

# Welcome to

# Computer Science 32

## Lecture #1

Professor: Carey Nachenberg (*Please call me "Carey"*)

E-mail: [climberkip@gmail.com](mailto:climberkip@gmail.com)

Class info: M/W 10am-12pm, Franz 1178

Office hours: 4760 Boelter Hall

Mondays 12pm-1pm (*after class*)

Wednesdays 9am-10am (*before class*)

My Office: 4531N Boelter Hall (*for 1-on-1 meetings*)

# Pick a # between 1 - 60

16	21	26	31	52	57
17	22	27	48	53	58
18	23	28	49	54	59
19	24	29	50	55	60
20	25	30	51	56	*

4	13	22	31	44	53
5	14	23	36	45	54
6	15	28	37	46	55
7	20	29	38	47	60
12	21	30	39	52	*

2	11	22	31	42	51
3	14	23	34	43	54
6	15	26	35	46	55
7	18	27	38	47	58
10	19	30	39	50	59

8	13	26	31	44	57
9	14	27	40	45	58
10	15	28	41	46	59
11	24	29	42	47	60
12	25	30	43	56	*

32	37	42	47	52	57
33	38	43	48	53	58
34	39	44	49	54	59
35	40	45	50	55	60
36	41	46	51	56	*

1	11	21	31	41	51
3	13	23	33	43	53
5	15	25	35	45	55
7	17	27	37	47	57
9	19	29	39	49	59

# Who Am I?

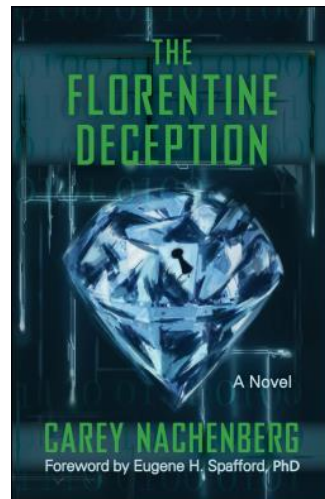


Carey Nachenberg

Age: 45

School: BS+MS in CS, UCLA '95

Work: Adjunct Prof at UCLA  
Engineer at Google [X]



Hobbies: Rock climbing,  
weight training,  
teaching CS!

My goal: To make an impact on  
your life (through  
getting you excited  
about programming)!

# CS32 Course Reader

If you'd like a course reader with all of my slides, you can either...

Download them from my website @  
[www.careynachenberg.com](http://www.careynachenberg.com)  
and print them out yourself, or...

Buy a printed course reader from:

Copymat Westwood  
10919 Weyburn Ave.  
(310) 824 5276

# Class Website

Official Class Website:

<http://www.cs.ucla.edu/classes/winter17/cs32/>

You should check the Official Class Website at least  
2-3 times a week for homework info, projects, etc.

I will not always announce homework/projects so you  
have to track this on your own and be on top of the trash!

I'll post my PowerPoint slides on my private website:  
<http://careynachenberg.com>

# What You'll Learn in CS32

## Advanced C++ Topics

Object Oriented Programming and C++ language features

## Data Structures

The most useful data structures (e.g., lists, trees, hash tables)

## Algorithms

The most useful algorithms (e.g., sorting, searching)

## Building Big Programs

How to write large (> 500 lines of code) programs

Basically, once you  
complete CS32, you'll know  
**95%** of what you need to  
**succeed in industry!**



# Important Dates

Project #1: Due Tues, Jan 17<sup>th</sup> (next tues!)

Midterm #1: Thurs, Feb 2<sup>nd</sup>  
6pm-8pm (not during class hours!!)

Midterm #2: Tues, Feb 28<sup>th</sup>  
6pm-8pm (not during class hours!!)

Final Exam: Sat, March 18<sup>th</sup>  
One choice: 11:30-2:30pm  
(This is the Saturday BEFORE Finals Week. Don't forget!)

# Project #1: Due Tues, Jan 17<sup>th</sup>

Your **first CS32 project** is already posted on the class website and is **due next Tues!**

In P1, **we provide you** with a simple **C++ program**.

Your job is to get the program **compiling** and then **make a few changes** to it.

The goal of P1 is to allow you to **self-evaluate** to see if you're ready for CS32.

If you **feel lost** on P1...  
You should seriously consider one of two things:

1. **Drop the c**  
your C++ th  
take CS32
2. **Suffer... B**  
history, if  
problems o  
**a C or lowe**





# Random Administrative Stuff

We grade on a curve with the **average student getting a B-**, but if everyone gets above ~90%, **everyone gets an A/A-**!



**But be careful!** CS32 is a weeder class and can easily take 30-40 hours per week of work! **Start projects EARLY!**



Read & sign the **academic integrity agreement** and **don't cheat** - we catch people every year!



We have a **special grading policy** to **discourage cheating** on projects. Read the Syllabus to understand it!



# Compilers, Compilers, Compilers!

You must make sure that all programs you turn in compile and work with **both Visual C++** and **gcc (under linux or Mac)**!

Note: Make sure your projects work with both compilers **at least a day or two** before submitting them!

You can get a free copy of Visual C++ from:

<http://www.visualstudio.com/downloads/download-visual-studio-vs#d-express-windows-desktop>

You can get a free copy of Apple Xcode/gcc from the Apple App store, or <http://developer.apple.com/xcode/>

You can also use **gcc** and **Visual C++** in the **lab**.

