SER 232

Computer Systems Fundamentals I

Dr. Heinrichs

Topics

- MSB
- LSB

MSB

- MSB stands for “Most Significant Bit”
  - MSB: Bit that has the highest value in binary number
    - E.g.: **1**111; MSB has value of decimal 8
  - Usually MSB is the leftmost bit in binary number

LSB

- LSB stands for “Least Significant Bit”
  - LSB: Bit that has the lowest value in binary number
    - E.g. 1111; LSB has value of decimal 1
  - Usually LSB is the rightmost bit in binary number
    - This is also called “LSB 0”: LSB is bit position 0
- Sometimes binary numbers are written in different order (LSB left, MSB right)
  - This is also called “MSB 0”: MSB is bit position 0

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Computer Systems Fundamentals I

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Topics

- Logic Component: Multiplexer

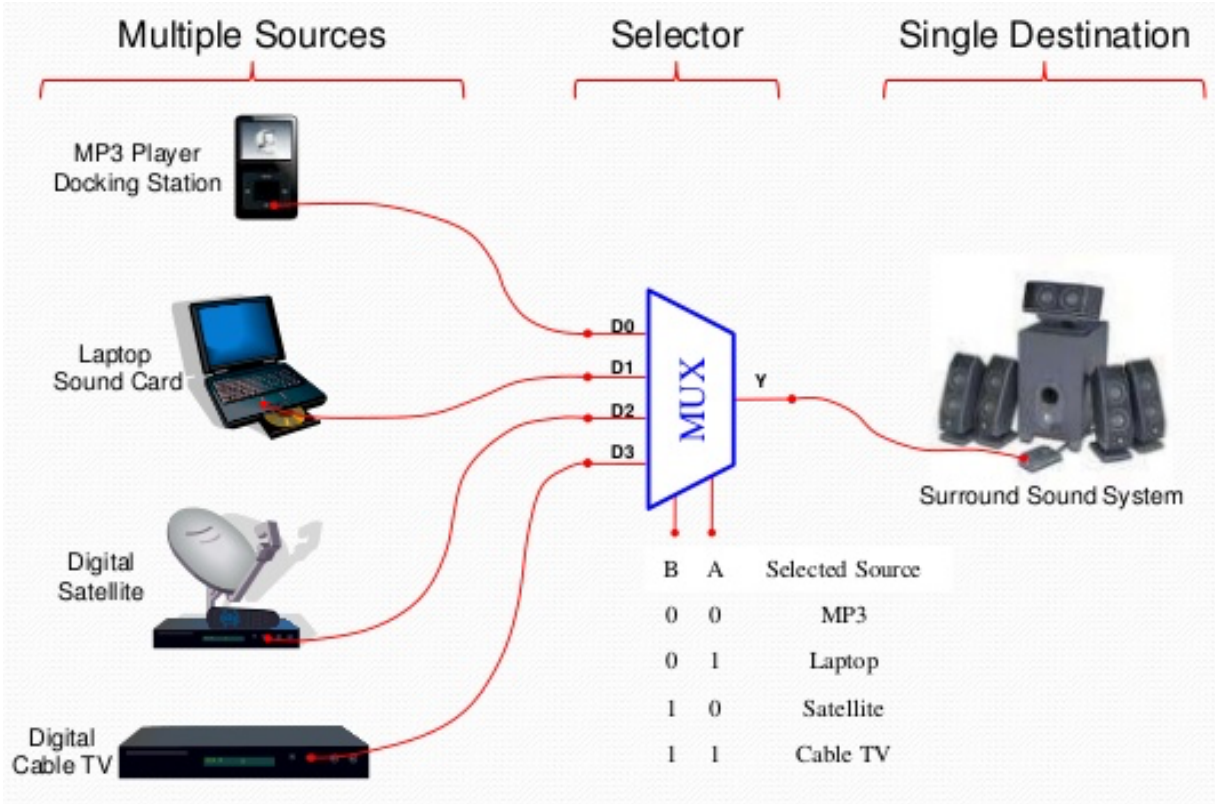
Logic Components

- Logic Components:
  - … have a specific function and purpose
  - … are made out of Logic Gates
- Most important / common components that we will look at:
  1. Multiplexer
  2. Demultiplexer
  3. Encoder
  4. Priority Encoder
  5. Decoder

Logic Components

- Notation: Usually the amount of inputs and outputs of logic component is indicated in name
  - AxB <logic component name>
  - A = number of inputs
  - B = number of outputs
- E.g. 4x2 means 4 inputs; 2 outputs
  - “2x1 multiplexer” (2 in, 1 out)
  - “1x4 demultiplexer” (1 in, 4 out)

Multiplexer



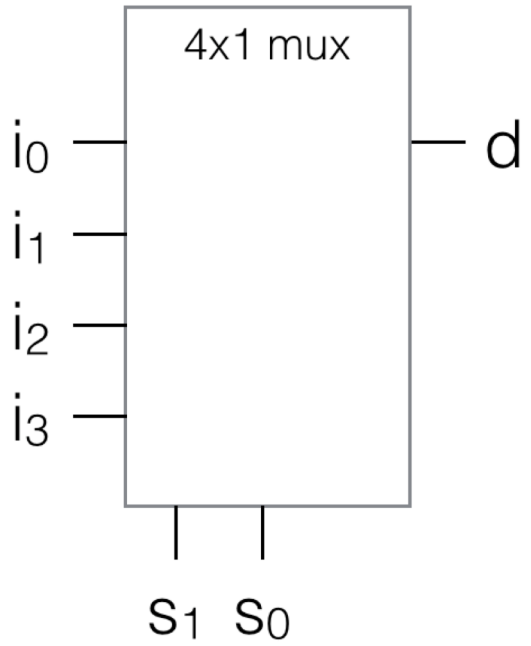
B	A	Selected Source
0	0	MP3
0	1	Laptop
1	0	Satellite
1	1	Cable TV

Multiplexer

- Multiple sources to single destination
- Analogies:
  - AV receiver
    - Connecting multiple devices (consoles, satellite, Blu-ray) output to one TV or one speaker system
  - Vehicle speedometer
    - One display, multiple information: milage, fuel consumption, oil / coolant temperatures, …

