Unordered Data Structures: Sets and Maps

What's an example of "unordered data" that you've encountered in your life?

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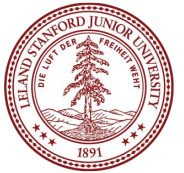
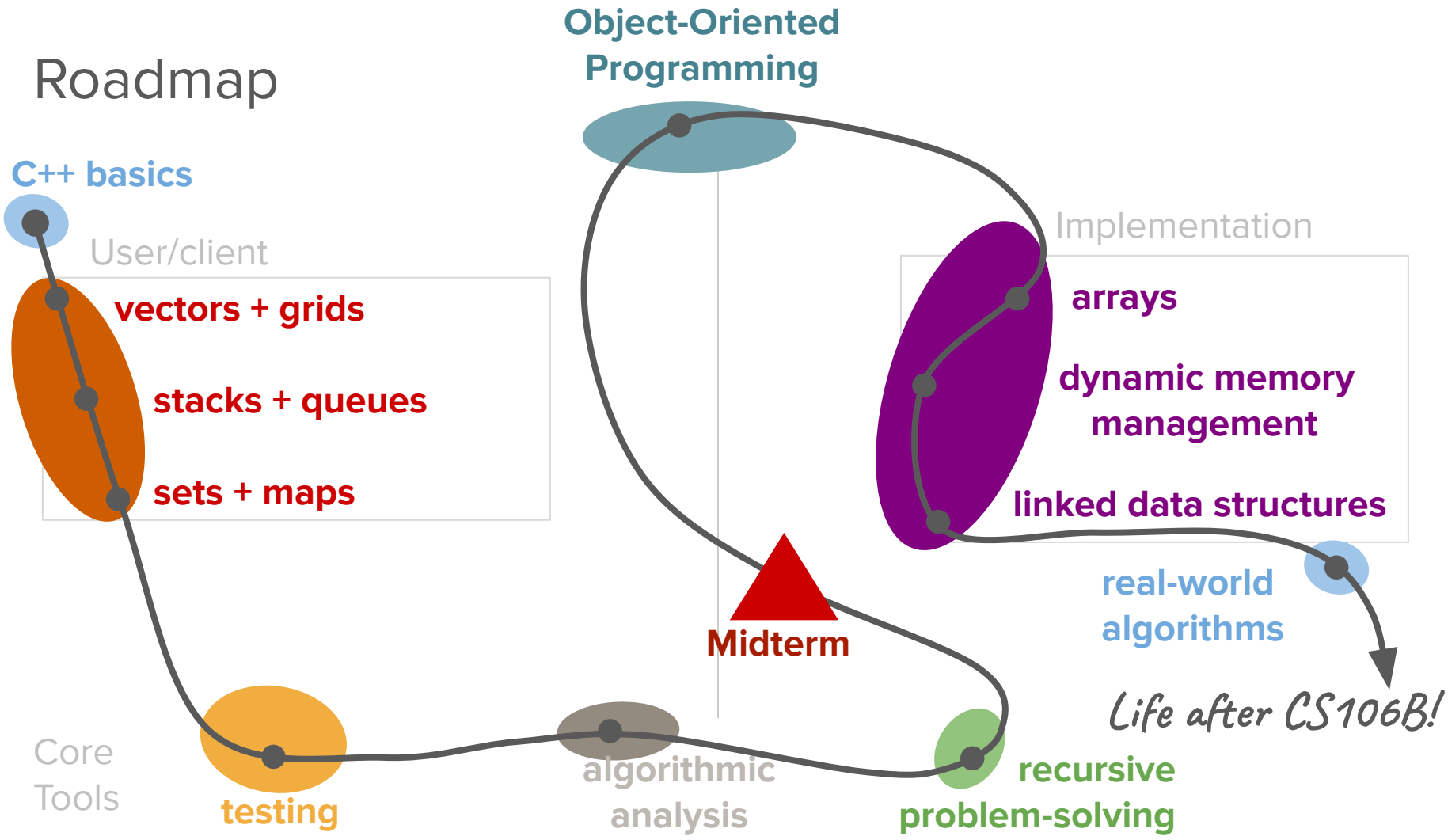
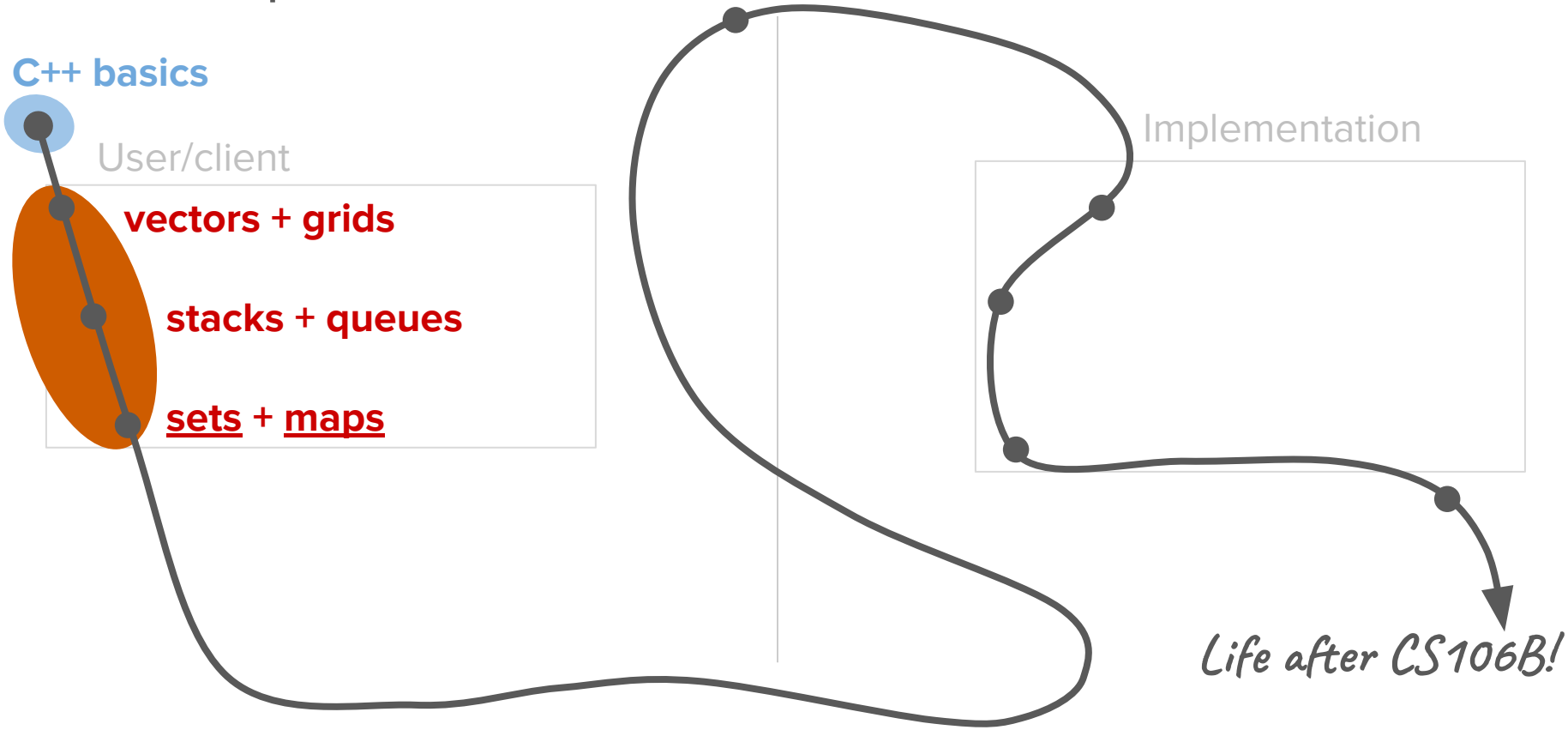


