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1. Binary and Hexadecimal Numbers

- In C, the **type** of a variable specifies the kind of values that can be stored in that variable; must answer three questions:
  - What is the **meaning** of the variable’s value?
  - How should the variable’s value be **stored** in the computer
  - What **operations** are allowed on the variable?

- Critical to keep concept of **types** separate from concept of **values**

- C is a **statically typed** language, meaning that the type of a variable must be known at compile time

- Keep in mind that no matter how complex the type, everything is ultimately stored as a binary number in the computer

1. Binary and Hexadecimal Numbers

Let’s review decimal, binary, and hexadecimal number representations.
2. Basic Data Types

We will primarily use the following primitive C types

- **int**: For representing integer numbers
- **char**: For representing characters
- **float** and **double**: For representing real numbers
- **const T**: For representing constant values of type T
- **void**: For representing situations where a value is not allowed

*zyBooks* The course zyBook includes more information on two’s complement representation and the float/double types for representing real numbers.

2.1. int Type

- **Meaning?**  
  Integer whole numbers in a limited range
- **Stored?**  
  32-bit two’s complement binary representation
- **Operations?**  
  Basic integer arithmetic

- Unlike some productivity-level programming languages, variables of type int cannot represent arbitrarily large or small integers
- Such variables have a fixed upper limit and lower limit
```c
int avg(int x, int y) {
    int sum = x + y;
    return sum / 2;
}

int main() {
    int a = 10;
    int b = 20;
    int c = avg(a, b);
    return 0;
}
```
4-Bit Unsigned Integers

- By default, an int is short-hand for the type signed int which can represent both positive and negative integers
- unsigned int can only represent positive integers
- To start, let’s focus on variables of type unsigned int and let’s assume all variables are only four bits

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<thead>
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<th>Bits</th>
<th>Unsigned</th>
</tr>
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<td>1110</td>
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<tr>
<td>1111</td>
<td>15</td>
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```c
unsigned int a = 4;
unsigned int b = 15;
unsigned int c = 0;
unsigned int d = a + 1;
unsigned int e = b + 1;
unsigned int f = c - 1;
```
4-Bit Signed Integers

- Now let’s consider variables of type `signed int` and let’s continue to assume all variables are only four bits.

- There can be multiple ways to encode a given value into a sequence of bits (e.g., sign magnitude, one’s complement, two’s complement).

- The C language specification does not actually specify the exact encoding, but essentially all machines use two’s complement.

<table>
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<th>One’s</th>
<th>Two’s</th>
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</tr>
<tr>
<td>1111</td>
<td>–7</td>
<td>0</td>
<td>–1</td>
</tr>
</tbody>
</table>

```c
signed int a = 4;
signed int b = 7;
signed int c = -8;
signed int d = a + 1;
signed int e = b + 1;
signed int f = c - 1;
```
• An int is a signed 32-bit binary number
• Can store values between -2,147,483,648 to 2,147,483,647
• What happens if you add one to 2,147,483,647?
• What happens if you subtract one from -2,147,483,648?

• An unsigned int is an unsigned 32-bit binary number
• Can store values from 0 to 4,294,967,295
• What happens if you add one to 4,294,967,295?
• What happens if you subtract one from 0?

```c
#include <stdio.h>

int main()
{
    int a = 2147483647;
    int b = a + 1;
    printf("%d + 1 = %d (%x)\n",a,b,b);

    int c = -2147483648;
    int d = c - 1;
    printf("%d - 1 = %d (%x)\n",c,d,d);

    unsigned int e = 4294967295;
    unsigned int f = e + 1;
    printf("%u + 1 = %u (%x)\n",e,f,f);

    unsigned int g = 0;
    unsigned int h = g - 1;
    printf("%u - 1 = %u (%x)\n",g,h,h);

    return 0;
}
```

• New format specifiers for hexadecimal (%x) and unsigned int (%u)
2.2. char Type

- **Meaning?** Character in a “word”
- **Stored?** 8-bit binary representation using ASCII standard
- **Operations?** Basic integer arithmetic

```
#include <stdio.h>

int main()
{
    char a = 'e';
    char b = 'c';
    char c = 'e';
    printf("%c%c%c\n", a, b, c);
    return 0;
}
```

- **New format specifier for char** (%c)
2.3. **const Types**

- **Meaning?** Indicates variable will not change
- **Stored?** Whatever is required for “base” type
- **Operations?** Read-only operations, cannot modify variable

```c
// Constant at global scope
const double PI = 3.1415926535;

int main()
{
    const double a = 2.0;
    int b = a * PI;

    const int d = 15;
    d = b; // compile time error!

    return 0;
}
```

2.4. **void Types**

- **Meaning?** No values are allowed
- **Stored?** No storage needed
- **Operations?** None

```c
void print_line( void )
{
    for ( int i = 0; i < 74; i++ )
        printf("-");
}
```

- Technically, we should use `void` for empty parameter lists
- This applies to `main` as well
3. Programmer-Defined Types

In addition to the default types that are included as part of the C programming language (e.g., int, unsigned int, char, float, double), C also enables programmers to define their own new types.

zyBooks The course zyBook includes more information on `enum` which enables creating multiple named constants.

3.1. Typedefs

- A `typedef` actually does not define a new type
- A typedef simply provides a new alias for an already defined type

```c
1 typedef type_name new_type_name;
```

- The following code is perfectly fine

