Lecture 02
Representations

CS213 – Intro to Computer Systems

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Slides adapted from:
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Northwestern

Announcements

- Slides are posted on Canvas
  - Recordings are under the Panopto tab on Canvas too

- Homework 1 available after class on Canvas page
  - Practice problems on binary-to-hex-to-decimal conversion and integer encodings
  - Today's lecture will finish the content you need for it

  - Due next week Wednesday
    - I need to create Gradescope so you can submit it. Should happen tomorrow.

Today's Goals

- Discuss data representation in memory

- Explore data representations
  - Integers, signed and unsigned
  - Different bit widths
  - Translating between encoding schemes
  - Other encodings besides integers

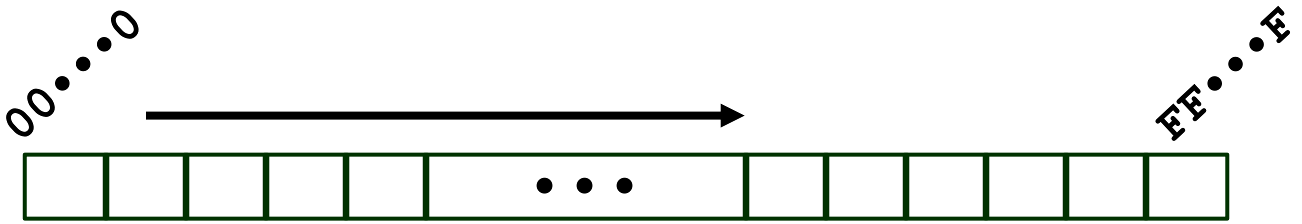
Outline

- **Memory**
- Encoding
- Integer Encodings
  - Signed Integers
  - Converting Sign
  - Converting Length
- Other encodings

Byte-oriented memory organization

- We've seen how sequences of bits can express numbers
  - And how we usually work with groups of 8 bits (***bytes***) for convenience

- In a computer system, bytes can be stored in memory
  - Conceptually, memory is a very large array of bytes
  - Each byte has its own address (≈ pointer)



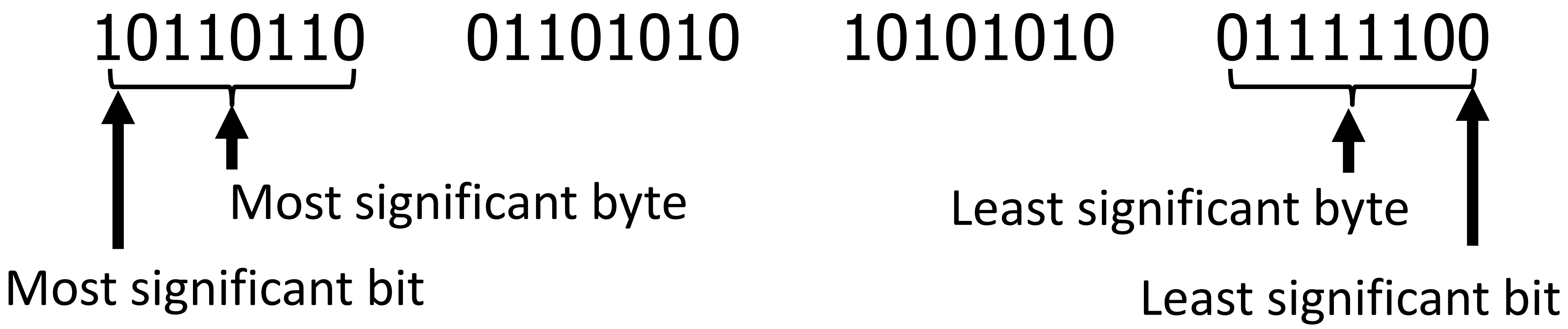
- Compiler + run-time system control allocation
  - Where different program objects should be stored
  - Multiple mechanisms, each with its own region: static, stack, and heap

Most/least significant bits/bytes

- When working with sequences of bits (or sequences of bytes), need to be able to talk about specific bits (bytes)

  - Most Significant bit (MSb) and Most Significant Byte (MSB)
    - Have the largest possible contribution to numeric value
    - Leftmost when writing out the binary sequence

  - Least Significant bit (LSb) and Least Significant Byte (LSB)
    - Have the smallest possible contribution to numeric value
    - Rightmost when writing out the binary sequence



