Final Projects

Start this week!

Wednesday lab will be on projects

Come to the lab of your CA mentor (or your regular lab, if Phil)

We will do demos during 5-7PM lab on 6/9 -- people in Europe can go first and those in Asia can go last

$20 parts budget per person; need to submit receipts (I'll put details in Piazza)

Sensors

Apple iPhone 7 teardown

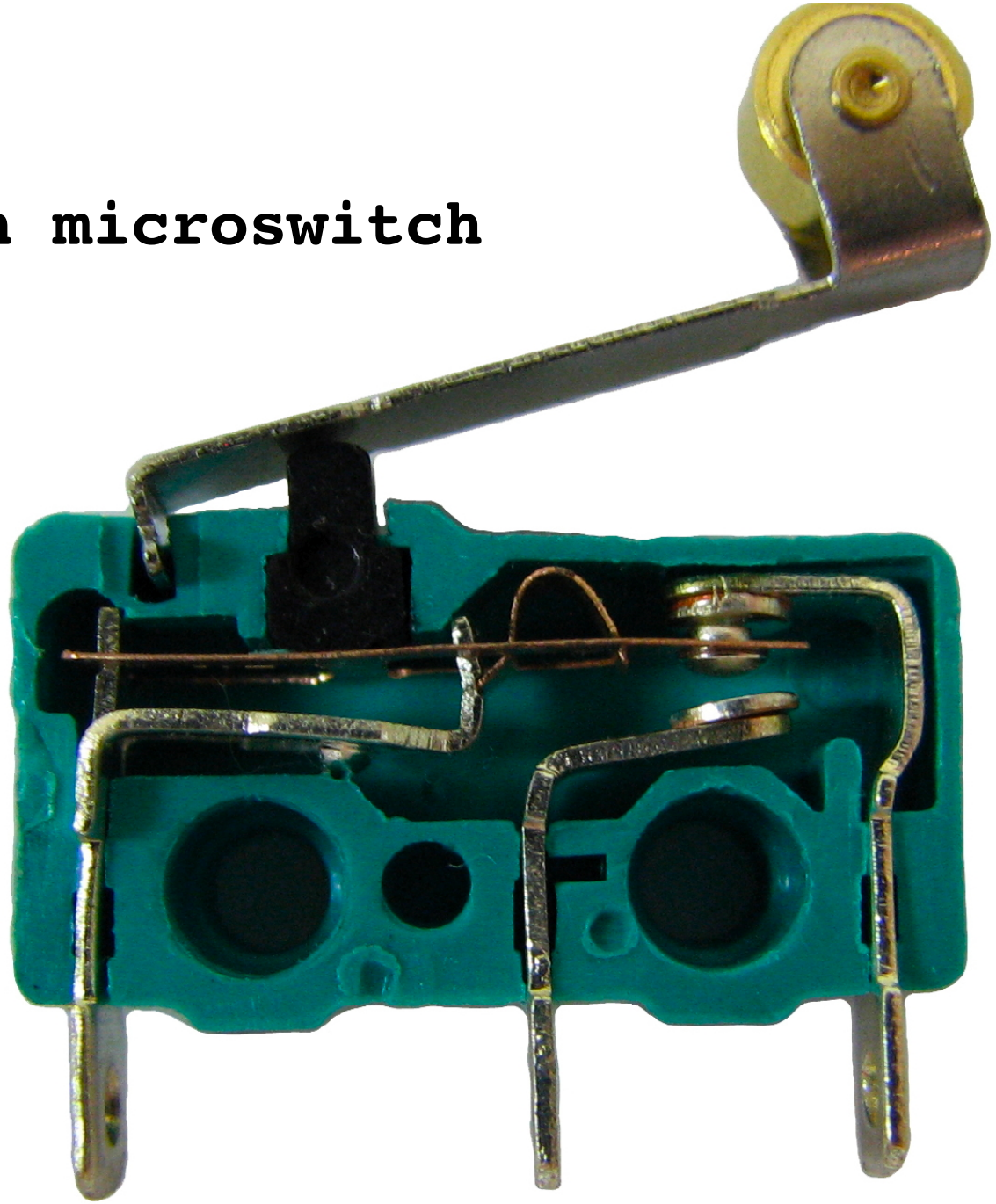
How many sensors?

Apple iPhone 7

How many sensors? At least 10

Dual 12MP wide-angle and telephoto cameras
Facetime camera
Infrared camera (for face recognition)
Microphones (2 at top, 2 at bottom)
Proximity sensor
Ambient light sensor
Accelerometer
Gyroscope
Compass (magnetometer)
Barometer (altimeter)
Touch ID fingerprint scanner
Pressure sensitive 3D multi-touch display

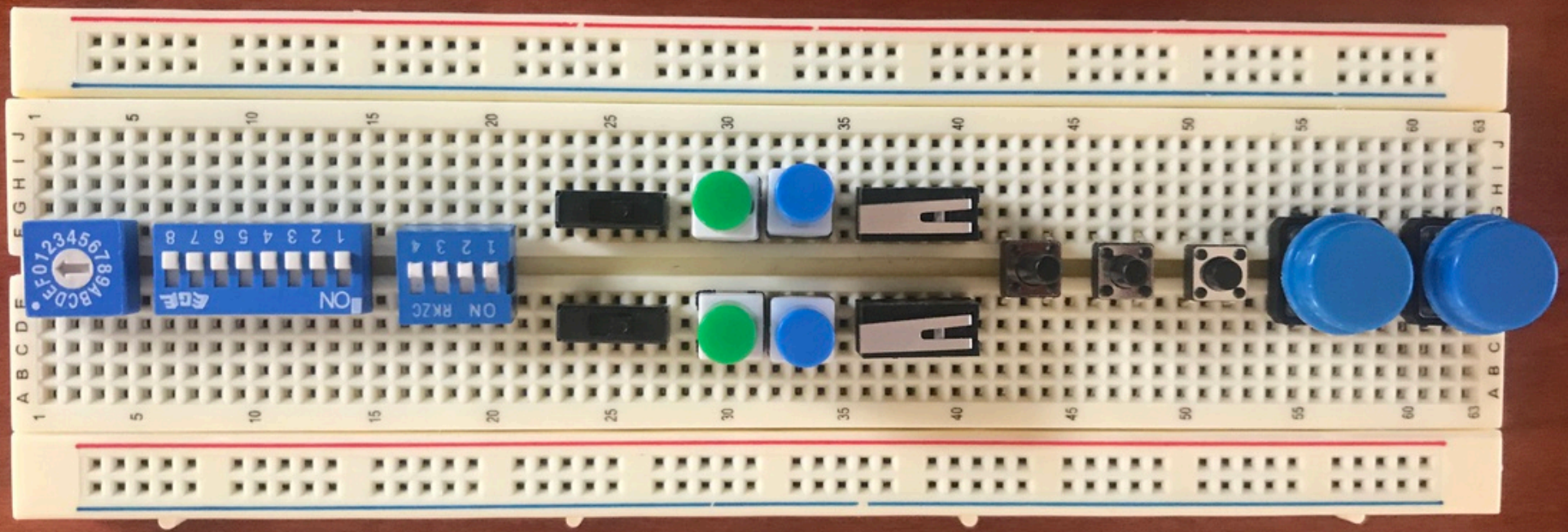
Snap-action microswitch



Common **NO** **NC**

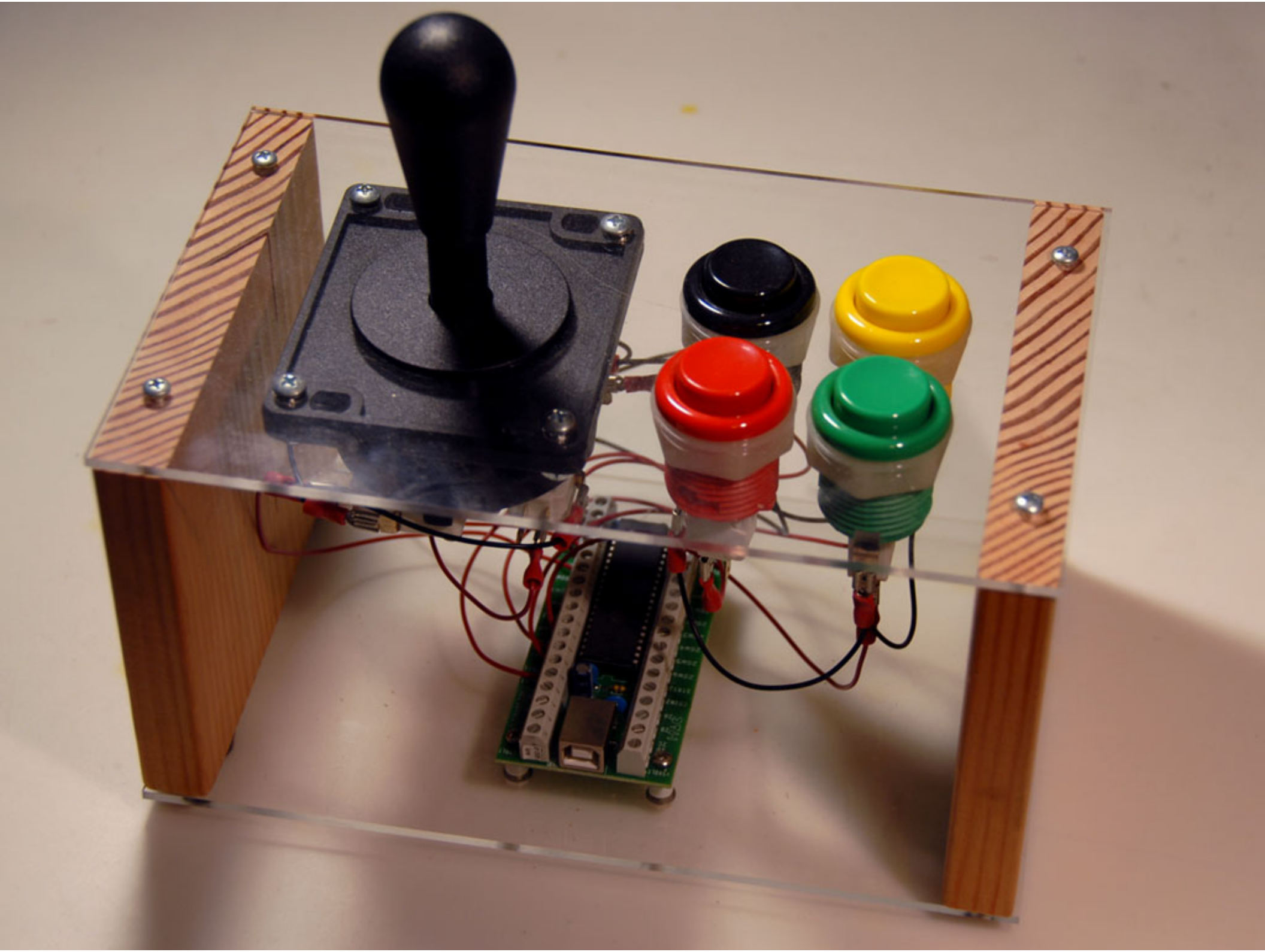
https://en.wikipedia.org/wiki/Miniature_snap-action_switch

