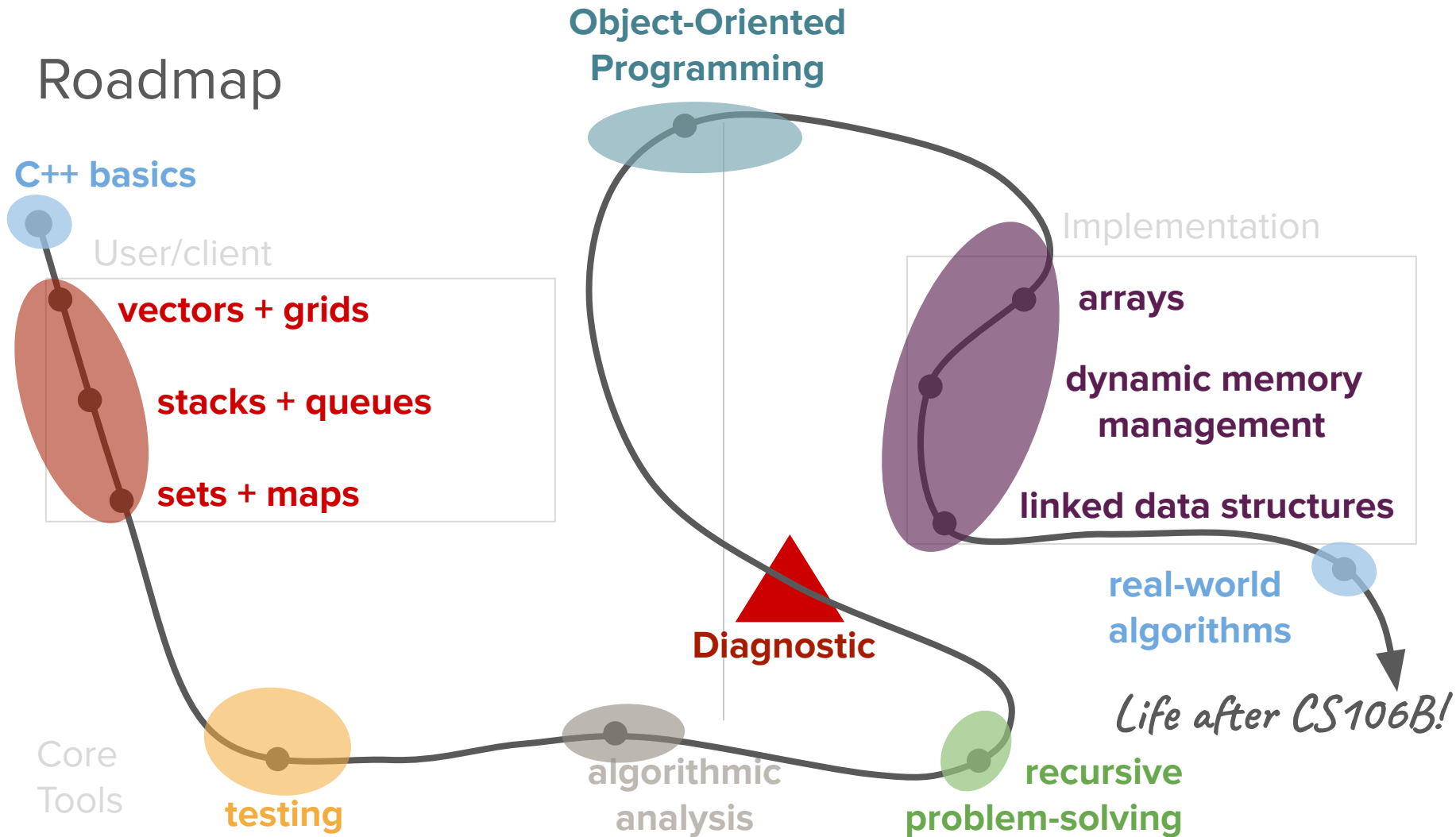


Unordered Data Structures: Sets and Maps

What's an example of “unordered data” that you've encountered in your life?
(put your answers the chat)



