The C Programming Language – Part 4

(with material from Dr. Bin Ren, William & Mary Computer Science, and www.cpp.com)

Overview

- Basic Concepts of Pointers
- Pointers and Arrays
- Pointers and Strings
- Dynamic Memory Allocation

Pointers

- pointer – the address of something
- values of variables are stored in memory, at particular locations
  - exact memory locations unknown at compile time
  - a location is identified and referenced with an address
    - analogous to identifying a house's location via an address

- use & to get the address of a variable

```
foo = &myvar;
```

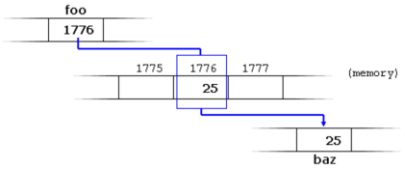

Pointers

```
1 myvar = 25;
2 foo = &myvar;
3 bar = myvar;
```

Pointers

- use * to get the value at a pointer (address)

```
baz = *foo;
```



Pointers

- & and * are complementary
- & means "get the address of"
  - **p = &c** means the address of c is assigned to the variable p
- * means "get the value at that address"
  - termed "dereferencing"
  - **int a = *p** means get the value at the address designated by p and assign it to a
  - ***p = 1** means assign the value of 1 to the memory location designated by the address of p

Pointers

- with following assignments

```
1 myvar = 25;
2 foo = &myvar;
```

all of the following are true

```
1 myvar == 25
2 &myvar == 1776
3 foo == 1776
4 *foo == 25
```

```
*foo == myvar
```

7

Declaring Pointers

- * is used in the declaration of a pointer type
  - int *p means variable p is a pointer that points to an integer
  - every pointer points to a specific data type
    - exception: void
- all pointers are the same size in memory

```
1 int * number;
2 char * character;
3 double * decimals;
```

- different

```
int * p1, * p2;
```

```
int * p1, p2;
```

8

Examples

```
#include <stdio.h>

int main()
{
    float i = 10, *j;
    void *k;

    k = &i;
     j = k;

    printf ("%f\n", *j);

    return 0;
}
```

9

Examples

```
#include <stdio.h>

int main (void)
{
   char ch = 'c';
   char *chptr = &ch;
   int i = 20;
   int *intptr = &i;
   float f = 1.20000;
   float *fptr = &f;
   char *ptr = "I am a string";

   printf ("\n [%c], [%d], [%f], [%c], [%s]\n", *chptr, *intptr, *fptr, *ptr,  ptr);

   return 0;
}
```

10

Examples

```
#include <stdio.h>

int main ()
{
   int firstvalue, secondvalue;
   int *mypointer;

   mypointer = &firstvalue;
   *mypointer = 10;

   mypointer = &secondvalue;
   *mypointer = 20;

  printf ("firstvalue is %d\n", firstvalue);
  printf ("secondvalue is %d\n", secondvalue);
}
```

```
firstvalue is 10
secondvalue is 20
```

11

Examples

```
#include <stdio.h>

int main ()
{
   int firstvalue = 5, secondvalue = 15;
   int *p1, *p2;

   p1 = &firstvalue;
   p2 = &secondvalue;

   *p1 = 10;
   *p2 = *p1;
   p1 = p2;
   *p1 = 20;

  printf ("firstvalue is %d\n", firstvalue);
  printf ("secondvalue is %d\n", secondvalue);
}
```

```
firstvalue is 10
secondvalue is 20
```

12

Pointers

- **if ip points to the integer x (ip = &x) then *ip can occur in any context where x could**
  - ex: *ip = *ip + 10 → x = x + 10
    - increments the contents of the address at ip by 10
- **unary operators * and & bind more tightly than arithmetic operators**
  - ex: y = *ip + 1 takes whatever ip points at, adds 1, and assigns the result to y
  - other ways to increment by 1:
    - *ip += 1 → *ip = *ip + 1
    - ++*ip
    - (*ip)++ (the parentheses are necessary because without them, the expression would increment ip instead of what it points to, because unary operators like * and ++ associate right to left)