Buttons and Switches



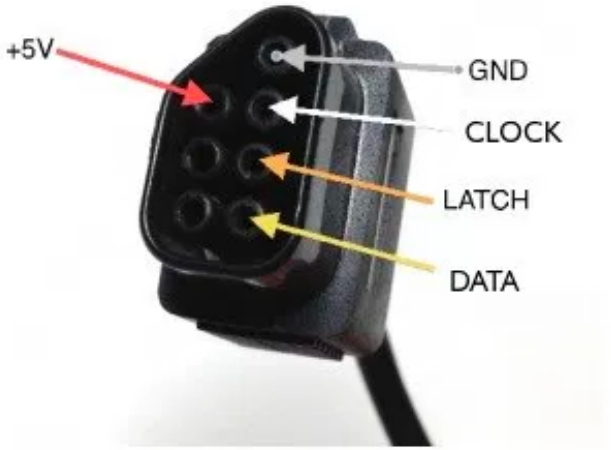
Happ Pushbutton

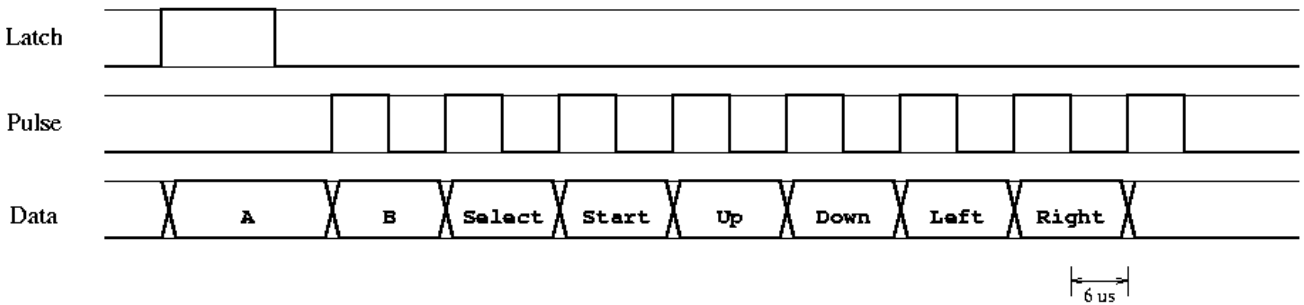
Happ Joystick



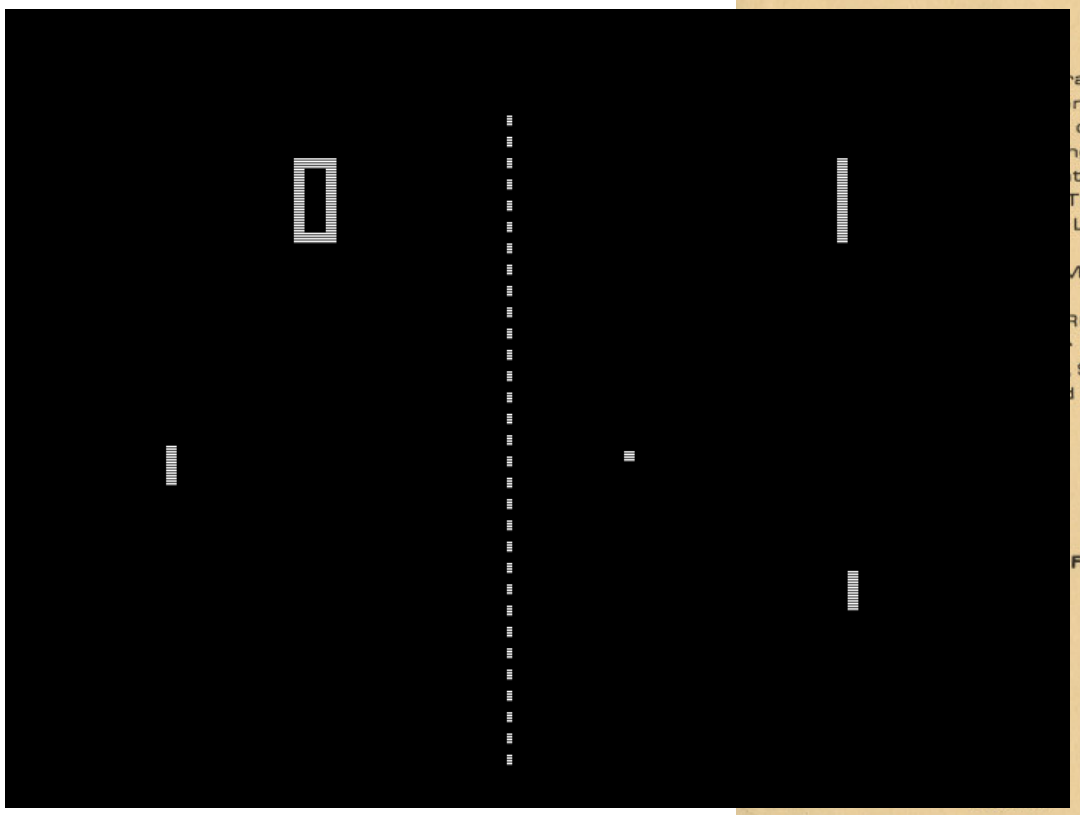
Famicon D-pad

NES D-pad





Analog to Digital (ADC)



THE NEWEST 2 PLAYER
VIDEO SKILL GAME

PONG

from ATARI CORPORATION
SYZYGY ENGINEERED

The Team That Pioneered Video Technology

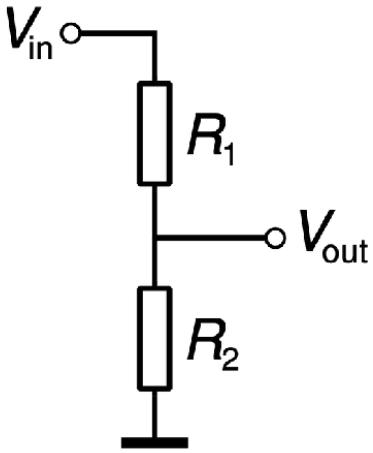
ract Mode
matically
of Ball
ng Paddle
te Controls
TE TV and
Long.

MPUTER

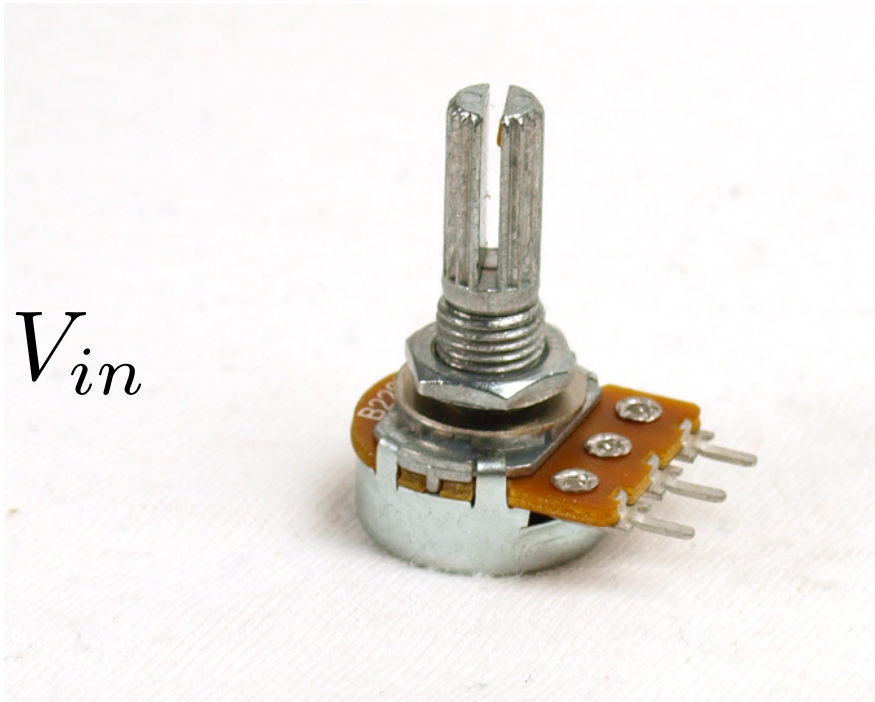
ROFITS
Location
Suitable
Locations

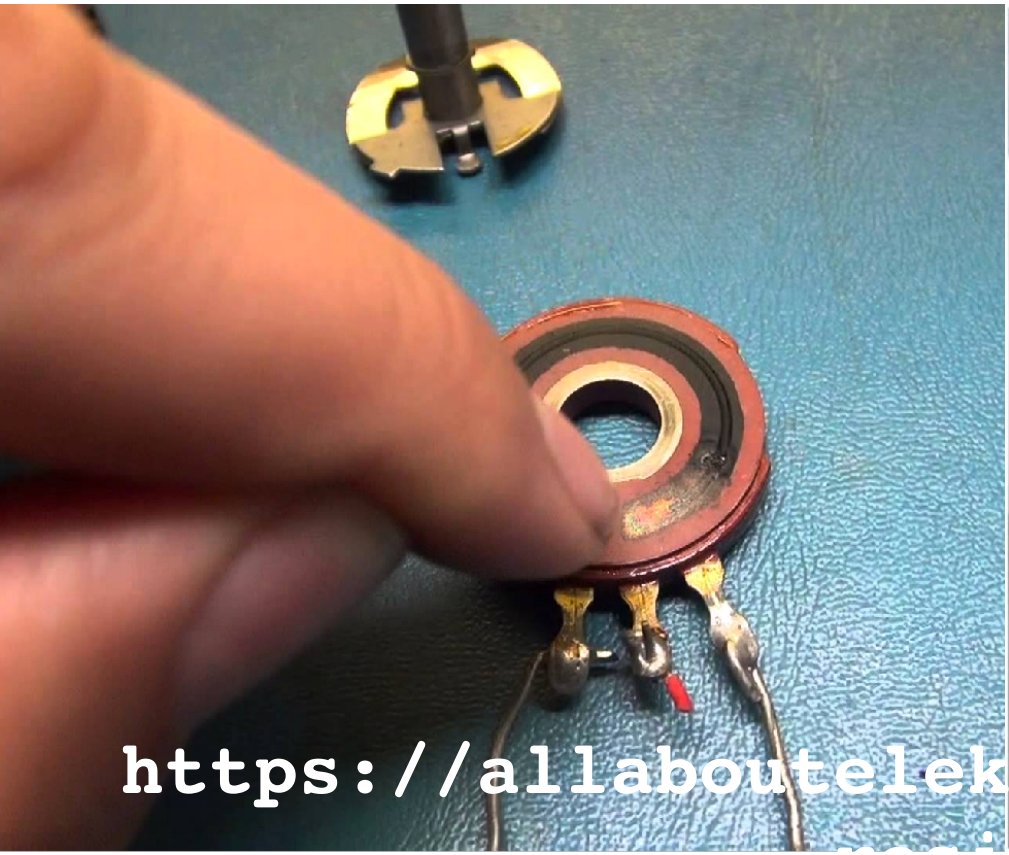
FROM YOUR LOCAL DISTRIBUTOR

Maximum Dimensions:
WIDTH - 26"
HEIGHT - 50"
DEPTH - 24
SHIPPING WEIGHT:
150 Lb.

