CS 362, Lecture 1

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Today's Outline

- Administrative Info
- Asymptotic Analysis Review
- Recurrence Relation Review

Formal Defn of Big-O

- Recall the formal definition of Big-O notation:
- *A function* $f(n)$ *is* $O(g(n))$ *if there exist positive constants* c *and* n_0 *such that* $f(n) \leq cg(n)$ *for all* $n \geq n_0$

Example

- Let's show that $f(n) = 10n + 100$ is $O(g(n))$ where $g(n) = n$
- We need to give constants c and n_0 such that $f(n) \leq cg(n)$ for all $n \geq n_0$
- In other words, we need constants c and n_0 such that $10n + 100 \leq cn$ for all $n \geq n_0$

Example

- We can solve for appropriate constants:

$$10n + 100 \leq cn \quad (1)$$
$$10 + 100/n \leq c \quad (2)$$

- So if $n > 1$, then c should be greater than 110.
- In other words, for all $n > 1$, $10n + 100 \leq 110n$
- So $10n + 100$ is $O(n)$

Relatives of big-O

Recall the following relatives of big-O:

O	"$\leq$"
Θ	"$=$"
Ω	"$\geq$"
o	"$<$"
ω	"$>$"

Relatives of big-O

When would you use each of these? Examples:

O	"$\leq$"	This algorithm is $O(n^2)$ (i.e. worst case is $\Theta(n^2)$)
Θ	"$=$"	This algorithm is $\Theta(n)$ (best and worst case are $\Theta(n)$)
Ω	"$\geq$"	Any comparison-based algorithm for sorting is $\Omega(n \log n)$
o	"$<$"	Can you write an algorithm for sorting that is $o(n^2)$?
ω	"$>$"	This algorithm is not linear, it can take time $\omega(n)$

Rule of Thumb

- Let $f(n)$, $g(n)$ be two functions of n
- Let $f_1(n)$, be the fastest growing term of $f(n)$, stripped of its coefficient.
- Let $g_1(n)$, be the fastest growing term of $g(n)$, stripped of its coefficient.

Then we can say:

- If $f_1(n) \leq g_1(n)$ then $f(n) = O(g(n))$
- If $f_1(n) \geq g_1(n)$ then $f(n) = \Omega(g(n))$
- If $f_1(n) = g_1(n)$ then $f(n) = \Theta(g(n))$
- If $f_1(n) < g_1(n)$ then $f(n) = o(g(n))$
- If $f_1(n) > g_1(n)$ then $f(n) = \omega(g(n))$

More Examples

The following are all true statements:

- $\sum_{i=1}^{n} i^2$ is $O(n^3)$, $\Omega(n^3)$ and $\Theta(n^3)$
- $\log n$ is $o(\sqrt{n})$
- $\log n$ is $o(\log^2 n)$
- $10,000n^2 + 25n$ is $\Theta(n^2)$

Problems

True or False? (Justify your answer)

- $n^3 + 4$ is $\omega(n^2)$
- $n \log n^3$ is $\Theta(n \log n)$
- $\log^3 5n^2$ is $\Theta(\log n)$
- $10^{-10}n^2 + n$ is $\Theta(n)$
- $n \log n$ is $\Omega(n)$
- $n^3 + 4$ is $o(n^4)$

Formal Defns

- $O(g(n)) = \{f(n) :$ there exist positive constants c and n_0 such that $0 \le f(n) \le cg(n)$ for all $n \ge n_0\}$
- $\Theta(g(n)) = \{f(n) :$ there exist positive constants $c_1, c_2,$ and n_0 such that $0 \le c_1 g(n) \le f(n) \le c_2 g(n)$ for all $n \ge n_0\}$
- $\Omega(g(n)) = \{f(n) :$ there exist positive constants c and n_0 such that $0 \le cg(n) \le f(n)$ for all $n \ge n_0\}$

Formal Defns (II)

- $o(g(n)) = \{f(n) :$ for any positive constant $c > 0$ there exists $n_0 > 0$ such that $0 \le f(n) < cg(n)$ for all $n \ge n_0\}$
- $\omega(g(n)) = \{f(n) :$ for any positive constant $c > 0$ there exists $n_0 > 0$ such that $0 \le cg(n) < f(n)$ for all $n \ge n_0\}$

Another Example

- Let $f(n) = 10\log^2 n + \log n$, $g(n) = \log^2 n$. Let's show that $f(n) = \Theta(g(n))$.
- We want positive constants c_1, c_2 and n_0 such that $0 \le c_1 g(n) \le f(n) \le c_2 g(n)$ for all $n \ge n_0$

$$0 \le c_1 \log^2 n \le 10\log^2 n + \log n \le c_2 \log^2 n$$

Dividing by $\log^2 n$, we get:

$$0 \le c_1 \le 10 + 1/\log n \le c_2$$

- If we choose $c_1 = 1$, $c_2 = 11$ and $n_0 = 2$, then the above inequality will hold for all $n \ge n_0$

In-Class Exercise

Show that for $f(n) = n + 100$ and $g(n) = (1/2)n^2$, that $f(n) \ne \Theta(g(n))$

- What statement would be true if $f(n) = \Theta(g(n))$?
- Show that this statement can not be true.

Recurrence Relation Review

"Oh how should I not lust after eternity and after the nuptial ring of rings, the ring of recurrence" - Friedrich Nietzsche, Thus Spoke Zarathustra

- $T(n) = 2 * T(n/2) + n$ is an example of a *recurrence* relation
- A *Recurrence Relation* is any equation for a function T, where T appears on both the left and right sides of the equation.
- We always want to "solve" these recurrence relation by getting an equation for T, where T appears on just the left side of the equation

Recurrence Relations

- Whenever we analyze the run time of a recursive algorithm, we will first get a recurrence relation
- To get the actual run time, we need to solve the recurrence relation

Substitution Method

- One way to solve recurrences is the substitution method aka "guess and check"
- What we do is make a good guess for the solution to $T(n)$, and then try to prove this is the solution by induction

Example

- Let's guess that the solution to $T(n) = 2 * T(n/2) + n$ is $T(n) = O(n \log n)$
- In other words, $T(n) \leq cn \log n$ for all $n \geq n_0$, for some positive constants c, n_0
- We can prove that $T(n) \leq cn \log n$ is true by plugging back into the recurrence

Proof by Induction

- I.H.: For all $j < n$, $T(j) \leq cj \log j$
- I.S.:

$$\begin{aligned} T(n) &= 2T(n/2) + n && (3) \\ &\leq 2(cn/2 \log(n/2)) + n && (4) \\ &= cn \log(n/2) + n && (5) \\ &= cn(\log n - \log 2) + n && (6) \\ &= cn \log n - cn + n && (7) \\ &\leq cn \log n && (8) \end{aligned}$$

The second step uses the I.H. and the last step holds for all $n > 0$ if $c \geq 1$

Todo

- Read Syllabus
- Visit the class web page off of www.cs.unm.edu/~saia/
- Sign up for the class mailing list (cs362)
- Read Chapter 3 and 4 in the text