Roadmap



Roadmap

C++ basics

User/client

vectors + grids

stacks + queues

sets + maps

Core
Tools

testing

algorithmic
analysis

recursive
problem-solving

Object-Oriented
Programming

Implementation

arrays

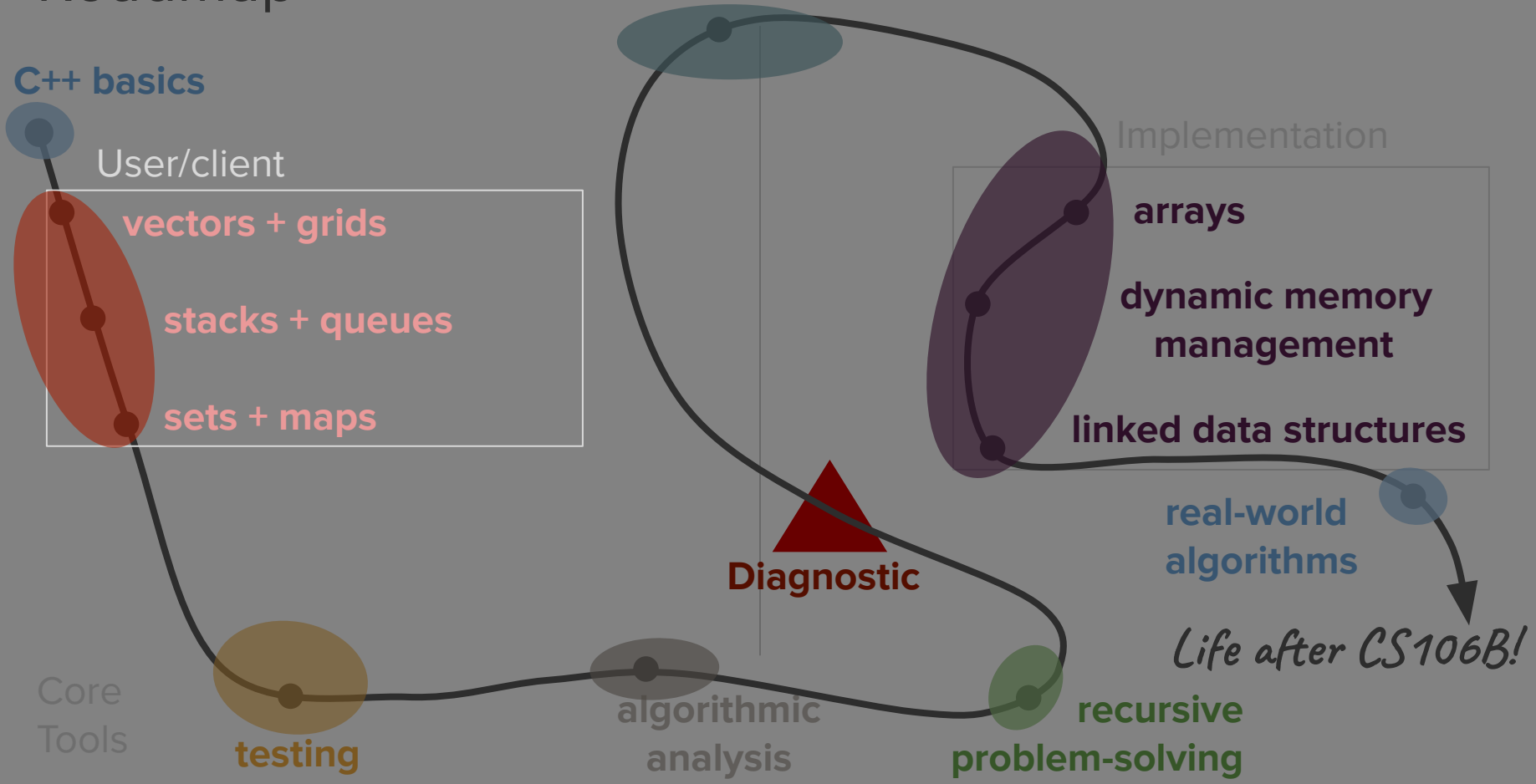
dynamic memory
management

linked data structures

real-world
algorithms

Life after CS106B!