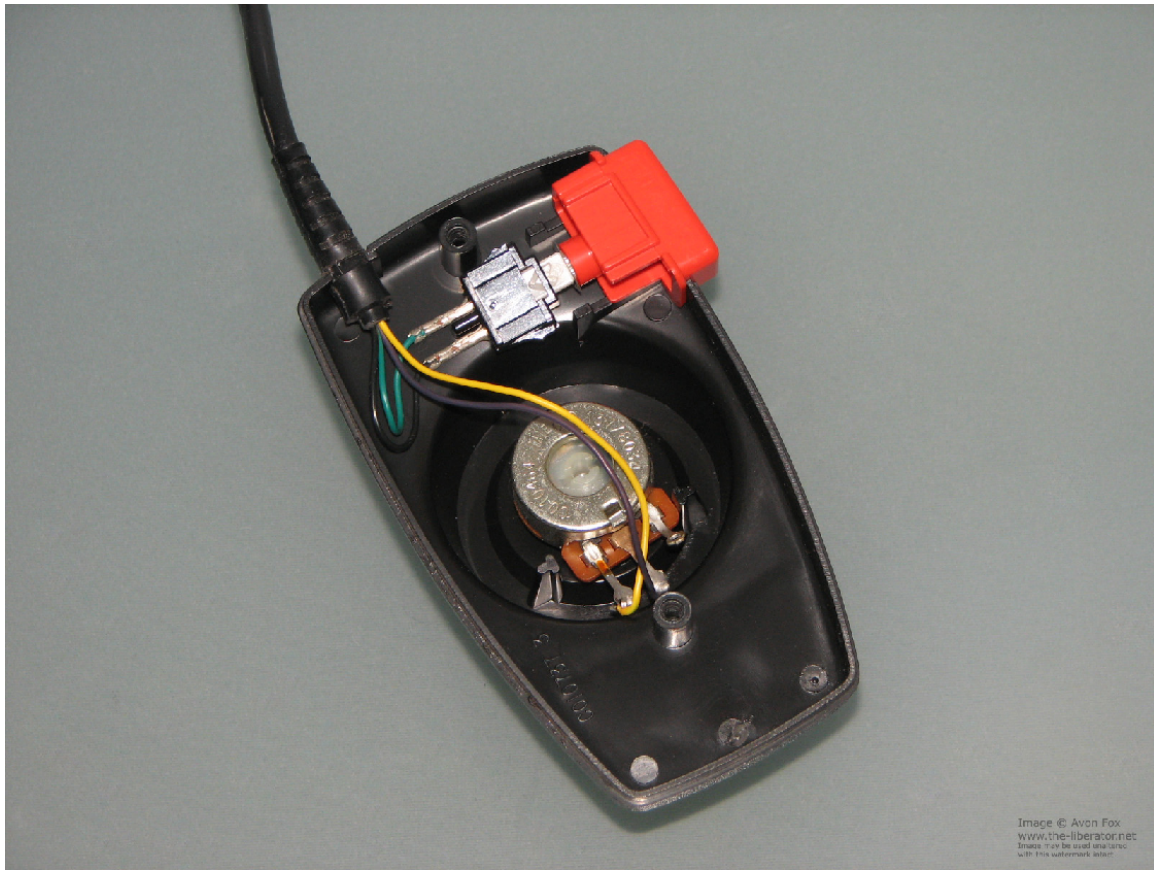


$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$



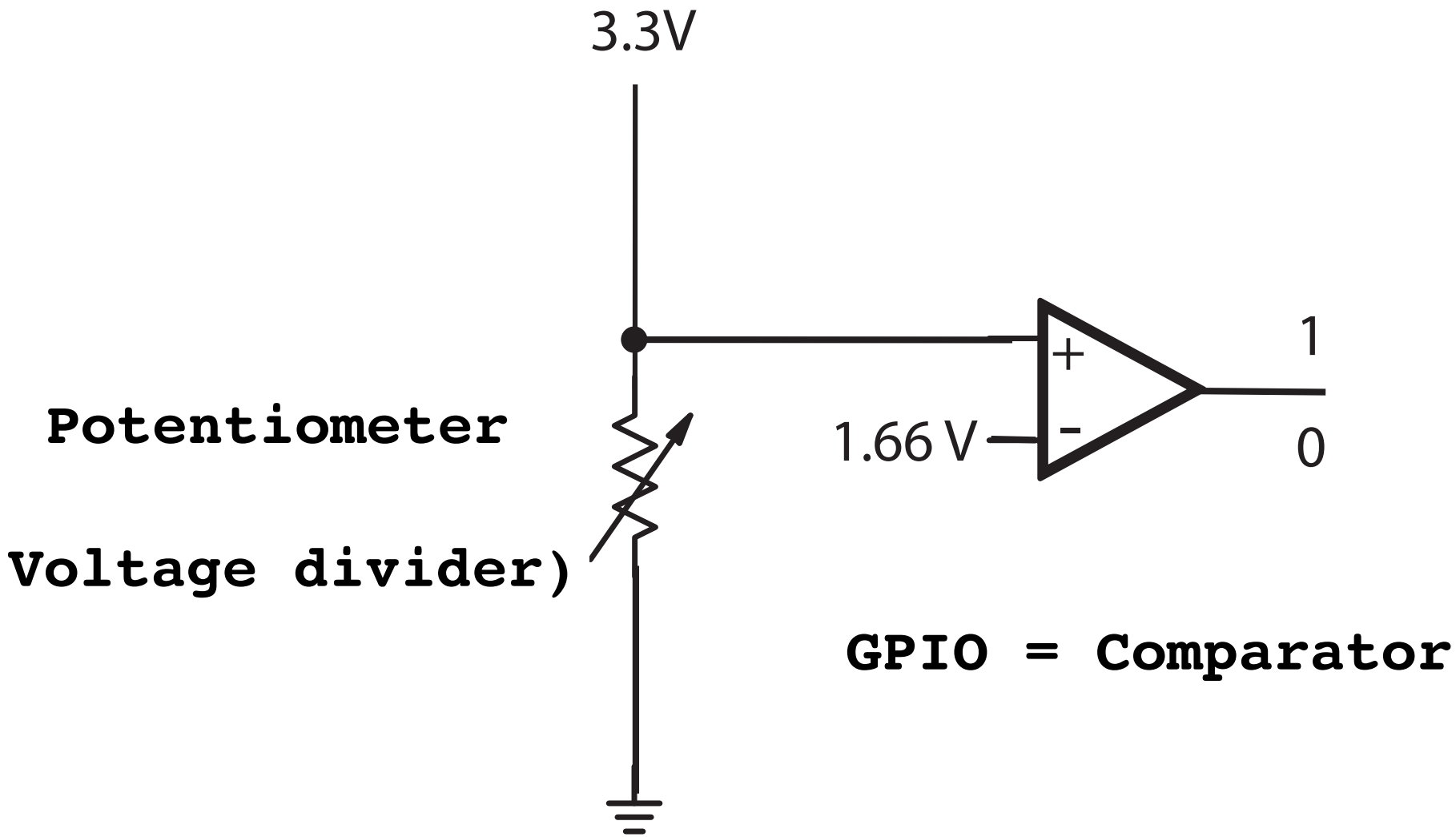


https://allaboutelektronics.wordpress.com/



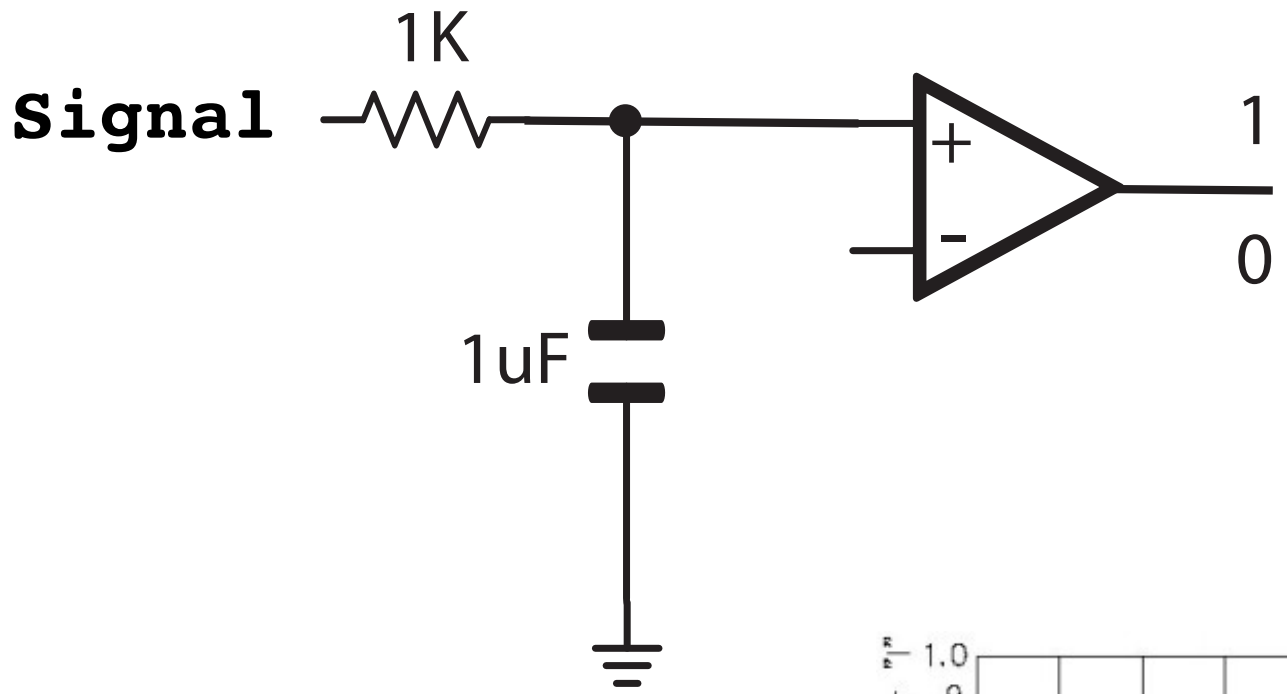
Atari 2600 Paddle

How would you measure the voltage?

