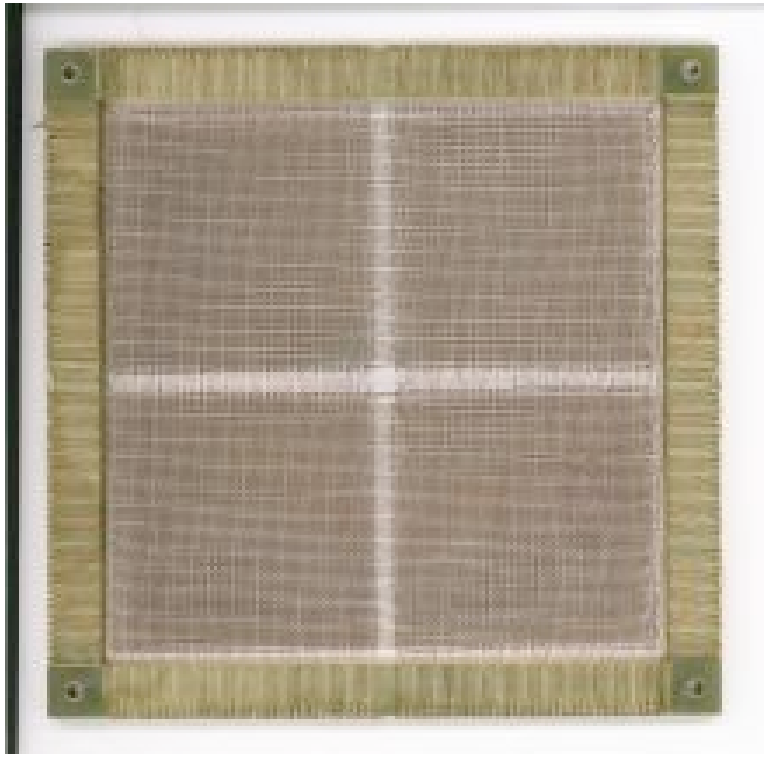
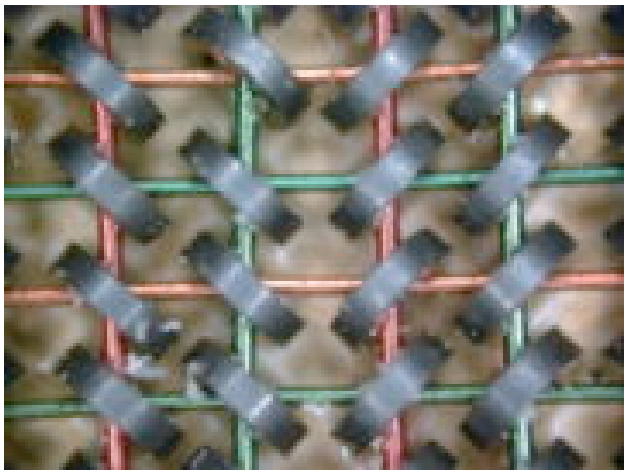
Memory management





Lecture 7

CS 113 – Spring 2008

Announcements

- Assignment 2 posted, due Friday
  - Do two of the three problems
- Assignment 1 graded
  - see grades on CMS

Safe user input

- If you use **`scanf()`**, include a maximum width in the format string

```
char string[1024];
scanf("%1023s", string);
```

- Never use **`gets()`**!
  - There's no way to use it safely
  - Use **`fgets()`** instead

```
char string[1024];
if(!fgets(string, 1024, stdin))
   goto error;

// remove newline character
if(string[strlen(string)-1] == '\n')
   string[strlen(string)-1] = 0;
```

Function pointers

- In C, you can also take the address of a function
  - I.e. the memory location of the function's machine code
- Example of declaring a function pointer:

```
int (*fctnptr)(int, int);
```

  - This is a pointer to a function that takes two parameters of type `int` and returns an integer
- Use the `&` operator to take the address of a function, and the `*` operator to dereference a function pointer

