

C and C++

3. Pointers — Structures

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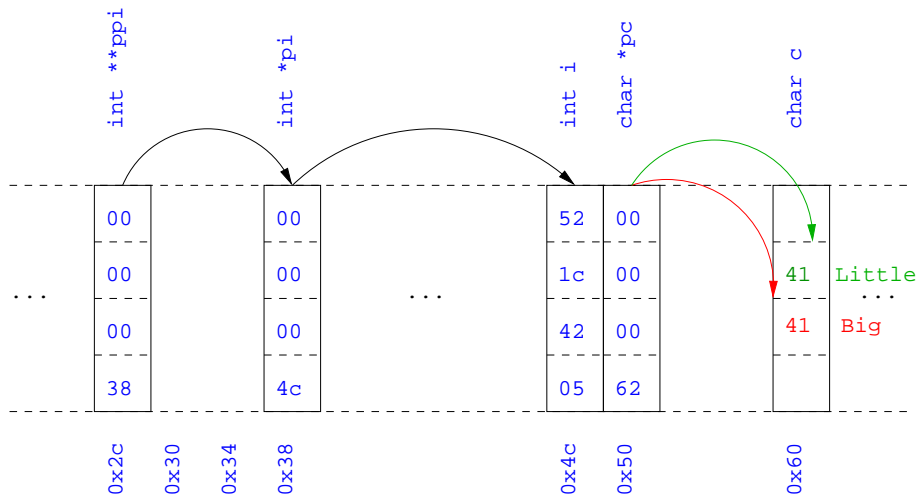
(heavily based on previous years' notes – thanks to Alastair Beresford and Andrew Moore)

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Pointers

- ▶ Computer memory is often abstracted as a sequence of bytes, grouped into words
- ▶ Each byte has a unique address or index into this sequence
- ▶ The size of a word (and byte!) determines the size of addressable memory in the machine
- ▶ A pointer in C is a variable which contains the memory address of another variable (this can, itself, be a pointer)
- ▶ Pointers are declared or defined using an asterisk(*); for example:
`char *pc;` or `int **ppi;`
- ▶ The asterisk binds to the variable name, not the type specifier; for example `char *pc, c;`
- ▶ A pointer does not necessarily take the same amount of storage space as the type it points to

Example



Manipulating pointers

- ▶ The value “pointed to” by a pointer can be “retrieved” or dereferenced by using the unary `*` operator; for example:

```
int *p = ...  
int x = *p;
```

- ▶ The memory address of a variable is returned with the unary ampersand (`&`) operator; for example

```
int *p = &x;
```

- ▶ Dereferenced pointer values can be used in normal expressions; for example: `*pi += 5;` or `(*pi)++`

Example

```
1 #include <stdio.h>
2
3 int main(void) {
4     int x=1,y=2;
5     int *pi;
6     int **ppi;
7
8     pi = &x; ppi = &pi;
9     printf("%p, %p, %d=%d=%d\n",ppi,pi,x,*pi,**ppi);
10    pi = &y;
11    printf("%p, %p, %d=%d=%d\n",ppi,pi,y,*pi,**ppi);
12
13    return 0;
14 }
```

Pointers and arrays

- ▶ A C array uses consecutive memory addresses without padding to store data
- ▶ An array name (used in an expression without an index) represents the memory address of the first element of the array; for example:

```
char c[10];
```

```
char *pc = c; is the same as
```

```
char *pc = &c[0];
```

- ▶ Pointers can be used to “index” into any element of an array; for example:

```
int i[10];
```

```
int *pi = &i[5];
```

Pointer arithmetic

- ▶ Pointer arithmetic can be used to adjust where a pointer points; for example, if `pc` points to the first element of an array, after executing `pc+=3`; then `pc` points to the fourth element
- ▶ A pointer can even be dereferenced using array notation; for example `pc[2]` represents the value of the array element which is two elements beyond the array element currently pointed to by `pc`
- ▶ In summary, for an array `c`, $*(c+i) \equiv c[i]$ and $c+i \equiv \&c[i]$
- ▶ A pointer is a variable, but an array name is not; therefore `pc=c` and `pc++` are valid, but `c=pc` and `c++` are not

