Bits, Bytes, and Integers

CSE4009: System Programming

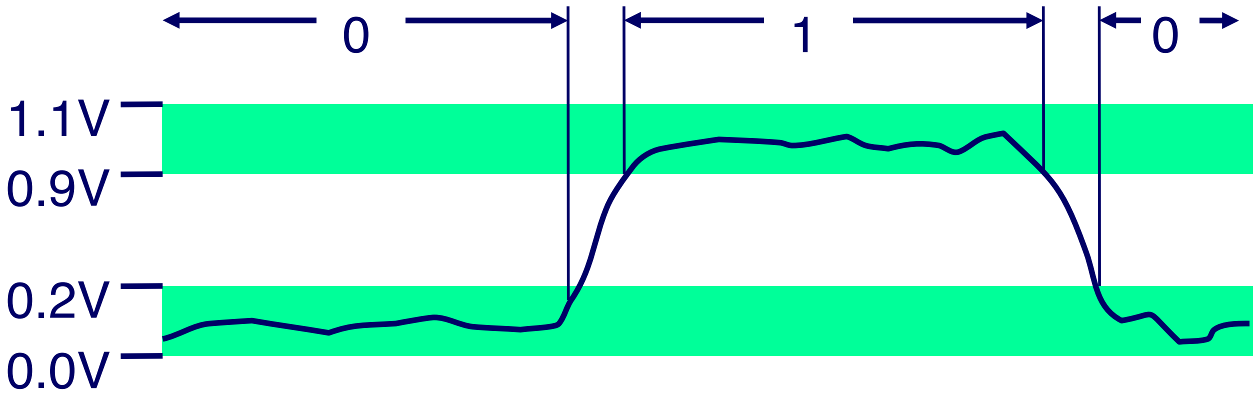
Woong Sul

Today: Bits, Bytes, and Integers

- Representing information as bits
- Bit-level manipulations
- Integers
    - Representation: unsigned and signed
    - Conversion, casting
    - Expanding, truncating
    - Addition, negation, multiplication, shifting
    - Summary
- Representations in memory, pointers, strings

Everything is Bits

- Each bit is 0 or 1
- By encoding/interpreting sets of bits in various ways
  - Computers determine what to do (instructions)
  - … and represent and manipulate numbers, sets, strings, etc…
- Why bits? Electronic Implementation
  - Easy to store with bistable elements
  - Reliably transmitted on noisy and inaccurate wires



Example: Counting in Binary

- Base 2 Number Representation
  - Represent 15213_{10} as 11101101101101_2
  - Represent 1.20_{10} as $1.0011001100110011[0011]\ldots_2$
  - Represent $1.5213 \text{ X } 10^4$ as $1.1101101101101_2 \text{ X } 2^{13}$

Encoding Byte Values

- Byte = 8 bits
  - Binary 00000000_2 to 11111111_2
  - Decimal: 0_{10} to 255_{10}
  - Hexadecimal 00_{16} to FF_{16}
    - Base 16 number representation
    - Use characters '0' to '9' and 'A' to 'F'
    - Write $FA1D37B_{16}$ in C as
      - 0xFA1D37B
      - 0xfa1d37b

Hex	Decimal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111

Data Representations Example

C Data Type	Typical 32-bit	Typical 64-bit	x86-64
`char`	1	1	1
`short`	2	2	2
`int`	4	4	4
`long`	4	8	8
`float`	4	4	4
`double`	8	8	8
`long double`	–	–	10/16
`pointer`	4	8	8

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Boolean Algebra

- Developed by George Boole in 19th Century
  - Algebraic representation of logic
    - Encode "True" as 1 and "False" as 0

And

- A&B = 1 when both A=1 and B=1

&	0	1
0	0	0
1	0	1

Or

- A|B = 1 when either A=1 or B=1

|	0	1
0	0	1
1	1	1

Not

- ~A = 1 when A=0

~	
0	1
1	0

Exclusive-Or (Xor)

- A^B = 1 when either A=1 or B=1, but not both

^	0	1
0	0	1
1	1	0

General Boolean Algebras

- Operate on Bit Vectors
  - Operations applied bitwise

```
  01101001     01101001     01101001
& 01010101   | 01010101   ^ 01010101   ~ 01010101
  01000001     01111101     00111100     10101010
```

- All of the Properties of Boolean Algebra Apply

Example: Representing & Manipulating Sets

- Representation
  - Width w bit vector represents subsets of {0, …, w–1}
  - $a_j = 1$ if $j \in A$

    01101001 { 0, 3, 5, 6 }

    76543210

    01010101 { 0, 2, 4, 6 }

    76543210

- Manipulation

&	Intersection	01000001	{ 0, 6 }
|	Union	01111101	{ 0, 2, 3, 4, 5, 6 }
^	Symmetric difference	00111100	{ 2, 3, 4, 5 }
~	Complement	10101010	{ 1, 3, 5, 7 }

Bit-Level Operations in C

- Operations `& | ~ ^` Available in C
  - Apply to any "integral" data type
    `long, int, short, char, unsigned`
  - View arguments as bit vectors
  - Arguments applied bit-wise
- Examples (**`char`** data type)
  - ~0x41 → 0xBE
    ~01000001_2 → 10111110_2
  - ~0x00 → 0xFF
    ~00000000_2 → 11111111_2
  - 0x69 & 0x55 → 0x41
    01101001_2 & 01010101_2 → 01000001_2
  - 0x69 | 0x55 → 0x7D
    01101001_2 | 01010101_2 → 01111101_2

Contrast: Logical Operations in C

- Contrast to Logical Operators
  - `&&, ||, !`
    - View 0 as "False"
    - Anything non-zero as "True"
    - Always return 0 or 1
    - Early termination

Watch out for && vs. & (and || vs. |)… one of the more common oopsies in C programming

- Examples (char data type)

```
!0x41   →  0x00
!0x00   →  0x01
!!0x41  →  0x01

0x69 && 0x55  →  0x01
0x69 || 0x55  →  0x01
p && *p
```

(avoids null pointer access)

Shift Operations

- Left Shift: `x << y`
  - Shift bit-vector **x** left **y** positions
    - Throw away extra bits on left
  - Fill with 0's on right
- Right Shift: `x >> y`
  - Shift bit-vector **x** right **y** positions
    - Throw away extra bits on right
  - Logical shift
    - Fill with 0's on left
  - Arithmetic shift
    - Replicate most significant bit on left
- Undefined Behavior
  - Shift amount < 0 or ≥ word size

Argument x	01100010
<< 3	00010000
Log. >> 2	00011000
Arith. >> 2	00011000

Argument x	10100010
<< 3	00010000
Log. >> 2	00101000
Arith. >> 2	11101000

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Encoding Integers

Unsigned

$$B2U(X) = \sum_{i=0}^{w-1} x_i \cdot 2^i$$

Two's Complement

$$B2T(X) = -x_{w-1} \cdot 2^{w-1} + \sum_{i=0}^{w-2} x_i \cdot 2^i$$

Sign Bit

```
short int x =  15213;
short int y = -15213;
```

- C **`short`** 2 bytes long

	Decimal	Hex	Binary
`x`	15213	`3B 6D`	`00111011 01101101`
`y`	-15213	`C4 93`	`11000100 10010011`

- Sign Bit
  - For 2's complement, most significant bit indicates sign
    - 0 for nonnegative
    - 1 for negative

Numeric Ranges

- Unsigned Values
  - *UMin* = 0
    000…0
  - *UMax* = $2^w - 1$
    111…1

- Two's Complement Values
  - *TMin* = -2^{w-1}
    100…0
  - *TMax* = $2^{w-1} - 1$
    011…1
- Other Values
  - Minus 1
    111…1

Values for *W* = 16

	Decimal	Hex	Binary
UMax	65535	FF FF	11111111 11111111
TMax	32767	7F FF	01111111 11111111
TMin	-32768	80 00	10000000 00000000
-1	-1	FF FF	11111111 11111111
0	0	00 00	00000000 00000000

Values for Different Word Sizes

	W			
	8	16	32	64
UMin	0	0	0	0
UMax	255	65,535	4,294,967,295	18,446,744,073,709,551,615
TMax	127	32,767	2,147,483,647	9,223,372,036,854,775,807
TMin	-128	-32,768	-2,147,483,648	-9,223,372,036,854,775,808

- Observations
  - Umin = 0
  - $|TMin|$ = $TMax + 1$
    - Asymmetric range
  - $UMax$ = $2 * TMax + 1$
- C Programming
  - `#include <limits.h>`
  - Declares contants, e.g.,
    - `ULONG_MAX`
    - `LONG_MAX`
    - `LONG_MIN`
  - Values are platform-specific

Unsigned & Signed Numeric Values

X	**B2U(*X*)**	**B2T(*X*)**
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	–8
1001	9	–7
1010	10	–6
1011	11	–5
1100	12	–4
1101	13	–3
1110	14	–2
1111	15	–1