Uses of function pointers

- Systems programming
  - e.g. setting up interrupt vector tables
- Writing generic code
  - A function can take a function as a parameter
  - Example: a generic function to compute integrals

```
double compute_integral(double a, double b, double (*f)(double))
  { /* lots of code */ }

double x_squared(double x) { return x * x; }
double x_cubed(double x) { return x * x * x; }

int main() {
  compute_integral(0, 1, x_squared);
  compute_integral(5, 9, x_cubed);
}
```

Function pointer example

```
#include <stdio.h>

void change_array( int *a, int size, int (*f)(int))
{
  int j;
  for( j=0; j < size; j++)
    a[j] = f(a[j]);
}

int add_one(int x) { return x + 1; }
int square(int x) { return x * x; }

int main()
{
  int a[5] = { 0, 1, 2, 3, 4 };

  change_array(a, 5, add_one); // increment every element
  change_array(a, 5, square);  // square every element
  return 0;
}
```

Other examples

- **`qsort()`**, **`heapsort`**(), **`mergesort`**() are standard library functions for generic sorting
  - defined in **`stdlib.h`**
  - They take a comparison function as a parameter
  - They can sort *any* type of array, as long as an appropriate comparison function is given

- Also available:
  - **`lsearch()`** : linear search
  - **`bsearch()`** : binary search through a sorted array

String headaches

- Remember that you are responsible for allocating enough space for strings!
  - This code crashes: s1 isn't big enough to hold s1 + s2

```
char s1[] = "Any person, ";
char s2[] = "any study."
strcat(s1, s2);  // crash
```

  - This code works:

```
char s1[1024] = "Any person, ";
char s2[] = "any study."
strcat(s1, s2);  // OK
```

More string headaches

- Idea: what if we create a wrapper function for strcat?
  - What is wrong here?

```
char *my_strcat(char *s1, char *s2) {
  char s3[1024];
  strcpy(s3, s1);
  strcat(s3, s2);
  return s3;
}

int main() {
  char s1[] = "hello", s2[] = "world";
  char *result = my_strcat(s1, s2);
  printf("%s\n", result);
  return 0;
}
```

Local variables

- Recall that local variables are stored on the stack
  - Memory for local variables is deallocated when function returns
  - Returning a pointer to a local variable is almost always a bug!

```
char *my_strcat(char *s1, char *s2) {
  char s3[1024];
  strcpy(s3, s1);
  strcat(s3, s2);
  return s3; // BUG! returns a pointer to a deallocated
             //   memory region.
}
```

  - C requires that the size of variables on the stack be known at compile time, so dynamically-sized arrays aren't possible

The Heap

- C can use space in another part of memory: the *heap*
  - The heap is separate from the execution stack
  - Heap regions are not deallocated when a function returns
  - Note: this is completely unrelated to the *Heap data structure*

- The programmer requests storage space on the heap
  - C never puts variables on the heap automatically
    - But local variables might point to locations on the heap
  - Heap space must be explicitly allocated and deallocated by the programmer

malloc

- Library function in stdlib.h
  - Stands for memory allocate
- Requests a memory region of a specified size
  - Syntax: `void *malloc(int size)`

address of memory region

size in *bytes*

  - `void *` is a generic pointer type
    - It cannot be dereferenced
    - But it can be cast to any other pointer type

```
int size = 4;
char *char_array = (char *) malloc(size);
// char_array now points to a memory region
//  of 4 bytes allocated to me
```

Using heap regions

- You can use the allocated memory however you'd like
  - e.g. treat it as an array, use pointer notation, etc.
  - Example:

```
int main()
{
  int size = 4;
  char *buf = (char *) malloc(size);
  buf[0] = 7;
  scanf("%c", buf+1);
  return 0;
}
```

Creating arrays using malloc

- `malloc()`'s parameter is the size in *bytes*
  - *Not* the number of elements in the array!
  - e.g. an array with 100 integers typically requires 400 bytes
  - Use the `sizeof` operator to find the size of a type, e.g.:

```
float *array =
     (float *) malloc(element_count * sizeof(float));
```

