Computer Science 20
Programming Methods

- Pre-requisites: CS 10 and Math 3B
- Main emphasis: learn about data structures
  - Including related topics, such as abstraction, specialized algorithms, and efficiency issues
- A main goal: increase your programming skills
  - In Java, as well as the design and application of object-oriented solutions to problems
  - Requires *practice* – and a commitment of time/effort

Stuff you should already know

- *Catch up by yourself* if necessary on any of these:
  - How to write/execute a Java *application*
  - Comments, primitive data types, basic operators, arithmetic, assignment, type casting for primitive types
  - Control structures – `if/else`, `switch`, `while`, `for`, `do/while`, conditional operator
  - Writing/using classes, and method basics – including parameters, scope and duration rules, and overloading
  - Other *elementary* Java or programming topics
- Tip: keep your CS 10 (or other Java) book handy

What CS 20 will reinforce (to start)

- Basics of objects and references
- Strings and arrays
- Exception handling
- Input and output
- Some OOP concepts and related Java issues
  – Class design and javadocs
  – Methods of `class Object`
  – Inheritance and polymorphism
  – Abstract classes and interfaces

Approximate schedule

(generally follows Dale/Joyce/Weems text)

1. Reinforce important Java and OOP topics
2. Complexity concepts, correctness and testing
3. Data abstraction ideas, and start priority queues
4. Stacks, Recursion, and 1^{st} midterm exam
5. Queues, and Lists
6. Trees, including heaps and faster priority queues
7. Binary search trees, and 2^{nd} midterm exam
8. Sorting algorithms
9. Searching algorithms, and hash tables
10. Maybe more *as time permits*

Requirements

- Students are *required* to monitor the course's web pages, starting at http://www.cs.ucsb.edu/~mikec/cs20
- Assignments – 30%
  - Weekly written homeworks and bi-weekly programming projects
  - Must work *individually* unless explicitly told otherwise
- Three exams – each 20%
- Attendance – 10%

To do *this week*

- Read chapters 1 and 2 in Dale/Joyce/Weems text
  - In general, try to read ahead of the lectures
  - Also Section 9.1, and browse Appendices as necessary
- Verify CSIL access
  - Need account @engineering.ucsb.edu (@cs is alias) – apply online if don't already have one
  - Change password if required – sign on and acclimate
- Attend class – inc. discussion section Thursday
- Questions?

What is a reference?

- Actually a reference variable
  - A variable that can store a memory address
  - Refer to objects or `null`, but not primitive types
- Very few operations allowed for references
  - Just assignment with `=` or equality test with `==`
  - Only exception is `+` for Strings
- Mostly references are used to operate on objects
  - Access internal field or call a method with `.` operator
  - Type conversion with `(`cast`)`, or test with `instanceof`

Dealing with objects

- Declaring and creating – 2 discrete steps
- Garbage collection – behind the scenes
- `=` – copies a reference – creates alias
- `==` – true if references are aliases
  - Use `equals` (if overridden for the class) to compare objects
- Parameters – always *copies* – even for references
  - But alias can be used to operate on the object
- No operator overloading allowed
  - Reason: what you see is what you get with Java (except for String `+` and `+=` operators)

Strings

- Immutable objects – means safe to share references
- `+` concatenates if either is string: `5 + "a"` → `"5a"`
- Comparing strings requires methods, not `==`, `<`, …
  - `s1.equals(s2)` – overridden `Object` method – true if all same characters in same order
  - `s1.compareTo(s2)` – from `interface Comparable` – returns `int`
- Converting from/to other types
  - `String.valueOf(x)` – overloaded many times
  - Other direction less standard – `Integer.parseInt(s)`

More string things

- StringBuffer and StringBuilder – mutable strings
  - `StringBuilder b = new StringBuilder(`aString`);`
  - `b.append(`anotherString`);`
  - Also `b.insert`, `b.setCharAt`, `b.reverse`, …
  - `b.toString()` – creates String when done
- StringTokenizer – handy way to break up a string
  - `StringTokenizer t = new StringTokenizer(`aString`);`

