and phone numbers.
3        Written by:
4        Date:
5  */
6  #include <stdio.h>
7  #include <stdlib.h>
8  #include <string.h>
9
10 // Global Declarations
11 typedef struct
12    {
13     char  name [31];
14     char  phone[16];
15    } LISTING;
16
17 const int cMax_Size = 53;
18
19 // Prototype Declarations
20    void buildList  (LISTING  phoneList[], int* last);
```

Hashed List Search Example (cont.)

```
21      void hashSearch (LISTING* phoneList,    int  last);
22      int hashKey     (char*    key,          int  last);
23      int collision   (int      last,         int  locn);
24
25  int main (void)
26  {
27  // Local Definitions
28      LISTING  phoneList[cMax_Size];
29      int      last;
30
31  // Statements
32      printf("Begin Phone Listing\n");
33
34      last = cMax_Size - 1;
35      buildList (phoneList, &last);
36      hashSearch(phoneList,  last);
37
38      printf("\nEnd Phone Listing\n");
39      return 0;
40  }   // main
41
```

Hashed List Search Example (cont.)

```
42  /* ==================== buildList ====================
43     Read phone number file and load into array.
44        Pre  phoneList is array to be filled
45             last is index to last element loaded
46        Post array filled
47  */
48  void buildList (LISTING phoneList[], int* last)
49     {
50  // Local Definitions
51     FILE*   fpPhoneNums;
52     LISTING aListing;
53     int     locn;
54     int     cntCol;
55     int     end;
56
```

Hashed List Search Example (cont.)

```
57  // Statements
58     fpPhoneNums = fopen ("P13-03.TXT", "r");
59     if (!fpPhoneNums)
60        {
61         printf("Can't open phone file\a\n");
62         exit (100);
63        } // if
64
65     // Set keys to null
66     for (int i = 0; i <= *last; i++)
67         phoneList[i].name[0] = '\0';
68
```

Hashed List Search Example (cont.)

```
69      while (!feof(fpPhoneNums))
70    {
71          fscanf(fpPhoneNums, " %30[^;]%*c %[^;]%*c",
72                  aListing.name, aListing.phone);
73          locn = hashKey(aListing.name, *last);
74
75          if (phoneList[locn].name[0] != '\0')
76             {
77              // Collision
78              end      = *last;
79              cntCol   =  0;
80              while (phoneList[locn].name[0] != '\0'
81                  && cntCol++ <= *last)
82                     locn = collision(*last, locn);
83
84              if (phoneList[locn].name[0] != '\0')
85                 {
86                  printf("List full. Not all read.\n");
87                  return;
88                 } // if full list
89              } // if collision
90          phoneList[locn] = aListing;
91         } // while
92      return;
93  }   // buildList
```

Hashed List Search Example (cont.)

```
 94
 95  /* ==================== hashKey ====================
 96     Given key, hash key to location in list.
 97        Pre  phoneList is hash array
 98             last is last index in list
 99             key is string to be hashed
100        Post returns hash location
101  */
102  int hashKey (char* key, int last)
103  {
104  // Local Definitions
105     int  addr;
106     int  keyLen;
107
```

Hashed List Search Example (cont.)

```
108 // Statements
109     keyLen = strlen(key);
110     addr   = 0;
111
112     for (int i = 0; i < keyLen; i++)
113         if (key[i] != ' ')
114             addr += key[i];
115     return (addr % last + 1);
116 }  // hashKey
```

Hashed List Search Example (cont.)

```
117
118 /* ==================== collision ====================
119    Have a collision. Resolve.
120       Pre  phoneList is hashed list
121            last is index of last element in list
122            locn is address of collision
123       Post returns next address in list
124 */
125 int collision (int  last, int  locn)
126 {
127 // Statements
128     return locn < last ? ++locn : 0;
129 }  // collision
130
```

Hashed List Search Example (cont.)

```
131 /* ===================== hashSearch ====================
132    Prompt user for name and lookup in array.
133       Pre  phoneList has been initialized
134       Post User requested quit
135 */
136 void hashSearch (LISTING* phoneList, int last)
137 {
138 // Local Definitions
139    char  srchName[31];
140    char  more;
141    int   locn;
142    int   maxSrch;
143    int   cntCol;
144
```

Hashed List Search Example (cont.)

```
145 // Statements
146    do
147      {
148       printf("Enter name: ");
149       scanf ("%s", srchName);
150
151       locn = hashKey (srchName, last);
152        if (strcmp(srchName, phoneList[locn].name) != 0)
153          {
154           // treat as collision
155           maxSrch = last;
156           cntCol  = 0;
157           while (strcmp (srchName,
158                          phoneList[locn].name) != 0
159              &&  cntCol++ <= maxSrch)
160             locn = collision(last, locn);
161          } // if
162
163       // Test for success
164       if (strcmp (srchName, phoneList[locn].name) == 0)
```

Hashed List Search Example (cont.)

```
165             printf("%-32s (%02d) %-15s\n",
166                     phoneList[locn].name,
167                     locn,
168                     phoneList[locn].phone);
169         else
170             printf("%s not found\n", srchName);
171
172         printf("\nLook up another number <Y/N>? ");
173         scanf (" %c", &more);
174       } while (more == 'Y' || more == 'y');
175   }  // hashSearch
```

Hashed List Search Example (cont.)

```
Results:
   Begin Phone Listing
   Enter name: Julie
   Julie (38)  (555) 916-1212

   Look up another number <Y/N>? y
   Enter name: Chris
   Chris (39)  (555) 946-2859

   Look up another number <Y/N>? y
   Enter name: Wyan
   Wyan (52)  (555) 866-1234

   Look up another number <Y/N>? y
   Enter name: Wayn
   Wayn (0)  (555) 345-0987

   Look up another number <Y/N>? y
   Enter name: Bill
   Bill not found

   Look up another number <Y/N>? n
   End Phone Listing
```

幾個分別了多年的同學相約去拜訪大學的老師。老師很高興，問他們生活得怎麼樣。

不料， 一句話就勾出了大家的滿腹牢騷， 大家紛紛訴說著生活的不如意:

工作壓力大呀， 生活煩惱多呀， 做生意的商戰失利呀， 當官的仕途受阻呀…

彷彿大家都成了時代的棄兒。

老師笑而不語，從廚房拿出一大堆杯子，擺在茶儿上。

這些杯子各式各樣，形態各異，有瓷器的，有玻璃的，有塑膠的，

有的杯子看起來豪華而高貴，有的則顯得普通而簡陋……

老師說:「我就不把你們當客人看了。你們要是渴了，就自己倒水喝吧。」

七嘴八舌，大家說得口乾舌燥了，便紛紛拿了自己看中的杯子倒水喝。

等我們手裏都端了一杯水時，老師又發言了。

他指著茶儿上剩下的杯子說:「你們有沒有發現，你們手裏的杯子是最好看最別緻的杯子，

而像這些塑膠杯沒有人選中它。」

當然，我們並不覺得奇怪， 誰都希望自己拿著的是一隻好看的杯子。

老師說:「這就是你們煩惱的根源」

大家需要的是水，而非杯子，但我們有意無意地會去選擇漂亮的杯子。

這就如我們的生活---如果生活是水的話， 那麼，工作、金錢、地位 這些東西就是杯子，

它們只是我們盛起生活之水的工具。

其實，杯子的好壞並不影響水的品質。

如果將心思花在杯子上，大家還有心情去品嘗水的苦甜，這不就是自尋煩惱嗎?