Recursion

Week 10
Gaddis:19.1-19.5

CS 5301
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What is recursion?

- Generally, when something contains a reference to itself
- Math: defining a function in terms of itself
- Computer science: when a function calls itself:

```cpp
void message() {
    cout << "This is a recursive function.\n";
    message();
}
int main() {
    message();
}
```

What happens when this is executed?

How can a function call itself?

- Infinite Recursion:
  This is a recursive function.
  This is a recursive function.
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  This is a recursive function.
  This is a recursive function.
  ...

Note: If you encounter infinite recursion in Lab, be sure to STOP your program BEFORE running it again!!!
Tracing the calls

- 6 nested calls to message:
  
  ```
  message(5):
    outputs “This is a recursive function”
  calls message(4):
    outputs “This is a recursive function”
  calls message(3):
    outputs “This is a recursive function”
  calls message(2):
    outputs “This is a recursive function”
  calls message(1):
    outputs “This is a recursive function”
  calls message(0):
    does nothing, just returns
  ```

- depth of recursion (#times it calls itself) = 5

How to write recursive functions

- Branching is required (If or switch)
- Find a base case
  - one (or more) values for which the result of the function is known (no repetition required to solve it)
  - no recursive call is allowed here
- Develop the recursive case
  - For a given argument (say n), assume the function works for a smaller value (n-1).
  - Use the result of calling the function on n-1 to form a solution for n

Recursive function example

factorial

- Mathematical definition of n! (factorial of n)
  
  ```
  if n=0 then n! = 1
  if n>0 then n! = 1 x 2 x 3 x ... x n
  ```

- What is the base case?
  - n=0 (the result is 1)

- Recursive case: If we assume (n-1)! can be computed, how can we get n! from that?
  - n! = n * (n-1)!

Recursive function example

int factorial(int n) {
  if (n==0)
    return 1;
  else
    return n * factorial(n-1);
}

int main() {
  int number;
  cout << “Enter a number “;
  cin >> number;
  cout << “The factorial of “ << number << “ is “
    << factorial(number) << endl;
}
Tracing the calls

- Calls to factorial:
  ```
  factorial(4):
  return 4 * factorial(3);  // 4 * 6 = 24
  calls factorial(3):
  return 3 * factorial(2);  // 3 * 2 = 6
  calls factorial(2):
  return 2 * factorial(1);  // 2 * 1 = 2
  calls factorial(1):
  return 1 * factorial(0);  // 1 * 1 = 1
  calls factorial(0):
  return 1;
  ```

- Every call except the last makes a recursive call
- Each call makes the argument smaller

Recursive functions: ints and lists

- Recursive functions over integers follow this pattern:
  ```
  type f(int n) {
    if (n==0) // do the base case
      return 0;
    else // ... f(n-1) ...
  }
  ```

- Recursive functions over lists (arrays, linked lists, strings) use the length of the list in place of n:
  - base case: if (length==0) ... // empty list
  - recursive case: assume f works for list of length n-1, compute the answer for a list with one more element.

Recursive function example

sum of the list

- Recursive function to compute sum of a list of numbers
- What is the base case?
  - length=0 (empty list) => sum = 0
- If we assume we can sum the first n-1 items in the list, how can we get the sum of the whole list from that?
  - sum (list) = sum (list[0]..list[n-2]) + list[n-1]

Assume I am given the answer to this

Recursive function example

sum of a list (array)

```
int sum(int a[], int size) {  // size is number of elems
  if (size==0)
    return 0;
  else
    return sum(a,size-1) + a[size-1];
}
```

### Recursive function example

#### count character occurrences in a string

- Write a recursive function to count the number of times a **specific** character appears in a string.
- We will use the string member function `substr` to make a smaller string.
  - `string str.substr(int pos, int length);`
  - Returns a newly constructed string object containing the portion of `str` that starts at character position `pos` and spans `len` characters (or until the end of the string, whichever comes first).

```cpp
string x = "hello there";
cout << x.substr(0,10) << endl;
cout << x.substr(1,10) << endl;
cout << x[4] << endl;
```

**Output:**
```
hello there
ello there
o
```

```cpp
int numChars(char target, string str) {
    if (str.empty()) {
        return 0;
    } else {
        //make recursive call, then modify the results:
        int result = numChars(target, str.substr(1,str.size()-1));
        if (str[0]==target)
            return 1+result;
        else
            return result;
    }
}

int main() {
    string a = "hello";
cout << a << " " << numChars('l',a) << endl;
}
```