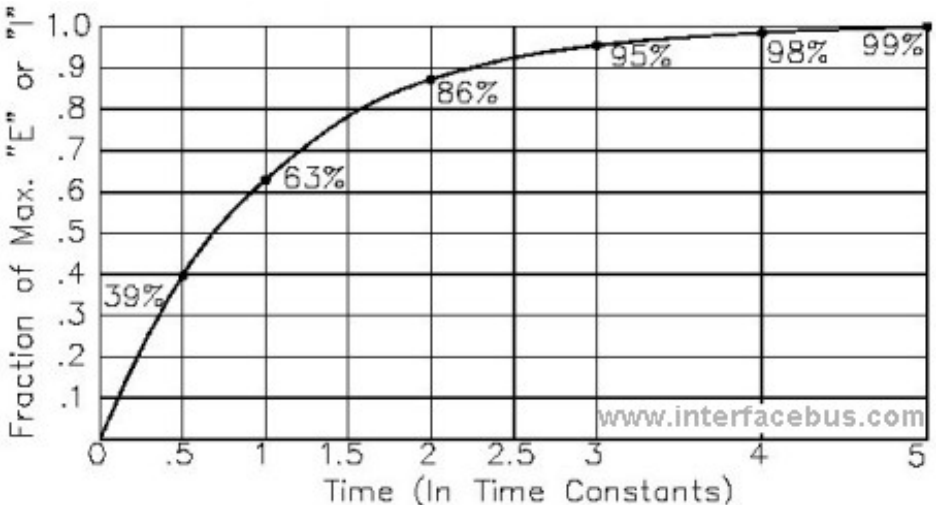

3.3V
Potentiometer
Voltage divider)
1.66 V
+
-
1
0
GPIO = Comparator

Charging Circuit

The time to fire depends on the input signal voltage

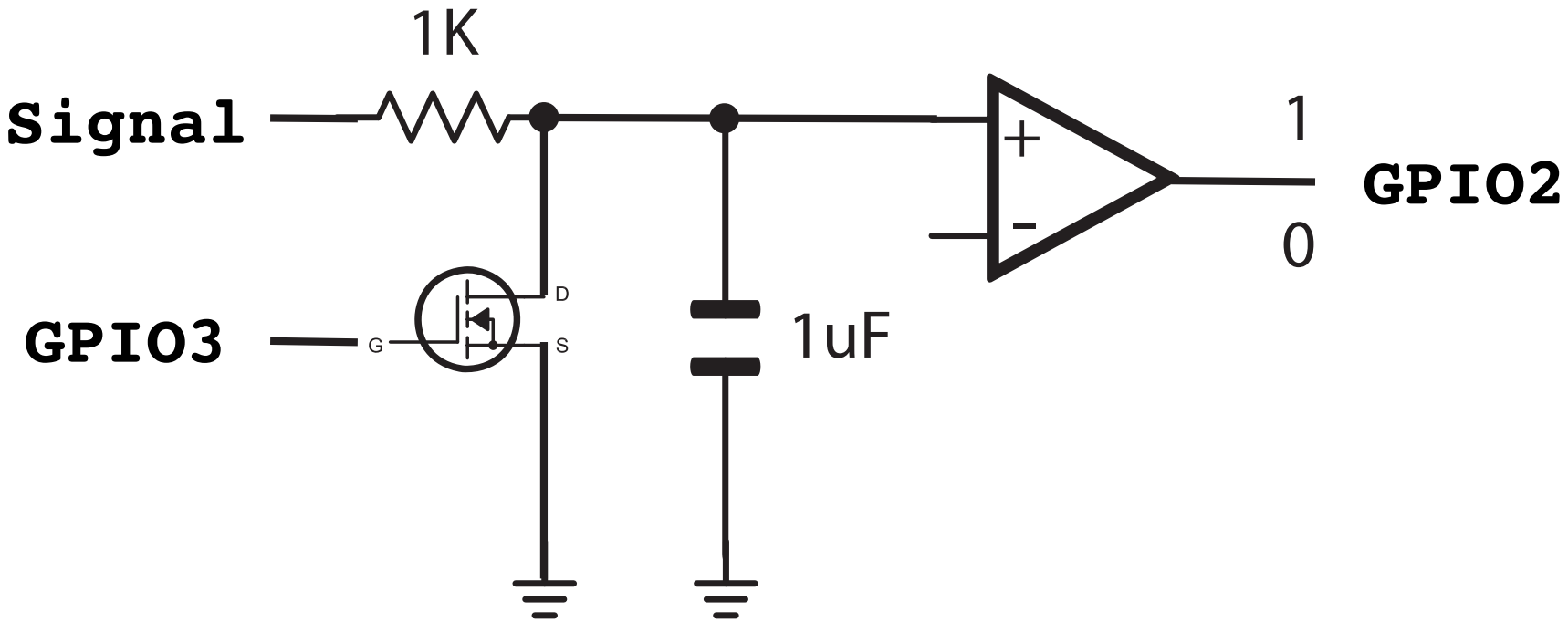


RC = 1000 usecs



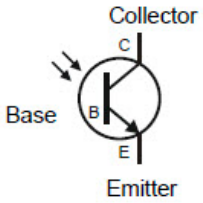
ADC

Time-to-charge then discharge, …, …, …

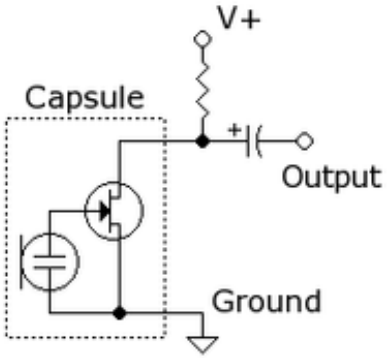


RC = 1000 usecs

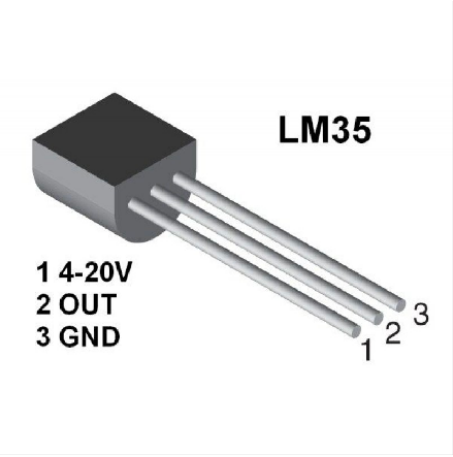
Analog Sensors



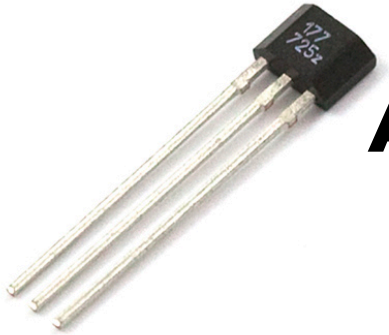
Phototransistor (light)



Electret Microphone (pressure)



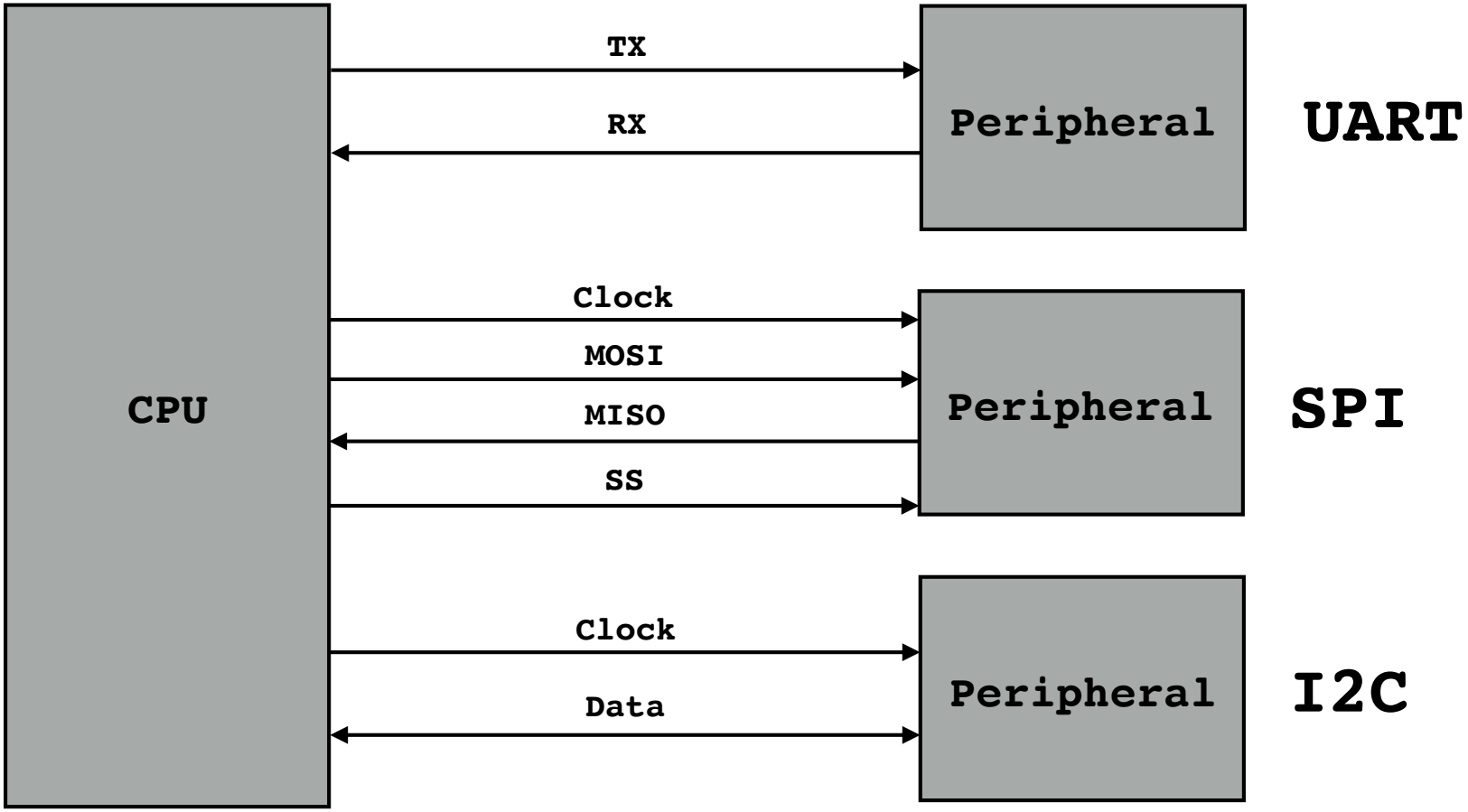
(temperature)

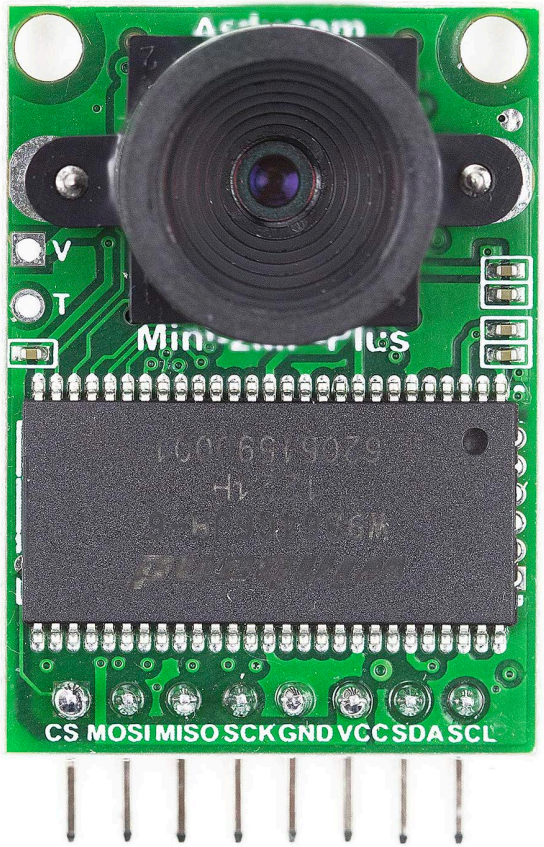


Analog Hall Effect (magnetic field)