Example

```
1 #include <stdio.h>
2
3 int main(void) {
4     char str[] = "A string.";
5     char *pc = str;
6
7     printf("%c %c %c\n",str[0],*pc,pc[3]);
8     pc += 2;
9     printf("%c %c %c\n",*pc, pc[2], pc[5]);
10
11     return 0;
12 }
```

Pointers as function arguments

- ▶ Recall that all arguments to a function are copied, i.e. passed-by-value; modification of the local value does not affect the original
- ▶ In the second lecture we defined functions which took an array as an argument; for example `void reverse(char s[])`
- ▶ Why, then, does `reverse` affect the values of the array after the function returns (i.e. the array values haven't been copied)?
 - ▶ because `s` is re-written to `char *s` and the caller implicitly passes a pointer to the start of the array
- ▶ Pointers of any type can be passed as parameters and return types of functions
- ▶ Pointers allow a function to alter parameters passed to it

Example

- Compare `swp1(a,b)` with `swp2(&a,&b)`:

```
1 void swp1(int x,int y)
2 {
3     int temp = x;
4     x = y;
5     y = temp;
6 }
```

```
1 void swp2(int *px,int *py)
2 {
3     int temp = *px;
4     *px = *py;
5     *py = temp;
6 }
```

Arrays of pointers

- ▶ C allows the creation of arrays of pointers; for example

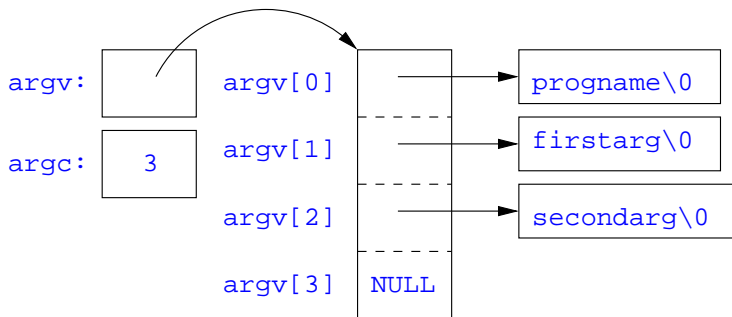
```
int *a[5];
```

- ▶ Arrays of pointers are particularly useful with strings
- ▶ An example is C support of command line arguments:

```
int main(int argc, char *argv[]) { ... }
```

- ▶ In this case `argv` is an array of character pointers, and `argc` tells the programmer the length of the array

Example



Multi-dimensional arrays

- ▶ Multi-dimensional arrays can be declared in C; for example:
`int i[5][10];`
- ▶ Values of the array can be accessed using square brackets; for example: `i[3][2]`
- ▶ When passing a two dimensional array to a function, the first dimension is not needed; for example, the following are equivalent:
`void f(int i[5][10]) { ... }`
`void f(int i[][10]) { ... }`
`void f(int (*i)[10]) { ... }`
- ▶ In arrays with higher dimensionality, all but the first dimension must be specified

Pointers to functions

- ▶ C allows the programmer to use pointers to functions
- ▶ This allows functions to be passed as arguments to functions
- ▶ For example, we may wish to parameterise a sort algorithm on different comparison operators (e.g. lexicographically or numerically)
- ▶ If the sort routine accepts a pointer to a function, the sort routine can call this function when deciding how to order values

Example

```
1 void sort(int a[], const int len,  
2           int (*compare)(int, int))  
3 {  
4     int i,j,tmp;  
5     for(i=0;i<len-1;i++)  
6         for(j=0;j<len-1-i;j++)  
7             if ((*compare)(a[j],a[j+1]))  
8                 tmp=a[j], a[j]=a[j+1], a[j+1]=tmp;  
9 }  
10  
11 int inc(int a, int b) {  
12     return a > b ? 1 : 0;  
13 }
```

Source of some confusion: either of both of the **s* in **compare* may be omitted due to language (over-)generosity.