- `malloc()` might fail
  - if there isn't enough memory available to satisfy the request
  - `malloc()` returns `NULL` in this case

Example: using malloc

```
#include <assert.h>
#include <stdlib.h>
#include <stdio.h>

int main()
{
  int item_count = 0;
  float *array;

  printf("How many items do you have? ");
  scanf("%d", &item_count);

  array = (float *) malloc(sizeof(float) * item_count);
  assert(array != NULL);

  for(j = 0; j<item_count; j++)
    scanf("%f", array+j);

  return 0;
}
```

free

- malloc()'ed memory is *not* freed automatically
  - Even after all pointers to it have been destroyed!
  - Must call `free()` to deallocate memory when done using it

```
void f()
{
  char *p;
  p = (char *) malloc(1000);
}

int main()
{
  while(1)
    f();
}
```

free

- malloc()'ed memory is *not* freed automatically
  - Even after all pointers to it have been destroyed!
  - Must call `free()` to deallocate memory when done using it

```
void f()
{
  char *p;
  p = (char *) malloc(1000);
  /* some code */
  free(p);
}

int main()
{
  while(1)
    f();
}
```

Memory leaks

- You need a call to free() for every call to malloc()
- Forgetting to call free() causes a *memory leak*
  - The memory is not being used but still allocated
  - Memory leaks are *very* common, but often difficult to find
- Other bad memory errors
  - Calling free() more than once
  - Calling free() on a pointer not returned by malloc()

strcat() wrapper

- Idea: what if we create a wrapper function for strcat?
  - This version didn't work:

```
char *my_strcat(char *s1, char *s2) {
  char s3[1024];
  strcpy(s3, s1);
  strcat(s3, s2);
  return s3;
}

int main() {
  char s1[] = "hello", s2[] = "world";
  char *result = my_strcat(s1, s2);
  printf("%s\n", result);
  return 0;
}
```

strcat() wrapper

- Solution: allocate the result on the *heap*
  - But the caller is responsible for free'ing it

```
char *my_strcat(char *s1, char *s2) {
  int length = strlen(s1) + strlen(s2) + 1;
  char *s3 = (char *) malloc(length);

  strcpy(s3, s1);
  strcat(s3, s2);
  return s3;
}

int main() {
  char s1[] = "hello", s2[] = "world";
  char *result = my_strcat(s1, s2);
  printf("%s\n", result);
  free(result);
  return 0;
}
```

An aside: Memory management in Java

- Java has similar memory management concepts
  - Primitive types and references are stored on the stack
  - You can allocate space on the heap using **new**

```
String getString() {
  return new String();
}

void main() {
  String s = getString();
  /* do stuff with the string */
}
```

  - But you don't have to worry about deallocating memory. Why?

Garbage collection

- Java uses a technique called *garbage collection*
  - The JVM occasionally scans for heap space no longer in use
  - It frees objects not pointed to by any reference
  - This *garbage collector* is run as a background thread

- Java was specifically designed for garbage collection
  - The JVM can figure out whether or not an object is in use
  - This isn't possible in C because of pointer arithmetic

Garbage collection in C

- Pointers make garbage collection difficult or impossible
  - It's very difficult to determine whether memory is still being used

```
char *s = (char *) malloc(1024);
s = s - 10000;
// nothing points to the allocated memory
//  region. Could it be garbage collected?
s = s + 10000;
// no, because now something points to it again!
```

  - Java's *references* are a restricted form of pointers that don't allow arithmetic, just because of this issue
  - There are garbage collecting libraries for C, but they aren't guaranteed to work with any program

Memory management: Java vs. C

Java

- Pro
  - Easier to program
  - Memory leaks impossible
  - Easier to write secure programs
- Con
  - Slower
  - No control over GC
  - Not suitable for systems programming

C

- Pro
  - Programmer can control, optimize memory use
  - Faster
- Con
  - More difficult to learn
  - Takes discipline to write safe, secure code

Multidimensional arrays

- C lets you create arrays of any dimensionality
  - e.g. to create a 3-dimensional array on the stack

```
int array[10][20][30];
```

