CSC215 Lecture

Pointers and Arrays

Outline

- Physical and virtual memory
- Pointers
  - Declaration, operators, casting
  - Passing as arguments and returning from functions
- Arrays
  - Declaration, initialization, accessing individual elements
  - Arrays as constant pointers
  - Multidimensional arrays
- Pointer Arithmetic
  - Assignment, addition and subtraction, increment and decrement, comparative operators
  - Unary operators precedency
- Cryptic C code

Pointers and Memory Addresses

- Physical memory: physical resources where data can be stored and accessed by your computer
  - Cache
  - RAM
  - hard disk
  - removable storage
- Physical memory considerations:
  - Different sizes and access speeds
  - Memory management – major function of OS
  - Optimization – to ensure your code makes the best use of physical memory available
  - OS moves around data in physical memory during execution
  - Embedded processors – may be very limited

Pointers and Memory Addresses

- Virtual memory:
  - abstraction by OS
  - addressable space accessible by your code
- How much physical memory do I have?
  Answer: 2 MB (cache) + 2 GB (RAM) + 100 GB (hard drive) + . . .
- How much virtual memory do I have?
  Answer: <4 GB (32-bit OS)
- Virtual memory maps to different parts of physical memory
- Usable parts of virtual memory: stack and heap
  - stack: where declared variables go
  - heap: where dynamic memory goes

Pointers and variables

- Every variable residing in memory has an address!
  - What doesn't have an address?
    - register variables
    - constants/literals/preprocessor defines
    - expressions (unless result is a variable)
- C provides two unary operators, `&` and `*`, for manipulating data using pointers
  - address operator `&`: when applied to a variable `x`, results in the address of `x`
  - dereferencing (indirection) operator `*`:
    when applied to a pointer, returns the value stored at the address specified by the pointer.
- All pointers are of the same size:
  - they hold the address (generally 4 bytes)
  - pointer to a variable of type T has type T*
  - a pointer of one type can be converted to a pointer of another type by using an explicit cast:

```
int *ip;     double *dp;     dp= (double *)ip;  OR  ip = (int*)dp;
```

Examples

```
char a;       /* Allocates 1 memory byte */
char *ptr;    /* Allocates memory space to store memory address */
ptr = &a;     /* store the address of a in ptr. so, ptr points to a */
int x = 1, y = 2, z[10]={0, 1, 2, 3, 4, 5, 4, 3, 2, 1};
int *ip;      /* ip is a pointer to int */
ip = &x;      /* ip now points to x */
y = *ip;      /* y is now 1 */
*ip = 0;      /* x is now 0 */
ip = &z[0];   /* ip now points to z[0] */
printf("%d %d %d", x, y, *ip);
y = *ip + 1;
printf("%d %d %d", x, y, *ip);
*ip += 1;
printf("%d %d %d", x, y, *ip);
```

```
0 1 00 1 00 1 1
```

Dereferencing & Casting Pointers

- You can treat dereferenced pointer same as any other variable:
  - get value, assign, increment/decrement
- Dereferenced pointer has new type, regardless of real type of data
- null pointer, i.e. 0 (NULL): pointer that does not reference anything
- Can explicitly cast any pointer type to any other pointer type

```
int* pn; ppi = (double *)pn;
```

- Implicit cast to/from `void *` also possible
- Possible to cause segmentation faults, other difficult-to-identify errors
  - What happens if we dereference ppi now?

Passing Pointers by Value

```
/* Does not work as expected*/
void swap(int a, int b){
  int temp = a;
  a = b;
  b = temp;
}

int main(){
  int a[] = {3, 5, 7, 9};
  swap(a[1], a[2]);
  printf("a[1]=%d, a[2]=%d\n", a[1], a[2]);
  return 0;
}
```

```
/* Works as expected*/
void swap(int *a, int *b){
  int temp = *a;
  *a = *b;
  *b = temp;
}

int main(){
  int a = {3, 5, 7, 9};
  swap(&a[1], &b[2]);
  printf("a[1]=%d, a[2]=%d\n",a[1], a[2]);
  return 0;
}
```