Addressing and byte ordering

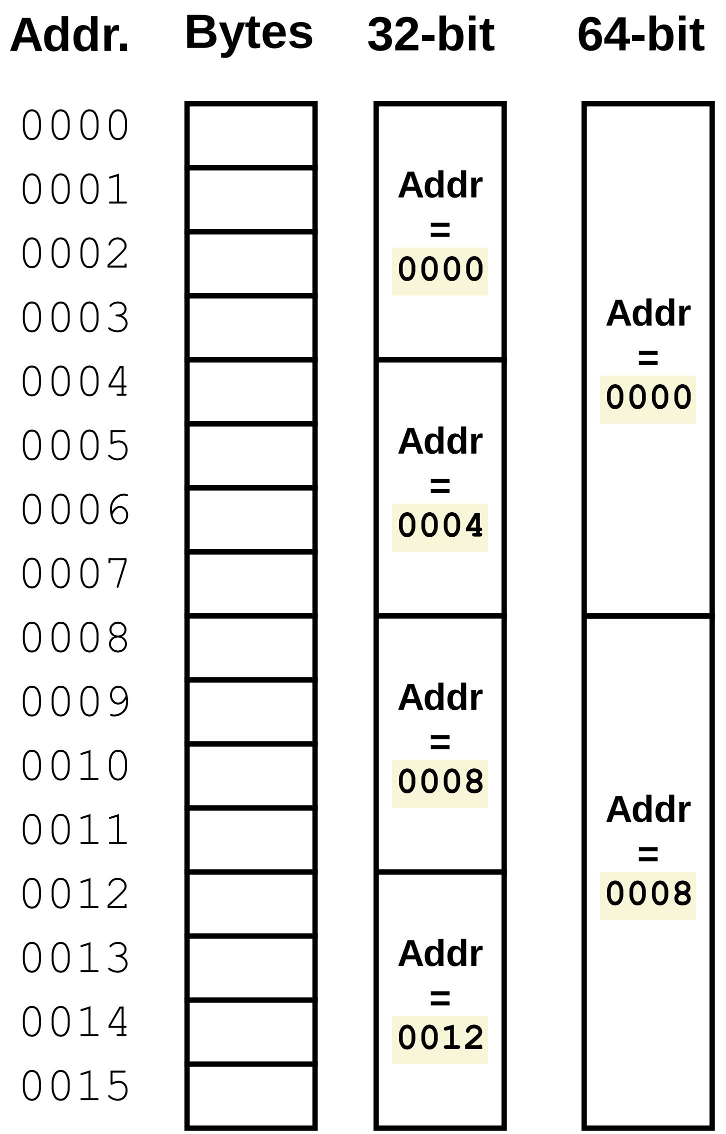
- For data that spans multiple bytes, need to agree on two things
  - **1. What should be the address of the object?** (each byte has its own!)
    - And by extension, given an address, how do we find the relevant bytes (same question!)
  - **2. How should we order the bytes in memory?**
    - Do we put the most or least significant byte at the first address?

There isn't always one correct answer

- Different systems can pick different answers! (mostly for 2nd Q)
  - Very nice illustration of two overarching principles in systems:
    You need to know the specifics of the system you're using!
    - Many questions don't really have right or wrong answers!
    - Instead, they have tradeoffs. What the "right" answer is depends on context!
  - Different answers across systems is perfectly fine
    - But all the parts of a given system must agree with each other!

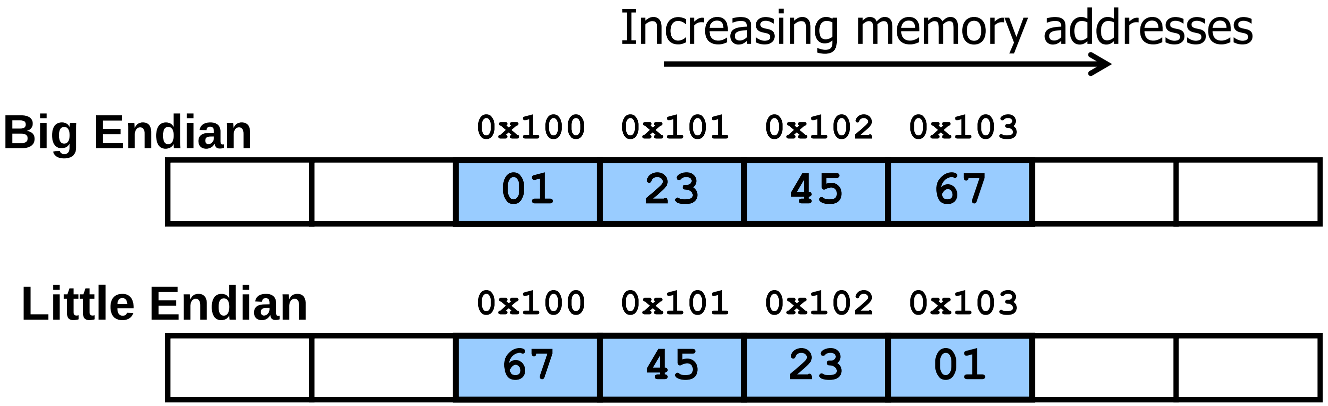
1. Addressing data in memory

- All addresses refer to bytes
  - Never bits
- For multi-byte objects, the lowest address refers to the entire object
  - Addresses of successive objects differ by 4 (32-bit) or 8 (64-bit)
- Systems pretty much universally use the address of the first byte as the address for the whole object
  - I’m not aware of any system that does otherwise
  - But there could be some weirdo systems out there (or historically)



