Space and Time Trade-Offs

(Chapter 7)

Space–time tradeoff

- **Space** refers to the memory consumed by an algorithm to complete its execution.
- **Time** refers to the required time for an algorithm to complete the execution.
- Best algorithm to solve a problem is one that
  - Requires less memory and
  - Takes less time to complete

In practice it is not always possible

Space–time tradeoff

- We have to sacrifice one at the cost of the other.
- If space is our constraint, then we have to choose an algorithm that requires less space at the cost of more execution time. (example: Bubblesort)
- if time is our constraint then we have to choose an algorithm that takes less time to complete its execution at the cost of more space. (example: Mergesort)

Space-for-time tradeoffs varieties

1. **Input enhancement:** preprocess the input to store some info to be used later in solving the problem
   - Comparison Counting Sort
   - Distribution Counting Sort
   - String Matching

2. **Pre-structuring:** uses extra space to facilitate faster access to the data.
   - Hashing
   - Hash Function
   - Collision Handling
   - Efficiency of Hashing

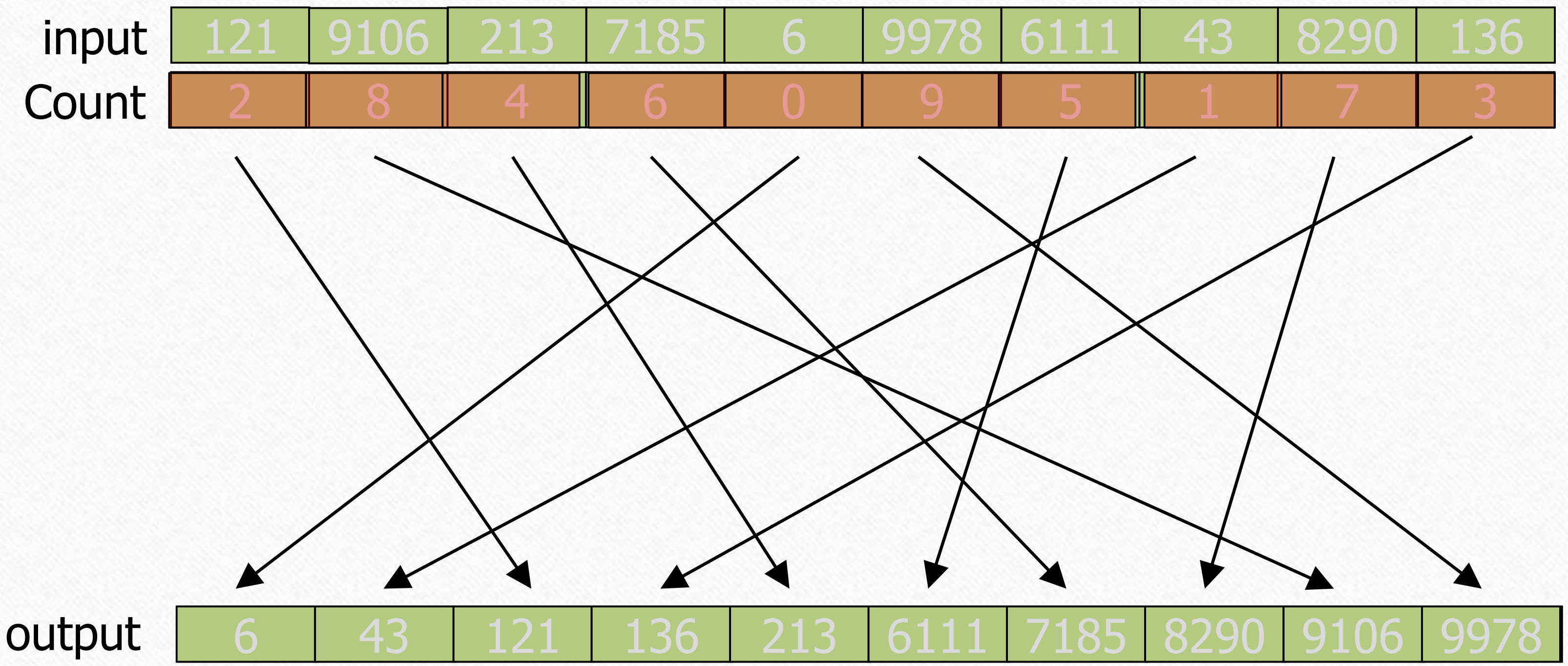
Comparison Counting Sort

- Idea: for each element of a list to be sorted, count the total number of elements smaller than this element and record the results in a table.

input	121	9106	213	7185	6	9978	6111	43	8290	136
Count	2	8	4	6	0	9	5	1	7	3

Comparison Counting Sort

- Move each input element to it’s corresponding position



Comparison Counting Sort

```
Algorithm ComparisionCountingSort A[0..n-1])
for i ← 0 to n-2
    for j ← i+1 to n-1
        if input[i] < input[j]
            Count[j]++
        else
            Count[i]++

for i ← 0 to n-1
        output[Count[i]] ← input[i]
```

What's the Big O?

Comparison Counting Sort

- Efficiency:
  - it is $O(n^2)$
    - But of course we have other sorts (mergesort, heapsort) that are O(nlogn)

Space-for-time tradeoffs varieties

1. **Input enhancement:** preprocess the input to store some info to be used later in solving the problem
    - Comparison Counting Sort
    - Distribution Counting Sort
    - String Matching

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Distribution Counting Sort

- Sort a known range of numbers
  - Playing cards
  - People by birth date or age
  - Seinfeld episodes from best to worst…
    - trick scenaio, they are all amazing.

Distribution Counting Sort Concept

1. Sum the occurrence of each number (There are three 1's, five 2's, etc)
2. Reserve a spot for each set of occurrences in return array
3. Fill in return array with the values

Source				
4	1	3	4	3

Return				
1	3	3	4	4
1's	3's		4's	

Distribution Counting Sort

Algo DistributionCountingSort (A[0.. n-1])

u = largest number in 'A'
l = lowest number in 'A'
n = length of 'A'

for $j \leftarrow 0$ **to** $u\text{-}l$ **do**
    $C[j] \leftarrow 0$

Initialize array 'C' to all 0's

for $i \leftarrow 0$ **to** $n\text{-}1$ **do**
    $C[A[\ i]\text{-}l] \leftarrow C[A[\ i]\text{-}l] + 1$

Sum the frequency of each number

for $j \leftarrow 1$ **to** $u\text{-}l$ **do**
    $C[j] \leftarrow C[j\text{-}1] + C[j]$

Reserve index in 'S' for each set of numbers

for $i \leftarrow n\text{-}1$ **downto** 0 **do**
    $j \leftarrow A[\ i]\text{-}\ l$
    $S[C[\ j]\ \text{-}1] \leftarrow A[\ i]$
    $C[\ j] \leftarrow C[\ j] - 1$

Decrement reserved count and add to array 'S'

return S

Distribution Counting Sort- example

A:

4	1	3	4	3

C:

1	2	3	4

S:

u = largest number in 'A'

l = lowest number in 'A'

u :4

l: 1

'C' length: u - l+1 = k = 4

Loop 1: initialization

A:

4	1	3	4	3

C:

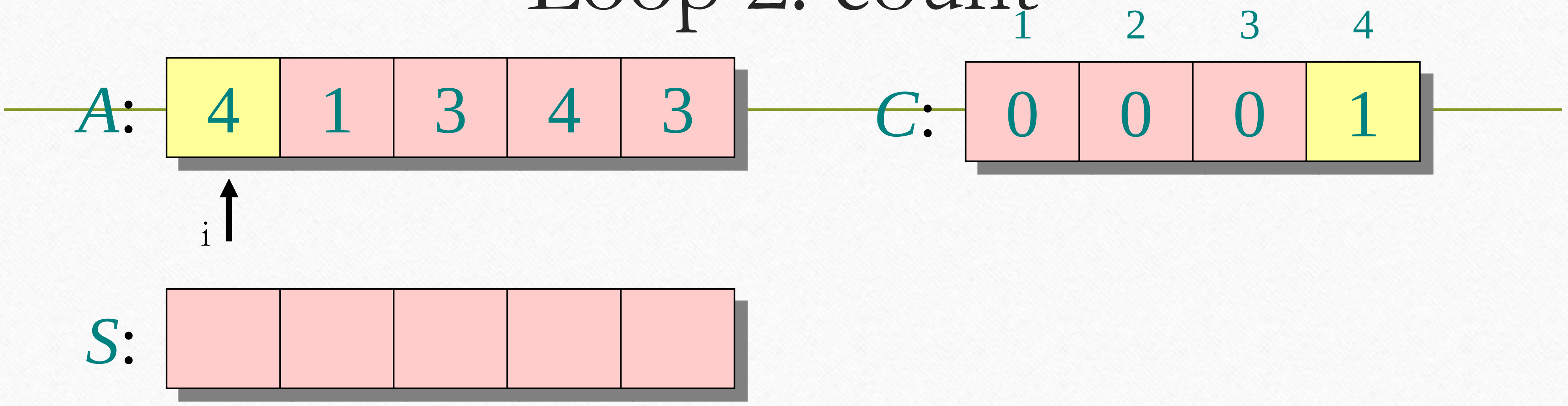
1	2	3	4
0	0	0	0

S:

