Programming in C and C++

4. Misc. Library Features, Gotchas, Hints and Tips

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(based on notes from and with thanks to Anil Madhavapeddy, Alan Mycroft, Alastair Beresford and Andrew Moore)

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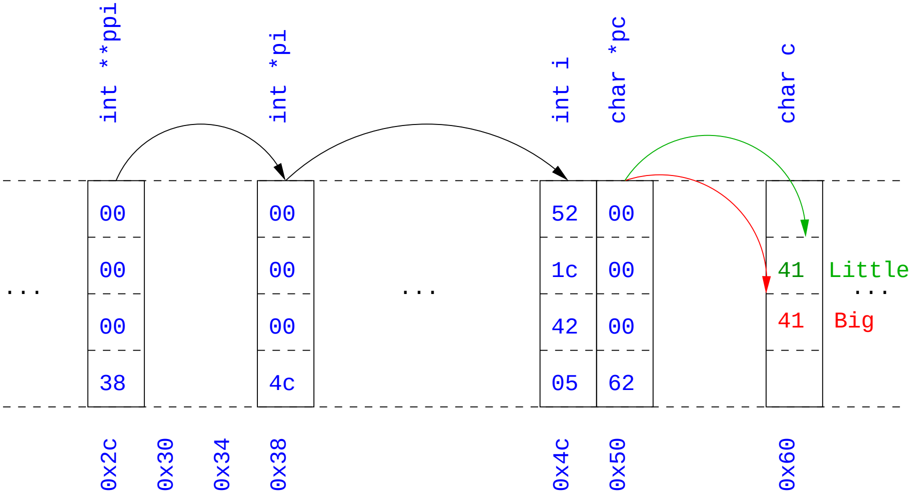
Example



int **ppi
int *pi
int i
char *pc
char c
00
00
00
38
00
00
00
4c
52
1c
42
05
00
00
00
62
41
Little
41
Big
...
...
...
0x2c
0x30
0x34
0x38
0x4c
0x50
0x60

Uses of const and volatile

- Any declaration can be prefixed with `const` or `volatile`
- A `const` variable can only be assigned a value when it is defined
- The `const` declaration can also be used for parameters in a function definition
- The `volatile` keyword can be used to state that a variable may be changed by hardware or the kernel.
  - For example, the `volatile` keyword may prevent unsafe compiler optimisations for memory-mapped input/output
- The use of pointers and the `const` keyword is quite subtle:
  - `const int *p` is a pointer to a `const` int
  - `int const *p` is also a pointer to a `const` int
  - `int *const p` is a `const` pointer to an int
  - `const int *const p` is a `const` pointer to a `const` int

Example

```c
int main(void) {
  int i = 42;
  int j = 28;

  const int *pc = &i;        //Also: "int const *pc"
  *pc = 41;                  //Wrong
  pc = &j;

  int *const cp = &i;
  *cp = 41;
  cp = &j;                   //Wrong

  const int *const cpc = &i;
  *cpc = 41;                 //Wrong
  cpc = &j;                  //Wrong
  return 0;
}
```

Typedefs

- The `typedef` operator, creates a synonym for a data type; for example, `typedef unsigned int Radius;`
- Once a new data type has been created, it can be used in place of the usual type name in declarations and casts; for example, `Radius r = 5; ...; r = (Radius) rshort;`
- A `typedef` declaration does not create a new type
  - It just creates a synonym for an existing type
- A `typedef` is particularly useful with structures and unions:

```
typedef struct llist *llptr;
typedef struct llist {
  int val;
  llptr next;
} linklist;
```

Inline functions

- A function in C can be declared `inline`; for example:

```
inline int fact(unsigned int n) {
        return n ? n*fact(n-1) : 1;
}
```

- The compiler will then try to "inline" the function
  - A clever compiler might generate `120` for `fact(5)`
- A compiler might not always be able to "inline" a function
- An `inline` function must be <u>defined</u> in the same execution unit as it is used
- The `inline` operator does not change function semantics
  - the inline function itself still has a unique address
  - static variables of an inline function still have a unique address
- Both `inline` and `register` are largely unnecessary with modern compilers and hardware

That's it!

