Getting in front

- Suppose we want to add a new element
  - At the back of a string or an ArrayList or a ...
  - At the front of a string or an ArrayList or a ...
  - Is there a difference? Why? What's complexity?

- Suppose this is an important problem: we want to grow at the front (and perhaps at the back)
  - Think editing film clips and film splicing
  - Think DNA and gene splicing

- Self-referential data structures to the rescue
  - References, reference problems, recursion, binky
What’s the Difference Here?

- How does find-a-track work? Fast forward?
Contrast LinkedList and ArrayList

- **Consider a Simple Linked List**
  - Nodes referring to other nodes
  - Essentially a chain

- **ArrayList --- why is access O(1) or constant time?**
  - Storage in memory is contiguous, all elements same size
  - Where is the 1st element? 40th? 360th?
  - Doesn’t matter what’s in the ArrayList, everything is a pointer or a reference (what about null?)
What about LinkedList?

- Why is access of N\textsuperscript{th} element linear time?
- Why is adding to front constant-time \(O(1)\)?
ArrayLists and linked lists as ADTs

- As an ADT (abstract data type) ArrayLists support
  - Constant-time or O(1) access to the k-th element
  - Amortized linear or O(n) storage/time with `add`
    - Total storage used in n-element vector is approx. 2n, spread over all accesses/additions (why?)
  - Adding a new value in the middle of an ArrayList is expensive, linear or O(n) because shifting required

- Linked lists as ADT
  - Constant-time or O(1) insertion/deletion anywhere, but...
  - Linear or O(n) time to find where, sequential search

- Good for sparse structures: when data are scarce, allocate exactly as many list elements as needed, no wasted space/copying (e.g., what happens when vector grows?)
Linked list applications

- Remove element from middle of a collection, maintain order, no shifting. Add an element in the middle, no shifting
  - What’s the problem with a vector (array)?
  - Emacs visits several files, internally keeps a linked-list of buffers
  - Naively keep characters in a linked list, but in practice too much storage, need more esoteric data structures

- What’s \((3x^5 + 2x^3 + x + 5) + (2x^4 + 5x^3 + x^2 + 4x)\)?
  - As a vector \((3, 0, 2, 0, 1, 5)\) and \((0, 2, 5, 1, 4, 0)\)
  - As a list \(((3, 5), (2, 3), (1, 1), (5, 0))\) and ________?
  - Most polynomial operations sequentially visit terms, don’t need random access, do need “splicing”

- What about \((3x^{100} + 5)\)?
Linked list applications continued

- If programming in C, there are no “growable-arrays”, so typically linked lists used when # elements in a collection varies, isn’t known, can’t be fixed at compile time
  - Could grow array, potentially expensive/wasteful especially if # elements is small.
  - Also need # elements in array, requires extra parameter
  - With linked list, one pointer used to access all the elements in a collection

- Simulation/modeling of DNA gene-splicing
  - Given list of millions of CGTA… for DNA strand, find locations where new DNA/gene can be spliced in
    - Remove target sequence, insert new sequence
Linked lists, CDT and ADT

- **As an ADT**
  - A list is empty, or contains an element and a list
  - ( ) or (x, (y, ( ) ) )

- **As a picture**

- **As a CDT (concrete data type)**
  ```java
  public class Node {
      String value;
      Node next;
  }
  ```
  Node p = new Node();
p.value = "hello";
p.next = null;
### Building linked lists

- **Add words to the front of a list (draw a picture)**
  - Create new node with next pointing to list, reset start of list

```java
public class Node {
    String value;
    Node next;
    Node(String s, Node link) {
        value = s;
        next = link;
    }
}
// ... declarations here
Node list = null;
while (scanner.hasNext()) {
    list = new Node(scanner.next(), list);
}
```

- **What about adding to the end of the list?**
Dissection of add-to-front

- List initially empty
- First node has first word

```java
Node(String s, Node link) {
    info = s;
    next = link;
}
```

- Each new word causes new node to be created
  - New node added to front
- Rhs of operator = completely evaluated before assignment
Standard list processing (iterative)

- Visit all nodes once, e.g., count them or process them

```java
public int size(Node list) {
    int count = 0;
    while (list != null) {
        count++;
        list = list.next;
    }
    return count;
}
```

- What changes in code above if we change what “process” means?
  - Print nodes?
  - Append “s” to all strings in list?
Nancy Leveson: Software Safety

Founded the field

- Mathematical and engineering aspects
  - Air traffic control
  - Microsoft word

"C++ is not state-of-the-art, it's only state-of-the-practice, which in recent years has been going backwards"

- Software and steam engines: once extremely dangerous?
  - [http://sunnyday.mit.edu/steam.pdf](http://sunnyday.mit.edu/steam.pdf)
- THERAC 25: Radiation machine that killed many people
Building linked lists continued

- What about adding a node to the end of the list?
  - Can we search and find the end?
  - If we do this every time, what’s complexity of building an N-node list? Why?

- Alternatively, keep pointers to first and last nodes of list
  - If we add node to end, which pointer changes?
  - What about initially empty list: values of pointers?
    - Will lead to consideration of header node to avoid special cases in writing code

- What about keeping list in order, adding nodes by splicing into list? Issues in writing code? When do we stop searching?
Standard list processing (recursive)

- Visit all nodes once, e.g., count them

```java
public int recsize(Node list) {
    if (list == null) return 0;
    return 1 + recsize(list.next);
}
```

- Base case is almost always empty list: null pointer
  - Must return correct value, perform correct action
  - Recursive calls use this value/state to anchor recursion
  - Sometimes one node list also used, two “base” cases

- Recursive calls make progress towards base case
  - Almost always using list.next as argument
Recursion with pictures

- **Counting recursively**

```java
int recsize(Node list) {
    if (list == null) {
        return 0;
    } else {
        return 1 + recsize(list.next);
    }
}
```

System.out.println(recsize(ptr));
Recursion and linked lists

- Print nodes in reverse order
  - Print all but first node and...
    - Print first node before or after other printing?

```java
public void print(Node list) {
    if (list != null) {
        System.out.println(list.info);
        print(list.next);
        System.out.println(list.info);
    }
}
```
Complexity Practice

❖ What is complexity of *Build*? (what does it do?)

```java
public Node build(int n) {
  if (0 == n) return null;
  Node first = new Node(n, build(n-1));
  for(int k = 0; k < n-1; k++) {
    first = new Node(n,first);
  }
  return first;
}
```

❖ Write an expression for $T(n)$ and for $T(0)$, solve.
- Let $T(n)$ be time for build to execute with n-node list
- $T(n) = T(n-1) + O(n)$
Changing a linked list recursively

- Pass list to method, return altered list, assign to list
  - Idiom for changing value parameters

```
list = change(list, "apple");
public Node change(Node list, String key) {
    if (list != null) {
        list.next = change(list.next, key);
        if (list.info.equals(key)) return list.next;
        else return list;
    }
    return null;
}
```

- What does this code do? How can we reason about it?
  - Empty list, one-node list, two-node list, n-node list
  - Similar to proof by induction