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CSE2421 Systems1

Introduction to Low-Level Programming and Computer Organization

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TWRF 8:00-8:55am

Pointers to Functions

- http://www.newty.de/fpt/fpt.html
  - Excellent reference/resource

What is a function pointer?

- A pointer, i.e. a variable, which points to the address of a function.

  - You must keep in mind, that a running program gets a certain space in the main-memory. Both, the executable compiled program code and the used variables, are put inside this memory. Thus a function in the program code is nothing other than an address. It is only important how you, or better your compiler/processor, interprets the memory a pointer points to.

Why use function pointers?

- Function Pointers provide some extremely interesting, efficient and elegant programming techniques.
- You can use them to:
  - replace *switch/if*-statements,
  - realize your own *late-binding* (simple discussion later)
  - implement *callbacks*
    - http://en.wikipedia.org/wiki/Callback_%28computer_programming%29
- Which leads to:
  - Greater flexibility and better code reuse
- Why *not* use function pointers
  - Complicated syntax
  - Do you really need a function pointer
- Why *use* function pointers
  - They are less error prone than normal pointers because you will never allocate or deallocate memory with them.
  - Run-time options

Introduction to function pointers

- A pointer variable can be declared as pointing to a function. The **declaration** of such a pointer is done by,

  *int (*func_pointer)();*

  - The parentheses around **func_pointer* are necessary, else the compiler will treat the declaration as a declaration of a function.
- To assign the address of a function to the pointer, the statement,

  *func_pointer = lookup; // **initialize** (use &?)*

  - where *lookup* is the function name, is sufficient.
- In the case where no arguments are passed to *lookup*, the call is

  *(*func_pointer)(); // **call/use***

  - The parentheses are needed to avoid an error.
- If the function *lookup* **returned a value**, the function call then becomes,

  *i = (*func_pointer)();*
- If the function accepted arguments, the call then becomes,

  *i = (*func_pointer)(argument1, argument2, argumentn);*

The basics of function pointers

- Let's start with a basic function to ***point to***:

```
int addInt(int n, int m) {
        return n+m;     }
```

- Next, define/declare a pointer to a function which receives 2 ints and returns an int… parentheses needed:

```
int (*functionPtr)(int,int);
```

- Now, point to the function:
  - give the pointer an initial value (always):

    ```
    functionPtr = &addInt;
    ```

  - can also be written (and often is) as

    ```
    functionPtr = addInt;
    ```

  - which is also valid since the standard says that a function name in this context is converted to the address of the function (similar to array name being a pointer)
- To use a pointer to the function:

```
int sum = (*functionPtr)(2, 3); // explicitly dereferencing
        OR
int sum = functionPtr (2,3);    //using name of function pointer
```

Function pointers in return values

- int (*functionFactory(int n)) (int, int) {
  printf("Got parameter %d", n);
  int (*functionPtr)(int,int) = &addInt;
  return functionPtr; }
- What does this do?
  - // this is a function called functionFactory which receives parameter n
  - // and returns a pointer to another function which receives two ints
  - // and it returns another int

Another example

```
#include <stdio.h>
void my_int_func(int x)
    { printf( "%d\n", x ); }
    // no return stmt because no return type
int main() {
    void (*foo)(int);
    /* the ampersand is actually optional */
    foo = &my_int_func;
    int a = 1;
    (*foo)(a);
  return 0;
}
```

In-class assignment

- //

```
int DoIt (float a, char b, char c) {
    printf("DoIt\n"); return a+b+c; }
int DoMore(float a, char b, char c) {
    printf("DoMore\n"); return a-b+c; }
```

- //

```
int (*pt2Function)(float, char, char) = NULL;
```

- //

```
pt2Function = DoIt; // short form
    OR
pt2Function = &DoMore; // use address operator
```

- //

```
if(pt2Function >0){   // check if initialized
      if(pt2Function == &DoIt)
              printf("Pointer points to DoIt\n"); }
else printf("Pointer not initialized!!\n");
```

- //

```
int result1 = pt2Function (12, 'a', 'b'); // C short way
    OR
int result2 = (*pt2Function) (12, 'a', 'b'); // more clear
```

