CS 64 Week 1 Lecture 1

Kyle Dewey

Overview

- Administrative stuff
- Class motivation
- Syllabus
- Working with different bases
- Bitwise operations
- Twos complement

Administrative Stuff

About Me

- 5th year Ph.D. candidate, doing programming languages research (automated testing)
- **<u>Not</u>** a professor; just call me Kyle
- Fifth time teaching; second time teaching CS64

About this Class

- See something wrong? Want something improved? Email me about it! (kyledewey@cs.ucsb.edu)
- I generally operate based on feedback

Bad Feedback

- This guy sucks.
- This class is boring.
- This material is useless.

Good Feedback

- This guy sucks, *I can't read his writing.*
- This class is boring, *it's way too slow.*
- This material is useless, *I don't see how it relates to anything in reality.*

- I can't fix anything if I don't know what's wrong

Questions

- Which best describes you?
  - CS major
  - ECE major
  - Other

Office Hours
Placement

Class Motivation

```
int main(int argc, char** argv) {
   ...
}
```

```
int main(int argc, char** argv) {
   ...
}
```

```
int main(int argc, char** argv) {
  ...
}
```

```
3.14956
```

```
int main(int argc, char** argv) {
   ...
}
```

3.14956

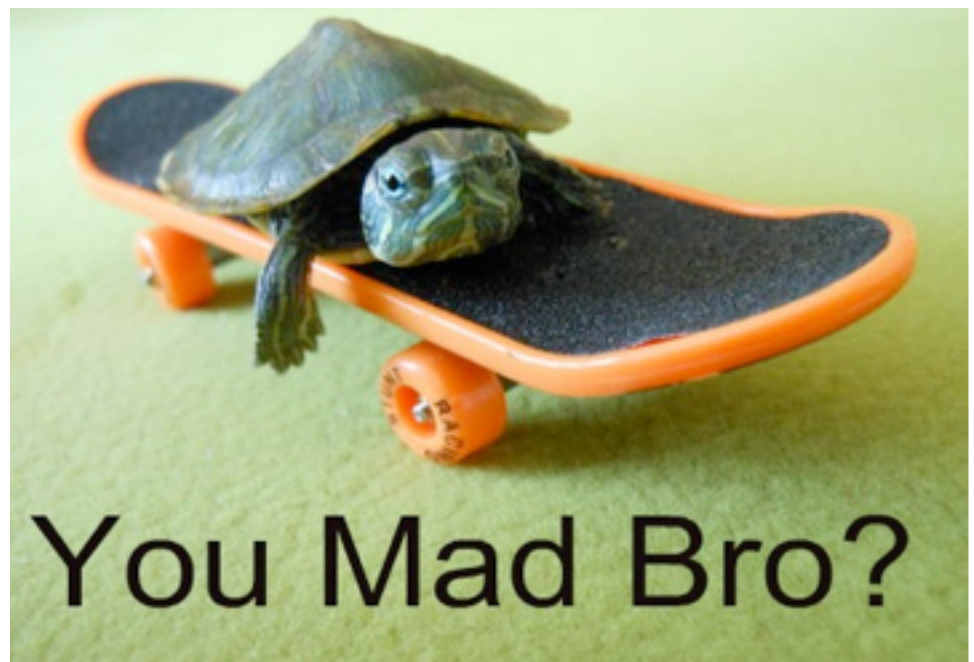
```
int main(int argc, char** argv) {
   ...
}
```

More Efficient Algorithms

3.14956

```
int main(int argc, char** argv) {
   ...
}
```

More Efficient Algorithms



3.14956

Why are things still slow?