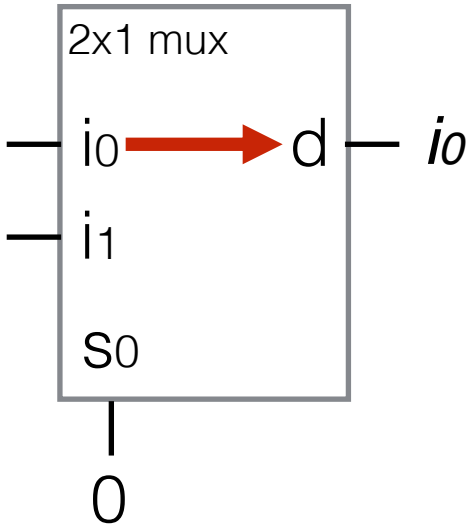
Multiplexer

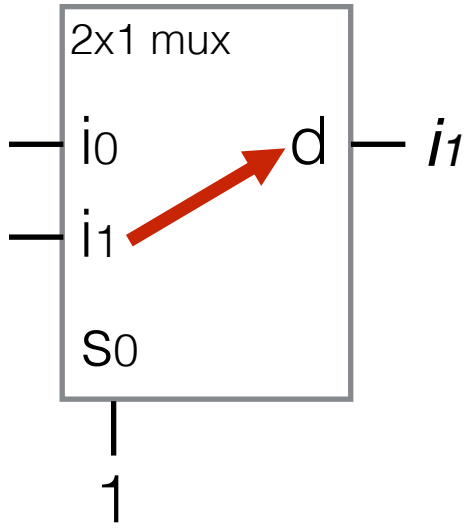
- Multiplexer is also called "**mux**"
- Has **multiple inputs** and a **single output** plus a set of select inputs
- Passes one input through to output
  - Select input value determines which output
  - Value of non-selected inputs are ignored
- Amount of select input bits determines amount of possible inputs (2^n relation, e.g. 2 select bits = 4 inputs (2^2))



Multiplexer

- 2x1 mux
  - If `s0 = 0` input `i0` is passed through to output `d`
  - If `s0 = 1` input `i1` is passed through to output `d`
  - Output `d` is aways equal to one input (`i0` or `i1`)





Multiplexer

- Similar to railyard switch:
  - Several tracks lead to one single track
  - Control lever selects which input track will connect to output track

Multiplexer

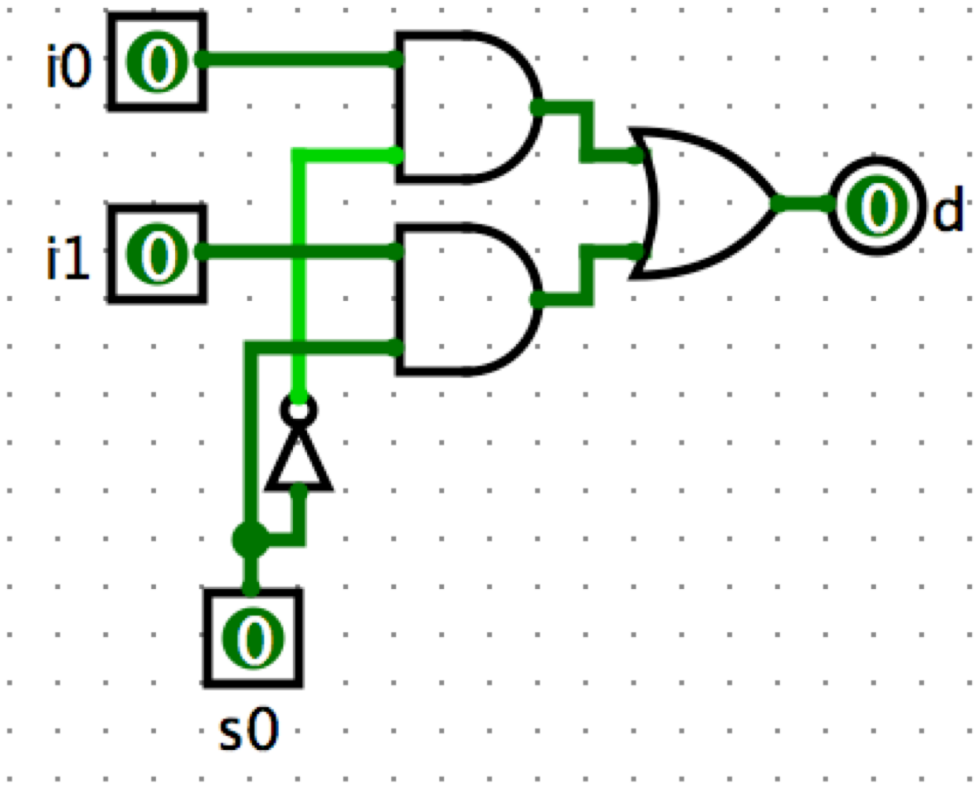
- 2x1 mux

s0	i_1	i_0		d
0	0	0		0
0	0	1		1
0	1	0		0
0	1	1		1
1	0	0		0
1	0	1		0
1	1	0		1
1	1	1		1