- Equivalence
  - Same encodings for nonnegative values
- Uniqueness
  - Every bit pattern represents unique integer value
  - Each representable integer has unique bit encoding

$\Rightarrow$ Can Invert Mappings

- U2B(x) = B2U^{-1}(x)
  - Bit pattern for unsigned integer
- T2B(x) = B2T^{-1}(x)
  - Bit pattern for two's comp integer

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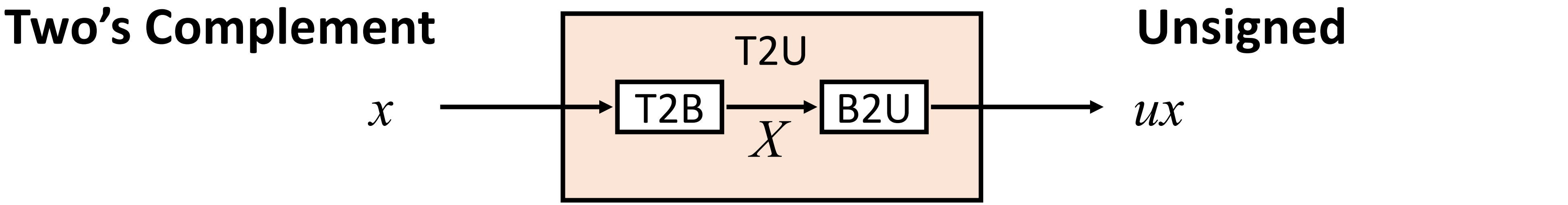
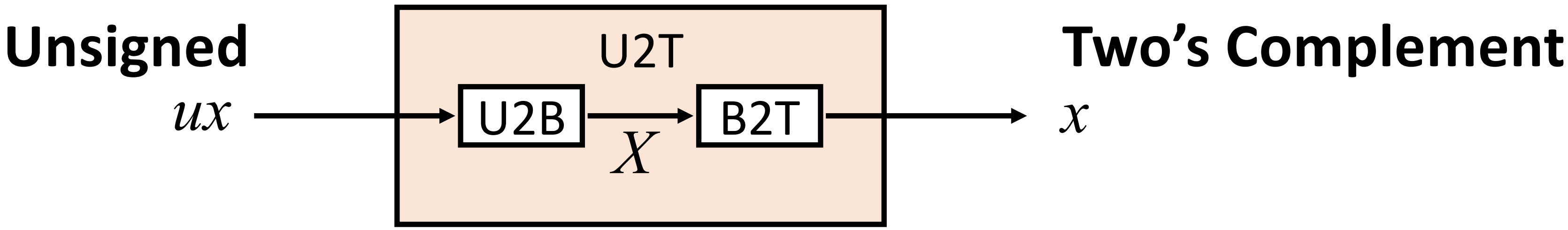
Mapping Between Signed & Unsigned



Maintain Same Bit Pattern



Maintain Same Bit Pattern

- Mappings between unsigned and two's complement numbers:
  Keep bit representations and reinterpret

Mapping Signed ↔ Unsigned

Bits	Signed	Unsigned
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	-8	8
1001	-7	9
1010	-6	10
1011	-5	11
1100	-4	12
1101	-3	13
1110	-2	14
1111	-1	15

Signed $\xrightarrow{\text{T2U}}$ Unsigned

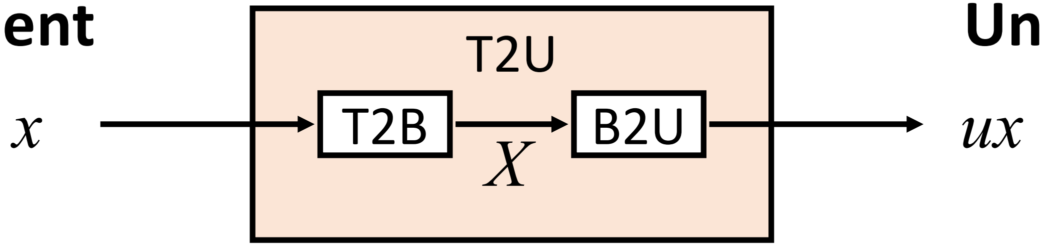
Signed $\xleftarrow{\text{U2T}}$ Unsigned

Mapping Signed ↔ Unsigned

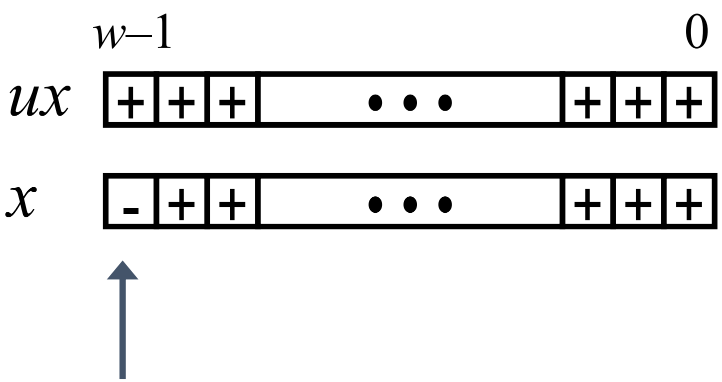
Bits	Signed		Unsigned
0000	0		0
0001	1		1
0010	2		2
0011	3		3
0100	4	=	4
0101	5		5
0110	6		6
0111	7		7
1000	-8		8
1001	-7		9
1010	-6		10
1011	-5	+/- 16	11
1100	-4		12
1101	-3		13
1110	-2		14
1111	-1		15

Relation between Signed & Unsigned

Two's Complement **Unsigned**



Maintain Same Bit Pattern



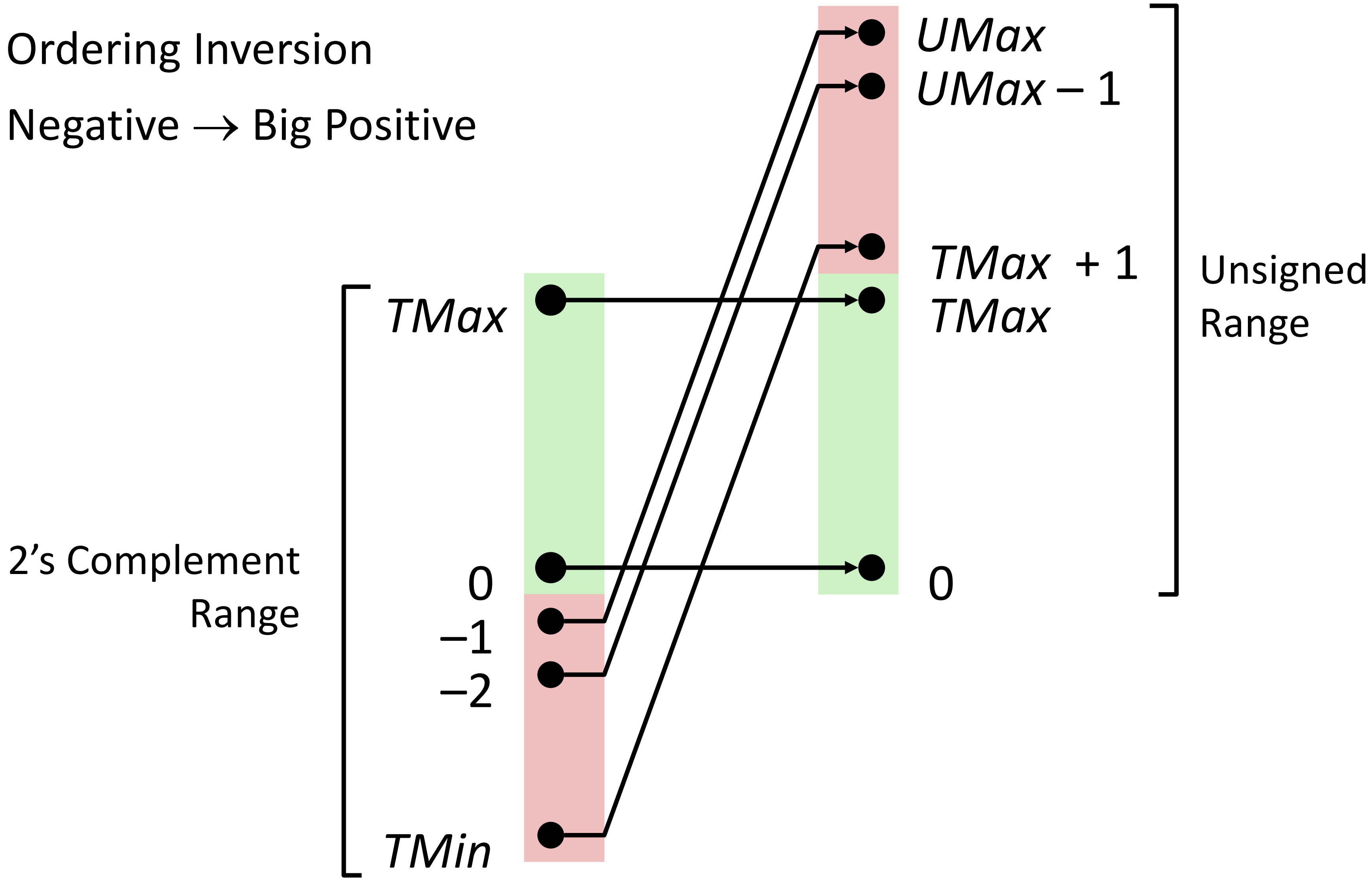
Large negative weight

becomes

Large positive weight

Conversion Visualized

- 2's Comp. → Unsigned
  - Ordering Inversion
  - Negative → Big Positive



Signed vs. Unsigned in C

- Constants
  - By default, considered as signed integers
  - Unsigned if have **"U"** as suffix

```
0U, 4294967259U
```

