CSCI 232:
Data Structures and Algorithms

Hashing (Part 1)

Reese Pearsall

Spring 2025

Map / Dictionary

A **map** or **dictionary** is an unordered collection of key/value pairs.

Maps a **key** to a **value**

Keys		Values
Dallas	→	Cowboys
Chicago	→	Bears
New England	→	Patriots
Denver	→	Broncos
Pittsburgh	→	Steelers
Kansas City	→	Chiefs
Miami	→	Dolphins
Tennessee	→	Titans
New York	→	Giants
Buffalo	→	Bills
Atlanta	→	Falcons

General Rules

1. Keys should not be shared
(no duplicate keys)

New York : Jets
New York : Giants

1. Keys should not be mutable

String 
int 
double 

Arrays 
Objects 

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Implementation?

General Rules

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   (no duplicate keys)

   New York : Jets
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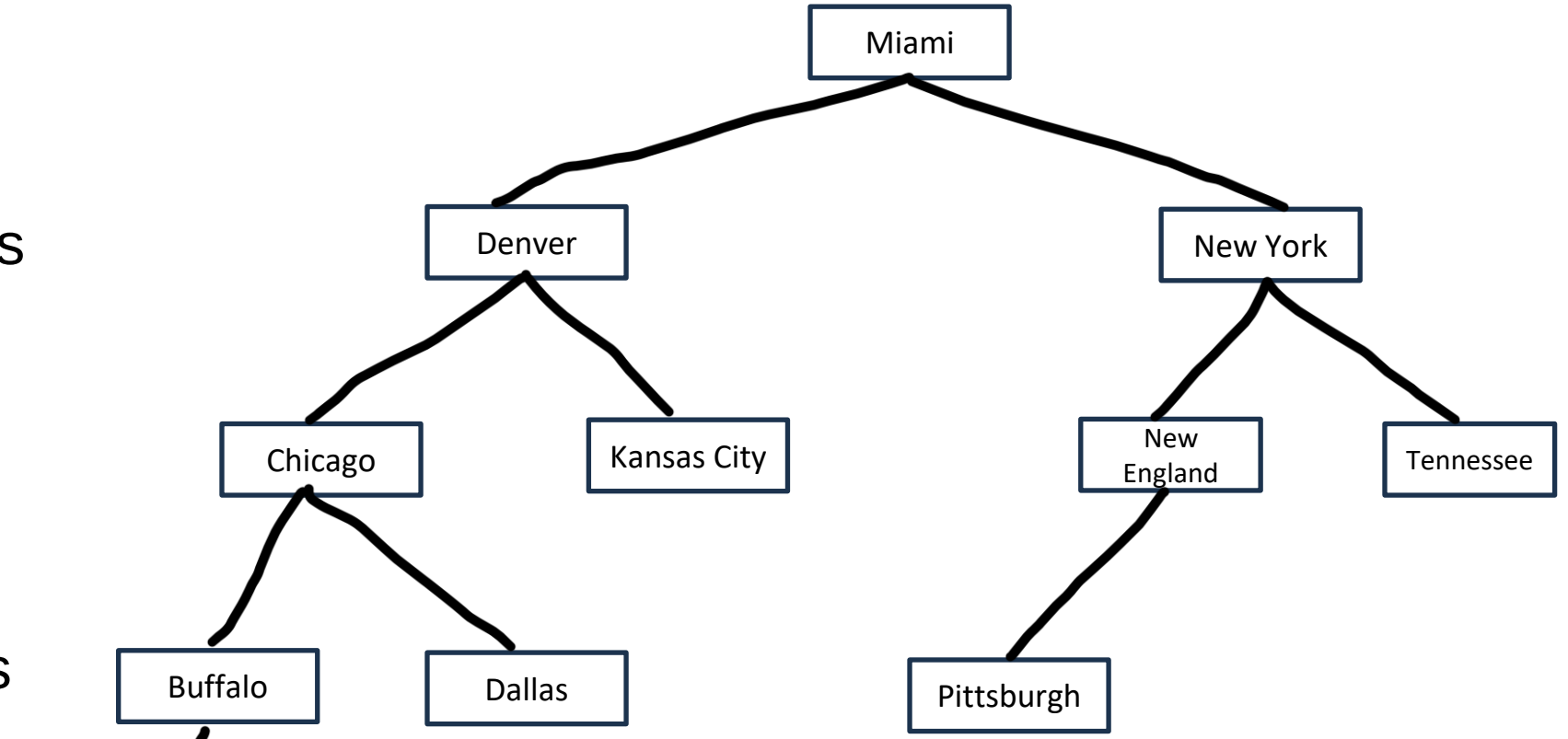


```
public class Node{
    private Node parent
    private Node leftChild
    private Node rightChild

    private String key;
    private String value;
```