```c
1 typedef unsigned int uint_t;
2 uint_t a = 2;
3 uint_t b = 3;
4 unsigned int c = a + b;
```

3.2. struct Types

- A struct enables bundling multiple variables into a single entity
- A struct definition creates a new type and specifies the type and names of the variables (fields) contained within the struct

```c
1 struct _complex_t
2 {
3     double real;
4     double imag;
5 }
6 typedef struct _complex_t complex_t;
```

```c
1 typedef struct
2 {
3     double real;
4     double imag;
5 } complex_t;
```
• Struct definitions are at global scope just like function definitions
• Can declare a struct variable just like any other variable

```c
complex_t a; // variable of type complex_t
```

• Structs require a **new operator** to access the fields
• The *dot* operator (.) composes a struct variable name with a struct field name to create a fully qualified variable name

```c
complex_t a; // variable of type complex_t
a.real = 1.0; // use dot operator to access real field
a.imag = 2.5; // use dot operator to access imag field

complex_t b; // variable of type complex_t
b.real = a.real; // use dot operator to copy real field
b.imag = a.imag; // use dot operator to copy imag field
```

• Can copy an entire struct in a single statement
• Semantics of such a copy are to simply copy each field individually

```c
complex_t a; // variable of type complex_t
a.real = 1.0; // use dot operator to access real field
a.imag = 2.5; // use dot operator to access imag field

complex_t b; // variable of type complex_t
b = a; // copy all fields from a to b
```
• Struct declaration statement simply creates multiple variables on the stack in a single statement

```c
typedef struct {
    int x;
    int y;
} point_t;

point_t point_add( point_t pt1, point_t pt2 ) {
    point_t pt3;
    pt3.x = pt1.x + pt2.x;
    pt3.y = pt1.y + pt2.y;
    return pt3;
}

int main( void ) {
    point_t pt_a;
    pt_a.x = 2;
    pt_a.y = 3;

    point_t pt_b;
    pt_b.x = 4;
    pt_b.y = 5;

    point_t pt_c;
    pt_c = point_add( pt_a, pt_b );
    return 0;
}
```
4. Working With Types

Types can offer strong static guarantees about correctness, but also need to be carefully managed.

4.1. Type Checking

- Compiler will check to ensure types are consistent
- Inconsistent types will cause a compile-time error

```c
typedef struct { int x; int y; } point_t;

point_t point_add( point_t pt1, point_t pt2 ) {
    point_t pt3;
    pt3.x = pt1.x + pt2.x;
    pt3.y = pt1.y + pt2.y;
    return pt3;
}

int main( void ) {
    int a = 2;
    int b = 3;
    point_t pt_c = point_add( a, b );
    return 0;
}

https://repl.it/@cbatten/ece2400-T03-ex3
```
4.2. Type Inference

• Compiler uses type inference to determine type of an expression

```c
int a = 2;
int b = 3;
int c = a + b; // expr (a + b) has type int
int d = a / b; // expr (a / b) has type int

float e = 2.0;
float f = 3.0;
float g = e + f; // expr (e + f) has type float
float h = e / f; // expr (e / f) has type float
```

4.3. Type Casting

• Type checking prevents assigning a value with a given type T to a variable with a different type

• Programmers can use type casting to explicitly convert a value of one type to a value of another type

• The cast operator can be used for explicit type casting

```c
unsigned int a = 1;
signed int b = (signed int) a;
signed int a = 1;
unsigned int b = (unsigned int) a;

int a = 2;
float b = (float) a;
float a = 2.0;
int b = (int) a;
```
4. Working With Types 4.3. Type Casting

1 float a = 2.5;
2 double b = (double) a;
3 
4 double a = 2.5;
5 float b = (float) a;

• Example of using explicit type casting

1 #include <stdio.h>
2 
3 float avg(int x, int y)
4 {
5     int sum = x + y;
6     return ((float) sum) / ((float) 2);
7 }
8 
9 int main( void )
10 {
11     float a = 10;
12     float b = 15;
13     float c = avg(a, b);
14     printf(" average of %f and %f is %f\n", a, b, c);
15     return 0;
16 }

https://repl.it/@cbatten/ece2400-T03-ex5
4.4. Type Conversion

- Compiler can also use implicit type conversion
- Compiler can automatically convert types so they match
- Lower precision types can be converted to higher precision types
- Higher precision types can be converted to lower precision types

```c
unsigned int a = 1;
signed int b = a;

signed int a = 1;
unsigned int b = a;

int a = 2;
float b = a;

float a = 2.0;
int b = a;

float a = 2.5;
double b = a;

double a = 2.5;
float b = a;

int a = 2;
float b = 3;
float c = a + b; // converts a to float
float d = a / b; // converts a to float

unsigned int a = 2;
signed int b = -3;
unsigned int c = a * b; // converts a to signed int
```
• Type conversion seems convenient but is at the heart of why C only supports weak static typing and can lead to many subtle bugs

```c
unsigned int a = 4294967295;
signed int b = a;       // careful! b == -1

signed int a = -1;
unsigned int b = a;     // careful! b == 4294967295

float a = 2.5;int b = a;          // careful! b == 2

double a = 3.14159265358;
float b = a;          // careful! b != 3.14159265358
```

• The following example illustrates automatic type conversion

```c
#include <stdio.h>

int avg( int x, int y )
{
    int sum = x + y;
    return sum / 2;
}

int main( void )
{
    float a = 10;
    float b = 15;
    float c = avg( a, b );
    printf("average of %f and %f is %f\n", a, b, c );
    return 0;
}

https://repl.it/@cbatten/ece2400-T03-ex4
```