Switch-Statement vs Function pointer

```
// The four arithmetic operations ... one of these functions is selected  at run time
float Plus (float a, float b) { return a+b; }
float Minus (float a, float b) { return a-b; }
float Multiply(float a, float b) { return a*b; }
float Divide (float a, float b) { return a/b; }
// <opCode> specifies which operation to execute
void Switch(float a, float b, char opCode) {
    float result; // execute operation
    switch(opCode) {
        case '+' : result = Plus (a, b); break;
        case '-' : result = Minus (a, b); break;
        case '*' : result = Multiply (a, b); break;
        case '/' : result = Divide (a, b); break; }
        printf("Switch: 2+5= is %f”, result);  // display result }
```

Switch-Statement vs Function pointer (cont)

- What if you want to select one function out of a pool of possible functions? Can you pass a function pointer as an argument?

```
// <pt2Func> is a function pointer and points to a function which takes two floats
// and returns a float. The function pointer  “specifies” which operation will execute
void Switch_With_Function_Pointer(float a, float b, float (*pt2Func)(float, float)) {
    float result = pt2Func (a, b);    // call using function pointer
    printf("Switch replaced by function pointer: 2-5=%f“,result); // display result
// Execute example code
void Replace_A_Switch() {
    printf("Executing function Replace_A_Switch\n“)
    Switch(2, 5, '+');
    Switch_With_Function_Pointer(2, 5, &Minus); }
```

Important note: A function pointer always points to a function with a specific signature! Thus all functions, you want to use with the same function pointer, must have the **same parameters and return-type!**

How to return a function pointer

```
// Function takes a char and returns a pointer to a function
// which is taking two floats and returns a float.
// <opCode> specifies which function to return
      float (*GetPtr1(const char opCode))(float, float) {
                  if(opCode == '+') return &Plus;
                  else return &Minus; // default if invalid op passed }

// Execute example code
      void Return_A_Function_Pointer() {
            // define a function pointer and initialize it to NULL
            float (*pt2Function)(float, float) = NULL;
            pt2Function=GetPtr1('+'); // get function pointer from 'GetPtr1' **
            float result1 = (*pt2Function)(2, 4); // call function using pointer **
            pt2Function=GetPtr1('-'); // get function pointer from 'GetPtr1'
            float result2 = (*pt2Function)(2, 4); // call function using the pointer }
```

result1 = ?   result2 = ?

** NOTE: These two statements are equivalent to: float result1 = GetPtr1('+')(2,4)

Arrays of Function Pointers (ex#1)

- Defining and using an array of function pointers offers the option to select a function using an index.

```
void Array_Of_Function_Pointers() {
// define arrays and init each element to NULL, <funcArr1> and <funcArr2> are arrays
// with 10 pointers to functions which return an int and take a float and two char
//directly defining the array
    int (*funcArr2[10])(float, char, char) = {NULL};
// assign the function's address - 'DoIt' and 'DoMore' are suitable functions
// like defined previously
    funcArr1[0] = funcArr2[1] = &DoIt;
    funcArr1[1] = funcArr2[0] = &DoMore; /* more assignments */
// calling a function using an index to address the function pointer
    printf("%d\n", funcArr1[1](12, 'a', 'b')); // short form
    printf("%d\n", (*funcArr1[0])(12, 'a', 'b')); // "correct" way of calling
    printf("%d\n", (*funcArr2[1])(56, 'a', 'b'));
    printf("%d\n", (*funcArr2[0])(34, 'a', 'b'));
}
```

Arrays of Function Pointers (ex#2)

- C treats pointers to functions just like pointers to data therefore we can have arrays of pointers to functions
- This offers the possibility to select a function using an index
- For example:
  - Suppose that we're writing a program that displays a menu of commands for the user to choose from. We can write functions that implement these commands, then store pointers to the functions in an array

```
void (*file_cmd[]) (void) =
{   new_cmd,
    open_cmd,
    close_cmd,
    save_cmd ,
    save_as_cmd,
    print_cmd,
    exit_cmd
};
```

If the user selects a command between 0 and 6, then we can subscript the file_cmd array to find out which function to call

```
file_cmd[n]();
```

