# Lecture 6: ArrayList Implementation & Complexity

## CS 62

Spring 2018

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# Lab

- Timing `ArrayList` operations
- Encourage working in pairs
- `Stopwatch` class: `start()`, `stop()`, `getTime()`, `reset()`
- Java has Just-In-Time compiler
- Must "warm-up" before you get accurate timing
  - What can mess up timing?
- Uses `Vector` from Bailey rather than `ArrayList` from Java libraries because can change way it increases in size.

# Programming Assignment

- Weak AI/Natural Language Processing:
- Generate text by building frequency lists based on pairs of words. `ArrayList` of `Associations` of `String` (words) and `Integer` (count of that word)

# ArrayList

- Not using Bailey implementation
  - see code on-line for implementation by Tamassia & Goodrich
- Standard Java libraries have lots of extra methods not in our implementation
- Many involve working on other collections
  - irrelevant for us at this point.
  - `addAll`, `clear` , `contains` , `containsAll` , `listIterator`, `removeAll` , `replaceAll` , `retainAll` , `sort` , `spliterator`, `sublist` , `toArray`

# Tamassia & Goodrich `ArrayList`

- Interface is `IndexList<E>`
- See `ArrayIndexList<E>`
  - Similar to `ArrayList`
  - Instance variables:
    - `elts`: array instance variable
    - `eltsFilled`: number of slots filled.
- Creating new `ArrayList` is weird
  - Can't construct array of variable type!
  - Create array of `Object`, but coerce to believe array of `E`

# `ArrayList` Implementation

- Some operations very cheap:
  - `size, isEmpty, get, set` take constant time (no search)
  - Others more expensive

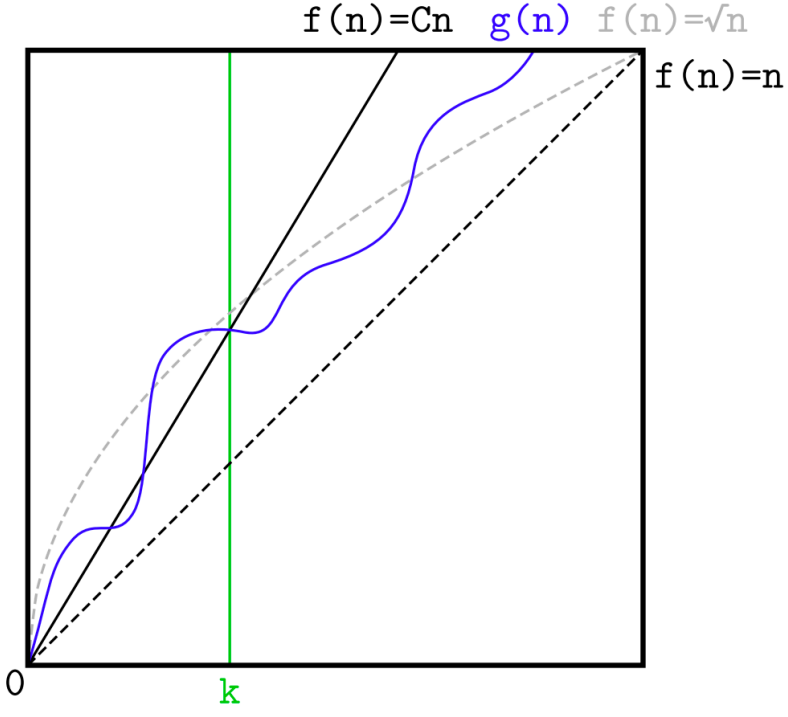
# Adding Elts in Slot i

- Easy if there is space:
  - At end, just add it
  - If before end, must move all elements at i and beyond to right before inserting
  - *Delete similar*
- What if we run out of space?
  - Create new array twice as big and copy old elements over before adding.
  - How expensive is this?

# Order of Magnitude

- Definition: We say that $g(n)$ is $O(f(n))$ if there exist two constants $C$ and $k$ such that
$$|g(n)| <= C\ |f(n)|, for\ all\ n\ >\ k.$$
- Used to measure time and space complexity of algorithms on data structures of size n.
- Examples:
  - $2n + 1$ is $O(n)$
  - $n^3 - n^2 + 83$ is $O(n^3)$
  - $2^n + n^2$ is $O(2^n)$
- Most common are:
  - $O(1)$ - for any constant
  - $O(\log n), O(n), O(n \log n), O(n^2), \ldots, O(2^n)$