1. **for** $j \leftarrow 0$ **to** $u\text{-}l$
   do $C[j] \leftarrow 0$

Initialize array ‘C’ to all 0’s

Loop 2: count

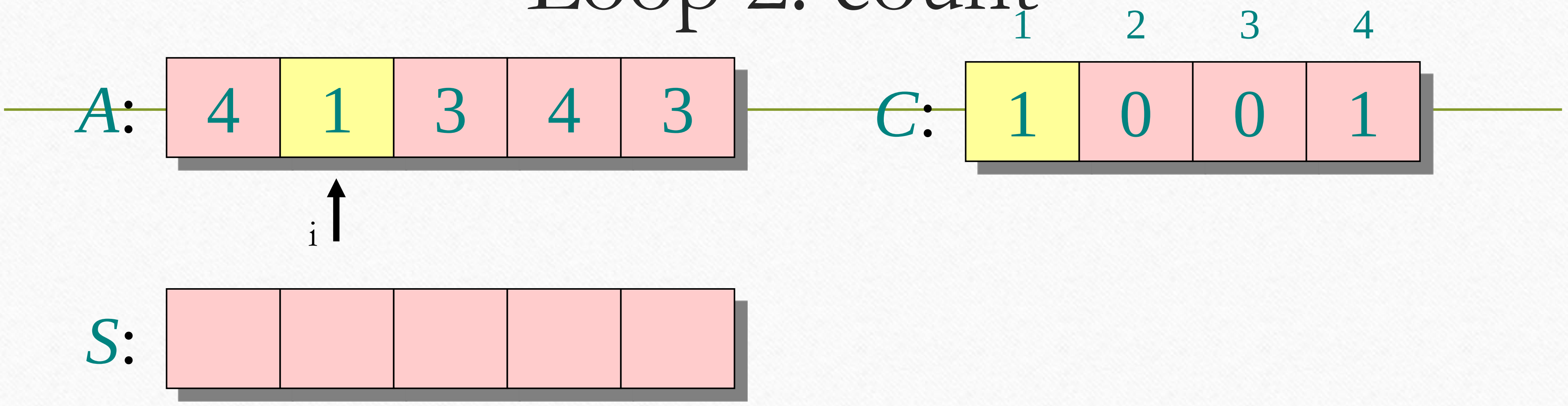


Sum the frequency of each number

2. **for** $i \leftarrow 0$ **to** $n\text{-}1$

   do $C[A[\,i]\text{-}l] \leftarrow C[A[\,i]\text{-}l] + 1$

Loop 2: count

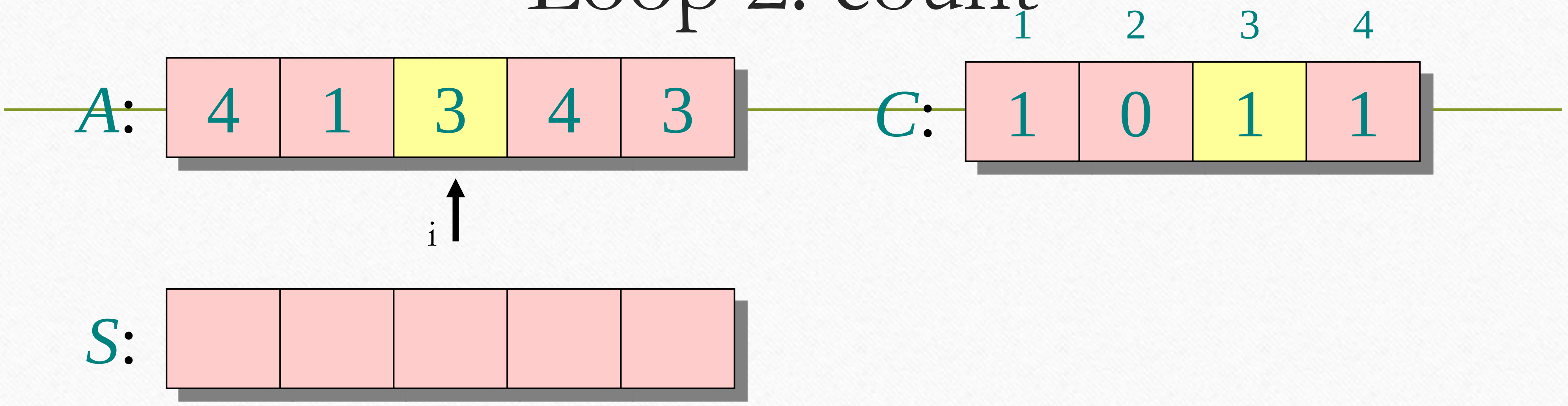


Sum the frequency of each number

2.**for** $i \leftarrow 0$ **to** $n\text{-}1$

do $C[A[\ i]\text{-}l] \leftarrow C[A[\ i]\text{-}l] + 1$

Loop 2: count

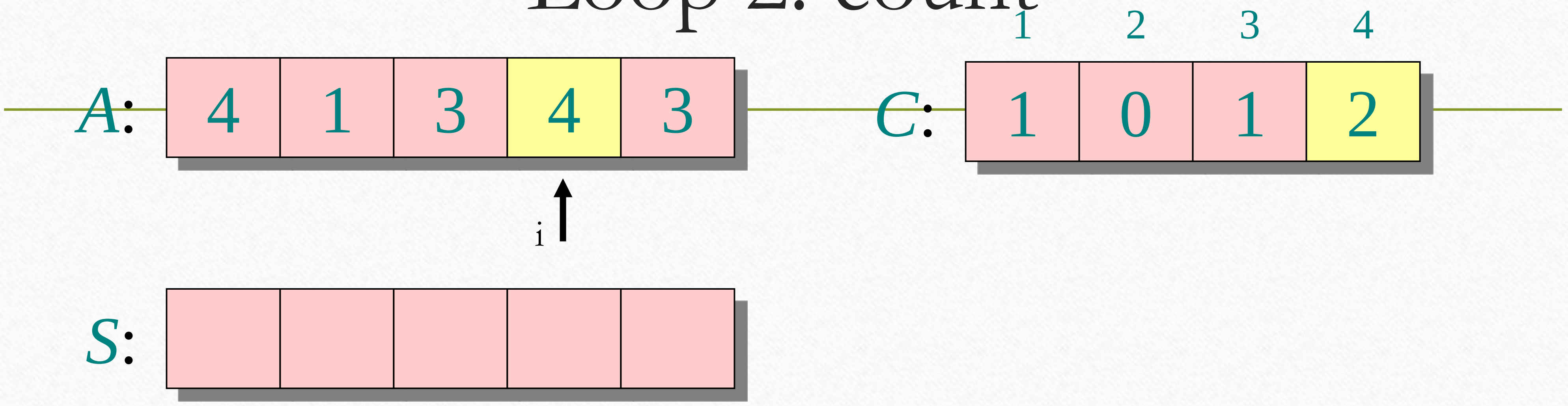


Sum the frequency of each number

2.**for** $i \leftarrow 0$ **to** $n\text{-}1$

do $C[A[\,i]\text{-}l] \leftarrow C[A[\,i]\text{-}l] + 1$

Loop 2: count

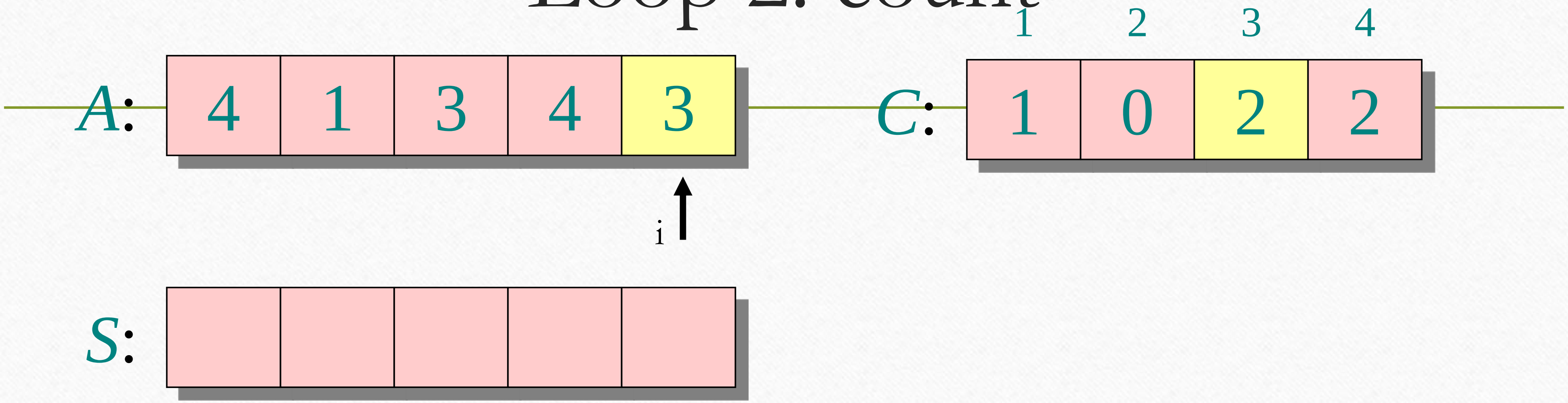


Sum the frequency of each number

2. **for** $i \leftarrow 0$ **to** $n\text{-}1$

do $C[A[\,i]\text{-}l] \leftarrow C[A[\,i]\text{-}l] + 1$

Loop 2: count



Sum the frequency of each number

2. **for** $i \leftarrow 0$ **to** $n\text{-}1$

  do $C[A[\ i]\text{-}l] \leftarrow C[A[\ i]\text{-}l] + 1$

Loop 3: compute running sum

A:	4	1	3	4	3

	1	2	3	4
C:	1	0	2	2

j

S:					

C:	1	1	2	2

Reserve index in ‘S’ for each set of numbers

3.**for** $j \leftarrow 1$ **to** $u\text{-}l$

do $C[j] \leftarrow C[j\text{-}1] + C[j]$

Loop 3: compute running sum

A:

4	1	3	4	3

C:

1	2	3	4
1	1	2	2

j

S:

C:

1	1	3	2

Reserve index in ‘S’ for each set of numbers

3. **for** $j \leftarrow 1$ **to** $u\text{-}l$
  do $C[j] \leftarrow C[j\text{-}1] + C[j]$

Loop 3: compute running sum

A:

4	1	3	4	3

C:

1	2	3	4
1	1	3	2

j

S:

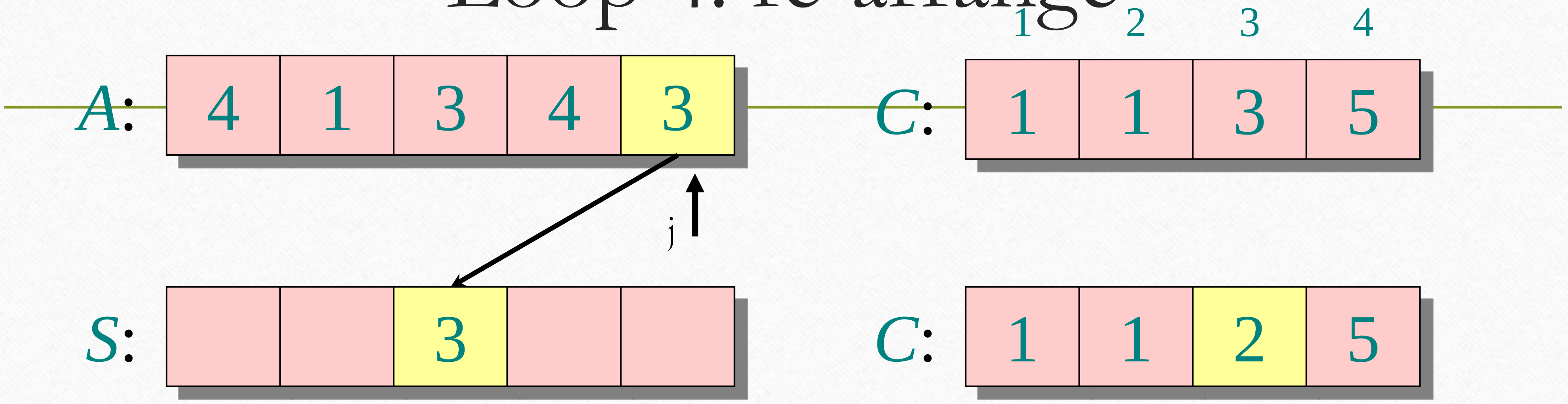
C:

1	1	3	5

Reserve index in ‘S’ for each set of numbers

3. **for** $j \leftarrow 1$ **to** $u\text{-}l$
   do $C[j] \leftarrow C[j\text{-}1] + C[j]$

Loop 4: re-arrange



4. **for** $i \leftarrow n\text{-}1$ **downto** 0

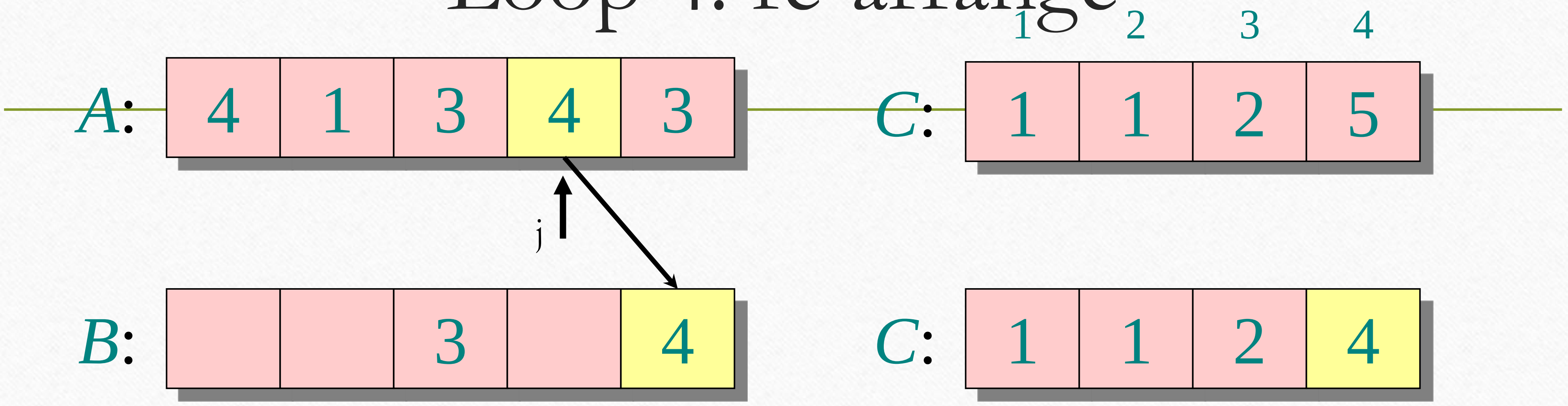
do $j \leftarrow \mathrm{A}[\,i]\text{-}\,l$

$S[C[\,j]\ \text{-}1] \leftarrow \mathrm{A}[\,i]$

$C[\,j] \leftarrow C[\,j] - 1$

Decrement reserved count and add to array 'S'

Loop 4: re-arrange



4. for $i \leftarrow n\text{-}1$ **downto** 0

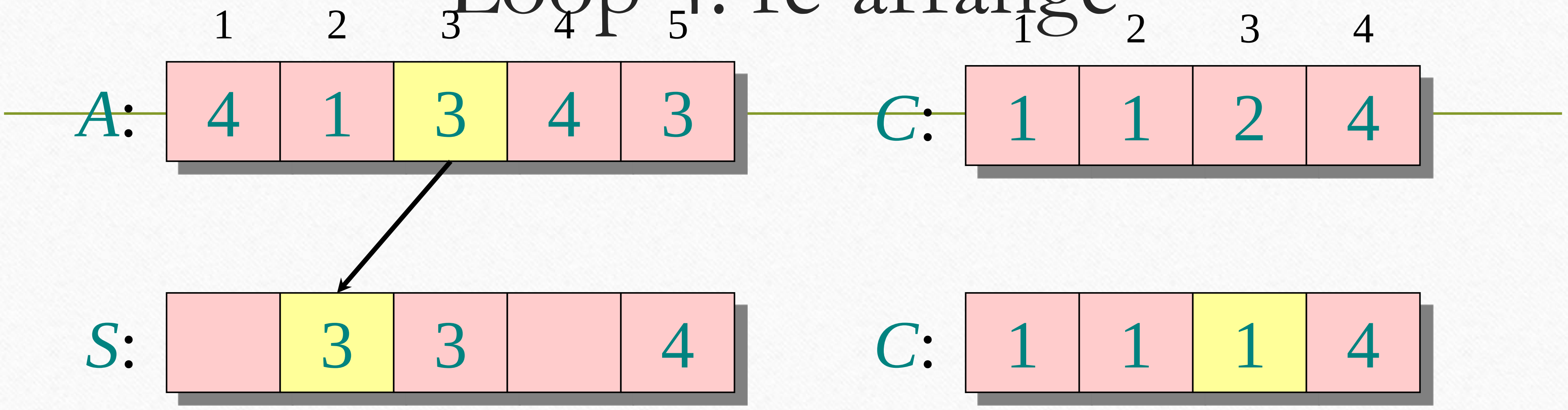
do $j \leftarrow A[i] - 1$

$S[C[j]-1] \leftarrow A[i]$

$C[j] \leftarrow C[j] - 1$

Decrement reserved count and add to array 'S'

Loop 4: re-arrange



4. for $i \leftarrow n\text{-}1$ **downto** 0

do $j \leftarrow A[i] - l$

$S[C[j]-1] \leftarrow A[i]$

$C[j] \leftarrow C[j] - 1$

Decrement reserved count and add to array ‘S’

Loop 4: re-arrange

	1	2	3	4	5
A:	4	1	3	4	3

	1	2	3	4
C:	1	1	1	4

S:	1	3	3		4

C:	0	1	1	4

4. **for** $i \leftarrow n\text{-}1$ **downto** 0
   do $j \leftarrow \mathrm{A}[\,i] - l$
   $S[C[\,j]\ \text{-}1] \leftarrow \mathrm{A}[\,i]$
   $C[\,j] \leftarrow C[\,j] - 1$

Decrement reserved count and add to array 'S'

Loop 4: re-arrange

	1	2	3	4	5
A:	4	1	3	4	3
S	1	3	3	4	4

	1	2	3	4
C:	0	1	1	4
C:	0	1	1	3

4. **for** *i* ← *n-1* **downto** 0
   do *j* ← A[*i*]- *l*
   S[*C*[*j*] -1] ← A[*i*]
   C[*j*] ← *C*[*j*] – 1

Decrement reserved count and add to array ‘S’

Algo DistributionCountingSort (A[0.. n-1])

$O(u)$ { **for** $j \leftarrow 0$ **to** u-l **do**

$C[j] \leftarrow 0$

$O(n)$ { **for** $i \leftarrow 0$ **to** n-1 **do**

$C[A[\,i]-l] \leftarrow C[A[\,i]-l] + 1$

$O(u)$ { **for** $j \leftarrow 1$ **to** u-l **do**

$C[j] \leftarrow C[j-1] + C[j]$

for $i \leftarrow n$-1 **downto** 0 **do**

$O(n)$ { $j \leftarrow A[\,i] - l$

$S[C[\,j] - 1] \leftarrow A[\,i]$

$C[\,j] \leftarrow C[\,j] - 1$

$O(n + u)$ **return S**

u = largest number in 'A'

n = length of 'A'

Distribution Counting Sort

Analysis

- As long as the ***range of valid input values is roughly less than or equal to the number of input values (n)***, **the algorithm is O(n)**

Whiteboard

this is very good efficiency, better than mergesort

Space-for-time tradeoffs varieties

1. **Input enhancement:** preprocess the input to store some info to be used later in solving the problem
    - Comparison Counting Sort
    - Distribution Counting Sort
    - String Matching

2. **Pre-structuring:** uses extra space to facilitate faster access to the data.
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String Matching: reminder

<u>Pattern</u>: a string of *m* characters to search for

<u>Text:</u> a (long) string of *n* characters to search in

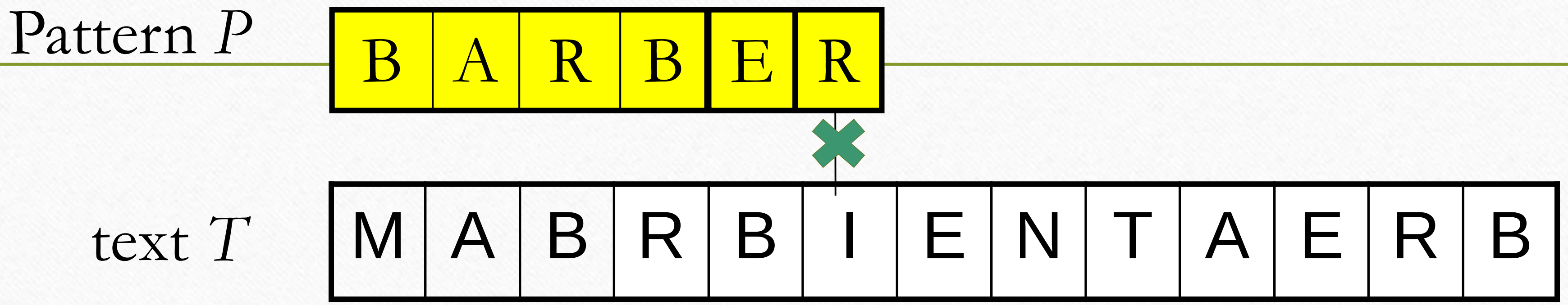
- **Brute force algorithm:**
    1. Align pattern at beginning of text
    2. Moving from left to right, compare each character of pattern to the corresponding character in text until
        - All characters are found to match (successful search); or
        - A mismatch is detected
    3. While pattern is not found and the text is not yet exhausted, realign pattern one position to the right and repeat step 2.
- **Time Complexity: O(n-m+1)× m**

Input Enhancement in String Matching

How can we improve string matching by using the concept of input enhancement?