- Casting
  - Explicit casting between signed & unsigned same as U2T and T2U

```
int tx, ty;
unsigned ux, uy;
tx = (int) ux;
uy = (unsigned) ty;
```

  - Implicit casting also occurs via assignments and procedure calls

```
tx = ux;
uy = ty;
```

Casting Surprises

- Expression Evaluation
  - If there is a mix of unsigned and signed in single expression, ***signed values implicitly cast into unsigned values***
  - Including comparison operations **<, >, ==, <=, >=**
  - Examples for $W = 32$: **TMIN = -2,147,483,648 , TMAX = 2,147,483,647**

Constant$_1$	Constant$_2$	Relation	Evaluation
`0`	`0U`	`==`	`unsigned`
`-1`	`0`	`<`	`signed`
`-1`	`0U`	`>`	`unsigned`
`2147483647`	`-2147483648`	`>`	`signed`
`2147483647U`	`-2147483648`	`<`	`unsigned`
`-1`	`-2`	`>`	`signed`
`(unsigned) -1`	`-2`	`>`	`unsigned`
`2147483647`	`2147483648U`	`<`	`unsigned`
`2147483647`	`(int) 2147483648U`	`>`	`signed`

Summary

- **Casting Signed ↔ Unsigned: Basic Rules**
  - Bit pattern is maintained
  - But reinterpreted
  - Can have unexpected effects: adding or subtracting 2^w

  - Expression containing signed and unsigned int
    - **`(signed) int`** is cast into **`unsigned int`**!!

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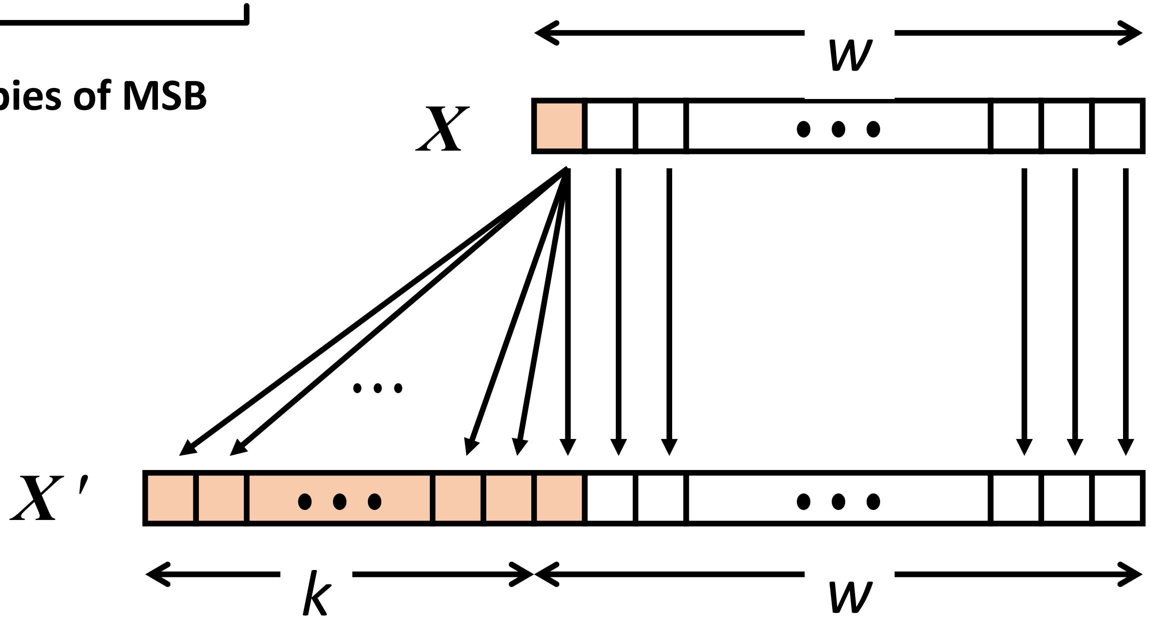
Sign Extension

- Task:
  - Given ***w***-bit signed integer *x*
  - Convert it to ***w+k***-bit integer with ***same value***
- Rule:
  - Make ***k*** copies of sign bit:
  - $X' = \underbrace{x_{w-1}, \ldots, x_{w-1}}_{k \text{ copies of MSB}}, x_{w-1}, x_{w-2}, \ldots, x_0$



Sign Extension Example

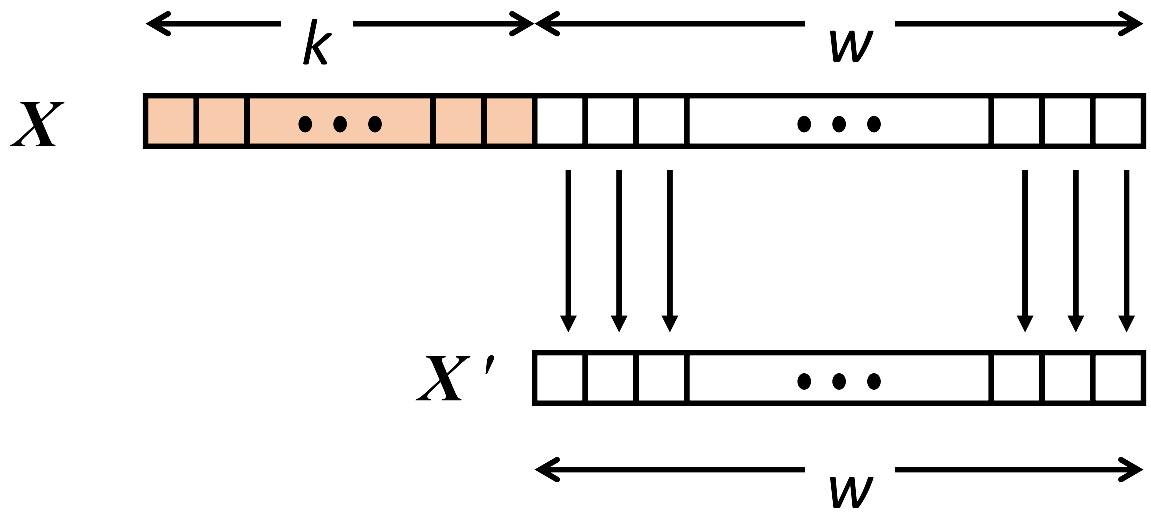
```
short int x =  15213;
int       ix = (int) x;
short int y = -15213;
int       iy = (int) y;
```

	Decimal	Hex	Binary
x	15213	3B 6D	00111011 01101101
ix	15213	00 00 3B 6D	00000000 00000000 00111011 01101101
y	-15213	C4 93	11000100 10010011
iy	-15213	FF FF C4 93	11111111 11111111 11000100 10010011

- Converting from smaller to larger integer data type
- C automatically performs sign extension

Truncate

- Task:
  - Given ***w+k***-bit signed integer *x*
  - Convert it to ***w***-bit integer ➔ ***Values may change!!***
- Rule:
  - ***k-***bit will be removed (as overflowed k-bit)
  - $X' = \underbrace{x_{2w-1}, \ldots, x_w}_{\text{To be truncated..}}, x_{w-1}, x_{w-2}, \ldots, x_0$



Summary

- **Expanding, Truncating: Basic Rules**
  - Expanding (e.g., short int to int)
    - Unsigned: zeros added
    - Signed: sign extension
    - Both yield expected result
  - Truncating (e.g., unsigned to unsigned short)
    - Unsigned/signed: bits are truncated
    - Result reinterpreted
    - Unsigned: mod operation
    - Signed: similar to mod
    - For small numbers yields expected behavior