Map / Dictionary

Keys		Values
Dallas	→	Cowboys
Chicago	→	Bears
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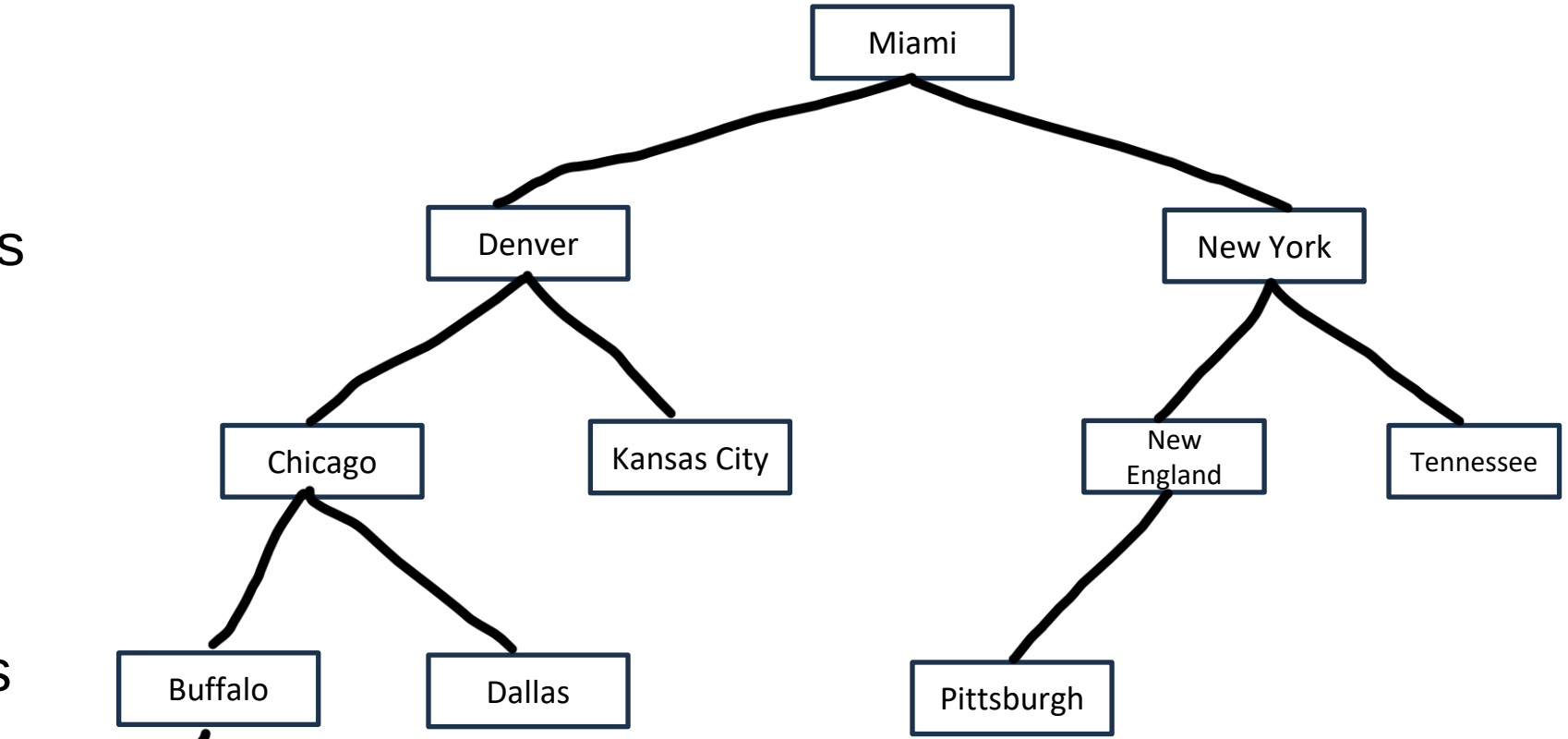
1. Build a BST based on Node key

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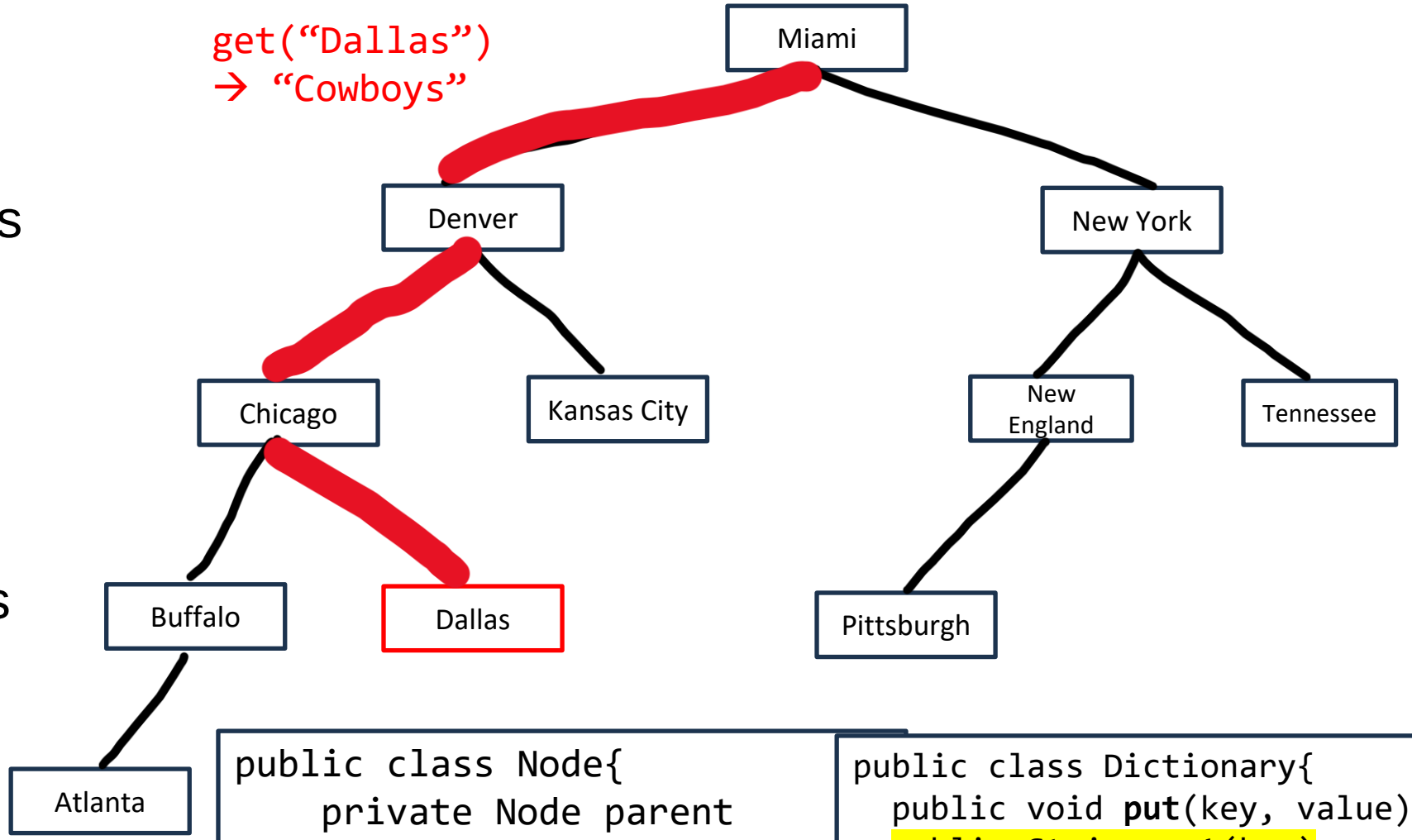
1. Build a BST based on Node key
2. Search for value using BST, return value of Node




```
public class Node{
    private Node parent
    private Node leftChild
    private Node rightChild

    private String key;
    private String value;
```

```
public class Dictionary{
  public void put(key, value)
  public String get(key)
  public void delete(key)
  …
}
```

