Introduction to Computer Science and Programming in C

Session 25: December 4, 2008

Columbia University

Announcements

- Final Exam: Tuesday, 12/16, 1:10 pm - 4:00 pm
  Mudd 233 (our normal room)

Variables Revisited

- What actually happens when we declare variables?
  `char a;`
- C reserves a byte in memory to store **a**.
- Where is that memory? At an **address**.
- Under the hood, C has been keeping track of variables and their addresses.

Pointers

- We can work with memory addresses too. We can use variables called **pointers**.
- **pointer:** an address variable
- All pointers are the same size, regardless of what they point to

Pointer Operators

- Declaring a pointer variable:
  ```
  int * x_ptr; /* declares a pointer to an int */
  ```
- The & operator means “the address of this thing”
- The * operator means “the thing this points to”

& and *

- ```
  int * x_ptr; /* declares a pointer to an int */
  int x, y;
  ```
- ```
  x_ptr = &x; /* set x_ptr to the address of x */
  ```
- ```
  y = *x_ptr;  /* set y to whatever x_ptr points to */
  ```
- ```
  /* is equivalent to */
  y = x;
  ```

Some vocabulary

- * operator is also known as **dereference**
- a pointer **references** a variable in memory

Pointers and Arrays

- C blurs the distinction between pointers and arrays
- When we declare an array
  `char A[10];`
  what is A?
  - A can be treated as a pointer to the first element of A

Pointers and Arrays

- In other words, the following two lines are equivalent:
  - `char * array_ptr = &A[0];`
  - `char * array_ptr = A;`
- This also means the following:
  - `A[0] == *array_ptr`
  - `A[1] == *(array_ptr+1)`

Pointers and Arrays

- When we want a function to be able to modify the value of a variable, we pass it **by reference**
```
sscanf(price, “$%f”, &dollars);
```

- Because arrays are basically pointers, this happens *automatically* when we pass arrays to functions.

- For example:
```
strcpy(stringA, stringB);
```

Pointer Arithmetic

- What if **A** was an array of ints?
  `A[1] == *(array_ptr+1) ??`
- Yes. C automatically keeps pointer arithmetic in terms of the size of the variable type being pointed to.
- Be careful to keep track of what C does for you and what it does not.

Memory Management

- We discussed before that C does not like to initialize arrays with variable sizes.
- To get around this, you can use stdlib.h's **malloc()** command.
- malloc() stands for memory allocation.
- malloc(N) returns a pointer to an allocated block of memory of N bytes.

malloc()

- Typical usage:
```
int N = 40000;
char *giantString = malloc(N*sizeof(char));
```

- Returns a null pointer if malloc fails.

- When we are done with the memory, we can free it with:
```
free(giantString);
```

Memory Leaks

- ```
  int N = 40000;
  char *giantString = malloc(N*sizeof(char));
  strcpy(giantString, argv[1]);
  giantString = malloc(N*sizeof(char));
  ```
- Now a huge block of memory is allocated but the program has no way of finding it.
- If this code runs a lot, the amount of memory the program is using will keep growing.
  ```

Measuring Algorithms

- In Computer Science, we want to be able to describe the running time and memory requirements of our algorithms
- A couple challenges:
  - Running time and space typically depend on input size
  - Algorithms are run on different machines

Measuring Algorithms

- For varying input sizes, we can write our time and space requirements as functions of **N**.
- For varying implementation, we need our description to not care about constant factors.

Example

- What is the running time of a function that sums an array of size 5 on a machine that takes 2 seconds to add numbers? $4 * 2 = 8$
- What if array is size **N**? $2(N\text{-}1)$
- What if it takes **c** seconds to add?

$c(N\text{-}1)$

Big-O

- $\boldsymbol{g(n) = \mathrm{O}(f(n))}$
  means that for some $\boldsymbol{c}$
  $\boldsymbol{g(n) \leq c(f(n))}$

- In other words, big-O means less than some constant scaling.

- In big-O notation, what is the running time to sum an array of size N? $c(N\text{-}1) = O(N)$

Sorting

- One of the most studied problems in CompSci
- We are given N numbers
- Put the numbers in order
  - least to greatest, greatest to least, alphabetical, etc.
  - compare two numbers at at time

Algorithm for Sorting

- In English: Given 50 index cards with numbers on them, how do you put them in order?
- Lots of different algorithms. We'll go over three

Bubble Sort

- Worst algorithm ever
- Start at beginning of deck
- Compare current and next cards. If next card should be before current, swap. Move to next card.
- Keep passing through deck until no more swaps necessary.

Selection Sort

- Smarter cousin of Bubble Sort
- Find the smallest unsorted card
- Swap smallest with the first unsorted card
- Consider that card sorted, and repeat

Merge Sort

- If deck is 2 or less cards, just sort and return
- Split deck into two halves
- Merge Sort each half-deck (recursion!)
- Then, merge the two half-decks:
  - Look at top of each deck. Take the smallest of the two. Repeat until decks are combined.

Running time

- Bubble Sort: O(N^2)
- Selection Sort: O(N^2)
  But the algorithm seems better organized.
- Merge Sort: O(N log(N))

Pseudocode

- Mix of English and programming language
- Use programming constructs to keep thoughts organized: loops, conditionals, variables
- But use any syntax that is clear and consistent
- And use functions that are obvious to abstract busywork

Pseudocode example