# Carey's Thoughts on Teaching



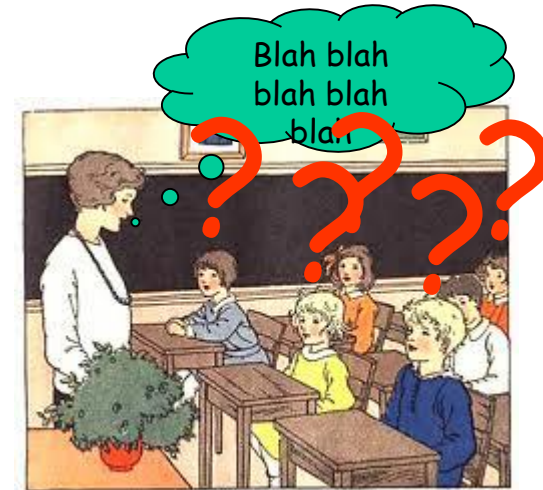
It's more important that **everyone understand** a topic than I **finish a lecture on time**.

Don't be shy!!!

If something **confuses you...**

it probably **confuses 5 other people** too.

So **always ask questions** if you're confused!



Always save more **advanced questions** for office hours or break.

I reserve the right to **wait until office hours** to answer advanced questions.



# Take Only 12 Units This Quarter

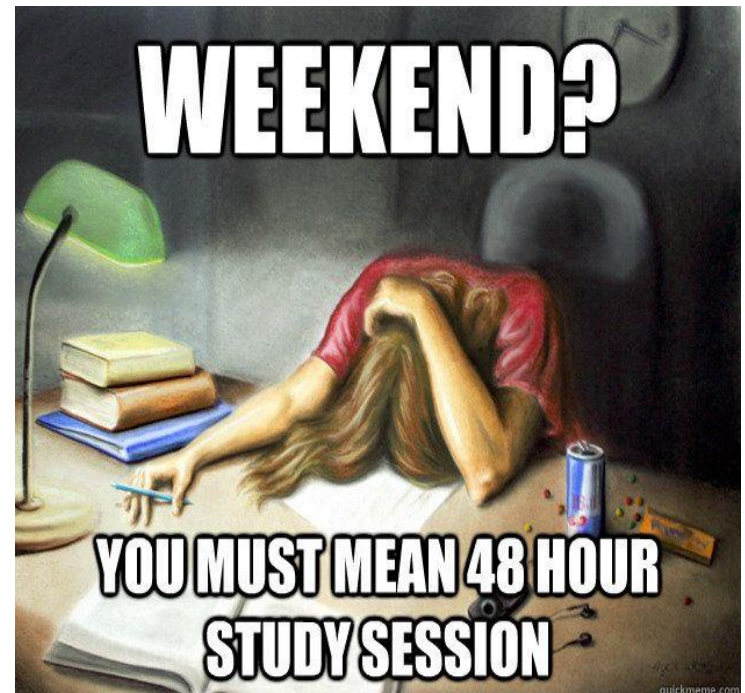
Really?

Yes. Many students **struggle** in CS32 even with **just 12 units** (let alone 16 or 20)...

You're only going to have one chance to learn **data structures & algorithms**...

and it's foundational to everything you'll study at UCLA, not to mention **job/internship interviews!**

**Take the time to do it right!**



# Use Me As a Resource!

If you're struggling with projects, stressing out on exams, not getting the material, or just need some advice about life.

Come meet with me  
Schedule a video chat  
Let's talk on the phone  
Or grab a coffee

Don't wait until 8<sup>th</sup> week  
when it's too late!


THE PROBLEM WITH  
THE WORLD IS THAT  
THE INTELLIGENT  
PEOPLE ARE FULL OF  
DOUBT, WHILE THE  
STUPID PEOPLE  
ARE FULL OF  
CONFIDENCE.

---

Charles Bukowski

# Letters of Recommendation

If you want a letter of recommendation from me...

<b>UNIVERSITY OF CALIFORNIA, LOS ANGELES</b>		<b>UCLA</b>
BERKELEY • <u>DAVIS</u> • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO		SANTA BARBARA • <u>SANTA CRUZ</u>
		
		MR. CAREY NACHENBERG DEPARTMENT OF COMPUTER SCIENCE THE HENRY SAMUEL SCHOOL OF ENGINEERING AND APPLIED SCIENCE CAMPUS <u>Box 951596</u> LOS ANGELES, CALIFORNIA 90095-1596 (424) 750-7519 CAREY_NACHENBERG@SYMANTEC.COM
Dear <fill-in-school-name>,		
I write to you to recommend <outstanding-student> for admission into your graduate program.		
I first had the pleasure of meeting <outstanding-student> in my Computer Science course, CS32 - Data Structures and Algorithms, in <u>Winter</u> of 2015. This course is arguably the most challenging lower-division Computer Science course at UCLA, and <outstanding-student> demonstrated an excellent mastery of the course material, earning a grade of A.		