    `while (t.hasMoreTokens())`

    `{   String word = t.nextToken();` … `}`
- See online documentation for class String, and others

Arrays

- Built-in data structures – a.k.a. collections
- Entities (array elements) are *all the same type*
  - Access each entity by array indexing operator – `[]`
- Declare, create, and assign values – 3 distinct steps
  1. Declare array variable: `int[] a;` // type restricted to `int`
  2. Create array object: `a = new int[5];` // size is fixed at 5
  3. Assign values: `for (int i = 0; i < 5; i++) a[i] =` …
- Treat whole array like any other `Object`
  - `int[] b = a;` // creates an alias – not a copy of array
  - `someMethod(a);` // passes alias – `a` can be changed
  - An instance variable (`a.length`), and inherited methods!

Preview: better collections

- java.util.ArrayList – an array-like structure
  - *Expands dynamically*, so no need to set fixed size
    ```
    ArrayList<Integer> a = new ArrayList<Integer>();
    ```
  - Note use of Java 5 generic type – `Integer` in this case
- Must *wrap* primitive types:
  ```
  a.add(new Integer(7));
  a.add(17); // or rely on "autoboxing"
  ```
- Unwrap on retrieval:
  ```
  int i = ( (Integer) a.get(0) ).intValue();
  int j = a.get(1); // or rely on "auto un-boxing"
  ```
- Overrides Object methods – to make more sense

How *complex* is that algorithm?

- *Count* the steps to find out
- Note that execution time depends on many things
  - Hardware features of particular computer
    - Processor type and speed
    - Available memory (cache and RAM)
    - Available disk space, and disk read/write speed
  - Programming language features
  - Language compiler/interpreter used
  - Computer's operating system software
- So execution times for algorithms differ for different systems – but complexity is more basic

A detailed computer model

- Assume constant times for various operations
  - T_{fetch} – time to fetch an operand from memory
  - T_{store} – time to store an operand in memory
  - T_{+}, T_{-}, T_{*}, $T_{\div}$, $T_{<}$, … – times to perform simple arithmetic operation or comparison
  - T_{call}, T_{return} – times to call and return from methods
  - $T_{[\cdot]}$ – time to calculate array element's address
- e.g., time to execute `y = x` is $T_{fetch} + T_{store}$
  - Note: `y =1` takes same time – 1 is stored somewhere

More counting steps

- `y = y + 1` → $2T_{fetch}+T_{+}+T_{store}$
  - Same as time for `y += 1`, `y++`, and `++y`
- `y = f(x)` → $T_{fetch}+2T_{store}+T_{call}+T_{f(x)}$
- Method example – `public int sumSeries(int n)`:

```
    int result = 0;     → T_fetch+T_store
    for (int i = 1;     → T_fetch+T_store
             i <= n;    → (2T_fetch+T_<) * (n+1)
             i++)       → (2T_fetch+T_+ +T_store) * n
         result += i;   → (2T_fetch+T_+ +T_store) * n
    return result;      → T_fetch+T_return
```

Let $t_1 = 5T_{fetch}+2T_{store}+T_{<}+T_{return}$ and $t_2 = 6T_{fetch}+2T_{store}+T_{<}+2T_{+}$ → then total time for method is $t_1 + t_2n$

Things to notice about counts

- Very tedious – even for simple algorithms
- Operation times are constant only for particular computer/compiler/… situations
- The size of the problem matters the most
- e.g., total of $t_1 + t_2n$ from previous slide
  - t_1 and t_2 vary, depending on platform
  - The second term dominates if n is large
- So is there a better way to compare algorithms?