- **key observation:** each time we have a "mismatch" (ie: a pattern char doesn't match the corresponding text char), we *may be able to shift more than one character* before starting to compare again

Input Enhancement in String Matching



- *Comparing the chars from* ***right to left***
- *There is no "I" in BARBER, so we should shift the pattern all the way past the "I"*
- Determines the umber of shifts by looking at the character of the text that is aligned against the last character of the pattern

String Matching: Key Observation

- Consider, as an example, searching for the pattern BARBER in some text:

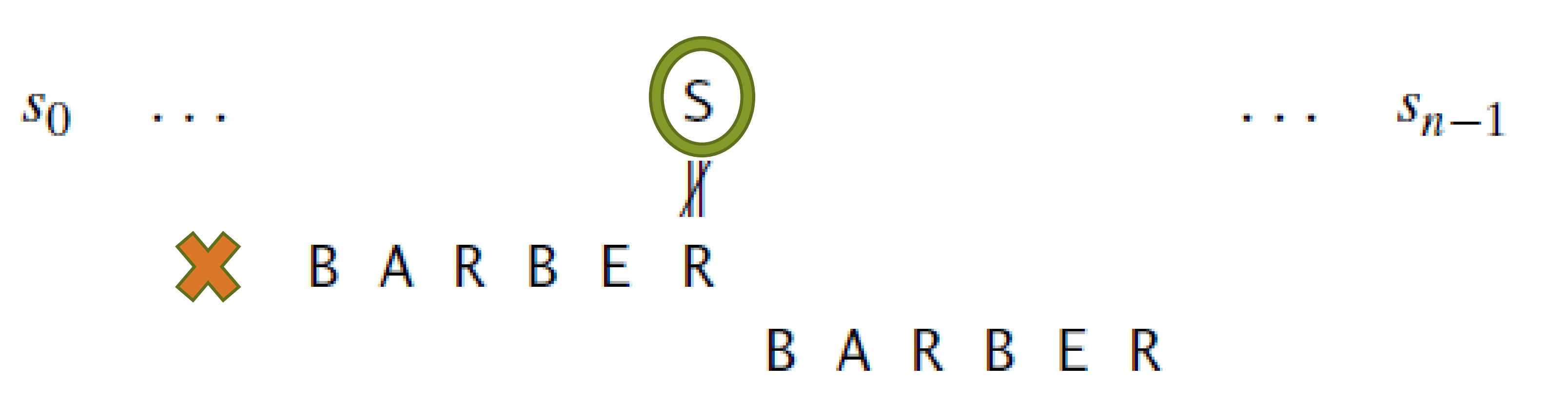
$$s_0 \quad \ldots \qquad\qquad\qquad\qquad c \quad \ldots \quad s_{n-1}$$

$$\mathrm{B\ A\ R\ B\ E\ R}$$

Starting with the last R of the pattern and moving right to left if a mismatch occurs shift to right by looking at character c

String Matching: Input Enhancement Cases

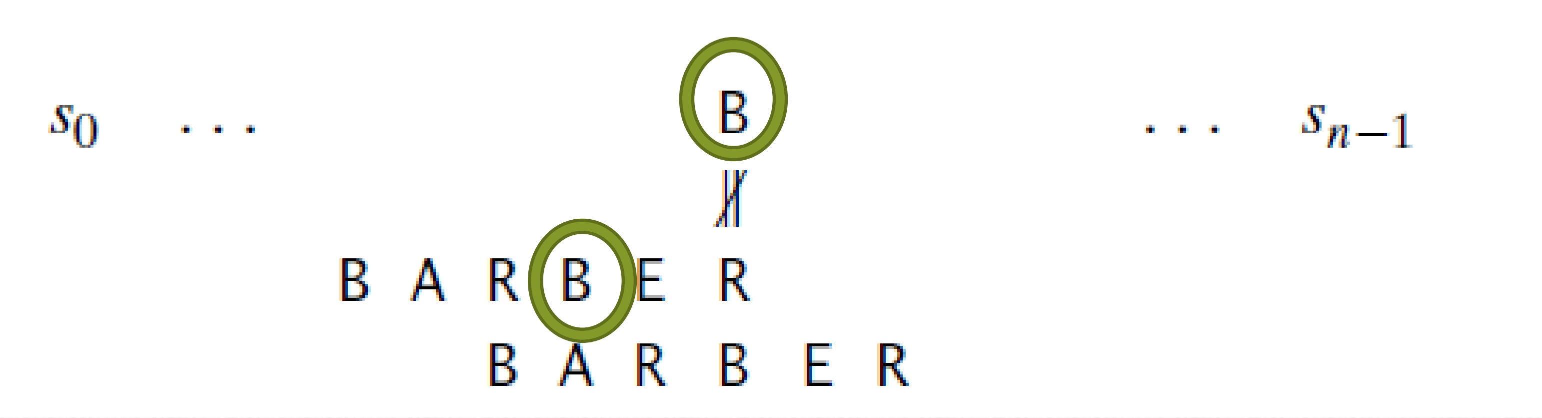
- Case1: If there is no character c in the pattern



shift the pattern by its entire length because ‘S’ isn’t in BARBER

String Matching: Input Enhancement Cases

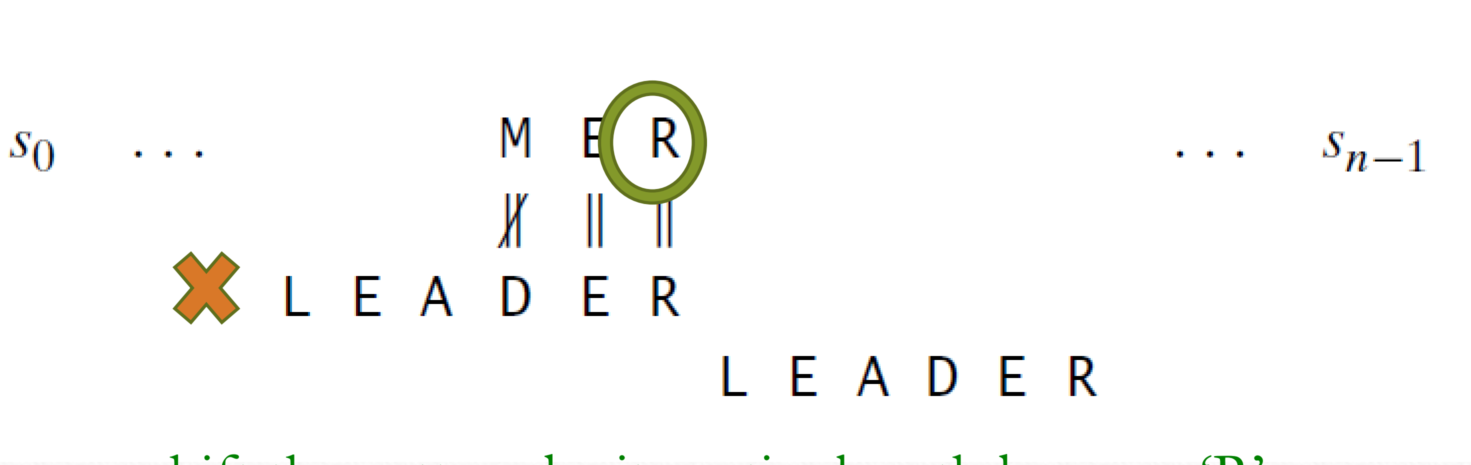
- Case2: If there are occurrences of character c in the pattern but it is not the last one there



shift to align the rightmost occurrence of c in the pattern with the c in the text

String Matching: Input Enhancement Cases

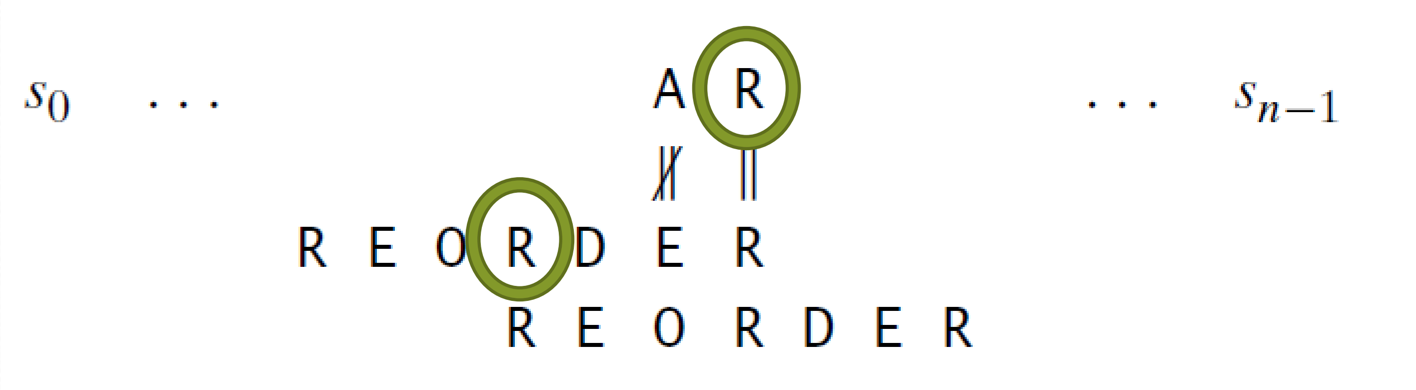
- Case3: If *c* is the last char in the pattern, and occurs only once in the pattern



shift the pattern by its entire length because ‘R’ appears only once in the pattern.

String Matching: Input Enhancement Cases

- Case4: if c the last char in the pattern, and occurs multiple times in the pattern



shift to align the rightmost occurrence of ‘R’ in the pattern with the ‘R’ in the text

The Strategy

- How can we use this observation for input enhancement?
- Strategy:
    - we are going to create a “shift table”.
        - It will have one entry for each possible value in the *input alphabet*
    - shift table will indicate the number of positions to shift the pattern to aling the next possible match.

Table	2	5	7	2	7	7	3	…	7	4	7
	0	1	2	3	4	5	6		23	24	25
	“A”	“B”	“C”	“D”	“E”	“F”	“G”		“x”	“y”	“z”

The Shift Table

- How to construct the shift table:
  - it will have a size equal to the number of elements in the input alphabet (so we have to know this in advance!)

Value in table =

- distance from *c*'s rightmost occurrence in pattern (length – index – 1)
- pattern's length *m*, if last character in pattern

The Shift Table

- Example: assume our pattern is IDIGDAB (m=7)

  Value in table =

  - distance from *c*'s rightmost occurrence in pattern (m – index in pattern – 1)
  - pattern's length *m*, if last character in pattern

Table

7-2-1 = 4	7-4-1 = 2	7-3-1 = 3	7-5-1 = 1	7	7
0	**1**	**2**	**3**	**4**	**5**
"I"	"D"	"G"	"A"	"B"	"*"

I D I G D A B

i i i i i i i

The Shift Table

- Example: assume our pattern is IDIGDAB (m=7)

  Value in table =

  - distance from *c*'s rightmost occurrence in pattern (m – index in pattern – 1)
  - pattern's length *m*, if last character in pattern

Table	4	2	3	1	7	7
	0	1	2	3	4	5
	"I"	"D"	"G"	"A"	"B"	"*"

Using the shift table ...

- Example: there is a mismatch on the first compare, so we lookup **table["D"]**, which returns **2**, so we shift by 2 ...