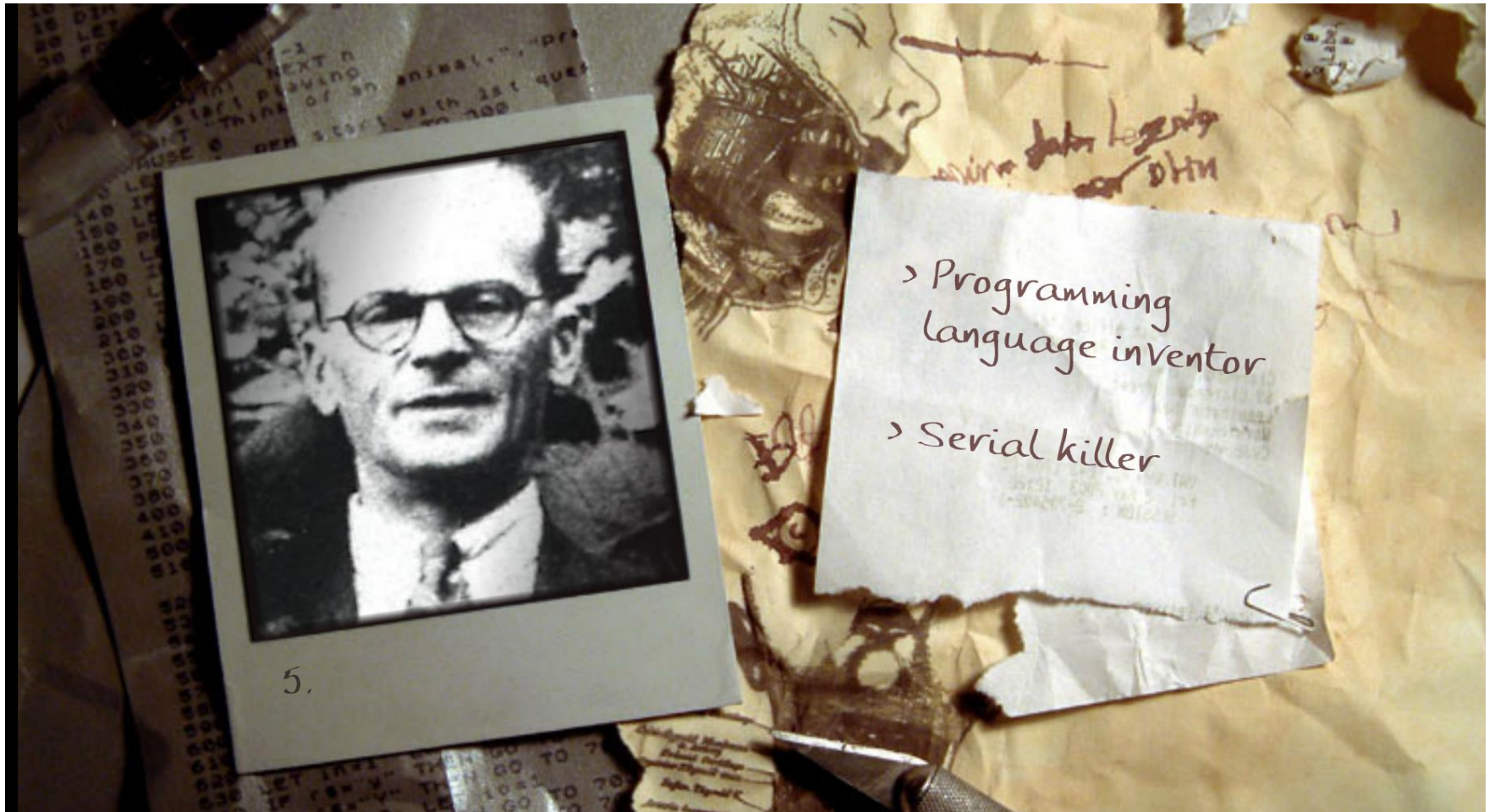
Be one of the **top 3 students** in my class.

Oh, and by the way, LoRs from **lower-division profs (like me)** actually **hurt your chances** of getting into grad school.

If you want to increase your odds of getting into grad school, do **research with an upper-div prof** and get a LoR from them!



# And now for a fun game!

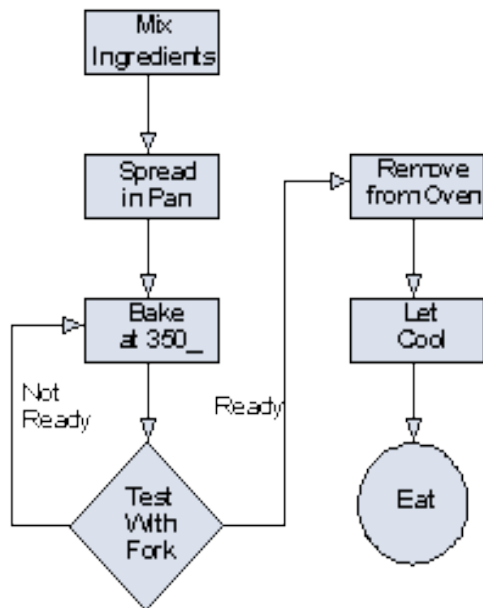


Is this guy a programming language inventor... or a **SERIAL KILLER?!?!**

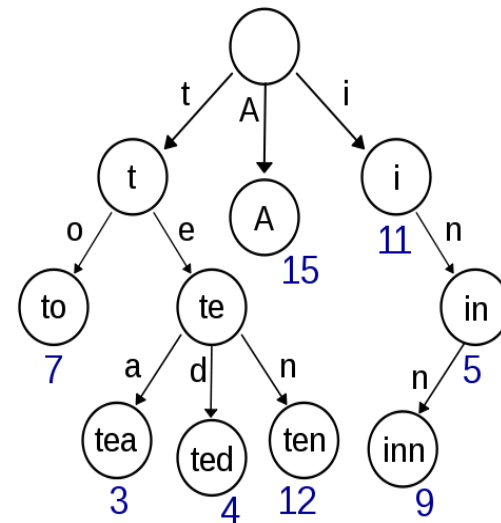
# Alright... Enough administration!

## Let's learn about...

### Algorithms



### Data Structures





# What is an Algorithm



An **algorithm** is a set of **instructions/steps** that solves a particular problem.

Each algorithm operates on **input data**.



42

Each algorithm produces an **output result**.

Each algorithm can be classified by **how long it takes to run** on a particular input.



Each algorithm can be classified by **the quality of its results**.