s0	i_1	i_0		d
0	x	0		0
0	x	1		1
1	0	x		0
1	1	x		1

Multiplexer

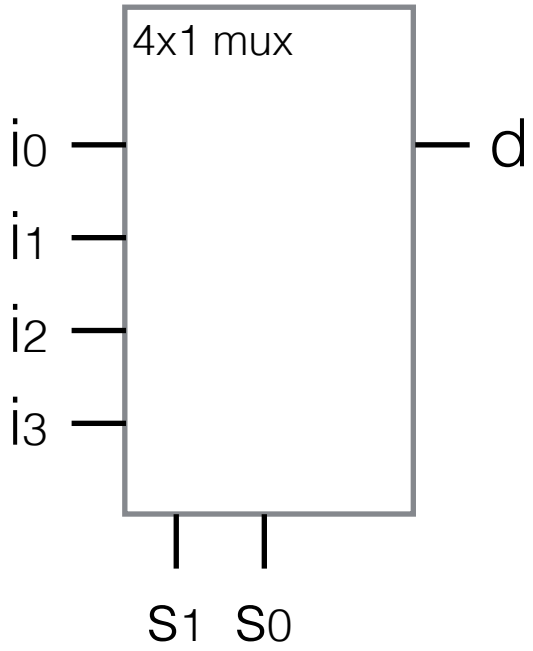
- 2x1 mux



s0	i_1	i_0		d
0	x	0		0
0	x	1		1
1	0	x		0
1	1	x		1

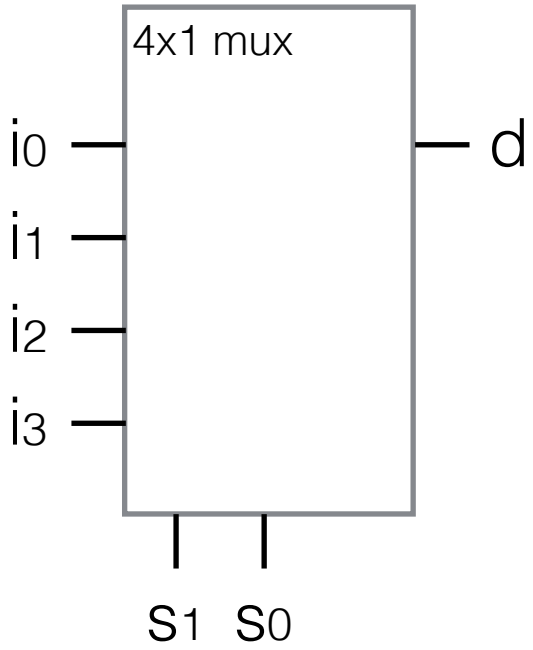
Multiplexer

- 4x1 mux
- Binary number $s_1 s_0$ in decimal is the same as input index
  - 0b00 = 0 = i_0 passed through
  - 0b01 = 1 = i_1 passed through
  - 0b10 = 2 = i_2 passed through
  - 0b11 = 3 = i_3 passed through



Multiplexer

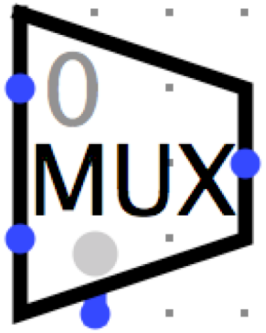
- 4x1 mux
  - 4 inputs + 2 select bits = 6 bits
  - 2^6 = 64 rows in truth table
  - Only 8 rows needed when using *don't care* symbols



i3	i2	i1	i0	s1	s0	d
x	x	x	**0**	0	0	**0**
x	x	x	**1**	0	0	**1**
x	x	**0**	x	0	1	**0**
x	x	**1**	x	0	1	**1**
x	**0**	x	x	1	0	**0**
x	**1**	x	x	1	0	**1**
0	x	x	x	1	1	**0**
1	x	x	x	1	1	**1**

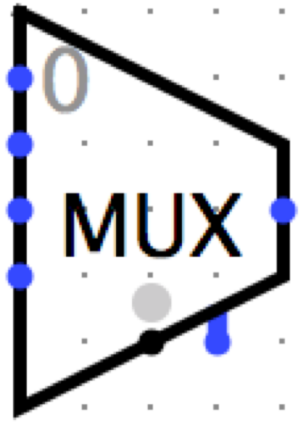
Multiplexer

- Schematic symbol
  - Most components in Logisim have an enable pin, which can turn a component completely off (can be disabled)



2x1 mux

Enable Pin



4x1 mux

Multiplexer

- 4x1 multiplexer with input values: 0011 (i3,i2,i1,i0)
  - Select input: 01 (s1,s0) - What is the output?
    - **1** (i1 passed through)
  - Select input: 11 (s1,s0) - What is the output?
    - **0** (i3 passed through)
  - How many select inputs needed for 16x1 mux?
    - **4 select inputs** ($16 = 2^{4)}$
  - How many data inputs can a multiplexer have with five select inputs?
    - 2^5 = **32 data inputs**

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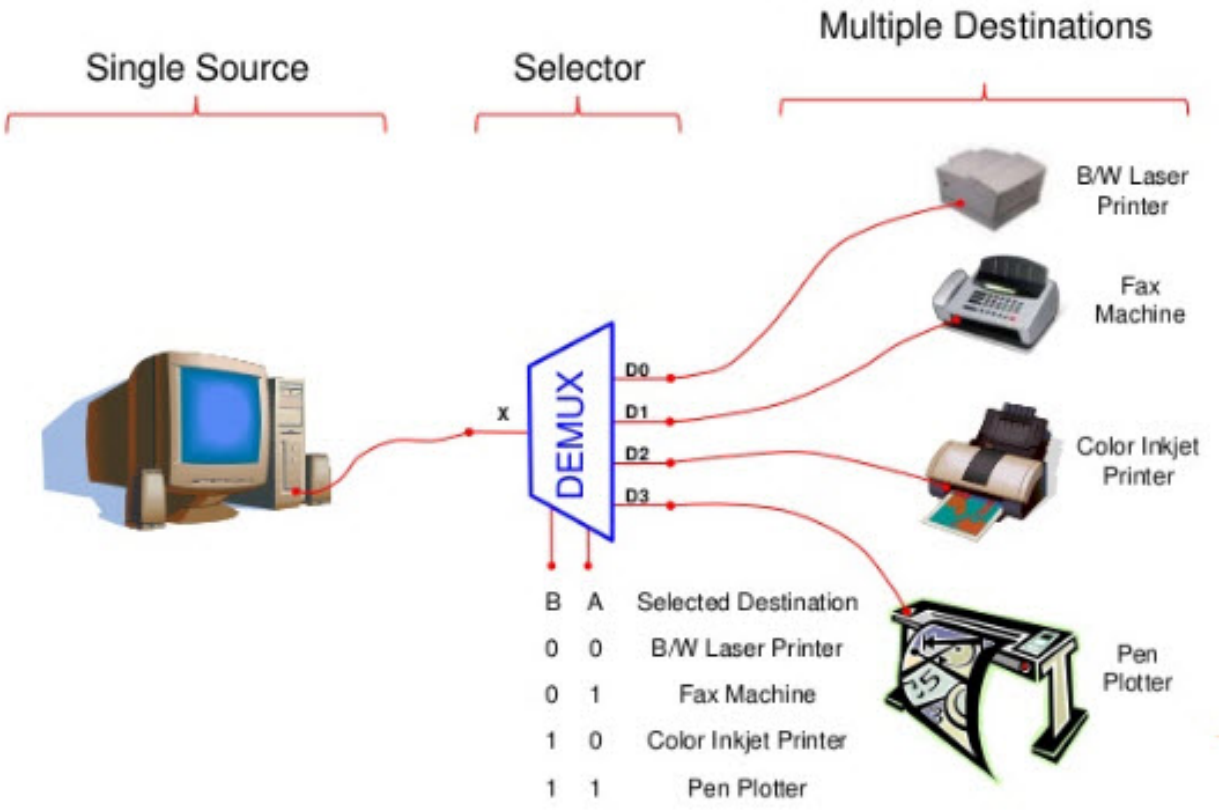
Computer Systems Fundamentals I