Map / Dictionary

Keys → **Values**

Dallas → Cowboys

Chic

New

Den

Pitts

Kan

Mia

Ten

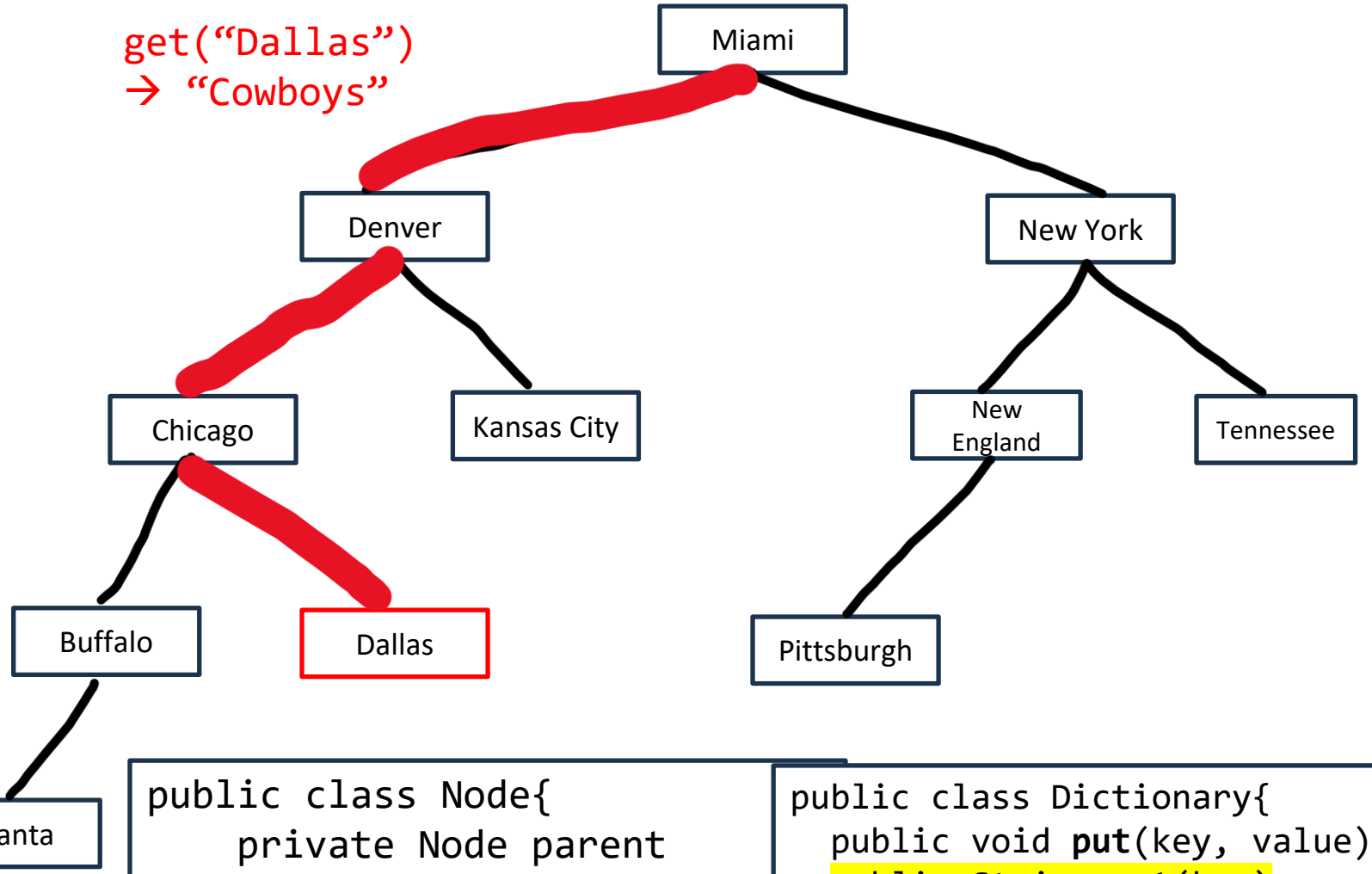
New

Buffalo → Bills

Atlanta → Falcons

Lookup time?

O(log n)



