

Carry and Overflow

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2024-04-29 Mon

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 - More examples of the overflow flag

- 1 "Self-service Linux: Mastering the Art of Problem Determination",

Mark Wilding

- 1 "Computer Architecture: A Programmer's Perspective", Bryant & O'Hallaron

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Compiling 32-bit program on 64-bit gcc

- `gcc -v`
- `gcc -m32 t.c`
- `sudo apt-get install gcc-multilib`
- `sudo apt-get install g++-multilib`
- `gcc-multilib`
- `g++-multilib`
- `gcc -m32`
- `objdump -m i386`

- Carry flag and overflow flag
- Signed and unsigned computations
- Flags for an unsigned number
- Flags for a signed number
- Detecting errors in unsigned and signed arithmetic
- The verb to overflow v.s. the overflow flag

Carry flag and overflow flag

- considering carry and overflow flags in **x86**
- do not confuse the **carry flag** with the **overflow flag** in integer arithmetic.
- the *ALU* always sets these flags appropriately when doing any integer math.
- these flags can occur on its *own*, or *both* together.

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Signed and unsigned computations

- the CPU's ALU doesn't care or know whether **signed** or **unsigned** computations are performed;
- the ALU just performs integer arithmetic and sets the flags appropriately.
- It's up to the programmer to know which flag to check after the arithmetic is done.

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Flags for an unsigned number

- if a word is treated as an **unsigned** number,
 - the **carry** flag must be used to check if the result is fit into n -bit or $(n+1)$ -bit number
 - the **overflow** flag is *irrelevant* to an **unsigned** number arithmetic

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Flags for a signed number

- if a word is treated as an **signed** number,
 - the **carry** flag is *irrelevant* to an **signed** number arithmetic
 - the **overflow** flag must be used to check if the result is wrong or not

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Detecting errors in unsigned and signed arithmetic (1)

unsigned integer
arithmetic

signed integer
arithmetic

CF Carry Flag

detects *overflows*
extends an n -bit result
into an $(n+1)$ -bit result

OF Overflow Flag

detects *overflows*
errors
the result cannot be used

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Detecting errors in unsigned and signed arithmetic (2)

- **unsigned** integer arithmetic *overflow*
is indicated by the **carry** flag
 - $P + P$ **CF=1** → carry out – the result is too large for an n -bit integer
 - $P - P$ **CF=1** → borrow in – the result is too small for an n -bit integer
- **signed** integer arithmetic *overflow*
is indicated by the **overflow** flag
 - $P + P \rightarrow N$ **OF=1** → overflow – the result is not correct
 - $N + N \rightarrow P$ **OF=1** → overflow – the result is not correct
- P (positive), N (negative)

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Detecting errors in unsigned and signed arithmetic (3)

- **unsigned** integer arithmetic *overflow* is indicated by the **carry** flag
 - the *overflowed* n -bit result can be extended into $(n+1)$ -bit result by using the carry flag
- **signed** integer arithmetic *overflow* is indicated by the **overflow** flag
 - the *overflowed* n -bit result cannot be used

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

The verb to overflow v.s. the overflow flag (1)

- Do not confuse the English verb *to overflow* with the **overflow flag** in the ALU.
- The verb *to overflow* is used casually to indicate that some math result doesn't fit in the number of bits available;
- it could be integer math, or floating-point math, or whatever.
- The **overflow flag** is set specifically by the ALU it isn't the same as the casual English verb "to overflow"

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

The verb to overflow v.s. the overflow flag (2)

- In English, we may say "the binary/integer math overflowed the number of bits available for the result, causing the carry flag to come on".
- Note how this English usage of the verb "to overflow" is **not** the same as saying the **overflow flag** is on".
- A math result can overflow (the verb) the number of bits available without turning on the ALU **overflow flag**

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Computing Carry and Overflow Flags

CF (carry flag) and OF (overflow flag) computation

ADD (addition)	SUB (subtraction)
$CF = C_n$	$CF = \overline{C_n}$
$OF = C_n \oplus C_{n-1}$	$OF = C_n \oplus C_{n-1}$
a 2's complement addition $A + B = A + B + 0$	a transformed addition $A - B = A + \overline{B} + 1$
$\{C_n, S_{n-1}\} = a_{n-1} + b_{n-1} + c_{n-1}$	$\{C_n, S_{n-1}\} = a_{n-1} + \overline{b_{n-1}} + c_{n-1}$
$\{C_{n-1}, S_{n-2}\} = a_{n-2} + b_{n-2} + c_{n-2}$	$\{C_{n-1}, S_{n-2}\} = a_{n-2} + \overline{b_{n-2}} + c_{n-2}$

https://www.csie.ntu.edu.tw/~cyy/courses/assembly/12fall/lectures/handouts/lec14_1

- Examples of signed and unsigned integer arithmetic
- Carry flag in unsigned and signed computations
- Rules for the carry flag
- Method for computing the carry flag
- More examples of the carry flag

TOC: Examples of signed and unsigned integer arithmetic

- Examples of interpreting **signed** and **unsigned** numbers
- Examples of **signed** and **unsigned** integer arithmetic
- 2's complements
- **Unsigned** subtraction
- **Signed** subtraction
- Interpreting the result as a **signed** or an **unsigned** integer
- Summary of **signed** and **unsigned** subtractions
- Examples of **unsigned** integer overflows
- Examples of **signed** integer overflows

Examples of interpreting **signed** and **unsigned** numbers (1)

- interpreting 0xFFFFBDC3

as an **unsigned** (positive) number +0xFFFFBDC3 +4294950339₁₀

as a **signed** (negative) number -0x0000423D -16957₁₀

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Examples of interpreting **signed** and **unsigned** numbers (2)

- interpreting 0xFFFFBDC3
 - as an **unsigned** (positive) number | +0xFFFFBDC3 | +4294950339₁₀ |

$$15 * 16^7 + 15 * 16^6 + 15 * 16^5 + 15 * 16^4 \\ + 11 * 16^3 + 13 * 16^2 + 12 * 16^1 + 3 * 16^0$$

- as a **signed** (negative) number | -0x0000423D | -16957₁₀ |

$$0 * 16^7 + 0 * 16^6 + 0 * 16^5 + 0 * 16^4 \\ + 4 * 16^3 + 2 * 16^2 + 3 * 16^1 + 13 * 16^0$$

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Examples of interpreting signed and unsigned numbers (3)

- the 2's complement of 0xFFFFBDC3 : 0x0000423D (= +16957₁₀)

	F	F	F	F	B	D	C	3
0xFFFFBDC3	0x1111	1111	1111	1111	1011	1101	1100	0011
0x0000423D	0x0000	0000	0000	0000	0100	0010	0011	1100
0x0000423D	0x0000	0000	0000	0000	0100	0010	0011	1101
	0	0	0	0	4	2	3	D

- the 2's complement of 0x0000423D : 0xFFFFBDC3 (= -16957₁₀)

	0	0	0	0	4	2	3	D
0x0000423D	0x0000	0000	0000	0000	0100	0010	0011	1101
0x0000BDC2	0x1111	1111	1111	1111	1011	1101	1100	0010
0xFFFFBDC3	0x1111	1111	1111	1111	1011	1101	1100	0011
	F	F	F	F	B	D	C	3

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Examples of **signed** and **unsigned** integer arithmetic

- subtracting **0x0000618D** from **0x0000195D**

0x0000195D - 0x0000618D **unsigned** subtraction

subtraction by hand

0x0000195D + (-0x0000618D) **signed** subtraction

the *transformed addition* using
the 2's complement of subtrahend

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

2's complements

- the 2's complement of **0x0000618D** : 0xFFFF8E73 (= -24973₁₀)

		F	F	F	F	8	E	7	3	
0xFFFF9E73		0x1111_1111_1111_1111_1001_1110_0111_0011								
0x0000617C		0x0000_0000_0000_0000_0110_0001_1000_1100								(1's complement)
0x0000618D		0x0000_0000_0000_0000_0110_0001_1000_1101								(2's complement)
		0	0	0	0	6	1	8	D	

- the 2's complement of **0xFFFF8E73** : 0x0000618D (= +24973₁₀)