Dr. Heinrichs

Topics

- Logic Component: Demultiplexer

Demultiplexer

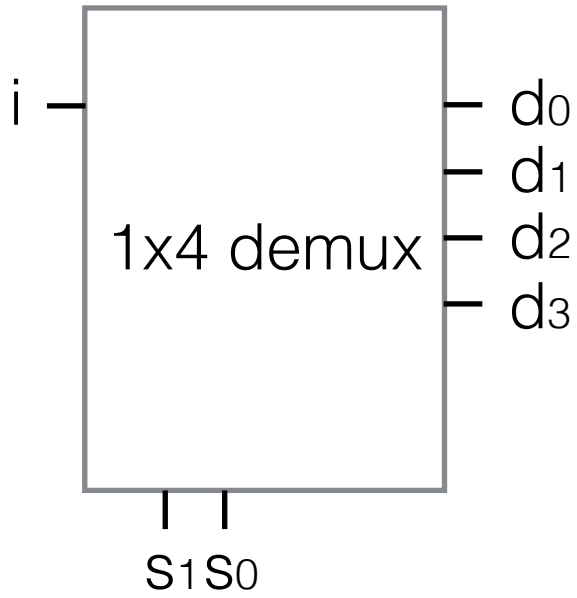


Demultiplexer

- Single source to multiple destinations
- Analogies:
  - Different printers, plotters and/or devices that take documents as input
  - HDMI switch (console attached to TV and projector)
  - Some AV receivers support switching between different “speaker zones” (living room, kitchen, patio, bedroom, …)

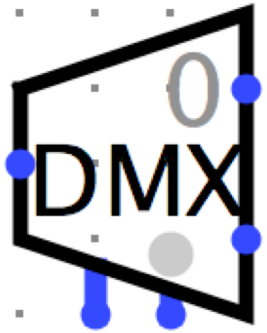
Demultiplexer

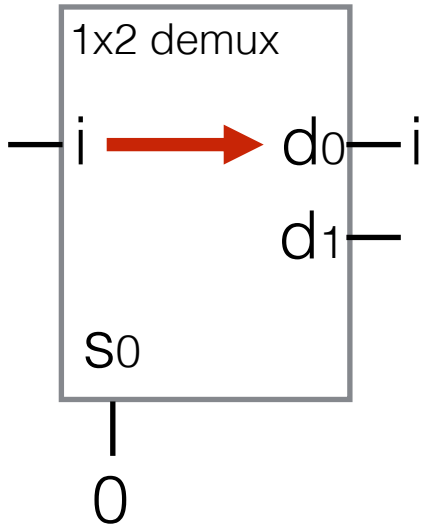
- Demultiplexer is also called "**demux**"
- Same as mux but inputs and output swapped
  - Has **single input** and **multiple outputs**
  - Select inputs indicate which output is passed through
- Same basic behavior as multiplexer but inputs and outputs swapped

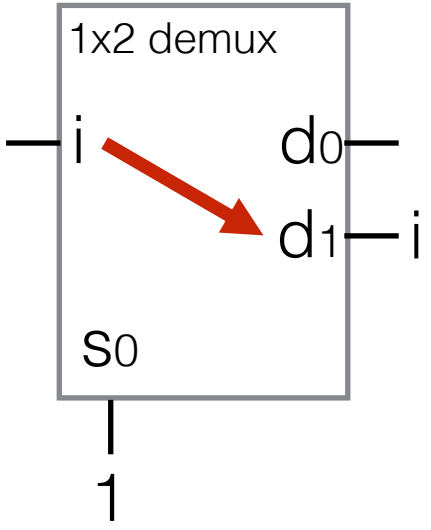


Demultiplexer

- 1x2 demux schematic symbol (including enable pin):
- Function:
  - s0 = 0; i is passed to d0
  - s0 = 1; i is passed to d1





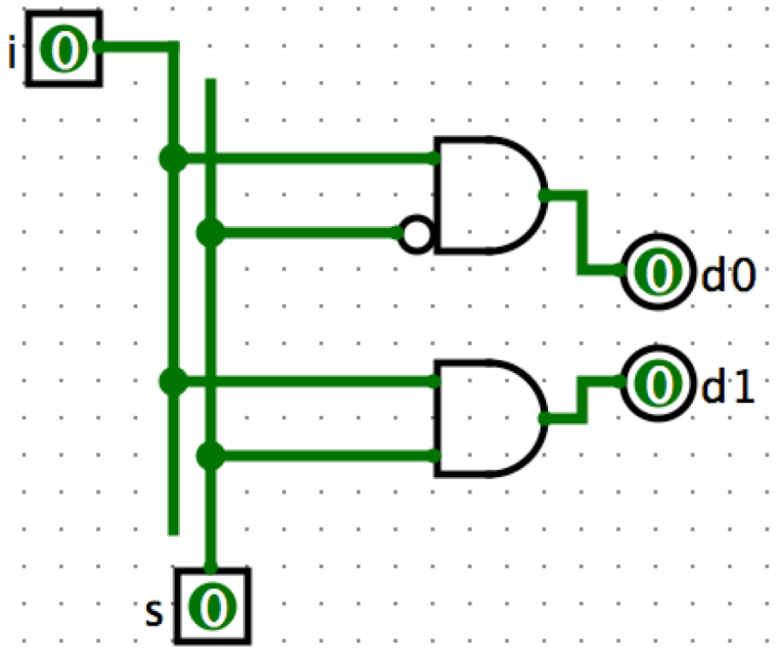


Demultiplexer

- Also similar to railyard switch:
  - One single track splits into several tracks
  - Control lever selects which track the train will continue on

