CS11 – Introduction to C++

Winter 2011-2012

Lecture 4

Topics for Today

- Inline functions
- Initializer-lists
- Classes and structs
- Lab 4

Inline Functions

- Calling functions incurs overhead
  - Creating a new stack-frame
  - Jumping to the function's code
  - Passing arguments and return-values
- Programs can have a lot of small functions

```
class CFoo {
  int x;
  ...
  int getX() { return x; }  // Accessor for x
};
...
cout << foo.getX();
```

- For small functions, the compiler can inline the code
  - Compiler can inline this code, producing, in effect:

```
cout << foo.x;
```

Inline Functions vs. Macros

- In C, macros can be used to inline code

```
#define max(x, y) ((x) > (y) ? (x) : (y))
```

  - C/C++ macros are simple text substitution!
  - Either **`x`** or **`y`** will be evaluated multiple times

```
k = max(i++, j--);
k = ((i++) > (j--) ? (i++) : (j--));
```

  - No type-safety
  - Extra parentheses to avoid precedence issues!
- Inline functions solve these problems
  - Inline function arguments are evaluated only once
  - Argument and return-value types are declared, and checked by compiler

Defining Inline Functions

- Function definitions in class declarations are *automatically* inline

```
class Point {
  double x, y;
  ...
  double getX() const { return x; }    // Inline!
  double getY() const { return y; }
  double distanceTo(const Point &p) const;
};
```

- Can also follow class declaration in header file

```
inline double Point::distanceTo(const Point &p) const {
  ...
}
```

  - Keeps class declaration from becoming cluttered
- Normal function definitions in `.cc` file are not inlined

Inlining Tips

- Inlining is a <u>hint</u>! Compiler may ignore you
- Certain operations can prevent inlining:
  - e.g. an inline function that recursively calls itself
  - Compiler also may simply choose not to do it!
- Inlining can potentially make your binary larger
  - The function's code is replicated everywhere
- Only inline small functions
  - Accessors are great candidates
- Or, let the compiler decide what to inline
  - Modern compilers can figure out what to inline on their own
  - e.g. **`gcc/g++`**, MS Visual C++

Constructors and Member Variables

- So far, have written constructors like this:

```
Point::Point(double x, double y) {
  x_coord = x;  // Store x and y values.
  y_coord = y;
}
```

- How come this works?
  - *How were* ***x_coord*** *and* ***y_coord*** *set up in the first place?!*
- Answer:
  - An object's data-members are constructed *before* the class' constructor body is run.

Classes with Class-Members

- A graphics-engine class:

```
class GraphicsEngine {
  Matrix viewportTransform;
  Matrix modelViewTransform;
  ...
public:
  GraphicsEngine();
  GraphicsEngine(const RenderConfig &conf);
  ...
};
```

  - **`Matrix`** constructors get called *before* **`GraphicsEngine`**'s constructor-body is run.
    - Specifically, the default constructors are called.

Constructing the Graphics Engine

- Graphics engine's constructor:

```
GraphicsEngine::GraphicsEngine() {
  viewportTransform  = Matrix(4, 4);
  modelViewTransform = Matrix(4, 4);
  ...  // Rest of graphics-engine initialization
}
```

  - …but the matrices were already constructed once!
  - This code does extra work:
    - 2 × default **Matrix** constructor
    - 2 × two-arg **Matrix** constructor (this is all we want!)
    - 2 × assignment-operator (and its cleanup/copy work)
    - 2 × destructor (clean up temporary objects)

Member Initializer Lists!

- Member initializer lists solve these problems
  - Can <u>specify</u> non-default construction of class data-members
- After constructor signature, before body

```
GraphicsEngine::GraphicsEngine() :
  viewportTransform(4, 4), modelViewTransform(4, 4) {
  ...  // Rest of graphics-engine initialization
}
```

  - Colon goes before initializer list
  - Member initializations separated with commas

More Initializer List Details

- Best for data-members that are objects
  - Avoid extra work – default initialization, assignment, etc.
  - Gives biggest performance benefit
- Also very useful for primitive data-members
  - Doesn't improve performance
  - Just simplifies initialization
- Some data-members <u>require</u> an initializer!
  - Members whose type doesn't have a default constructor
  - **`const`** data-members
  - Reference data-members
    - (references aren't allowed to refer to nothing…)
  - These types require initialization details that the compiler can't guess

Classes and Structs

- In C++, structs are just like classes
  - They can have constructors, member functions, access modifiers, etc.
  - Only difference is that default access is public
    - `struct s { ... };`
    - `class s { public: ... };` (same thing)
- Constructors for structs are particularly useful
  - Check for valid values, or initialize defaults
  - Can also write copy-constructors, destructors, etc.