Unordered Data

Roadmap


Object-Oriented Programming
C++ basics
User/client
vectors + grids
stacks + queues
sets + maps
Implementation
arrays
dynamic memory management
linked data structures
real-world algorithms
Midterm
Life after CS106B!
Core Tools
testing
algorithmic analysis
recursive problem-solving

Roadmap


C++ basics
User/client
vectors + grids
stacks + queues
sets + maps
Implementation
Life after CS106B!


The Container Store

Today's question

When is it appropriate to use different types of **unordered** data structures?

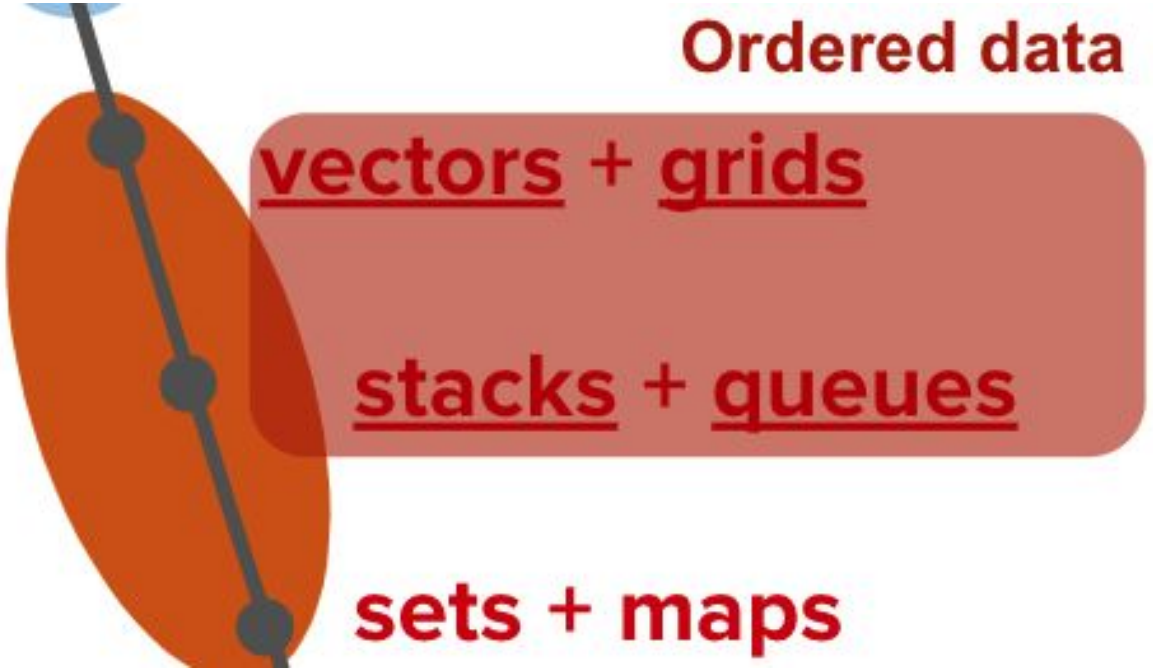
Today's topics

1. Review
2. Sets
3. Maps
4. (if time) Nested ADTs

Review

(grids and queues and stacks, oh my!)

The “container store”



What is a grid?

a0	a1	a2
b0	b1	b2
c0	c1	c2

- A 2D array, defined with a particular width and height
- Useful for spreadsheets, game boards, etc.
- Three ways to declare a grid
  - Grid<type> gridName;
  - Grid<type> gridName(numRows, numCols);
  - Grid<type> gridName = {{r0c0, r0c1, r0c2}, {r1c0, r1c1, r1c2},...};
- We could use a combination of Vectors to simulate a 2D matrix, but a Grid is easier!

Definition

struct

A way to bundle different types of information in C++ – like creating a custom data structure.

The **GridLocation** struct

```
struct GridLocation {
   int row;
   int col;
}
```

- A pre-defined struct in the Stanford C++ libraries that makes it more convenient to store Grid locations

- To declare a struct, you can either assign each of its members separately or assign it when it's created:

```
GridLocation origin = {0, 0};
```

```
GridLocation origin;
origin.row = 0;
origin.col = 0;
```

What is a queue?

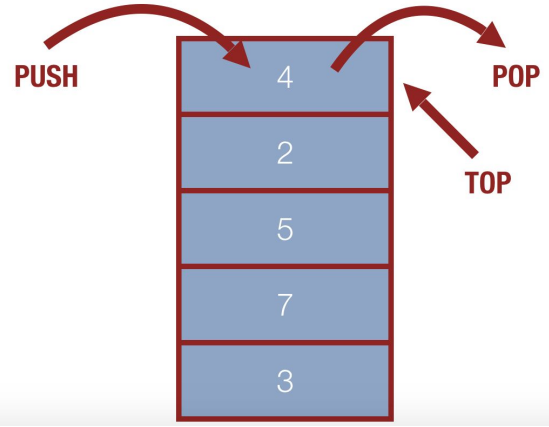
- Like a real queue/line!

- **F**irst person **I**n is the **F**irst person **O**ut (FIFO)
  - When you remove (dequeue) people from the queue, you remove them from the front of the line.

- Last person in is the last person served
  - When you insert (enqueue) people into a queue, you insert them at the back (the end of the line).

What is a stack?

- Modeled like an actual stack (of pancakes)
- Only the top element in a stack is accessible.
  - The **L**ast item **I**n is the **F**irst one **O**ut. (LIFO)
- The push, pop, and top operations are the only operations allowed by the stack ADT.