Demultiplexer

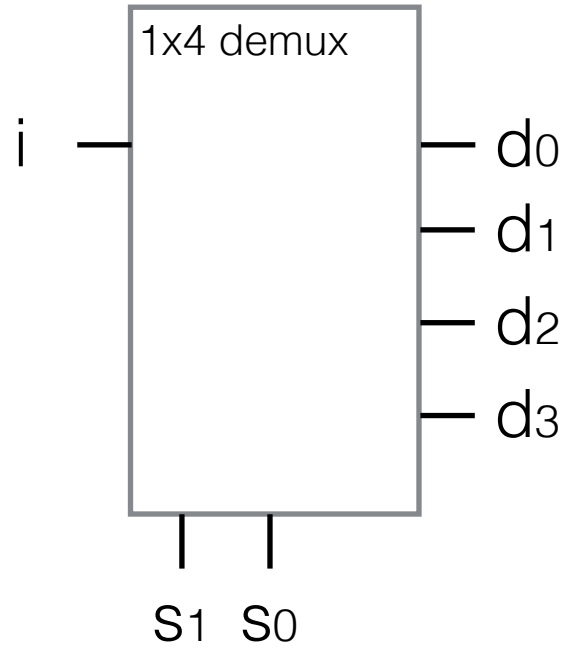
- Circuit and truth table of 1x2 demux



i	s	d1	d0
0	0	0	**0**
1	0	0	**1**
0	1	**0**	0
1	1	**1**	0

Demultiplexer

- Binary number $s_1 s_0$ in decimal is the same as output index
- For 1x4 demux:
  - 0b00 = 0 = passed through to d_0
  - 0b01 = 1 = passed through to d_1
  - 0b10 = 2 = passed through to d_2
  - 0b11 = 3 = passed through to d_3
- Demultiplexer with $\boldsymbol{2^n}$ outputs has $\boldsymbol{n}$ select inputs



Demultiplexer

- Truth table for a 1x4 demux

i	s1	s0	d3	d2	d1	d0
0	0	0	0	0	0	**0**
1	0	0	0	0	0	**1**
0	0	1	0	0	**0**	0
1	0	1	0	0	**1**	0
0	1	0	0	**0**	0	0
1	1	0	0	**1**	0	0
0	1	1	**0**	0	0	0
1	1	1	**1**	0	0	0

Demultiplexer

- 1x4 demultiplexer
  - Select input: 01 (s1,s0) - What is the output of d2?
    - **0** (input passed through to d1, everything else is 0)
  - Select input: 11 (s1,s0) - What is the output of d3?
    - **Value of input i** (i is passed through to d3, i=0 then d=0, i=1 then d=1)
  - How many select inputs needed for 1x32 demultiplexer?
    - **5 select inputs** ($32 = 2^5$)
  - How many data outputs can a demultiplexer have with four select inputs?
    - **2^4 = 16 data outputs**

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Computer Systems Fundamentals I

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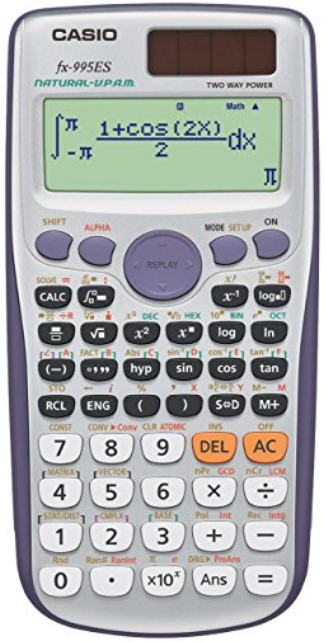
Topics

- Logic Component: Encoder

Encoder


HEAVY DUTY
NORMAL
PERM PRESS
COLORS/DARKS
ACTIVE WEAR
BEDDING
QUICK WASH
DELICATES
SPIN
WATERPROOF
RINSE+SPIN
AquaJet


G710+
Logitech

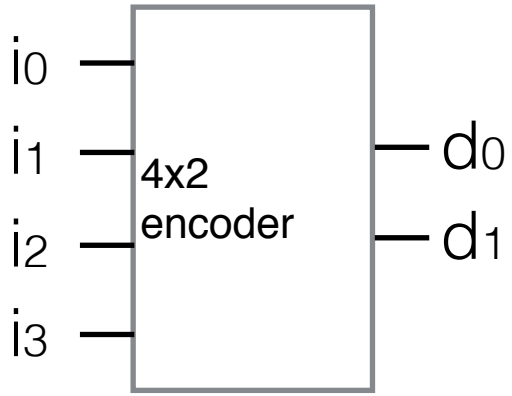

CASIO
fx-995ES
NATURAL-V.P.A.M.
TWO WAY POWER

Encoder

- A lot of connected devices can be encoded into a binary number to save pins
- Analogies:
  - Washer dial for different programs
  - Digital calculator
  - Keyboard (full size has 104 keys)

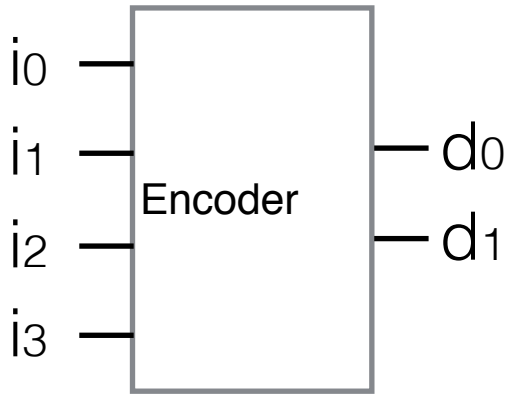
Encoder

- **Expected**: Only one of the inputs is 1 at any given time & one input has to be 1
- Output: Binary value of input which is 1
- For 2^n inputs, **n** outputs are needed (or: **n** outputs require 2^n inputs)
  - $4 = 2^2$ inputs, **2** outputs
  - $8 = 2^3$ inputs, **3** outputs
- Example: 4x2 encoder