# Complexity



# Complexity

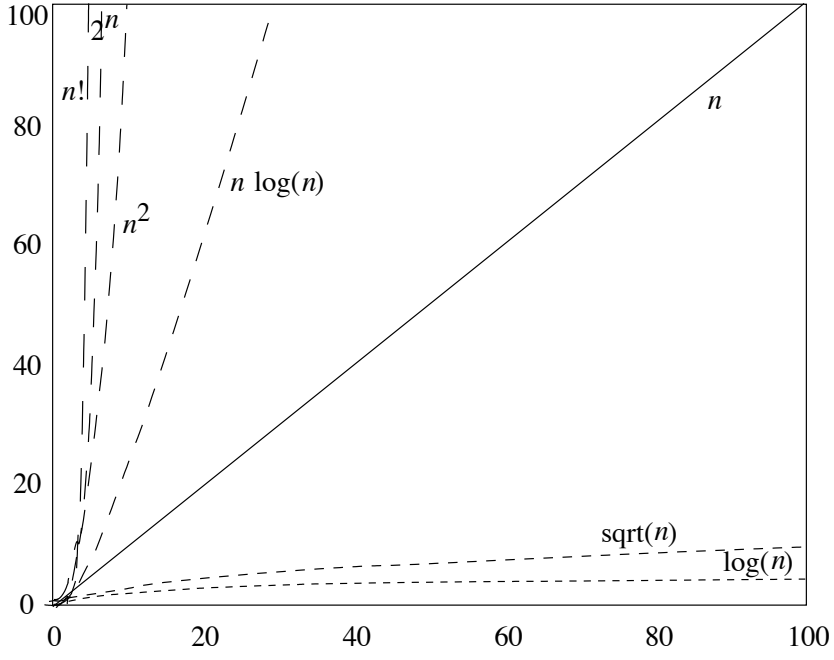


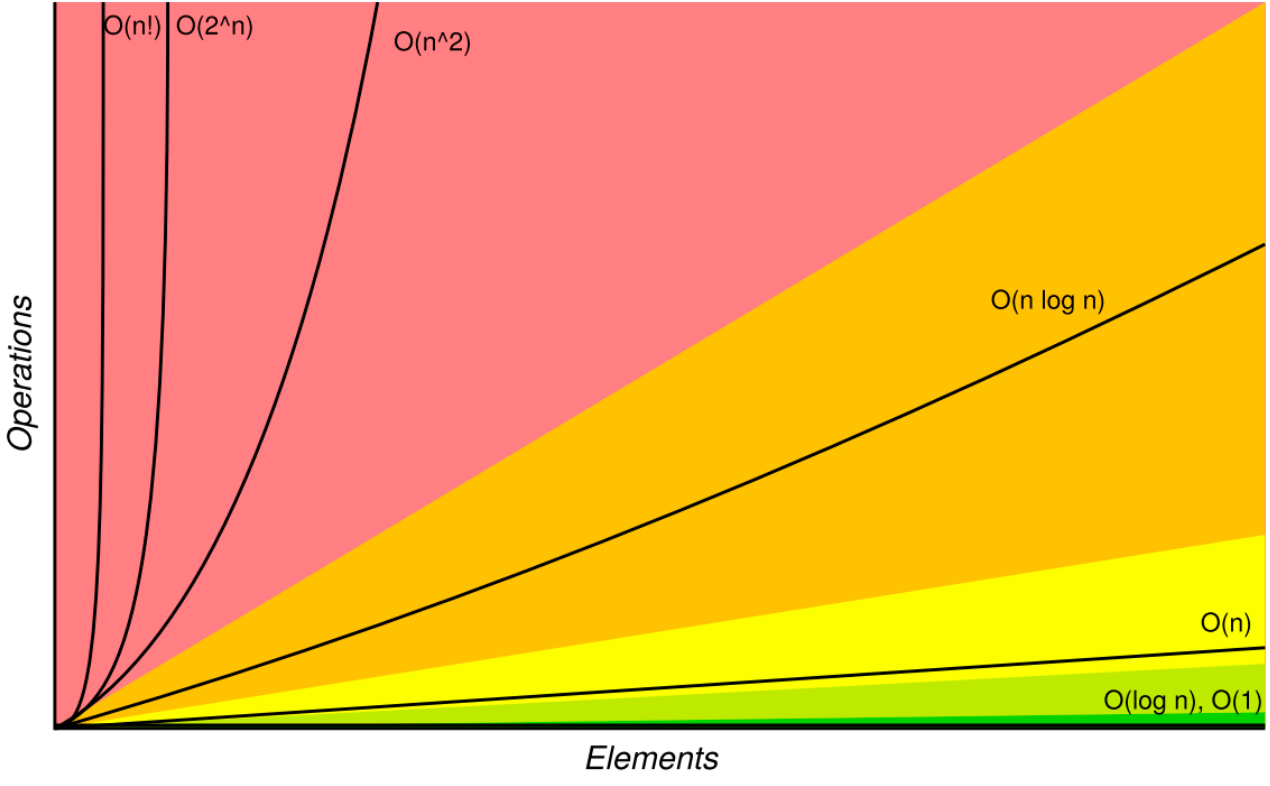

**Figure 5.3** Long-range trends of common curves. Compare with Figure 5.2.

# Comparing Orders of Magnitude

- Suppose have ops w/complexities given & problem of size n taking time t.
- How long if increase size of problem?

| *Problem Size:* | *10 n* | *100n* | *1000n* |
|---|---|---|---|
| $O(\log n)$ | 3+t | 7 + t | 10+ t |
| $O(n)$ | 10 t | 100 t | 1000 t |
| $O(n \log n)$ | > 10 t | > 100 t | > 1000 t |
| $O(n^2)$ | 100 t | 10,000 t | 1,000,000 t |
| $O(2^n)$ | ~ $t^{10}$ | ~ $t^{100}$ | ~ $t^{1000}$ |

# Rule of thumb




bigocheatsheet.com

# Adding to `ArrayList`

- Suppose $n$ elements in `ArrayList` and add 1.
- If space:
  - Add to end is $O(1)$
  - Add to beginning is $O(n)$
- If not space:
  - What is cost of `ensureCapacity`?
  - $O(n)$ because $n$ elements in array

# `EnsureCapacity`

- What if only increase in size by 1 each time?
  - Adding $n$ elements one at a time to end
    - Total cost of copying over arrays: $1 + 2 + 3 + \cdots + (n-1) = n(n-1)/2$
    - Total cost of $O(n^2)$
  - Average cost of each is $O(n)$

- What if double in size each time?
  - Suppose add $n = 2^m$ new `elts` to end
    - Total cost of copying over arrays: $1 + 2 + 4 + \cdots + n/2 = n - 1, O(n)$
    - Average cost of $O(1)$, but "lumpy"

# `ArrayList` Operations

- Worst case:
  - $O(1)$: **`size, isEmpty, get, set`**
  - $O(n)$: **`remove, add`**

- Add to end is on average $O(1)$