Ordered ADTs with accessible indices

Types:

- Vectors (1D)
- Grids (2D)

Traits:

- Easily able to search through all elements
- Can use the indices as a way of structuring the data

Ordered ADTs where you can't access elements by index

Types:

- Queues (FIFO)
- Stacks (LIFO)

Traits:

- Constrains the way you can insert and access data
- More efficient for solving specific LIFO/FIFO problems

What ADT should we use?

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For each of the tasks, pick which ADT is best suited for the task:

Vectors

Grids

Queues

Stacks

- The undo button in a text editor
- Jobs submitted to a printer that can also be cancelled
- LaIR requests
- Your browsing history
- Google spreadsheets
- Call centers (“your call will be handled by the next available agent”)

Which ADT(s) would you use?

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Queues

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(Queues)

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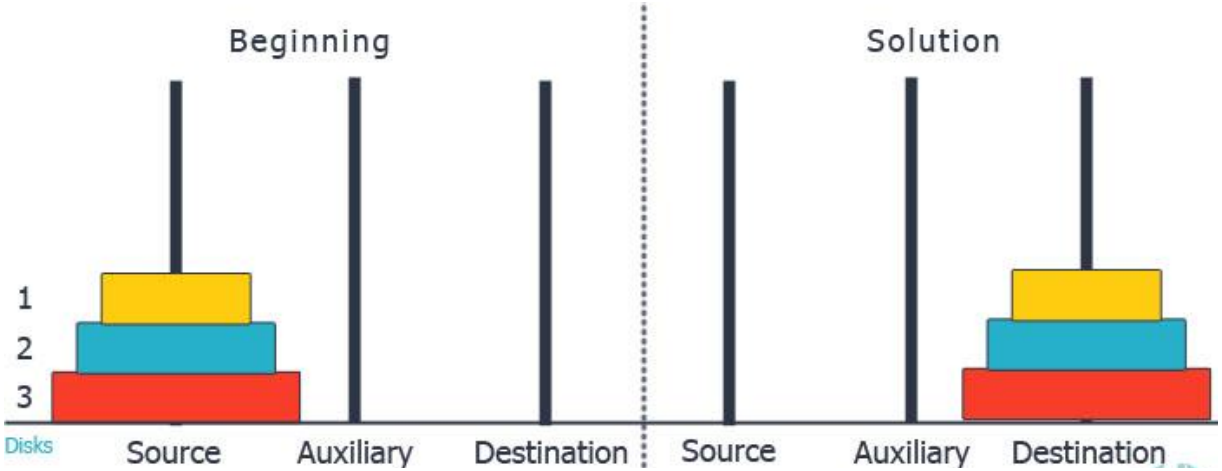
- Your browsing history
- Google spreadsheets
- **Call centers (“your call will be handled by the next available agent”)**

Using data structures:
Towers of Hanoi

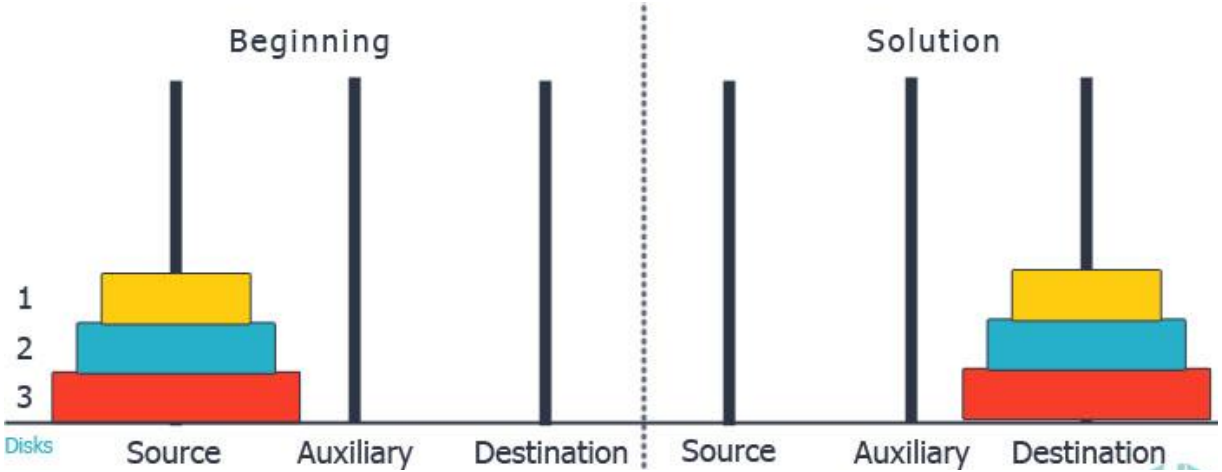
Towers of Hanoi

- Setup:
  - Three “towers”
  - N disks of decreasing sizes (below: N = 3)
- Goal: Move the disk stack from the first peg to the last peg



Towers of Hanoi

- Rules:
  - Can only move one disk at a time
  - You cannot place a larger disk on top of a smaller disk

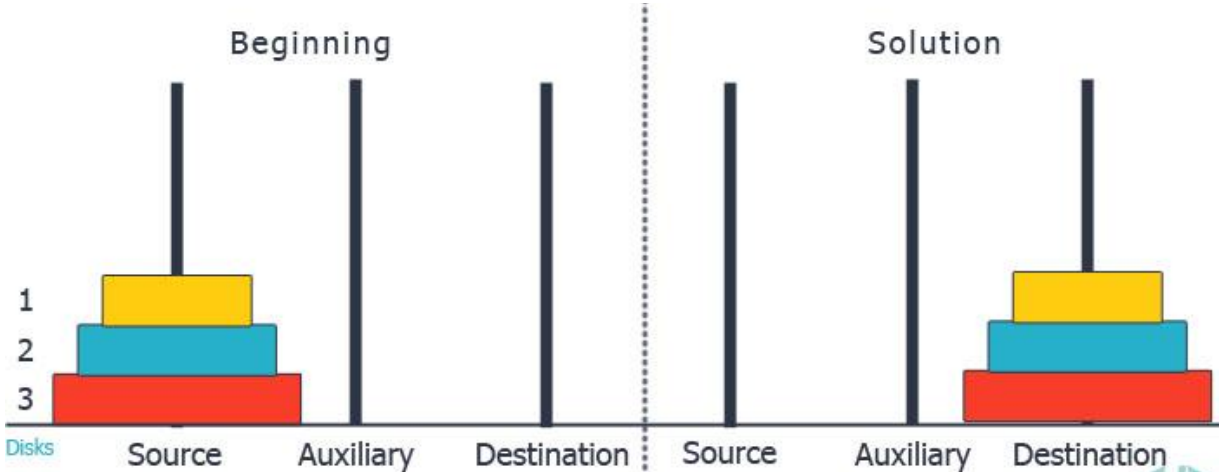


Attendance ticket:

https://tinyurl.com/cs106btowers

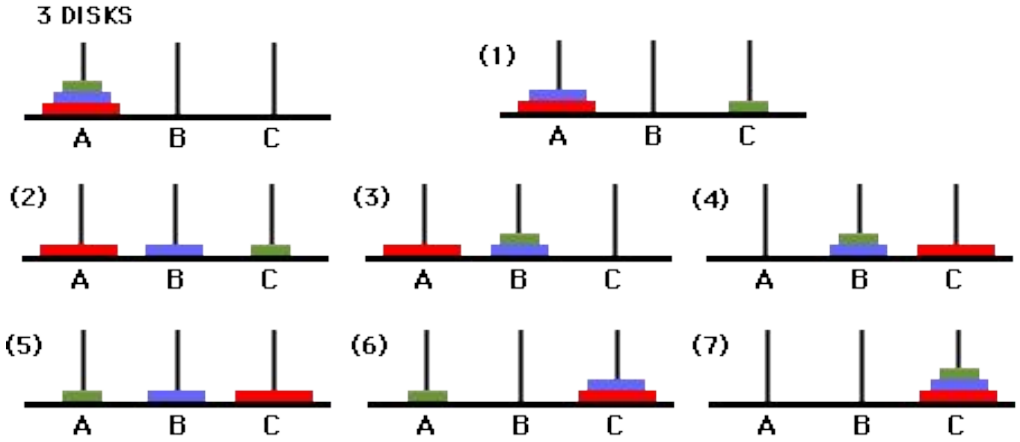
Please don’t send this link to students who are not here. It’s on your honor!

Towers of Hanoi




```
Stack <int> source = {3, 2, 1};
Stack <int> auxiliary;
Stack <int> destination;  // this should become {3, 2, 1}
```

Pseudocode



(1) Move disk 1 to destination
(2) Move disk 2 to auxiliary
(3) Move disk 1 to auxiliary
(4) Move disk 3 to destination
(5) Move disk 1 to source
(6) Move disk 2 to destination
(7) Move disk 1 to destination

Let’s look at the code solution for three disks!

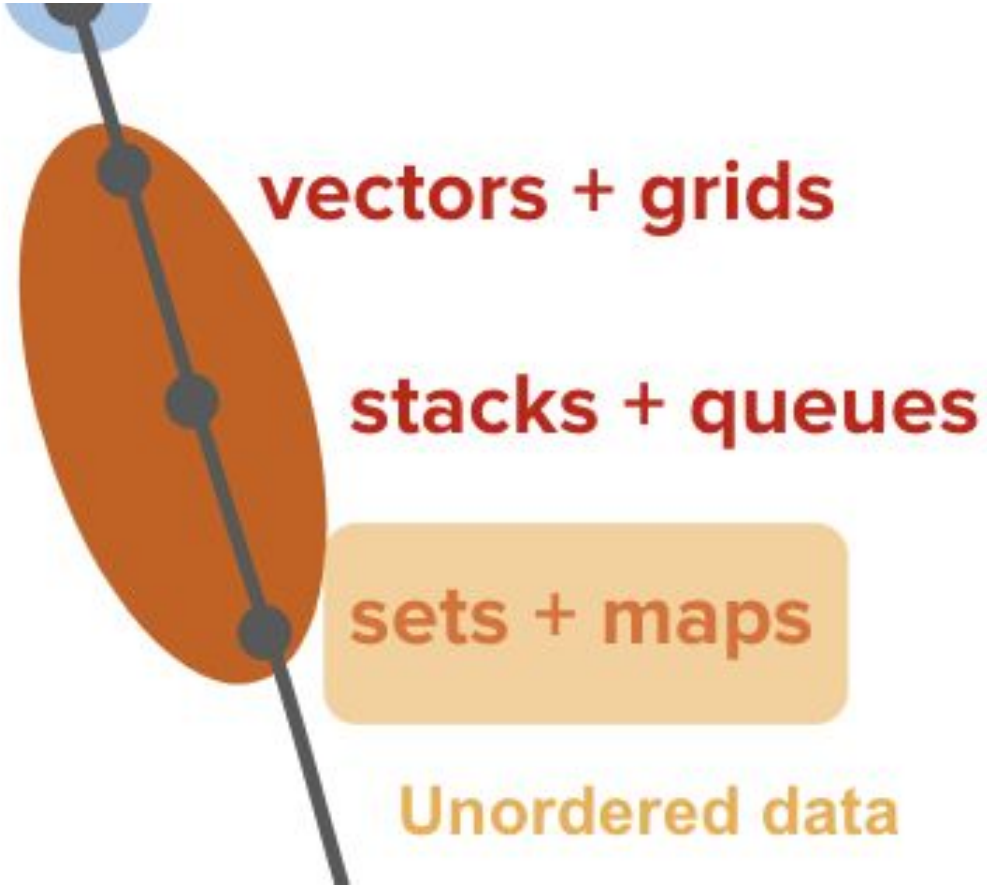
[Ed workspace]

Let’s look at the code solution for three disks!

Challenge for home: How would you generalize your solution to N disks instead of just 3?

Why do we use unordered ADTs?

The “container store”



Examples of unordered data

- Unique visitors to a website
- Shuffled playlist with no duplicate songs
- People and their passport numbers on a particular flight
- A recipe with ingredients and their quantities
- Products placed into categories in an online storefront

Examples of unordered data

When we say "unordered" vs. "ordered," we're referring specifically to numerical orderings.

- Unique visitors to a website
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Examples of unordered data

- Unique visitors to a website
- Shuffled playlist with no duplicate songs
- People and their passport numbers on a particular flight
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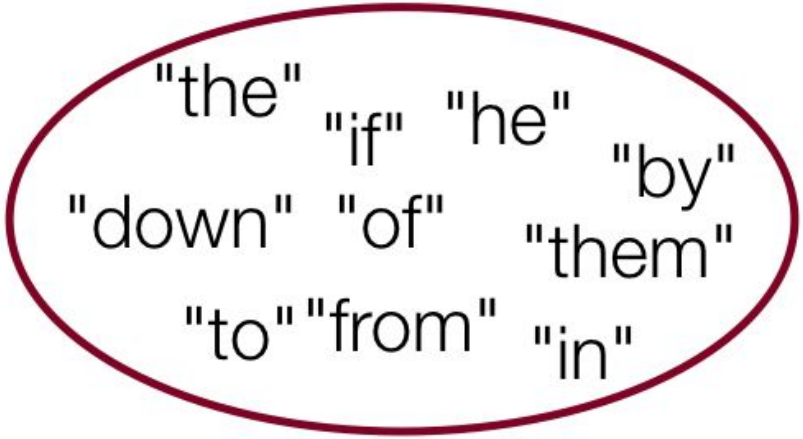
Sometimes numerical indices/ordering is not the most efficient way to store information!