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    private String key;
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public class Dictionary{
  public void put(key, value)
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  public void delete(key)
  …
}
```

Pokedex

Key (Pokemon #)	**Value** (Pokemon)
1	Bulbasaur
2	Ivysaur
3	Venasaur
…	…
98	Krabby
99	Kingler

Pokedex

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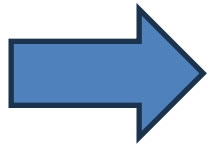
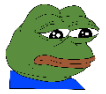


Index	
0	 (null)
1	Bulbasuar
2	Ivysaur
3	Venasaur
…	…
98	Krabby
99	Kingler

Pokedex

Key (Pokemon #)	**Value** (Pokemon)
1	Bulbasaur
2	Ivysaur
3	Venasaur
…	…
98	Krabby
99	Kingler

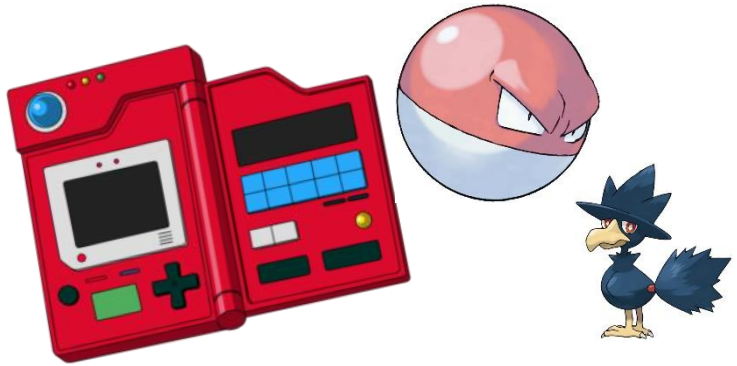
Lookup time?

O(1) !!

Index	
0	 (null)
1	Bulbasuar
2	Ivysaur
3	Venasaur
…	…
98	Krabby
99	Kingler

Pokedex

Key (Pokemon #)	Value (Pokemon)
100	Voltorb
101	Electrode
102	Exeggcute
…	…
198	Murkrow
199	Slowking



Index	
0	null
…	…
99	null
100	Voltorb
101	Electrode
102	Exeggcute
103	Exeggutor
…	…
198	Murkrow
199	Slowking

Pokedex

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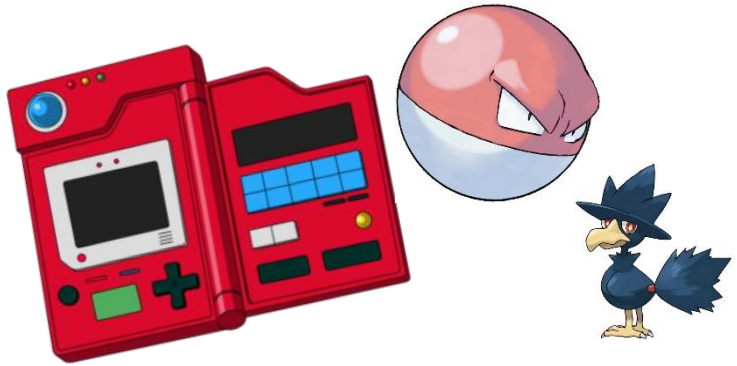

Lots of wasted space that won't be used… not ideal

Index	
0	null
…	…
99	null
100	Voltorb
101	Electrode
102	Exeggcute
103	Exeggutor
…	…
198	Murkrow
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Pokedex

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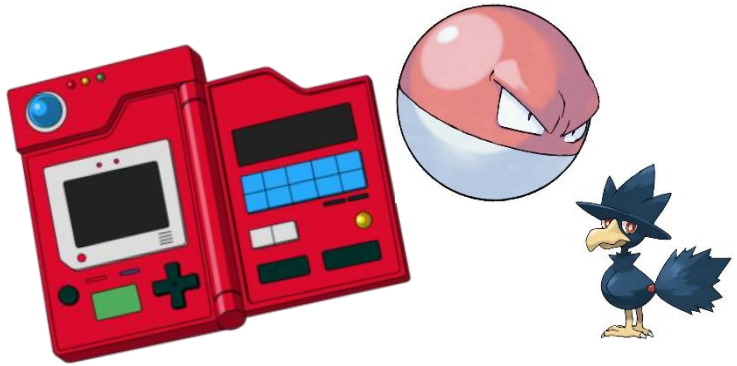