Algorithm analysis

- Really want to compare *just the algorithms*
  - i.e., holding constant things that don't matter
  - Question becomes – which algorithm is more efficient on *any computer in any language*?
- Solution – 'O' notation
  - Simplest is worst case analysis – Big-Oh
    - Provides an upper bound on expected running time
  - Others include Little-Oh, Big Ω (omega), and Big Θ (theta) – all useful, but not as commonly used

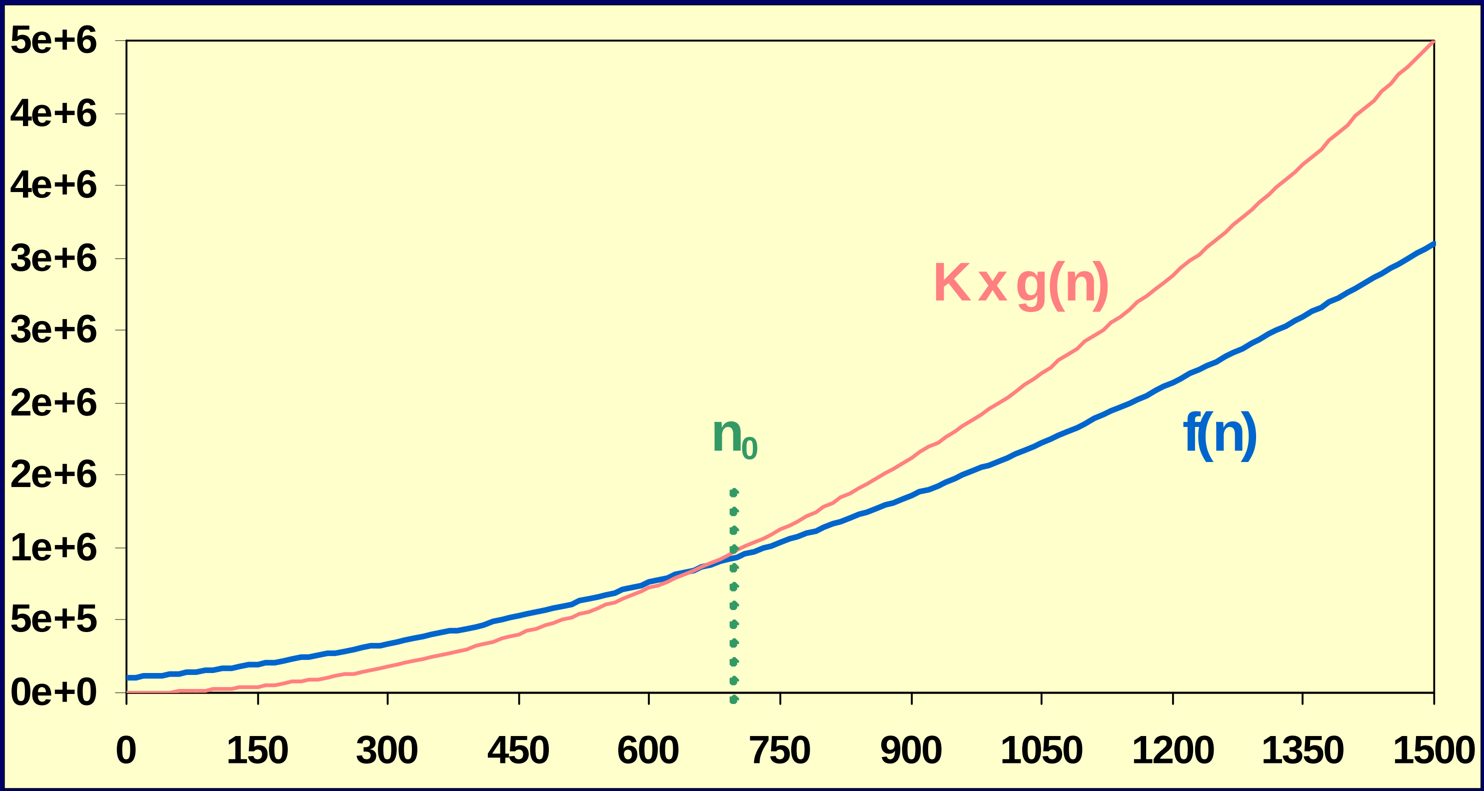
Big-Oh notation

- Strips problem of inconsequential details
  - All but the "dominant" term are ignored
    - e.g., say algorithm takes $3n^2 + 15n + 100$ steps, for a problem of size n
    - Note: as n gets large, first term ($3n^2$) dominates, so okay to ignore the other terms
  - Constants associated with processor speed and language features are ignored too
    - In above example, ignore the 3
- So this example algorithm is $O(n^2)$
  - Pronounced "Oh of n-squared"
    - Belongs to the "quadratic complexity" class of algorithms