# Algorithm Comparison

## "Guess My Word"

Let's say you're building a word guessing game.

The user secretly picks a random word from the dictionary.



Our program then must figure out what word the user picked.

Let's consider **two** different algorithms...

# Algorithm #1: Linear Search

Let's try a simple algorithm: We'll search linearly from top to bottom and ask the user about each word:

```
j = 0
While I haven't guessed the user's word
{
    Select word j from the dictionary
    Ask the user if word j is the word they picked
    j = j + 1
}
```

**Question:** If there are **N total words** in our dictionary, on average, how many guesses will our algorithm require?

# Algorithm #2: Binary Search

Alright, for our second strategy let's try a more intelligent approach called **binary search**:

```
SearchArea = The entire dictionary
While I haven't guessed the user's word
{
    Pick the middle word w in the SearchArea
    Ask the user: "Is w your word?"
    If so, you're done! Woohoo!
    If not, ask: "Does your word come before or after w?"
    If their word comes before our middle word w
        SearchArea = first  $\frac{1}{2}$  of the current SearchArea
    If their word comes after our middle word w
        SearchArea = second  $\frac{1}{2}$  of the current SearchArea
}
```

**Question:** If there are ***N* total words** in our dictionary, on average, how many guesses will our algorithm require?

# Binary Search: How Many Guesses?

We keep on dividing our search area in half until we finally arrive at our word.

In the worst case, we must keep halving our search area until it contains just a single word – our word!



If our dictionary had  $N=16$  words, how many times would we need to halve it until we have just one word left?

16   8   4   2   1

It would take 4 steps

Ok, what if our dictionary had  $N=131,072$  words?

131072   65536   32768   16384   8192   4096   2048   1024   512   256   128   64   32   16   8   4   2   1

It would take just 17 steps!!! WOW!

Can we come up with a general formula to determine the # of steps?

# Binary Search: Estimating the # of Steps

Well, if you remember your math...

You know that  $\log_2(N)$  is equal to the number of times you can divide  $N$  by 2 before you reach a value of 1.

$$\log_2(8) = 3, \text{ since } 8 \rightarrow 4 \rightarrow 2 \rightarrow 1$$

$$\log_2(64) = 6, \text{ since } 64 \rightarrow 32 \rightarrow 16 \rightarrow 8 \rightarrow 4 \rightarrow 2 \rightarrow 1$$

$$\log_2(1 \text{ billion}) = ? \quad 1\text{B} \rightarrow 500\text{M} \rightarrow 250\text{M} \rightarrow 125\text{M} \rightarrow \dots$$

So no matter what word the user picks, we can find it in  $\log_2(N)$  steps for a dictionary with  $N$  words!

# Wow! That's Significant!

Our linear search algorithm requires  $N/2$  steps, on average, to guess the user's secret word.  
(~50,000 steps for a dictionary with 100,000 words)

But our binary search algorithm only requires  $\log_2(N)$  steps, on average, to guess the user's secret word.  
(~17 steps for a dictionary with 100,000 words)

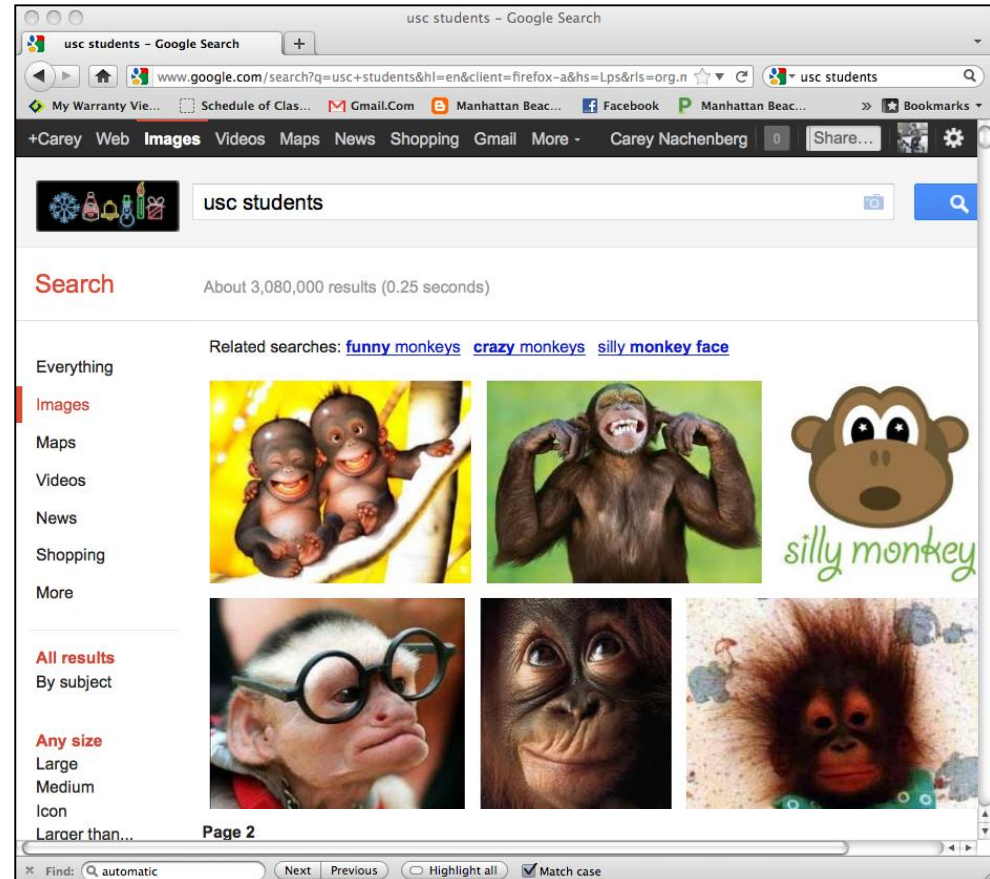
If, instead of a dictionary, we had to search a database of 300 million people, which algorithm would you choose?