		0	0	0	0	6	1	8	D	
0x0000618D		0x0000_0000_0000_0000_0110_0001_1000_1101								
0xFFFF9E72		0x1111_1111_1111_1111_1001_1110_0111_0010								(1's complement)
0xFFFF9E73		0x1111_1111_1111_1111_1001_1110_0111_0011								(2's complement)
		F	F	F	F	8	E	7	3	

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Unsigned subtraction

- **0x0000195D - 0x0000618D** : unsigned subtraction
subtraction by hand

```

                0  0  0  0  1  9  5  D
0x0000195D      0x0000_0000_0000_0000_0001_1001_0101_1101
- 0x0000618D    0x0000_0000_0000_0000_0110_0001_1000_1101
                0  0  0  0  6  1  8  D
-----
0xFFFFB7D0     1 0x1111_1111_1111_1111_1011_0111_1101_0000 (hand subtraction)
                1   F   F   F   F   B   7   D   0
                .
                V borrow (CF=1) : unsigned integer overflow
```

- A **borrow** is indicated by the **carry** flag (CF=1)
 - whenever an **unsigned** integer overflow happened
 - $A - B$, when $A < B$, for non-negative integers A, B

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Signed subtraction

- $0x0000195D + (-0x0000618D)$: signed subtraction
the *transformed addition* using the 2's complement of subtrahend

```

          0  0  0  0  1  9  5  D
0x0000195D  0x0000_0000_0000_0000_0001_1001_0101_1101 (+0x0000195D)
+ 0xFFFF9E73 0x1111_1111_1111_1111_1001_1110_0111_0011 (-0x0000618D)
              F  F  F  F  9  E  7  3
-----
0xFFFFB7D0 0 0x1111_1111_1111_1111_1011_0111_1101_0000 (hand addition)
          0  F  F  F  F  B  7  D  0
-0x00004830 . 0x0000_0000_0000_0000_0100_1000_0011_0000 (2's complement)
          .  0  0  0  0  4  8  3  0
          V no carry in the transformed addition (Cn=0) --> (CF=1)
```

- signed integer overflow is indicated by the **overflow** flag (OF)
 - the **carry** flag is set by the **inverted** carry of a transformed addition

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Interpreting the result as a **signed** or an **unsigned** integer

- subtracting **0x0000618D** from **0x0000195D**
the results of **unsigned** and **signed** subtractions have
the same bit pattern **0xFFFFB7D0**

- the 2's complement of **0xFFFFB7D0** : $0x00004830$ ($= +18480_{10}$)

	F	F	F	F	B	7	D	0
0xFFFFB7D0	0x1111_1111_1111_1111_1011_0111_1101_0000							
0x0000482F	0x0000_0000_0000_0000_0100_1000_0010_1111							(1's complement)
0x00004830	0x0000_0000_0000_0000_0100_1000_0011_0000							(2's complement)
	0	0	0	0	4	8	3	0

- the 2's complement of **0x00004830** : $0xFFFFB7D0$ ($= -18480_{10}$)

	0	0	0	0	4	8	3	0
0x00004830	0x0000_0000_0000_0000_0100_1000_0011_0000							
0xFFFFB7CF	0x1111_1111_1111_1111_1011_0111_1100_1111							(1's complement)
0xFFFFB7D0	0x1111_1111_1111_1111_1011_0111_1101_0000							(2's complement)
	F	F	F	F	B	7	D	0

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Summary of signed and unsigned subtractions (1)

- subtracting $0x0000618D$ from $0x0000195D$
 - $0x0000195D - 0x0000618D$: unsigned integer subtraction
hand subtraction
 - $0x0000195D + (-0x0000618D)$: signed integer subtraction
the *transformed addition* using the 2's complement of the subtrahend
 - the same result : $0xFFFFB7D0$ (the same bit pattern)
 - interpreting as a unsigned integer 4294948816_{10}
 $0xFFFFB7D0$ with a borrow (CF=1)
 - interpreting as a signed integer -18480_{10}
 $-0x00004830$ (meaningless CF=1)

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Summary of **signed** and **unsigned** subtractions (2)

0xFFFFB7D0 the result of **unsigned** subtraction 4294948816₁₀
with CF=1 with **unsigned** integer overflow

-0x00004830 the result of **signed** subtraction -18480₁₀

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Examples of **unsigned** integer overflows

- $0x0000195D - 0x0000618D$: **unsigned** subtraction
 - there is an **unsigned** integer overflow
so the **carry** flag will be set ($CF=1$) to indicate a **borrow**
 - $A - B$, when $A < B$, for non-negative integers A, B
(unsigned integers can't be negative),

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Examples of signed integer overflows

- $0x0000195D + (-0x0000618D)$: signed subtraction
 - there is no signed integer overflow
the overflow flag won't be set (OF=0)
 - signed overflow occurs , in the transformed addition,
 - two *positive* numbers are added and
the result is a *negative*, ($P + P \rightarrow N$), or
 - two *negative* numbers are added and
the result is a *positive*, ($N + N \rightarrow P$)

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

TOC Carry flag in unsigned and signed computations

- 2's complement numbers : 4-bit
- Addend and augend in a n -bit addition
- Full adder operation in each bit position
- Internal and external carry bits
- Addition and Subtraction
- Using the Carry Flag as a borrow

2's complement numbers : 4-bit

0111	(+7)	1000	(-8)
0110	(+6)	1001	(-7)
0101	(+5)	1010	(-6)
0100	(+4)	1011	(-5)
0011	(+3)	1100	(-4)
0010	(+2)	1101	(-3)
0001	(+1)	1110	(-2)
0000	(0)	1111	(-1)

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Addend and augend in a n -bit addition

n	bits	addened	A	$\{a_{n-1}, a_{n-2}, \dots, a_1, a_0\}$
n	bits	augend	B	$\{b_{n-1}, b_{n-2}, \dots, b_1, b_0\}$
$(n+1)$	bits	carry bits	C	$\{C_n, C_{n-1}, C_{n-2}, \dots, C_1, C_0\}$
n	bits	sum bits	S	$\{S_{n-1}, S_{n-2}, \dots, S_1, S_0\}$

external carry bits : C_n carry out, C_0 carry in

$$\begin{array}{cccccc} a_{n-1} & a_{n-2} & \cdots & a_1 & a_0 & \\ b_{n-1} & b_{n-2} & \cdots & b_1 & b_0 & \\ \hline C_n & S_{n-1} & S_{n-2} & \cdots & S_1 & S_0 \end{array}$$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Full adder operation in each bit position

full adder operation in the i^{th} bit position

$$\{C_{i+1}, S_i\} = a_i + b_i + C_i$$

$$\begin{array}{r} a_i \\ b_i \\ C_i \\ \hline C_{i+1} \quad S_i \end{array}$$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Internal and external carry bits

external carries C_n output, C_0 input
 internal carries $\{C_{n-1}, C_{n-2}, \dots, C_2, C_1\}$ output / input
 sum bits $\{S_{n-1}, S_{n-2}, \dots, S_1, S_0\}$ output

$$\begin{array}{rcccccc}
 & a_{n-1} & a_{n-2} & \dots & a_1 & a_0 \\
 & b_{n-1} & b_{n-2} & \dots & b_1 & b_0 \\
 \hline
 C_n & C_{n-1} & C_{n-2} & \dots & C_1 & C_0 \\
 \hline
 & S_{n-1} & S_{n-2} & \dots & S_1 & S_0
 \end{array}$$

$$\begin{array}{rcccccc}
 & a_{n-1} & a_{n-2} & \dots & a_1 & a_0 \\
 & b_{n-1} & b_{n-2} & \dots & b_1 & b_0 \\
 & & & & & C_0 \\
 \hline
 C_n & S_{n-1} & S_{n-2} & \dots & S_1 & S_0
 \end{array}$$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Addition and Subtraction

- addition

$$\{C_n, S\} = A + B = A + B + 0$$

$$\begin{array}{rcccccc} & a_{n-1} & a_{n-2} & \cdots & a_1 & a_0 \\ & b_{n-1} & b_{n-2} & \cdots & b_1 & b_0 \\ \hline & C_{n-1} & C_{n-2} & \cdots & C_1 & 0 \\ \hline C_n & S_{n-1} & S_{n-2} & \cdots & S_1 & S_0 \end{array}$$