The magic box isn't so magic

Array Access

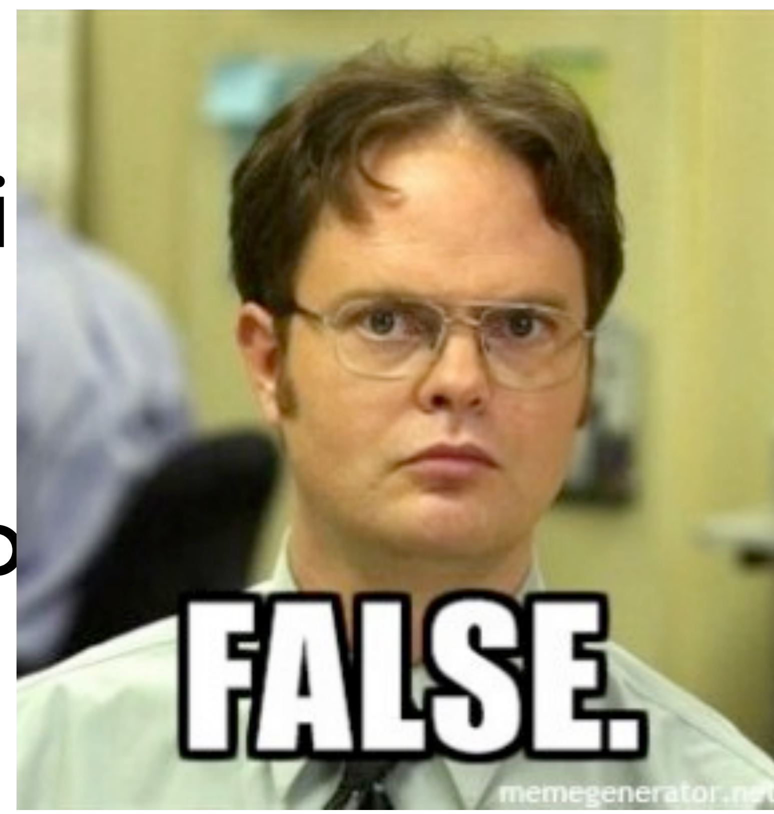
`arr[x]`

- Constant time! (O(1))
- Where the **random** in random access memory comes from!

Array Access

`arr[x]`

- Constant ti
- Where the dom access memory co



Array Access

- Memory is loaded as chunks into *caches*
  - Cache access is much faster (e.g., 10x)
  - Iterating through an array is fast
  - Jumping around any which way is slow
- Can change time complexity if accounted for
  - O(N^3) versus ~O(N^4)

Instruction Ordering

```
int x = a + b;
int y = c * d;
int z = e - f;
```

```
int z = e - f;
int y = c * d;
int x = a + b;
```

Instruction Ordering

```
int x = a + b;
int y = c * d;
int z = e - f;
```

3 Milliseconds?

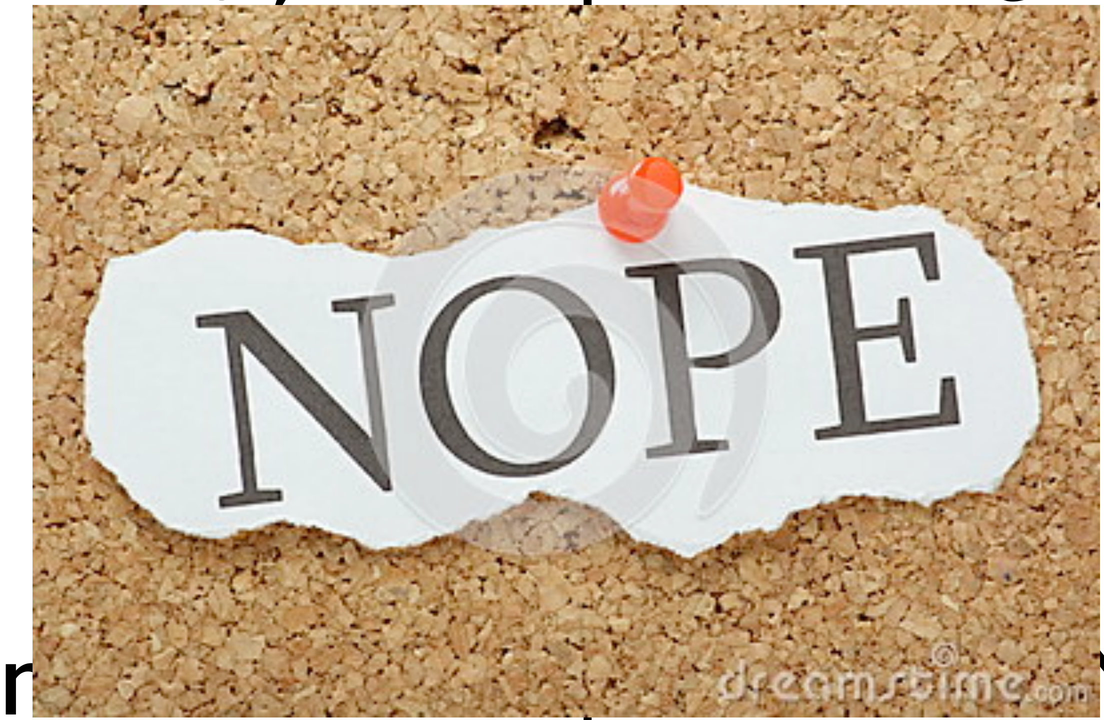
```
int z = e - f;
int y = c * d;
int x = a + b;
```

