CS113: Lecture 6

Topics:

- Arrays
- Pointers and Arrays
- Pointer arithmetic
- Function pointers
- Strings

Arrays

- Often, programs use homogeneous data. For example, if we want to manipulate some grades, we might declare

  ```
  int grade0, grade1, grade2, grade3;
  ```

- If we have a large number of grades, it becomes cumbersome to represent/manipulate the grades, when each grade has a unique identifier. (How to find average? maximum? etc.)

- *Arrays* (a feature of many programming languages) allow us to refer to a number of instances of the same data type, using a single name.

- For example,

  ```
  int grade[4];
  ```

  makes available the use of `int` variables `grade[0]`, `grade[1]`, `grade[2]`, `grade[3]`, in a program.

- Note that arrays in C are *zero-indexed* – numbering begins at zero. If the size of an array `a` is `SIZE`, then the first accessible element of `a` is `a[0]`, and the last is `a[SIZE - 1]`.

- Now, to access elements of this array, we can write `grade[expr]`, where `expr` is any expression (evaluating to an integer within the appropriate range).

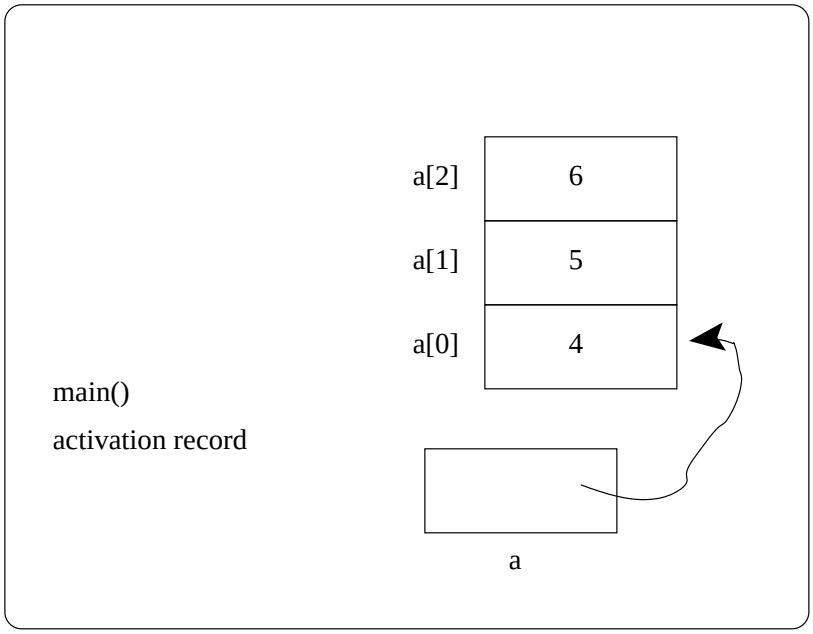
Array example: grades

```
#include <stdio.h>

void main() {
   int grades[11], num_grades = 0;
   int i;
   float sum, average;

   printf( "Please enter up to 10 grades, "
           "terminated by 0.\n" );
   scanf( "%d", &(grades[num_grades]));
   while( grades[num_grades] != 0 ) {
      num_grades++;
      scanf( "%d", &(grades[num_grades]));
   }

   /* Compute average */
   sum = 0;
   for( i = 0; i < num_grades; i++ ) {
      sum += grades[i];
   }
   /* Assume more than one grade entered */
   average = sum / num_grades;
   printf( "The average of the grades is: %f",
           average );
}
```

Arrays Are Also Pointers!

Pointers and arrays are almost exactly the same.

```
void main() {
  int a[3];
  a[0] = 4;
  a[1] = 5;
  a[2] = 6;
}
```



- The type of `a` is `(int *)`.
- As a pointer, `a` points to the first memory location in the array.
- Stay tuned for details...

Arrays in C

- No bounds checking. Make sure that you only access array elements `0` through `N - 1` for an array of size `N`.

  A program that writes to "out-of-bounds" locations will compile and often run – beware! Writing to such invalid locations corrupts memory, sometimes the values of other variables. Very bad!

- The size of an array must be a constant. Here, "constant" means that the value can be determined at compile-time (so we know how much space to allocate in the activation record for the function).

```
void func( int size ) {
    int b[size];          /* illegal */
    int g[(8 * 5) + 2];   /* fine */
}
```

- C has no internal mechanism for copying or comparing arrays.