2. Byte ordering

- How to order bytes within a multi-byte object in memory
  - Only relevant when working with data larger than a byte!
- Conventions
  - Big Endian: Oracle/Sun (SPARC), IBM (PowerPC), Computer Networks
    - Most significant byte has lowest address (comes first)
  - Little Endian: Intel (x86, x86-64)
    - Least significant byte has lowest address (comes first)
- Example
  - 4-byte piece of data: **`0x01234567`**
  - Address of that data is **`0x100`**



Practice: reading memory

- Assume memory is **Little Endian**
  - So the Least Significant Byte comes first

1. What is the four-byte value at 0x2010?

2. What is the two-byte value at 0x2014?

3. What is the one-byte value at 0x2016?

Address	**Value**
0x2010	0x37
0x2011	0x1A
0x2012	0xBE
0x2013	0x98
0x2014	0x0C
0x2015	0x80
0x2016	0x42

Practice: reading memory

- Assume memory is **Little Endian**
  - So the Least Significant Byte comes first

1. What is the four-byte value at 0x2010?
   0x98BE1A37
2. What is the two-byte value at 0x2014?
   0x800C
3. What is the one-byte value at 0x2016?
   0x42

Address	**Value**
0x2010	0x37
0x2011	0x1A
0x2012	0xBE
0x2013	0x98
0x2014	0x0C
0x2015	0x80
0x2016	0x42

Practice: reading memory

- Change: assume memory is **Big Endian**
  - So the Most Significant Byte comes first

1. What is the four-byte value at 0x2010?
   0x371ABE98

2. What is the two-byte value at 0x2014?
   0x0C80

3. What is the one-byte value at 0x2016?
   0x42

Note: endianness doesn't affect one-byte values!

Address	**Value**
0x2010	0x37
0x2011	0x1A
0x2012	0xBE
0x2013	0x98
0x2014	0x0C
0x2015	0x80
0x2016	0x42

Outline

- Memory
- **Encoding**
- Integer Encodings
  - Signed Integers
  - Converting Sign
  - Converting Length
- Other encodings

What do bits and bytes ***mean*** in a system?

- The answer is: it depends!

- Depending on the context, the bits `11000011` could mean
  - The number 195
  - The number -61
  - The number -19/16
  - The character '├'
  - The **`ret`** x86 instruction

- You have to know the context to make sense of any bits you have!
  - Looking at the same bits in different contexts can lead to interesting results
  - Information = bits + context!

- An ***encoding*** is a set of rules that gives meaning to bits

An example encoding: ASCII characters

- ASCII = American Standard Code for Information Interchange
  - Standard dating from the 60s
- Maps 8-bit* bit patterns to characters
  - (* the standard is actually 7-bit, leaving the 8^{th} bit unused)
  - We already know how to go from sequences of bits (base 2) to integers
  - Need to take one more step, and interpret these integers as characters
- Examples
  - $0100\ 0001_2$ = 0x41 = 65_{10} = **`A'**
  - $0100\ 0010_2$ = 0x42 = 66_{10} = **`B'**
  - $0011\ 0000_2$ = 0x30 = 48_{10} = **`0'**
  - $0011\ 0001_2$ = 0x31 = 49_{10} = **`1'**
- Reference: https://www.asciitable.com/

Full ASCII table

Values listed in:

Decimal

Hexadecimal

Octal

HTML

Character

Dec	Hx	Oct	Char		Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL	(null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH	(start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX	(start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX	(end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT	(end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ	(enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK	(acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL	(bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB	(horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF	(NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT	(vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF	(NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR	(carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO	(shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI	(shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE	(data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1	(device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2	(device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3	(device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4	(device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK	(negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN	(synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB	(end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN	(cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM	(end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB	(substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC	(escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS	(file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS	(group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS	(record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US	(unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

Encodings are just determined by people

- There's no inherent **truth** in the design of an encoding
  - Although some encodings are nice or annoying for various reasons
  - Example: it's nice in ASCII that letters are in alphabetical order

- You could come up with an entirely new way of encoding characters
  - The hard part would be getting everyone else to agree to use it

Open Question + Break

- **What things might we want to encode?**

Open Question + Break

- **What things might we want to encode?**

  - Numbers
    - Signed and unsigned integers
    - Real numbers
    - Mathematical symbols: ∞ π

  - Language
    - Characters in various different languages ΩИس서北
    - Emoji 😱😠😁😭🤷‍♀️🦃🎶🎂✨🚀🍢

  - Colors, Playing Cards, User Actions, anything!

Outline

- Memory
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- **Integer Encodings**
  - Signed Integers
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Integer types in C

- C type provides both size and encoding rules

- Integer types in C come in two flavors
  - Signed: **`short`**, **`signed short`**, **`int`**, **`long`**, …
  - Unsigned: **`unsigned char`**, **`unsigned short`**, **`unsigned int`**, …

- And in multiple different sizes
  - 1 byte: **`signed char`**, **`unsigned char`**
  - 2 bytes: **`short`**, **`unsigned short`**
  - 4 bytes: **`int`**, **`unsigned int`**
  - Etc.

