CSCI 210: Computer Architecture
Lecture 9: Logical Operations

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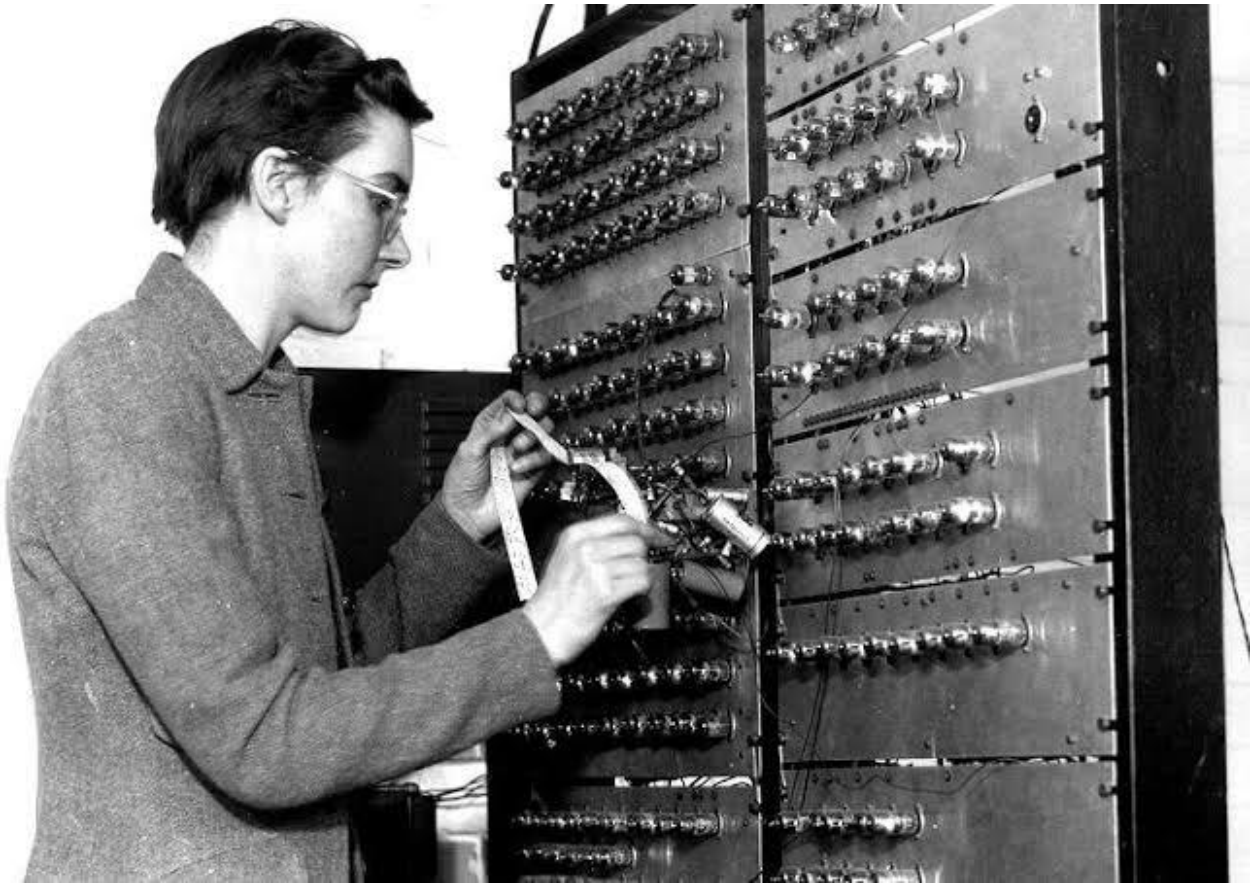


- Applied mathematician and computer scientist
- Wrote the first assembly language and assembler in 1947
- Collaborated with Andrew Booth to develop three early computers: the ARC (Automatic Relay Calculator), SEC (Simple Electronic Computer), and APE(X)C
- Later worked with neural nets