13

Pointers

- **pointers are variables so can be used without dereferencing**
  - ex: int *iq, *ip;
    iq = ip;
    - copies the contents of ip (an address) into iq, thus making iq point to whatever ip pointed to

14

Example

```
#include <stdio.h>

main ()
{
   int x, *p;

   p = &x;
   *p = 0;

   printf ("x is %d\n", x);
   printf ("*p is %d\n", *p);

   *p += 1;

   printf ("x is %d\n", x);

   (*p)++;

   printf ("x is %d\n", x);

   return 0;
}
```

15

Pointer Initialization

- **pointers can be initialized at declaration**

```
1 int myvar;
2 int * myptr = &myvar;
```

- **same as**

```
1 int myvar;
2 int * myptr;
3 myptr = &myvar;
```

- **not valid**

```
1 int myvar;
2 int * myptr;
3 *myptr = &myvar;
```

- **OK**

```
1 int myvar;
2 int *foo = &myvar;
3 int *bar = foo;
```

16

Pointer Arithmetic

- **pointers can be used in arithmetic expressions, with underlying size taken into account**
- **suppose the following have addresses 1000, 2000, 3000**

```
1 char *mychar;
2 short *myshort;
3 long *mylong;
```

- **after the following**

```
1 ++mychar;
2 ++myshort;
3 ++mylong;
```

  - values are 1001, 2002, 3004
- **same results for**

```
1 mychar = mychar + 1;
2 myshort = myshort + 1;
3 mylong = mylong + 1;
```

17

Pointer Arithmetic

- **the following is equivalent to *(p++)**

```
*p++
```

- **other examples**

```
1 *p++   // same as *(p++): increment pointer, and dereference unincremented address
2 *++p   // same as *(++p): increment pointer, and dereference incremented address
3 ++*p   // same as ++(*p): dereference pointer, and increment the value it points to
4 (*p)++ // dereference pointer, and post-increment the value it points to
```

- **assignment done before increment**

```
*p++ = *q++;
```

- **same as**

```
1 *p = *q;
2 ++p;
3 ++q;
```

18

Pointer Arithmetic

- void pointers point to no particular type

```
#include <stdio.h>

void increase (void *data, int psize)
{
  if (psize == sizeof (char))  {
    char &pchar;  pchar = (char *) data;  ++(*pchar);  }
  else if (psize == sizeof (int)) {
    int *pint; pint = (int *(data);  ++(*pint); }
}

int main ()
{
  char a;
  int b = 1602;

  increase (&a, sizeof (a));
  increase (&b, sizeof (b));
  printf ("%d, %d%d\n", a, b);
  return 0;
}
```

19

Pointers

- pointers can point to any address

```
int * p;              // uninitialized pointer (local variable)

int myarray[10];
int * q = myarray+20;  // element out of bounds
```

- pointers can point to nothing

```
int * p = 0;
int * q = nullptr;
```

- or simply

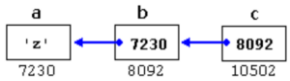
```
int * r = NULL;
```

- NULL pointers and void pointers are different

20

Pointer to Pointers

```
char a;
char * b;
char ** c;
a = 'z';
b = &a;
c = &b;
```



21

Pointers and Arrays

- array name with no index is a pointer to the first element
- the name of the array refers to the whole array; it works by representing a pointer to the start of the array
- when passed to functions, an array without any brackets acts like a pointer
  - pass the array directly without using &

22

Pointers and Arrays

- arrays can always be converted to pointers

```
int myarray [20];
int * mypointer;

mypointer = myarray;
```

- not valid to go the other way

```
myarray = mypointer;
```

- array with index is a simply a pointer with an offset
  - can be represented with pointer

```
a[5] = 0;       // a [offset of 5] = 0
*(a+5) = 0;     // pointed to by (a+5) = 0
```

23

Pointers and Arrays

```
Prototype/Call

void intSwap (int *x, int *y);
intSwap (&a[i], &a[n – i - 1]);

void printIntArray (int a[], int n);
printIntArray (x, hmny);

int getIntArray (int a[], int nmax, int sentinel);
hmny = getIntArray (x, 10, 0);

void reverseIntArray (int a[], int n);
reverseIntArray (x, hmny);
```