Sizes of C types are system dependent

- Portability
  - Some programmers assume an **`int`** can be used to store a pointer
  - OK for most 32-bit machines, but fails for 64-bit machines!
- How I program
  - Use fixed width integer types from <stdint.h>
  - int8_t, int16_t, int32_t
  - uint8_t, uint16_t, uint32_t

C Data Type	Intel IA32	x86-64	C Standard* (C99)
char	1	1	≥1
short	2	2	≥2
int	4	4	≥2
long	4	8	≥4
long long	8	8	≥8
float	4	4	
double	8	8	
pointer	4	8	Widths for data, code pointers may differ!

Expressing C types in bits

- Two families of encodings to express integers using bits
  - ***Unsigned*** encoding for unsigned integers
  - ***Two's complement*** encoding for signed integers

- Each encoding will use a fixed size (# of bits)
  - For a given machine
  - Size + encoding family determine which C type we're representing
  - Fixed size is because computers are finite!

Unsigned integer encoding

- Just write out the number in binary
  - Works for 0 and all positive integers

- Example: encode 104_{10} as an **unsigned** 8-bit integer
  - $104_{10} = 0\times2^7 + 1\times2^6 + 1\times2^5 + 0\times2^4 + 1\times2^3 + 0\times2^2 + 0\times2^1 + 0\times2^0$

⇒ **`01101000`**

⇒ **`0x68`**

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

(Binary To Unsigned)

Bounds of unsigned integers

- For a fixed width ***w***, a limited range of integers can be expressed
  - Smallest value (we will call ***UMin***):
    - all 0s bit pattern: 000…0, value of 0
  - Largest value (we will call ***UMax***):
    - all 1s bit pattern: 111...1, value of $2^w – 1$
    - $2^w – 1 = 1×2^{w-1} + 1×2^{w-2} + ... + 1×2^1 + 1×2^0 = 11111...$
- Maximum 8-bit number = 2^8-1 = 256-1 = 255

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- Memory
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  - **Signed Integers**
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Encoding signed integers

- What’s different about representing a signed number?
  - It can be negative!

- So, we’re going to have to somehow represent values that are negative and positive

- There are actually many different encodings capable of doing this
  - This is when that “nice encoding” versus “annoying encoding” matters

Attempting signed encoding

- Goal: encode integers that can be positive or negative

- First attempt: we can use the most significant bit for sign
  - "Sign-and-magnitude" encoding

  - In 8-bits:
    - +4 = 00000100
    - -4 = 10000100

+127 = 01111111
-127 = 11111111

+0 = 00000000
-0 = 10000000

- Annoying problem: we have two representations of zero!

- Also annoying: hardware to do math with signed and unsigned numbers gets complicated…

Two's complement encoding

- Bad news: need to make the encoding more complicated
- Good news: it will actually work

- Plan:
  - Start with unsigned encoding, but make ONLY the largest power negative
  - Example: for 8 bits, most significant bit is worth -2^7 not $+2^7$ (other bits are still positive)

- To encode a negative integer
  - First, set the most significant bit to 1 to start with a big negative number
  - Then, add positive powers of 2 (the other bits) to "get back" to number we want

- Example: encode -6 as a 4-bit two's complement integer
  - $-6_{10} = 1 \times -2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^1$ ⇒ `0b1010` ⇒ **`0xa`**

Two's complement examples

- Encode -100 as an 8-bit two's complement number

  - $-100_{10} = 1 \times -2^7 + 0 \times 2^6 + 0 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$

    $-128 \quad + 0 \quad + 0 \quad + 16 \quad + 8 \quad +4 \quad +0 \quad +0$

    Problem becomes:
    encode +28 as a 7-bit unsigned number

  - -100_{10} = 0b10011100 = 0x9C

  - **Shortcut:** determine positive version of number, flip it, and add one
    - 100_{10} = 0b01100100
    - Flipped = 0b10011011
    - Plus 1 = 0b10011100 = 0x9C   We'll talk about binary addition next lecture

Interpreting binary signed values

- Converting binary to signed:

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

Sign bit

- Note: most significant bit still tells us sign!! 1-> negative
  - Checking if a number is negative is just checking that top bit

- Zero problem is solved too
  - 0b00000000 = 0 0b10000000 = -128

- -1: 0b111…1 = -1 (regardless of number of bits!)

Bounds of two's complement integers

- For a fixed width ***w***, a limited range of integers can be expressed
  - Smallest value, most negative (we will call ***TMin***):
    - 1 followed by all 0s bit pattern: 100…0 = -2^{w-1}
  - Largest value, most positive (we will call ***TMax***):
    - 0 followed by all 1s bit pattern: 01...1, value of $2^{w-1} - 1$
- Beware the asymmetry! Bigger negative number than positive

Ranges for different bit amounts

	W			
	8	**16**	**32**	**64**
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
  - $|TMin| = TMax + 1$
    - Asymmetric range
  - $UMax = 2 * TMax + 1$
- C Programming
  - #include <limits.h>
  - Declares constants, 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 non-negative values
- **Uniqueness**
  - Every bit pattern represents unique integer value
  - Each representable integer has unique bit encoding
- $\Rightarrow$ **Can Invert Mappings**
  - Can go from bits to number and back, and vice versa
  - $U2B(x) = B2U^{-1}(x)$
    - Bit pattern for unsigned integer
  - $T2B(x) = B2T^{-1}(x)$
    - Bit pattern for two's complement integer

Practice + Break

- What range of integers can be represented with 5-bit two’s complement?