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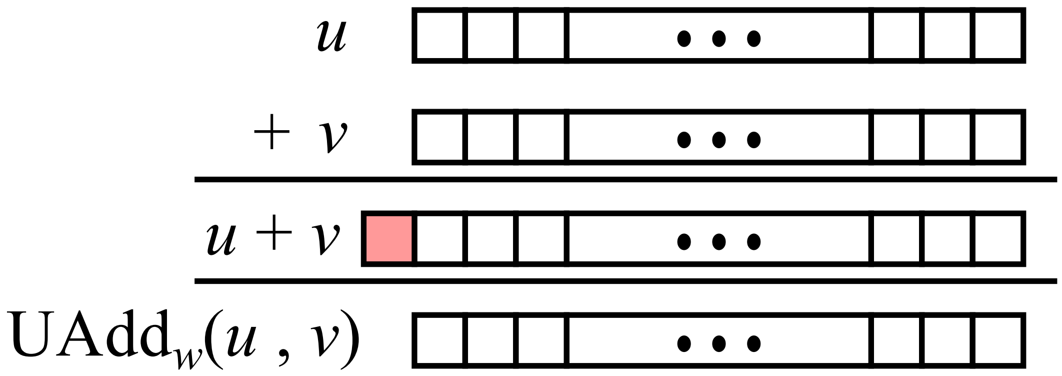
Unsigned Addition

Operands: *w* bits

True Sum: *w*+1 bits

Discard Carry: *w* bits



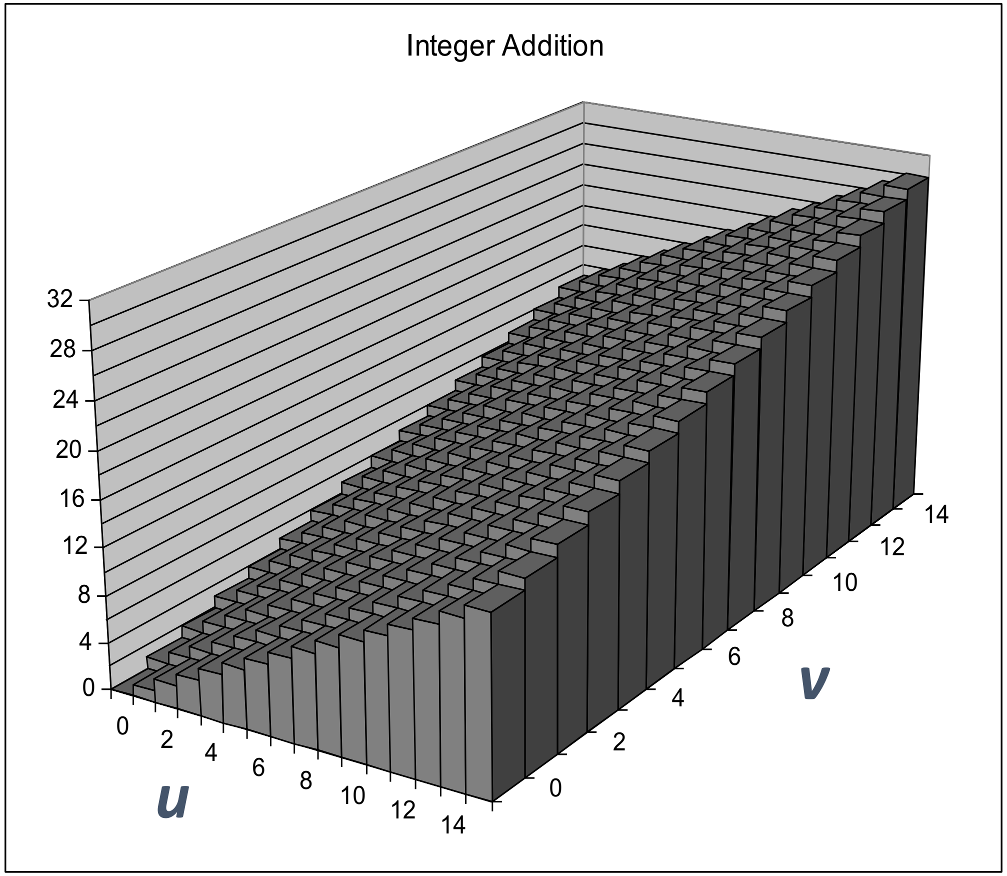
- Standard Addition Function
  - Ignores carry output
- Implements Modular Arithmetic

$$s \quad = \quad \mathrm{UAdd}_w(u\ ,\ v) \quad = \quad u + v \mod 2^w$$

Visualizing (Mathematical) Integer Addition

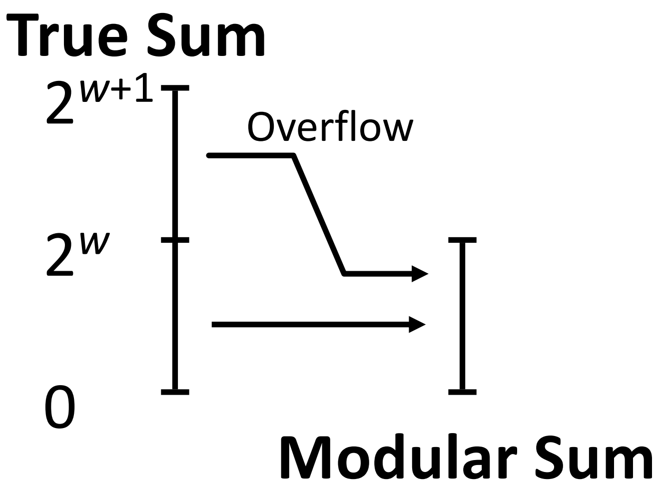
- Integer Addition
  - 4-bit integers *u*, *v*
  - Compute true sum $\text{Add}_4(u, v)$
  - Values increase linearly with *u* and *v*
  - Forms planar surface