- We have now explored most of the C language
- The language is quite subtle in places; in particular watch out for:
  - operator precedence
  - pointer assignment (particularly function pointers)
  - implicit casts between `int`s of different sizes and `char`s
- There is also extensive standard library support, including:
  - shell and file I/O (`stdio.h`)
  - dynamic memory allocation (`stdlib.h`)
  - string manipulation (`string.h`)
  - character class tests (`ctype.h`)
  - ...
  - (Read, for example, K&R Appendix B for a quick introduction)
  - (Or type "`man` *function*" at a Unix shell for details)

Library support: I/O

I/O is not managed directly by the compiler; support in `stdio.h`:

- `FILE *stdin, *stdout, *stderr;`
- `int printf(const char *format, ...);`
- `int sprintf(char *str, const char *format, ...);`
- `int fprintf(FILE *stream, const char *format, ...);`
- `int scanf(const char *format, ...); // sscanf,fscanf`

- `FILE *fopen(const char *path, const char *mode);`
- `int fclose(FILE *fp);`
- ```
  size_t fread(void *ptr, size_t size, size_t nmemb,
               FILE *stream);
  ```
- ```
  size_t fwrite(const void *ptr, size_t size, size_t nmemb,
                FILE *stream);
  ```

```c
#include<stdio.h>
#define BUFSIZE 1024

int main(void) {
  FILE *fp;
  char buffer[BUFSIZE];

  if ((fp=fopen("somefile.txt","rb")) == 0) {
    perror("fopen error:");
    return 1;
  }

  while(!feof(fp)) {
      int r = fread(buffer,sizeof(char),BUFSIZE,fp);
      fwrite(buffer,sizeof(char),r,stdout);
  }

  fclose(fp);
  return 0;
}
```

Library support: dynamic memory allocation

- Dynamic memory allocation is not managed directly by the C compiler
- Support is available in `stdlib.h`:
  - `void *malloc(size_t size)`
  - `void *calloc(size_t nobj, size_t size)`
  - `void *realloc(void *p, size_t size)`
  - `void free(void *p)`
- The C `sizeof` unary operator is handy when using `malloc`:

  ```
  p = (char *) malloc(sizeof(char)*1000)
  ```
- Any successfully allocated memory must be deallocated manually
  - Note: `free()` needs the pointer to the allocated memory
- Failure to deallocate will result in a memory leak

Gotchas: operator precedence

```
#include<stdio.h>

struct test {int i;};
typedef struct test test_t;

int main(void) {

  test_t a,b;
  test_t *p[] = {&a,&b};
  p[0]->i=0;
  p[1]->i=0;
  test_t *q = p[0];

  printf("%d\n",++q->i); //What does this do?

  return 0;
}
```

Gotchas: `i++`

```c
#include <stdio.h>

int main(void) {

  int i=2;
  int j=i++ + ++i;
  printf("%d %d\n",i,j); //What does this print?

  return 0;
}
```

Expressions like `i++ + ++i` are known as grey (or gray) expressions in that their meaning is compiler dependent in C (even if they are defined in Java)

Gotchas: local stack

```c
#include <stdio.h>

char *unary(unsigned short s) {
  char local[s+1];
  int i;
  for (i=0;i<s;i++) local[i]='1';
  local[s]='\0';
  return local;
}

int main(void) {
  printf("%s\n",unary(6)); //What does this print?
  return 0;
}
```

Gotchas: local stack (contd.)

```c
#include <stdio.h>

char global[10];

char *unary(unsigned short s) {
  char local[s+1];
  char *p = s%2 ? global : local;
  int i;
  for (i=0;i<s;i++) p[i]='1';
  p[s]='\0';
  return p;
}

int main(void) {
  printf("%s\n",unary(6)); //What does this print?
  return 0;
}
```