3 Milliseconds?

Instruction Ordering

```
int x = a + b;
int y = c * d;
int z = e
```

```
int z = e - f;
int y = c * d;
     x = a + b;
```



3 Millisecon

Milliseconds?

Instruction Ordering

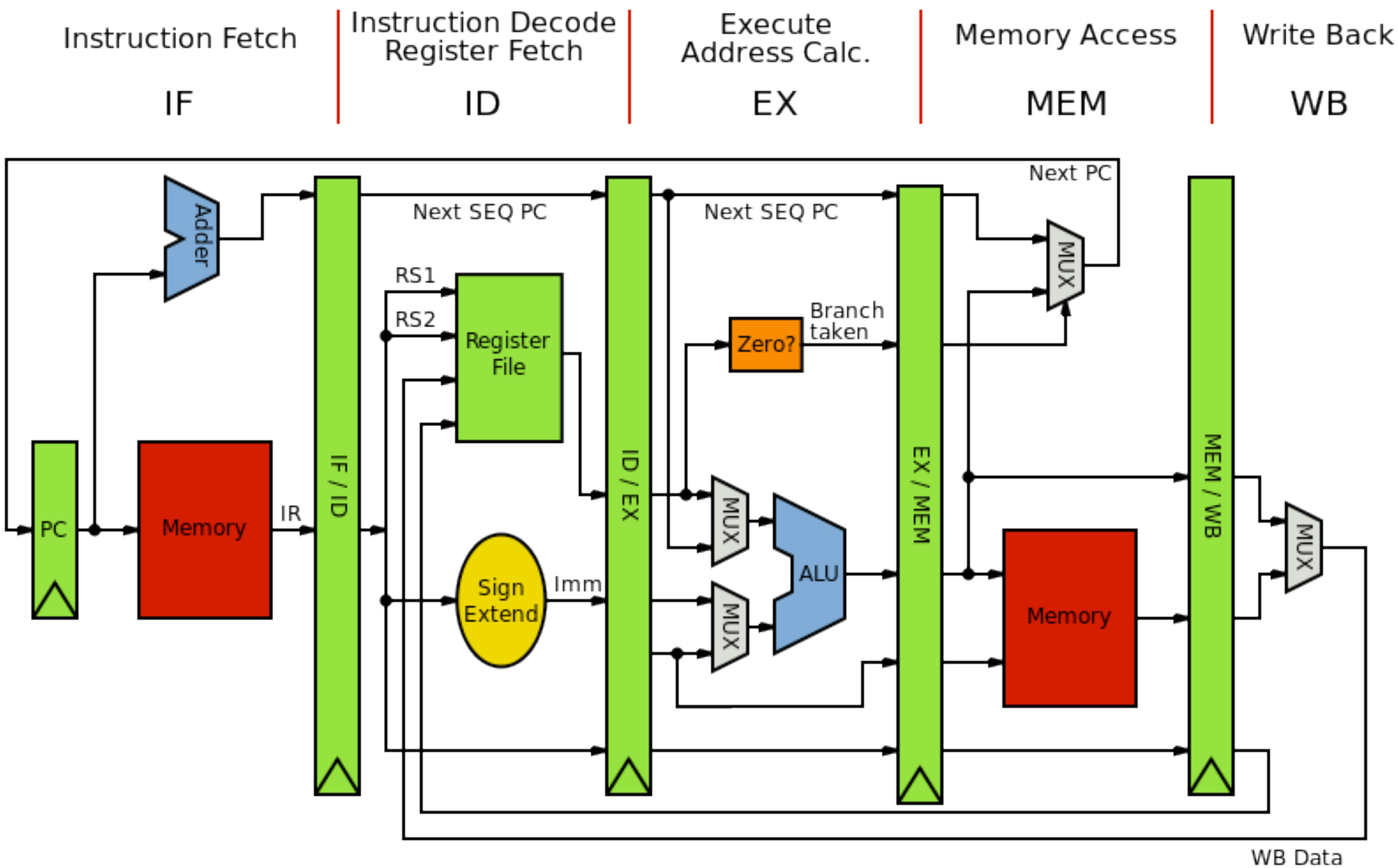
- Modern processors are *pipelined*, and can execute sub-portions of instructions in parallel
  - Depends on when instructions are encountered
- Some can execute whole instructions in different orders
- If your processor is from Intel, it is insane.