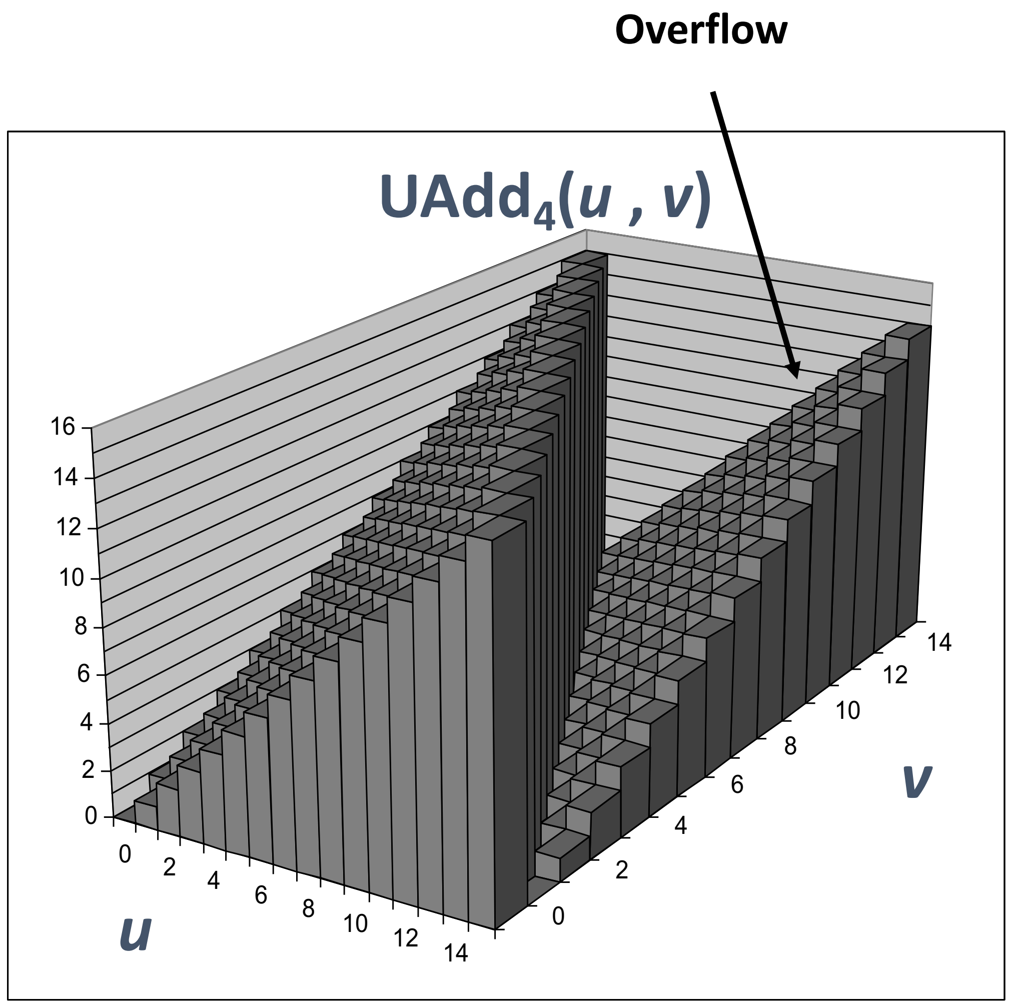
$\text{Add}_4(u, v)$



Visualizing Unsigned Addition

- Wraps Around
  - If true sum ≥ 2^w
  - At most once



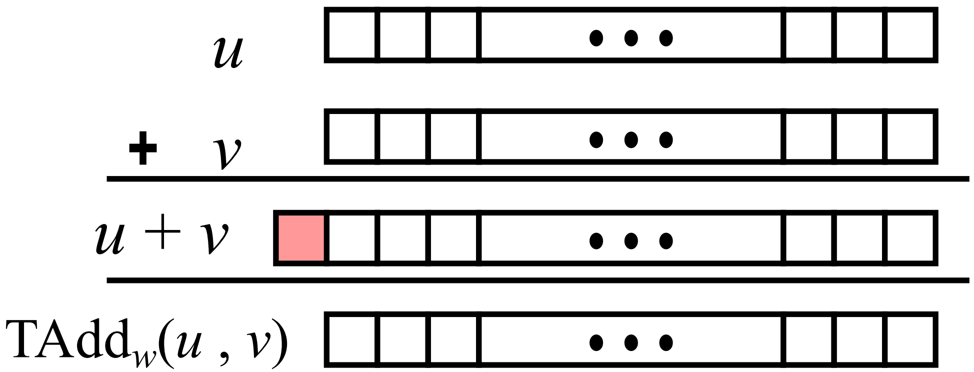


Two's Complement Addition

Operands: *w* bits

True Sum: *w*+1 bits

Discard Carry: *w* bits



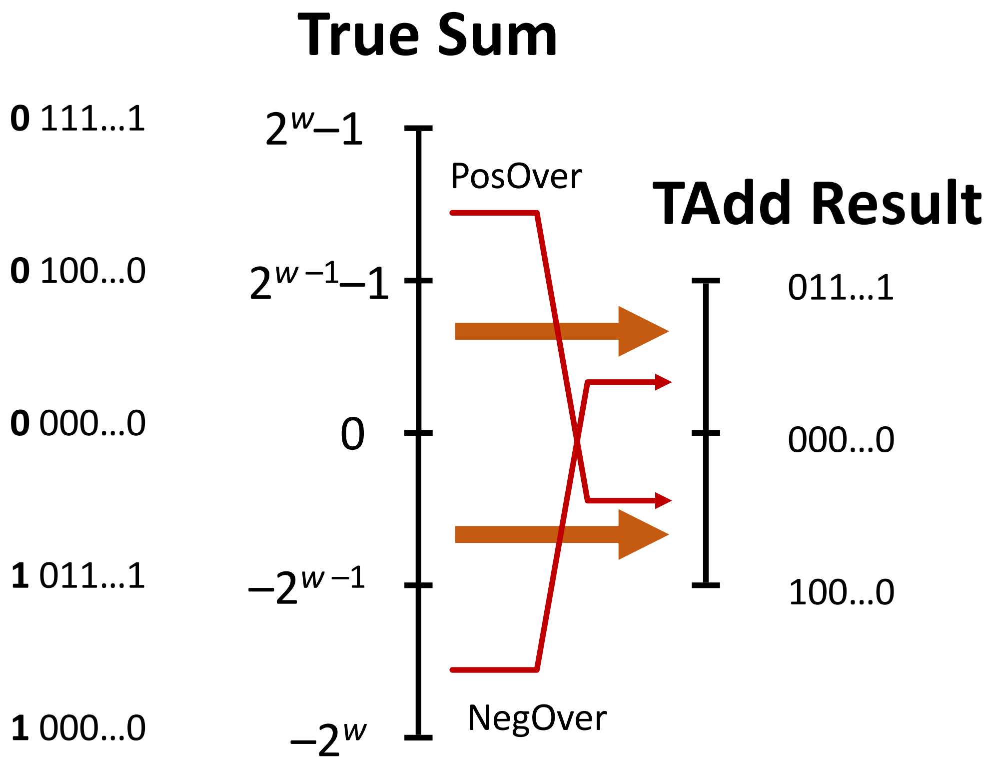
- TAdd and UAdd have Identical ***bit-level behavior (why?)***
  - Signed vs. unsigned addition in C:

```
int s, t, u, v;
s = (int) ((unsigned) u + (unsigned) v);
t = u + v
```

  - Will give `s == t`

TAdd Overflow

- Functionality
  - True sum requires w+1 bits
  - Drop off MSB
  - Treat remaining bits as 2's comp. integer

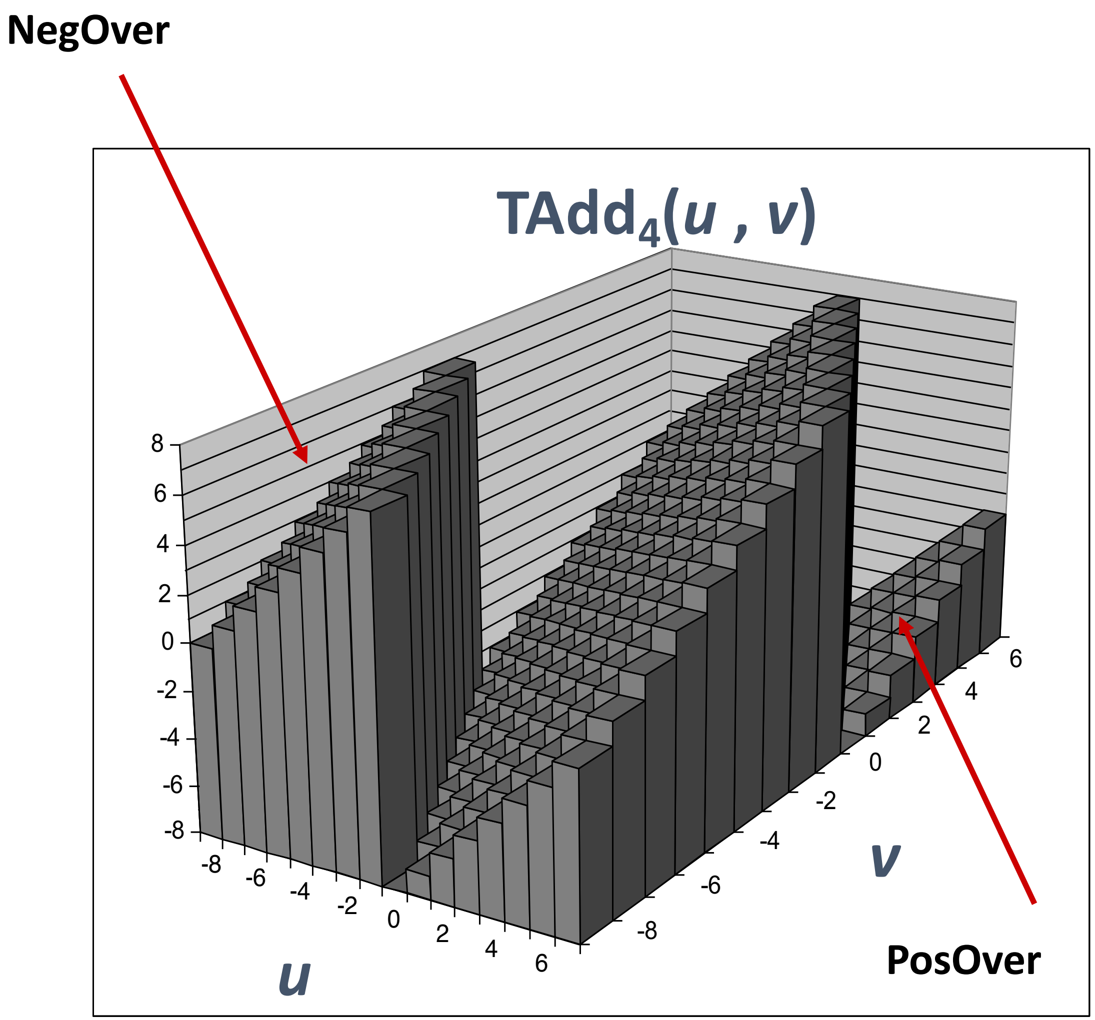


Example)

```
  127        01111111
+ 127      + 01111111
-----      ----------
  254(-2)    11111110(-2)
```

Visualizing 2's Complement Addition

- Values
  - 4-bit two's comp.
  - Range from -8 to +7
- Wraps Around
  - If sum $\geq 2^{w-1}$
    - Becomes negative
    - At most once
  - If sum $< -2^{w-1}$
    - Becomes positive
    - At most once