Late/Runtime Binding

- Runtime binding—useful when alternative functions maybe used to perform similar tasks on data (eg sorting)
  - Determine sorting function based on type of data at run time
    - Eg: insertion sort for smaller data sets (n <100)
    - Eg: Quicksort for large data sets (n > 100000)
    - Other sorting algorithms based on type of data set

Sort Example

- In <stdlib.h>, we have a sorting function:

  void qsort (void *base , size_t num , size_t size ,

  int (*comp_func) (const void *, const void *))

- Consists of three parts
  - ✓ a comparison that determines the ordering of any pair of objects
  - ✓ an exchange that reverses their order
  - ✓ A sorting algorithm that makes comparisons and exchange until the objects are in order.
    <the sorting algorithm is independent of comparison and exchange operator>
- qsort will sort an array of elements. This is a wild function that uses a pointer to another function that performs the required comparisons.

Sort Example

- In <stdlib.h>, we have a sorting function:

  void qsort (void *base , size_t num , size_t size ,

  int (*comp_func) (const void *, const void *))

- Some explanation
  - ✓ void * base is a pointer to the array to be sorted. This can be a pointer to any data type
  - ✓ size_t num The number of elements.
  - ✓ size_t size The element size.
  - ✓ int (*comp_func)(const void *, const void *))This is a pointer to a function.

Sort Example

- qsort thus maintains it's data type independence by giving the comparison responsibility to the user.
- The compare function must return integer values according to the comparison result:
  - ✓ less than zero : if first value is less than the second value
  - ✓ zero : if first value is equal to the second value
  - ✓ greater than zero : if first value is greater than the second value
- Some quite complicated data structures can be sorted in this manner.
- The generic pointer type void * is used for the pointer arguments, any pointer can be cast to void * and back again without loss of information.

Reminder: void qsort (void *base , size_t num , size_t size ,
int (*comp_func) (const void *, const void *))

```
#include <stdlib.h>
int int_sorter( const void *first_arg, const void
*second_arg ){
  int first = *(int*)first_arg; // deref (cast)
  int second = *(int*)second_arg;
  if ( first < second ) {
    return -1;
  } else if ( first == second ) {
    return 0;
  } else {
    return 1;  }    }
int main() {
  int array[10];
  int i;
  /* fill array */
  for ( i = 0; i < 10; ++i ) {
    array[ i ] = 10 - i; }
  qsort( array, 10 , sizeof( int ), int_sorter );
  for ( i = 0; i < 10; ++i ) {
    printf ( "%d\n" ,array[ i ] );   }   }
```

Structures

- What is a structure?
  - One or more values, called members, with possibly dissimilar types that are stored together.
  - Used to group together different types of variables under the same name.
  - Aggregates a fixed set of labeled objects, possibly of different types, into a single object (like a record)
- What is a structure NOT?
  - Since members are NOT the same type/size, they are not as easy to access as array elements that are the same size.
  - Structure variable names are NOT replaced with a pointer in an expression (like arrays)
  - A structure is NOT an array of its members so can NOT use subscripts.

Structure Declarations (preview)

struct tag {member_list} variable_list;

```
struct S {
    int a;
    float b;
} x;
```

Declares x to be a structure having two members, a and b. In addition, the structure tag S is created for use in future declarations.

```
struct  {
int a;
float b;
} z;
```

Omitting the tag field; cannot create any more variables with the same type as z

```
struct S {
int a;
float b;
};
```

Omitting the variable list defines the tag S for use in later declarations

```
struct S y;
```

Omitting the member list declares another structure variable y with the same type as x

```
struct S;
```

Incomplete declaration which informs the compiler that S is a structure tag to be defined later

Struct storage issues

- A struct declaration consists of a list of fields, each of which can have any type. The total storage required for a struct object is the sum of the storage requirements of all the fields, plus any **internal padding**.
- A struct has no place in memory until a variable has been assigned to it.