  - A   -31 to +31
  - B   -15 to +15
  - C   0 to +31
  - D   -16 to +15
  - E   -32 to +31

Practice + Break

- What range of integers can be represented with 5-bit two’s complement?

• A	-31 to +31	No asymmetry and 6-bits
• B	-15 to +15	No asymmetry
• C	0 to +31	Unsigned
• D	-16 to +15	Correct
• E	-32 to +31	6-bits

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Casting signed to unsigned

- C allows conversions from signed to unsigned (and vice versa)

```
short int          x =  15213;
unsigned short int ux = (unsigned short) x;
short int          y  = -15213;
unsigned short int uy = y; /* implicit cast! */
```

- Resulting value
  - Not based on a numeric perspective: keep the bits and ***reinterpret*** them!
  - Non-negative values unchanged
    - *ux* = 15213
  - Negative values change into (large) positive values (and vice versa)
    - *uy* = 50323
- Warning: Casts can be implicit in assignments or function calls!
  - More on that in a few slides

Mapping Signed ↔ Unsigned (4 bits)

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 ↔ Unsigned for 0000–0111: =

Signed → Unsigned for 1000–1111: + 16 (i.e., 2^4)

Unsigned → Signed for 1000–1111: - 16 (i.e., 2^4)

Large negative factor becomes large positive!

Signed vs Unsigned in C

- Constants
  - By default constants are considered to be **signed integers**
  - Unsigned with "U/u" as suffix: `0U, 4294967259U`
- **Expression evaluation**
  - If there is a mix of unsigned and signed in a single expression, ***signed values are converted to unsigned***
  - Including comparison operations!! **<, >, ==, <=, >=**
- Can lead to surprising behavior!
  - `-1 < 0U` ⇒ **false!**
  - -1 gets converted to unsigned
  - All 1s bit pattern ⇒ UMax! Definitely not less than 0!

Example

- Convert signed 8-bit number -120 into an unsigned number

1. Convert -120 into binary

2. Convert binary back into unsigned decimal

Example

- Convert signed 8-bit number -120 into an unsigned number

1. Convert -120 into binary
   -120 = -128 + 8 =

2. Convert binary back into unsigned decimal

Example

- Convert signed 8-bit number -120 into an unsigned number

1. Convert -120 into binary
   -120 = -128 + 8 =
   1x(-128) + 0x64 + 0x32 + 0x16 + 1x8 + 0x4 + 0x2 + 0x1

2. Convert binary back into unsigned decimal

Example

- Convert signed 8-bit number -120 into an unsigned number

1. Convert -120 into binary
   -120 = -128 + 8 =
   1x(-128) + 0x64 + 0x32 + 0x16 + 1x8 + 0x4 + 0x2 + 0x1
   0b 1000 1000

2. Convert binary back into unsigned decimal
   1x128 + 0x64 + 0x32 + 0x16 + 1x8 + 0x4 + 0x2 + 0x1
   128 + 8 = 136

Code Security Example

```
/* Kernel memory region holding user-accessible data */
#define KSIZE 1024
char kbuf[KSIZE];

/* Copy at most maxlen bytes from kernel region to user buffer */
int copy_from_kernel(void *user_dest, int maxlen) {
    /* Byte count len is minimum of buffer size and maxlen */
    int len = KSIZE < maxlen ? KSIZE : maxlen;
    memcpy(user_dest, kbuf, len);
    return len;
}
```

- Simplified example of code found in FreeBSD's implementation of **`getpeername`**
- There are legions of experts trying to find vulnerabilities in programs, not all with good intentions

Typical Usage

```
/* Kernel memory region holding user-accessible data */
#define KSIZE 1024
char kbuf[KSIZE];

/* Copy at most maxlen bytes from kernel region to user buffer */
int copy_from_kernel(void *user_dest, int maxlen) {
    /* Byte count len is minimum of buffer size and maxlen */
    int len = KSIZE < maxlen ? KSIZE : maxlen;
    memcpy(user_dest, kbuf, len);
    return len;
}
```

```
#define MSIZE 528

void getstuff() {
    char mybuf[MSIZE];
    copy_from_kernel(mybuf, MSIZE);
    printf("%s\n", mybuf);
}
```

Malicious Usage

```
/* Declaration of library function memcpy */
void *memcpy(void *dest, void *src, size_t n);
```

```
/* Kernel memory region holding user-accessible data */
#define KSIZE 1024
char kbuf[KSIZE];

/* Copy at most maxlen bytes from kernel region to user buffer */
int copy_from_kernel(void *user_dest, int maxlen) {
    /* Byte count len is minimum of buffer size and maxlen */
    int len = KSIZE < maxlen ? KSIZE : maxlen;
    memcpy(user_dest, kbuf, len);
    return len;
}
```

```
#define MSIZE 528

void getstuff() {
    char mybuf[MSIZE];
    copy_from_kernel(mybuf, -MSIZE);
    . . .
}
```

`size_t` is unsigned!