Sets

What is a set?



- A set is a collection of elements with no duplicates.

- Sets are faster than ordered data structures like vectors – since there are no duplicates, it's faster for them to find things.
  - (Later in the quarter we'll learn about the details of the underlying implementation that makes this abstraction efficient.)
  - We'll formally define "faster" tomorrow.

- Sets don't have indices!

Set methods

- Sets have (at least) the following operations (and they are *fast*):
  - **`add(value)`**: adds a value to a set, and ignores if the set already contains the value
  - **`contains(value)`**: returns **`true`** if the set contains the value, **`false`** otherwise.
  - **`remove(value)`**: removes the value from the set. Does nothing if the value is not in the set.
  - **`size()`**: returns the number of elements in the set
  - **`isEmpty()`**: returns **`true`** if the set is empty, **`false`** otherwise

- For the exhaustive list, check out the Stanford libraries documentation.

Set example

```
Set<string> friends;
friends.add("jenny");
friends.add("kylie");
friends.add("trip");
// can also use: Set<string> friends = {“jenny”, “kylie”, “trip”};
```

Set example

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Set<string> friends;
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cout << boolalpha << friends.contains("voldemort") << noboolalpha
    << endl;
```

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// can also use: Set<string> friends = {“jenny”, “kylie”, “trip”};

cout << boolalpha << friends.contains("voldemort") << noboolalpha
    << endl;

for(string person : friends) {
    cout << person << endl;
}
```

Set example

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// can also use: Set<string> friends = {“jenny”, “kylie”, “trip”};

cout << boolalpha << friends.contains("voldemort") << noboolalpha
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for(string person : friends) {
    cout << person << endl;
}
```

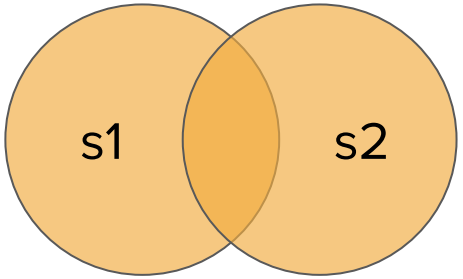
```
false
jenny
kylie
trip
```

Set operands

Sets can be compared, combined, etc.

- `s1 == s2`
  `true` if the sets contain exactly the same elements
- `s1 != s2`
  `true` if the sets don't contain the exact same elements

Set operands



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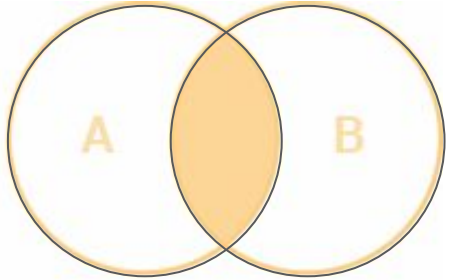
- **`s1 + s2`**
  returns the *union* of **`s1`** and **`s2`** (i.e., all elements in both)

Set operands



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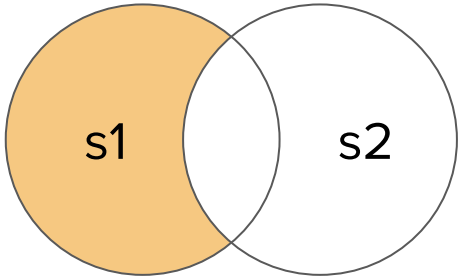
Set operands



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- **`s1 * s2`**
  returns the *intersection* of **`s1`** and **`s2`** (i.e., only the elements in both sets)
- **`s1 - s2`**
  returns the *difference* of **`s1`** and **`s2`** (the elements in **`s1`** but not in **`s2`**)

Common Set patterns and pitfalls

- Use for each loops to iterate over sets

```
for (type currElem : set) {
    // process elements one at a time
}
```

- You cannot use anything that attempts to index into the set (e.g. `for (int i = 0;..)` or `set[i]`)

Unique words program

[live coding]

Announcements

Announcements

- Assignment 1 is due Friday at 11:59pm PDT.

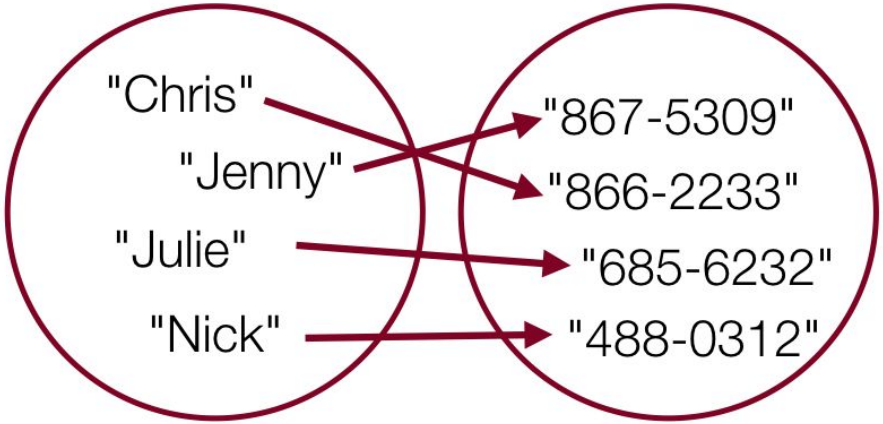
- Assignment 2 will be out by the end-of-the-day on Thursday and will be due next Thursday at 11:59pm PDT.
    - We're still finalizing YEAH timing and will announce that tomorrow.

- No lecture on Monday! But we will be releasing a shorter required video over the weekend to help you get started with nested ADTs for A2 instead.

- Jenny will be covering my group OH today since I'm not in person.

Maps

What is a map?



- A map is a collection of key/value pairs, and the key is used to quickly find the value.

- Other terms you may hear for a map are dictionary (Python) or associative array.

- A map is an alternative to an ordered data structure, where the “indices” no longer need to be integers.

Map methods

- The following functions are part of the **`Map`** class:
  - **`m.clear()`** : removes all key/value pairs from the map
  - **`m.containsKey(key)`** : returns **`true`** if the map contains a value for the given key
  - **`m[key]`**
    `m.get(key)` : returns the value associated with key in this map. If **`key`** is not found, returns the default value for ValueType.
  - **`m.isEmpty()`** : returns **`true`** if the map contains no key/value pairs (size 0)
  - **`m.keys()`** : returns a **`Vector`** copy of all keys in the map
  - **`m[key] = value`**
    `m.put(key, value)` : adds a mapping from the given key to the given value; if the key already exists, **replaces** its value with the given one
  - **`m.remove(key)`** : removes any existing mapping for the given **`key`** (ignored if the **`key`** doesn't exist in the map)
  - **`m.size()`** : returns the number of key/value pairs in the map
  - **`m.values()`** : returns a **`Vector`** copy of all the values in the map
- For the exhaustive list, check out the Stanford library documentation.

Map example