Structure Example Preview

- This declaration introduces the type struct fraction (both words are required) as a new type.
- C uses the period (.) to access the fields in a record.
- You can copy two records of the same type using a single assignment statement, however == does not work on structs (see note link).

```
struct fraction {
   int numerator;
   int denominator;            // can't initialize
};

struct fraction f1, f2;        // declare two fractions
f1.numerator = 25;
f1.denominator = 10;
f2 = f1;                       // this copies over the whole struct
```

Structure Declarations (cont)

- So tag, member_list and variable_list are all optional, but cannot all be omitted; at least two must appear for a complete declaration.

```
struct  {
    int a;
    char b;
    float c;
} x;
```

Single variable x contains 3 members

Treated different by the compiler
DIFFERENT TYPES
i.e. z = &x is ILLEGAL

So all structures of a given type must be created in a single declaration? NO.

```
struct  {
    int a;
    char b;
    float c;
}  y[20], *z;
```

An array of 20 structures (y); and
A pointer to a structure of this type (z)

More Structure Declarations

- The TAG field
  - Allows a name to be given to the member list so that it can be referenced in subsequent declarations
  - Allows many declarations to use the same member list and thus create structures of the same type

```
struct  SIMPLE {
    int a;
    char b;
    float c;
} ;
```

Associates tag with member list; does not create any variables

So ➔
```
struct SIMPLE  x;
struct SIMPLE y[20], *z;
```

Now x, y, and z are all the same kind of structure

In-class Assignment

- How are structure members different from array elements? Consider the type, the name and any memory accessing issues.
- Complete the following declaration to initialize x so that the member a is three, b is the string “hello” and c is zero:
  - struct { int a; char b[10]; float c; } x =
- Given: struct abc {int a; int b; int c;};
  - How do you access member a?

Typedefs ➔ typedef <type> <name>;

- Ex1:
- #define true 1
- #define false 0
- typedef int bool;
- bool flag = false;

- Ex2:
- char *ptr_to_char; // new variable
- typedef char* ptr_to_char; // new type
- ptr_to_char a; // new variable

Using typedefs with Structures

- A typedef statement introduces a shorthand name for a type. The syntax is...
  - typedef <type> <name>;
    - shorter to write
    - can simplify more complex type definitions

```
typedef struct  {
    int a;
    char b;
    float c;
} Simple;
```

So →
```
Simple  x;
Simple y[20], *z;
```

Now x, y, and z are all the same TYPE.

Similar to →
```
int x;
int y[20], *z;
```

Typedef Structure Example

```
#include <stdio.h>
typedef struct {
    int x;
    int y;
} point;
int main(void)
{ /* Define a variable p of type point, and initialize all its members inline! */
    point p = {1,2};
    point q;
    q = p;  // q.x = 1 and q.y=2
     q.x = 2;
/* Demonstrate we have a copy and that they are now different. */
    if (p.x != q.x)
         printf("The members are not equal! %d != %d", p.x, q.x);
return 0; }
```

Function pointers and Typedef

- **We can use function pointers in return values as well**

```
// this function called functionFactory receives parameter n
// and returns a pointer to another function which receives
// two integers and it returns another integer
int (*functionFactory(int n))(int, int)          {
    printf("Got parameter %d", n);
    int (*functionPtr)(int,int) = &addInt;
    return functionPtr;                            }
```

- **But it's much nicer to use a typedef:**

```
typedef int (*myFuncDef)(int, int);
// note that the typedef name is indeed myFuncDef

myFuncDef functionFactory(int n)                 {
    printf("Got parameter %d", n);
    myFuncDef functionPtr = &addInt;
    return functionPtr;                          }
```

Typedef with Function Pointers

- Original function definition is:
  - **float** (*GetPtr1(**const char** opCode))(**float**, **float**)
- Using a typedef, define a pointer to a function which takes two floats and returns a float
  - **typedef float**(*pt2Func)(**float**, **float**);
- Then you can change the function definition to:
  - pt2Func GetPtr1(**const char** opCode)

- Define an Array of Function Pointers:
  - **int** (*funcArr2[10])(**float**, **char**, **char**) = {NULL};
- Using a typedef:
  - **typedef int** (*pt2Function)(**float**, **char**, **char**);
- You can define an array of function pointers:
  - pt2Function funcArr1[10] = {NULL};

