- Understand MIPS instruction set and design principle

- Translate a MIPS instruction into machine code

MIPS ISA

- ✅ We introduced the MIPS architecture.
  - Developed by John Hennessy and his colleagues at Stanford and in the 1980's.
  - Used in many commercial systems, including Silicon Graphics, Nintendo, and Cisco.

- ✅ RISC ISA: Reduced instruction set computing
  - As opposed to CISC (e.g. x86)

- ✅ Simple, elegant, easy to implement
  - That's why we choose it in COMP1047.
  - Once you've learned one architecture, it's easy to learn others.

- ✅ Designed with decades of continuous ISA design efforts
  - The prototype of a lot of modern ISAs

Think about it:

What's the relationship between von Neumann Architecture and MIPS ISA?

Image Link

Instruction Set Architecture

◀ Defines the set of operations that a computer/processor can execute

◀ The contract between the hardware and software
  ➡ "Contract": given an ISA, your sw and hw must be designed for the ISA! A glue for high and low levels of the system!

◀ Example ISAs:
  ➡ x86: intel Xeon, intel Core i7/i5/i3, intel atom, AMD Athlon/Opteron, AMD FX, AMD A-series
  ➡ ARM: Apple A-Series, Qualcomm Snapdragon, TIOMAP, NVidia Tegra
  ➡ MIPS: Sony/Toshiba Emotion Engine, MIPS R-4000(PSP)
  ➡ DEC Alpha, PowerPC, IA-64, SPARC and many more …

- We've been using assembly language

- Recall that an assembler is a program that translates a symbolic version of instructions into the binary versions

- MIPS32: Each machine instruction is 32-bit long and contains several fields

MIPS instruction	add $s0, $s1, $s2
Hexadecimal (machine code)	$0232\ 8020_{16}$
Binary (machine code)	$0000\ 0010\ 0011\ 0010\ 1000\ 0000\ 0010\ 0000_2$

Instructions as numbers

- Currently we worked with words (32-bit blocks):
  - Each register is a word.
  - `lw` and `sw` both access memory one word at a time.

- So how do we represent instructions?
  - Design principle: Simplicity favors regularity
  - MIPS wants simplicity: since data is in words, make instructions be in words too...
  - Best case: define a single format for all types of instructions – too restrictive.
  - In practice: Defined 3 basic types of instruction formats: R-format, I-format, J-format.

- One instruction is in 32 bits
  - Divide the instruction word into "fields".
  - Each "field" tells computer the info about the operands and operations.

3 Instruction Formats: all 32 bits wide

OP	$rs	$rt	$rd	sa	funct

OP	$rs	$rt	immediate		

OP	jump target				

MIPS ISA as an Example

- All instructions are 32 bits

- 32 32-bit registers
  - $zero is always 0

- 50 opcodes
  - Arithmetic/Logic operations
  - Load/store operations
  - Branch/jump operations

- 3 instruction formats
  - R-type: all operands are registers
  - I-type: one of the operands is an immediate value
  - J-type: non-conditional, nonrelative branches

3 Instruction Formats: all 32 bits wide

OP	$rs	$rt	$rd	sa	funct

OP	$rs	$rt	immediate		

OP	jump target				

Simplicity favors regularity

R-format instructions

✅ Define the following fields:

6	5	5	5	5	6
opcode	rs	rt	rd	shamt	funct

- ❯ `opcode`: partially specifies what instruction it is (Note: '0' for all R-Format instructions)
- ❯ `funct`: combined with `opcode` to specify the instruction
  - ▪ E.g. add: op(0), funct(32). sub: op(0), funct(34).
- ❯ `rs` (Source Register): used to specify register containing first operand
- ❯ `rt` (S-next Register): used to specify register containing second operand
- ❯ `rd` (Destination Register): used to specify register which will receive result of calculation
- ❯ `shamt` (shift amount): contains the amount a shift instruction will shift by. Set to zero in other cases.

Think about it:

Why are only 5 bits needed for `rs`, `rt`, or `rd`?

Why 5 for `shamt`?