24

Pointers and Arrays

```
#include <stdio.h>

int main (void)
{
    int numbers [5];
    int *p, n;

    p = numbers;          *p = 10;
    p++;                  *p = 20;
    p = &numbers [2];     *p = 30;
    p = numbers + 3;      *p = 40;
    p = numbers;    *(p + 4) = 50;

    for (n = 0; n < 5; n++)
        printf ("%d, ", numbers [n]);

    return 0;
}
```

```
10, 20, 30, 40, 50,
```

25

Pointers and Strings

- **a string is an array of characters**
  - no string pointers in C – character pointers instead
  - a pointer to a string holds the address of the first character of the string (just like an array)
- **a string with no index is a memory address without a reference operator (&)**

```
char *ptr;
char str[40];
ptr = str;
```

26

Pointers and Strings

- **strings end with an implied '\0' by default**
  - "I am a string" = I_am_a_string\0
  - sizeof operator returns number of bytes, or characters
  - strlen() function
    - need string.h header file
    - returns the length of the null-terminated string *s* in bytes
      - or, the offset (i.e. starting at position zero) of the terminating null character within the array

```
char string[32] = "hello, world";
sizeof (string) ⇒ 32
strlen (string) ⇒ 12
```

      - this will only work on the character array itself, not a pointer to it

27

Pointers and Strings

- **summary of string functions**
  - need #include <string.h>

Function	Work of Function
strlen()	Calculates the length of string
strcpy()	Copies a string to another string
strcat()	Concatenates(joins) two strings
strcmp()	Compares two string
strlwr()	Converts string to lowercase
strupr()	Converts string to uppercase

https://www.programiz.com/c-programming/string-handling-functions

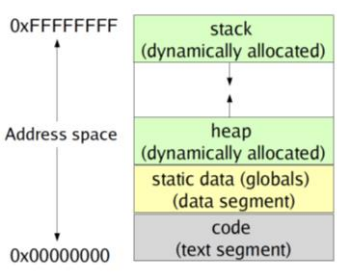
28

Pointers and Strings

```
#include <stdio.h>
#include <string.h>

int main (void)
{
    char arr [4];              // for accommodating 3 characters and one null '\0' byte
    char *ptr = "abc";         // a string containing 'a', 'b', 'c', '\0'

    // reset all the bytes so that none of the bytes contains any junk value
    memset (arr, '\0', sizeof (arr));

    strncpy (arr, ptr, sizeof ("abc"));   // copy the string "abc" into the array arr
    printf ("\n %s \n",arr);              // print the array as string
    arr [0] = 'p';                        // change the first character in the array
    printf ("\n %s \n",arr);              // again print the array as string
    return 0;
}
```

29

Dynamic Memory Allocation



Address space is just array of 8-bit bytes

Typical total size is: 2^{32}

We will assume that integer is 4 bytes

A *pointer* is just an index into this array

30

Dynamic Memory Functions

- **found in stdlib.h**
  - malloc () general-purpose memory block
  - calloc () array memory allocation
  - free () de-allocate memory; return to the system

31

Dynamic Memory Functions: malloc ()

- **malloc () allocates a block of memory**
  - number of bytes passed as argument
  - returns a pointer to that memory if successful
    - NULL otherwise
  - values in memory are uninitialized
- **prototype: void *malloc (size_t size);**
  - size: number of bytes requested
  - returns void* so pointer returned can point to any type of data

32

Dynamic Memory Functions: malloc ()

- **example**

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

int main()
{
   int *buffer;

   buffer = (int *) malloc (10 * sizeof (int));
   if (buffer == NULL) {

      printf ("Error allocating memory.\n");
      exit (1);
   }

   free (buffer);
   return 0;
}
```

http://www.codingunit.com/c-reference-stdlib-h-function-malloc

33

Dynamic Memory Functions: malloc ()

- **another example:**

```
#include <stdlib.h>

// set ptr to point to a memory address of size int
int *ptr = (int *) malloc (sizeof (int));