```
// maps from string keys to string values
Map<string, string> phoneBook;

//  key                 value
phoneBook["Jenny"] = "867-5309"; // or
phoneBook.put("Jenny", "867-5309");
```

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```

Inserting new values

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// maps from string keys to string values
Map<string, string> phoneBook;

//  key                 value
phoneBook["Jenny"] = "867-5309"; // or
phoneBook.put("Jenny", "867-5309");

string jennyNumber = phoneBook["Jenny"]; // or
string jennyNumber = phoneBook.get("Jenny");
cout << jennyNumber << endl;
```

Accessing values

Map example

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// maps from string keys to string values
Map<string, string> phoneBook;

//  key                  value
phoneBook["Jenny"] = "867-5309"; // or
phoneBook.put("Jenny", "867-5309");

string jennyNumber = phoneBook["Jenny"]; // or
string jennyNumber = phoneBook.get("Jenny");
cout << jennyNumber << endl;

// maps from string keys to Vector<double> values
Map<string, Vector<double>> accounts;
```

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

```
for (type curKey : map) {
    // see map values using map[curKey]
}
```

Common Map patterns and pitfalls

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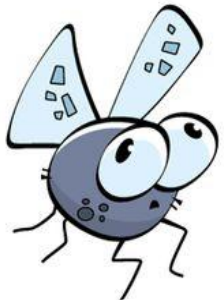

But don't remove keys within the loop as you're iterating!

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

```
for (type curKey : map.keys()) {
    // see map values using map[curKey]
}
```

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

```
for (type curKey : map.keys()) {
    // see map values using map[curKey]
}
```

Okay to edit map within this loop because `.values()/.keys()` *makes a Vector copy of the values/keys.*

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

- Auto-insert: a map feature that can also cause bugs

```
Map<string, int> freqMap;
while (true) {
    string text = getLine("Enter some text: ");
    cout << "Times seen: " << freqMap[text] << endl;
    freqMap[text]++;
}
```

Common Map patterns and pitfalls

- Use for each loops to iterate over maps
- Auto-insert: a map feature that can also cause bugs

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Map<string, int> freqMap;
while (true) {
    string text = getLine("Enter some text: ");
    cout << "Times seen: " << freqMap[text] << endl;
    freqMap[text]++;
}
```

This auto-inserts the key `text` *into the map if it doesn't already exist!*

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

- Auto-insert: a map feature that can also cause bugs

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Map<string, int> freqMap;
while (true) {
    string text = getLine("Enter some text: ");
    cout << "Times seen: " << freqMap[text] << endl;
    freqMap[text]++;
}
```

Note: auto-insertion only happens with the [] operator, not the .get() function

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

- Auto-insert: a map feature that can also cause bugs

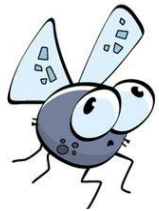
```
Map<string, int> playerPointsMap;
...
// get key to test if it's in the map
if (playerPointsMap[key] == 0) {
    cout << key << " already exists" << endl;
}
```

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

- Auto-insert: a map feature that can also cause bugs

```
Map<string, int> playerPointsMap;
...
// get key to test if it's in the map
if (playerPointsMap[key] == 0) { // will always be true!
    cout << key << " already exists" << endl;
}
```



Common Map patterns and pitfalls

- Use for each loops to iterate over maps

- Auto-insert: a map feature that can also cause bugs