- subtraction - transformed addition

$$\{C_n, S\} = A - B = A + \overline{B} + 1$$

$$\begin{array}{rcccccc} & a_{n-1} & a_{n-2} & \cdots & a_1 & a_0 \\ & b_{n-1} & b_{n-2} & \cdots & b_1 & b_0 \\ \hline & C_{n-1} & C_{n-2} & \cdots & C_1 & 1 \\ \hline C_n & S_{n-1} & S_{n-2} & \cdots & S_1 & S_0 \end{array}$$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Using the Carry Flag as a borrow (1)

- a **borrow** (CF=1) occurs in the **subtraction** $A - B$ when b is larger than a ($A < B$) as unsigned numbers
- Computer hardware can detect a **borrow** (CF=1) in **subtraction** by looking at whether a carry out (Cn) occurred in the transformed addition

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Using the Carry flag as a borrow (2)

- a **borrow** ($CF=1$) occurs in the **subtraction** $A - B$ ($A < B$) as unsigned numbers
- a carry out (C_n) in the transformed addition
 - If there is no **carry** ($C_n=0$) then there is a **borrow** ($CF=1$)
 - If there is a **carry** ($C_n=1$) then there is no **borrow** ($CF=0$)
 - **$CF = !C_n$**

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

Using the Carry Flag as a borrow (3)

- the same *addition* and *subtraction* instructions are used for both **unsigned** and **signed** integer arithmetic.
 - no special *addition* and *subtraction* instructions for **unsigned** and **signed** integer arithmetic
- the only difference is
 - which flags you *test* afterwards and
 - how you *interpret* the result

<https://stackoverflow.com/questions/47333458/assembly-x86-64-setting-carry-flag-f>

TOC Rules for the carry flag

- 2's complement numbers : 4-bit
- The 1st rule for setting the carry flag
- The 2nd rule for setting the carry flag
- Cases for clearing the carry flag
- Computing CF in unsigned additions and subtractions

2's complement numbers : 4-bit

0111	(+7)	1000	(-8)
0110	(+6)	1001	(-7)
0101	(+5)	1010	(-6)
0100	(+4)	1011	(-5)
0011	(+3)	1100	(-4)
0010	(+2)	1101	(-3)
0001	(+1)	1110	(-2)
0000	(0)	1111	(-1)

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

The 1st rule for setting the carry flag

- ① **CF = 1** : carry in unsigned addition
 - the carry flag is set if the addition of two unsigned numbers causes a carry out of the most significant bits added.
 - unsigned integer overflow in unsigned addition
 - hand addition rule*

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

The 2nd rule for setting the carry flag

- ② **CF = 1 : borrow in unsigned subtraction**
 - the **carry flag** is also set if the **subtraction** of two **unsigned** numbers requires a **borrow** into the most significant bits subtracted.
 - **unsigned integer overflow in unsigned subtraction**
 - *hand subtraction rule*

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the carry flag (1)

- Otherwise, the **carry flag** is turned off (zero).
 - all three interpretations have the same CF=1, the same S=0000

unsigned addition		signed addition		signed subtraction
0111 (7)		0111 (+7)		0111 (+7)
+1001 +(9)		+1001 +(-7)		-0111 -(+7)
-----		-----		-----
10000 (16)		10000 (0)		10000 (0)
CF=1		Cn=1 -> CF=1		Cn=1 -> CF=1
CF means 16		CF meaningless		CF meaningless
S = 0000		S = 0000		S = 0000
* think hand		* think Cn of the corresponding addition		
addition		CF <- Cn		

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the carry flag (2)

- Otherwise, the **carry flag** is turned off (zero).
 - all three interpretations have the same CF=0, the same S=1111

unsigned addition		signed addition		signed subtraction
0111 (7)		0111 (+7)		0111 (+7)
+1001 +(- 9)		+1001 +(-7)		-0111 -(+7)
-----		-----		-----
10000 (16)		10000 (0)		10000 (0)
CF=1		Cn=1 -> CF=1		Cn=1 -> CF=1
CF means 16		CF meaningless		CF meaningless
S = 0000		S = 0000		S = 0000
* think hand		* think Cn of the corresponding addition		
addition		CF <- Cn		

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Computing CF in unsigned additions and subtractions

- Computing CF in an **unsigned** addition
 - do the **signed** addition
 - C_n is the carry out
 - $CF \leftarrow C_n$
- Computing CF in an **unsigned** subtraction
 - do the transformed **signed** addition
 - do the **signed** addition
 - C_n is the carry out
 - $CF \leftarrow !C_n$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

- Carry flag computation

Carry flag computation (1)

ADD (addition)	SUB (subtraction)
$CF = C_n$	$CF = \overline{C_n}$
normal carry of a 2's complement addition	inverted carry of a transformed addition
$A + B = A + B + 0$	$A - B = A + \overline{B} + 1$
$\{C_n, S_{n-1}\}$ $= a_{n-1} + b_{n-1} + c_{n-1}$	$\{C_n, S_{n-1}\}$ $= a_{n-1} + \overline{b_{n-1}} + c_{n-1}$

https://www.csie.ntu.edu.tw/~cyy/courses/assembly/12fall/lectures/handouts/lec14_1

Carry flag computation (2)

- In **unsigned** arithmetic,
 - the **carry flag** is used to detect *overflow*
 - the **carry flag** is used to extend *n-bit* result into *(n+1)-bit* result
 - for **addition**, the **carry flag** is a **carry out**
 - for **subtraction**, the **carry flag** is a **borrow in**
- In **signed** arithmetic,
 - the **carry flag** is useless
 - the **carry flag** neither detects overflow nor extends n-bit result

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Carry flag computation (3)

- In **unsigned** arithmetic,

Addition	CF = 1 means carry out	when Cn = 1
Subtraction	CF = 1 means borrow in	when Cn = 0

- **CF** - Carry Flag in x86
- **Cn** - the normal carry out
 - the carry out of a 2's complement addition for **ADD**
 - the carry out of a *transformed* addition for **SUB**
- In **signed** arithmetic,
 - the **carry** flag is useless

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

TOC: More examples of the carry flag

- Summary I
- Summary II
- Cases for setting the carry flag
- Cases for clearing the carry flag

Summary I

unsigned add/sub			signed addition			signed subtraction			CF	OF
1101	(13)		1101	(-3)		1101	(-3)			
+1110	+(14)	ADD	+1110	+(-2)	ADD	-0010	-(-2)			
-----	-----		-----	-----		-----	-----			
11011	(11)	(+16)	11011	(-5)		11011	(-5)		1	0
0011	(3)		0011	(+3)		0011	(+3)			
-1110	-(14)	SUB	+0010	+(+2)		-1110	-(-2)	SUB		
-----	-----		-----	-----		-----	-----			
10101	(5)	(-16)	00101	(+5)		00101	(+5)		1	0
0011	(3)		0011	(+3)		0011	(+3)			
+0010	+(2)	ADD	+0010	+(+2)	ADD	-1110	-(-2)			
-----	-----		-----	-----		-----	-----			
00101	(5)	(+ 0)	00101	(+5)		00101	(+5)		0	0
1101	(13)		1101	(-3)		1101	(-3)			
-0010	-(2)	SUB	+1110	+(-2)		-0010	-(-2)	SUB		
-----	-----		-----	-----		-----	-----			
11011	(11)	(-16)	11011	(-5)		11011	(-5)		0	0

Summary II

unsigned add/sub			signed addition			signed subtraction			CF	OF
1011	(11)		1011	(-5)		1011	(-5)			
+1100	+(12)	ADD	+1100	+(-4)	ADD	-0100	-(+4)			
-----	-----		-----	-----		-----	-----			
10111	(7) (+16)		10111	(+7)		10111	(+7)		1	1
0101	(5)		0101	(+5)		0101	(+5)			
-1100	-(12)	SUB	+0100	+(+4)		-1100	-(-4)	SUB		
-----	-----		-----	-----		-----	-----			
11001	(9) (-16)		01001	(-7)		01001	(-7)		1	1
0101	(5)		0101	(+5)		0101	(+5)			
+0100	+(4)	ADD	+0100	+(+4)	ADD	-1100	-(-4)			
-----	-----		-----	-----		-----	-----			
01001	(9) (+ 0)		01001	(-7)		01001	(-7)		0	1
1011	(11)		1011	(-5)		1011	(-5)			
-0100	-(4)	SUB	+1100	+(-4)		-0100	-(+4)	SUB		
-----	-----		-----	-----		-----	-----			
00111	(7) (0)		10111	(+7)		10111	(+7)		0	1