Encoder

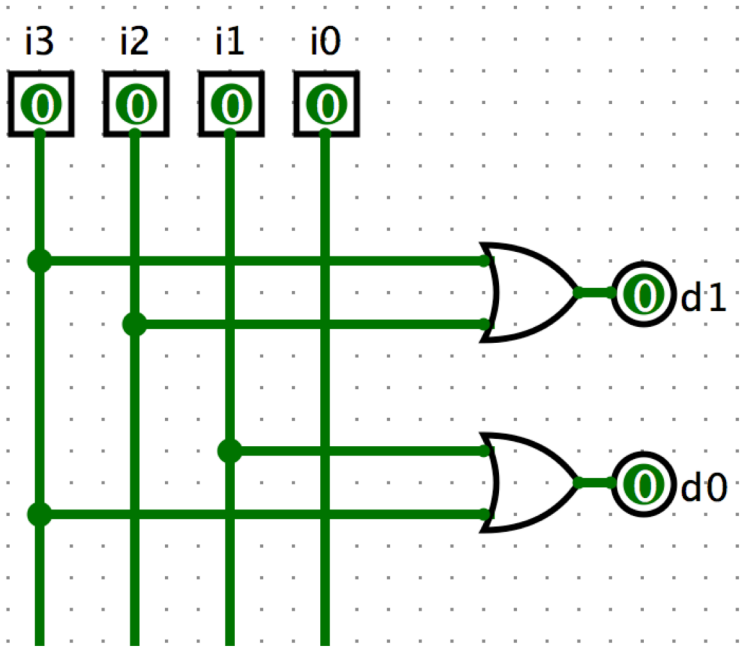
- Truth Table of a 4x2 encoder
  - Any other input combination would be considered invalid



i_3	i_2	i_1	i_0	d_1	d_0
0	0	0	**1**	0	0
0	0	**1**	0	0	1
0	**1**	0	0	1	0
1	0	0	0	1	1

Encoder

- Circuit of a 4x2 encoder



i_3	i_2	i_1	i_0	d_1	d_0
0	0	0	**1**	0	0
0	0	**1**	0	0	1
0	**1**	0	0	1	0
1	0	0	0	1	1

Encoder

- Truth table for 8x3 encoder
  - Only combinations listed that have defined behavior (8 rows)
- For 2^n inputs, n outputs are needed
  - In this case: n = 3 ($2^3 = 8$, for a 8x3 encoder)

i_7	i_6	i_5	i_4	i_3	i_2	i_1	i_0	d_2	d_1	d_0
0	0	0	0	0	0	0	**1**	0	0	0
0	0	0	0	0	0	**1**	0	0	0	1
0	0	0	0	0	**1**	0	0	0	1	0
0	0	0	0	**1**	0	0	0	0	1	1
0	0	0	**1**	0	0	0	0	1	0	0
0	0	**1**	0	0	0	0	0	1	0	1
0	**1**	0	0	0	0	0	0	1	1	0
1	0	0	0	0	0	0	0	1	1	1

Encoder

- How many outputs does a 32 input encoder have?
  -
- How many outputs does a 16 input encoder have?
  -
- How many inputs does a 6 output encoder have?
  -

Encoder

- 4x2 encoder
  - Input (i3, i2, i1, i0) is: 0100 - What is the output (d1, d0)?
    -
  - Input (i3, i2, i1, i0) is: 0010 - What is the output (d1, d0)?
    -
  - Input (i3, i2, i1, i0) is: 1111 - What is the output (d1, d0)?
    -
  - Output (d1, d0) is: 00 - What is the input (i3, i2, i1, i0)?
    -
  - Output (d1, d0) is: 11 - What is the input (i3, i2, i1, i0)?
    -

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Computer Systems Fundamentals I

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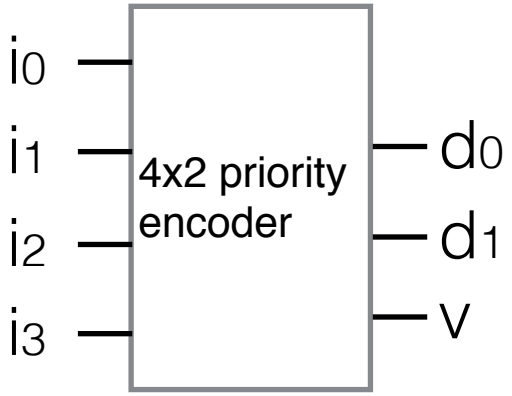
Topics

- Logic Component: Priority Encoder

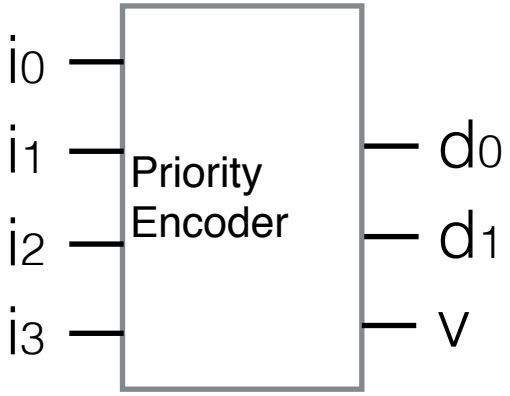
Priority Encoder

- Input: More than one of the inputs can be 1
- Output: Binary value of input with highest number value (or bit in highest position) that is 1
- For 2^n inputs, **n** outputs are needed
- Optional: Valid output v
  - Indicates if at least 1 input is 1: v = 1
  - If all inputs are 0 then v = 0