- ```
  print “Enter your friends’ names:”
  while input is not “quit”
      input = keyboardInput
      add input to array Contacts

  sort Contacts
  output Contacts
  ```

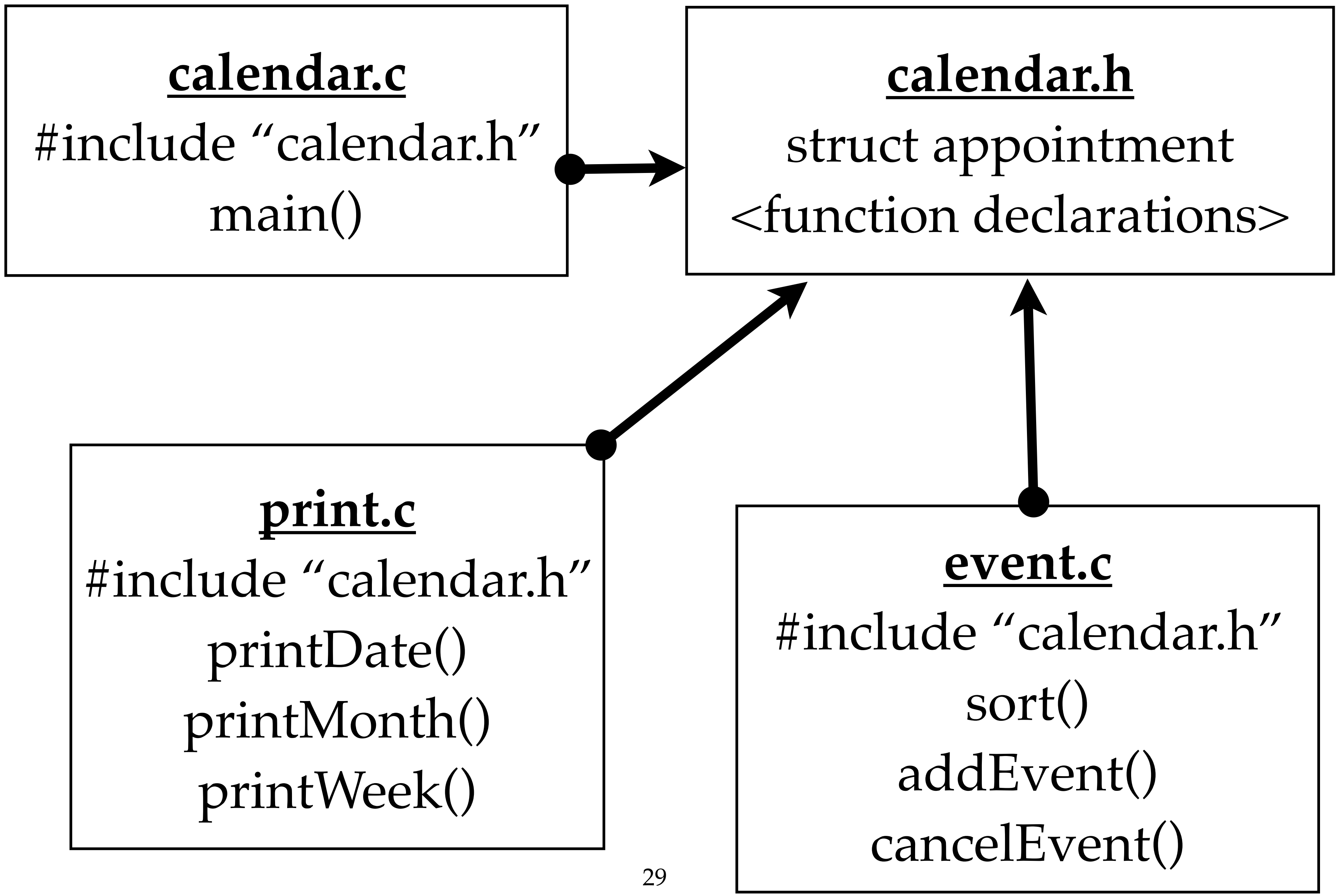
- Even though this is a simple piece of code, if it were written in C, it would be much harder to understand
  ```