Multiplication

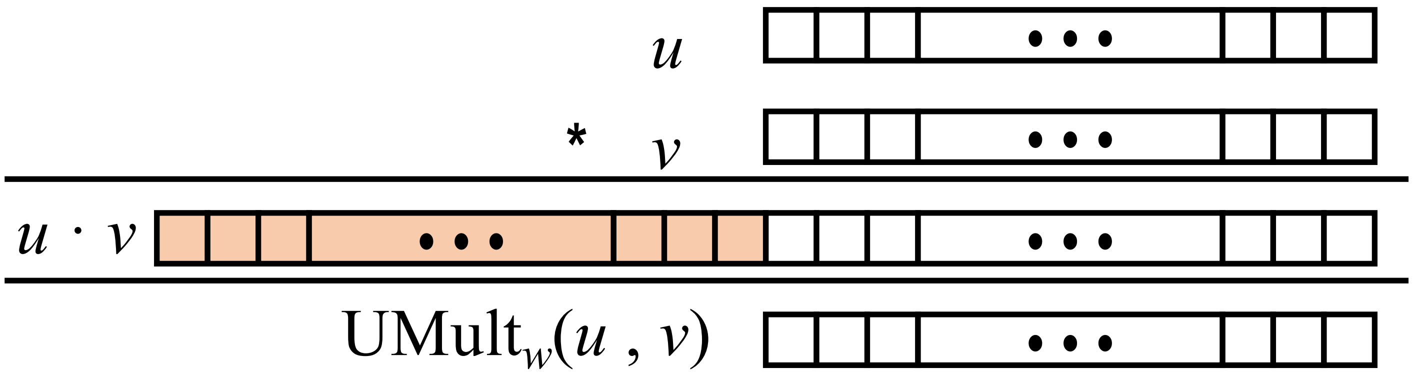
- Goal: Computing Product of *w*-bit numbers *x*, *y*
  - Either signed or unsigned
- But, exact results can be bigger than *w* bits
  - Unsigned: up to 2*w* bits
    - Result range: $0 \le x * y \le (2^{w} - 1)^{2} = 2^{2w} - 2^{w+1} + 1$
  - Two's complement min (negative): Up to 2*w*-1 bits
    - Result range: $x * y \ge (-2^{w-1})*(2^{w-1}-1) = -2^{2w-2} + 2^{w-1}$
  - Two's complement max (positive): Up to 2*w* bits, but only for $(TMin_w)^2$
    - Result range: $x * y \le (-2^{w-1})^{2} = 2^{2w-2}$
- So, maintaining exact results…
  - would need to keep expanding word size with each product computed
  - is done in software, if needed
    - e.g., by "arbitrary precision" arithmetic packages

Unsigned Multiplication in C

Operands: *w* bits

True Product: 2**w* bits

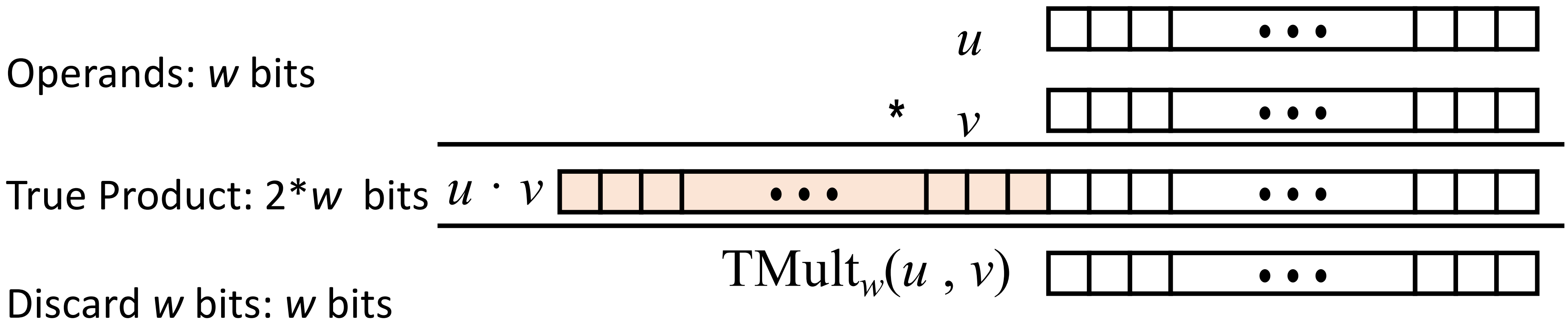
Discard *w* bits: *w* bits



- Standard Multiplication Function
  - Ignores high order *w* bits
- Implements Modular Arithmetic

$$\text{UMult}_w(u\ ,\ v) = u \cdot v \bmod 2^w$$

Signed Multiplication in C



- Standard Multiplication Function
  - Ignores high order *w* bits
  - Some of which are different for signed vs. unsigned multiplication
  - Lower bits are the same

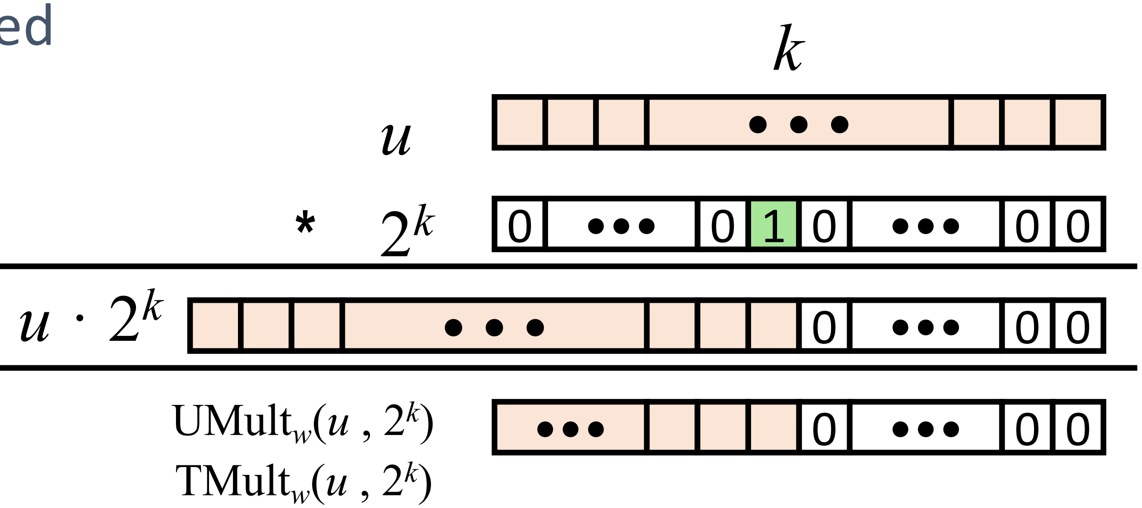
Power-of-2 Multiply with Shift

- Operation
  - **`u << k`** gives **`u * 2`**^{k}
    - Both signed and unsigned

Operands: *w* bits

True Product: *w*+*k* bits

Discard *k* bits: *w* bits



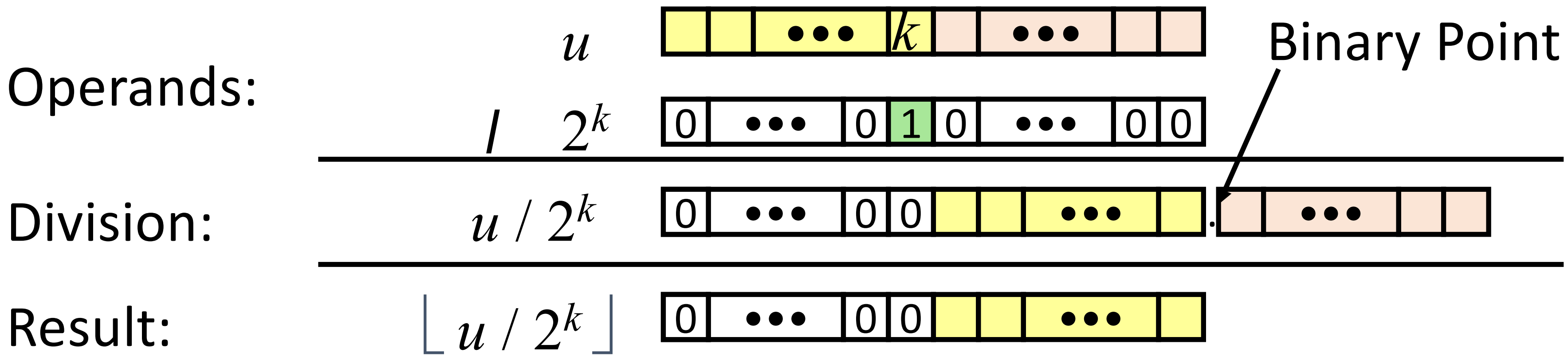
- Examples

```
 u << 3              ==    u * 8
(u << 5) - (u << 3)  ==    u * 24
```

  - Most machines shift and add faster than multiply
    - Compiler generates this code automatically

Unsigned Power-of-2 Divide with Shift

- Quotient of Unsigned by Power of 2
  - `u >> k` gives $\lfloor u / 2^k \rfloor$
  - Uses ***logical* right shift**



	Division	Computed	Hex	Binary
`x`	15213	15213	`3B 6D`	`00111011 01101101`
`x >> 1`	7606.5	7606	`1D B6`	`00011101 10110110`
`x >> 4`	950.8125	950	`03 B6`	`00000011 10110110`
`x >> 8`	59.4257813	59	`00 3B`	`00000000 00111011`