Priority Encoder

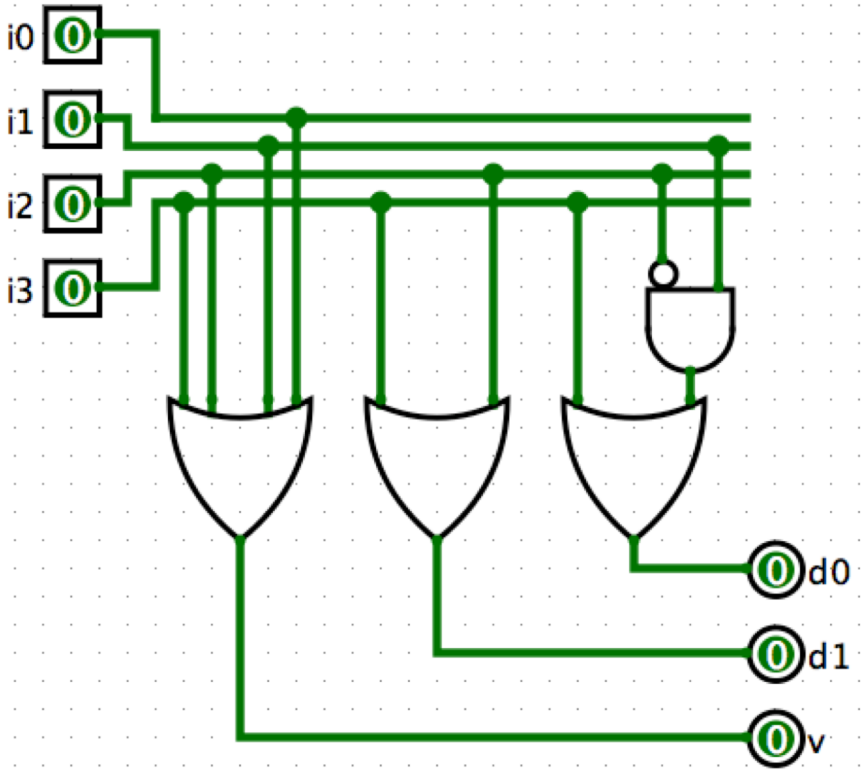
- Truth Table of a 4x2 priority encoder



i_3	i_2	i_1	i_0	d_1	d_0	v
0	0	0	0	0/x	0/x	0
0	0	0	1	0	0	1
0	0	1	x	0	1	1
0	1	x	x	1	0	1
1	x	x	x	1	1	1

Priority Encoder

- Circuit schematic of a 4x2 priority encoder



i_3	i_2	i_1	i_0	d_1	d_0	v
0	0	0	0	0/x	0/x	0
0	0	0	1	0	0	1
0	0	1	x	0	1	1
0	1	x	x	1	0	1
1	x	x	x	1	1	1

Priority Encoder

- 4x2 priority encoder
  - Input (i3, i2, i1, i0) is: 0001 - What is the output (d1, d0)?
    - **00**
  - Input (i3, i2, i1, i0) is: 1010 - What is the output (d1, d0)?
    - **11**
  - Input (i3, i2, i1, i0) is: 1111 - What is the output (d1, d0)?
    - **11**
  - Input (i3, i2, i1, i0) is: 0101 - What is the output (d1, d0)?
    - **10**
  - Input (i3, i2, i1, i0) is: 0100 - What is the output (d1, d0)?
    - **10**

Priority Encoder

- 4x2 priority encoder
  - Output (d1, d0) is: 00 - What is the input (i3, i2, i1, i0)?
    - **0001**
  - Output (d1, d0) is: 01 - What is the input (i3, i2, i1, i0)?
    - **0010 or 0011; 001x**
  - Output (d1, d0) is: 10 - What is the input (i3, i2, i1, i0)?
    - **0100, 0101, 0110 or 0111; 01xx**
  - Output (d1, d0) is: 11 - What is the input (i3, i2, i1, i0)?
    - **1xxx**

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Computer Systems Fundamentals I

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Topics

- Logic Component: Decoder

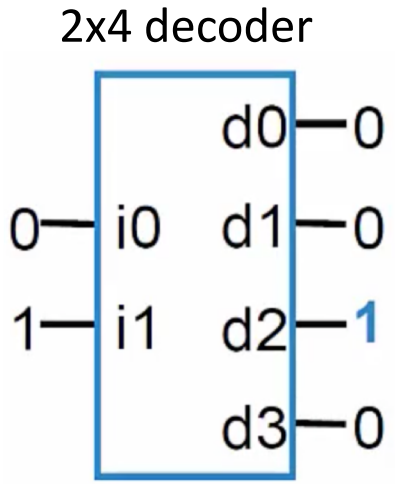
Decoder

Decoder

- Analogies
  - Sprinkler system zones (insufficient water pressure for all sprinklers at once requires to cycle through zones)
  - Digital New Year's Eve countdown (light up one LED out of 60 to count down seconds of last minute)
- Instead of connecting all LEDs/pumps separately with each 2 wires, binary value can be transmitted which then turns on the correct LED/pump
  - 60 LEDs can be controlled by 6 bits (60 wires vs. 12 wires)