# Bad Algorithms Can Kill a Program!




Bad algorithms can be way too slow!

Bad algorithms can produce bad results:



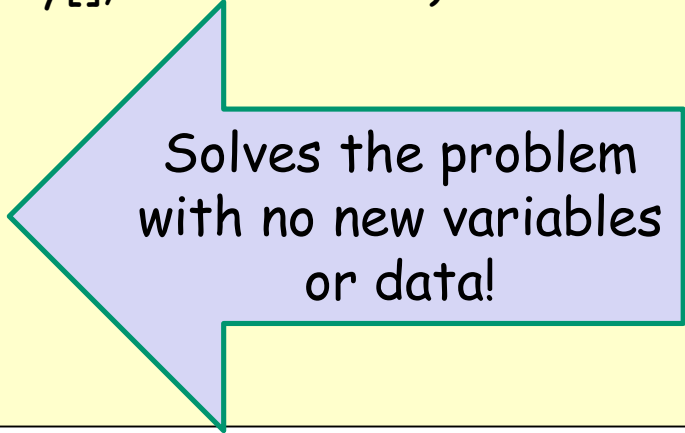


# Data Structures

 A **data structure** is the **data** that's operated on by an algorithm to solve a problem.

Sometimes an algorithm can operate just on the data passed in to it:

```
void printNumbersBackward(int array[], int numItems)
{
    while (numItems > 0)
    {
        --numItems;
        cout << array[numItems];
    }
}
```



Solves the problem  
with no new variables  
or data!

Other times an algorithm will have to create its own secondary data structures to solve a problem.

# A Data Structure for Facebook

Imagine that you're building a social network website like Facebook...



<u>Friend A</u>	<u>Friend B</u>
Danny Hsu	Jenny Oh
Danny Hsu	Rich Lim
Jenny Oh	David Sun
Danny Hsu	Carey Nash
Carey Nash	Scott Wilhelm
Melani Kan	Danny Hsu
Carey Nash	David Small
Jenny Oh	Len Kleinrock
Jenny Oh	Mario Giso
Mario Giso	Rich Nguyen

And you want to keep track of who made friends with whom...

How would you do it?

Well, one *data structure* we could use would be a long list of every pair of friends...

Now how could I find out if *Jenny Oh* is a friend of *Mario Giso*?

Well, we could search through every pair until we find the friendship we are looking for...

Hmmm. But if we had 100 million users with 10 billion friendships, that might be a bit too slow! 😊

# A Better Friendship Data Structure

What if instead we assigned each of our **N** users a number...

And kept an **alphabetized list** of each **user** → **number** pair.

User	Number
Carey Nash	0
Danny Hsu	1
David Small	2
David Sun	3
Jenny Oh	4
Len Kleinrock	5

FriendA	FriendB
Danny Hsu	Jenny Oh
David Sun	Carey Nash
Jenny Oh	David Sun
Danny Hsu	Carey Nash
Carey Nash	Scott Wilhelm
Melani Kan	Danny Hsu
Carey Nash	David Small

Now given a user's name, how can we quickly find their number?

Right - just use a **Binary Search**!

1. Look up their numbers **A, B**
2. Check (**A,B**) or (**B,A**) in our array
3. If we find a **\***, they're buddies!  
to represent relationships!

	0	1	2	3	4	5	6	7	8	9	10
0				*							
1	*										
2											
3	*				*						*
4		*		*			*	*	*		
5											
6					*						
7					*						
8					*					*	
9									*		
10				*							

# A Better Friendship Data Structure

So what we've done is created a new **data structure** that makes it faster to determine if two people are friends!

Coupled with our new, more efficient **algorithm**, we can quickly find out if two people are friends!

<u>User</u>	<u>Number</u>
Carey Nash	0
Danny Hsu	1
David Small	2
David Sun	3
Jenny Oh	4
Len Kleinrock	5
Mario Giso	6
Melani Kan	7

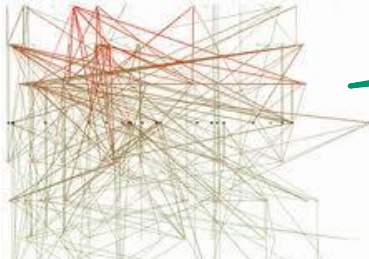
	0	1	2	3	4	5	6	7	8	9	10
0		*	*	*							
1	*										
2	*										
3	*				*	*					*
4				*			*	*	*		
5				*							
6					*						
7					*						
8											
9											
10											

## Friend-finding Algorithm:

1. Look up their numbers **A**, **B**
2. Check (**A**,**B**) or (**B**,**A**) in our array
3. If we find a **\***, they're buddies!

# Data Structures + Algorithms = Confusion!

Of course, your data structures and algorithms can get quite complex.



Without having to understand any of the **sordid details**!

Such a collection of simple functions is called an **"interface."**

```
bool AreTheyFriends(string UserA, string UserB)
void BecomeFriends(string UserA, string UserB)
void BreakUp(string UserA, string UserB)
```

If you gave your code to another programmer, he/she would have no idea how to use it! Therefore, every time you **create** a new set of **data structures/algorithms**, it helps to also **create** a few **simple functions** that hide the gory details...

```
int main()
{
    BecomeFriends("Rob Crouch", "Eric Chien");
    if (AreTheyFriends("Carey N", "David S") == true)
        cout << "Carey & David are BFFs!\n";
}
```

An **interface** lets any programmer use your code...