Example

```
1 #include <stdio.h>
2 #include "example8.h"
3
4 int main(void) {
5     int a[] = {1,4,3,2,5};
6     unsigned int len = 5;
7     sort(a,len,inc); //or sort(a,len,&inc);
8
9     int *pa = a; //C99
10    printf("[");
11    while (len--)
12        printf("%d%s",*pa++,len?" ":"");
13    printf("]\n");
14
15    return 0;
16 }
```

The void * pointer

- ▶ C has a “typeless” or “generic” pointer: `void *p`
- ▶ This can be a pointer to any object (but not legally to a function)
- ▶ This can be useful when dealing with dynamic memory
- ▶ Enables “polymorphic” code; for example:

```
1  sort(void *p, const unsigned int len,  
2      int (*comp)(void *,void *));
```

- ▶ However this is also a big “hole” in the type system
- ▶ Therefore `void *` pointers should only be used where necessary

Structure declaration

- ▶ A structure is a collection of one or more members (fields)
- ▶ It provides a simple method of abstraction and grouping
- ▶ A structure may itself contain structures
- ▶ A structure can be assigned to, as well as passed to, and returned from functions
- ▶ We declare a structure using the keyword `struct`
- ▶ For example, to declare a structure `circle` we write
`struct circle {int x; int y; unsigned int r;};`
- ▶ Declaring a structure creates a new type

Structure definition

- ▶ To define an instance of the structure `circle` we write
`struct circle c;`
- ▶ A structure can also be initialised with values:
`struct circle c = {12, 23, 5};`
- ▶ An automatic, or local, structure variable can be initialised by function call:
`struct circle c = circle_init();`
- ▶ A structure can be declared, and several instances defined in one go:
`struct circle {int x; int y; unsigned int r;} a, b;`

Member access

- ▶ A structure member can be accessed using '.' notation: structname.member; for example: `vect.x`
- ▶ Comparison (e.g. `vect1 > vect2`) is undefined
- ▶ Pointers to structures may be defined; for example:
`struct circle *pc`
- ▶ When using a pointer to a struct, member access can be achieved with the '.' operator, but can look clumsy; for example: `(*pc).x`
- ▶ Equivalently, the '->' operator can be used; for example: `pc->x`

Self-referential structures

- ▶ A structure declaration cannot contain itself as a member, but it can contain a member which is a pointer whose type is the structure declaration itself
- ▶ This means we can build recursive data structures; for example:

```
1 struct tree {  
2   int val;  
3   struct tree *left;  
4   struct tree *right;  
5 }
```

```
1 struct link {  
2   int val;  
3   struct link *next;  
4 }
```

Unions

- ▶ A union variable is a single variable which can hold one of a number of different types
- ▶ A union variable is declared using a notation similar to structures; for example: `union u { int i; float f; char c;};`
- ▶ The size of a union variable is the size of its largest member
- ▶ The type held can change during program execution
- ▶ The type retrieved must be the type most recently stored
- ▶ Member access to unions is the same as for structures (‘.’ and ‘->’)
- ▶ Unions can be nested inside structures, and vice versa

Bit fields

- ▶ Bit fields allow low-level access to individual bits of a word
- ▶ Useful when memory is limited, or to interact with hardware
- ▶ A bit field is specified inside a struct by appending a declaration with a colon (:) and number of bits; for example:

```
struct fields { int f1 : 2; int f2 : 3;};
```
- ▶ Members are accessed in the same way as for structs and unions
- ▶ A bit field member does not have an address (no & operator)
- ▶ Lots of details about bit fields are implementation specific:
 - ▶ word boundary overlap & alignment, assignment direction, etc.

Example (adapted from K&R)

```
1 struct { /* a compiler symbol table */
2     char *name;
3     struct {
4         unsigned int is_keyword : 1;
5         unsigned int is_extern : 1;
6         unsigned int is_static : 1;
7         ...
8     } flags;
9     int utype;
10    union {
11        int ival; /* accessed as symtab[i].u.ival */
12        float fval;
13        char *sval;
14    } u;
15 } symtab[NSYM];
```

Exercises

1. If `p` is a pointer, what does `p[-2]` mean? When is this legal?
2. Write a string search function with a declaration of `char *strfind(const char *s, const char *f);` which returns a pointer to first occurrence of `s` in `f` (and `NULL` otherwise)
3. If `p` is a pointer to a structure, write some C code which uses all the following code snippets: `++p->i`, `p++->i`, `*p->i`, `*p->i++`, `(*p->i)++` and `*p++->i`; describe the action of each code snippet
4. Write a program `calc` which evaluates a reverse Polish expression given on the command line; for example
 `$ calc 2 3 4 + *`
should print `14` (K&R Exercise 5-10)