// slightly cleaner to write malloc statements by taking the size of the
//  variable pointed to by using the pointer directly
int *ptr = (int *) malloc (sizeof (*ptr));

float *ptr = (float *) malloc (sizeof (*ptr));

float *ptr;
// hundreds of lines of code
ptr = malloc (sizeof (*ptr));
```

34

Dynamic Memory Functions: calloc ()

- **calloc () allocates a block of memory**
  - number of items and number bytes per item passed as argument
  - returns a pointer to that memory if successful
    - NULL otherwise
  - values in memory are initialized to zero
- **prototype: void *calloc (size_t num, size_t size);**
  - num: number of items requested
  - size: size of each element
  - returns void* so pointer returned can point to any type of data

35

Dynamic Memory Functions: calloc ()

- **example**

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

int main()
{
   int a, n, *buffer;

   scanf ("%d", &a);
   buffer = (int *) calloc (a, sizeof (int));
   if (buffer == NULL) { /* error */ }

   for (n = 0; n < a; n++ ) {
      printf ("Enter number #%d: ", n);
      scanf ("%d", &buffer [n]); }

   printf ("Output: ");
   for (n = 0; n < a; n++)
      printf ("%d", buffer [n]);

   free (buffer);
   return 0;
}
```

36

malloc () vs. calloc ()

- **number of arguments**
  - malloc () takes a single argument: memory required in bytes
  - calloc () needs two arguments: number of items and size of single item
- **initialization of memory**
  - malloc () does not initialize memory allocated
  - calloc () initializes each element of allocated memory to zero

37

Dynamic Memory Functions: free ()

- **free () returns allocated memory back to the operating system**
  - pointer to first location in allocated memory passed as argument
  - after freeing a pointer, reset it to NULL
- **prototype: void free (void *p);**
  - p: pointer to memory that will be de-allocated
- **NULL pointer**
  - 0 is assigned to a pointer
  - pointer points to nothing
  - errors can be uncovered immediately when something foolish is done with the pointer (it happens a lot, even with experienced programmers) instead of later, after considerable damage has been done

38

Structures

- **struct**

```
typedef struct {
   int weight;
   double price;
} FRUIT_T;

FRUIT_T apple;
FRUIT_T banana, melon;
```

- **or**

```
struct {
   int weight;
   double price;
} apple, banana, melon;
```

- **access**

```
apple.weight
apple.price
banana.weight
banana.price
melon.weight
melon.price
```

39

Structures

```
#include <stdio.h>
#include <string.h>

typedef struct {
   char title [40];
   int year;
} MOVIE_T;

void print_movie (MOVIE_T movie)
{
   printf ("%s (%d)\n", movie.title, movie.year);
}

int main()
{
   MOVIE_T mine, yours;

   strcpy (mine.title, "2001: A Space Odyssey");
   mine.year = 1968;

   printf ("Enter title: ");
   scanf ("%[^\n]s", yours.title);
   printf ("Enter year: ");
   scanf ("%d", &yours.year);

   printf ("My favorite movie is: ");
   print_movie (mine);
   printf ("And yours is: \n");
   print_movie (yours);
}
```

```
Enter title: Alien
Enter year: 1979

My favorite movie is:
 2001 A Space Odyssey (1968)
And yours is:
 Alien (1979)
```

40

Structures

```
#include <stdio.h>

typedef struct {
   char title [40];
   int year;
} MOVIE_T;

void print_movie (MOVIE_T movie)
{
   printf ("%s (%d)\n", movie.title, movie.year);
}

int main()
{
   MOVIE_T  films [3];
   int n;

   for (n = 0; n < 3; n++) {
      printf ("Enter title: ");
      scanf (" %[^\n]s", films [n].title);
      printf ("Enter year: ");
      scanf ("%d", &films [n].year);
   }

   printf ("\nYou have entered these movies: \n");
   for (n = 0; n < 3; n++)
      print_movie (films [n]);
}
```

```
Enter title: Blade Runner
Enter year: 1982
Enter title: The Matrix
Enter year: 1999
Enter title: Taxi Driver
Enter year: 1976

You have entered these movies:
Blade Runner (1982)
The Matrix (1999)
Taxi Driver (1976)
```