# Algorithms & Data Structures Are a Perfect Couple!

Algorithms and data structures are like **peas** and **carrots** - they belong together!



To solve a problem, you have to design both the **algorithms** and the **data structures** together.

Then you provide a set of simple **"interface" functions** to let any programmer use them easily.

And in fact, we even have a name for such a  
(**data structure** + **algorithm** + **interface**)  
solution to a problem...

# The Abstract Data Type (ADT)

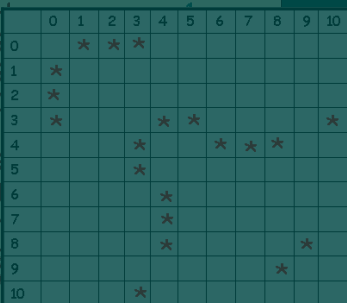
An **Abstract Data Type** or **ADT** is:

"A coordinated group of

(a) **data structures**, (b) **algorithms** and (c) **interface functions** that is used to solve a particular problem."

## Abstract Data Type (for finding friends)

User	Number
Carey Nash	0
Danny H	
David S	0
David S	1
Jenny C	2
Len Kle	3
Mario G	4
Melani	5
Rich Lir	6
Rich Ng	7
Scott V	8



### Add Friend Algorithm:

1. Look up each person's #s
2. Stick a \* in grid[n1][n2]
3. Stick a \* in grid[n2][n1]

### Friend-finding Algorithm

1. Look up each person's #s
2. Check grid[n1][n2] and grid[n2][n1]
3. If we find a \*, they're buddies!

```
bool AreTheyFriends(UserA, UserB)
void BecomeFriends(UserA, UserB)
void BreakUp(UserA, UserB)
...
```

In an ADT, the **data structures** and **algorithms** are **secret**.

The ADT provides an **interface** (a simple set of functions) to enable the rest of the program to use the ADT.

Typically, we **build programs** from a **collection of ADTs**, each of which **solves a different sub-problem**.

**[TOP SECRET]**

User	Number
Carey Nash	0
Scott Wilhelm	1
David Smallberg	2
Danny Hsu	3
Jenny Oh	4
Rich Lim	5
David Sun	6
...	...

	0	1	2	3	4	5	6	7	8	9	10
0		*	*	*							
1	*										
2	*										
3	*										*
4			*	*	*	*	*	*	*		
5			*	*	*	*	*	*	*		
6				*	*	*	*	*	*		
7				*	*	*	*	*	*		

Friend-finding Algorithm:

1. Look up their numbers **A, B**
2. Check **(A,B)** or **(B,A)** in our array
3. If we find a **\***, they're buddies!

++

We can use **C++ classes** to define ADTs in our C++ programs! Each C++ class can hold **algorithms**, **data** and **interface funcs**.

```
int main()
```

```
{
```

```
    FriendFinder x;
```

```
    x.BecomeFriends("Carey Nash",  
                    "Scott Wilhelm");
```

```
    x.BecomeFriends("Jenny Oh",  
                    "David Sun");
```

```
    ...
```

```
    string userA, userB;
```

```
    cin >> userA >> userB;
```

```
    if (x.AreTheyFriends(userA,  
                          userB) == true)
```

```
        cout << userA << " is friends with "  
              << userB;
```

```
}
```



Once we've defined our class, the rest of our program can use it trivially.

All our program needs to do is call the functions in our class's public **interface**!

And yet all of its underlying **data structures** and **algorithms** are **hidden**!

The rest of the program can ignore the details of how our class works and just use its features!

This is the **power** of the ADT/class!



**[TOP SECRET]**

User	Number	0	1	2	3	4	5	6	7	8	9	10
Carey Nash	0		*	*	*							
Scott Wilhelm	1		*									
David Smallberg	2		*			*	*				*	
Danny Hsu	3				*			*	*	*		
Jenny Oh	4			*								
Rich Lim	5				*							
David S										*		
...												

Friend-finding Algorithm:  
1. Look up their numbers **A**, **B**  
2. Check (**A**,**B**) or (**B**,**A**) in our array  
3. If we find a \*, they're buddies!

```
int main()
```

```
{
```

```
    FriendFinder x;
```

```
    x.BecomeFriends("Carey Nash",  
                    "Scott Wilhelm");
```

```
    x.BecomeFriends("Jenny Oh",  
                    "David Sun");
```

```
    ...
```

```
    string userA, userB;
```

```
    cin >> userA >> userB;
```

```
    if (x.AreTheyFriends(userA,  
                          userB) == true)
```

```
        cout << userA << " is friends with "  
              << userB;
```

```
}
```



++

We use a similar approach to construct real-life objects!

Consider your car...



It has an easy-to-use **interface** like the steering wheel, brake and accelerator pedals.

The **complicated machinery** is **hidden** from you - you don't need to know how it works to use it!

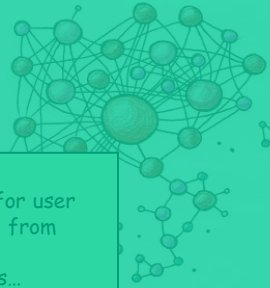


**[TOP SECRET]**

User	Number
Carey Nash	0
Scott Wilhelm	1
David Smallberg	2
Danny Hsu	3
Jenny Oh	4

Friend-finding Algorithm:

1. Identify the node in the graph for user
2. Perform a breadth-first search from this node
3. Do not follow more than 2 edges...