Digital Sensors

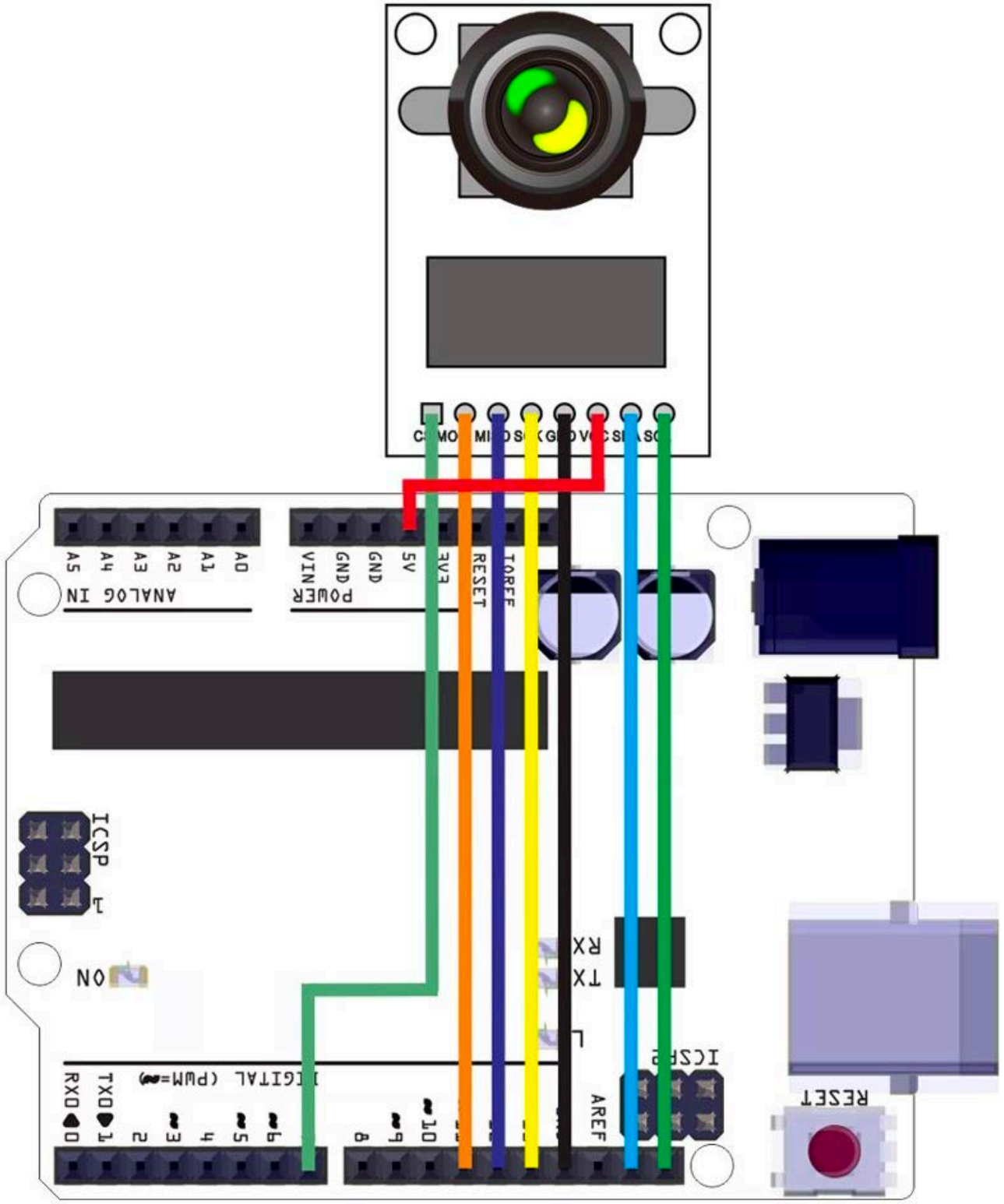
Bus Protocols





Arducam

SPI + I2C



Sensing the World

Resistance (conduction, capacitance)-

Convert energy to voltage/current

- Light (phototransistor)
- Sound/pressure/deformation (piezo, electret, strain gauge)
- Temperature (heat), humidity, pressure
- Electromagnetic fields (hall effect, compass, antenna)

Smart sensors (sensor with a digital interface)

- Acceleration/Orientation/Magnetic (force direction)
- Camera, IMU (inertial management unit), …

Computer Arithmetic

What is the difference between `signed int` and `unsigned int`?

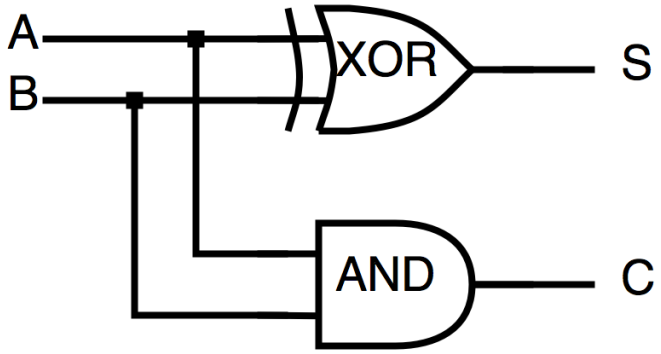
Addition

Adding 2 1-bit numbers: sum = a + b

a	b	sum
0	0	00
0	1	01
1	0	01
1	1	10

Adding 2 1-bit numbers (Half Adder)

```
a b sum
0 0  00
0 1  01
1 0  01
1 1  10
```




```
bit 0 of sum: S = a^b
bit 1 of sum: C = a&b
```

Have reduced addition to logical operations!

Adding 2 8-bit numbers

```
            Carry
  00000111 A
 +00001011 B
 ----------
            Sum
```

Adding 2 8-bit numbers

```
        1  Carry
 00000111 A
+00001011 B
 ---------
         0 Sum
```

Adding 2 8-bit numbers

```
       11  Carry
  00000111 A
 +00001011 B
 ---------
        10 Sum
```

Adding 2 8-bit numbers

```
 00001111  Carry
  00000111 A
 +00001011 B
 ---------
  00010010 Sum
```

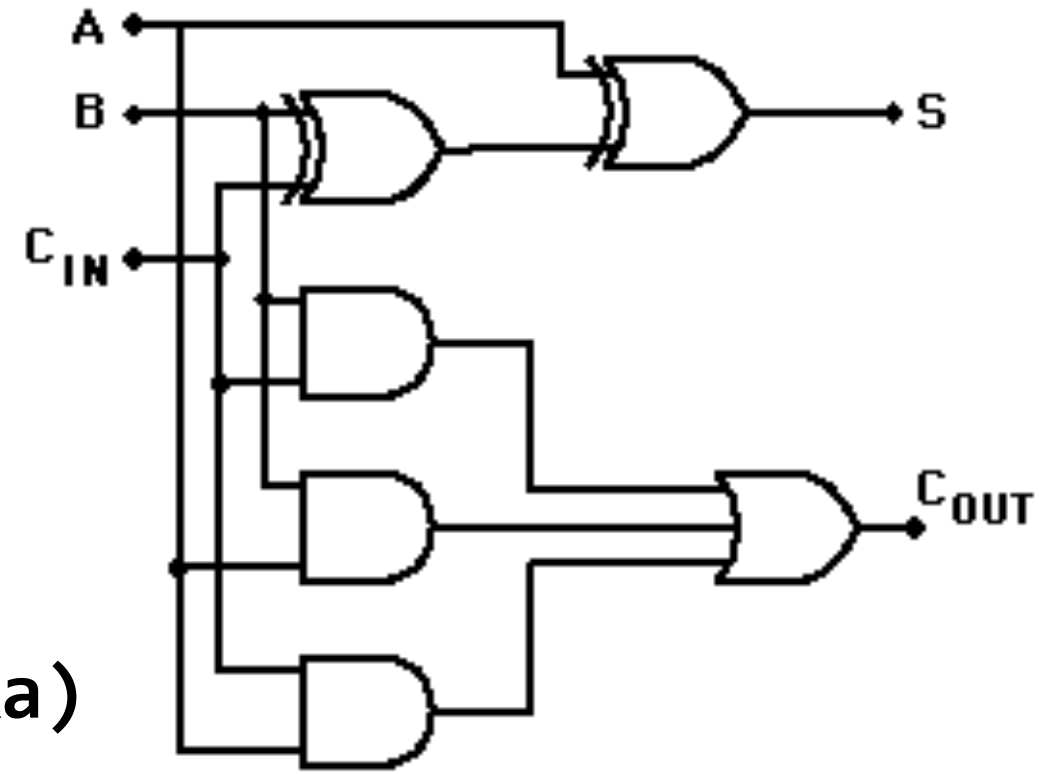
Adding 3 1-bit numbers

a	b	c	=	c	s
0	0	0		0	0
0	1	0		0	1
1	0	0		0	1
1	1	0		1	0
0	0	1		0	1
0	1	1		1	0
1	0	1		1	0
1	1	1		1	1

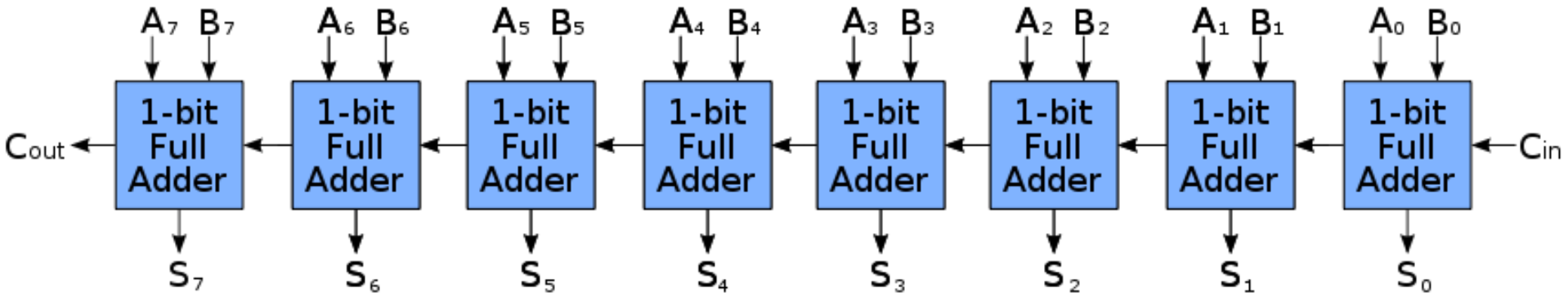
Adding 3 1-bit numbers (Full Adder)

a	b	ci	=	co	s
0	0	0		0	0
0	1	0		0	1
1	0	0		0	1
1	1	0		1	0
0	0	1		0	1
0	1	1		1	0
1	0	1		1	0
1	1	1		1	1

```
s  = a^b^ci
co = (a&b)|(b&c)|(c&a)
```