Pattern P

I	D	I	G	D	A	B

text T

I	B	A	G	H	J	D	A	B	A	D	A	B

I	D	I	G	D	A	B

Table	4	2	3	1	7	7
	0	1	2	3	4	5
	"I"	"D"	"G"	"A"	"B"	"*"

Using the shift table …

- Example: there is a mismatch, so we lookup **table["B"]**, which returns **7**, so we shift by 7 .

text T

I	B	A	G	H	J	D	A	B	A	D	A	B

I	D	I	G	D	A	B

We look up 'B' not 'J' because B is the last letter compared to the pattern.
In other words, there is no B in the rest of the pattern, so move the entire length

Table	4	2	3	1	7	7
	0	1	2	3	4	5
	"I"	"D"	"G"	"A"	"B"	"*"

Note: the algorithm is spelled out in detail in your textbook.

(it is called Horspool's algorithm)

A great video can be found here: https://youtu.be/PHXAOKQk2dw

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Fast Storage of Keyed Records

Goal: want some way to do fast storage/lookups/retrieval of information, based on an arbitrary key

eg:
```
key = A00043526
value = Jimmy
```

Let's consider traditional data structures …

<u>Array:</u>How would you use an array (or arrays) to store this

- use either 2 1D arrays or 1 2D array or an array of objects
  - store key in a sorted array (for fast retrieve)
  - use the second array (or column) to store the record or a pointer to the record … or …
- alternatively, create an object 'Employee', and store in an array of objects

Using Sorted Array

2 1D Array ...

1	A00043522
2	A00666666
3	
4	
	⋮
n-1	
n	

1	Bob
2	beelzebub
3	
4	
	⋮
n-1	
n	

1 2D Array ...

1	A00043522	Bob
2	A00666666	beelzebub
3		
4		
	⋮	⋮
n-1		
n		

Using Sorted Array (2)

Inserting a new element … eg: ***`insert(A00099999, "foo")`***

1	A00043522	Bob
2	A00066666	beelzebub
3	A00100000	186A0
4	A00111111	jimmy
5	A00123456	n(n+1)/2
6	A00444444	bertcubed
7	A00666666	Beelzebub
8		
9		
10		

Using Sorted Array (3)

Inserting a new element ... eg: ***`insert(A00099999, "foo")`***

1	A00043522	Bob
2	A00066666	beelzebub
3	A00100000	186A0
4	A00111111	jimmy
5	A00123456	n(n+1)/2
6	A00444444	bertcubed
7	A00666666	Beelzebub
8		
9		
10		

```
find location
    - (use binary search)
    - O(logn) operation
```

Using Sorted Array (4)

Inserting a new element … eg: ***`insert(A00099999, "foo")`***

1	A00043522	Bob
2	A00066666	beelzebub
3		
4	A00100000	186A0
5	A00111111	jimmy
6	A00123456	n(n+1)/2
7	A00444444	bertcubed
8	A00666666	Beelzebub
9		
10		

```
find location
      - (use binary search)
      - O(logn) operation

create space
      - (move existing elements)
      - O(n) operation
```

Using Sorted Array (5)

Inserting a new element ... eg: ***insert(A00099999, "foo")***

1	A00043522	Bob
2	A00066666	beelzebub
3	A00099999	foo
4	A00100000	186A0
5	A00111111	jimmy
6	A00123456	n(n+1)/2
7	A00444444	bertcubed
8	A00666666	Beelzebub
9		
10		

```
find location
     - (use binary search)
     - O(logn) operation
create space
     - (move existing elements)
     - O(n) operation
put the new element
     - direct access to array
     - O(1) operation
```

Overall efficiency is:

O(logn)+O(n)+O(1) = O(n)

Using Sorted Array (6)

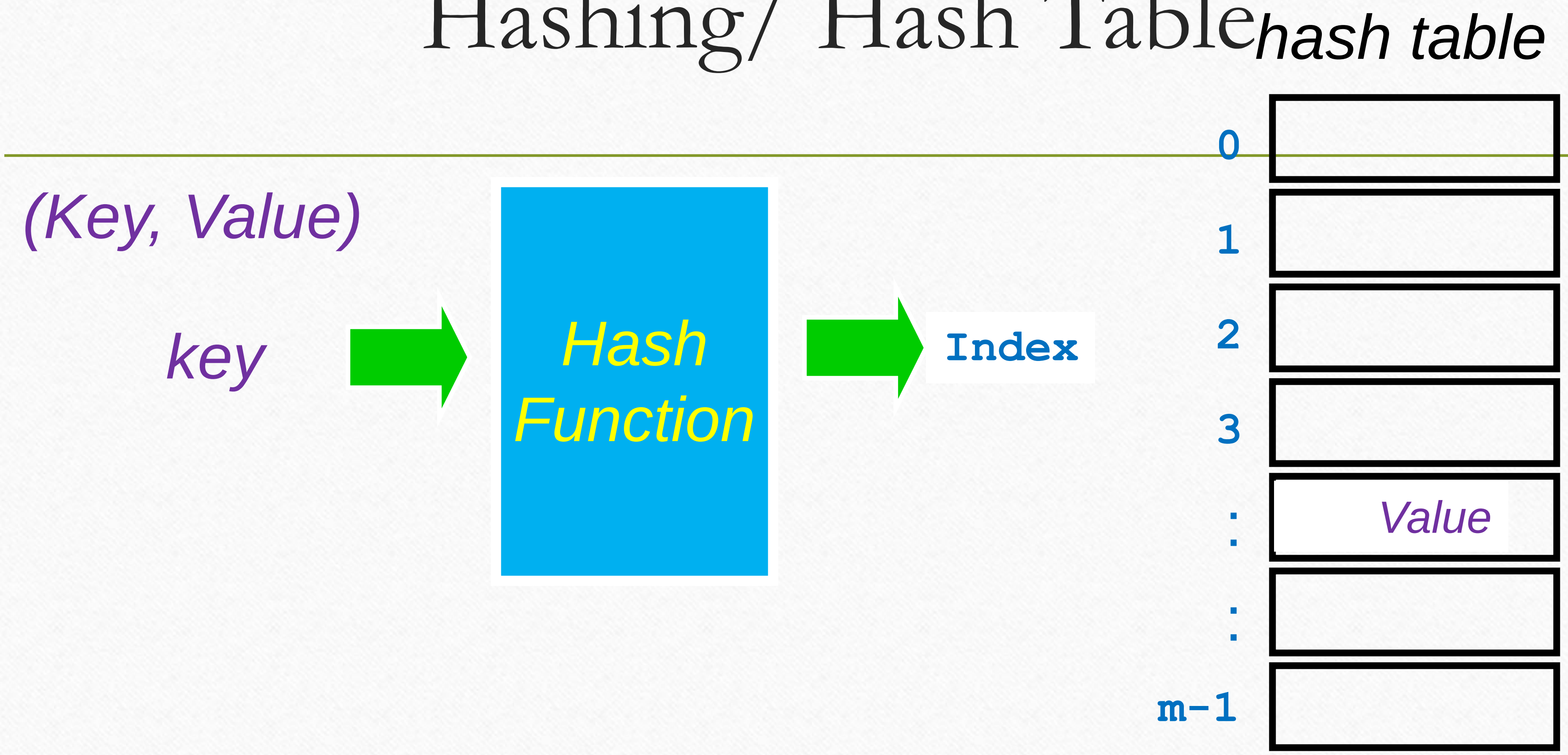
- *Search* operation is $\boldsymbol{O(logn)}$
- *Retrieval* is $\boldsymbol{O(logn)}$
- *Deletion* is $\boldsymbol{O(n)}$

What if we use an unsorted Array:

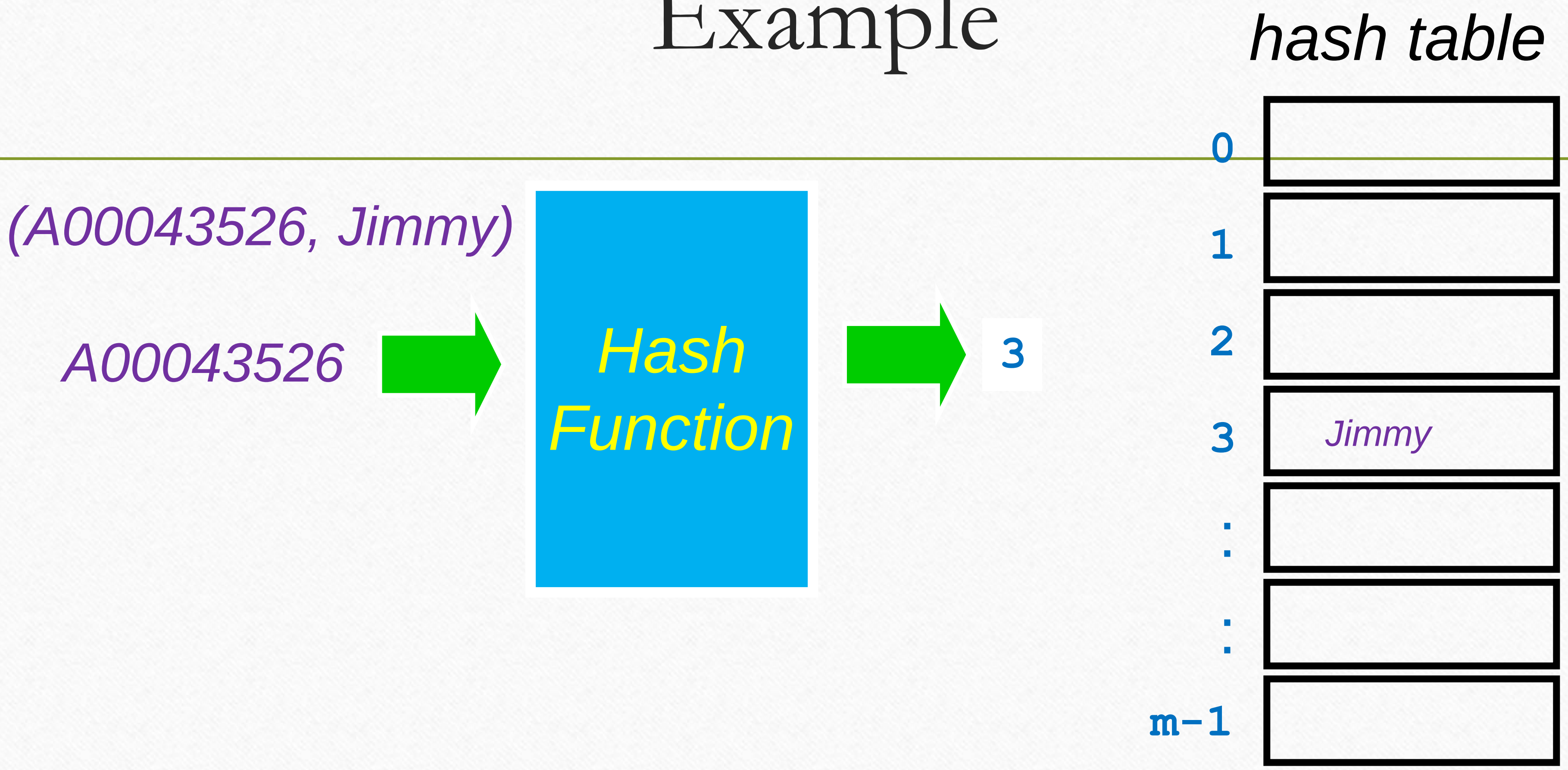
- *Insertion* will be much faster – O(1)
- *Searching, retrieve* will be slower – O(n)
- *Deletion* will be the same O(n)