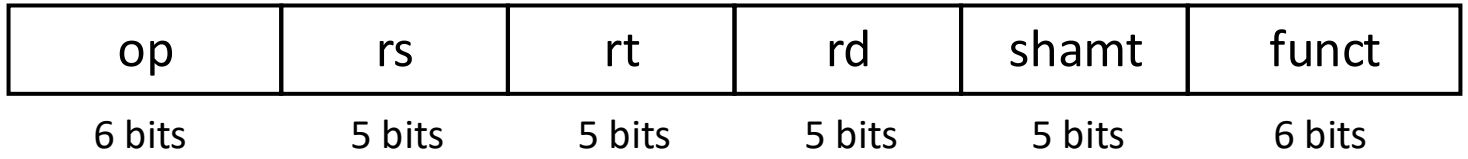
Logical Operations

- Instructions for bitwise manipulation

Operation	C	Java	MIPS
Shift left	<<	<<	sll
Shift right	>>	>>>	srl
Bitwise AND	&	&	and, andi
Bitwise OR	|	|	or, ori
Bitwise NOT	~	~	nor

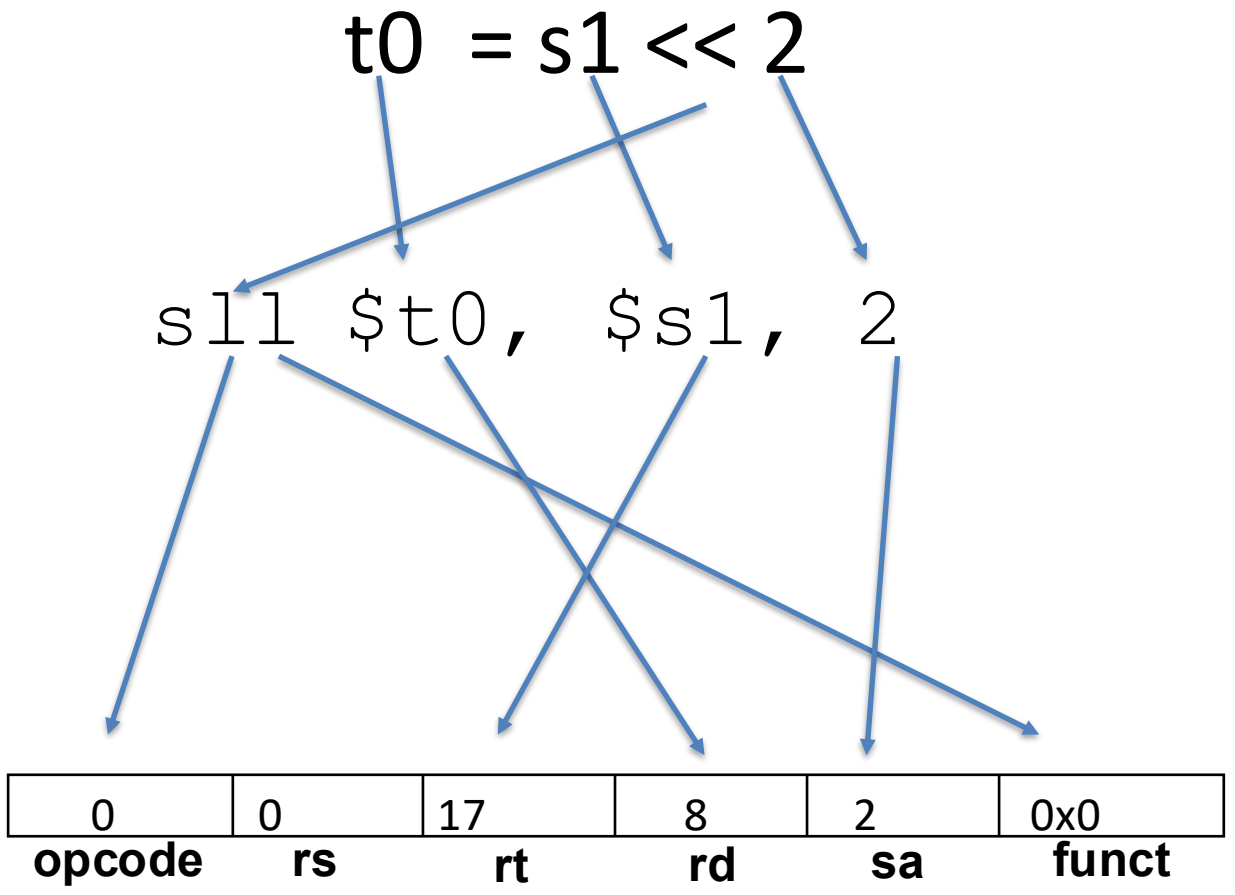
- Useful for extracting and inserting groups of bits in a word