Formally, `f(n)` is `O(g(n))` if

$\exists$ two positive constants (K, n_0), such that

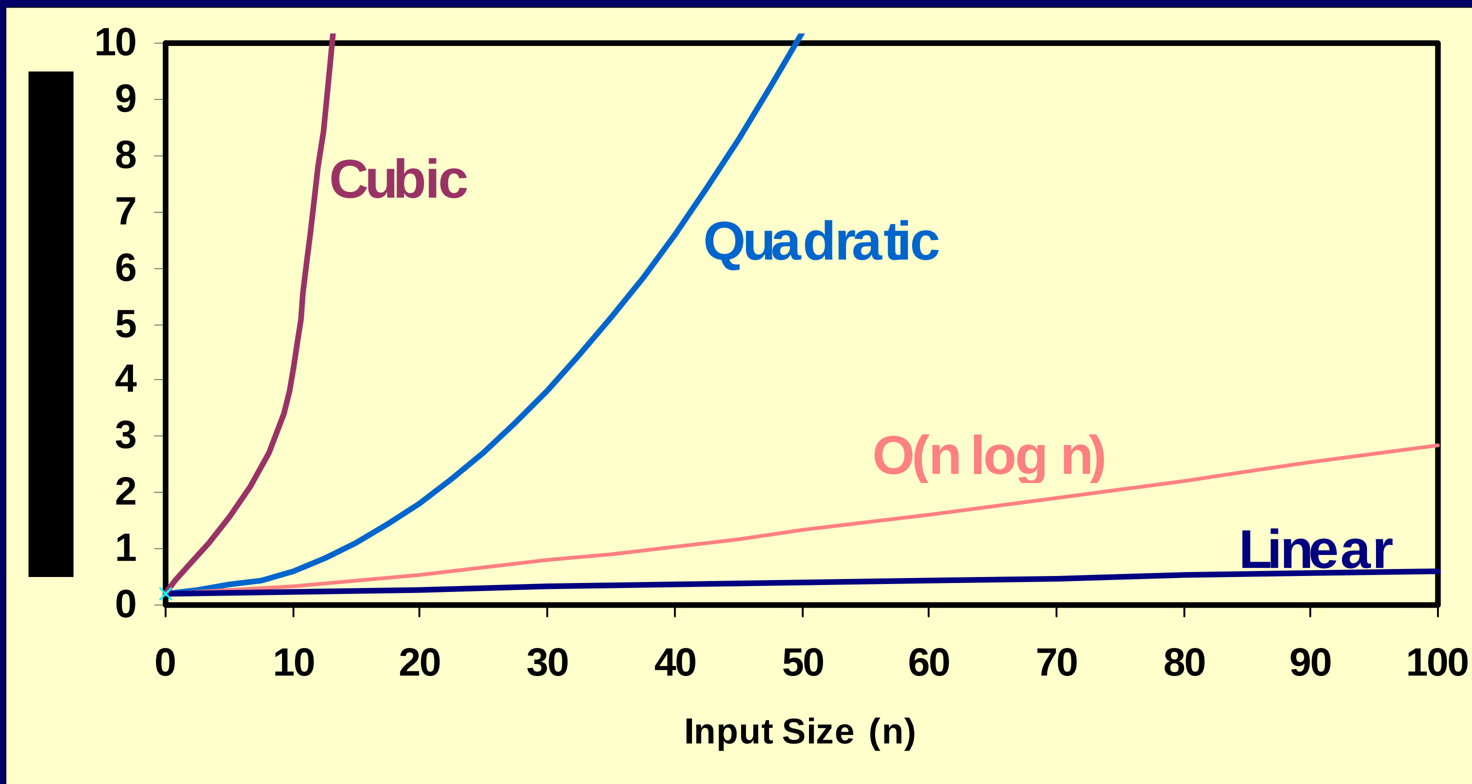
$$|f(n)| \le K|g(n)|, \forall (n \ge n_0)$$