Function Returning a Pointer

- Functions can return a pointer
  Example: `int * myFunction() { . . . }`
- But: never return a pointer to a local variable

```
#include <stdio.h>
char * get_message ( ) {
  char msg[] = "Hello";
  return msg;
}
int main ( void ){
  char * str = get_message() ;
  puts(str);
  return 0;
}
```

```
#include <stdio.h>
char * get_message ( ) {
  static char msg[] = "Hello";
  return msg;
}
int main ( void ){
  char * str = get_message() ;
  puts(str);
  return 0;
}
```

- unless it is defined as static
- Multiple returns? Use extra parameters and pass addresses as arguments.

Arrays

- Fixed-size sequential collection of elements of the same type
- Primitive arrays implemented as a pointer to block of contiguous memory locations
  - lowest address corresponds to the first element and highest address to the last element
- **Declaration:** `<element_type> <array_name> [<positive_int_array_size> ];`
  Example: `int balance[8]; /* allocate 8 int elements*/`
- **Accessing individual elements:** <array_name>[<element_index>]
  Example `int a = balance[3]; /* gets the 4th element's value*/`
- **Array Initializer:** `<type> <name> [<optional_size> ] = {<comma-sep elements> };`
  `<optional_size> must be >= # of elements`

Arrays

- Under the hood: the array is constant pointer to the first element

```
int *pa = arr;  ⇔  int *pa = &arr[0];
```

- Array variable is not modifiable/reassignable like a pointer

```
int a[5];
int b[] = {-1, 3, -5, 7, -9};
a = b;
error: assignment to expression with array type
```

- `arr[3]` is the same as `*(arr+3)`: to be explained in few minutes

- Iterating over an array:

```
int i;
for(i = 0; i < n; i++)
  arr[i]++;
```

⇔

```
int *pi;
for(pi = a; pi < a + n; pi++)
  (*pi)++;
```

Strings

- There is no string type, we implement strings as arrays of chars

```
char str[10];  /* is an array of 10 chars or a string */
char *str;  /* points to 1st char of a string of unspecified length
*/
```

- There is a string.h library with numerous string functions
  - they all operate on arrays of chars and include:

    `strcpy(s1, s2)` : copies s2 into s1 (including '\0' as last char)

    `strncpy(s1, s2, n)` : same but only copies up to n chars of s2

    `strcmp(s1, s2)` : returns a negative int if s1 < s2, 0 if s1 = = s2 and a positive int if s1 > s2

    `strncmp(s1, s2, n)` : same but only compares up to n chars

    `strcat(s1, s2)` : concatenates s2 onto s1 (this changes s1, but not s2)

    `strncat(s1, s2, n)` : same but only concatenates up to n chars

    `strlen(s1)` : returns the integer length of s1

    `strchr(s1, ch)` : returns a pointer to the 1st occurrence of ch in s1 (or NULL if not found)

Arrays

- Array length? no native function

```
#include <stdio.h>
int main() {
  char* pstr = "CSC215";
  printf("%s\t%d\n", pstr, sizeof(pstr));
  char astr[7] = "CSC215";
  printf("%s\t%d\n", astr, sizeof(astr));
  int aint[10];
  printf("%d\t%d\n", sizeof(aint[0]), sizeof(aint));
  int* pint = aint;
  printf("%d\t%d\n", sizeof(pint[0]), sizeof(pint));
  return 0;
}
```

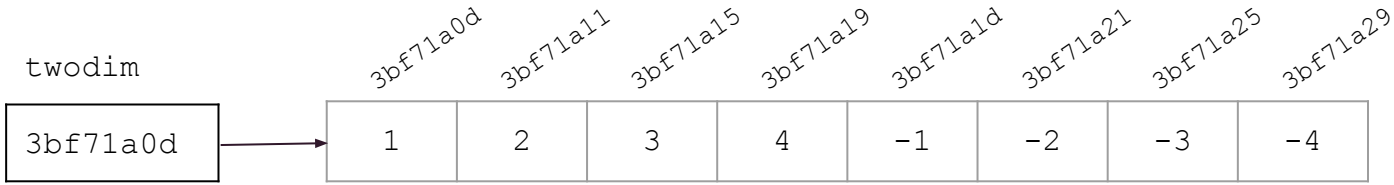
```
CSC215   4
CSC215   7
4    40
4    4
```