Cases for setting the carry flag (1) CF=1, OF=0

- unsigned integer overflow (CF=1 means +16)

* unsigned addition		* signed addition		signed subtraction
1101 (13)		1101 (-3)		1101 (-3)
+1110 +(14) ADD		+1110 +(-2) ADD		-0010 -(+2)
-----		-----		-----
11011 (11) (+16)		11011 (-5)		11011 (-5)
CF=1		Cn=1 -> CF=1		Cn=1 -> CF=1
CF means 16		CF meaningless		CF meaningless
S = 0000		S = 0000		S = 0000
* think hand		* think Cn of the corresponding addition		
addition		CF <- Cn (for unsigned addition)		

* CF=1, S=1011, OF=0 for all three interpretations

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Cases for setting the carry flag (2) CF=1, OF=0

- unsigned integer overflow (CF=1 means -16)

* unsigned subtraction		signed addition		* signed subtraction
0011 (3)		0011 (+3)		0011 (+3)
-1110 -(14) SUB		+0010 +(2)		-1110 -(-2) SUB
-----		-----		-----
10101 (5) (-16)		00101 (+5)		00101 (+5)
CF=1		Cn=0 -> CF=1		Cn=0 -> CF=1
CF means -16		CF meaningless		CF meaningless
S = 0101		S = 0101		S = 0101
-----		-----		-----
* think hand subtraction		* think Cn of the transformed addition		
		CF <- !Cn (for unsigned subtraction)		
-----		-----		-----

* CF=1, S=0101, OF=0 for all three interpretations

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Cases for setting the carry flag (3) CF=1, OF=1

- unsigned integer overflow (CF=1 means +16)

* unsigned addition		* signed addition		signed subtraction
1011 (11)		1011 (-5)		1011 (-5)
+1100 +(12) ADD		+1100 +(-4) ADD		-0100 -(+4)
-----		-----		-----
10111 (7) (+16)		10111 (+7)		10111 (+7)
CF=1		Cn=1 -> CF=1		Cn=1 -> CF=1
CF means +16		CF meaningless		CF meaningless
S = 0111		S = 0111		S = 0111
* think hand		* think Cn of the corresponding addition		
addition		CF <- Cn (for unsigned addition)		

* CF=1, S=0111, OF=1 for all three interpretations

Cases for setting the carry flag (4) CF=1, OF=1

- unsigned integer overflow (CF=1 means -16)

* unsigned subtraction		signed addition		* signed subtraction
0101 (5)		0101 (+5)		0101 (+5)
-1100 -(12) SUB		+0100 +(4)		-1100 -(-4) SUB
-----		-----		-----
11001 (9) (-16)		01001 (-7)		01001 (-7)
CF=1		Cn=0 -> CF=1		Cn=0 -> CF=1
CF means -16		CF meaningless		CF meaningless
S = 1001		S = 1001		S = 1001
* think hand subtraction		* think Cn of the transformed addition		CF <- !Cn (for unsigned subtraction)

* CF=1, S=1001, OF=1 for all three interpretations

Cases for clearing the carry flag (1) CF=0, OF=0

- no unsigned integer overflow (CF=0)

* unsigned addition		* signed addition	signed subtraction
0011 (3)		0011 (+3)	0011 (+3)
+0010 +(2) ADD		+0010 +(2) ADD	-1110 -(-2)
-----		-----	-----
00101 (5) (+ 0)		00101 (+5)	00101 (+5)
CF=0		Cn=0 -> CF=0	Cn=0 -> CF=0
CF means 0		CF meaningless	CF meaningless
S = 0101		S = 0101	S = 0101
* think hand		* think Cn of the corresponding addition	
addition		CF <- Cn (for unsigned addition)	

* CF=0, S=0101, OF=0 for all three interpretations

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Cases for clearing the carry flag (2) CF=0, OF=0

- no unsigned integer overflow (CF=0)

* unsigned addition		* signed addition		signed subtraction
1101 (13)		1101 (-3)		1101 (-3)
-0010 -(2) SUB		+1110 +(-2)		-0010 -(+2) SUB
-----		-----		-----
11011 (11) (-16)		11011 (-5)		11011 (-5)
CF=0		Cn=0 -> CF=0		Cn=0 -> CF=0
CF means 0		CF meaningless		CF meaningless
S = 1011		S = 1011		S = 1011
* think hand		* think Cn of the corresponding addition		
subtraction		CF <- Cn (for unsigned addition)		

* CF=0, S=1011, OF=0 for all three interpretations

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Cases for clearing the carry flag (3) CF=0, OF=1

- no unsigned integer overflow (CF=0)

* unsigned addition		* signed addition		signed subtraction
0101 (5)		0101 (+5)		0101 (+5)
+0100 +(4) ADD		+0100 +(+4) ADD		-1100 -(-4)
-----		-----		-----
01001 (9) (+ 0)		01001 (-7)		01001 (-7)
CF=0		Cn=0 -> CF=0		Cn=0 -> CF=0
CF means +0		CF meaningless		CF meaningless
S = 1001		S = 1001		S = 1001
* think hand		* think Cn of the corresponding addition		
addition		CF <- Cn (for unsigned addition)		

* CF=0, S=1001, OF=1 for all three interpretations

Cases for clearing the carry flag (4) CF=0, OF=1

- no unsigned integer overflow (CF=0)

* unsigned subtraction		signed addition		* signed subtraction
1011 (11)		1011 (-5)		1011 (-5)
-0100 -(4) SUB		+1100 +(-4)		-0100 -(+4) SUB
-----		-----		-----
00111 (7) (0)		10111 (+7)		10111 (+7)
CF=0		Cn=1 -> CF=0		Cn=1 -> CF=0
CF means 0		CF meaningless		CF meaningless
S = 0111		S = 0111		S = 0111
* think hand subtraction		* think Cn of the transformed addition		CF <- !Cn (for unsigned subtraction)

* CF=0, S=0111, OF=1 for all three interpretations

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TOC: Overflow flag

- Overflow flag in unsigned and signed computations
- Rules for the overflow flag
- Method 1 for computing the overflow flag
- Method 2 for computing the overflow flag
- More examples of the overflow flag

- Overflow flag

Overflow flag (1)

- only need to look at the **sign bits** (leftmost) of the three numbers

$$\begin{array}{rclcl} \text{augend} & + & \text{addend} & = & \text{sum} \\ \text{minuend} & - & \text{subrahend} & = & \text{difference} \end{array}$$

to decide if the **overflow** flag is turned on or off.

- overflow** flag is based on **signed** arithmetic

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Overflow flag (2)

- in **signed** arithmetic,
 - watch the **overflow** flag to detect errors
 - **overflow** flag on means the result is wrong
 - errors can be detected by examining the sign of the result, in the 2's complement arithmetic
- in **unsigned** arithmetic,
 - the **overflow** flag tells you nothing interesting

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Overflow flag (3)

- when two positive numbers are added
 - if the result is a negative, ($P + P \rightarrow N$), then overflow
 - if the result is a positive, ($P + P \rightarrow P$), then no overflow
- when two negative numbers are added
 - the result is a positive, ($N + N \rightarrow P$), then overflow
 - the result is a negative, ($N + N \rightarrow N$), then no overflow

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Overflow flag (4)

- adding negative and positive numbers cannot be wrong, because the sum is between the addends.
 - mixed-sign addition never turns on the **overflow** flag.
 - opposite signed numbers are added, then no **overflow**
 - both of the addends lies in the allowable range of numbers, and their sum is between the addends, therefore the sum lies also in the allowable range
- $(P + N \rightarrow P)$ no overflow
- $(P + N \rightarrow N)$ no overflow
- $(N + P \rightarrow P)$ no overflow
- $(N + P \rightarrow N)$ no overflow

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TOC Rules for the overflow flag

- the 1st rule for setting OF
- the 2nd rule for setting OF
- cases for clearing OF (1 ~ 6)