Outline

- Memory
- Encoding
- **Integer Encodings**
  - Signed Integers
  - Converting Sign
  - **Converting Length**
- Other encodings

Truncation

- May want to convert between numeric types of different sizes

- Going from a larger to a smaller number of bits is easy
  - ***Truncation***: drop bits from the most significant side until we fit
    - Values that can be represented by both types are preserved!
      - Including negative values!
    - Values that can't be represented by the smaller type are mapped to some that can (modular (= modulo) behavior)

- Example
  - 16 bits → 8 bits: ~~`10110010`~~ `01001000` → `01001000`

  - Unsigned: $45640_{10} \rightarrow 72_{10}$
    - $72_{10} = 45640_{10}$ modulo 2^8

  - Signed: $-52664_{10} \rightarrow 72_{10}$
    - $72_{10} = -52664_{10}$ modulo 2^8

This can cause bugs!!

See Ariane 5 explosion…

Extension

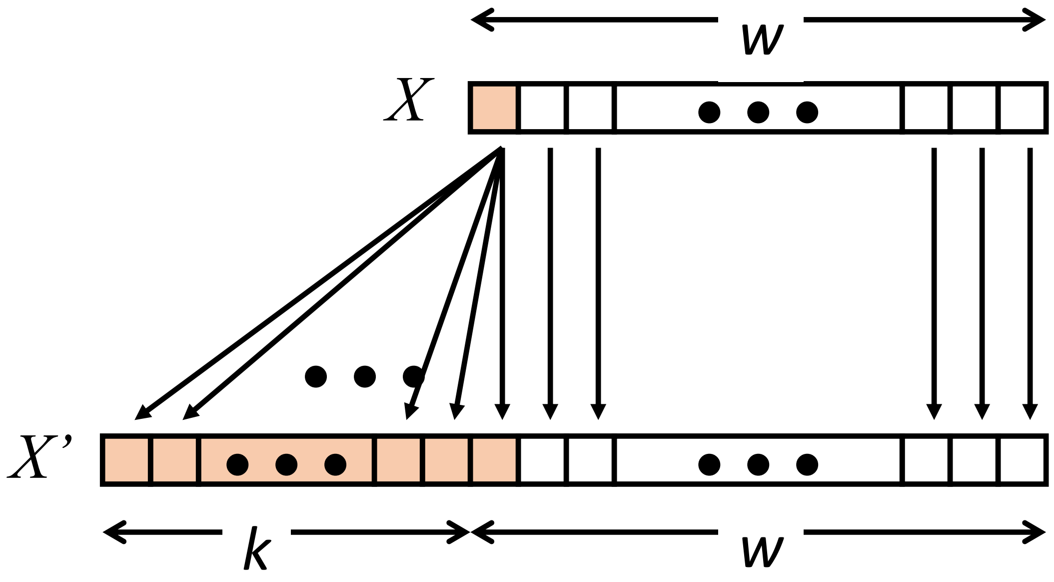
- Going from smaller to larger: what to do with the “new” bits?
  - These “new” bits go on the most significant side

- **Unsigned**: easy, pad with 0s!
  - Always safe to add 0s on the most significant end: $15213_{10} = 00015213_{10}$
  - Example: 8 bits → 16 bits: `01001000` → `00000000 01001000`
    - $72_{10} = 72_{10}$
  - Value is preserved!

Sign Extension

- Extending signed encodings takes more effort to preserve the value

- Duplicate Most significant bit when extending
  - If it's a zero, extend with zeros. If it's a one, extend with ones.