The Point

- If you really want performance, you need to know how the magic works
  - "But it scales!" - empirically, probably not
  - Chrome is fast for a reason
- If you want to write a naive compiler (CS160), you need to know some low-level details
- If you want to write a *fast* compiler, you need to know *tons* of low-level details

So Why Digital Design?

So Why Digital Design?



So Why Digital Design?

- Basically, circuits are the programming language of hardware
  - Yes, everything goes back to physics

Syllabus

Working with Different Bases

What's In a Number?

- Question: why exactly does 123 have the value 123? As in, what does it *mean*?

What’s In a Number?

123

What's In a Number?

1	2	3

What's In a Number?

1	2	3
Hundreds	Tens	Ones

What's In a Number?

1	2	3
Hundreds	Tens	Ones
100	10 10	1 1 1

Question

- Why did we go to tens? Hundreds?

1	2	3
Hundreds	Tens	Ones
100	10 10	1 1 1

Answer

- Because we are in decimal (base 10)

1	2	3
Hundreds	Tens	Ones
100	10 10	1 1 1

Another View

123

Another View

1	2	3

Another View

1	2	3
1×10^2	2×10^1	3×10^0

Conversion from Some Base to Decimal

- Involves repeated division by the value of the base
  - From right to left: list the remainders
  - Continue until 0 is reached
  - Final value is result of reading remainders from bottom to top
- For example: what is 231 decimal to decimal?

Conversion from Some Base to Decimal

231

Conversion from Some Base to Decimal

	Remainder
$10 \overline{\smash{)}231}$	
23	1

Conversion from Some Base to Decimal

	Remainder
$10 \overline{)231}$	
$10 \overline{)23}$	1
2	3

Conversion from Some Base to Decimal

	Remainder
$10 \overline{)231}$	
$10 \overline{)23}$	1
$10 \overline{)2}$	3
0	2

Now for Binary

- Binary is base 2
- Useful because circuits are either on or off, representable as two states, 0 and 1

Now for Binary

1010

Now for Binary

1	0	1	0

Now for Binary

1	0	1	0
Eights	Fours	Twos	Ones

Now for Binary

1	0	1	0
Eights	Fours	Twos	Ones
1×2^3	0×2^2	1×2^1	0×2^0
8	0	2	0

Question

- What is binary 0101 as a decimal number?