Diagnostic



Roadmap

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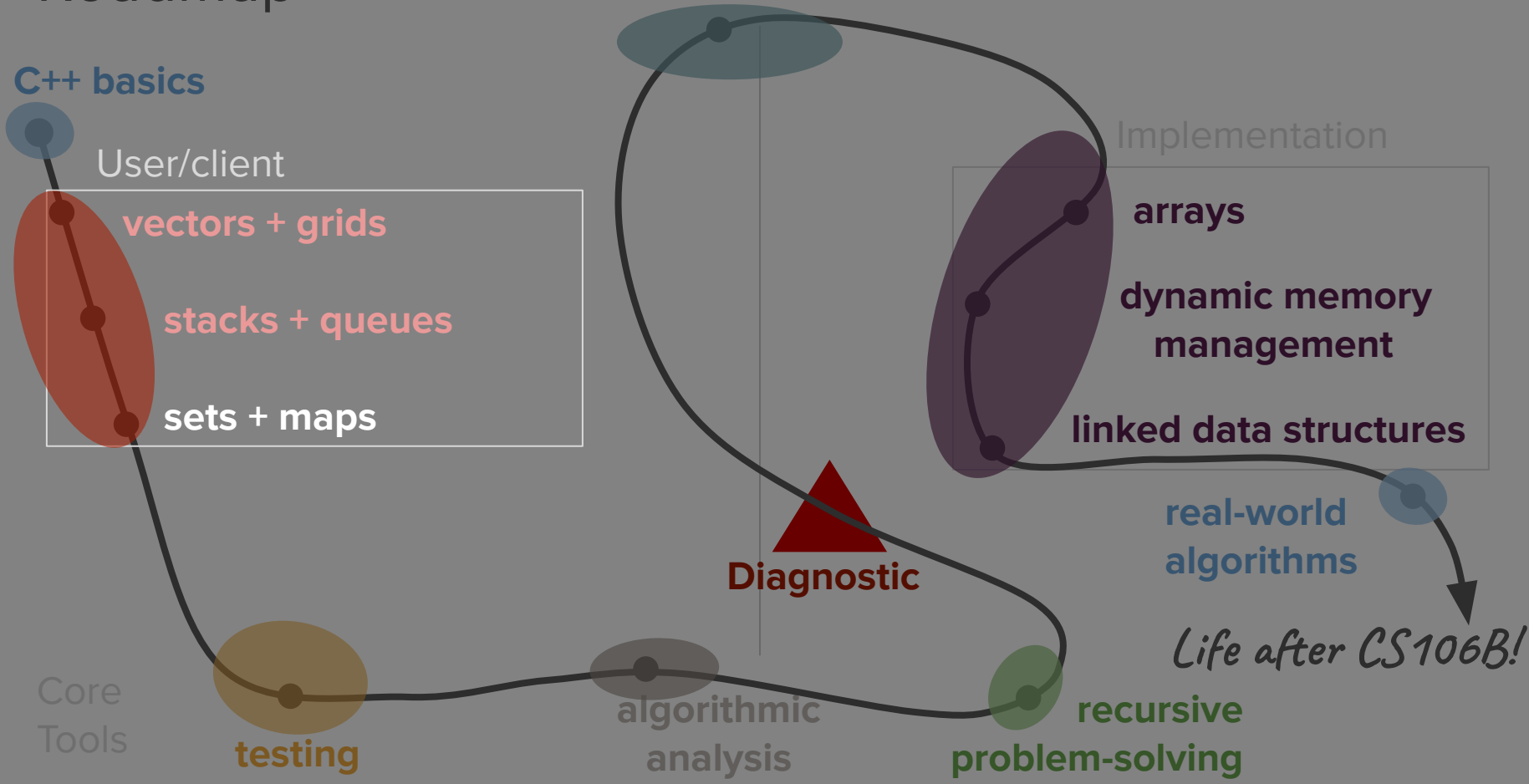
dynamic memory
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Diagnostic



Today's question

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

Today's topics

1. Review
2. Sets
3. Maps

Review

(grids and queues and stacks, oh my!)