‘O’ and related notation

- Big-Oh – upper bound on running time
  - f(n) is O(g(n)) if there are positive constants, c and n_0, such that $f(n) \le cg(n)$ when $n \ge n_0$
- Big Ω – lower bound on running time
  - f(n) is Ω(g(n)) if … $f(n) \ge cg(n)$ when $n \ge n_0$
- Big Θ – both an upper *and* lower bound
  - f(n) is Θ(g(n)) iff f(n) is O(g(n)) and f(n) is Ω(g(n))
- Little-Oh – a “strictly-less” than upper bound
  - f(n) is o(g(n)) iff f(n) is O(g(n)) and f(n) is not Θ(g(n))

Some complexity classes



- Linear - `O(n)`; Quadratic - `O(n²)`; Cubic - `O(n³)`
  - Also slower than cubic – e.g., Exponential - `O(2ⁿ)`
  - And faster than linear – `O(log n)`, and Constant - `O(1)`

Applies to large problems only

- Big-Oh measures asymptotic complexity
  - Mostly irrelevant for small problems
  - But some algorithms become impractical as n grows, even if n isn't very large
- For example, imagine n = 256
  - And say a linear algorithm takes 256 microseconds
  - Cubic time is 16.8 seconds
  - Exponential time (base 2) is 3.7×10^{63} years!!!

(See related calculations on next slide.)

Big O	Microsec.	Millisec.	Seconds	Years
O(n)	256			
O(log n)	8			
O(n log n)	2,048	2.05		
O(n^2)	65,536	65.54		
O(n^3)	16,777,216	16,777	16.8	
O(2^n)	1.158E+77	1.158E+74	1.158E+71	3.7E+63

Algorithm analysis example

```
double[] prefixAverages1(double[] x) →
  double[] result = new double[x.length];
  for (int i=0; i<x.length; i++)
  {  double sum = 0;  // happens n times
     for (int j=0; j<=i; j++)
          sum += x[i]; // happens n(n+1)/2 times
     result[i] = sum / (i+1);  // n times
  }return result;  // happens once
```

- Running time dominated by *nested* for loops
  - Approximate total is (n + n(n+1)/2 + n + 1) → so $O(n^2)$

Improved algorithm

```
double[] prefixAverages2(double[] x) →
  double[] result = new double[x.length];
  double runningSum = 0; // O(1)
  for (int i=0; i<x.length; i++)
  {  runningSum += x[i]; // O(n)
     result[i] = runningSum/(i+1);// also O(n)
  }return result; // O(1)
```

- Just one for loop this time – max term is O(n)
  - So overall complexity is O(n)

Runtime analysis

- Use to *complement (not replace)* algorithm analysis
  - Calculate elapsed clock time for operations

```
long startTime = System.currentTimeMillis();
{…}  // operation to time here
long finishTime = System.currentTimeMillis();
long elapsedTime = finishTime - startTime;
```

  - Java 1.5 addition: `long instant = System.nanoTime();`
    - 1 millisecond → 1,000,000 nanoseconds !!!
- e.g., Timing_Random.java (Collins text, pp. 88-89)
- Of course results are infected by competing processes
  - Also by machine, compiler and system characteristics
  - But often can crudely estimate Big O anyway – Collins lab 4

What Big-Oh doesn't cover

- Small problems
  - Often dominated by lesser terms or constants
- What to count?
  - Comparisons? Assignments? Reads? Writes?
    - Some operations take longer than others
  - So usually just count iterations – see CountSteps.java
- Notice the definition is not restrictive
  - e.g., an algorithm that is $O(n)$ is also $O(n^2)$, etc.
  - So *agree* to express bound as tightly as possible, and to not include lesser terms in $g(n)$