Answer

- What is binary 0101 as a decimal number?
  - 5

0	1	0	1
Eights 0×2^3	Fours 1×2^2	Twos 0×2^1	Ones 1×2^0
0	4	0	1

From Decimal to Binary

- What is decimal 57 to binary?

From Decimal to Binary

57

From Decimal to Binary

	Remainder
$2 \,\underline{\big\lvert\, 57}$	
28	1

From Decimal to Binary

	Remainder
$2 \,\underline{\big\vert\, 57}$	
$2 \,\underline{\big\vert 28}$	1
14	0

From Decimal to Binary

	Remainder
$2 \,\lfloor\, 57$	
$2 \,\lfloor\, 28$	1
$2 \,\lfloor\, 14$	0
7	0

From Decimal to Binary

	Remainder
2 | 57	
2 | 28	1
2 | 14	0
2 | 7	0
3	1

From Decimal to Binary

	Remainder
2 | 57	
2 | 28	1
2 | 14	0
2 | 7	0
2 | 3	1
1	1

From Decimal to Binary

	Remainder
2 | 57	
2 | 28	1
2 | 14	0
2 | 7	0
2 | 3	1
2 | 1	1
0	1

Octal

- Octal is base 8
- Same idea

Octal Example

- What is 172 octal in decimal?

Octal Example

172

Octal Example

1	7	2

Octal Example

1	7	2
Sixty-fours 1×8^2	Eights 7×8^1	Ones 2×8^0

Octal Example

1	7	2
Sixty-fours	Eights	Ones
1×8^2	7×8^1	2×8^0
64	8 8 8 8 8 8 8 (56)	1 1

Octal Example

Answer: 122

1	7	2
Sixty-fours 1×8^2	Eights 7×8^1	Ones 2×8^0
64	8 8 8 8 8 8 8 (56)	1 1

From Decimal to Octal

- What is 182 decimal to octal?

From Decimal to Octal

182

From Decimal to Octal

	Remainder
$8 \overline{)182}$	
22	6

From Decimal to Octal

	Remainder
$8 \,\underline{\lfloor 182}$	
$8 \,\underline{\lfloor 22}$	6
2	6

From Decimal to Octal

	Remainder
8 | 182	
8 | 22	6
8 | 2	6
0	2

Hexadecimal

- Base 16
- Binary is horribly inconvenient to write out
- Easier to convert between hexadecimal (which is more convenient) and binary
  - Each hexadecimal digit maps to four binary digits
  - Can just memorize a table

Hexadecimal

- Digits 0-9, along with A (10), B (11), C (12), D (13), E (14), F (15)

Hexadecimal Example

- What is 1AF hexadecimal in decimal?

Hexadecimal Example

I	A	F

Hexadecimal Example

1	A	F
Two-fifty-sixes	Sixteens	Ones

Hexadecimal Example

1	A	F
Two-fifty-sixes	Sixteens	Ones
1×16^2	10×16^1	15×16^0

Hexadecimal Example

1	A	F
Two-fifty-sixes	Sixteens	Ones
1×16^2	10×16^1	15×16^0
256	16 16 16 16 16 16 16 16 16 16 (160)	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 (15)

Hexadecimal to Binary

- Previous techniques all work, using decimal as an intermediate
- The faster way: memorize a table (which can be easily reconstructed)

Hexadecimal to Binary

Hexadecimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111

Hexadecimal	Binary
8	1000
9	1001
A (10)	1010
B (11)	1011
C (12)	1100
D (13)	1101
E (14)	1110
F (15)	1111

Bitwise Operations

Bitwise AND

- Similar to logical AND (`&&`), except it works on a bit-by-bit manner
- Denoted by a single ampersand: `&`

```
(1001 &
 0101)=
 0001
```

Bitwise OR

- Similar to logical OR (||), except it works on a bit-by-bit manner
- Denoted by a single pipe character: |

```
(1001 |
 0101)=
 1101
```

Bitwise XOR

- Exclusive OR, denoted by a carat: ^
- Similar to bitwise OR, except that if both inputs are `1` then the result is `0`

```
(1001 ^
 0101)=
 1100
```