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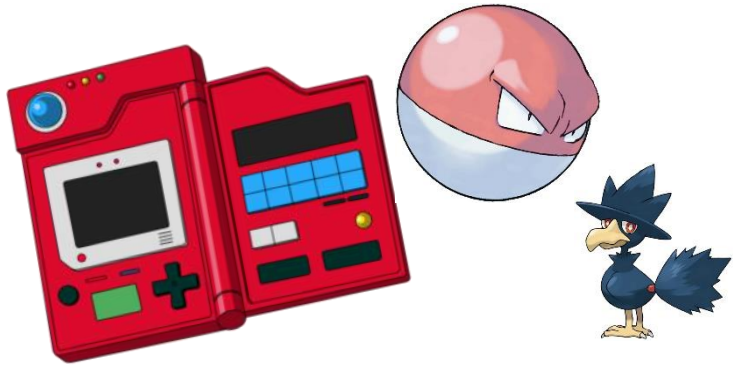

Index	
0	Voltorb
1	Electrode
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…	…
98	Murkrow
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What array index does Pokemon number **x** go into **?**

Pokedex

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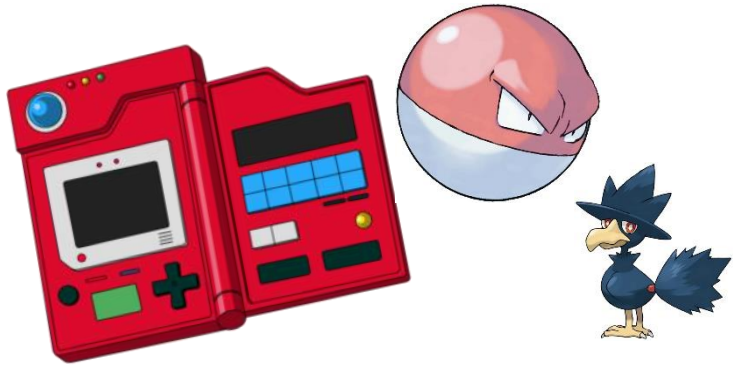

X % 100

Index	
0	Voltorb
1	Electrode
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98	Murkrow
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What array index does Pokemon number **x** go into **?**

Pokedex

Key
(Pokemon #)

Value

Index

100 V
101 E
102 E
… ..
198 M
199 S

% - modulo operator

a % b = remainder when a is divided by b

Pokemon number **x** go into ?

Pokedex

Key
(Pokemon #)

Value

Index

100 V
101 E
102 E
… ..
198 M
199 S

% - modulo operator

a % b = remainder when a is divided by b

12 % 7 =

Pokemon number **x** go into ?

Pokedex

Key
(Pokemon #)

Value

Index

100 V
101 E
102 E
… ..
198 M
199 S

% - modulo operator

a % b = remainder when a is divided by b

12 % 7 = 5

7 % 12 =

Pokemon number **x** go into ?

Pokedex

Key
(Pokemon #)

Value

Index

100 V
101 E
102 E
… ..
198 M
199 S

% - modulo operator

a % b = remainder when a is divided by b

12 % 7 = 5

7 % 12 = 7

132 % 100 =

Pokemon number **x** go into ?

Pokedex

Key
(Pokemon #)

Value

Index

100 V
101 E