8-bit Ripple Adder



Note Cin (carry in) and Cout (carry out)

```
// Multiple precision addition
// https://gcc.godbolt.org/z/6TRmY8

uint64_t add64(uint64_t a, uint64_t b)
{
  return a + b;
}

add64:
  adds r0, r0, r2
  adc  r1, r1, r3
  bx   lr
```

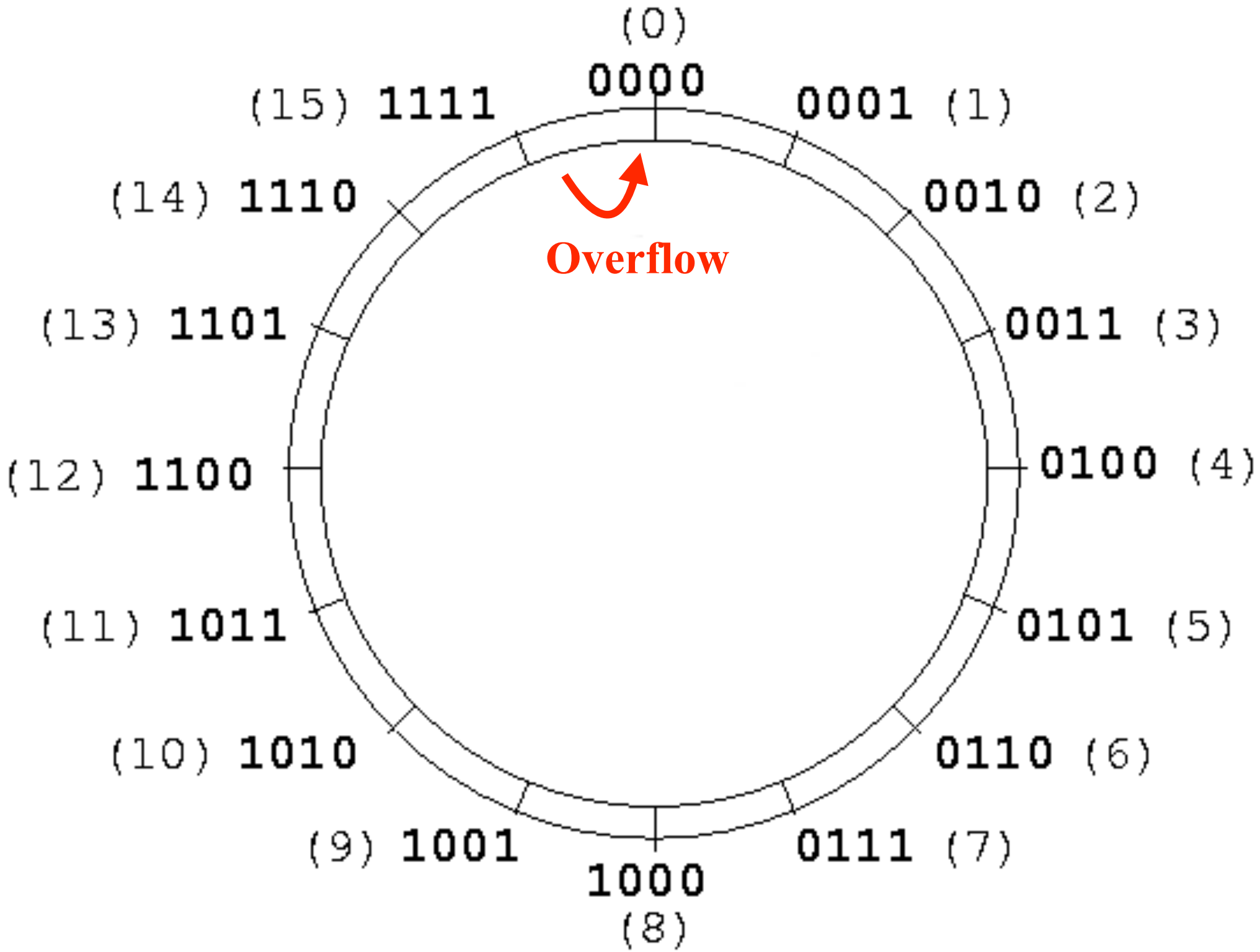
Binary Addition - Modular Arithmetic

```
 11111111  Carry
  11111111 A
 +00000001 B
 ---------
 100000000 Sum
```

To represent the result of adding two n-bit numbers to full precision requires n+1 bits

But we only have 8-bits!

sum = (A+B)%256 = 0b00000000

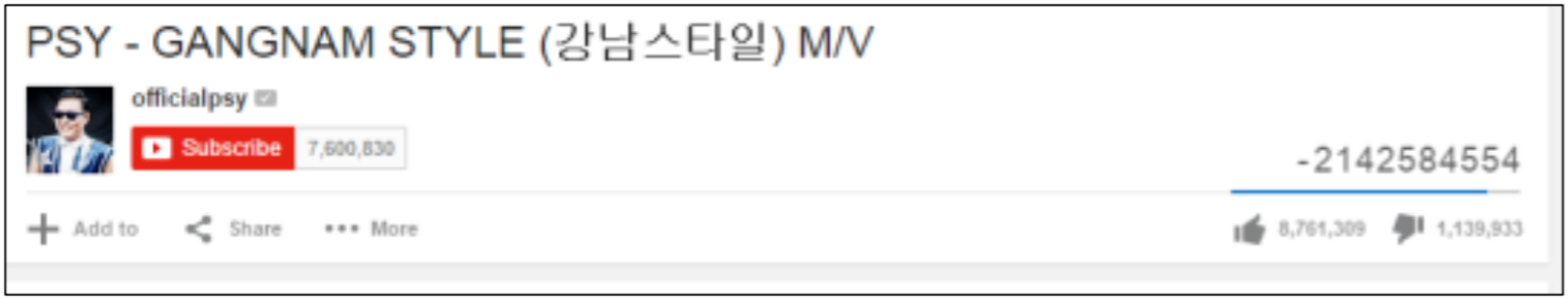

(0)
0000
0001 (1)
0010 (2)
0011 (3)
0100 (4)
0101 (5)
0110 (6)
0111 (7)
1000
(8)
(9) 1001
(10) 1010
(11) 1011
(12) 1100
(13) 1101
(14) 1110
(15) 1111
Overflow

Gangnam Style overflows INT_MAX, forces YouTube to go 64-bit

Psy's hit song has been watched an awful lot of times.

PETER BRIGHT - 12/3/2014, 2:32 PM

- In two's complement, when you exceed the maximum value of int (2,147,483,647), you "wrap around" to negative numbers:



- Here is the link after Google upgraded to 64-bit integers:

Subtraction

BIG IDEA: Define subtraction using addition

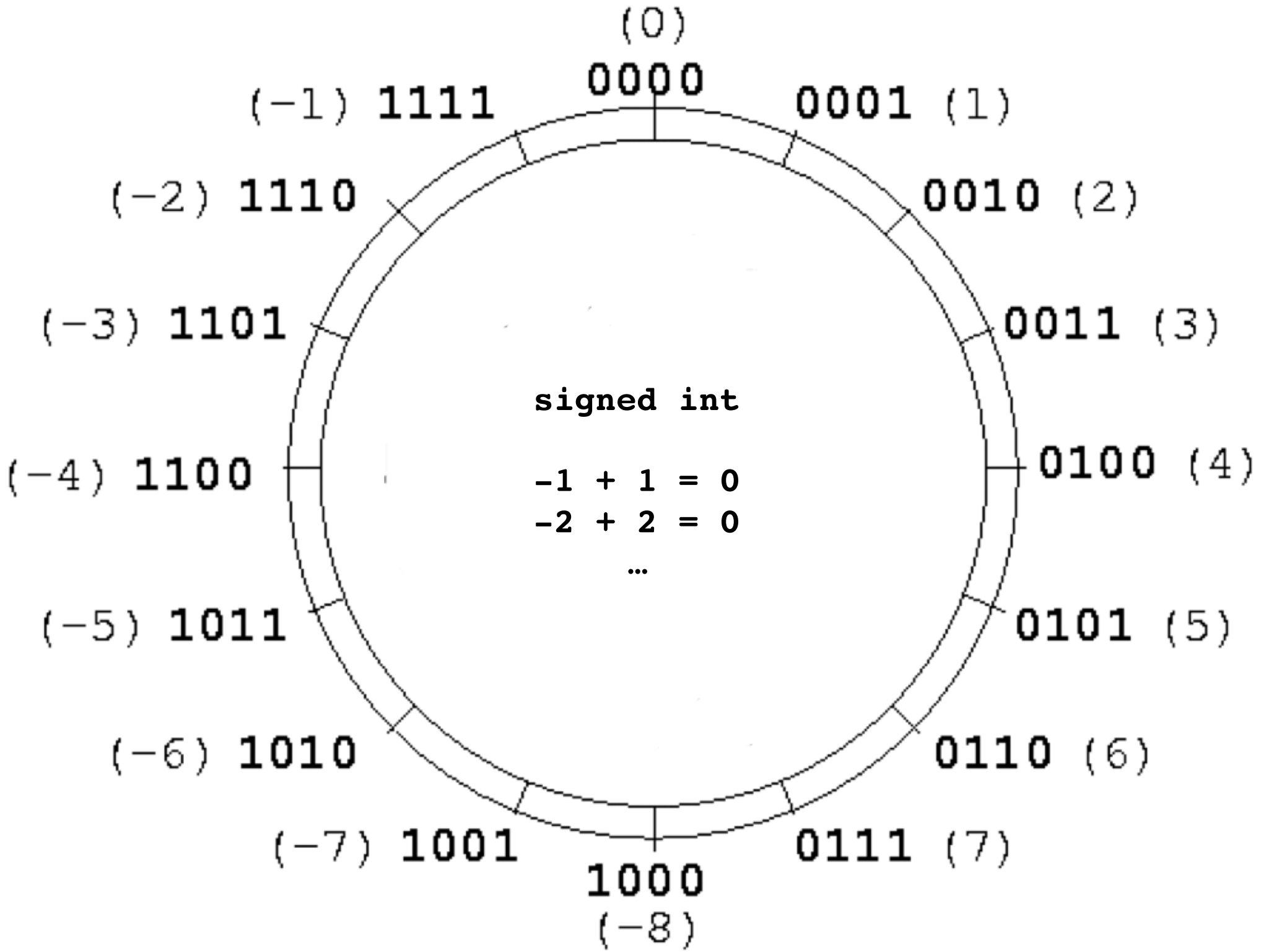
A clever way of defining subtraction by 1 is to find a number to add that yields the same result as the subtract by 1.

This number is the *negative* of the number.