++

Now what if I wanted to **improve** my FriendFinder data structures?

```
int main()
```

```
{
```

```
    FriendFinder x;
```

```
    x.BecomeFriends("Carey Nash",  
                   "Scott Wilhelm");
```

```
    x.BecomeFriends("Jenny Oh",  
                   "David Sun");
```

```
    ...
```

```
    string userA, userB;
```

```
    cin >> userA >> userB;
```

```
    if (x.AreTheyFriends(userA,  
                        userB) == true)
```

```
        cout << userA << " is friends with "  
             << userB;
```

```
}
```



Let's say I made a **radical change** to our **friend network** data structures...

Would the **user** of my class need to **change** any part of her program?

**No!** Because the rest of the program doesn't rely on these details - it knows nothing about them!

The same is true for your car!  
If you **replace your engine**, you don't care - you just use the **steering wheel, accelerator** and **brakes** like you did before!

# What is Object Oriented Programming?



Object Oriented Programming (OOP) is simply a programming model based on the Abstract Data Type (ADT) concept we just learned!

In OOP, programs are constructed from multiple self-contained **classes**.

Each class holds a set of **data** and **algorithms** - we then access the class using a **simple set of interface functions**!

Classes **talk to each other** only by using **public interface functions** - each class knows nothing about how the others work inside.

So to sum up:

OOP is using classes (aka ADTs) to build programs - **plus some other goodies we'll learn soon!**

# C++ Class Review

Ok, since I know you're rusty, let's do a quick review of C++ **structs** and **classes**.



# Topic #1: C++ structs

Sometimes we want to group together multiple related pieces of data and store them in a single variable.

For instance, to represent a **person** in my program, I need to store their **name**, **age**, **phone number**, **address**, etc.

The problem is that I have to define **four separate variables** to represent a single entity (like a person).

It'd be nice if we had some way to define a **single variable** that can hold all of our related values.

```
int main()
{
    string name;
    int age;
    int phoneNum;
    string address;
    name = "Carey";
    age = 44;
    ...

    PERSON p;
    p.name = "Carey";
    p.age = 44;
    ...
}
```

# Topic #1: C++ structs

The C++ **struct** allows us to define a whole new **type of variable** that holds multiple related pieces of data rather than just one value.

Let's see how to use this feature to define a **nerd** type!



Each nerd has:

A name

An IQ

A GPA

# C++ struct types

```
struct NERD
{
    string name;
    int    IQ;
    float  GPA;
};
```

First, write the word **struct**.

Then we give our new struct a **name**...

Then we specify all of the **variables** that our new structure contains in between **{** and **}**

Finally, we add a semicolon **;** at the end.

This defines an entirely new **data type**, like **string**, that we can now use in our program.

Alert: **NERD** is **not a variable**! It's a new **data type**!

# C++ struct types

Once we define our new **data type**, like **NERD**, we can use it to define variables like any traditional data type.

nerd.h

```
struct NERD
{
    string name;
    int IQ;
    float GPA;
};
```

You typically define a new struct type in a header file.

nerd.cpp

```
#include "nerd.h"
int main()
{
    float f1;
    NERD n1, n2;

    n1.name = "David";
    ...
}
```

After you define a new struct type, you can create variables with it throughout your program.

Just as **f1** is a **floating-point variable**...

**n1** and **n2** are **NERD variables**...



# C++ struct type

Notice that if you **don't initialize** a member in a struct variable, then it has a **random value!** This holds for all built-in types: **chars, ints, doubles**, etc...

nerd.h

```
struct NERD
{
    string name;
    int IQ;
    float GPA;
};
```

nerd.cpp

```
#include "nerd.h"
int main()
{
    NERD t, u;

    t.name = "Carey";
    t.IQ = 101;
    t.GPA = 3.99;

    u.name = "David";
    u.GPA = 1.12;
```

Let's see how we can use our new struct type in action!

t	name	"Carey"
	IQ	101
	GPA	3.99

u	name	"David"
	IQ	???
	GPA	1.12

Neato! C++ structs let us **group related data** together into one common unit.

But wait! Wouldn't it be cool if our struct could also hold **algorithms** to operate on that data, as well as **interface functions**?

Then we could represent a complete, self-contained **Abstract Data Type**!

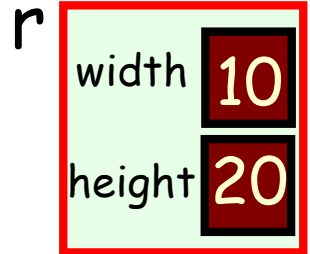
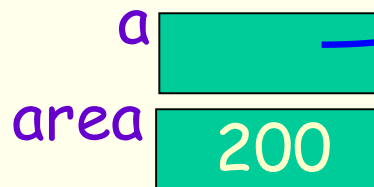
# Topic #2: C++ classes

Consider the following structure and associated function(s).

```
struct Rect
```

```
{  
    int width;  
    int height;  
};
```

```
int GetArea(Rect &a)  
{  
    int area = a.width *  
               a.height;  
    return(area);  
}
```



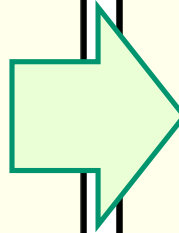
```
int main(void)  
{  
    Rect r;  
  
    r.width = 10;  
    r.height = 20;  
  
    cout << GetArea(r);  
}
```

# Topic #2: C++ classes

A **class** is basically a **struct** with **built-in functions** in addition to member variables.

```
struct Rect
{
    int width;
    int height;
};

int GetArea(Rect &a)
{
    int area = a.width *
               a.height;
    return(area);
}
```



```
class Rect
{
    int GetArea()
    {
        int area = width *
                   height;
        return(area);
    }

    int width;
    int height;
};
```