  If `a`, `b` are arrays of the same type:

  – expression `a = b` is illegal – a declared array name cannot be treated as a variable, as `a` is here.

  – expression `a == b` is legal – it checks to see if the pointers a and b point to the same memory location, and will return 0 (FALSE) if `a` and `b` are two *different* arrays with the *same* elements in them.

Example: Change-and-sum

```
#include <stdio.h>

int change_and_sum( int *a, int size ) {
   int i, sum = 0;
   a[0] = 100;
   for( i = 0; i < size; i++ )
      sum += a[i];
   return sum;
}

void main() {
   int a[5] = { 0, 1, 2, 3, 4 };
   printf( "Sum of elements of a: %d\n",
           change_and_sum( a, 5 ));
   printf( "Value of a[0]: %d\n", a[0] );
}
```

Notice:

- The shortcut to initialize the array
- Array passed as parameter – along with the size
- Function `change_and_sum` takes a *pointer*, and then treats it like an array
- Changes made to array persist!

Example: sorting numbers

```
void sort_ints( int *a, int size ) {
   int i, j, k, temp;
   for( i = 0; i < size; i++ ) {
      /* find largest elt. of
         a[i], ..., a[size-1] */
      k = i;
      for( j = i + 1; j < size; j++ )
         if( a[j] > a[k] ) k = j;

      /* swap a[i], a[k] */
      temp = a[k];
      a[k] = a[i];
      a[i] = temp;
   }
}

void main() {
   int a[6] = { 3, 2, 8, 1, 5, 9 }, i;

   sort_ints( a, 6 );
   for( i = 0; i < 6; i++ )
      printf( "%d\n", a[i] );
}
```

More on pointers and arrays

- Suppose that `a` is an `int` array of size 10.

- If `pa` is a pointer to an integer, i.e.,

  `int *pa;`

  then the assignment

  `pa = &a[0];`

  sets `pa` to point to element zero of `a`.

- When does `x = *pa;` make sense – what does the type of `x` have to be? What does it do?

- If `pa` points to an element of an array, then (by definition) `pa + 1` points to the next element.

  In general, `pa + i` points to the `i`th element after the element pointed to by `pa`.

- Example.

```
int a[4] = { 0, 1, 2, 3 };
int *p;
p = &a[0];
printf( "%d\n", *(p + 2));
scanf( "%d", p + 3 );
printf( "You typed: %d\n", a[3] );
```

Even more on pointers and arrays

- In fact, the name of an array is a synonym for the address of the initial element. As an example, when we have the declarations

  ```
  int a[10];
  int *pa;
  ```

  `&a[0]` is the same as `a`, and thus `pa = &a[0];` is the same as `pa = a;`.

- This is why the changes to an array made by a function persist: we were simply passing in a pointer to the first (zero indexed) element of the array.

- Accordingly, for any expression `b` of type `int *`, `b[i]` can always be written as `*(b + i)`, and vice-versa.

  For example, given the above declarations:

  `a[i]` and `*(a + i)` are equivalent

  `pa[i]` and `*(pa + i)` are equivalent

- Note that an array name (like `a` assuming the above declarations) is *not* a variable, so statements like `a = pa;` and `a++;` are illegal. (You also don't want to form the expression `&a`.)

Practice: Pointers and Arrays

```
void main() {
  int a[4] = { 0, 1, 2, 3 };
  int *pa;

  pa = a + 1;
  printf( "%d\n", *pa );
  printf( "%d\n", pa[2] );
  pa++;
  printf( "%d\n", pa[0] );
  scanf( "%d", pa + 1 );
  printf( "You typed: %d\n", a[3] );
}
```

Pointer Arithmetic

- Pointer addition: pointer plus `int`

  Saw that if a pointer `p` points to an element of an array, then `p + i` is a pointer (of the same type) pointing to the `i`th element after the element pointed to by `p`.

- Pointer subtraction: pointer minus pointer

  If `p` and `q` point to elements of the same array, then `q - p` gives the number of elements between `p` and `q`.

- Pointer comparison: pointer relation pointer

  Permissible relations: `==, !=, <, <=, >, >=`

  If `p` and `q` point to elements of the same array, then

  `p < q`

  is true if `p` points to an earlier member of the array than `q` does.

- Note: CAN'T add two pointers, or perform any sort of multiplication, etc.

  – A pointer is a physical memory location, represented by an integer, but you should never think of them as integers. (Try it!).