Structures and Pointers

```
#include<stdio.h>

typedef struct
{    char  *name;
     int  number;
} TELEPHONE;

int main()
{  TELEPHONE  index;
   TELEPHONE *ptr_myindex;
   ptr_myindex = &index;
   ptr_myindex->name = "Jane Doe";   // (*ptr_myindex).name
   ptr_myindex->number = 12345;       // (*ptr_myindex).number
   printf("Name: %s\n", ptr_myindex->name);
   printf("Telephone number: %d\n", ptr_myindex->number);
 return 0; }
```

What is going on here?
Remember: TELEPHONE is a *type* of structure;

-> is a "struct member through pointer" operator… see operator precedence (top)

Structures and Pointers

```
#include<stdio.h>
#include <stdlib.h>
typedef struct rec
{     int i;
      float PI;
      char A; }   RECORD;
int main()
{     RECORD *ptr_one;
      ptr_one = (RECORD *) malloc (sizeof(RECORD));
      (*ptr_one).i = 10;
      (*ptr_one).PI = 3.14;
      (*ptr_one).A = 'a';
      printf("First value: %d\n",(*ptr_one).i);
      printf("Second value: %f\n", (*ptr_one).PI);
      printf("Third value: %c\n", (*ptr_one).A);
      free(ptr_one);
      return 0;   }
```

"rec" is not necessary for given/left code, but *is* necessary for below code update

For below, without RECORD, warning: useless storage class specifier in empty declaration

```
struct rec *ptr_one;
ptr_one =(struct rec *) malloc (sizeof(struct rec));
ptr_one->i = 10;
ptr_one->PI = 3.14;
ptr_one->A = 'a';
printf("First value: %d\n", ptr_one->i);
printf("Second value: %f\n", ptr_one->PI);
printf("Third value: %c\n", ptr_one->A);
```

Structures and Pointers

- how set "pb" to be a pointer to member “b” within structure “mystruct“?
- offsetof →tells you the offset of a variable within a structure (stddef.h)

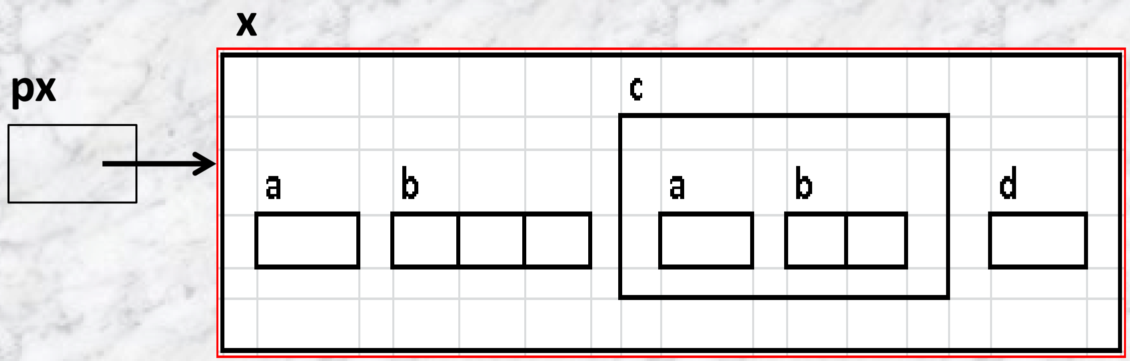
```
struct mystruct {
    int a;
    char* b; } ;     //note: could put st here instead
struct mystruct st;
char* pb = (char*)&st + offsetof(struct mystruct, b);
```

Structure memory (again)

- What does memory look like?

```
typedef struct  {
    int       a;
    short    b[2];
}  Ex2;

typedef struct EX  {
    int        a;
    char      b[3];
    Ex2        c;
    struct    EX   *d;
}  Ex;
```



Given the following declaration, fill in the above memory locations:

```
Ex  x = {  10, “Hi”, { 5 , { -1, 25 }  } , 0 };
Ex *px = &x;
```

In-class exercise

- Missing values cause the remaining members to get default initialization… whatever that might be!

```
typedef struct  {
    int       a;
    char     b;
    float     c;
}  Simple;

struct INIT_EX  {
    int        a;
    short     b[10];
    Simple  c;
}  x = {  10,
          { 1, 2, 3, 4, 5 } ,
          { 25, 'x', 1.9 }
} ;
```