More precisely, this number is the number that when added to 1, results in 0 (mod 16)

`0x1 - 0x1 = 0x1 + 0xf = 0x10 % 16 = 0x0`

`0xf` can be *interpreted* as `-1`


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

Signed 4-bit numbers,

0x0 = 0
0xf = -1
0xe = -2
…
0x8 = -8 (could be interpreted as 8)
0x7 = 7
…
0x1 = 1
0x0 = 0

if we choose to *interpret* 0x8 as -8, then the most-significant bit of the number indicates that it is negative (n)

`signed int` **vs as** `unsigned int`

Are just *different interpretations* of the bits comprising the number

`0xff` **vs** `-1`

Negation

How do we negate an 8-bit number?

Find a number -x, s.t. (x + (-x)) % 256 = 0
Subtract it from 256 = 2^8 = 100000000

-x = 100000000 - x

Since then (x + (-x)) % 256 = 0

```
 11111111  Borrow      100000000 Carry
 100000000              00000001
 -00000001             +11111111
 ---------             ---------
  11111111              00000000
```

This method of representing negative numbers is called *two's complement*

Two's Complement

Almost all the code and computers you'll use rely on two's complement

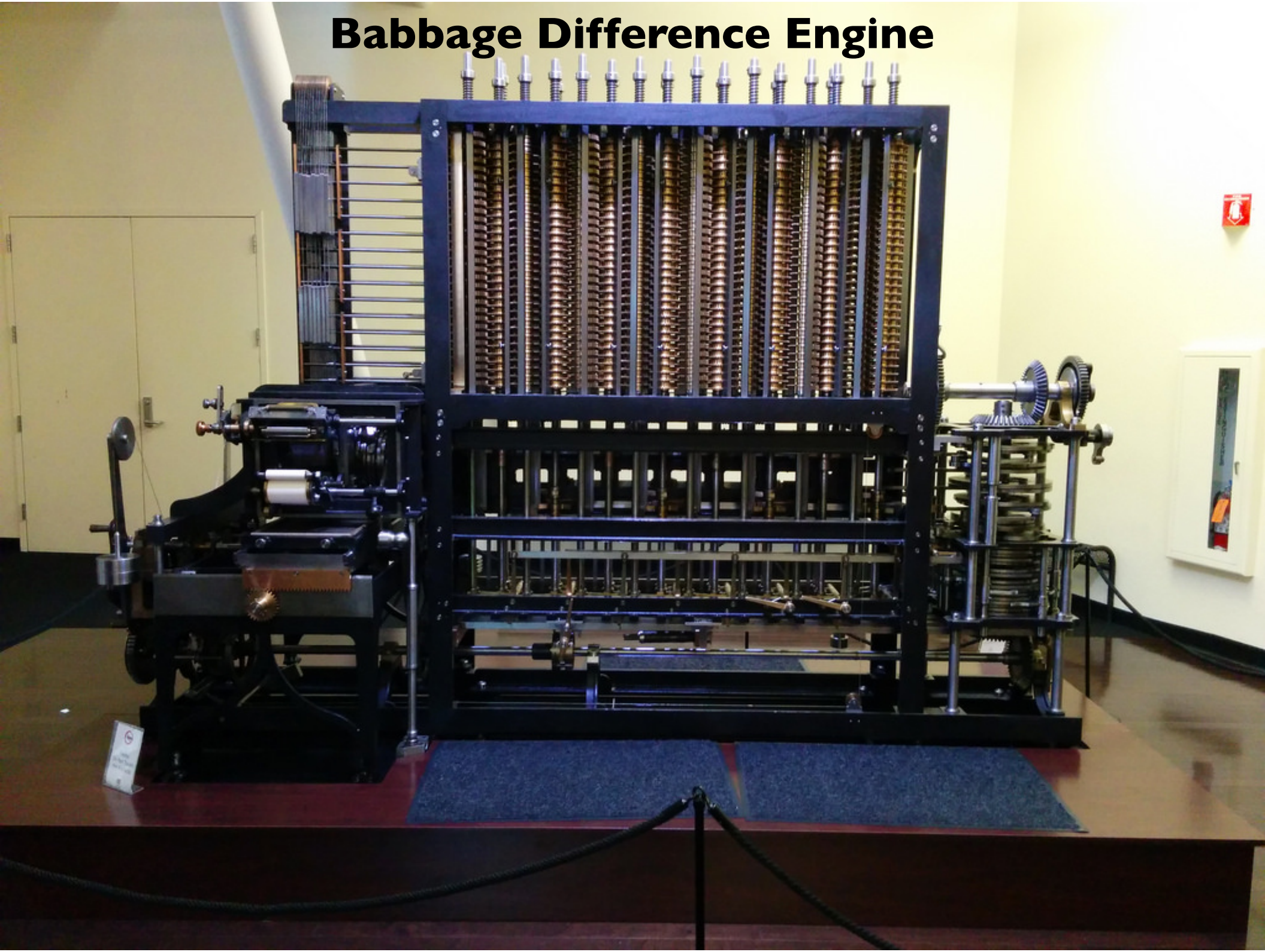
But this didn't settle down until the 1970s

There are other ways to represent numbers and negative numbers

- One's complement: negative is just flip all the bits
  - There are two zeroes, -0 + 1 != 0 (0xff + 0x01)
- Binary coded decimal: each digit is encoded by 4 bits (ignore 0xa-0xf): supported on Intel except in 64 bit mode

IBM 3/60

Babbage Difference Engine



Addition and Subtraction of `signed` and `unsigned` numbers are the same!

Methods used to *compare*
`signed` and `unsigned` numbers
are NOT the same!

Types
and
Type Conversion

Type Conversion

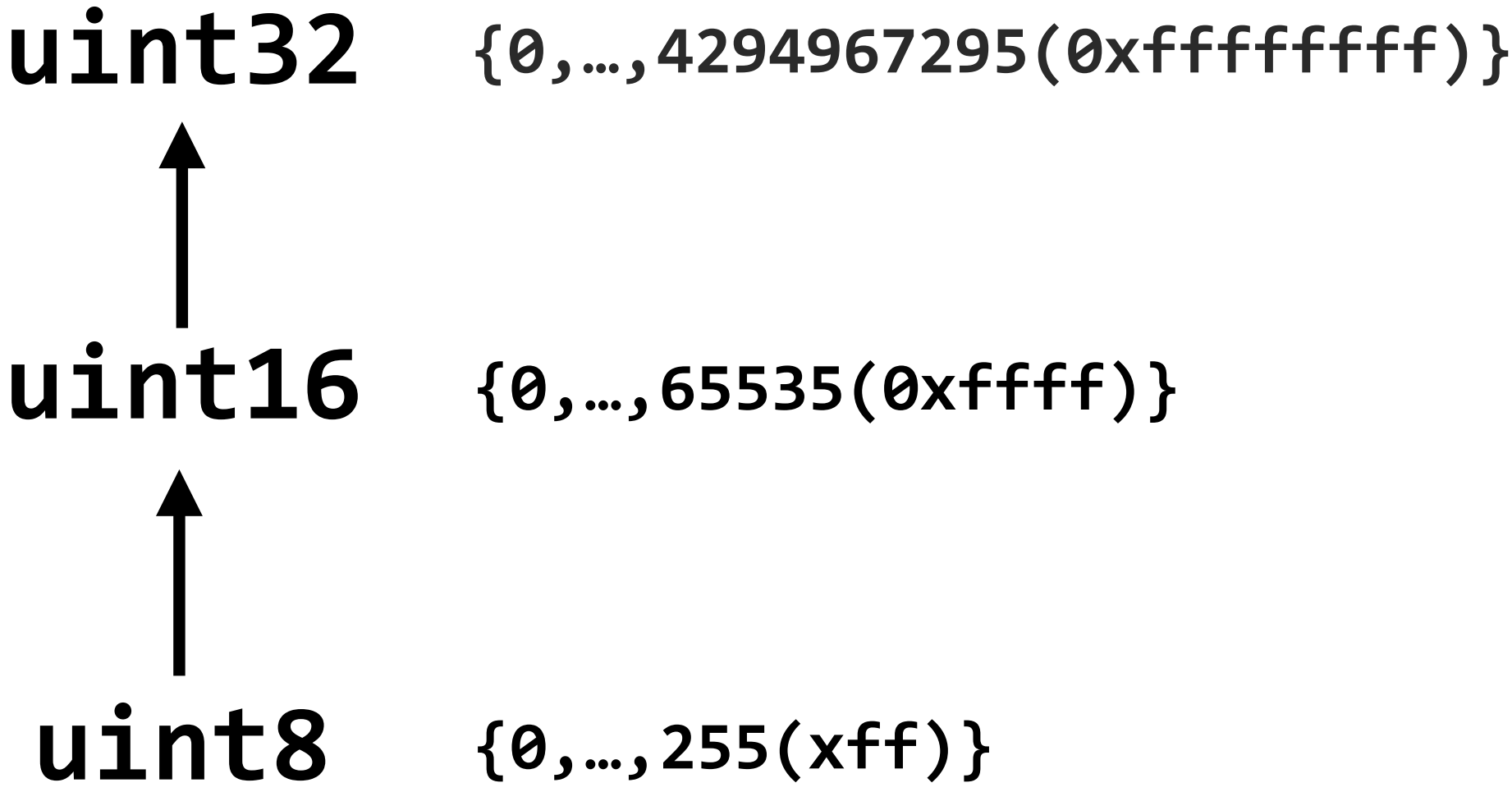
Type conversion is a way of converting data from one type to another type

Explicit type conversion means that the programmer must specify type conversions. Often called *casting*.

Implicit type conversions means that the language will have rules for performing type conversion for you. Often called *coercion*

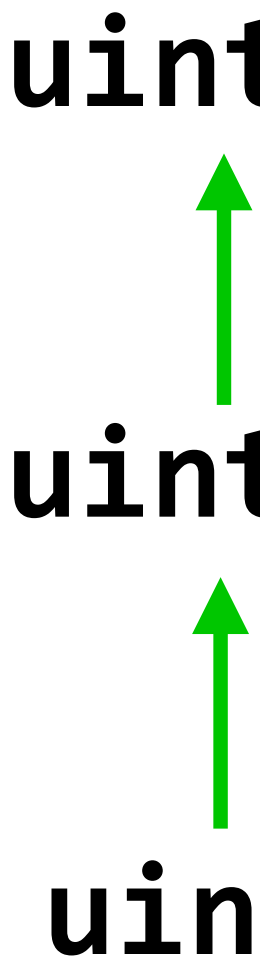
Casting sometimes refers to just a reinterpretation of the same bits.