Example

op	rs	rt	rd	shamt	funct
6 bits	5 bits	5 bits	5 bits	5 bits	6 bits

add $t0, $s1, $s2

R	$s1	$s2	$t0	0	add

0	17	18	8	0	32

000000	10001	10010	01000	00000	100000

$00000010001100100100000000100000_2 = 02324020_{16}$

Table B.1 Instructions, sorted by opcode

Opcode	Name	Description	Operation
000000 (0)	R-type	all R-type instructions	see Table B.2
000001 (1) (rt = 0/1)	bltz/bgez	branch less than zero/ branch greater than or equal to zero	if ([rs] < 0) PC = BTA/ if ([rs] ≥ 0) PC = BTA
000010 (2)	j	jump	PC = JTA
000011 (3)	jal	jump and link	$ra = PC+4, PC = JTA
000100 (4)	beq	branch if equal	if ([rs]==[rt]) PC = BTA
000101 (5)	bne	branch if not equal	if ([rs]!=[rt]) PC = BTA
000110 (6)	blez	branch if less than or equal to zero	if ([rs] ≤ 0) PC = BTA
000111 (7)	bgtz	branch if greater than zero	if ([rs] > 0) PC = BTA
001000 (8)	addi	add immediate	[rt] = [rs] + SignImm
001001 (9)	addiu	add immediate unsigned	[rt] = [rs] + SignImm
001010 (10)	slti	set less than immediate	[rs] < SignImm ? [rt]=1 : [rt]=0

Table B.1 in Appendix B, in the Harris & Harris Book

Table B.2 R-type instructions, sorted by funct field—Cont'd

Funct	Name	Description	Operation
011011 (27)	divu	divide unsigned	[lo] = [rs]/[rt], [hi] = [rs]%[rt]
100000 (32)	add	add	[rd] = [rs] + [rt]
100001 (33)	addu	add unsigned	[rd] = [rs] + [rt]
100010 (34)	sub	subtract	[rd] = [rs] − [rt]
100011 (35)	subu	subtract unsigned	[rd] = [rs] − [rt]
100100 (36)	and	and	[rd] = [rs] & [rt]
100101 (37)	or	or	[rd] = [rs] | [rt]
100110 (38)	xor	xor	[rd] = [rs] $^\wedge$ [rt]
100111 (39)	nor	nor	[rd] = ~([rs] | [rt])
101010 (42)	slt	set less than	[rs] < [rt] ? [rd] = 1 : [rd] = 0
101011 (43)	sltu	set less than unsigned	[rs] < [rt] ? [rd] = 1 : [rd] = 0

Table B.2 in Appendix B, in the Harris & Harris Book

Question: translate the following instruction into machine code (in Hex format)

```
sub $s0, $s1, $s2
```

Question: translate the following instruction into machine code (in Hex format)

```
sub $s0, $s1, $s2
```

op	rs	rt	rd	shamt	funct
000000	10001	10010	10000	00000	100010

```
       sub    $s1    $s2    $s0
```

- **Machine code in hexadecimal: 02328022_{16}**

I-format instructions

✅ Define the following fields:

6	5	5	16
opcode	rs	rt	immediate

- ❯ **opcode**: *uniquely* specifies an I-format instruction

- ❯ **rs**: specifies the *only* register operand

- ❯ **rt**: specifies the register which receives the result of calculation (*target register*)

- ❯ **immediate**: 16-bit signed integer, can represent up to 2^{16} different immediate values.
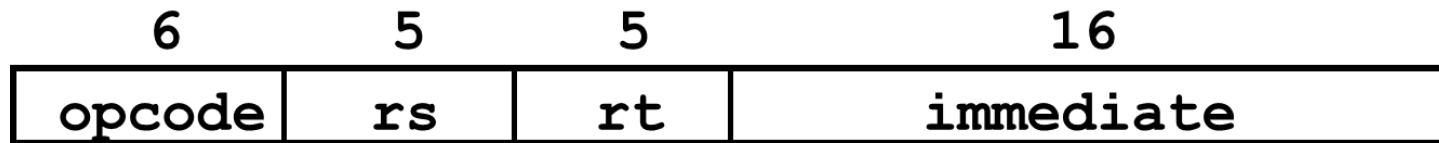
Think about it:

How many different *I-format* instructions can be represented?