- *So how to get better performance … ?*
    - *Hashing*

Hashing/ Hash Table



Example



(A00043526, Jimmy)
A00043526
Hash Function
3
hash table
0
1
2
3
Jimmy
:
:
m-1

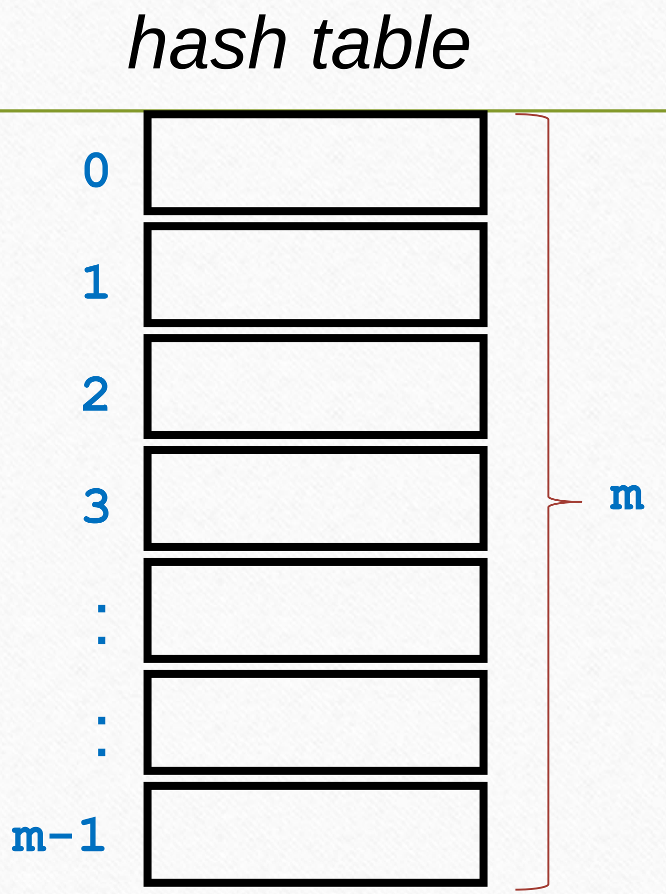
Hashing

- Each item has a unique key.
- Use a large array called a Hash Table.
- Use a Hash Function that maps keys to a index in the Hash Table.

```
f(key) = index
```

Hash Functions

Common hash function for numerical keys

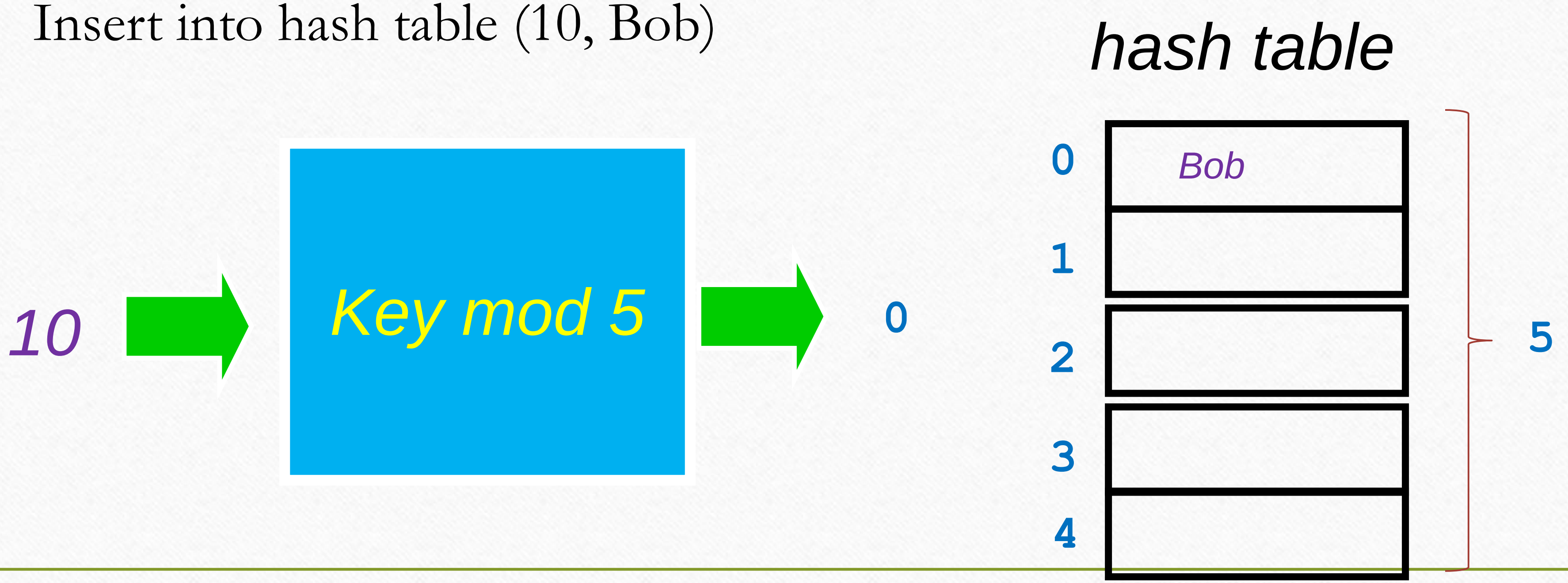


Hash Functions

Example

assume m=5

Insert into hash table (10, Bob)



Hash Functions

- What do we do if our key is not a number?
  - *answer: map it to a number!*

- Example

assume m=5

Insert into hash table (Emily, 6046321)

Hash Functions

Example

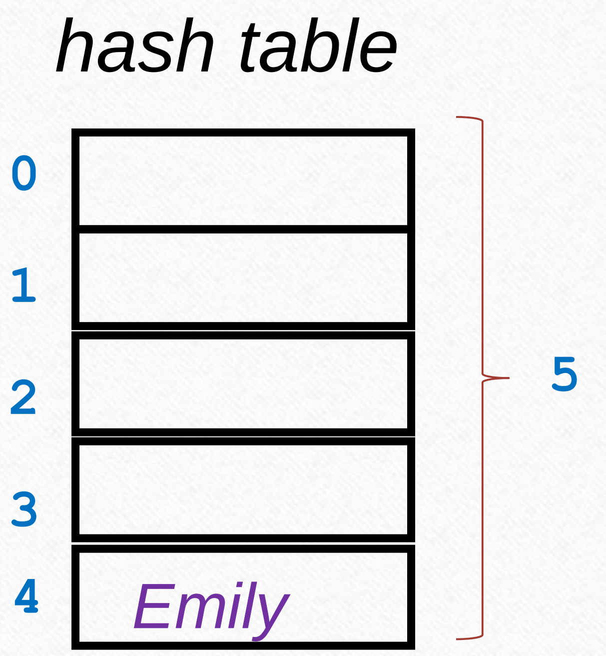
assume m=5

Insert into hash table (Emily, 6046321)

Emily → *ord(e) +ord(m) + ord(i) + ord(l)+ ord(y)=*

5+ 13+ 9 + 12+ 25 =

64 → **Key mod 5** → 4



Hash Functions

- Sample Hash function for the keys that are not number

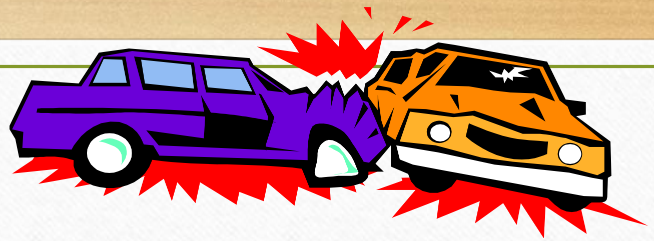
```
h ← 0                          // input is a string S of length s
for i ← 0 to s-1 do            // cᵢ is the char in iᵗʰ posn i of S
    h ← h + ord(cᵢ)            // ord(cᵢ) is the relative posn ...
                               // ... of cᵢ in the alphabet
hashcode ← h mod numBuckets    // map sum of posns into range
```

the actual hashcode depends on the number of buckets

Space-for-time tradeoffs varieties

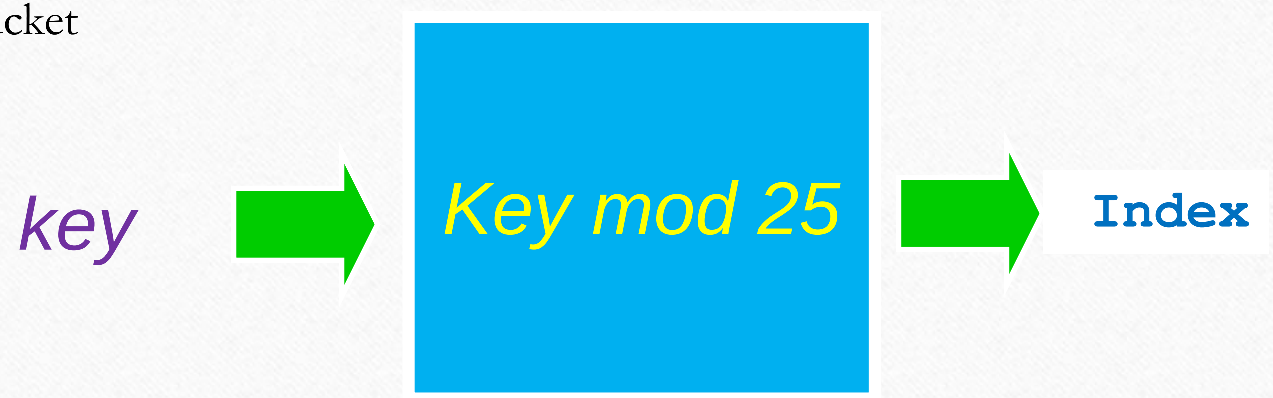
1. **Input enhancement:** preprocess the input to store some info to be used later in solving the problem
   - Comparison Counting Sort
   - Distribution Counting Sort
   - String Matching