Type Hierarchy



Types are *sets* of allowed values

Arrow indicate *subsets*: uint16 ⊂ uint32



Type Promotion is Safe
(values preserved)

```
#include <stdint.h>

uint16_t x = 0xffff;
uint32_t y = x;

// x = 0xffff
// y = ?
```

```
#include <stdint.h>

uint16_t x = 0xffff;
uint32_t y = x;

// x = 0xffff
// y = 0x0000ffff
```

```
int16_t x = -1;
int32_t y =  x;

// x = -1
// y = ?
```

```
int16_t x = -1;
int32_t y =  x;

// x = -1
// y = -1
```

int32 {-2,147,483,648,…,2,147,483,647}

int16 {-32768,…,32767}

int8 {-128,…,127}

Type Conversion is Safe
(values preserved)

```
int16_t x = -1;
int32_t y =  x;

// x = -1 = 0xffff
// y = -1 = 0xffffffff

int16_t x =  1;
int32_t y =  x;

// x = 1 = 0x0001
// y = 1 = 0x00000001
```

```
// To preserve signed values need sign extension

int8_t 0xfe -> int32_t 0xfffffffe
int8_t 0x7e -> int32_t 0x0000007e


// Sign extend instructions:
//
//  sxtb - sign extend byte to word
//  sxth - sign extend half word to word
//
```

```
int32_t x = 0x80000;
int16_t y = x;

// x = 0x80000
// y = ?
```

```
int32_t x = 0x80000;
int16_t y = x;

// x = 0x80000
// y =  0x0000
```

value has changed

Defined (remove most significant bits)

Dangerous (doesn't preserve all values)

```
int32_t  x = -1;
uint32_t y =  x;

// x = -1
// y =  ?
```

```
int32_t  x = -1;
uint32_t y =  x;

// x = -1
// y = 0xffffffff = 4294967295
```

 value has changed

x is negative, but y is positive!

Defined (copies bits)

Dangerous! (neg maps to pos)

uint32 → int32

uint16 → int16

uint8 → int8

Technically Not Defined
(arm: copies bits)

uint32 → int32

uint16 → int16

uint8 → int8

Dangerous!
(large positive numbers change)

"Whenever you mix
signed and unsigned numbers
you get in trouble."

Bjarne Stroustrup

Implicit Type Promotion

in

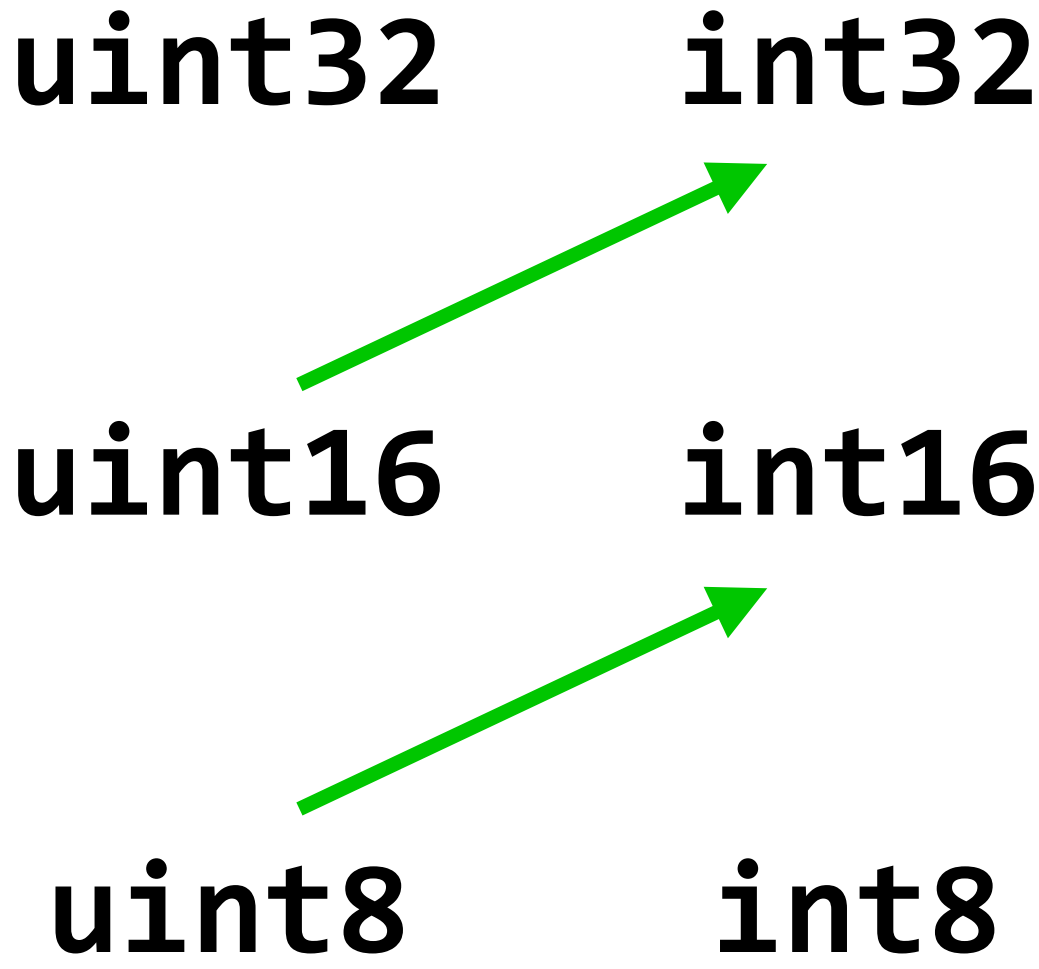
Binary Operators

Type promotions for binary operations

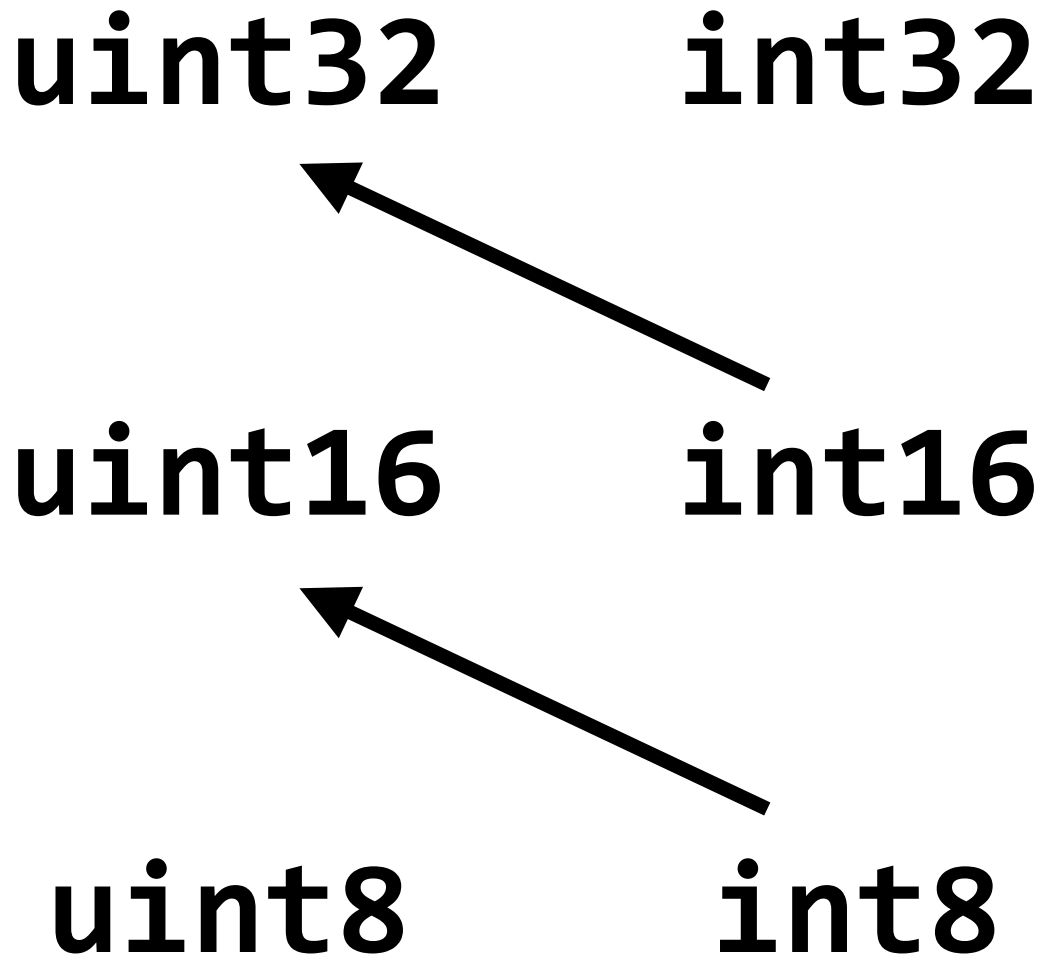
Note that the type of the result can be different than the type of the operands!

	u8	u16	u32	u64	i8	i16	i32	i64
u8	i32	i32	u32	u64	i32	i32	i32	i64
u16	i32	i32	u32	u64	i32	i32	i32	i64
u32	u32	u32	u32	u64	u32	u32	u32	i64
u64	u64	u64	u64	u64	u64	u64	u64	u64
i8	i32	i32	u32	u64	i32	i32	i32	i64
i16	i32	i32	u32	u64	i32	i32	i32	i64
i32	i32	i32	u32	u64	i32	i32	i32	i64
i64	i64	i64	i64	u64	i64	i64	i64	i64

arm-none-eabi-gcc type promotions



Safe?



Safe?

Bugs, Bugs, Bugs

A significant fraction of major Linux security vulnerabilities today are integer bugs.

```c
#include <stdio.h>

int main(void)
{
    int a = -20;
    unsigned int b = 6;

    if( a < b )
        printf("-20<6 - all is well\n");
    else
        printf("-20>=6 - omg \n");
}
```

Be Wary of Implicit Type Conversion

Modern languages like `rust` and `go` do not perform implicit type conversion

Summary

Negation is performed by forming the two's complement

- Signed numbers are represented in two's complement (-x = 2^n-x = ~x+1)

In 2's complement,

- Arithmetic between signed and unsigned numbers is identical
- Comparison between signed and unsigned numbers is different

Know the rules for type conversion, watch out for implicit type conversions and promotions

C Type Conversion and Promotion Rules

The semantics of numeric casts are:

Casting from a larger integer to a smaller integer (e.g. u32 -> u8) will truncate

Casting from a smaller integer to a larger integer (e.g. u8 -> u32) will
- **zero-extend if the source is unsigned**
- **sign-extend if the source is signed**

Casting between two integers of the same size (e.g. i32 -> u32) is a no-op

6.3.1.3 Signed and unsigned integers conversions

1 When a value with integer type is converted to another integer type, if the value can be represented by the new type, it is unchanged.

2 Otherwise, if the new type is unsigned, the value is converted by repeatedly adding or subtracting one more than the maximum value that can be represented in the new type until the value is in the range of the new type.

3 Otherwise, if the new type is signed and the value cannot be represented in it; either the result is implementation-defined or an implementation-defined signal is raised.

6.3.1.8 Usual arithmetic conversions

1 If both operands have the same type, then no further conversion is needed.

2 Otherwise, if both operands have signed integer types or both have unsigned integer types, the operand with the type of lesser integer conversion rank is converted to the type of the operand with greater rank.

3 Otherwise, if the operand that has unsigned integer type has rank greater or equal to the rank of the type of the other operand, then the operand with signed integer type is converted to the type of the operand with unsigned integer type.

4 Otherwise, if the type of the operand with signed integer type can represent all of the values of the type of the operand with unsigned integer type, then the operand with unsigned integer type is converted to the type of the operand with signed integer type.

5 Otherwise, both operands are converted to the unsigned integer type corresponding to the type of the operand with signed integer type.