```
Map<string, int> playerPointsMap;
...
// use containsKey function, no auto-insert
if (playerPointsMap.containsKey(key)) { // correct way
    cout << key << " already exists" << endl;
}
```

Unique words program (extended)

[live coding]

ADT summary...

Ordered ADTs

Elements accessible by indices:

- Vectors (1D)
- Grids (2D)

Elements not accessible by indices:

- Queues (FIFO)
- Stacks (LIFO)

Unordered ADTs

- Sets (elements unique)
- Maps (keys unique)

Ordered ADTs

Elements accessible by indices:

- Vectors (1D)
- Grids (2D)

Elements not accessible by indices:

- Queues (FIFO)
- Stacks (LIFO)

Unordered ADTs

- Sets (elements unique)
- Maps (keys unique)

Useful when numerical ordering of data isn't optimal

Ordered ADTs

Elements accessible by indices:

- Vectors (1D)
- Grids (2D)

Elements not acces

- Queues (FIFO)
- Stacks (LIFO)

Unordered ADTs

- Sets (elements unique)
- Keys (keys unique)

Just like numerical ordering of

ADTs Takeaway: Matching structure with purpose results in better efficiency!

Nested Data Structures

Nested Data Structures

- Nesting data structures (using one ADTs as the data type inside of another ADT) is a great way of organizing data with complex structure.

Nested Data Structures

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- This weekend's recorded video will go into an in-depth example of using nested data structures.

Nested Data Structures Example

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Quick lookup by animal name

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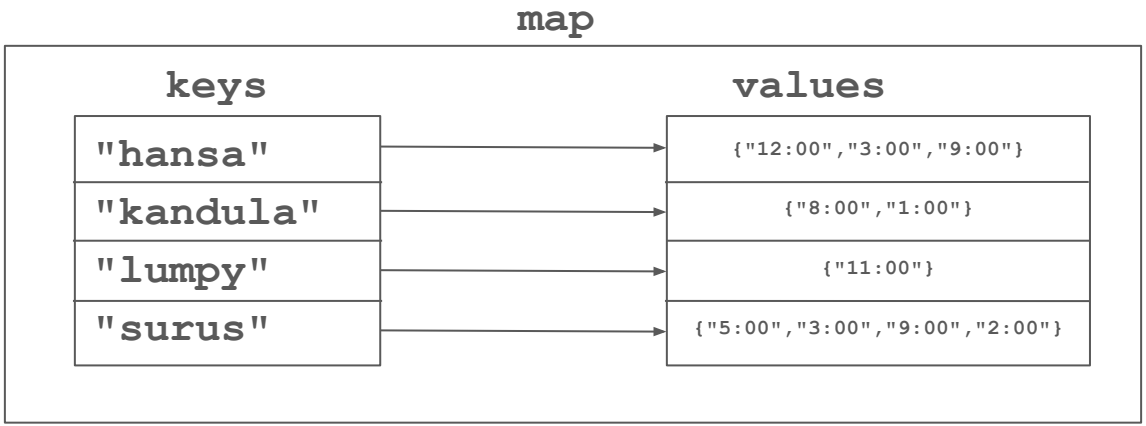
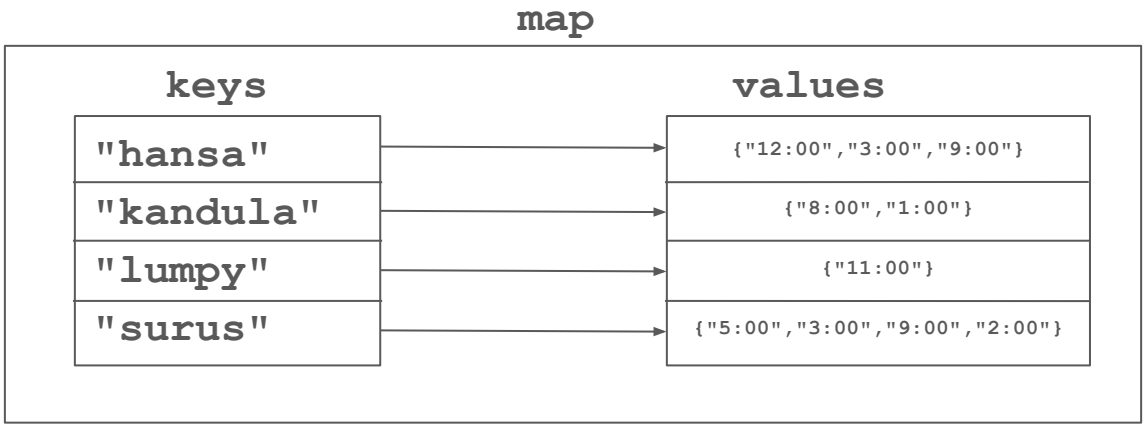
Store multiple, ordered feeding times per animal

Nested Data Structures Example



Wonderful diagram and animal naming borrowed from Sonja Johnson-Yu

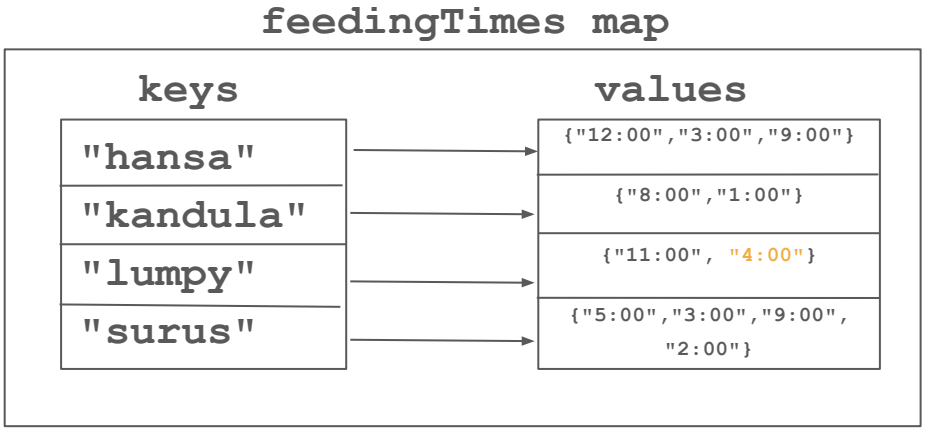
Nested Data Structures Example



How do we use modify the internal values of this map?

Nested Data Structures Example

Goal: We want to add a second feeding time of 4:00 for "lumpy".



Nested Data Structures Example

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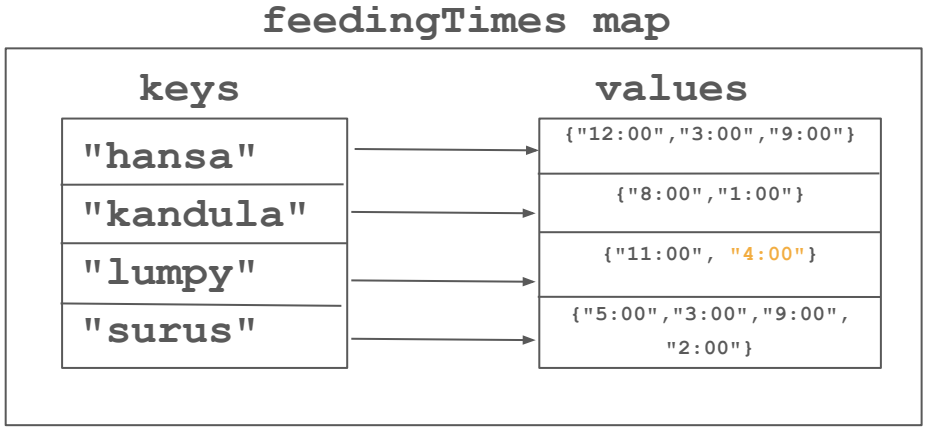
Which of the following three snippets of code will correctly update the state of the map?



1.
```
feedingTimes["lumpy"].add("4:00");
```

2.
```
Vector<string> times = feedingTimes["lumpy"];
times.add("4:00");
```

3.
```
Vector<string> times = feedingTimes["lumpy"];
times.add("4:00");
feedingTimes["lumpy"] = times;
```

PollEv.com/cs106bpolls

Nested Data Structures: Which snippet of code will correctly update the state of the map?

1.
2.
3.

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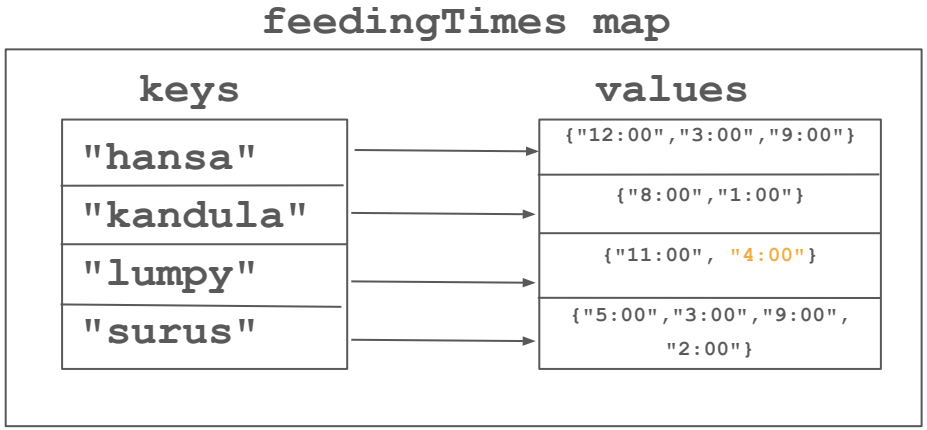


```
1.  feedingTimes["lumpy"].add("4:00");
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```
2.  Vector<string> times = feedingTimes["lumpy"];
    times.add("4:00");
```

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    feedingTimes["lumpy"] = times;
```

[] Operator and = Operator Nuances

- When you use the [] operator to access an element from a map, you get a reference to the map, which means that any changes you make to the reference will be persistent in the map.

```
feedingTimes["lumpy"].add("4:00");
```

[] Operator and = Operator Nuances

- When you use the [] operator to access an element from a map, you get a reference to the map, which means that any changes you make to the reference will be persistent in the map.