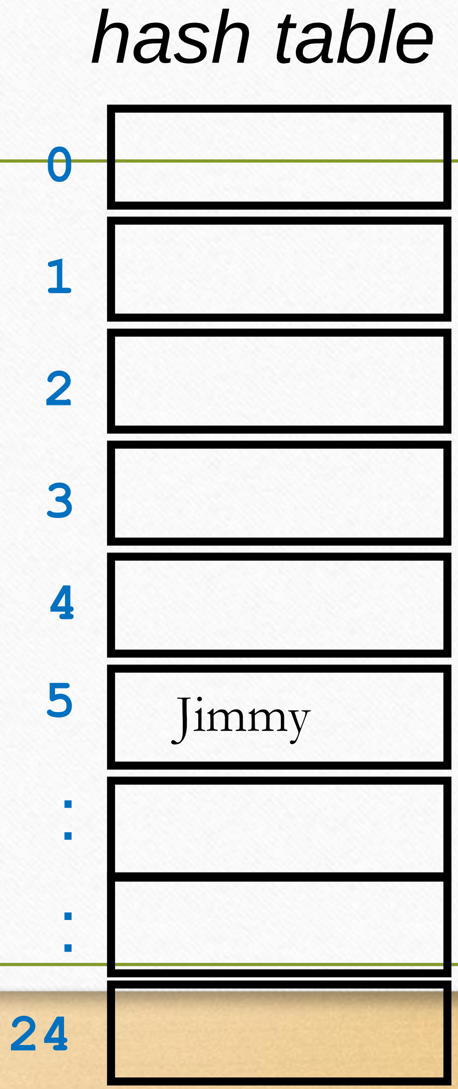
2. **Pre-structuring:** uses extra space to facilitate faster access to the data.
   - Hashing
   - Hash Function
   - Collision Handling
   - Efficiency of Hashing



Collisions

Collisions occur when different keys are mapped to the same bucket





1.Insert into hash table (30, Jimmy)
index = 30 mod 25 = 5

2. Insert into hash table (105, Anthony)
index = 105 mod 25 = 5

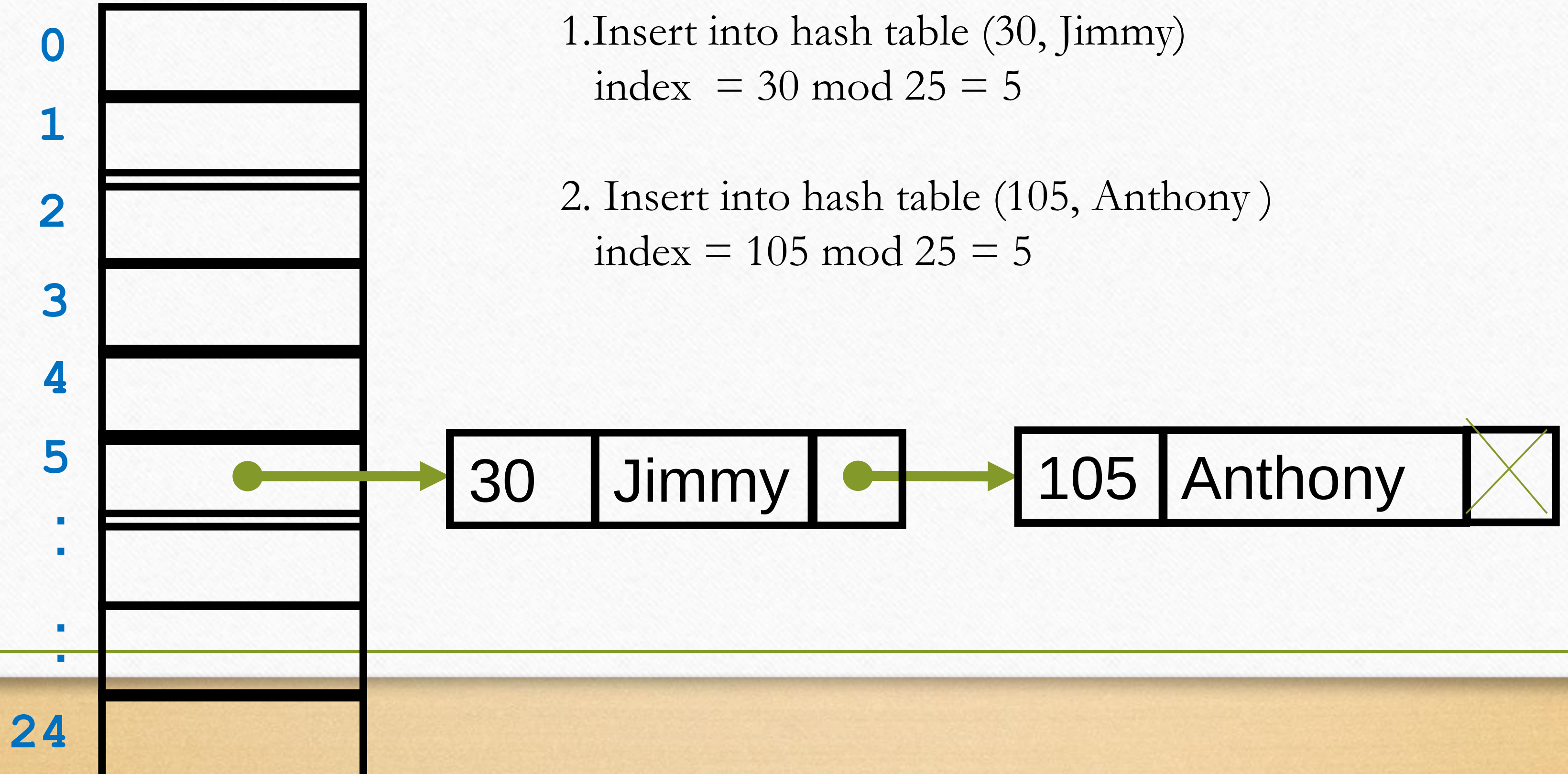
Collisions Handling

Two way to handle collision:

1. Separate Chaining
2. Closed Hashing

Collisions Handling (Separate Chaining)

- Each bucket in the table point to a list of entries that map there



1.Insert into hash table (30, Jimmy)
index = 30 mod 25 = 5

2. Insert into hash table (105, Anthony)
index = 105 mod 25 = 5

Separate Chaining
Exercise 1

- Use the hash function h(i) = i mod 7
- Draw the Separate chaining hash table resulting from inserting following keys and values:

(44, name1)

(12, name2)

(23, name3)

(16, name4)

(5, name5)

(28, name6)

Separate Chaining
Exercise 1

(44, name1)

(12, name2)

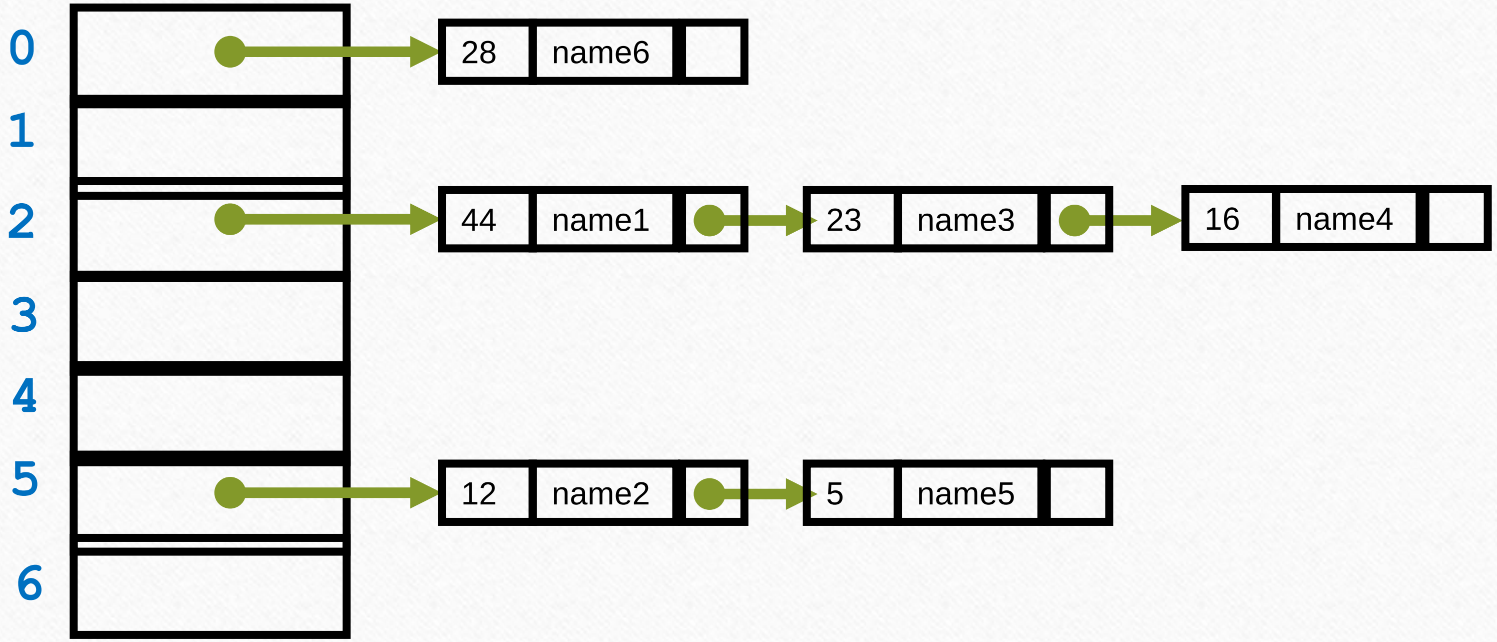
(23, name3)

(16, name4)

(5, name5)