What is a grid?

- 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!

a0	a1	a2
b0	b1	b2
c0	c1	c2

Definition

struct

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

The **GridLocation** struct

- 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;
```

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

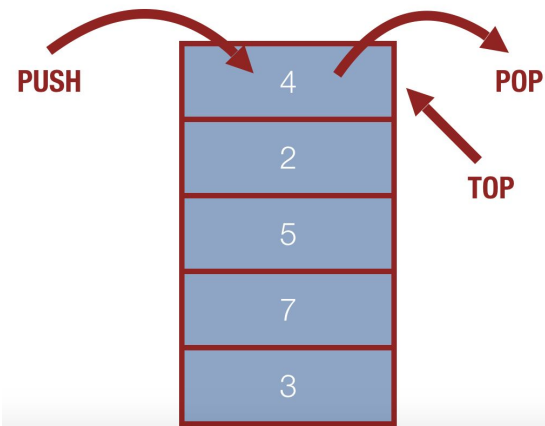
What is a queue?

- 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:

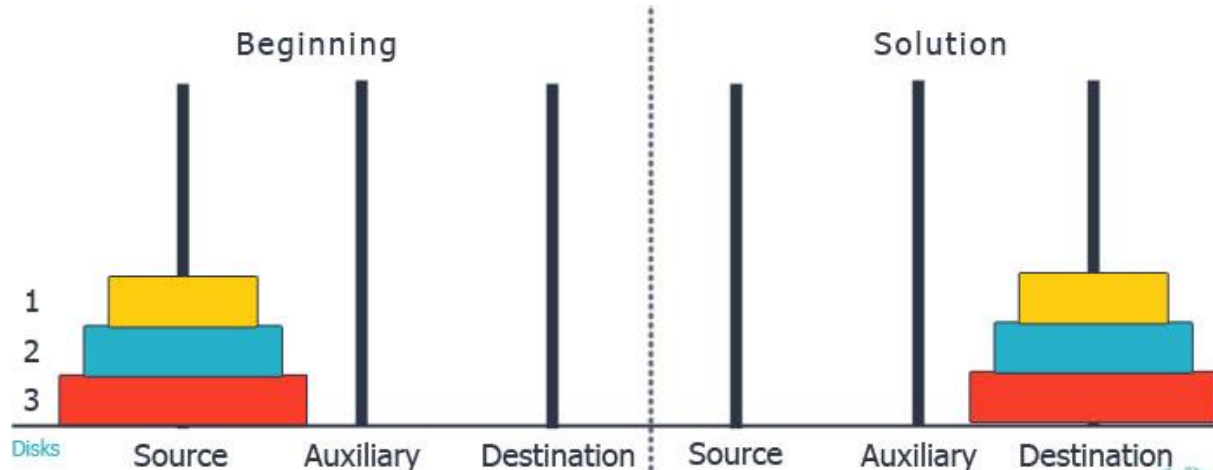
- Constrains the way you can insert and access data
- More efficient for solving specific LIFO/FIFO problems

Activity:

towersOfHanoi()

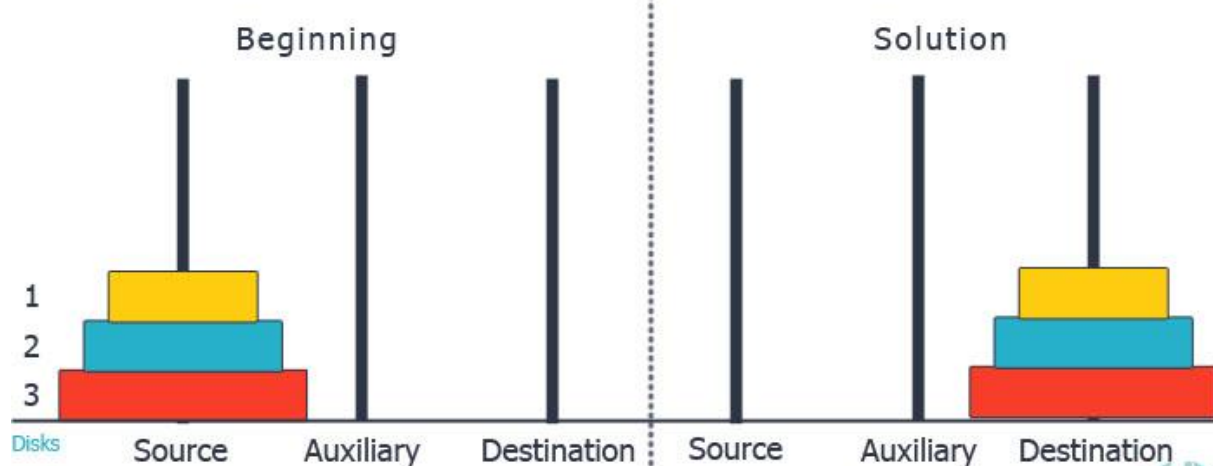
Towers of Hanoi

- 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

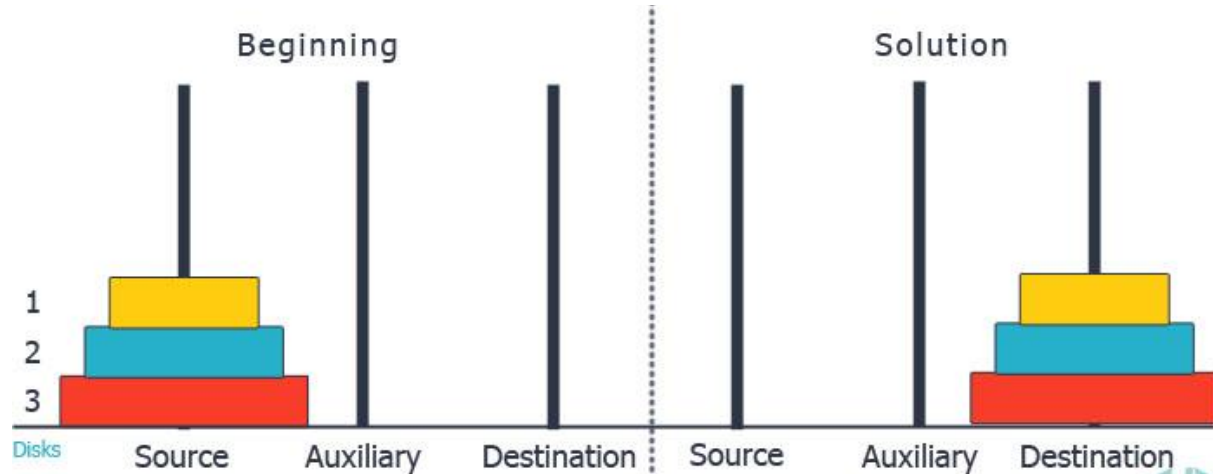
- Rules:
 - Can only move one disk at a time
 - You cannot place a larger disk on top of a smaller disk



Discuss: How would
you solve this problem?

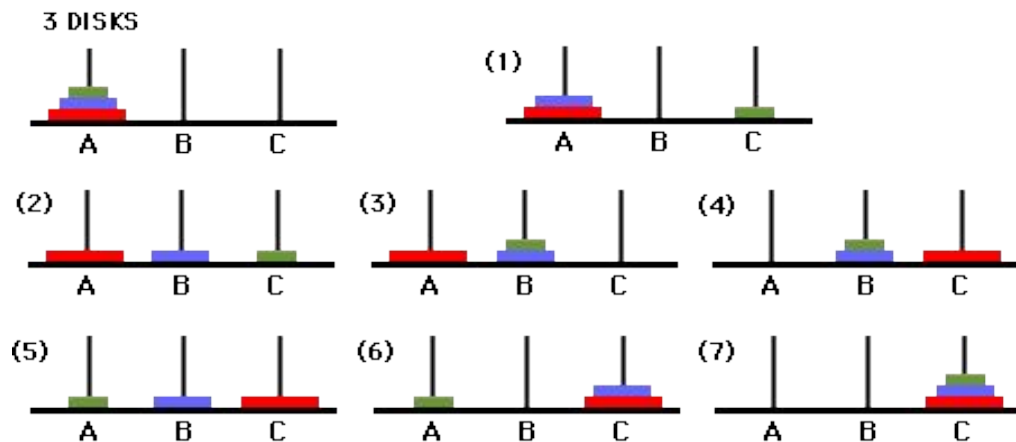
[breakout rooms]

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