102 E
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% - modulo operator

a % b = remainder when a is divided by b

12 % 7 = 5

7 % 12 = 7

132 % 100 = 32

100 % 100 =

Pokemon number **x** go into ?

Pokedex

Key
(Pokemon #)

Value

Index

100 V
101 E
102 E
… ..
198 M
199 S

% - modulo operator

a % b = remainder when a is divided by b

12 % 7 = 5

7 % 12 = 7

132 % 100 = 32

100 % 100 = 0

Pokemon number **x** go into ?

Pokedex

Key
(Pokemon #)

Value

Index

100 V
101 E
102 E
… ..
198 M
199 S

% - modulo operator

a % b = remainder when a is divided by b

X % 100

Possible output values?

Pokemon number **x** go into ?

Pokedex

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100 V
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199 S

% - modulo operator

a % b = remainder when a is divided by b

X % 100

Possible output values?

0, 1, 2, 3, … , 98, 99

Pokemon number **x** go into ?

Pokedex

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(Pokemon #)

Value

Index

100 V
101 E
102 E
… ..
198 M
199 S

% - modulo operator

a % b = remainder when a is divided by b

X % 100

Possible output values?

0, 1, 2, 3, … , 98, 99

All array spots are used!

Pokemon number **x** go into ?

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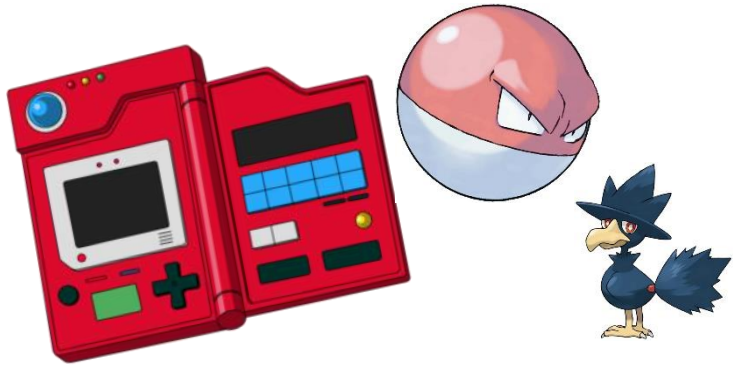

Why 100?

X % 100

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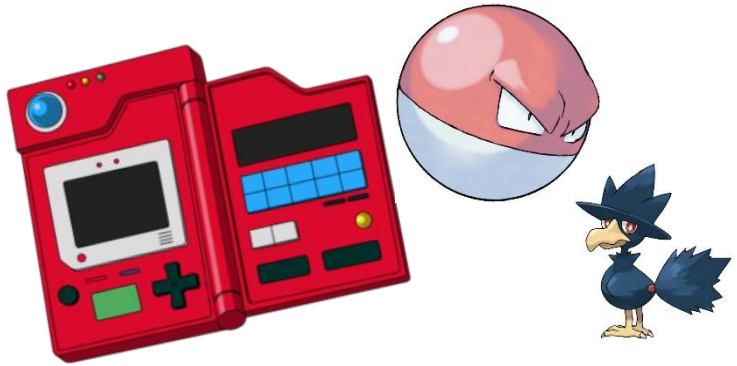

X % 100