  – Pointer arithmetic works at the level of "the next element in the array", *NOT* at "the next physical memory address".

Example: Elements before zero

(Example from PCP)

```
void main() {
   int array[] = { 4, 5, 8, 9, 0, 1, 3, 2 };
   int index;

   index = 0;
   while( array[index] != 0 )
      index++;

   printf( "Number of elements before 0: %d\n", index );
}
```

```
void main() {
   int array[] = { 4, 5, 8, 9, 0, 1, 3, 2 };
   int *array_ptr;

   array_ptr = array;
   while(( *array_ptr ) != 0 )
      array_ptr++;

   printf( "Number of elements before 0: %d\n",
           array_ptr - array );
}
```

Function pointers

- Compiled code is just a bunch of 1's and 0's interpreted by the computer as instructions. Functions are just chunks of compiled code; they are stored at fixed memory locations and the chunks are copied onto the execution stack (as activation records) when the functions are invoked.

- *Function pointers* hold the addresses of functions; dereferencing a function pointer invokes the function. Function pointers can only point to functions that have the same kind of prototype.

- Declare a function pointer by writing a prototype for the kind of function you it to be able to point to, then add a `*` and parentheses, e.g.:

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

  declares `fctnptr` to be a pointer to a function that takes two ints as arguments and returns an int.

- Use the `&` operator applied to a function's name to get the address of a function; use the `*` operator to dereference and invoke the function pointer.

- Function pointers can be placed in arrays, be used with typecasts, and follow the normal rules of pointer arithmetic.

Example: Function pointers

```
/* Function prototypes for functions defined later in the sour
int add( int x, int y );
int subtract( int x, int y );
int multiply( int x, int y );

void main() {
   int (*ptr)( int, int );
   int a = 3, b = 4;

   ptr = &add;

/* Prints 7 */
   printf( "Add: %d + %d = %d\n", a, b, (*ptr)(a,b) );

      ptr = &multiply;

/* Prints 12 */
   printf( "Multiply: %d * %d = %d\n", a, b, (*ptr)(a,b) );

}
```

Example: Arrays of function pointers

```
/* Function prototypes for functions defined later in the sour
int add( int x, int y );
int subtract( int x, int y );
int multiply( int x, int y );


void main() {
   int (*ptr)( int, int )[3];
   int a = 3, b = 4;

   ptr[0] = &add;
   ptr[1] = &subtract;
   ptr[2]= &multiply;

/* Prints 7 */
   printf( "Add: %d + %d = %d\n", a, b, (*ptr[0])(a,b));


/* Prints 12 */
   printf( "Multiply: %d * %d = %d\n", a, b, (*ptr[2])(a,b));
}
```

Strings: they're just arrays!

- Strings are one-dimensional arrays of `char`s.
- By convention, a string in C is terminated by the null character, `'\0'`, or `0`. (We have `'\0' == 0`.)
- String constants (such as those passed to the function `printf`) are enclosed in double quotes.
- When allocating `char` arrays that will hold strings, make sure you allocate enough space!
  - When dealing with strings in C, you should always think of the underlying array of characters.
  - Also: always think in terms of the activation records! You must explicitly allocate all the space for every string you use, and space allocated as part of a function call will be destroyed when the function finishes.
  - We're not in Java anymore. Are you starting to miss it?

Example: “Double” printing

```
#include <stdio.h>

void dprint( char *s ) {
   int i;
   /* for this loop to exit, s
      better terminate with 0! */
   for( i = 0; s[i] != 0; i++ )
      printf( "%c%c", s[i], s[i] );
}

void main() {
   /* s and s2 are the same strings */
   char s[] = "Hi!";
   char s2[] = { 'H', 'i', '!', '\0' };

   dprint( s ); /* HHii!! */
   if( s == s2 ) {
     printf("Points to identical string");
   } else {
     printf("Does not");
   }
}
```

Example: “squeeze” function

(Based on an example from K&R)

```
#include <stdio.h>

/* squeeze deletes all instances of the
   character c from the string s. */
void squeeze( char *s, int c ) {
   int i, j;

   for( i = j = 0; s[i] != 0; i++ ) {
      if( s[i] != c ) {
         s[j] = s[i];
         j++;
      }
   }
   s[j] = 0;
}

void main() {
   char s[100];
   strcpy( s, "Clzzeazn mez zup!" );
   printf( "Before squeeze: %s\n", s );
   squeeze( s, 'z' );
   printf( "After squeeze: %s\n", s );
}
```

String handling functions

These are from `string.h`. See Appendix B3 of K&R for an exhaustive list.