Code the solution for three disks!

[breakout rooms]

Code the solution for three disks!

[breakout rooms]

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

Why do we use
unordered ADTs?

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
- 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

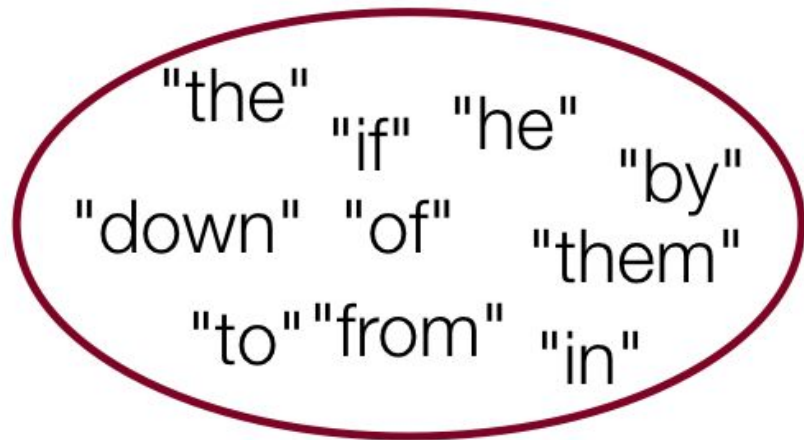
- Unique visitors to a website
- Shuffled playlist with no duplicate songs
- People and their passport numbers on a particular flight
- A recipe with ingredients and their quantities
- Products placed into categories in an online storefront

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” on Thursday.
- 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("nick");  
friends.add("kylie");  
friends.add("trip");  
// can also use: Set<string> friends = {"nick", "kylie", "trip"};  
  
cout << boolalpha << friends.contains("voldemort") << noboolalpha  
    << endl;  
  
for(string person : friends) {  
    cout << person << endl;  
}
```