Structs for Internal Data

- Structs typically used for objects that don't need all the features of classes
  - e.g. helper-objects inside an implementation
  - "a chunk of data"
- Hiding internal structs is a good idea!
  - Part of encapsulation/abstraction
  - Good object-oriented design

Hiding Structs

- Can declare structs in your class-declaration

```
class Scheduler {
  // A "scheduled task" struct, for internal use only
  struct task {
    int id;
    string desc;
    task *next;   // Can chain tasks together into a list
  };

  task *schedTasks;   // My list of scheduled tasks

public:
  ...
  int addTask(const string &description); // Returns taskID
  boolean setCompleted(int taskID);
};
```

Hiding Structs (2)

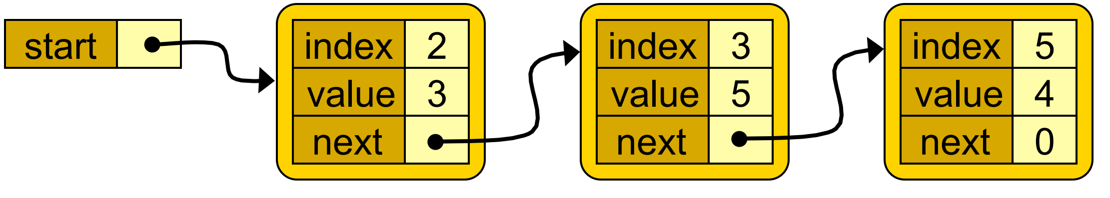
- Public **`Scheduler`** methods don't expose task type
  - But, can be used to simplify method implementations!

```
class Scheduler {
  struct task {
    int id;
    string desc;
    task *next;    // Can chain tasks together into a list
  };
  ...
public:
  ...
  int addTask(const string &description);
  boolean setCompleted(int taskID);
};
```

  - **`task`** is inaccessible outside of **`Scheduler`**
    - If it were public, its name would be **`Scheduler::task`**

Homework Tips!

- Lab 4 is challenging and fun!
  - Implement a sparse vector of integers
  - Only store nonzero values!
  - Singly linked list of nodes, ordered by index
- Example:
  - Vector (0, 0, 3, 5, 0, 4)
  - Stored as:



Lab 4 Approach

- Lab 4 is broken into two one-week parts
  - Lab 4a involves implementation of basic features
  - Lab 4b involves more sophisticated operations
- Each part specifies a sequence of steps
  - Solve problems in an easy-to-hard approach
  - Reuse your efforts, to maximize your results

Linked-List Nodes

- A linked-list node type:

```
struct node {
  int index;
  int value;
  node *next;      // Pointer to next node in list
};
```

- This is a singly linked list
  - Each node only points to *next* node
  - Can only traverse list in one direction
  - Makes things trickier than a doubly-linked list
- Put **`node`** type inside your **`SparseVector`** class
  - **`node`** is only used within **`SparseVector`**

Why a Singly Linked List?

- Sparse data structures try to minimize space usage
  - Each element takes more space than in dense version
  - …ideally, number of nonzero elements will be “small enough” to see a benefit
- Size of values: **`int`** = 4 bytes, pointer = 4 bytes
- Dense representation: T total elements
  - Requires 4T bytes
- Sparse representation: N nonzero elements
  - Singly linked: Requires $N \times (4_{idx} + 4_{val} + 4_{nxt}) = 12N$ bytes
  - Doubly linked: Requires $N \times (4_{idx} + 4_{val} + 4_{prv} + 4_{nxt}) = 16N$ bytes
- In singly linked list, $N \leq T/3$ for a benefit
- In doubly linked list, $N \leq T/4$ for a benefit

Linked List Construction

- Make a **node** constructor:

```
struct node {
  int index;      // Index of element in vector
  int value;      // Value of element in vector
  node *next;     // Pointer to next element, or 0
                                             default value
  node(int idx, int val, node *nxt = 0) :
    index(idx), value(val), next(nxt) { }
};
```

  - Empty constructor body, because setup is done with initializers

- C++ allows us to specify default values for args

```
node *n1 = new node(7, -4);     // n1->next set to 0
node *n2 = new node(3, 2, n1);  // n2->next set to n1
```

Linked List Construction (2)

- Arguments with default values must be at end of argument-list
  - This is invalid:

```
void foo(int i, char *psz = 0, double x, int j = -1);
```

  - Move all default args to end:

```
void foo(int i, double x, char *psz = 0, int j = -1);
```

- Can manually link nodes together, too:

```
node *n1 = new node(3, 5);     // Elem 3 = value 5
node *n2 = new node(5, -2);    // Elem 5 = value -2
n1->next = n2;
```

General Linked-List Tips

- Use meaningful variable names!
  - **`start`**, **`curr`**, **`prev`**, **`next`** are good candidates
  - **`start`** = first node of list (the “head”)
  - **`curr`** = current node
  - **`prev`** = previous node
  - **`next`** = next node
- Really clear and obvious meanings
  - Makes things clear to you, and to others!