Overflow flag setting and clearing conditions

ADD conditions SUB conditions

OF=1	$P + P \rightarrow N$	$P - N \rightarrow N$	$C_n \oplus C_{n-1} = 1$
OF=1	$N + N \rightarrow P$	$N - P \rightarrow P$	$C_n \oplus C_{n-1} = 1$
OF=0	$P + P \rightarrow P$	$P - N \rightarrow P$	$C_n \oplus C_{n-1} = 0$
OF=0	$N + N \rightarrow N$	$N - P \rightarrow N$	$C_n \oplus C_{n-1} = 0$
OF=0	$P + N \rightarrow P$	$P - N \rightarrow P$	$C_n \oplus C_{n-1} = 0$
OF=0	$P + N \rightarrow N$	$P - P \rightarrow N$	$C_n \oplus C_{n-1} = 0$
OF=0	$N + P \rightarrow P$	$N - N \rightarrow P$	$C_n \oplus C_{n-1} = 0$
OF=0	$N + P \rightarrow N$	$N - P \rightarrow N$	$C_n \oplus C_{n-1} = 0$

$$+P = -(-P) = -N$$

$$+N = -(-N) = -P$$

The 1st rule for setting the overflow flag

- 1 If the **sum** of two **signed** numbers with the sign bits off (0, 0) yields a result number with the sign bit on (1) the **overflow flag** is turned on ($OF = 1 : P + P \rightarrow N$)

signed addition

```
0100 carries
 0100 (+4)
+0100 +(4)
-----
01000 (-8)
```

signed subtraction

```
0100 (+4)
-1100 -(-4)
-----
01000 (-8)
```

unsigned addition

```
0100 ( 4)
+0100 +( 4)
-----
01000 ( 8)
```

$$\bullet OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 0 \oplus 1 = 1$$

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The 2nd rule for setting the overflow flag

- 2 If the **sum** of two numbers with the sign bits on (1, 1) yields a result number with the sign bit off (0) the **overflow flag** is turned on. ($OF = 1 : N + N \rightarrow P$)

signed addition

```
1001 carries
 1001 (-7)
+1001 +(-7)
-----
10010 ( 2)
```

signed subtraction

```
1001 (-7)
-0111 -(+7)
-----
10010 ( 2)
```

unsigned addition

```
1001 ( 9)
+1001 +( 9)
-----
10010 (18)
```

$$\bullet OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 1 \oplus 0 = 1$$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the overflow flag (1)

- **overflow flag** is turned off. ($OF = 0 : P + P \rightarrow P$)

signed addition

```
0011  carries
0011  (+3)
+0011  +(+3)
-----
00110  (+6)
```

signed subtraction

```
0011  (+3)
-1101  -(-3)
-----
00110  (+6)
```

unsigned addition

```
0011  ( 3)
+0011  +( 3)
-----
00110  ( 6)
```

- $OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 0 \oplus 0 = 0$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the overflow flag (2)

- **overflow flag** is turned off. ($OF = 0 : N + N \rightarrow N$)

signed addition

```
1101 carries
 1101 (-3)
+1101 +(-3)
-----
11010 (-6)
```

signed subtraction

```
1101 (-3)
-0011 -(+3)
-----
11010 (-6)
```

unsigned addition

```
1101 (13)
+1101 +(13)
-----
11010 (26)
```

- $OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 1 \oplus 1 = 0$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the overflow flag (3)

- **overflow flag** is turned off. ($OF = 0 : P + N \rightarrow P$)

signed addition

```
1100 carries
 0100 (+4)
+1101 +(-3)
-----
10001 (+1)
```

signed subtraction

```
0100 (+4)
-0011 -(+3)
-----
10001 (+1)
```

unsigned addition

```
0100 ( 4)
+1101 +(13)
-----
10001 (17)
```

- $OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 1 \oplus 1 = 0$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the overflow flag (4)

- **overflow flag** is turned off. ($OF = 0 : P + N \rightarrow N$)

signed addition

```
0000 carries
 0011 (+3)
+1100 +(-4)
-----
01111 (-1)
```

signed subtraction

```
0011 (+3)
-0100 -(+4)
-----
01111 (-1)
```

unsigned addition

```
0011 ( 3)
+1100 +(12)
-----
01111 (15)
```

- $OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 0 \oplus 0 = 0$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the overflow flag (5)

- **overflow flag** is turned off. ($OF = 0 : N + P \rightarrow P$)

signed addition

```
1100 carries
 1101 (-3)
+0100 (+4)
-----
10001 (+1)
```

signed subtraction

```
0011 (-3)
-1100 -(-4)
-----
10001 (+1)
```

unsigned addition

```
1101 (13)
+0100 +( 4)
-----
10001 (17)
```

- $OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 1 \oplus 1 = 0$

http://teaching.idallen.com/dat2343/10f/notes/040_overflow.txt

Cases for clearing the overflow flag (6)

- **overflow flag** is turned off. ($OF = 0 : N + P \rightarrow N$)

signed addition

```
0000 carries
1100 (-4)
+0011 +(+3)
-----
01111 (-1)
```

signed subtraction

```
0100 (-4)
-1101 -(-3)
-----
01111 (-1)
```

unsigned addition

```
1100 (12)
+0011 +( 3)
-----
01111 (15)
```

- $OF = C_n \oplus C_{n-1} = C_4 \oplus C_3 = 0 \oplus 0 = 0$

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TOC Method 1 for computing the overflow flag

- Adding two numbers with the same sign
- Overflow conditions for additions and subtractions
- Overflow condition for an addition
- Overflow conditions for a subtraction
- Overflow in signed computations

Adding two numbers with the same sign

- **overflow** can only happen when adding two numbers of the same sign results in a different sign ($P + P \rightarrow N$, $N + N \rightarrow P$)

- n -bit **signed** binary arithmetic $A + B = C$

$$A = (a_{n-1}, \dots, a_1, a_0)$$

$$B = (b_{n-1}, \dots, b_1, b_0)$$

$$C = (c_{n-1}, \dots, c_1, c_0)$$

- to detect overflow
 - only the **sign** bits are considered
 - **msb** (most significant bit) $a_{n-1}, b_{n-1}, c_{n-1}$
 - the other bits are ignored

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Overflow conditions for additions and subtractions

- with two operands (A and B) and one result (C), three sign bits ($a_{n-1}, b_{n-1}, c_{n-1}$) are considered
→ $2^3 = 8$ possible combinations
- only two cases result in **overflow** for an addition
 - 0 0 1 ($p + p \rightarrow n$)
 - 1 1 0 ($n + n \rightarrow p$)
- only two cases are considered as **overflow** for an subtraction
 - 0 1 1 ($p - n \rightarrow n$)
 - 1 0 0 ($n - p \rightarrow p$)

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Overflow condition for an addition

- Overflow in an addition ($A + B$)

	a_{n-1}	b_{n-1}	c_{n-1}	
	0	0	0	$p + p \rightarrow p$
OVER	0	0	1	$p + p \rightarrow n$
	0	1	0	$p + n \rightarrow p$
	0	1	1	$p + n \rightarrow n$
	1	0	0	$n + p \rightarrow p$
	1	0	1	$n + p \rightarrow n$
OVER	1	1	0	$n + n \rightarrow p$
	1	1	1	$n + n \rightarrow n$

- adding two positives should be positive
- adding two negatives should be negative

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Overflow conditions for a subtraction

- Overflow in a subtraction ($A - B$)

	a_{n-1}	b_{n-1}	c_{n-1}	
	0	0	0	$p - p \rightarrow p$
	0	0	1	$p - p \rightarrow n$
	0	1	0	$p - n \rightarrow p$
OVER	0	1	1	$p - n \rightarrow n$
OVER	1	0	0	$n - p \rightarrow p$
	1	0	1	$n - p \rightarrow n$
	1	1	0	$n - n \rightarrow p$
	1	1	1	$n - n \rightarrow n$

- subtracting a negative is the same as adding a positive
- subtracting a positive is the same as adding a negative

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Overflow in signed computations

- ALU might contain a small logic that sets the **overflow** flag to "1" if and only if any one of the above four **OV conditions** is met.
- in **signed** computations, adding two numbers of the same sign must produce a result of the same sign, otherwise overflow happened.