Set example

```
Set<string> friends;  
friends.add("nick");  
friends.add("kylie");  
friends.add("trip");  
// can also use: Set<string> friends = {"nick", "kylie", "trip"};  
  
cout << boolalpha << friends.contains("voldemort") << noboolalpha  
    << endl;  
  
for(string person : friends) {  
    cout << person << endl;  
}
```

```
false  
kylie  
nick  
trip
```

Set operands

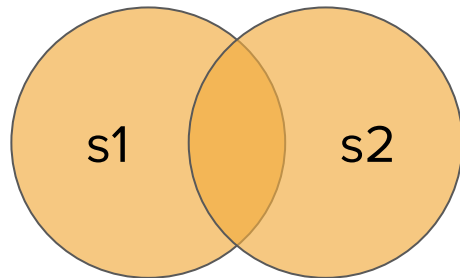
Sets can be compared, combined, etc.

- **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

Sets can be compared, combined, etc.

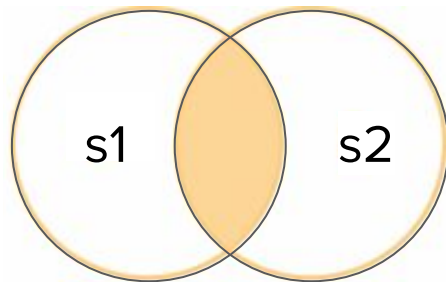
- **`s1 == s2`**
true if the sets contain exactly the same elements
- **`s1 != s2`**
true if the sets don't contain the exact same elements
- **`s1 + s2`**
returns the *union* of **`s1`** and **`s2`** (i.e., all elements in both)