Modular Programming

- **modular** - Designed with standardized units or dimensions, as for easy assembly and repair or flexible arrangement and use: *modular furniture; modular homes.*
- Organize programs into interchangeable parts
- Keep functions that deal with a certain type together, but separate them from functions that deal with other types.

calendar.c

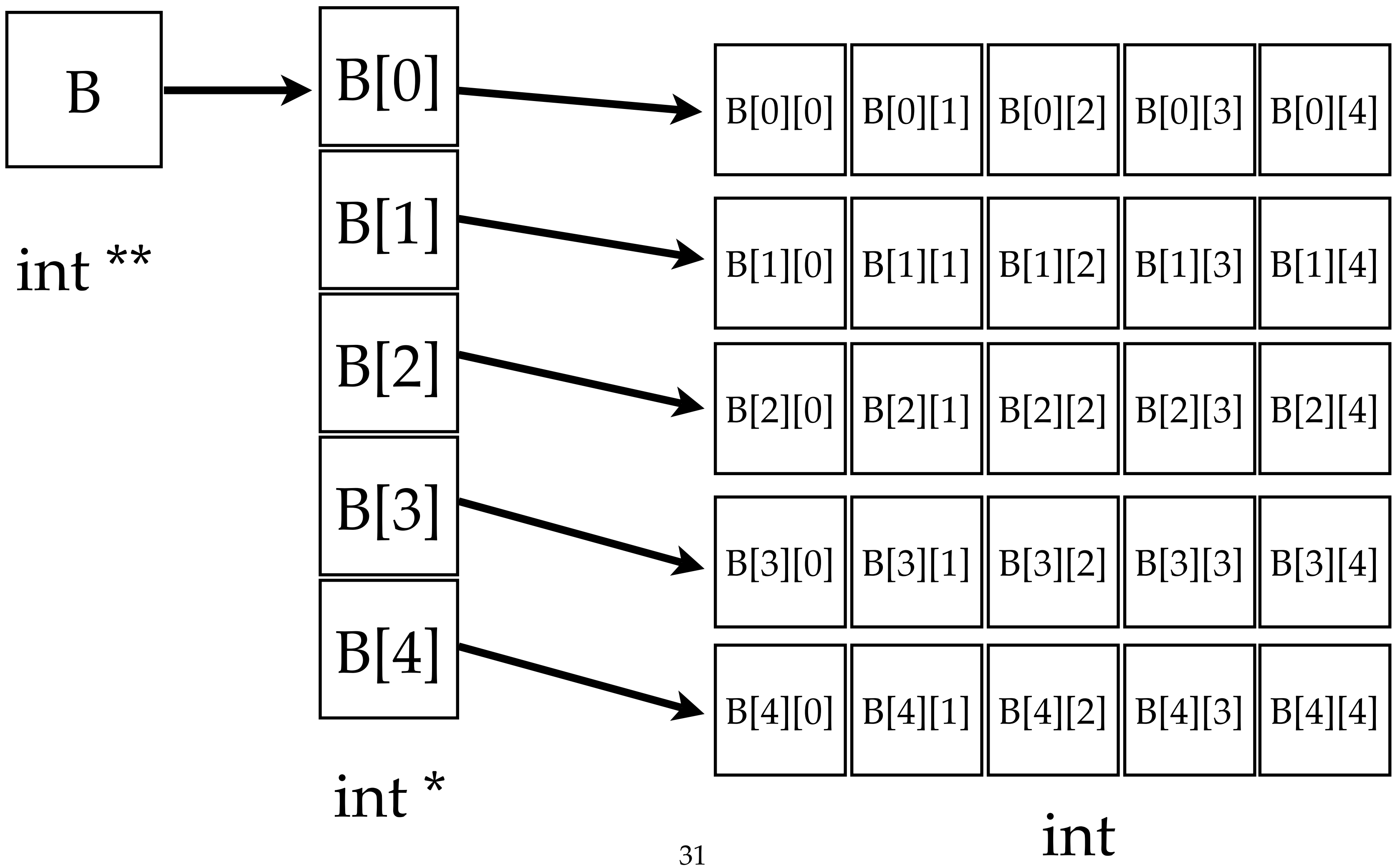
struct appointment
sort()
addEvent()
cancelEvent()
printDate()
printMonth()
printWeek()
...
main()


calendar.c
#include “calendar.h”
main()
calendar.h
struct appointment
<function declarations>
print.c
#include “calendar.h”
printDate()
printMonth()
printWeek()
event.c
#include “calendar.h”
sort()
addEvent()
cancelEvent()