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TOC Method 2 for computing the overflow flag

- Carry into and carry out of the sign bit
- Overflow in 2's complement arithmetic
- Overflow flag = $C_n \oplus C_{n-1}$
- Examples of 4-bit signed additions
- C_n and C_{n-1} in a n -bit addition
- Overflow flag computation
- Examples of computing overflow flag
- Hexadecimal carry, octal carry, decimal carry
- No carry into the sign bit

Carry into and carry out of the sign bit

- When adding two n -bit binary values, consider
 - the **carry coming into** the most significant bit (msb)
 C_{n-1} : **carry into** the **sign** bit
 - the **carry going out of** the most significant bit (msb)
 C_n : **carry out of** the **sign** bit
this is the **carry flag (CF)** in the processor

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Overflow in 2's complement arithmetic

- **overflow** in 2's complement happens (**OF=1**) when
 - there is a **carry into** the **sign** bit ($C_{n-1} = 1$)
but no carry out of the **sign** bit ($C_n = 0$)
 - there is no carry into the **sign** bit ($C_{n-1} = 0$)
but a **carry out** of the **sign** bit ($C_n = 1$)

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$$\text{Overflow flag} = C_n \oplus C_{n-1}$$

- the **overflow** flag is the **XOR** ($C_n \oplus C_{n-1}$) of
 - of the **carry coming into** the **sign** bit (C_{n-1})
 - with the **carry going out of** the **sign** bit (C_n)
- **overflow** happens when the **carry in** (C_{n-1}) does not equal to the **carry out** (C_n)

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Examples of 4-bit signed additions (1)

- 4-bit 2's complement addition examples

```
0000
 0100 (+4) (pos sign 0)
+1000 (-8) (neg sign 1)
=====
01100 (-4) (neg sign 1)
```

```
C4 carry out 0 (1+0+0)
C3 carry in 0 (0+1+0)
0 XOR 0 = NO OVERFLOW
```

```
1100
 1100 (-4) (neg sign 1)
+0100 (+4) (pos sign 0)
=====
10000 ( 0) (pos sign 0)
```

```
C4 carry out 1 (1+0+1)
C3 carry in 1 (1+1+0)
1 XOR 1 = NO OVERFLOW
```

```
0100
 0100 (+4) (pos sign 0)
+0100 (+4) (pos sign 0)
=====
01000 (-8) (neg sign 1)
```

```
C4 carry out 0 (0+0+1)
C3 carry in 1 (1+1+0)
0 XOR 1 = OVERFLOW!
```

```
1000
 1100 (-4) (neg sign 1)
+1000 (-8) (neg sign 1)
=====
10100 (+4) (pos sign 0)
```

```
C4 carry out 1 (1+1+0)
C3 carry in 0 (1+0+0)
1 XOR 0 = OVERFLOW!
```

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Examples of 4-bit signed additions (2)

- same sign addition → possible overflow

----- + +, - -----	----- - -, + -----	----- + +, + -----	----- - -, - -----
+5 +5	-5 -5	+5 +1	-5 -1
----- -6(OF)	----- +6(OF)	----- +6	----- -6

0101 0101 0101	1011 1011 1011	0001 0101 0001	1111 1011 1111
----- 01010	----- 10110	----- 00110	----- 11010
----- C4 = 0	----- C4 = 1	----- C4 = 0	----- C4 = 1
----- C3 = 1	----- C3 = 0	----- C3 = 0	----- C3 = 1
----- OF = 1	----- OF = 1	----- OF = 0	----- OF = 0

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Examples of 4-bit signed additions (3)

- mixed sign addition → no overflow

----- + -, + ----- +5 -1 ----- +4	----- + -, - ----- +5 -6 ----- -1	----- - +, + ----- -5 +6 ----- +1	----- - +, - ----- -5 +1 ----- -4
1111 0101 1111 ----- 10100 ----- C4 = 1 C3 = 1 ----- OF = 0	0000 0101 1010 ----- 01111 ----- C4 = 0 C3 = 0 ----- OF = 0	1110 1011 0110 ----- 10001 ----- C4 = 1 C3 = 1 ----- OF = 0	0011 1011 0001 ----- 01100 ----- C4 = 0 C3 = 0 ----- OF = 0

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C_n and C_{n-1} in a n -bit addition

$(n-1)^{th}$ bit – MSB

- adding operations at the $(n-1)$ bit position
- $\{C_n, S_{n-1}\} =$
 $a_{n-1} + b_{n-1} + c_{n-1}$

$$\begin{array}{r} \text{msb} \\ a_{n-1} \\ b_{n-1} \\ \hline C_{n-1} \\ \hline C_n \quad S_{n-1} \end{array}$$

- C_n :
carry coming out of the msb

$(n-2)^{th}$ bit

- adding operations at the $(n-2)$ bit position
- $\{C_{n-1}, S_{n-2}\} =$
 $a_{n-2} + b_{n-2} + c_{n-2}$

$$\begin{array}{r} \text{msb} \\ a_{n-2} \\ b_{n-2} \\ \hline C_{n-2} \\ \hline C_{n-1} \quad S_{n-2} \end{array}$$

- C_{n-1} :
carry coming into the msb

Overflow flag computation

ADD (addition)

$$OF = C_n \oplus C_{n-1}$$

a 2's complement addition

$$A + B = A + B + \mathbf{0} \quad (C_0 = 0)$$

$$\begin{aligned} & \{C_n, S_{n-1}\} \\ & = a_{n-1} + b_{n-1} + c_{n-1} \end{aligned}$$

$$\begin{aligned} & \{C_{n-1}, S_{n-2}\} \\ & = a_{n-2} + b_{n-2} + c_{n-2} \end{aligned}$$

SUB (subtraction)

$$OF = C_n \oplus C_{n-1}$$

the transformed addition

$$A - B = A + \overline{B} + \mathbf{1} \quad (C_0 = 1)$$

$$\begin{aligned} & \{C_n, S_{n-1}\} \\ & = a_{n-1} + \overline{b_{n-1}} + c_{n-1} \end{aligned}$$

$$\begin{aligned} & \{C_{n-1}, S_{n-2}\} \\ & = a_{n-2} + \overline{b_{n-2}} + c_{n-2} \end{aligned}$$

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Hexadecimal carry, octal carry, decimal carry

- Note that this XOR method only works with the **binary** carry that goes into the sign **bit**.
- not works with **hexadecimal carry**
decimal carry, **octal carry**
 - the carry doesn't go into the sign **bit**
 - can't XOR that non-binary carry with the outgoing carry.

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No carry into the sign bit

- Hexadecimal addition example
(showing that XOR doesn't work for hex carry):

```
8Ah
+8Ah
====
114h
```

- The hexadecimal carry of 1 resulting from A+A does not affect the sign bit.
- If you do the math in binary, you'll see that there is **no** carry **into** the sign bit; but, there is carry out of the sign bit. Therefore, the above example sets OVERFLOW on. (The example adds two negative numbers and gets a positive number.)

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Summary I

unsigned add/sub			signed addition			signed subtraction			CF	OF
1101	(13)		1101	(-3)		1101	(-3)			
+1110	+(14)	ADD	+1110	+(-2)	ADD	-0010	-(-2)			
-----	-----		-----	-----		-----	-----			
11011	(11)	(+16)	11011	(-5)		11011	(-5)		1	0
0011	(3)		0011	(+3)		0011	(+3)			
-1110	-(14)	SUB	+0010	+(+2)		-1110	-(-2)	SUB		
-----	-----		-----	-----		-----	-----			
10101	(5)	(-16)	00101	(+5)		00101	(+5)		1	0
0011	(3)		0011	(+3)		0011	(+3)			
+0010	+(2)	ADD	+0010	+(+2)	ADD	-1110	-(-2)			
-----	-----		-----	-----		-----	-----			
00101	(5)	(+ 0)	00101	(+5)		00101	(+5)		0	0
1101	(13)		1101	(-3)		1101	(-3)			
-0010	-(2)	SUB	+1110	+(-2)		-0010	-(-2)	SUB		
-----	-----		-----	-----		-----	-----			
11011	(11)	(-16)	11011	(-5)		11011	(-5)		0	0

Summary II

unsigned add/sub			signed addition			signed subtraction			CF	OF
1011	(11)		1011	(-5)		1011	(-5)			
+1100	+(12)	ADD	+1100	+(-4)	ADD	-0100	-(+4)			
-----	-----		-----	-----		-----	-----			
10111	(7) (+16)		10111	(+7)		10111	(+7)		1	1
0101	(5)		0101	(+5)		0101	(+5)			
-1100	-(12)	SUB	+0100	+(+4)		-1100	-(-4)	SUB		
-----	-----		-----	-----		-----	-----			
11001	(9) (-16)		01001	(-7)		01001	(-7)		1	1
0101	(5)		0101	(+5)		0101	(+5)			
+0100	+(4)	ADD	+0100	+(+4)	ADD	-1100	-(-4)			
-----	-----		-----	-----		-----	-----			
01001	(9) (+ 0)		01001	(-7)		01001	(-7)		0	1
1011	(11)		1011	(-5)		1011	(-5)			
-0100	-(4)	SUB	+1100	+(-4)		-0100	-(+4)	SUB		
-----	-----		-----	-----		-----	-----			
00111	(7) (0)		10111	(+7)		10111	(+7)		0	1