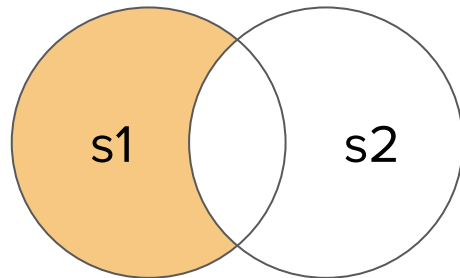
Set operands

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- **`s1 * s2`**
returns the *intersection* of **`s1`** and **`s2`** (i.e., only the elements in both sets)



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

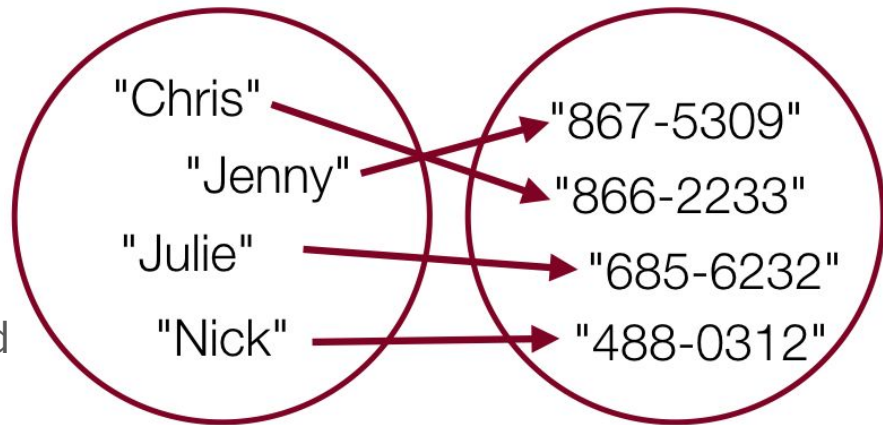
Announcements

- Assignment 1 is due tonight at 11:59pm in your timezone.
- Assignment 2 will be out by the end-of-the-day tomorrow.
 - YEAH hours: Hosted by Trip this Thursday, 7/2 at 7pm PDT. (Zoom info coming soon!)
- The [schedule page](#) on the course website now has associated readings posted!
- When signing up for LaIR, please don't forget to include a Zoom link (with associated password + ID).

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, get 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");
```

```
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;
```

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");
```

} *Inserting new
values*

```
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;
```

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");
```

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

} *Accessing values*

// maps from string keys to Vector<double> values

```
Map<string, Vector<double>> accounts;
```

Common Map patterns and pitfalls

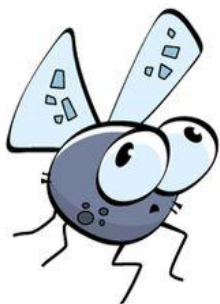
- Use for each loops to iterate over maps

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

Common Map patterns and pitfalls

- Use for each loops to iterate over maps

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



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

```
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

```
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

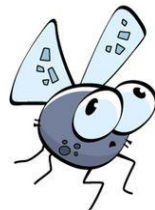
- Use for each loops to iterate over maps
- Auto-insert: a map feature that can also cause bugs

```
Map<string, int> freqMap;  
...  
// get key to test if it's in the map  
if (freqMap[key] == 0) {  
    cout << key << " is in the map" << 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> freqMap;  
...  
// get key to test if it's in the map  
if (freqMap[key] == 0) { // this will always be true!  
    cout << key << " is in the map" << 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> freqMap;  
...  
// use containsKey function, no auto-insert  
if (freqMap.containsKey(key)) { // correct way to do it  
    cout << key << " is in the map" << 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)
- Keys (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)
- Keys (keys unique)



Useful when numerical ordering of data isn't optimal

Ordered ADTs

Elements accessible by indices:

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

Elements not accessible by indices:

- Queues (FIFO)
- Stacks (LIFO)

Unordered ADTs

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

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

Unordered ADTs: no numerical ordering of elements

What's next?