`GetArea()` is a "member function" of our Rect class.

```
class Rect
```

```
{  
    int GetArea()  
    {  
        int area = width * height;  
        return(area);  
    }  
}
```

```
int width;  
int height;
```

```
};
```

```
int main(void)  
{
```

```
    Rect r;
```

```
    r.width = 10;  
    r.height = 20;
```

```
    cout << r.GetArea();
```

`width` and `height` are called "member variables"

When you define your `r` variable, it gets its own copy of all of the `functions` and `variables` defined in your class!

```
int GetArea()  
{  
    int area = width * height;  
    return(area);  
}
```

```
width  
height
```

area

In addition to calling `r` a variable (which it is), we also sometimes call it an "instance" or an "object".  
"r is an instance of the Rect class"  
"r is a Rect object"

# Using a Class

```
class Rect
```

```
{  
    int GetArea()  
    {  
        int area = width * height;  
        return(area);  
    }  
}
```

```
int width;  
int height;
```

```
};
```

```
int main(void)  
{
```

```
    Rect r, s;
```

```
    r.width = 10;  
    r.height = 20;
```

```
    cout << r.GetArea();
```

You should **ONLY** add a **member variable** to your class if you want it to remember the value permanently.

And of course, I can define as many Rect objects as I like!

On the other hand, **ALWAYS** use **local variables** for temporary computations.

Each "instance" gets its own **copy** of the **GetArea()** function...

and its own **width** and **height** member variables.

```
int GetArea()  
{  
    int area = width * height;  
    return(area);  
}
```

width   
height 

S

```
int GetArea()  
{  
    int area = width * height;  
    return(area);  
}
```

width   
height 

# Classes

```
class Rect
{
    int GetArea()
    {
        int area = width * height;
        return(area);
    }
    void Initialize(int startW, int startH)
    {
        width = startW;
        height = startH;
    }

    int width;
    int height;
};
```

We can add as many member functions as we like to our class...

```
int main(void)
{
    Rect r;
    r.Initialize(10,20);
    cout << r.GetArea();
}
```

# Public

The **public** keyword tells C++ what part of your class you want to expose publicly... This is how you "interface" with it!

```
class Rect
```

```
{  
  public:
```

```
    int GetArea()  
    {
```

```
        int area = width * height;  
        return(area);  
    }
```

```
    void Initialize(int startW, int startH)  
    {
```

```
        width = startW;  
        height = startH;  
    }
```

```
  private:
```

```
    int width;  
    int height;  
};
```

Since **GetArea()** is in the public section, it can be used by all parts of your program.

Similarly, since **Initialize()** is in the public section, it can be used by all parts of your program.

And here we see our main() function using the **GetArea()** function!

Oh, and there're two more things we have to add to make our syntax **correct**...

And here we see our main() function using the **Initialize()** function!

```
int main(  
{
```

```
    Rect r;
```

```
    r.Initialize(10,7);
```

```
    cout << r.GetArea();  
}
```



# Public vs. Private

```
class Rect
```

```
{  
  public:
```

```
    int GetArea()  
    {
```

```
        int area = width * height;  
        return(area);  
    }
```

```
    void Initialize(int startW, int startH)  
    {
```

```
        width = startW;
```

```
        height = startH;  
    }
```

```
    private:
```

```
        int width;
```

```
        int height;
```

```
};
```

Only your member functions may access this private stuff!

The **private** keyword tells C++ what part of your class you want to **hide** from the outside world.

This is where you put your class's **private data** & **functions**.

Any attempt to access private members outside your class will result in an **error**!

```
int main(void)
```

```
{
```

```
    Rect r;
```

```
    r.Initialize(10,7);
```

```
    cout << r.GetArea();
```

```
    r.width = 10; // ERROR!
```

# Using Public+Private Properly

```
class Rect
{
    public:
        int GetArea()
        {
            int area = width * height;
            return(area);
        }

        void Initialize(int startW, int startH)
        {
            width = startW;
            height = startH;
        }

    private:
        void myComplexAlgorithm(float angle)
        {
            width = height * exp(arctan(angle),2);
        }

        int width;
        int height
};
```

Put all **member variables** and any **internal algorithm functions** in the **private section** to hide them...

(Only your class should know what variables and algorithms it has and how they're used!)

And place all of the **functions used to interface** with your class in the **public section**... So they're usable by the rest of your program.

This is called "**encapsulation**."

```
int main(void)
{
    Rect r;

    r.Initialize(10,7);
    cout << r.GetArea();
}
```

# Class Challenge!

**Part 1:** Convert the following code into a **Cylinder** class.

The class must have two methods:

**init(r,h)** to initialize the cylinder's radius/height

**getVolume()** to get its volume

**Part 2:** Show how to convert the **main()** function so it uses your new class.

```
double getVolume(int r, int h)
{
    const double pi = 3.1415926535;
    double vol = pi * r*r * h;

    return vol;
}
```

```
int main()
{
    int radius;    // define the attributes
    int height;    // of a cylinder

    radius = 10;   // init radius and height
    height = 20;

    double v = getVolume(radius,height);
    cout << "The volume is: " << v;
}
```

# Self-contained Problem Solvers

Each class is a self-contained, problem-solving unit... *an ADT!*

It contains all of the necessary **data** and **algorithms** to solve a certain problem - and **simple interface functions** to use it.

The rest of our program **doesn't need to know how it works**, only **how to talk to it** using simple interface functions!

Since we **hide** our class's **algorithms** and **variables** ...

We can **improve** its internal logic and variables **later** and the rest of our program will still **work as-is!**