### Recursive function example

#### greatest common divisor

- Greatest common divisor of two non-zero ints is the largest positive integer that divides the numbers evenly (without a remainder).
- This is a variant of Euclid’s algorithm:
  
  \[ \text{gcd}(x,y) = \begin{cases} y & \text{if } x/y \text{ has no remainder} \\ \text{gcd}(y, \text{remainder of } x/y) & \text{otherwise} \end{cases} \]

- It's a recursive definition, correctness is proven elsewhere.

```cpp
int gcd(int x, int y) {
    if (x % y == 0) {
        return y;
    } else {
        return gcd(y, x % y);
    }
}

int main() {
    cout << "GCD(9,1): " << gcd(9,1) << endl;
cout << "GCD(1,9): " << gcd(1,9) << endl;
cout << "GCD(9,2): " << gcd(9,2) << endl;
cout << "GCD(70,25): " << gcd(70,25) << endl;
cout << "GCD(25,70): " << gcd(25,70) << endl;
}
```
Recursive function example

Fibonacci numbers

• Series of Fibonacci numbers:
  0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, ...

• Starts with 0, 1. Then each number is the sum of
  the two previous numbers

  \[ F_0 = 0 \]
  \[ F_1 = 1 \]
  \[ F_i = F_{i-1} + F_{i-2} \quad \text{(for } i > 1) \]

• It’s a recursive definition

```c
int fib(int x) {
    if (x==0 || x==1)
        return x;
    else
        return fib(x-1) + fib(x-2);
}
```

Note: the recursive fibonacci functions works as
written, but it is VERY inefficient.

Counting the recursive calls to fib:

The first 40 fibonacci numbers:

<table>
<thead>
<tr>
<th>Number</th>
<th>Recursive calls to fib</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>41</td>
</tr>
<tr>
<td>8</td>
<td>67</td>
</tr>
<tr>
<td>9</td>
<td>109</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>331,160,281</td>
</tr>
</tbody>
</table>

Recursive functions over linked lists

• Member functions of a linked list class can be
defined recursively.
  - These functions take a pointer to a node in the list
    as a parameter
  - They compute the function for the list starting at the
    node p points to.

• The pattern:
  - base case: empty list, when p is NULL
  - recursive case: assume f works for list starting at
    p->next, what is the answer for the list starting at p?
    (it has one more element).

```c
class NumberList
{
    struct ListNode
    {
        double value;
        struct ListNode *next;
    };
    ListNode *head;
    int countNodes(ListNode *); //private version, recursive

public:
    NumberList();
    NumberList(const NumberList & src);
    ~NumberList();
    void appendNode(double);
    void insertNode(double);
    void deleteNode(double);
    void displayList();
    int countNodes(); //public version, calls private
};
```
Recursive function example
count the number of nodes in a list

// the private version, has a pointer parameter
// How many nodes are in the list starting at the pointer?
int NumberList::countNodes(ListNode *p) {
    if (p == NULL)
        return 0;
    else
        return 1 + countNodes(p->next);
}

// the public version, no arguments (Nodes are private)
// calls the recursive function starting at head
int NumberList::countNodes() {
    return countNodes(head);
}

Note that this function is overloaded

Recursive function example
display the node values in reverse order

// the private version, needs a pointer parameter
void NumberList::reverseDisplay(ListNode *p) {
    if (p == NULL) {
        //do nothing
    } else {
        //display the “rest” of the list in reverse order
        reverseDisplay(p->next);
        cout << p->value << " ";
    }
}

// the public version, no arguments
void NumberList::reverseDisplay() {
    reverseDisplay(head);
    cout << endl;
}

Linked List example:
• Append x to the end of a singly linked list:
  - Pass the node pointer by reference
  - Recursive

void List::append (double x) {
    append(x, head);
}

void List::append (double x, Node *& p) {
    if (p == NULL) {
        p = new Node;
        p->data = x;
        p->next = NULL;
    } else
        append (x, p->next);
}

Why use recursion?
• It is true that recursion is never required to
  solve a problem
  - Any problem that can be solved with recursion can
    also be solved using iteration.
• Recursion requires extra overhead: function call
  + return mechanism uses extra resources
However:
• Some repetitive problems are more easily and
  naturally solved with recursion
  - the recursive solution is often shorter, more elegant,
    easier to read and debug.