Cases for setting the overflow flag (1) CF=1, OF=1

- signed integer overflow (OF=1 means incorrect S)

* unsigned addition		* signed addition	signed subtraction
1011 (11)		1000	
+1100 +(12) ADD		1011 (-5)	1011 (-5)
-----		+1100 +(-4) ADD	-0100 -(+4)
10111 (7) (+16)		-----	-----
		10111 (+7)	10111 (+7)
OF=1		n + n -> p (OF=1)	n - p -> p (OF=1)
OF meaningless		-> incorrect S	-> incorrect S
S = 0111		S = 0111	S = 0111
* think hand		* OF <- C4 XOR C3 = 1 XOR 0 = 1	
addition		of signed addition	

* CF=1, S=0111, OF=1 for all three interpretations

Cases for setting the overflow flag (2) CF=1, OF=1

- signed integer overflow (OF=1 means incorrect S)

* unsigned subtraction		signed addition		* signed subtraction
0101 (5)		0100		0101 (+5)
-1100 -(12) SUB		+0100 +(4)		-1100 -(-4) SUB
-----		-----		-----
11001 (9) (-16)		01001 (-7)		01001 (-7)
OF=1		p + p -> n (OF=1)		p - n -> n (OF=1)
OF meaningless		-> incorrect S		-> incorrect S
S = 1001		S = 1001		S = 1001

* think hand subtraction		* OF <- C4 XOR C3 = 0 XOR 1 = 1		of signed addition

* CF=1, S=1001, OF=1 for all three interpretations

Cases for setting the overflow flag (3) CF=0, OF=1

- signed integer overflow (OF=1 means incorrect S)

* unsigned addition		* signed addition	signed subtraction
0101 (5)		0100	
+0100 +(4) ADD		0101 (+5)	0101 (+5)
-----		+0100 +(4) ADD	-1100 -(-4)
01001 (9) (+ 0)		-----	-----
		01001 (-7)	01001 (-7)
OF=1		p + p -> n (OF=1)	p - n -> n (OF=1)
OF meaningless		-> incorrect S	-> incorrect S
S = 1001		S = 1001	S = 1001
* think hand		* OF <- C4 XOR C3 = 0 XOR 1 = 1	
addition		of signed addition	

* CF=0, S=1001, OF=1 for all three interpretations

Cases for setting the overflow flag (4) CF=0, OF=1

- signed integer overflow (OF=1 means incorrect S)

* unsigned subtraction		signed addition		* signed subtraction
1011 (11)		1000		1011 (-5)
-0100 -(4) SUB		+1100 +(-4)		-0100 -(+4) SUB
-----		-----		-----
00111 (7) (0)		10111 (+7)		10111 (+7)
OF=1		n + n -> p (OF=1)		n - p -> p (OF=1)
OF meaningless		-> incorrect S		-> incorrect S
S = 0111		S = 0111		S = 0111
* think hand subtraction		* OF <- C4 XOR C3 = 1 XOR 0 = 1		of signed addition

* CF=0, S=0111, OF=1 for all three interpretations

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Cases for clearing the overflow flag (1) CF=1, OF=0

- no signed integer overflow (CF=0 means correct S)

* unsigned addition		* signed addition		signed subtraction
1101 (13)		1100		
+1110 +(14) ADD		1101 (-3)		1101 (-3)
-----		+1110 +(-2) ADD		-0010 -(+2)
-----		-----		-----
11011 (11) (+16)		11011 (-5)		11011 (-5)
OF=0		n + n -> n (OF=0)		n - p -> n (OF=0)
OF meaningless		-> correct S		-> correct S
S = 0000		S = 0000		S = 0000
* think hand		* OF <- C4 XOR C3 = 1 XOR 1 = 0		
addition		of signed addition		

* CF=1, S=1011, OF=0 for all three interpretations

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Cases for clearing the overflow flag (2) CF=1, OF=0

- no signed integer overflow (CF=0 means correct S)

* unsigned subtraction		signed addition		* signed subtraction
0011 (3)		0010		0011 (+3)
-1110 -(14) SUB		+0010 +(2)		-1110 -(-2) SUB
-----		-----		-----
10101 (5) (-16)		00101 (+5)		00101 (+5)
CF=1		p + p -> p (OF=0)		p - n -> p (OF=0)
OF meaningless		-> correct S		-> correct S
S = 0101		S = 0101		S = 0101
* think hand subtraction		* OF <- C4 XOR C3 = 0 XOR 0 = 0		of signed addition

* CF=1, S=0101, OF=0 for all three interpretations

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Cases for clearing the overflow flag (3) CF=0, OF=0

- no signed integer overflow (CF=0 means correct S)

* unsigned addition	* signed addition	signed subtraction
0011 (3)	0010	
+0010 +(2) ADD	+0010 +(2) ADD	0011 (+3)
-----	-----	-1110 -(-2)
00101 (5) (+0)	00101 (+5)	00101 (+5)
OF=0	p + p -> p (OF=0)	p - n -> p (OF=0)
OF meaningless	-> correct S	-> correct S
S = 0101	S = 0101	S = 0101
* think hand	* OF <- C4 XOR C3 = 0 XOR 0 = 0	
addition	of signed addition	

* CF=0, S=0101, OF=0 for all three interpretations

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Cases for clearing the overflow flag (4) CF=0, OF=0

- no signed integer overflow (CF=0 means correct S)

* unsigned addition	* signed addition	signed subtraction
1101 (13)	1100	
-0010 -(2) SUB	+1110 +(-2)	1101 (-3)
-----	-----	-0010 -(+2) SUB
11011 (11) (-16)	11011 (-5)	-----
		11011 (-5)
OF=0	n + n -> n (OF=0)	n - p -> n (OF=0)
OF meaningless	-> correct S	-> correct S
S = 1011	S = 1011	S = 1011
* think hand	* OF <- C4 XOR C3 = 1 XOR 1 = 0	
subtraction	of signed addition	

* CF=0, S=1011, OF=0 for all three interpretations

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2's complement numbers : 4-bit

0111	(+7)	1000	(-8)
0110	(+6)	1001	(-7)
0101	(+5)	1010	(-6)
0100	(+4)	1011	(-5)
0011	(+3)	1100	(-4)
0010	(+2)	1101	(-3)
0001	(+1)	1110	(-2)
0000	(0)	1111	(-1)

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Unsigned 4-bit addition table (1)

	0000 (0)	0001 (1)	0010 (2)	0011 (3)	0100 (4)	0101 (5)	0110 (6)	0111 (7)
0000 (0)	0000 (0)	0001 (1)	0010 (2)	0011 (3)	0100 (4)	0101 (5)	0110 (6)	0111 (7)
0001 (1)	0001 (1)	0010 (2)	0011 (3)	0100 (4)	0101 (5)	0110 (6)	0111 (7)	1000 (8)
0010 (2)	0010 (2)	0011 (3)	0100 (4)	0101 (5)	0110 (6)	0111 (7)	1000 (8)	1001 (9)
0011 (3)	0011 (3)	0100 (4)	0101 (5)	0110 (6)	0111 (7)	1000 (8)	1001 (9)	1010 (10)
0100 (4)	0100 (4)	0101 (5)	0110 (6)	0111 (7)	1000 (8)	1001 (9)	1010 (10)	1011 (11)
0101 (5)	0101 (5)	0110 (6)	0111 (7)	1000 (8)	1001 (9)	1010 (10)	1011 (11)	1100 (12)
0110 (6)	0110 (6)	0111 (7)	1000 (8)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)
0111 (7)	0111 (7)	1000 (8)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)

.....