Example sign extension

- Extend -128 from an 8-bit to bigger versions

- 8-bit version:
  - -128 + 0 = 1x(-128) + all zeros = 0b1000 0000

- 9-bit version:
  - -256 + 128 = 1x(-256) + 1x128 + all zeros = 0b1 1000 0000

- 10-bit version:
  - -512 + 256 + 128 = 0b11 1000 0000

Sign Extension Examples

```
signed short x =  15213;
signed int  ix = (int) x;
signed short y = -15213;
signed 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 for signed types
  - If cast changes both sign and size, extends based on ***source*** signedness
  - But less confusing to write code that makes the types (and casts) explicit

Break + Practice

- Convert 16-bit 0x3427 to an 8-bit signed integer

- Convert 8-bit 0xF0 to a 16-bit signed integer

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

Break + Practice

- Convert 16-bit 0x3427 to an 8-bit signed integer
  - Process: truncate extra bits
  - Answer is **0x27**
- Convert 8-bit 0xF0 to a 16-bit signed integer
  - Process: sign extend. Is the most-significant bit one? Yes!
  - Answer is **0xFFF0**

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
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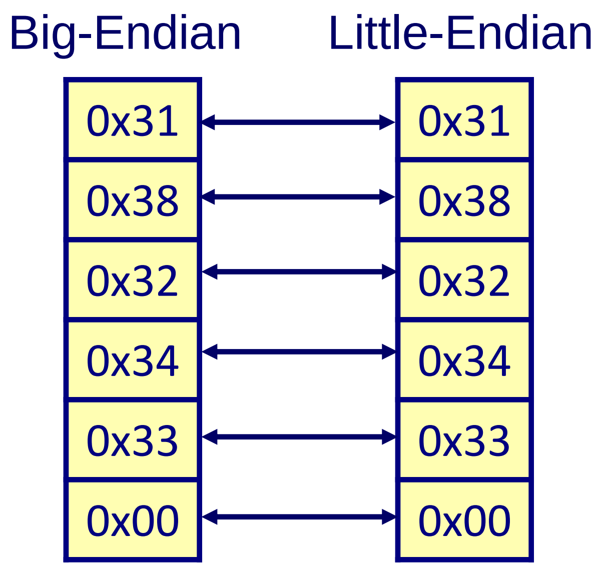
Encoding strings (The C way)

- Represented by array of characters
  - Each character encoded in ASCII format
  - NULL character (code 0) to mark the end

```
char S[6] = "18243";
```



- Compatibility
  - Byte ordering not an issue (data all single-byte!)
  - ASCII text files generally platform independent
    - Except for different conventions of line termination character(s)!

Encoding color

- RGB colors
  - 3-byte values
  - First byte is Red, then Green, then Blue

- Usually specified in hexadecimal
  - #FF0000 -> maximum red, zero green or blue
  - #4E2A84 -> 1/4 red, 1/8 blue, 1/2 green (Northwestern Purple)

- 2^{24} possible colors = 16777216 colors

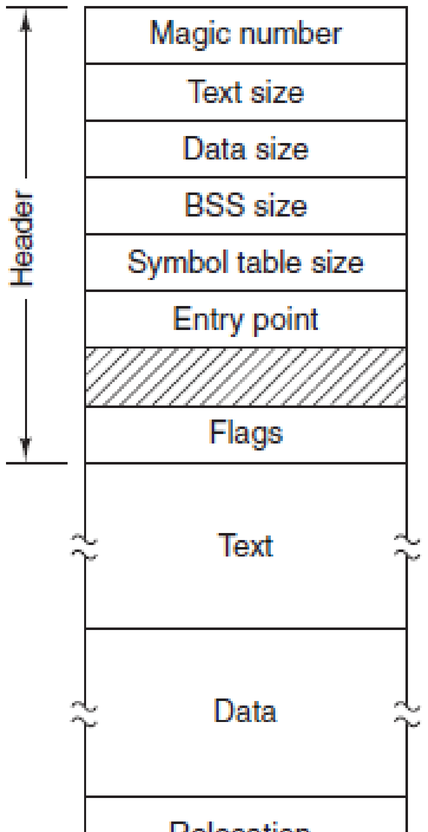
Interpreting file contents

- Collections of data
  - Usually in permanent storage on your computer

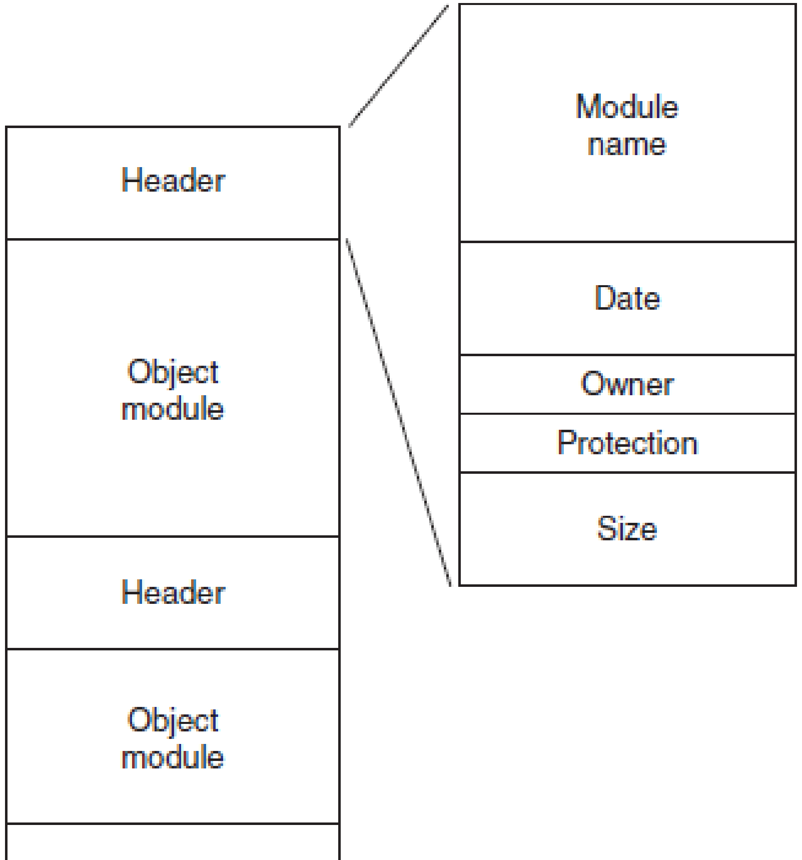
- Regular files
  - Arbitrary data
  - Think of as a big array of bytes

Sidebar: what about types of regular files?

- Text files versus Executables versus Tar files
  - All just differing patterns of bytes!
  - It really is just all data. The meaning is in how you interpret it.



Executable File



Archive (tar)

Identifying regular files

- **`file`** in Linux command line can help determine the type of a file
  - https://github.com/file/file