Linked-List Algorithms

- It takes <u>practice</u> to write clean algorithms with singly linked lists
  - Think about efficiency of your implementations
  - “Can I make this simpler?”
  - “Can I incorporate special cases more cleanly?”
  - Don’t be afraid to experiment and refine
- The fewer special cases, the easier it is to find and fix bugs.

General Theme

- Most operations follow this form:

```
node *curr = start;

while (curr != 0) {
  ...  // Do something with current node

  // Go to next node in list
  curr = curr->next;
}
```

  - Simple list traversal
  - Copying, deleting, comparing lists – all variations on this theme

Deleting a Singly Linked List

- Deleting a list requires deleting all of its nodes
- First try:

```
node *curr = start;

while (curr != 0) {
  // Delete this node.
  delete curr;

  // Go to next node in list
  curr = curr->next;
}
```

- This won't work!
  - Can't delete a **`node`** object, then try to access it!
  - Need to fetch out what comes next, *before* deleting **`curr`**

Deleting a Singly Linked List (take 2)

- Add a **`next`** pointer to our code:

```
node *curr = start;

while (curr != 0) {
  // Get what is next, before deleting curr.
  node *next = curr->next;

  // Delete this node.
  delete curr;

  // Go to next node in list
  curr = next;
}
```

Copying a Singly Linked List

- Make a copy of another list
  - Need to traverse the other list in sequence
  - Also need the *previously created* node, to append another node to it
    - Each node only knows what node comes next…
- Start with these variables:

```
// Get a pointer to other list's first node
node *otherCurr = other.start;

// Use prev and curr to create the copy.
node *prev = 0;
node *curr;
```

Copying a Singly Linked List

```
// Get a pointer to other list's first node
node *otherCurr = other.start;

// Use prev and curr to create the copy
node *prev = 0;
node *curr;
while (otherCurr != 0) {
  // Copy other list's current node
  curr = new node(otherCurr->index, otherCurr->value);

  if (prev == 0)
    start = curr;      // curr is the first node in our copy!
  else
    prev->next = curr; // Make previous node point to current

  prev = curr;                  // Done with current node!
  otherCurr = otherCurr->next;  // Move to next node to copy
}
```

Retrieving Values

- **`int getElem(int index)`**
  - An index is specified
  - Find the node with the requested index, and return its value
  - If no node has the requested index, return 0
- Iterate over all nodes in list.
  - If current node is 0, we hit end of list! Return 0.
  - If current node's index matches requested index, return the node's value.
- Can stop early, if current node's index is larger than requested index.
  - Nodes are ordered by index…

Loop Guards

- In C++, logical Boolean operators are lazy
- Example:

```
while (curr != 0 && curr->index != index) {
   ...
}
```

  - **Note:** Your code may need to be different. This is just an example…
- This works because:
  - After the first false condition, no more conditions are evaluated
  - **`false && `**$\langle$***`anything`***$\rangle$**` == `**<u>**`false`**</u>
- Similarly, **`||`** is lazy
  - After the first true condition, no more conditions are evaluated
  - **`true || `**$\langle$***`anything`***$\rangle$**` == `**<u>**`true`**</u>

Setting Values

- **`void setElem(int index, int value)`**
- This one is trickier:
  - If **`index`** is already in the list, but **`value`** is 0, must remove that element
  - If **`index`** isn't already in list, must add a new node
    - (This means we need a **`prev`** pointer.)
    - And, we must add it in the correct place.
- Doing all this in one function is a mess:
    - The node exists, value != 0
    - The node exists, value == 0
    - The node doesn't exist, value != 0
    - The node doesn't exist, value == 0

Setting Values (2)

- Simplify the problem by breaking it down:
  - Write one function for when setting value to 0:
    - **`removeElem(int index)`**
  - Another for when **`value`** isn't 0:
    - **`setNonzeroElem(int index, int value)`**
    - Use an **`assert`** in this function to check **`value`**!
  - Both functions traverse the list to find the node, or the place where the node should go.
- These are helper functions: *not* for the user!
  - Make them <u>private</u>.

Final Notes

- A test program will exercise this week’s features
- Comment your code well, follow good style!
  - This will help you at least as much as it helps your grader!

- Ask for help if you get totally stuck! ☺