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- Representations in memory, pointers, strings

Arithmetic: Basic Rules

- Addition:
  - Unsigned/signed: Normal addition followed by truncate, same operation on bit level
  - Unsigned: addition mod 2^w
    - Mathematical addition + possible subtraction of 2^w
  - Signed: modified addition mod 2^w (result in proper range)
    - Mathematical addition + possible addition or subtraction of 2^w

- Multiplication:
  - Unsigned/signed: Normal multiplication followed by truncate, same operation on bit level
  - Unsigned: multiplication mod 2^w
  - Signed: modified multiplication mod 2^w (result in proper range)

When to Use Unsigned

- *Don't* use without understanding implications
  - Easy to make mistakes

```
unsigned i;
for (i = cnt-2; i >= 0; i--)
  a[i] += a[i+1];
```

  - Can be very subtle

```
#define DELTA sizeof(int)
int i;
for (i = CNT; i-DELTA >= 0; i-= DELTA)
  . . .
```

Counting Down with Unsigned

- Proper way to use unsigned as loop index

```
unsigned i;
for (i = cnt-2; i < cnt; i--)
  a[i] += a[i+1];
```

- See Robert Seacord, *Secure Coding in C and C++*
  - C Standard guarantees that unsigned addition will behave like modular arithmetic
    - 0 – 1 → *UMax*
- Even better

```
size_t i;
for (i = cnt-2; i < cnt; i--)
  a[i] += a[i+1];
```

  - Data type **size_t** defined as unsigned value with length = word size
  - Code will work even if **cnt** = *UMax*
  - What if **cnt** is signed and < 0?

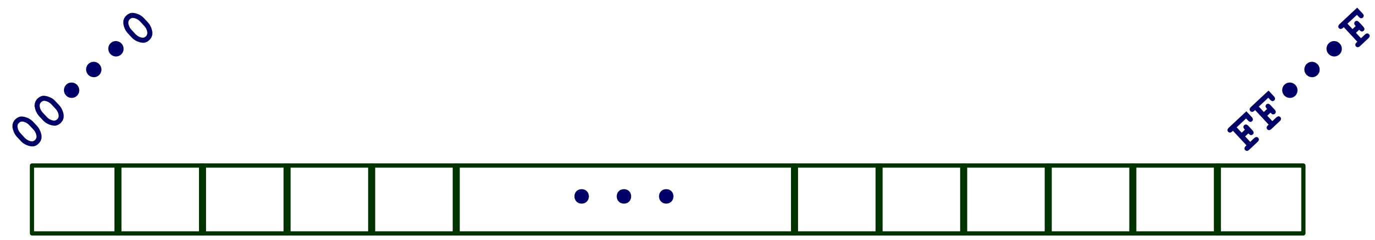
When to Use Unsigned (Con't)

- Do use when performing ***modular*** arithmetic
  - Multi-precision arithmetic
- Do use when using bits to represent **sets**
  - Logical right shift, no sign extension

Today: Bits, Bytes, and Integers

- Representing information as bits
- Bit-level manipulations
- Integers
  - Representation: unsigned and signed
  - Conversion, casting
  - Expanding, truncating
  - Addition, negation, multiplication, shifting
  - Summary
- Representations in memory, pointers, strings

Byte-Oriented Memory Organization



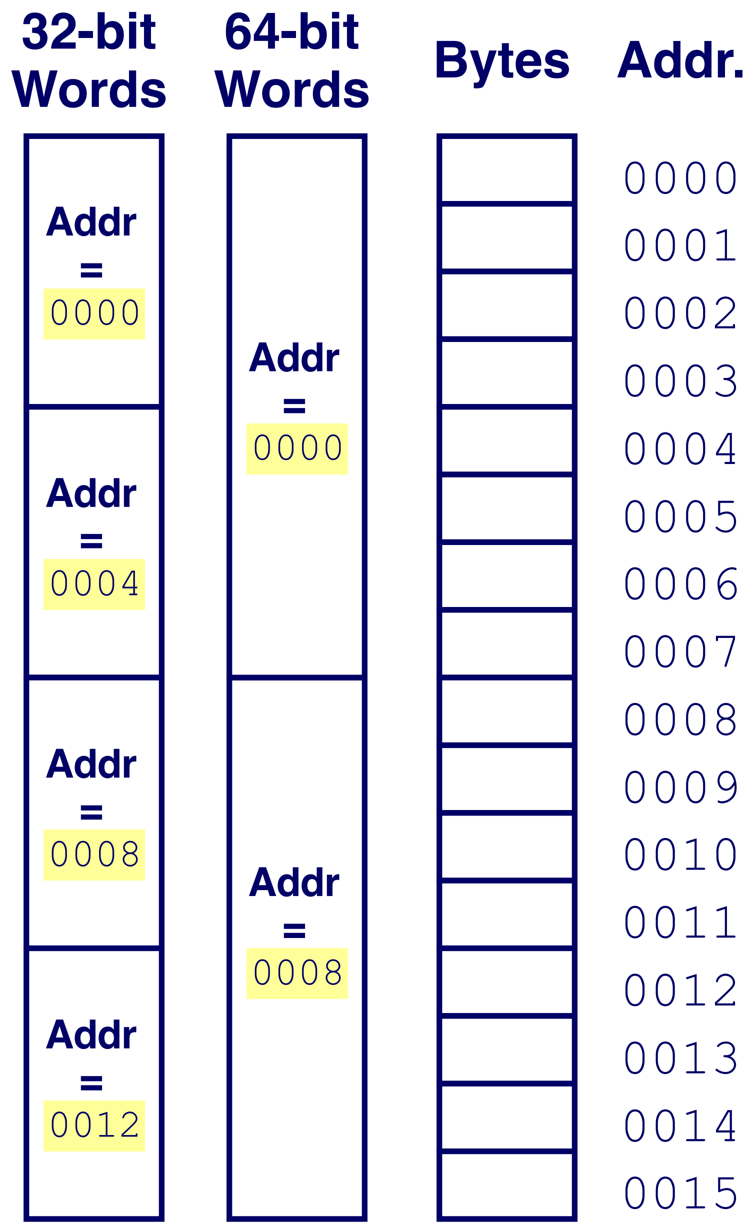
- Programs refer to data by address
  - Conceptually, envision it as a very large array of bytes
    - In reality, it’s not, but can think of it that way
  - An address is like an index into that array
    - A pointer variable stores an address
- Note: system provides private address spaces to each ***process***

Machine Words

- Any given computer has a fixed-size **word**
  - Nominal size of integer-valued data and addresses
- Decades ago, most machines used 32 bits (4 bytes) as word size
  - Limits addresses to 4GB (2^{32} bytes)
- Most machines now have 64-bit word size
  - Potentially, could have 18 EB (exabytes) of addressable memory
- Machines still support multiple data formats
  - Fractions or multiples of word size
  - Always integral number of bytes

Word-Oriented Memory Organization

- Addresses Specify Byte Locations
  - Address of first byte in word
  - Addresses of successive words differ by 4 (32-bit) or 8 (64-bit)



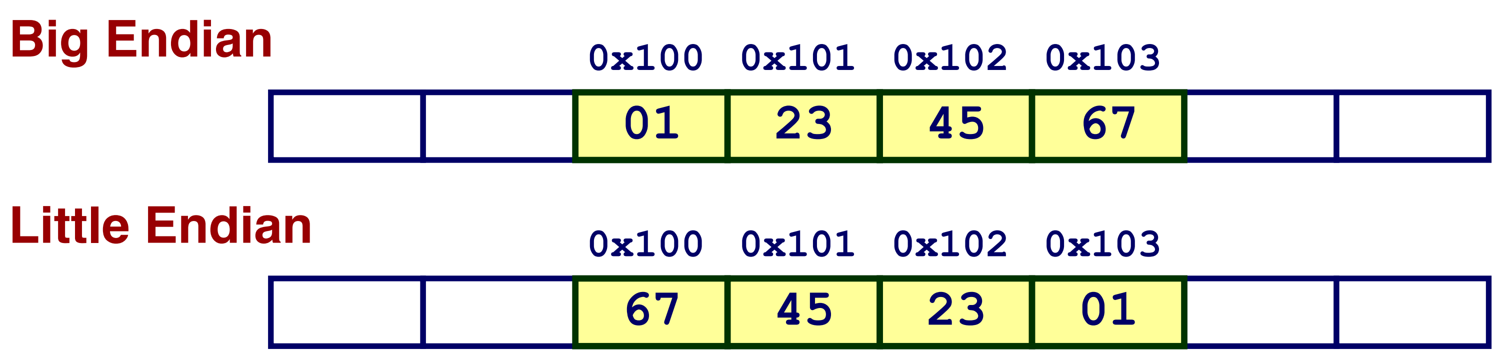
Byte Ordering

- So, how are the bytes within a multi-byte word ordered in memory?