Shift Operations



- shamt: how many positions to shift
- Shift left logical
  - Shift left and fill with 0 bits
  - **sll by n bits multiplies by 2^n**
- Shift right logical
  - Shift right and fill with 0 bits
  - **srl by n bits divides by 2^n (unsigned only)**

MIPS shift instructions



Shift left logical

- 0110 1001 << 2 in 8 bits
  - Most significant 2 bits are dropped
  - 2 0s are added to become the least significant bits
  - Result: ~~01~~ 1010 0100 => 1010 0100

Shift right logical

- 1010 1001 >>> 3 in 8 bits
  - Least significant 3 bits are dropped
  - 3 0s are added to become the most significant bits
  - Result: 0001 0101 ~~001~~ => 0001 0101

Shift right arithmetic

- sra rd, rt, shamt
  - Shift right and copy the sign bit
- 1010 1001 >> 3 in 8 bits
  - Least significant 3 bits are dropped
  - 3 1s are added because the MSB is 1 to become the most significant bits
  - Result: 1111 0101 ~~001~~ => 1111 0101

A new op HEXSHIFTRIGHT shifts hex numbers right by a digit. HEXSHIFTRIGHT *i* times is equivalent to

A. Dividing by *i*

B. Dividing by 2^i

C. Dividing by 16^i

D. Multiplying by 16^i

Remember Boolean Operations?

- and, or, not . . .
- Now we'll apply them to bits!
- Just think of 1 as True, and 0 as False

And Truth Table

	0	***1***
0	0	0
1	0	1

AND Operations

- Useful to mask bits in a word
  - Select some bits, clear others to 0

```
and $t0, $t1, $t2
```

$t2	0000 0000 0000 0000 0000 1101 1100 0000
$t1	0000 0000 0000 0000 0011 1100 0000 0000
$t0	0000 0000 0000 0000 0000 1100 0000 0000

AND identities (for a single bit)

- x & 0 =
- x & 1 =

```
  01101001
& 11000111
```

A. 00010000

B. 01000001

C. 10101110

D. 11101111

If we want to zero out bits* 3 – 0 in a byte we should AND with

A. 00000000

B. 00001111

C. 11110000

D. 11111111

*MSB (bit 7) is on the left,
LSB (bit 0) is on the right

One way to represent colors is to specify the amount of red, green, and blue (RGB) that makes up the color. The three color "channels" are often packed into a 32-bit integer as follows:

`00000000 rrrrrrrr gggggggg bbbbbbbb`

where each color is represented in 8 bits. If `color` is a 32-bit RGB color, which high-level expression extracts the green channel as an 8-bit value in the range 0–255?

```
A.green = (color >> 8) & 0xFF
B.green = (color >> 16) & 0xFF
C.green = (color & 0xFF) >> 8
D.green = (color & 0xFF00) >> 16
```

