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A **word** on the ARM Cortex M will have 32 bits. Consider an unsigned number with 32 bits, where each bit b_{31}, \dots, b_0 is binary and has the value 1 or 0. If a 32-bit number is used to represent an unsigned integer, then the value of the number is

$$N = 2^{31} \cdot b_{31} + 2^{30} \cdot b_{30} + \dots + 2 \cdot b_1 + b_0 = \sum(2^i \cdot b_i) \text{ for } i=0 \text{ to } 31$$

There are 2^{32} different unsigned 32-bit numbers. The smallest unsigned 32-bit number is 0 and the largest is $2^{32}-1$. This range is 0 to about 4 billion.

A **halfword** or **double byte** contains 16 bits, where each bit b_{15}, \dots, b_0 is binary and has the value 1 or 0, as shown in Figure 2.4.

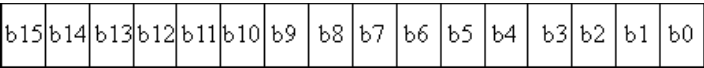


Figure 2.4

Similar to the unsigned algorithm, we can use the basis to convert a decimal number into signed binary. We will work through the algorithm with the example of converting -100 to 8-bit binary: We start with the most significant bit (in this case -128) and decide do we need to include it to make -100? Yes (without -128, we would be unable to add the other basis elements together to get any negative result), so we set bit 7 and subtract the basis element from our value. Our new value equals -100 minus -128, which is 28. We go the next largest basis element, 64 and ask, “do we need it?” We do not need 64 to generate our 28, so bit 6 is zero. Next we go the next basis element, 32 and ask, “do we need it?” We do not need 32 to generate our 28, so bit 5 is zero. Now we need the basis element 16, so we set bit 4, and subtract 16 from our number 28 (28-16=12). Continuing along, we need basis elements 8 and 4 but not 2, 1. Putting it together we get 10011100_2 (which means -128+16+8+4).

Number	Basis	Need it	bit	Operation
-100	-128	yes	bit 7=1	subtract -100 - -128
28	64	no	bit 6=0	none
28	32	no	bit 5=0	none

28	16	yes	bit 4=1	subtract 28-16
12	8	yes	bit 3=1	subtract 12-8
4	4	yes	bit 2=1	subtract 4-4
0	2	no	bit 1=0	none
0	1	no	bit 0=0	none

Table 2.6. Example conversion from decimal to signed 8-bit binary.

A second way to convert negative numbers into binary is to first convert them into unsigned binary, then do a two's complement negate. For example, we earlier found that +100 is 01100100_2 . The two's complement negate is a two-step process. First we do a logic complement (flip all bits) to get 10011011_2 . Then add one to the result to get 10011100_2 .

A third way to convert negative numbers into binary uses the number wheel. Let n be the number of bits in the binary representation. We specify **precision**, $M=2^n$, as the number of distinct values that can be represented. To convert negative numbers into binary is to first add M to the number, then convert the unsigned result to binary using the unsigned method. This works because binary numbers with a finite n are like the minute-hand on a clock. If we add 60 minutes, the minute-hand is in the same position. Similarly if we add M to or subtract M from an n -bit number, we go around the number wheel and arrive at the same place. This is one of the beautiful properties of 2's complement: unsigned and signed addition/subtraction are same operation. In this example we have an 8-bit number so the precision is 256. So, first we add 256 to the number, then convert the unsigned result to binary using the unsigned method. For example, to find -100, we add 256 plus -100 to get 156. Then we convert 156 to binary resulting in 10011100_2 . This method works because in 8-bit binary math adding 256 to number does not change the value. E.g., 256-100 has the same 8-bit binary value as -100.

When dealing with numbers on the computer, it will be convenient to memorize some **Powers of 2** as shown in Table 2.7.

exponent	decimal
2^0	1
2^1	2
2^2	4
2^3	8
2^4	16
2^5	32
2^6	64
2^7	128

2^8	256
2^9	512
2^{10}	1024 about a thousand
2^{11}	2048
2^{12}	4096
2^{13}	8192
2^{14}	16384
2^{15}	32768
2^{16}	65536
2^{20}	about a million
2^{30}	about a billion
2^{40}	about a trillion

Table 2.7. Some powers of two that will be useful to memorize.

CHECKPOINT 2.16

Give the representations of -54 in 8-bit binary and hexadecimal.

Hide Answer

Combine signed binary basis elements to create the desired value. $-54 = -128 + 64 + 8 + 2 = 11001010_2 = 0xCA$.

CHECKPOINT 2.17

Why can't you represent the number 150 using 8-bit signed binary?

Hide Answer

Because the range of 8-bit signed numbers is -128 to +127.

CHECKPOINT 2.18

Use Table 2.7 to determine the approximate value of 2^{32} ?

Hide Answer

2^{32} is 4 times 2^{30} , and 2^{30} is about a billion, so 2^{32} is about 4 billion.

CHECKPOINT 2.19

Convert the 16-bit binary number 0010000001101010₂ to unsigned decimal.

[Hide Answer](#)

$8192+64+32+8+2=8298$.

CHECKPOINT 2.20

Convert the 16-bit hex number 0x1234 to unsigned decimal.

[Hide Answer](#)

$1*4096+2*256+3*16+4=4660$.

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