- Conventions
  - Big Endian: Sun, PPC Mac, Internet
    - Least significant byte has highest address
  - Little Endian: x86, ARM processors running Android, iOS, and Windows
    - Least significant byte has lowest address

Byte Ordering Example

- Example
  - Variable x has 4-byte value of 0x01234567
  - Address given by &x is 0x100



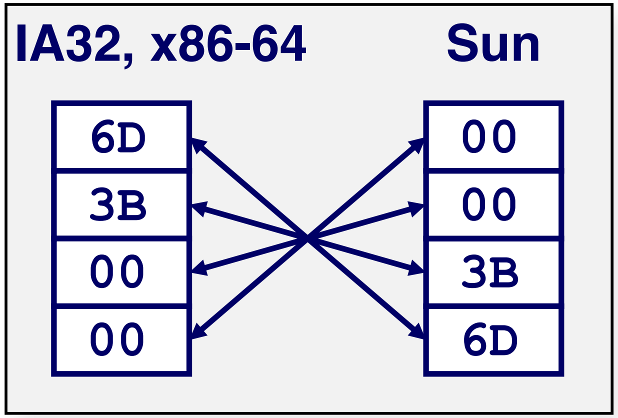
Representing Integers

Decimal: `15213`

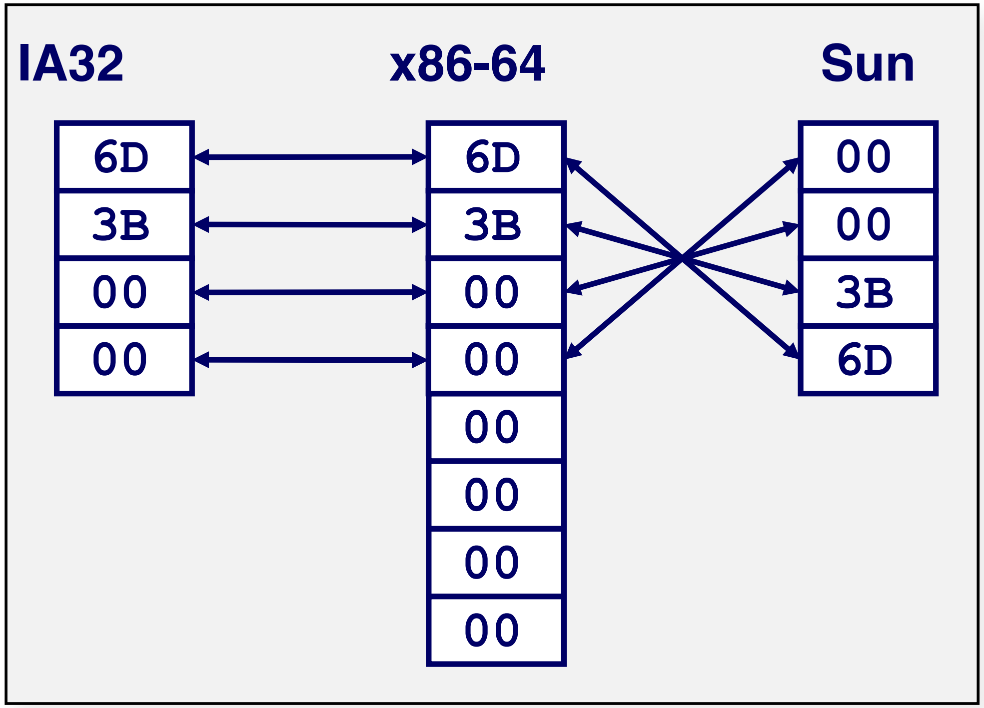
Binary: `0011 1011 0110 1101`

Hex: `3 B 6 D`

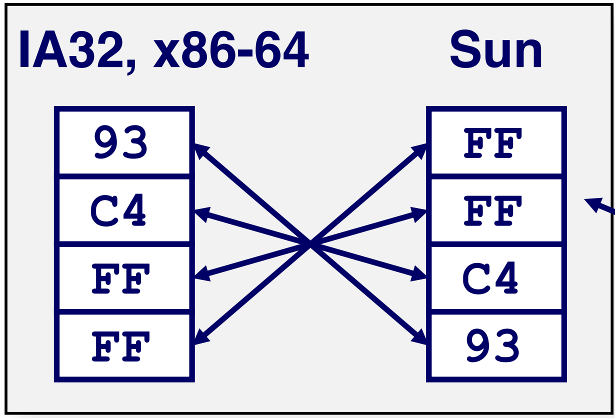
```
int A = 15213;
```




```
long int C = 15213;
```




```
int B = -15213;
```



Two's complement representation

Examining Data Representations

- Code to print byte-representation of data
  - Casting pointer to **`unsigned char*`** allows treatment as a byte array

```
typedef unsigned char *pointer;

void show_bytes(pointer start, size_t len){
  size_t i;
  for (i = 0; i < len; i++)
    printf(”%p\t%.2x\n",start+i, start[i]);
  printf("\n");
}
```

`printf` directives:

`%p`: Print pointer

`%x`: Print Hexadecimal

show_bytes Execution Example

```
int a = 15213;
printf("int a = 15213;\n");
show_bytes((pointer) &a, sizeof(int));
```

Result (Linux x86-64):

```
int a = 15213;
0x7fffb7f71dbc    6d
0x7fffb7f71dbd    3b
0x7fffb7f71dbe    00
0x7fffb7f71dbf    00
```

Representing Pointers

```
int B = -15213;
int *P = &B;
```

Sun	IA32	x86-64
EF	AC	3C
FF	28	1B
FB	F5	FE
2C	FF	82
		FD
		7F
		00
		00

- Different compilers & machines assign different locations to objects
- Even get different results each time run program

Representing Strings

```
char S[6] = "18213";
```

- Strings in C
  - Represented by array of characters
  - Each character encoded in ASCII format
    - Standard 7-bit encoding of character set
    - Character “0” has code 0x30
      - Digit *i* has code 0x30+*i*
  - String should be null-terminated
    - Final character = 0
- Compatibility
  - Byte ordering not an issue?

ASCII control characters			ASCII printable characters					
00	NULL	(Null character)	32	space	64	@	96	`
01	SOH	(Start of Header)	33	!	65	A	97	a
02	STX	(Start of Text)	34	"	66	B	98	b
03	ETX	(End of Text)	35	#	67	C	99	c
04	EOT	(End of Trans.)	36	$	68	D	100	d
05	ENQ	(Enquiry)	37	%	69	E	101	e
06	ACK	(Acknowledgement)	38	&	70	F	102	f
07	BEL	(Bell)	39	'	71	G	103	g
08	BS	(Backspace)	40	(	72	H	104	h
09	HT	(Horizontal Tab)	41	)	73	I	105	i
10	LF	(Line feed)	42	*	74	J	106	j
11	VT	(Vertical Tab)	43	+	75	K	107	k
12	FF	(Form feed)	44	,	76	L	108	l
13	CR	(Carriage return)	45	-	77	M	109	m
14	SO	(Shift Out)	46	.	78	N	110	n
15	SI	(Shift In)	47	/	79	O	111	o
16	DLE	(Data link escape)	48	0	80	P	112	p
17	DC1	(Device control 1)	49	1	81	Q	113	q
18	DC2	(Device control 2)	50	2	82	R	114	r
19	DC3	(Device control 3)	51	3	83	S	115	s
20	DC4	(Device control 4)	52	4	84	T	116	t
21	NAK	(Negative acknowl.)	53	5	85	U	117	u
22	SYN	(Synchronous idle)	54	6	86	V	118	v
23	ETB	(End of trans. block)	55	7	87	W	119	w
24	CAN	(Cancel)	56	8	88	X	120	x
25	EM	(End of medium)	57	9	89	Y	121	y
26	SUB	(Substitute)	58	:	90	Z	122	z
27	ESC	(Escape)	59	;	91	[	123	{
28	FS	(File separator)	60	<	92	\	124	|
29	GS	(Group separator)	61	=	93	]	125	}
30	RS	(Record separator)	62	>	94	^	126	~
31	US	(Unit separator)	63	?	95	_		
127	DEL	(Delete)						

Integer C Puzzles

- `x < 0` ➔ `((x*2) < 0)`
- `ux >= 0`
- `x & 7 == 7` ➔ `(x<<30) < 0`
- `ux > -1`
- `x > y` ➔ `-x < -y`
- `x * x >= 0`
- `x > 0 && y > 0` ➔ `x + y > 0`
- `x >= 0` ➔ `-x <= 0`
- `x <= 0` ➔ `-x >= 0`
- `(x|-x)>>31 == -1`
- `ux >> 3 == ux/8`
- `x >> 3 == x/8`
- `x & (x-1) != 0`

Initialization

```
int x = foo();

int y = bar();

unsigned ux = x;

unsigned uy = y;
```