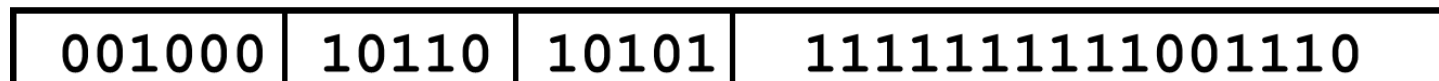**What is the maximum number that the `immediate` field can carry?**

Example

6	5	5	16
opcode	rs	rt	immediate

```
addi $21, $22, -50
```

decimal representation:

8	22	21	-50

binary representation:

001000	10110	10101	1111111111001110

look up opcode for 'addi' in Table B.1 in Appendix B, in the Harris & Harris Book

Example

6	5	5	16
opcode	rs	rt	immediate
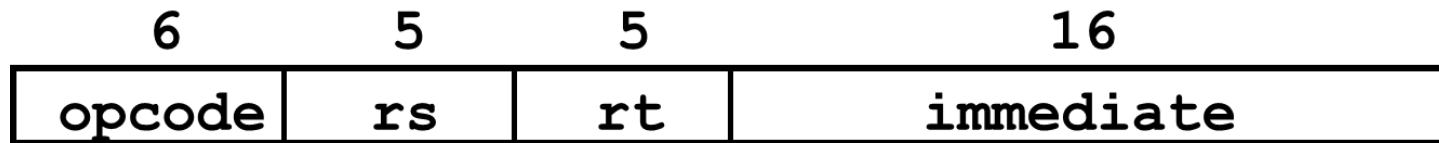
lw $t0, 1200($t1)

decimal representation:

35	9	8	1200

binary representation:

100011	01001	01000	0000010010110000
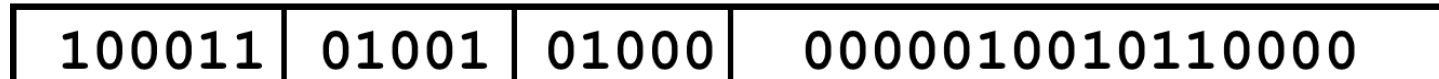
look up opcode for 'lw' in Table B.1 in Appendix B, in the Harris & Harris Book

Question: translate the following instruction into machine code (in Hex format)

```
addi $t0,$t1,100
```

Question: translate the following instruction into machine code (in Hex format)

```
addi $t0,$t1,100
```

op	rs	rd	imm
001000	01001	01000	**0000 0000 0110 0100**
addi	$t1	$t0	100

- **Machine code in hexadecimal: 21280064_{16}**

Question: translate the following instruction into machine code (in Hex format)

```
addi $21,$22,-50
```

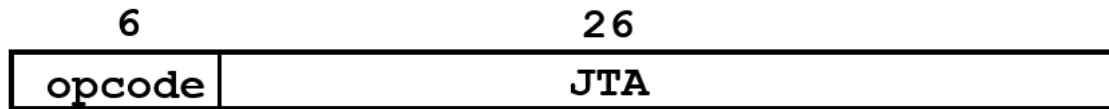Question: translate the following instruction into machine code (in Hex format)

`addi $21,$22,-50`

op	rs	rd	imm
001000	10110	10101	**1111 1111 1100 1110**
addi	$22	$21	-50

• **Machine code in hexadecimal: 22d5ffce$_{16}$**

J-format instructions

✅ Define the following fields:

6	26
opcode	JTA

❯ **opcode**: *uniquely* specifies an J-format instruction, so far, we've learnt **j** and **jal**

❯ **JTA**: 26-bit jump target address, jump relative to the current PC value, jump in words not in bytes.

Think about it:

What is the range of the jump?

- MIPS instruction set

- {R, I, J}-type instructions

Stay Tuned.