- How about: `sizeof(arr)==0?0 : sizeof(arr)/sizeof(arr[0]);`
  can be defined as a macro:

```
#define arr_length(arr)(sizeof(arr)==0?0 : sizeof(arr)/sizeof((arr)[0]))
```

Multidimensional Arrays

- **Syntax**: `<type> <name>[<size1>][<size2>]...[<sizeN>];`
  Example: `int threedim[5][10][4];`
- **Initializer**: `= { { {..},{..},{..}}, {...}, {...}}`
  Example:
  ```
  int twodim[2][4]={{1,2,3,4},{-1,-2,-3,-4}}; /* or simply: */
  int twodim[2][4]={1, 2, 3, 4, -1, -2, -3, -4};
  ```
  - You cannot omit any dimension size
- **Accessing individual elements**:
  `<name>[<dim1index>][<dim2index>]...[<dimNindex>]`
  Example: `twodim[1][2]=5; printf("%d\n", twodim[0][3]);`
- **Allocation**:



Multidimensional Arrays

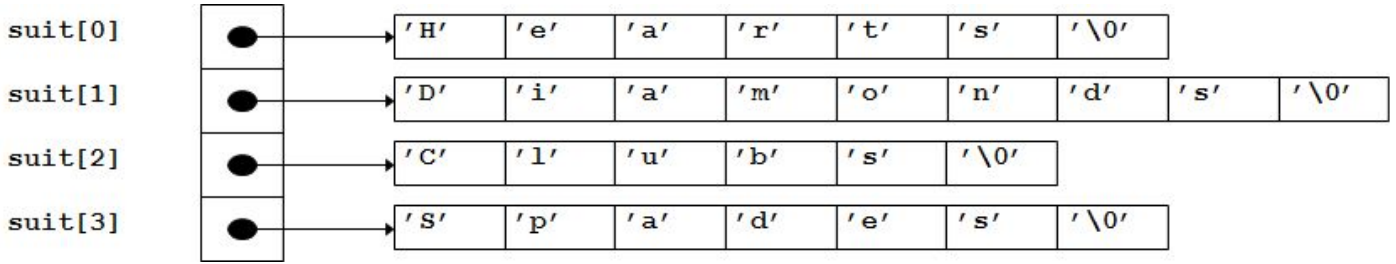
- **Pointer style**: `<type> ** <name>; /* add * for every extra dimension */`
  a pointer to the 1st element of an array, each element of which is a pointer to the 1st element in an array
- More flexibility:
  Example:
  ```
  char b[4][7] = {"CSC111", "CSC113", "CSC212", "CSC215"};
  char *bb[] = {"CSC215", "This is a beautiful morning","M","I guess so"};
  ```
- Still have [ ]?
  - To define pure pointer 2D array:
    - Declare `<type>** x` variable
    - Allocate memory for N elements of type `<type>*` (1st dimension)
    - For each of these elements, allocate memory for elements of type `<type>` () (2nd dimension)
  - Ignore it for now, you learn first about memory managements in C.
- Arguments to main: `int main(int argc, char** argv){ … }`
  - Name of the executable is always the element at index 0
    ```
    for (i=0; i<argc; i++) printf("%s\n", argv[i]);
    ```

Arrays of Pointers

- Example is an array of strings:

```
char *suit[ 4 ] = { "Hearts", "Diamonds", "Clubs", "Spades" };
```

  - strings are pointers to the first character
  - `char *` each element of suit is a pointer to a char
  - strings are not actually stored in the array `suit`, only pointers to the strings are stored
  - `suit` array has a fixed size, but strings can be of any size