- `int strlen( char *s );`

  Returns the length of the string s.

- `char *strcat( char *s1, char *s2 );`

  Takes two strings as arguments, concatenates them, and puts the result in `s1`. The programmer must ensure that `s1` points to enough space to hold the result. The string `s1` is returned.

- `char *strcpy( char *s1, char *s2 );`

  The string `s2` is copied into `s1`. Whatever exists in `s1` is overwritten. It is assumed that `s1` has enough space to hold the result. The value of `s1` is returned.

  (Remember, using = to assign one string to another only copies pointers, it doesn't actually give a new copy of the string. And it won't work at all if the left hand side is a string array.)

- `int strcmp( char *s1, char *s2 );`

  Integer is returned that is less than, equal to, or greater than zero, depending on whether `s1` is lexicographically less than, equal to, or greater than `s2` (respectively).

A good exercise is to implement these functions yourself.

The strcmp ordering: think dictionary

From “lowest” to “highest”:

```
"1"
"128"
"16"
"2"
"32"
"4"
"64"
"8"
"Avocado"
"Can"
"Can not"
"Can't"
"Cannot"
"Cantor"
"Lime"
"apple"
"banana"
"c"
"c language"
"c programmer"
"cantaloupe"
```

Example: Reversing a string

```
#include <string.h>

void reverse( char *s ) {
   int halflen, len, i;
   char temp;

   len = strlen( s );
   halflen = len / 2;

   for( i = 0; i < halflen; i++ ) {
      /* swap s[i] and s[len - 1 - i] */
      temp = s[i];
      s[i] = s[len - 1 - i];
      s[len - 1 - i] = temp;
   }
}

void main() {
   char s[20];
   strcpy( s, ".desrever ma I" );
   printf( "Before reversal: %s\n", s );
   reverse( s );
   printf( "After reversal: %s\n", s );
}
```

Multidimensional arrays

- Arrays can have more than one dimension.

- Example of declaring a two-dimensional array of `int`s:

  ```
  int b[3][7];
  ```

  Makes available 21 ints for use: `b[i][j]` where `i` ranges from 0 to 2, and `j` ranges from 0 to 6.

- Can also declare three-dimensional, etc. arrays.

  ```
  int c[2][4][10];
  ```

Arrays of Strings

```
void get_string( char s[] ) {
   scanf( "%s", s );
   printf( "Length of your string: " );
   printf( "%d\n", strlen( s ));
}


void main() {
   char arr[8][81];
   get_string( arr[1] );
   printf( "You typed the string: %s\n", arr[1] );
   printf( "The first character you typed was: " );
   printf( "%c\n", arr[1][0] );
}
```

Notice:

- Two-dimensional array of `char`s acts as array of strings (of size 8): `arr[0]`, ..., `arr[7]`

- `scanf( "%s", ... );` used to read strings. (It's dangerous – we'll see a better next time.)

- To refer to a specific character of one of the strings `arr[i]`, tack on another index: `arr[1][0]` for instance refers to the first (zero-indexed) character of the string `arr[1]`

strlen implementations

(from K&R)

```
int strlen( char *s ) {
   int n;
   for( n = 0; *s != '\0'; s++ )
      n++;
   return n;
}

/* pointer arithmetic version */
int strlen( char *s ) {
   char *p = s;

   while( *p != '\0' ) p++;
   return( p - s );
}
```

strcpy implementations

```
/* "obvious" way */
void strcpy( char *s, char *t ) {
   int i = 0;

   do {
     s[i] = t[i];
   } while (t[i++] != '\0');
}


/* slick pointer version */
void strcpy( char *s, char *t ) {
  while( *s++ = *t++ ) ;
}
```

What does == do here?

```
void main() {
   char s[20];

   strcpy( s, "Hello" );

   if( s == "Hello" ) {
      printf( "Equal.\n" );
   } else {
      printf( "Not equal.\n" );
   }
}
```

What's going on?

- A *string literal* like `"Hello"` is represented in the function's activation record as a `char` array, like a regular string. (It has to go somewhere, right?!)

- BUT the array is static (which we'll talk about later) AND it can't be modified.

- Thus `s = "Hello";` doesn't behave as you might think.

- Are the two instances of `"Hello"` in the function above stored in distinct arrays? It's implementation-dependent.