41

Pointers to Structures

- **pointers to struct**

```
pmovie -> title
```

```
(*pmovie).title
```

- **different from**

```
*pmovie -> title
```

```
*(pmovie -> title)
```

Expression	What is evaluated	Equivalent
a.b	Member b of object a	
a->b	Member b of object pointed to by a	(*a).b
*a.b	Value pointed to by member b of object a	*(a.b)

42

Pointers to Structures

```
#include <stdio.h>

typedef struct {
   char title [40];
   int year;
} MOVIE_T;

int main()
{
   MOVIE_T movie;
   MOVIE_T *pmovie;

   pmovie = &movie;

   printf ("Enter title: ");
   scanf ("%[^\n]s%*c", pmovie -> title);
   printf ("Enter year: ");
   scanf ("%d", &pmovie -> year);

   printf ("\nYou have entered: \n %s (%d)\n",  movie.title, pmovie -> year);
}
```

```
Enter title: Invasion of the body snatchers
Enter year: 1978

You have entered:
Invasion of the body snatchers (1978)
```


Pointers to Structures

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

typedef struct {
   char title [40];
   int year;
} MOVIE_T;

int main()
{
   MOVIE_T *pmovie;

   pmovie = (MOVIE_T *) malloc (sizeof (MOVIE_T));

   printf ("Enter title: ");
   scanf ("%[^\n]s%*c", pmovie -> title);
   printf ("Enter year: ");
   scanf ("%d", &pmovie -> year);

   printf ("\nYou have entered: \n %s (%d)\n",  pmovie -> title, pmovie -> year);
}
```

```
Enter title: Invasion of the body snatchers
Enter year: 1978

You have entered:
Invasion of the body snatchers (1978)
```


Nested Structures

- nested struct

```
typedef struct {
   char title [40];
   int year;
} MOVIE_T;

typedef struct {
   char name [30];
   char email [40];
   MOVIE_T favorite_movie;
} FRIEND_T;

FRIEND_T charlie, maria;
FRIEND_T *pfriend = &charlie;
```

- access

```
charlie.name
maria.favorite_movie
charlie.favorite_movie.year
pfriend -> favorite_movie.year
```


Type Definition

- define a new type with typedef

```
typedef char C;
typedef unsigned int WORD;
typedef char * pChar;
typedef char field [50];
```

- define variables with new type

```
C mychar, anotherchar, *ptc1;
WORD myword;
pChar ptc2;
field name;
```


Unions

- union
  - similar to a struct, but all fields share the same memory
  - used to save space, or to easily reinterpret bits

```
union mytypes_t {
   char c;
   int i;
   float f;
} mytypes;
```

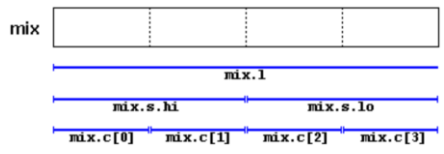
- access

```
mytypes.c
mytypes.i
mytypes.f
```


Unions

- union

```
union mix_t {
   int l;
   struct {
      short hi;
      short lo;
      } s;
   char c[4];
} mix;
```



Unions

- anonymous union

structure with regular union	structure with anonymous union

struct book1_t {
  char title[50];
  char author[50];
  union {
  float dollars;
  int yen;
  } price;
} book1;
	struct book2_t {
	  char title[50];
	  char author[50];
	  union {
	  float dollars;
	  int yen;
	  };
	} book2;

```
book1.price.dollars
book1.price.yen
```

```
book2.dollars
book2.yen
```

49

Enumerated Types

- declaration

```
enum colors_t {black, blue, green, cyan, red, purple, yellow, white};
```

- usage

```
colors_t mycolor;

mycolor = blue;
if (mycolor == green) mycolor = red;
```

- alternatively, can assign integer values
  - by default, starts at 0

```
enum months_t { january=1, february, march, april,
                may, june, july, august,
                september, october, november, december} y2k;
```

50