What goes here (hint in blue below)?

```
struct INIT_EX   y = { 0 , {10,  20, 30, 40, 50,
                        60, 70, 80, 90, 100 },
                       { 1000, 'a', 3.14 }
                   } ;
```

Name all the variables and their initial values:

y.a = 0;
y.b[0] = 10; y.b[1] = 20; y.b[2] = 30; etc
y.c.a = 1000;
y.c.b = ‘a’;
y.c.c = 3.14;

More on Structure Declarations

- MEMBERS
  - Any kind of variable that can be declared outside a structure may also be used as a structure member.
  - Structure members can be scalars, arrays, pointers and even other structures.
- ACCESS using dot operator
- Two operands
  - Left = name of structure variable
  - Right = name of the desired member
  - Result = the designated member
- OPERATOR PRECEDENCE
  - The subscript and dot operators have the same precedence and all associate left to right.
  - The dot operator has higher precedence then the indirection

- Pointer2Structure
  - → operator
  - Left = *must* be a pointer to a structure
  - Right = member
- Example
  - (*sp).a == sp→a
  - Indirection built into arrow/infix operator
  - Follow the address to the structure

```
struct COMPLEX {
    float     f;
    int       a[20];
    long      *lp;
    struct    SIMPLE   s;
    struct    SIMPLE   sa[10];
    struct    SIMPLE   *sp;
} cmplx, cmp[10];
```

Structure example

```
struct  SIMPLE {
   int a;
   char b;
   float c;  } ;

struct COMPLEX {
    float       f;
    int         a[20];
    long        *lp;
    struct      SIMPLE   s;
    struct      SIMPLE   sa[10];
    struct      SIMPLE   *sp;
} cmplx, cmp[10];
```

```
cmplx.a[1] = 1;
cmplx.s.a = 2;
cmplx.sa[1].b = 'A';
cmplx.sp = &cmplx.s;
cmp[1].f = 3.14;
cmp[5].s.a = 3;
cmp[7].sa[2].b = 'B';

int z = cmplx.a[1];
int j = cmplx.s.a;
char k = cmplx.sa[1].b;
int x = cmplx.sp->a;
float r = cmp[1].f;
int t = cmp[5].s.a;
char y = cmp[7].sa[2].b;
```

Self-Referential Structures

- Illegal - infinite

```
struct SELF_REF {
      int       a;
      struct  SELF_REF  b;
      int       c;
};
```

- Correction

```
struct SELF_REF {
      int       a;
      struct  SELF_REF  *b;
      int       c;
};
```

- Watch out

```
typedef struct {
      int       a;
      struct  SELF_REF  *b;
      int       c;
} SELF_REF ;
```

- Correction

```
typedef struct SELF_REF_TAG {
      int       a;
      struct  SELF_REF_TAG  *b;
      int       c;
} SELF_REF ;
```

Incomplete Declarations

- Structures that are mutually dependent
- As with self referential structures, at least one of the structures must refer to the other only through pointers
- So, which one gets declared first???

```
struct B;

struct A  {
      struct  B   *partner;
      /* etc */
} ;

struct B  {
      struct  A   *partner;
      /* etc */
} ;
```

- **Declares an identifier to be a structure tag**
- **Use this tag in declarations where the size of the structure is not needed (pointer!)**
- **Needed in the member list of A**

- **Doesn't have to be a pointer**

Structures as Function arguments

- Legal to pass a structure to a function similar to any other variable but often inefficient

```
/* electronic cash register individual
transaction receipt */
#define PRODUCT_SIZE   20;
typedef struct  {
    char     product[PRODUCT_SIZE];
    int       qty;
    float     unit_price;
    float     total_amount;
}  Transaction;
```

- Function call:
  - print_receipt(current_trans);
  - Copy by value copies 32 bytes to the stack which can then be discarded later
- Instead…
  - (Transaction *trans)
  - trans->product   // fyi: (*trans).product
  - trans->qty
  - trans->unit_price
  - trans->total_amount
  - print_receipt(&current_trans);
  - void print_receipt(Transaction *trans)

```
void print_receipt (Transaction trans)  {
  printf("%s\n, trans.product);
  printf(%d @ %.2f total %.2f\n", trans.qty, trans.unit_price, trans.total_amount);
}
```