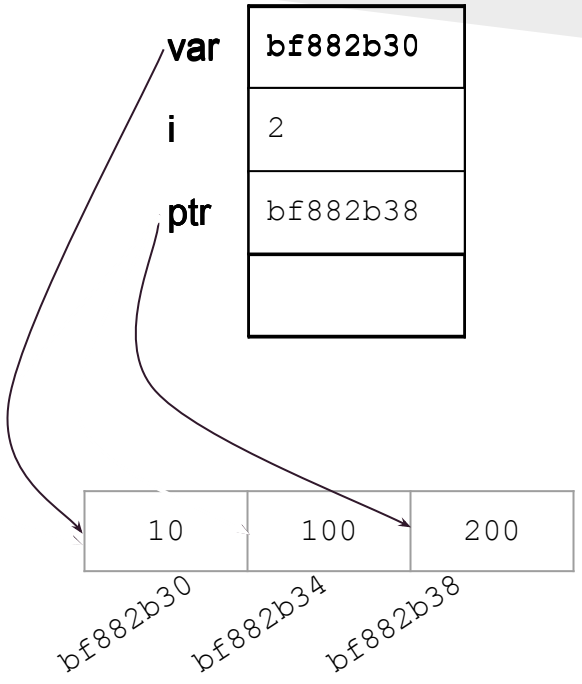
Pointer Arithmetic

- Assignment operator = : initialize or assign a value to a pointer
  - value such as 0 (`NULL`), or
  - expression involving the address of previously defined data of appropriate type, or
  - value of a pointer of the same type, or different type casted to the correct type
- Arithmetic operators + , −: scaling is applied
  - adds a pointer and an integer to get a pointer to an element of the same array
  - subtract an integer from a pointer to get a pointer to an element of the same array
  - Subtract a pointer from a pointer to get number of elements of the same array between them
- Increment/Decrement ++ , --: scaling is applied
  - result is undefined if the resulting pointer does not point to element within the same array
- Comparative operators:
  - == , ! = : can be used to compare a pointer to 0 (NULL)
  - == , ! = , > , >= , < , <= : can be used between two pointers to elements in the same array
- All other pointer arithmetic is illegal

Example: Increment/Decrement Operators

```
#include <stdio.h>
int main (){
  int var[] = {10, 100, 200};
  int i, *ptr;
  /* let us have array address in pointer */
  ptr = var;
  for ( i = 0; i < 3; i++){
    printf("Address of var[%d] = %x\n", i, ptr );
    printf("Value of var[%d] = %d\n", i, *ptr );
    /* move to the next location */
    ptr++;
  }
  return 0;
}
```

```
Address of var[0] = bf882b30
Value of var[0] = 10
Address of var[1] = bf882b34
Value of var[1] = 100
Address of var[2] = bf882b38
Value of var[2] = 200
```



Example: Comparative operators

```
#include <stdio.h>
const int MAX = 3;
int main (){
  int var[] = {10, 100, 200};
  int i, *ptr;
  /* let us have address of the first element in pointer */
  ptr = var;
  i = 0;
  while ( ptr <= &var[MAX - 1] ){
    printf("Address of var[%d] = %x\n", i, ptr );
    printf("Value of var[%d] = %d\n", i, *ptr );
    /* point to the next location */
    ptr++;
    i++;
  }
  return 0;
}
```

Precedence of Pointer Operators

- Unary operators `&` and `*` have same precedence as any other unary operator
  - with associativity from right to left.
- Examples:

`c=*++cp`	`c=*(++cp)`
`c=*cp++`	`c=*(cp++)`
`c=++*cp`	`c=++(*cp)`
`???`	`c=(*cp)++`

Cryptic vs. Short C Code

- Consider the following function that copies a string into another:

```
void strcpy(char *s, char *t){
  int i;
  i = 0;
  while ((*s = *t) != '\0') {
    S++;
    T++;
  }
}
```

  - Now, consider this

```
void strcpy(char *s, char *t){
  while ((*s++ = *t++) != '\0');
}
```

  - and this

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

- Obfuscation (software)
- The International Obfuscated C Code Contest
  http://www.ioccc.org/