(28, name6)

hash function h(i) = i mod 7

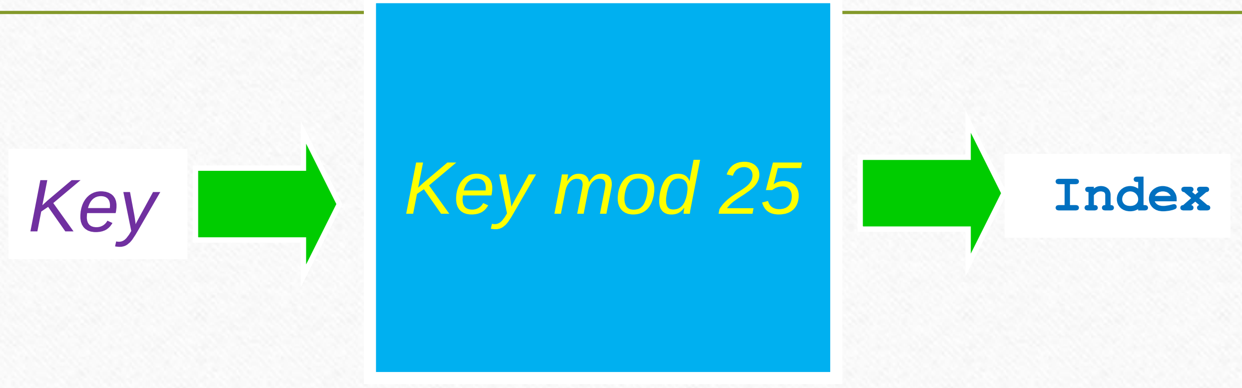


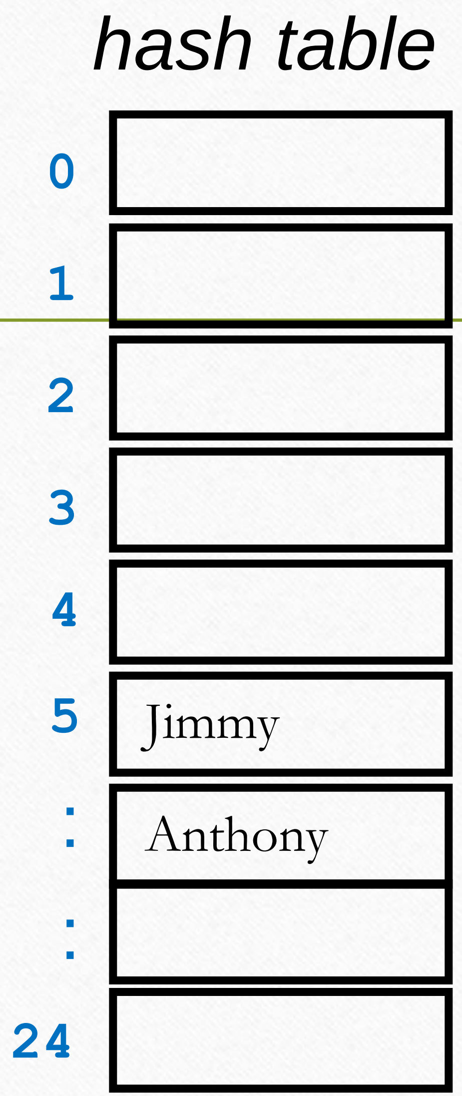
Closed Hashing

- It works like this:
  - compute the hash
  - if the bucket is empty, store the value in it
  - if there is a collision, linearly scan for next free bucket and put the key there
    - note: treat the table as a circular array

- Note: important - with this technique the size of the table must be at least n (or there would not be enough room!)

Closed Hashing





1.Insert into hash table (30, Jimmy)
index = 30 mod 25 = 5

2. Insert into hash table (105, Anthony)
index = 105 mod 25 = 5

Closed Hashing Exercise

- Use the hash function h(i) = i mod 10
- Draw the hash table resulting from inserting following key and values:

(44, name1)

(12, name2)

(13, name3)

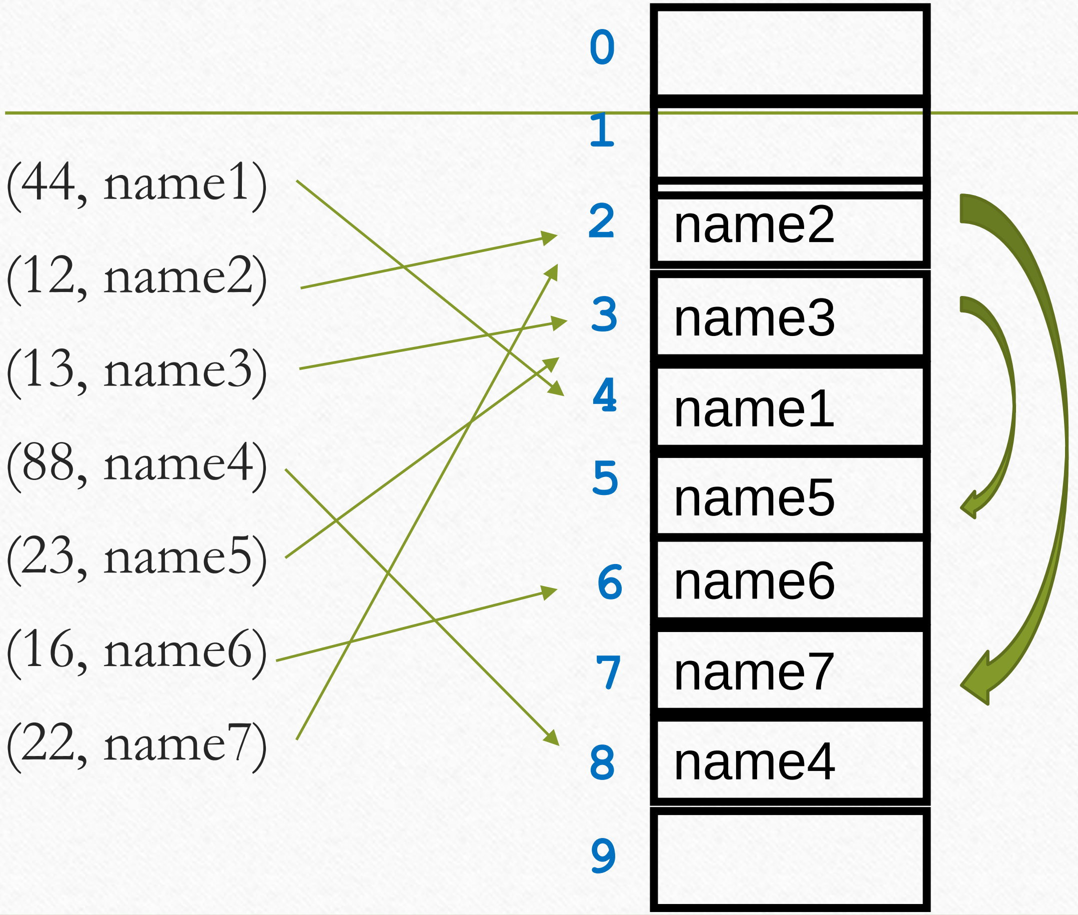
(88, name4)

(23, name5)

(16, name6)

(22, name6)

Closed Hashing Exercise



hash function h(i) = i mod 10

Space-for-time tradeoffs varieties

1. **Input enhancement:** preprocess the input to store some info to be used later in solving the problem
    - Comparison Counting Sort
    - Distribution Counting Sort
    - String Matching

2. **Pre-structuring:** uses extra space to facilitate faster access to the data.
    - Hashing
    - Hash Function
    - Collision Handling
    - Efficiency of Hashing

Efficiency of Hashing

What is the efficiency of the hashtable structure?

- **add**(key, value) ... is $\boldsymbol{O(1)}$
- value ← **get**(key) ... is $\boldsymbol{O(1)}$
- **delete**(key) ... is $\boldsymbol{O(1)}$

- of course there could always be a degenerate case, where every insert causes a collision ... in this case we would end up with O(n)

→ ***conclusion : implementation of the hashing function is important***

→ ***it must distribute the keys evenly over the buckets***

Hash Functions

- the efficiency of hashing depends on the quality of the **hash function**

A "good" hash function will

1. distribute the keys uniformly over the buckets
2. produce very different hashcodes for similar data

- hashing of numbers is relatively easy, as we just distribute them over the buckets with

key mod *numBuckets*

Hashing Strings

- most keys are Strings, and Strings are a bit trickier
  - consider the algo (from the book):

```
h ← 0
for i ← 0 to s-1 do
     h ← h + ord(ci) // ord(ci) is the relative posn of char i
code ← h mod numBuckets
```

- Is that a good hash function? (think about anagrams)
  - sample: assume numbuckets = 99
    - hash("dog") = 26
    - hash("god") = 26
    - hash("add") = 9
    - hash("dad") = 9

Better String Hash Function

- a better hashcode algorithm for strings

```
alpha  ← |alphabet|  // size of the alphabet used
h ← 0
for i ← 0 to s-1 do
    h ← h + (ascii(c_i) * alpha^(i))
code ← h mod numBuckets
```

  - Assuming alpha = 128 (number of ascii codes)
  - Assuming numbuckets = 99
    - dog = 64
    - god = 46
    - add = 26
    - dad = 65

Java's String.hashCode()

No need to memorize this.

```
public int hashCode() {
    int h = 0;                  // the final hashcode
    int off = 0;                // offset in to the string
    char val[] = value;         // put the string in an array
    of char
    int len = count;
    if (len < 16) {
      for (int i = len ; i > 0; i--) {
          h = (h * 37) + val[off++];
      }
    } else { // only sample some characters
      int skip = len / 8;
      for (int i=len ; i>0; i-=skip, off+=skip) {
          h = (h * 39) + val[off];
      }
    }
    return h;
 }
```

Java’s String.hashCode()

- Java’s hashcode() produces the following results …
    - dog = 9
    - god = 90
    - add = 50
    - dad = 59

Try it/ homework

1. Chapter 7.1, page 257, questions 3, 7
2. Chapter 7.2, page 267, question 1,2
3. Chapter 7.3, page 275, question 1,2,7

Hashing Exercise 3

- Devise an hash function to map the keys to buckets
- Draw a 10-element hashmap resulting from hashing of the keys using your hash function
- Use separate chaining for handling collision

```
a8s:elvis
se3:weasil
22a:pepper
14c:chili
aba:pretzel
1s1:elvis
d6e:angus
```

Hashing Exercise 3 (solution part 1)

One possible algorithm is similar to the one discussed earlier for strings, but we don't take the ordinal value for integers (ie: the char "4" is just assigned the integer value 4)

For example: the string c7 is Ord("c") + 7 = 3+7 = 10

Using this algorithm we get:

KEY VALUE	ORD SUM	HASHCODE
a8s:elvis	1+8+19=28	28 mod 10 = 8
se3:weasil	19+5+3=27	27 mod 10 = 7
22a:pepper	2+2+1=5	5 mod 10 = 5
14c:chili	1+4+3=8	8 mod 10 = 8
aba:pretzel	1+2+1=4	4 mod 10 = 4
1s1:elvis	1+19+1=21	21 mod 10 = 1
d6e:angus	4+6+5=15	15 mod 10 = 5

a=1
b=2
c=3
d=4
e=5
f=6
g=7
h=8
i=9
j=10
k=11
l=12
m=13
n=14
o=15
p=16
q=17
r=18
s=19
t=20
u=21
v=22
w=23
x=24
y=25
z=26

Hashing Exercise 3 (solution part 2)

- now we draw the hashmap
  - we will need to store the keys as well as the values …