  - You can also initialize multidimensional arrays, e.g.

```
int array[][] = { { 1 , 2 , 3 }, { 4, 5, 6 } }
```

creates a 2-D array that looks like:

1	2	3
4	5	6

Accessing array elements

- Access array elements using brackets [ ]

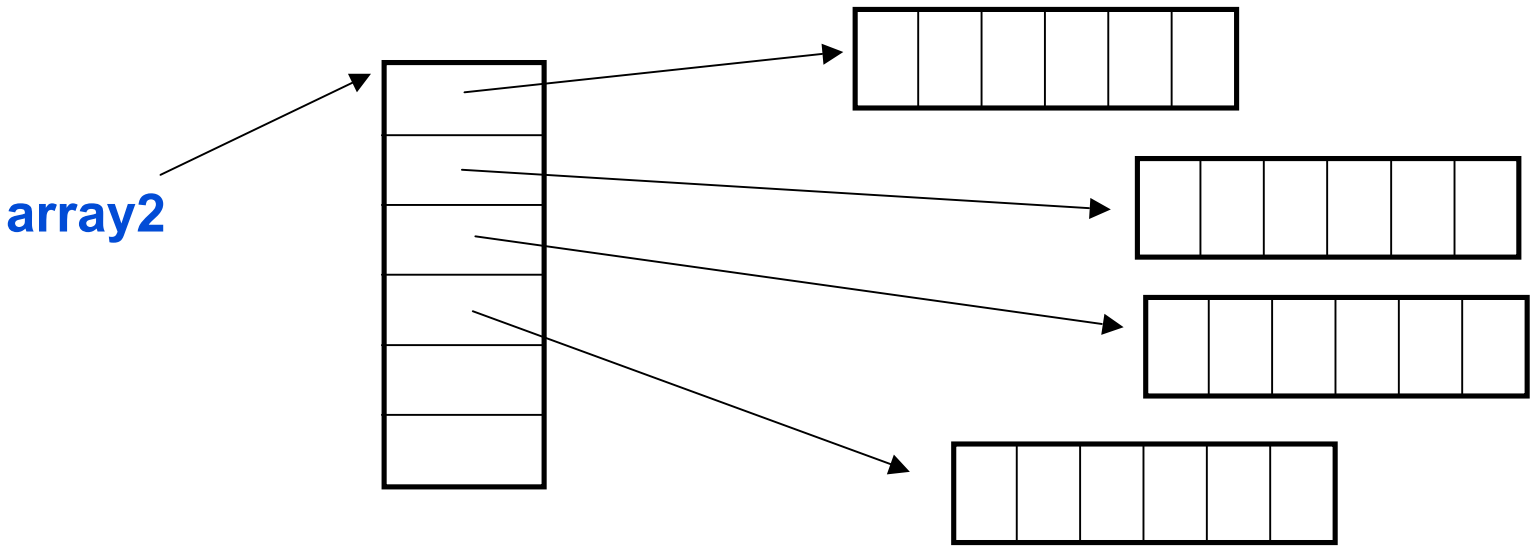
```
int i, j, k, array[10][20][30];
for(i=0; i<10; i++)
  for(j=0; j<20; j++)
    for(k=0; k<30; k++)
      array[i][j][k] = i+j+k;
```

Multidimensional arrays and pointers

- Recall: a 1-D array is just a pointer
- A 2-D array is just an array of arrays

```
int array2[10][20];  // type of array is int **
```

  - `array2` is a *pointer to a pointer* to an integer
  - e.g. `*array2` or `array2[0]` has type `int *`, and is a pointer to the beginning of the first row of the array



Multidimensional arrays on the heap

- Creating a multi-D array on the heap is more involved
  - Setup the array of row pointers and each row array explicitly

```
// create array with 10 rows, 20 columns
int **array2 = (int **) malloc(10 * sizeof(int *));
for(i=0; i<10; i++)
  array2[i] = (int *) malloc(20 * sizeof(int));
```