Bitwise NOT

- Similar to logical NOT (`!`), except it works on a bit-by-bit manner
- Denoted by a tilde character: `~`

```
~1001 =
 0110
```

Shift Left

- Move all the bits `N` positions to the left, subbing in `N` `0`s on the right

Shift Left

- Move all the bits `N` positions to the left, subbing in `N` `0`s on the right

`1001`

Shift Left

- Move all the bits `N` positions to the left, subbing in `N` `0`s on the right

```
1001 << 2 =
100100
```

Shift Left

- Useful as a restricted form of multiplication
- Question: how?

```
1001 << 2 =
100100
```

Shift Left as Multiplication

- Equivalent decimal operation:

```
234
```

Shift Left as Multiplication

- Equivalent decimal operation:

```
234 << 1 =
2340
```

Shift Left as Multiplication

- Equivalent decimal operation:

```
234 << 1 =
2340

234 << 2 =
23400
```

Multiplication

- Shifting left `N` positions multiplies by `(base)`^{N}
- Multiplying by 2 or 4 is often necessary (shift left 1 or 2 positions, respectively)
- Often a whooole lot faster than telling the processor to multiply
- Compilers try hard to do this

```
234 << 2 =
23400
```

Shift Right

- Move all the bits `N` positions to the right, subbing in **either** `N` `0`s or `N` `1`s on the left
    - Two different forms

Shift Right

- Move all the bits `N` positions to the right, subbing in **either** `N` `0`s or `N` (whatever the leftmost bit is)s on the left
  - Two different forms

```
1001 >> 2 =
either 0010 or 1110
```

Shift Right Trick

- Question: If shifting left multiplies, what does shift right do?

Shift Right Trick

- Question: If shifting left multiplies, what does shift right do?
    - Answer: divides in a similar way, but truncates result

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```
234 >> 1 =
23
```

Two Forms of Shift Right

- Subbing in `0`s makes sense
- What about subbing in the leftmost bit?
  - And why is this called "arithmetic" shift right?

```
1100 (arithmetic)>> 1 =
1110
```

Answer...Sort of

- Arithmetic form is intended for numbers in *twos complement*, whereas the non-arithmetic form is intended for *unsigned* numbers

Twos Complement

Problem

- Binary representation so far makes it easy to represent positive numbers and zero
- Question: What about representing negative numbers?

Twos Complement

- Way to represent positive integers, negative integers, and zero
- If `1` is in the *most significant bit* (generally leftmost bit in this class), then it is negative

Decimal to Twos Complement

- Example: -5 decimal to binary (twos complement)

Decimal to Twos Complement

- Example: -5 decimal to binary (twos complement)
- First, convert the magnitude to an unsigned representation

Decimal to Twos Complement

- Example: -5 decimal to binary (twos complement)
- First, convert the magnitude to an unsigned representation

`5` (decimal) = `0101` (binary)

Decimal to Twos Complement

- Then, take the bits, and negate them

Decimal to Twos Complement

- Then, take the bits, and negate them

`0101`

Decimal to Twos Complement

- Then, take the bits, and negate them

```
~0101 =
 1010
```

Decimal to Twos Complement

- Finally, add one:

Decimal to Twos Complement

- Finally, add one:

```
1010
```

Decimal to Twos Complement

- Finally, add one:

```
1010 + 1 =
1011
```

Twos Complement to Decimal

- Same operation: negate the bits, and add one

Twos Complement to Decimal

- Same operation: negate the bits, and add one

`1011`

Twos Complement to Decimal

- Same operation: negate the bits, and add one

```
~1011 =
 0100
```

Twos Complement to Decimal

- Same operation: negate the bits, and add one

`0100`

Twos Complement to Decimal

- Same operation: negate the bits, and add one

```
0100 + 1 =
0101
```

Where Is Twos Complement From?

- Intuition: try to subtract 1 from 0, in decimal
  - Involves borrowing from an invisible number on the left
  - Twos complement is based on the same idea