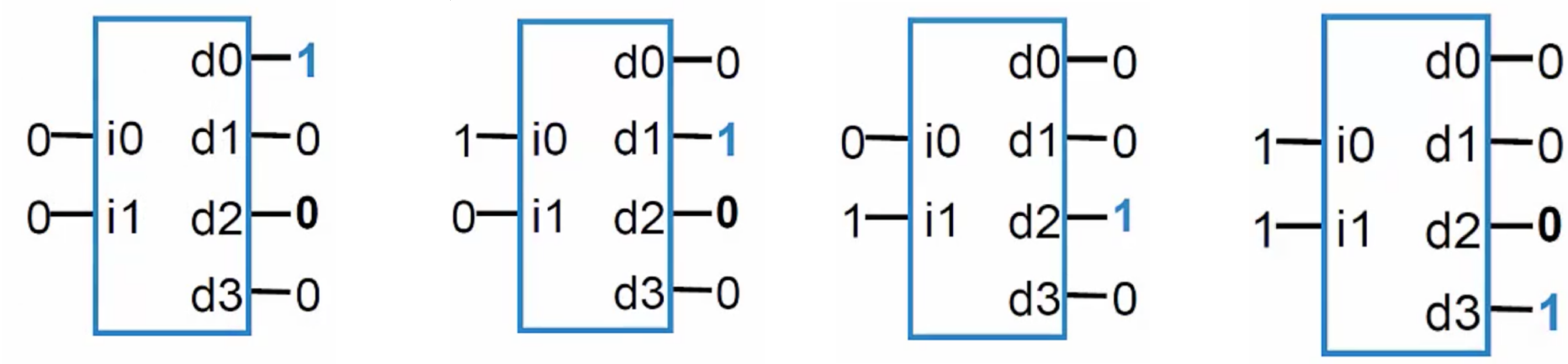
Decoder

- Decodes an input n-bit binary number by setting exactly one of the decoder's 2^n outputs to 1
  - Inputs: n inputs
  - 2^n outputs: The output with index equal to input value in decimal is 1
    - E.g. input value is 0b10 = 2 = output d2 is 1; rest 0



Decoder

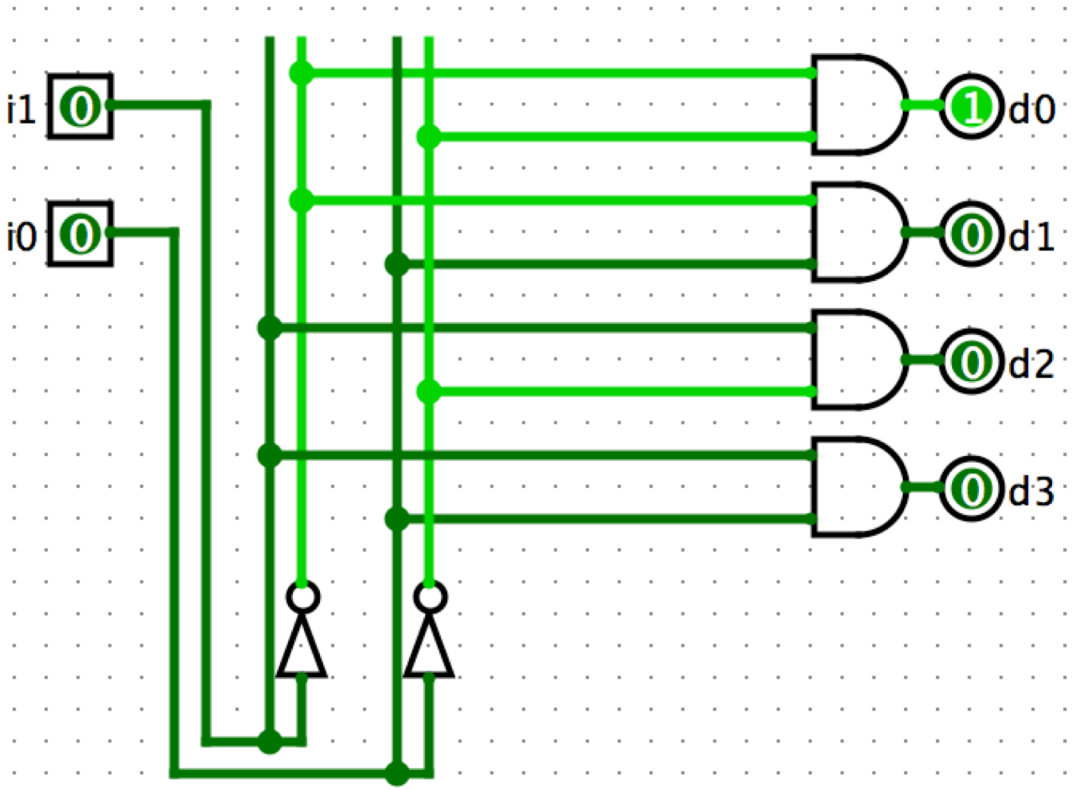
- Binary number on inputs indicates which output will be 1
  - 0b00 = 0; d0 = 1, rest 0
  - 0b01 = 1; d1 = 1, rest 0
  - 0b10 = 2; d2 = 1, rest 0
  - 0b11 = 3; d3 = 1, rest 0



Decoder

- Truth table and circuit of 2x4 decoder

i_1	i_0		d_3	d_2	d_1	d_0
0	0		0	0	0	**1**
0	1		0	0	**1**	0
1	0		0	**1**	0	0
1	1		**1**	0	0	0



Decoder

- Truth table for a 3x8 decoder
  - n inputs, 2^n outputs

i_2	i_1	i_0	d_7	d_6	d_5	d_4	d_3	d_2	d_1	d_0
0	0	0	0	0	0	0	0	0	0	**1**
0	0	1	0	0	0	0	0	0	**1**	0
0	1	0	0	0	0	0	0	**1**	0	0
0	1	1	0	0	0	0	**1**	0	0	0
1	0	0	0	0	0	**1**	0	0	0	0
1	0	1	0	0	**1**	0	0	0	0	0
1	1	0	0	**1**	0	0	0	0	0	0
1	1	1	**1**	0	0	0	0	0	0	0

Decoder

- How many pins / wires are needed to connect 60 LEDs using a decoder?
  - **6 pins / decoder inputs** (up to 64 outputs)
- How many are needed to connect 120 LEDs using a decoder?
  - **7 pins / decoder inputs** (up to 128 outputs)
- 256 LEDs? 257 LEDs?
  - **8 pins / decoder inputs; 9 pins / decoder inputs**

Decoder

- How many outputs does a 5 input decoder have?
  - **2^5 = 32 outputs**
- How many outputs does a 3 input decoder have?
  - **2^3 = 8 outputs**

Decoder

- 2x4 decoder
  - Input (i1, i0) is: 00 - What is the output (d3, d2, d1, d0)?
    - **0001**
  - Input (i1, i0) is: 10 - What is the output (d3, d2, d1, d0)?
    - **0100**
  - Input (i1, i0) is: 01 - What is the output (d3, d2, d1, d0)?
    - **0010**
  - Output (d3, d2, d1, d0) is: 1000 - What is the input (i1, i0)?
    - **11**
  - Output (d3, d2, d1, d0) is: 1101 - What is the input (i1, i0)?
    - **Not defined.**