E. More than one of the above (which?)

Assume `color` is stored in `$t0` and `green` should be extracted to `$t1`. Which sequence of MIPS instructions corresponds to

```
green = (color >> 8) & 0xFF
```

```
A.sll   $t1, $t0, 8
  andi  $t1, $t1, 0xFF
B.srl   $t1, $t0, 8
  andi  $t1, $t1, 0xFF
C.andi  $t1, $t0, 0xFF
  sll   $t1, $t1, 8
D.andi  $t1, $t0, 0xFF
  srl   $t1, $t1, 8
```

Or Truth Table

	0	***1***
0	0	1
1	1	1

OR Operations

- Useful to set bits in a word
  - Set some bits to 1, leave others unchanged

```
or $t0, $t1, $t2
```

$t2	0000 0000 0000 0000 0000 1101 1100 0000
$t1	0000 0000 0000 0000 0011 1100 0000 0000
$t0	0000 0000 0000 0000 0011 1101 1100 0000

OR Identities (for a single bit)

- x | 0 =
- x | 1 =

```
  01101001
| 11000111
```

A.00010000

B.01000001

C.10101110

D.11101111

Recall RGB:

`00000000 rrrrrrrr gggggggg bbbbbbbb`

If `r`, `g`, and `b` are values in the range 0–255, how can we construct the RGB value, `c`, whose channels are `r`, `g`, and `b`?

```
A.c = (r << 16) | (g << 8) | b
B.c = (r << 24) | (g << 16) | (b << 8)
C.c = (r >> 8) | (g >> 16) | (b >> 24)
D.c = (r >> 16) | (g >> 24) | (b >> 32)
```

E. More than one of the above (which?)

Nor Truth Table

	0	***1***
0	1	0
1	0	0

NOR Operations

- MIPS has NOR 3-operand instruction
  - a NOR b = NOT (a OR b)

```
nor $t0, $t1, $t2
```

$t2	0000 0000 0000 0000 0000 1101 1100 0000
$t1	0000 0000 0000 0000 0011 1100 0000 0000
$t0	1111 1111 1111 1111 1100 0010 0011 1111

```
  01101001
NOR 11000111
```

A. 00010000

B. 01000001

C. 10101110

D. 11101111

NOT operations

- Inverts all the bits in a word
  - Change 0 to 1, and 1 to 0

MIPS does not need a NOT operation because we can use ____ for NOT $t1, $t2

A. `nor $t1, $t2, $zero`

B. `nor $t1, $t2, $t3`, where all bits in `$t3` are set to 1

C. `nori $t1, $t2, 0b1111111_11111111`, where nori is Nor Immediate

D. It does require a NOT operation

E. None of the above are correct

XOR Truth Table

	0	***1***
0	0	1
1	1	0

XOR Operations

- Exclusive OR (written x ⊕ y or x ^ y)
  - Set bits to one only if they are not the same

```
xor $t0, $t1, $t2
```

$t2	0000 0000 0000 0000 0000 1101 1100 0000
$t1	0000 0000 0000 0000 0011 1100 0000 0000
$t0	0000 0000 0000 0000 0011 0001 1100 0000

```
  01101001
XOR 11000111
```

A. 00010000

B. 01000001

C. 10101110

D. 11101111

XOR Identities (for a single bit)

- x XOR 0 =
- x XOR 1 =

10 & 7

A. 0

B. 2

C. 7

D. 10

E. None of the above

Set bit 4 in byte x to 1, leaving the rest of the bits unchanged

A. x = x AND 00010000

B. x = x AND 11101111

C. x = x OR 00010000

D. x = x NOR 11101111

Invert bits 2–0 of x

A. x = x AND 00000111

B. x = x OR 00000111

C. x = x NOR 00000111

D. x = x XOR 00000111

Find the ones' complement of x (in 8 bits)

A. x XOR 00000000

B. x XOR 11111111

C. x XOR 11111110

D. x OR 11111111

Reading

- Next lecture: Branching instructions