```
arguments  arguments.c
[brghena@ubuntu code] $ file arguments.c
arguments.c: C source, ASCII text
[brghena@ubuntu code] $ file arguments
arguments: ELF 64-bit LSB shared object, x86-64, version 1 (SYSV), dynamically linked, interpreter /lib64
/ld-linux-x86-64.so.2, BuildID[sha1]=8731c4961d371f4989cd1b056f796ad54b711e6f, for GNU/Linux 3.2.0, not s
tripped
[brghena@ubuntu code] $ file ./
./: directory
[brghena@ubuntu code] $ file ~/scratch/GlobalProtect_UI_deb-5.1.0.0-101.deb
/home/brghena/scratch/GlobalProtect_UI_deb-5.1.0.0-101.deb: Debian binary package (format 2.0), with cont
rol.tar.gz, data compression xz
```

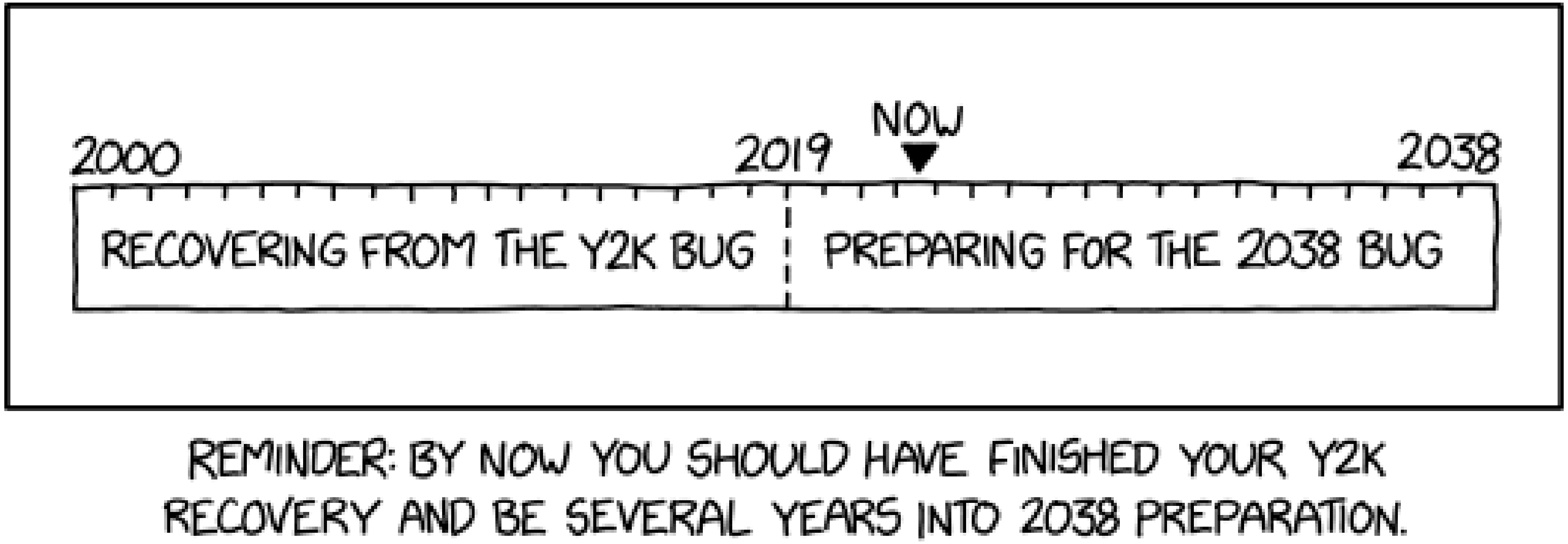
Encoding time

- Unix time:
  - 32-bit signed integer counting seconds elapsed since initial time
  - Initial time was January 1st at midnight UTC, 1970

- Current Unix time (as of last editing this slide): 1672850392
  - Negative numbers would mean times before 1970

- Problem: when does Unix time hit the maximum value?
  - 2147483647 seconds from January 1st 1970
  - Result: January 19th, 2038
  - This is the "Year 2038 Problem"

Bonus xkcd comic



https://xkcd.com/2697/

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