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Unsigned 4-bit addition table (2)

.....
	0000 (0)	0001 (1)	0010 (2)	0011 (3)	0100 (4)	0101 (5)	0110 (6)	0111 (7)
1000 (8)	1000 (8)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)
1001 (9)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)
1010 (10)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)
1011 (11)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)
1100 (12)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)
1101 (13)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)
1110 (14)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)
1111 (15)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)	0110 CF (16+6)

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Unsigned 4-bit addition table (3)

	1000 (8)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	
0000 (0)	1000 (8)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	
0001 (1)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	
0010 (2)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	
0011 (3)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	
0100 (4)	1100 (12)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	
0101 (5)	1101 (13)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	
0110 (6)	1110 (14)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)	
0111 (7)	1111 (15)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)	0110 CF (16+6)	

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Unsigned 4-bit addition table (4)

.....
	1000 (8)	1001 (9)	1010 (10)	1011 (11)	1100 (12)	1101 (13)	1110 (14)	1111 (15)
1000 (8)	0000 CF (16+0)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)	0110 CF (16+6)	0111 CF (16+7)
1001 (9)	0001 CF (16+1)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)	0110 CF (16+6)	0111 CF (16+7)	1000 CF (16+8)
1010 (10)	0010 CF (16+2)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)	0110 CF (16+6)	0111 CF (16+7)	1000 CF (16+8)	1001 CF (16+9)
1011 (11)	0011 CF (16+3)	0100 CF (16+4)	0101 CF (16+5)	0110 CF (16+6)	0111 CF (16+7)	1000 CF (16+8)	1001 CF (16+9)	1010 CF (16+10)
1100 (12)	0100 CF (16+4)	0101 CF (16+5)	0110 CF (16+6)	0111 CF (16+7)	1000 CF (16+8)	1001 CF (16+9)	1010 CF (16+10)	1011 CF (16+11)
1101 (13)	0101 CF (16+5)	0110 CF (16+6)	0111 CF (16+7)	1000 CF (16+8)	1001 CF (16+9)	1010 CF (16+10)	1011 CF (16+11)	1100 CF (16+12)
1110 (14)	0110 CF (16+6)	0111 CF (16+7)	1000 CF (16+8)	1001 CF (16+9)	1010 CF (16+10)	1011 CF (16+11)	1100 CF (16+12)	1101 CF (16+13)
1111 (15)	0111 CF (16+7)	1000 CF (16+8)	1001 CF (16+9)	1010 CF (16+10)	1011 CF (16+11)	1100 CF (16+12)	1101 CF (16+13)	1110 CF (16+14)

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Unsigned 4-bit addition table (5)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	C0
2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	C0	C1
3	3	4	5	6	7	8	9	10	11	12	13	14	15	C0	C1	C2
4	4	5	6	7	8	9	10	11	12	13	14	15	C0	C1	C2	C3
5	5	6	7	8	9	10	11	12	13	14	15	C0	C1	C2	C3	C4
6	6	7	8	9	10	11	12	13	14	15	C0	C1	C2	C3	C4	C5
7	7	8	9	10	11	12	13	14	15	C0	C1	C2	C3	C4	C5	C6
8	8	9	10	11	12	13	14	15	C0	C1	C2	C3	C4	C5	C6	C7
9	9	10	11	12	13	14	15	C0	C1	C2	C3	C4	C5	C6	C7	C8
10	10	11	12	13	14	15	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9
11	11	12	13	14	15	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
12	12	13	14	15	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
13	13	14	15	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
14	14	15	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
15	15	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14

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Signed 4-bit addition table (1)

	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)	0111 (+7)
0000 (0)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)	0111 (+7)
0001 (+1)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)	0111 (+7)	1000 (-8) OF
0010 (+2)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)	0111 (+7)	1000 (-8) OF	1001 (-7) OF
0011 (+3)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)	0111 (+7)	1000 (-8) OF	1001 (-7) OF	1010 (-6) OF
0100 (+4)	0100 (+4)	0101 (+5)	0110 (+6)	0111 (+7)	1000 (-8) OF	1001 (-7) OF	1010 (-6) OF	1011 (-5) OF
0101 (+5)	0101 (+5)	0110 (+6)	0111 (+7)	1000 (-8) OF	1001 (-7) OF	1010 (-6) OF	1011 (-5) OF	1100 (-4) OF
0110 (+6)	0110 (+6)	0111 (+7)	1000 (-8) OF	1001 (-7) OF	1010 (-6) OF	1011 (-5) OF	1100 (-4) OF	1101 (-3) OF
0111 (+7)	0111 (+7)	1000 (-8) OF	1001 (-7) OF	1010 (-6) OF	1011 (-5) OF	1100 (-4) OF	1101 (-3) OF	1110 (-2) OF

.....

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Signed 4-bit addition table (2)

	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)	0111 (+7)
1000 (-8)	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)
1001 (-7)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)
1010 (-6)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)
1011 (-5)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)
1100 (-4)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)
1101 (-3)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)
1110 (-2)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)
1111 (-1)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)

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Signed 4-bit addition table (3)

	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)
0000 (0)	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)
0001 (+1)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)
0010 (+2)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)
0011 (+3)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)
0100 (+4)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)
0101 (+5)	1101 (-3)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)
0110 (+6)	1110 (-2)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)
0111 (+7)	1111 (-1)	0000 (0)	0001 (+1)	0010 (+2)	0011 (+3)	0100 (+4)	0101 (+5)	0110 (+6)

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Signed 4-bit addition table (4)

	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)	1111 (-1)
1000 (-8)	0000 (0) OF	0001 (+1) OF	0010 (+2) OF	0011 (+3) OF	0100 (+4) OF	0101 (+5) OF	0110 (+6) OF	0111 (+7) OF
1001 (-7)	0001 (+1) OF	0010 (+2) OF	0011 (+3) OF	0100 (+4) OF	0101 (+5) OF	0110 (+6) OF	0111 (+7) OF	1000 (-8)
1010 (-6)	0010 (+2) OF	0011 (+3) OF	0100 (+4) OF	0101 (+5) OF	0110 (+6) OF	0111 (+7) OF	1000 (-8)	1001 (-7)
1011 (-5)	0011 (+3) OF	0100 (+4) OF	0101 (+5) OF	0110 (+6) OF	0111 (+7) OF	1000 (-8)	1001 (-7)	1010 (-6)
1100 (-4)	0100 (+4) OF	0101 (+5) OF	0110 (+6) OF	0111 (+7) OF	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)
1101 (-3)	0101 (+5) OF	0110 (+6) OF	0111 (+7) OF	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)
1110 (-2)	0110 (+6) OF	0111 (+7) OF	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)
1111 (-1)	0111 (+7) OF	1000 (-8)	1001 (-7)	1010 (-6)	1011 (-5)	1100 (-4)	1101 (-3)	1110 (-2)

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Signed 4-bit addition table (5)

	0	1	2	3	4	5	6	7	-8	-7	-6	-5	-4	-3	-2	-1
0	0	1	2	3	4	5	6	7	-8	-7	-6	-5	-4	-3	-2	-1
1	1	2	3	4	5	6	7	<u>-8x</u>	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0
2	2	3	4	5	6	7	<u>-8x</u>	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1
3	3	4	5	6	7	<u>-8x</u>	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2
4	4	5	6	7	<u>-8x</u>	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2	3
5	5	6	7	<u>-8x</u>	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2	3	4
6	6	7	<u>-8x</u>	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2	3	4	5
7	7	<u>-8x</u>	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2	3	4	5	6
-8	-8	<u>-7x</u>	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0x	1x	2x	3x	4x	5x	6x	7x
-7	-7	<u>-6x</u>	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1x	2x	3x	4x	5x	6x	7x	-8
-6	-6	<u>-5x</u>	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2x	3x	4x	5x	6x	7x	-8	-7
-5	-5	<u>-4x</u>	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2	3x	4x	5x	6x	7x	-8	-7	-6
-4	-4	<u>-3x</u>	<u>-2x</u>	<u>-1x</u>	0	1	2	3	4x	5x	6x	7x	-8	-7	-6	-5
-3	-3	<u>-2x</u>	<u>-1x</u>	0	1	2	3	4	5x	6x	7x	-8	-7	-6	-5	-4
-2	-2	<u>-1x</u>	0	1	2	3	4	5	6x	7x	-8	-7	-6	-5	-4	-3
-1	-1	0	1	2	3	4	5	6	7x	-8	-7	-6	-5	-4	-3	-2

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