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This is our (simple) **hash function**

Hash Function: Function that translates keys into array indices (hash values)

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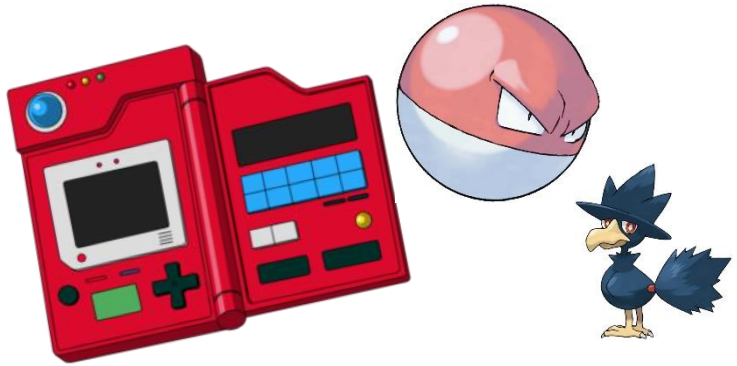

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Can accept any arbitrary sized input!

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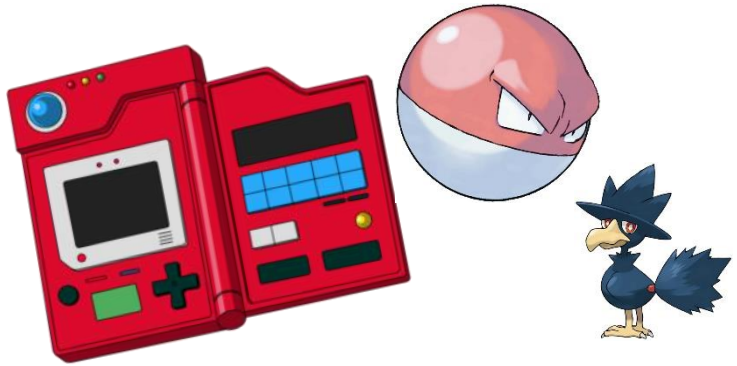

Runs in O(1) time

X % 100

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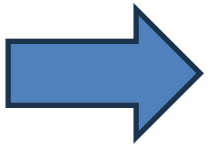

X % 100

Index	
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What could possibly go wrong?

Pokedex

Key (Pokemon #)	**Value** (Pokemon)
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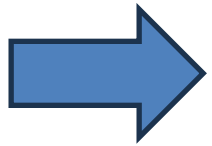
101	Electrode
102	Exeggcute
…	…
198	Murkrow
199	Slowking
200	Misdreavus

X % 100



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Pokedex

X % 100

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We have two keys that map to the same “bucket” (array index)

→ A **collision**

Pokedex

X % 100

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…	…
198	Murkrow
199	Slowking
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Index	
0	~~Voltorb~~ **Misdreavus**
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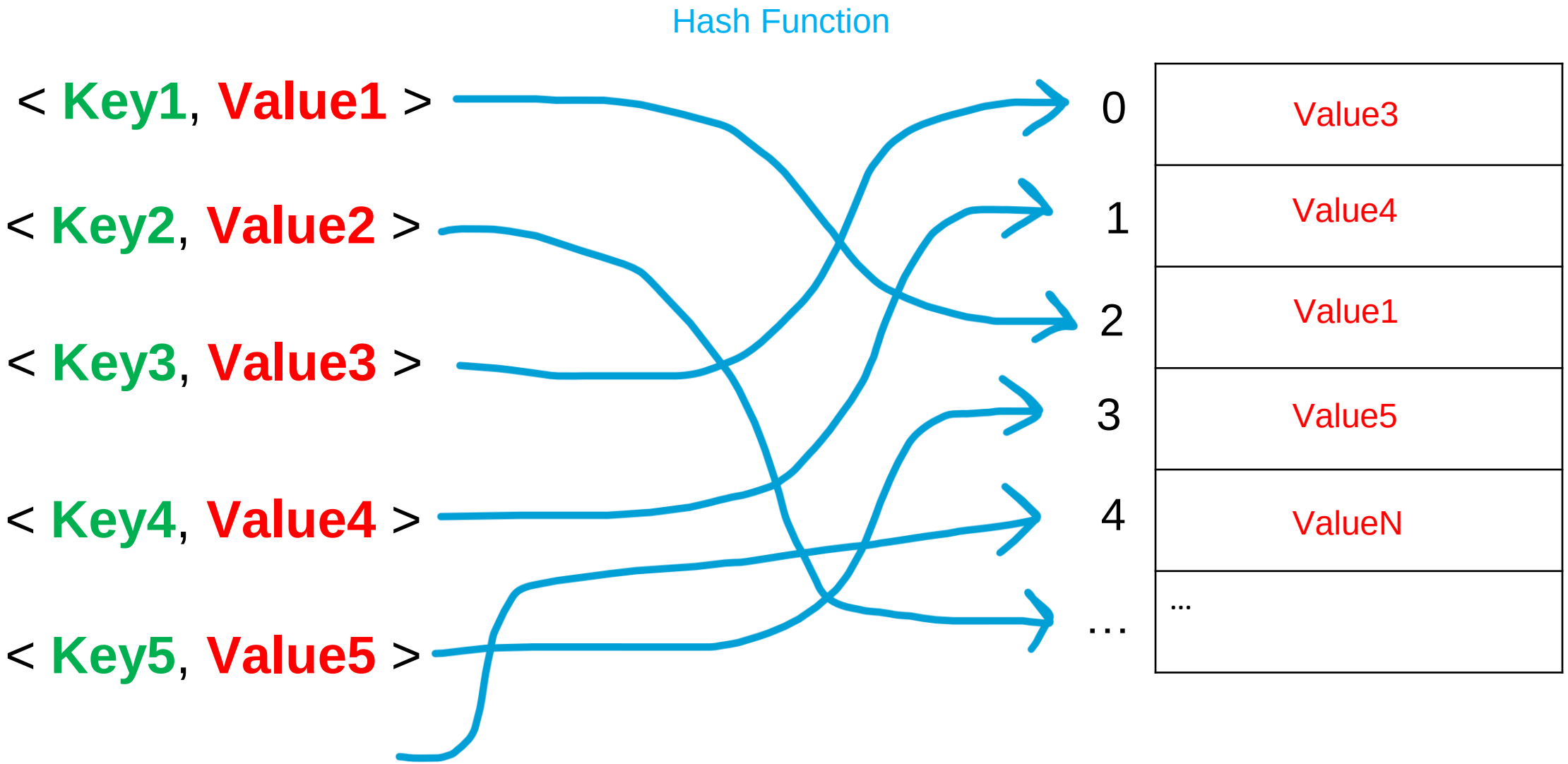
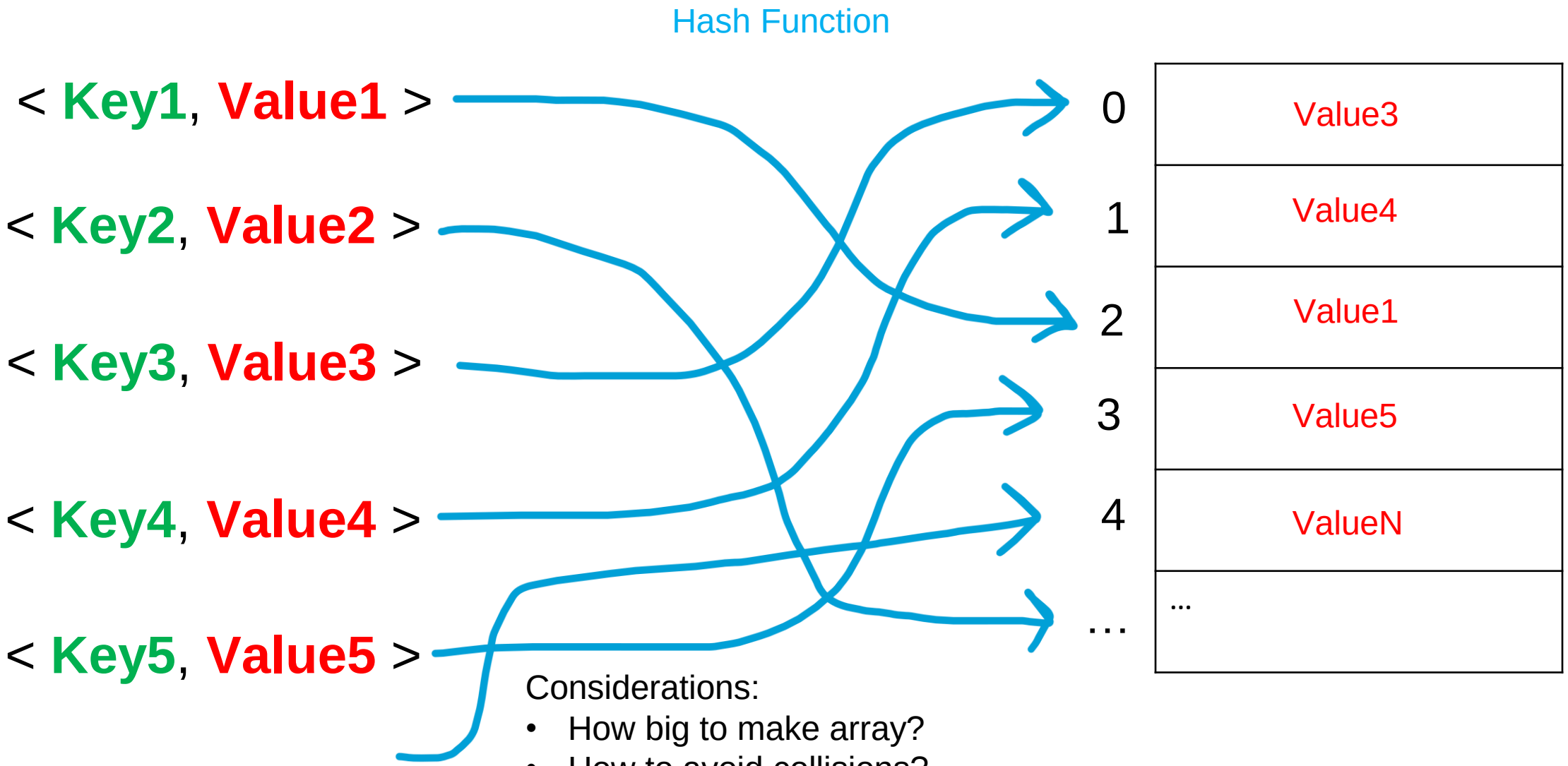
We have two keys that map to the same “bucket” (array index)