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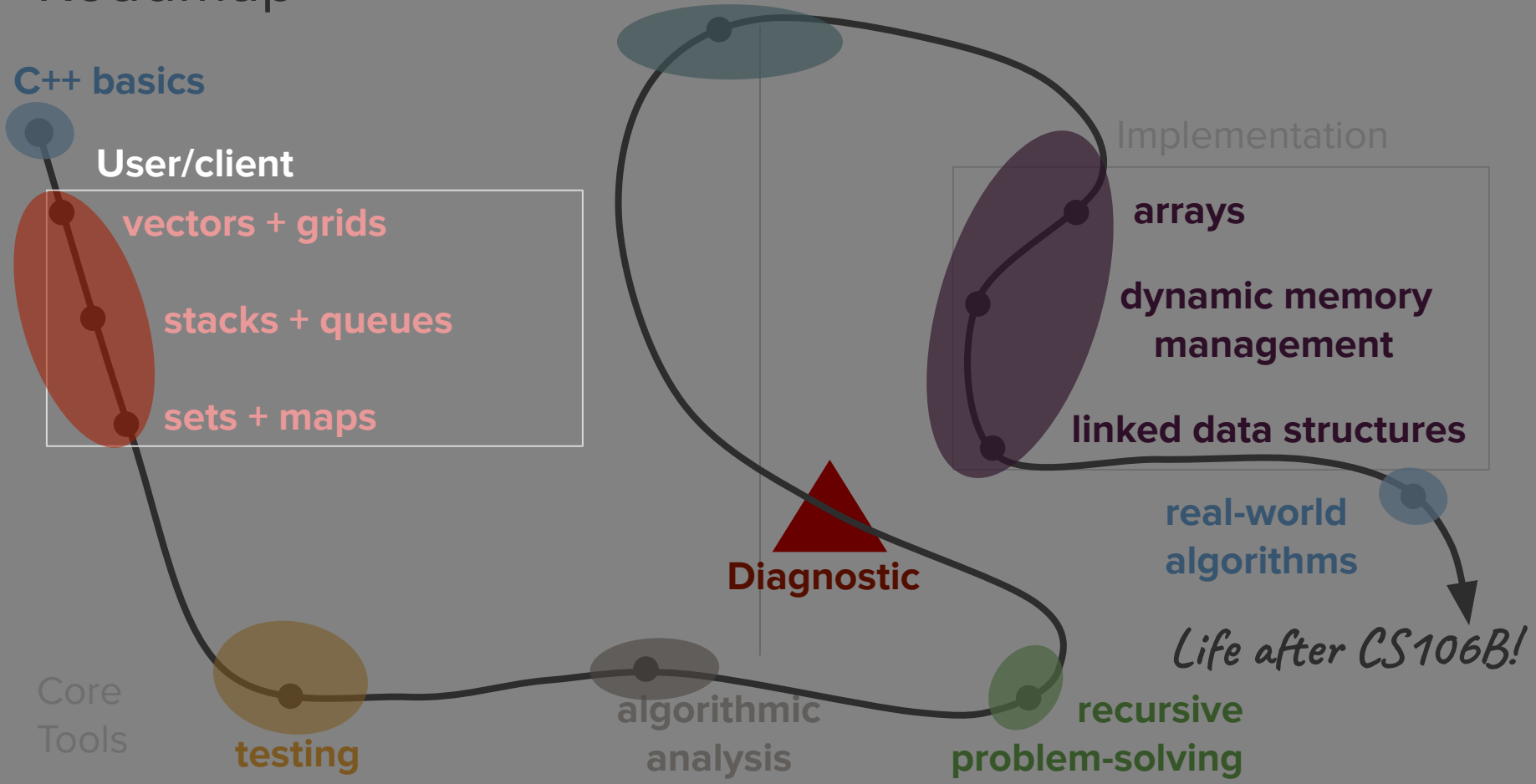
dynamic memory
management

linked data structures

real-world
algorithms

Life after CS106B!

Diagnostic











Tomorrow:

Name: _____

Date: _____

Top to Him Word Ladder

Fill in the missing letter in each word to help top become him.

	T	O	P	
	__	O	P	
	__	O	P	
	C	__	P	
	__	A	P	
	L	__	P	
	__	I	P	
	H	I	__	

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