Pointers to pointers

- Recall that C arrays and pointers are basically the same:
  ```
  int A[10];
  int *A_ptr = A;
  ```
- How does C store 2d arrays?
  ```
  int B[10][10];
  ```
- **B** is a pointer to an array of pointers

Pointers to pointers



malloc()

- We can dynamically allocate multi-dimensional arrays

- ```
  int **C;
  C = (int**) malloc(N*sizeof(int*));
  ```

- ```
  for (i=0; i<N; i++) {
      C[i] = (int*)malloc(N*sizeof(int));
  }
  ```

Pointers to functions

- It is occasionally useful to use pointers to functions
- Since functions are stored in memory, we can reason about their addresses too
- This allows us to say, “run the function at address _____ on these arguments”
- Useful for being truly general, e.g. stdlib qsort

Function Pointer Syntax

- ```
  int (*f_ptr)();
  /* pointer to function that returns an int */
  ```
- Parentheses are important. Without parentheses, **f_ptr** looks like it returns a pointer to an int.
- ```
  int (*f_ptr)(int, int);
  /* function takes 2 ints as arguments */
  ```
- ```
  int greater_than(int a, int b);
  f_ptr = greater_than;
  ```
  ```

qsort example

- Stdlib's qsort function is a general sorting function.
- Sort an array of any type, using any comparison criterion
- Define that comparison as a function pointer
-
```
void qsort(void *base, size_t n, size_t size,
      int (*cmp)(const void *, const void *));
```

qsort example

- Compare function should take two entries A and B,
  - return +1 if A>B
  - return -1 if A<B
  - return 0 if A==B

qsort example

```
int greater_than(const void *x, const void *y)
{
  float *a = (float*)x, *b = (float*)y;

  if (*a>*b)
    return 1;
  if (*a<*b)
    return -1;
  return 0;
}

void mySort(float A[], int N)
{
  int (*f_ptr)(const void *, const void *)
          = greater_than;
  qsort((void*)A, N, sizeof(float), f_ptr);
}
```

Linked Lists

- Store each element in a struct that contains the data and a pointer to the next struct: a **node**
- Keep a pointer to the first node
- Following a linked list is like a scavenger hunt

Linked Lists

- ```
  struct node {
    int data;
    struct node * next;
  };

  struct node *start;
  ```
- How do we add a node at beginning of list?
  - Allocate new node, set **next** pointer to **start**, set **start** to new node.
  ```

Linked Lists

- How do we add a node to the end of the list?
  - Follow pointers to last node, allocate new node, set last node's **next** to new node.
- How do we add in the middle of the list?
  - Set previous node's **next** to new node, set new node's **next** to next node.
- How do we delete a node?

Doubly Linked Lists

- Keep a **next** pointer and a **previous** pointer.
- A little extra work for adding and removing, but allows for faster backtracking.

Binary Trees

- Finding an item in a list or array is usually an O(N) operation.
- We can create a structure that makes it faster (at a cost; a tradeoff)
- We use a tree structure, which is like a linked list, except each node has more than one pointer.

Binary Trees

- Binary tree: Each node has left and right child.
  - Left child is less than, right child is greater than
- ```
  struct node {
     int data;
     struct node *left;
     struct node *right;
  }

  struct node *root;
  ```
  ```

Binary Trees

- Inserting number **x** into a Binary Tree:
  - 0. Start at root
  - 1. If current node is NULL, create new node and set node to **x**
  - 2. Otherwise,
    if **x** >= current node, follow right pointer,
    else follow left pointer. Goto 1.

Binary Trees

- Finding an item **x** in a binary tree:
  - 0. Start at root
  - 1. If current node is **x**, return
  - 2. If **x >=** current node, follow right pointer else, follow left pointer
  - 3. If node is NULL, return "not found", otherwise goto 1.

Binary Trees

- On average, lookup and insertion take O(log N) time
- But worst case is still O(N)