→ A **collision**

Hash Tables 101



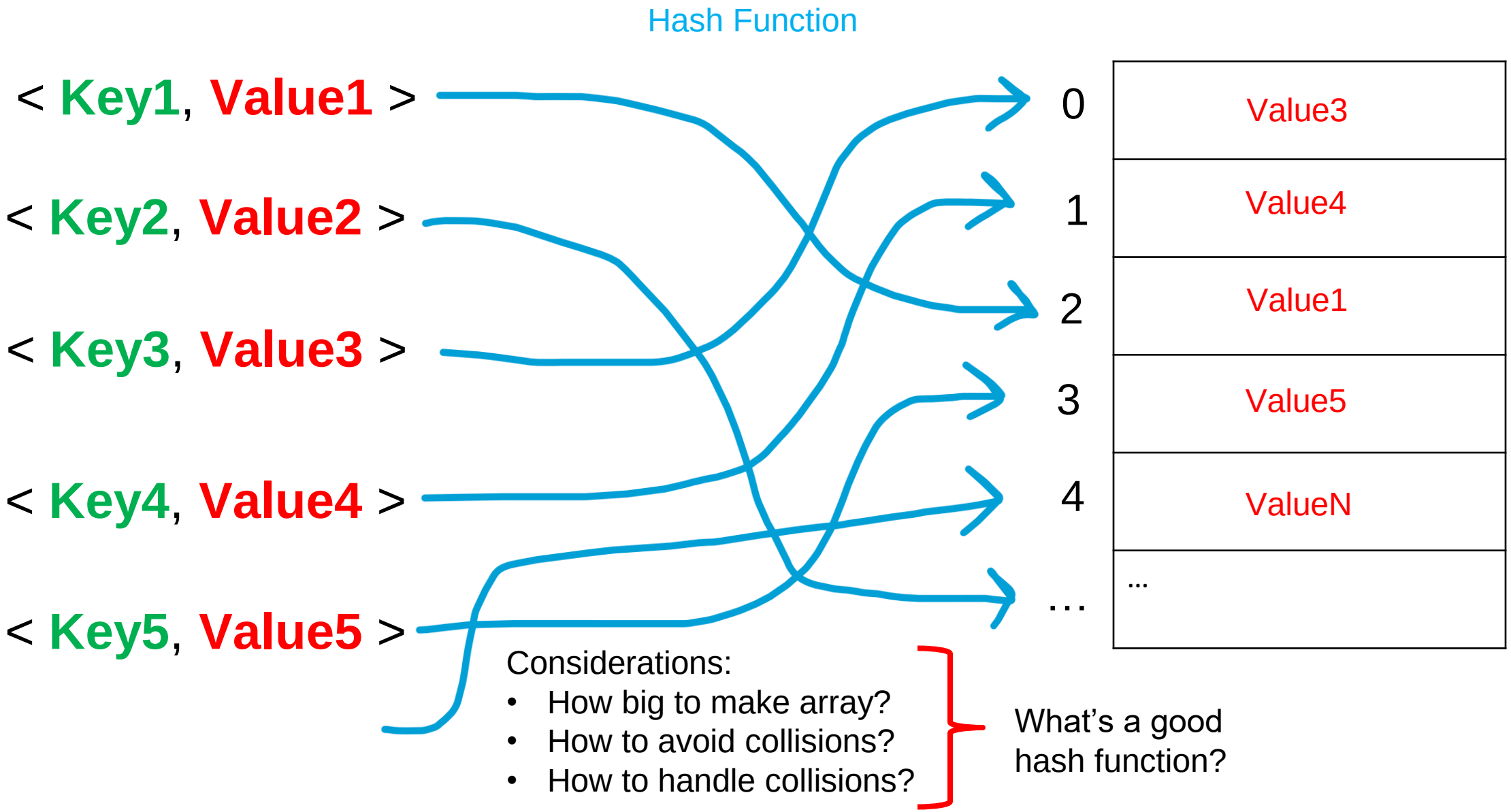
Hash Tables 101



Considerations:

- How big to make array?
- How to avoid collisions?
- How to handle collisions?

Hash Tables 101



Considerations:

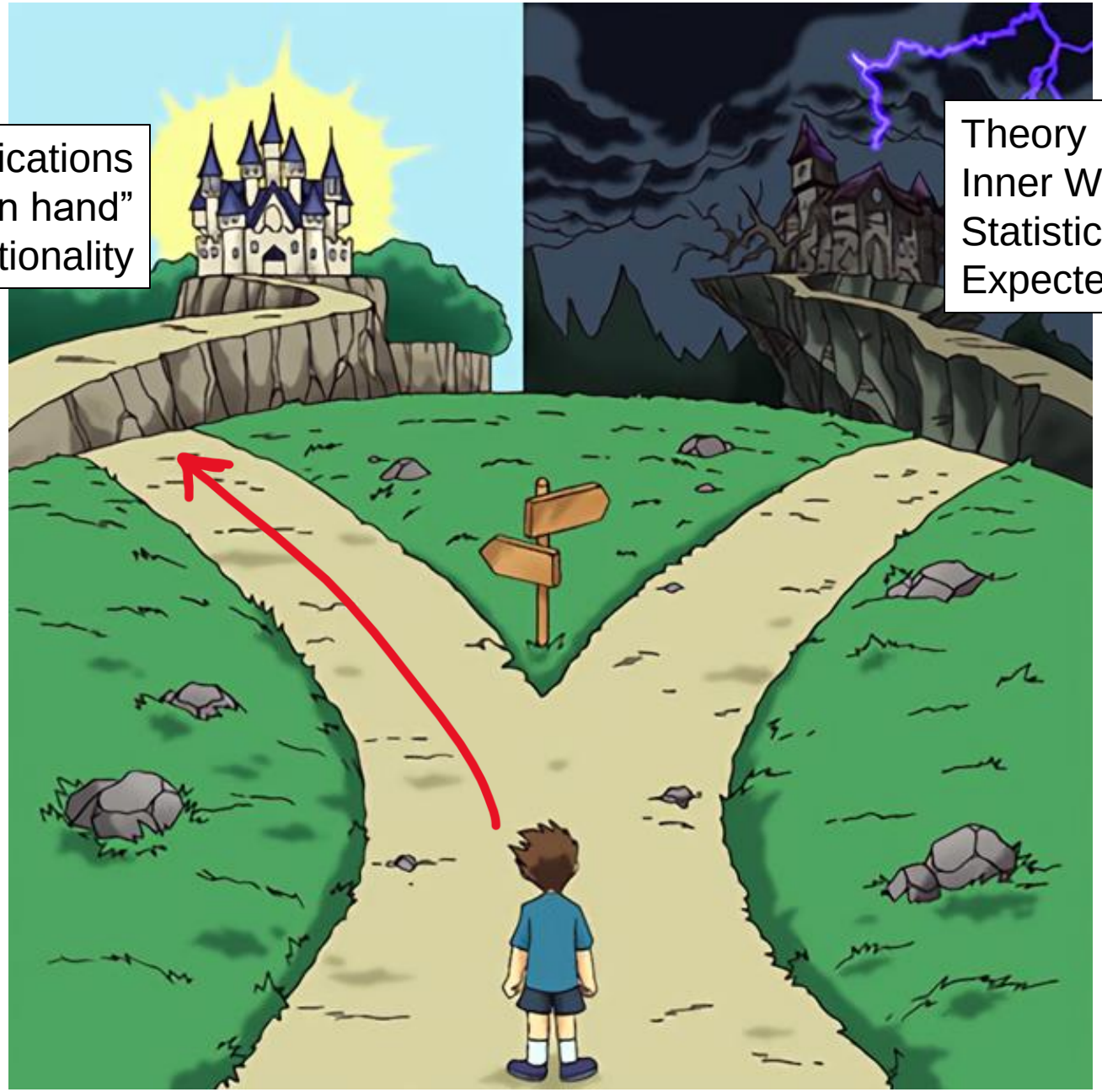
- How big to make array?
- How to avoid collisions?
- How to handle collisions?

What's a good hash function?

Hash Tables 101

Hash Tables 101

Applications
“Tools in hand”
Java Functionality



Theory
Inner Workings of Hash Functions
Statistical Likelihood
Expected Performance

Hash Tables are probably the most useful thing you learn in this class

Hash Tables 101

I use HashMap, HashTable, and Dictionary interchangeably, but there are very small differences between these

Let's build a Hash Table for a **Student Database**

Keys need to be unique, what could we use for a key ?

Hash Tables 101

I use HashMap, HashTable, and Dictionary interchangeably, but there are very small differences between these

Let's build a Hash Table for a **Student Database**

Keys need to be unique, what could we use for a key? Student ID!

Hash Tables 101

I use HashMap, HashTable, and Dictionary interchangeably, but there are very small differences between these

Let's build a Hash Table for a **Student Database**

Keys need to be unique, what could we use for a key? Student ID!

Keys = Student ID
Values = **`Student`** Object

-01561200

-12345005