- However, when you use the = operator to assign the result of the [] operator to a variable, you get a copy of the internal data structure.

```
// makes and modifies a copy, not the actual map value:
Vector<string> times = feedingTimes["lumpy"];
times.add("4:00");
```

[] Operator and = Operator Nuances

- When you use the [] operator to access an element from a map, you get a reference to the map, which means that any changes you make to the reference will be persistent in the map.

- However, when you use the = operator to assign the result of the [] operator to a variable, you get a copy of the internal data structure.

- If you choose to store the internal data structure in an intermediate variable, you must do an explicit reassignment to get your changes to persist.

```
// would store the modified `times` copy in the map
feedingTimes["lumpy"] = times;
```

Nested ADTs Summary

- Powerful
  - Can express highly structured and complex data
  - Used in many real-world systems

- Tricky
  - With increased complexity comes increased cognitive load in differentiating the information stored at each level of the nesting.
  - Specifically in C++, working with nested data structures can be tricky due the use of references and copies. Follow the correct paradigms to stay on track!

One final note... **`const`** reference

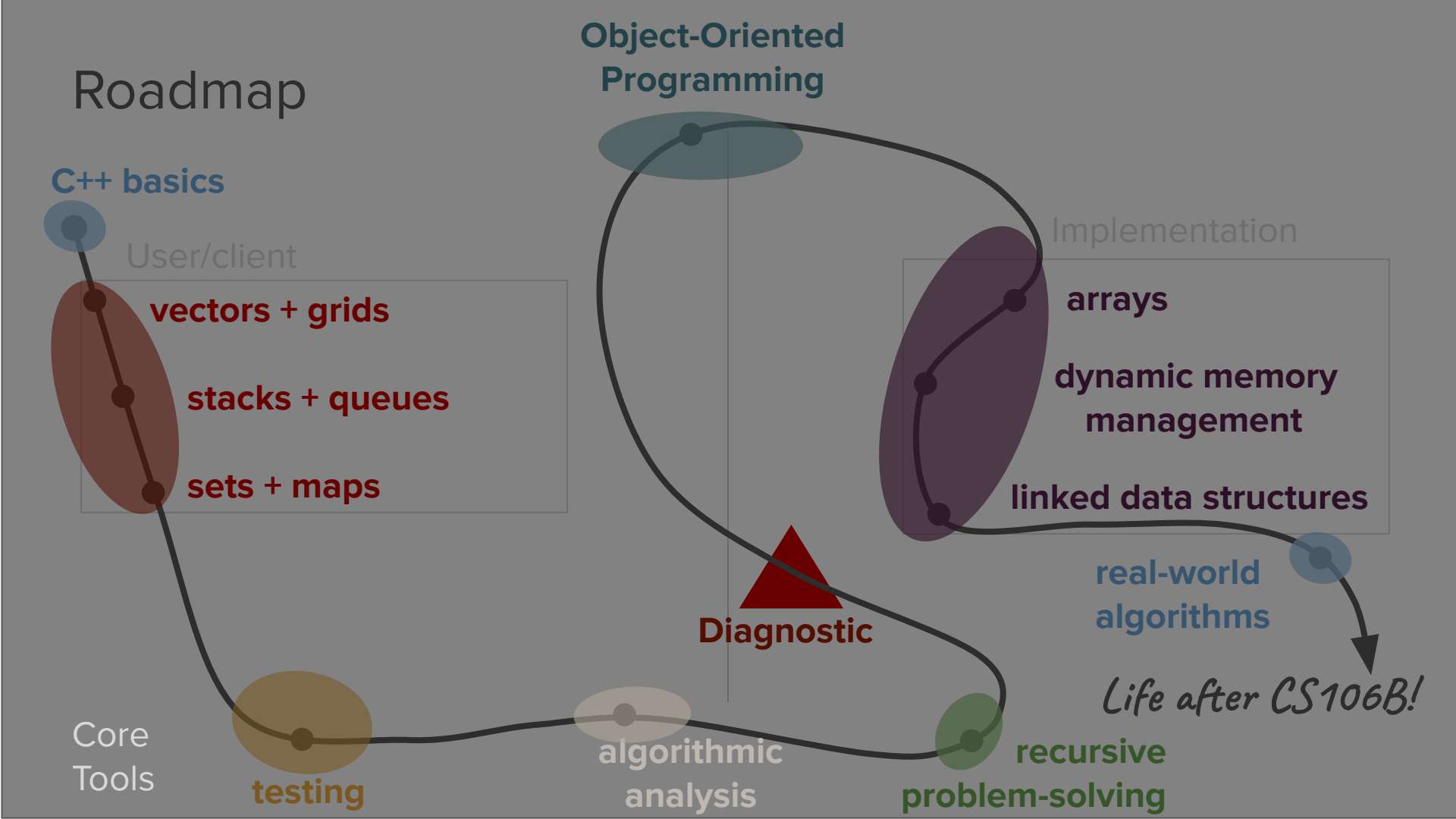
- Passing a large object (e.g. a million-element Vector) by value makes a copy, which is inefficient in time and space.
- Passing parameters by reference avoids making a copy, but creates risk that a function may modify a piece of data that you don't want it to edit.

- Solution: **`const`** reference!
  - The "by reference" part avoids a copy.
  - The "const" (constant) part means that the function can't change that argument.

```
void proofreadLongEssay(const string& essay) {
    /* can read, but not change, the essay. */
}
```


The Container Store

What’s next?


Roadmap
Object-Oriented Programming
C++ basics
User/client
vectors + grids
stacks + queues
sets + maps
Implementation
arrays
dynamic memory management
linked data structures
real-world algorithms
Diagnostic
Life after CS106B!
Core Tools
testing
algorithmic analysis
recursive problem-solving

Big O and Algorithmic Analysis