Gotchas: careful with pointers

```
#include <stdio.h>

struct values { int a; int b; };

int main(void) {
 struct values  test2 = {2,3};
 struct values  test1 = {0,1};

 int *pi = &(test1.a);
 pi += 1; //Is this sensible?
 printf("%d\n",*pi);
 pi += 2; //What could this point at?
 printf("%d\n",*pi);

 return 0;
}
```

Gotchas: XKCD pointers

Tricks: Duff's device

```
boring_send(int *to, int *from, int count) {
  do {
    *to = *from++;
  } while(--count > 0);
}

send(int *to, int *from, int count) {
  int n = (count+7)/8;
  switch (count%8) {
  case 0: do{ *to = *from++;
  case 7:     *to = *from++;
  case 6:     *to = *from++;
  case 5:     *to = *from++;
  case 4:     *to = *from++;
  case 3:     *to = *from++;
  case 2:     *to = *from++;
  case 1:     *to = *from++;
          } while(--n>0);
  }
}
```

Assessed Exercise

See "Head of Department's Announcement"

- To be completed by noon on Monday 23 January 2017
- Viva examinations 1330-1630 on Thursday 26 January 2016
- Viva examinations 1330-1630 on Friday 27 January 2016
- Download the starter pack from:
  `http://www.cl.cam.ac.uk/Teaching/current/CandC++/`
- This should contain eight files:

`server.c`	`client.c`	`rfc0791.txt`	`rfc0793.txt`
`message1`	`message2`	`message3`	`message4`

Exercise aims

Demonstrate an ability to:

- Understand (simple) networking code
- Use control flow, functions, structures and pointers
- Use libraries, including reading and writing files
- Understand a specification
- Compile and test code
- Comprehending man pages

Task is split into three parts:

- Comprehension and debugging
- Preliminary analysis
- Completed code and testing

Exercise submission

- Assessment is in the form of a 'tick'
- There will be a short viva; remember to sign up!
- Submission is via email to `c-tick@cl.cam.ac.uk`
- Your submission should include seven files, packed in to a ZIP file called crsid`.zip` and attached to your submission email:

`answers.txt`	`client1.c`	`summary.c`	`message1.txt`
	`server1.c`	`extract.c`	`message2.jpg`

Hints: IP header

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Hints: IP header (in C)

```c
#include <stdint.h>

struct ip {
  uint8_t hlenver;
  uint8_t tos;
  uint16_t len;
  uint16_t id;
  uint16_t off;
  uint8_t ttl;
  uint8_t p;
  uint16_t sum;
  uint32_t src;
  uint32_t dst;
};

#define IP_HLEN(lenver) (lenver & 0x0f)
#define IP_VER(lenver) (lenver >> 4)
```

Hints: network byte order

- The IP network is big-endian; x86 is little-endian; ARM can be either
- Reading multi-byte values requires possible conversion
- The BSD API specifies:
  - `uint16_t ntohs(uint16_t netshort)`
  - `uint32_t ntohl(uint32_t netlong)`
  - `uint16_t htons(uint16_t hostshort)`
  - `uint32_t htonl(uint32_t hostlong)`

  which encapsulate the notions of host and network and their interconversion (which may be a no-op)

Exercises

1. What is the value of `i` after executing each of the following:
    1.1 `i = sizeof(char);`
    1.2 `i = sizeof(int);`
    1.3 `int a; i = sizeof a;`
    1.4 `char b[5]; i = sizeof(b);`
    1.5 `char *c=b; i = sizeof(c);`
    1.6 `struct {int d;char e;} s; i = sizeof s;`
    1.7 `void f(int j[5]) { i = sizeof j;}`
    1.8 `void f(int j[][10]) { i = sizeof j;}`
2. Use `struct` to define a data structure suitable for representing a binary tree of integers. Write a function `heapify()`, which takes a pointer to an integer array of values and a pointer to the head of an (empty) tree and builds a binary heap of the integer array values. (Hint: you should `malloc()` and a binary tree data structure)
3. What other C data structure can be used to represent a heap? Would using this structure lead to a more efficient implementation of `heapify()`?