723

Numbers

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723

Binary Numbers Binary Numbers Binary Numbers
Binary Numbers


$723=7 \times 100+2 \times 10+3 \times 1$
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723=7 \times 100+2 \times 10+3 \times 1
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Binary Numbers

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\begin{aligned}
723 & =7 \times 100+2 \times 10+3 \times 1 \\
& =7 \times 10^{2}+2 \times 10^{1}+3 \times 10^{0}
\end{aligned}
$$

Binary Numbers

$$
5349=5 \times 10^{3}+3 \times 10^{2}+4 \times 10^{1}+9 \times 10^{0}
$$

Binary Numbers


Why base I0?

Binary Numbers

$$
\begin{gathered}
257 \text { (base } 8 \text { ) } \\
2 \times 8^{2}+5 \times 8^{1}+7 \times 8^{0} \\
2 \times 64+5 \times 8+7 \times 1 \\
175 \text { (base 10) }
\end{gathered}
$$

Binary Numbers

$$
\begin{gathered}
0110(\text { base } 2) \\
0 \times 2^{3}+1 \times 2^{2}+1 \times 2^{1}+0 \times 2^{0} \\
0 \times 8+1 \times 4+1 \times 2+0 \times 1 \\
6(\text { base } 10)
\end{gathered}
$$

Binary Numbers


2-bit binary number

Binary Numbers

| 000 | 0 |  |
| :--- | :--- | :--- |
| 001 | 1 |  |
| 010 | 2 |  |
| 011 | 3 |  |
| 100 | 4 |  |
| 101 | 5 |  |
| 110 | 6 |  |
| 111 | 7 | $\max$ value $=2^{3}-I$ |

3-bit binary number

Binary Numbers

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

## 4-bit binary number

Binary Numbers (why?)

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reliability!<br>reliability!<br>-

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Binary Numbers (why?)


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$\begin{array}{ll}9 & \square \\ 8 & \square \\ 7 & \square \\ 6 & \square \\ 5 & \square \\ 4 & \square \\ 3 & \square \\ 2 & \square \\ 1 & \square \\ 0 & \square\end{array}$

6

Binary Numbers (why?)
$\square$



How do we encode negative numbers?
How .


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| $\vdots$ |
| $\frac{0}{6}$ |
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| $\frac{\mathrm{o}}{\frac{o}{2}}$ |
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Binary Numbers
use left-most bit to represent sign

$$
0="+"
$$

| = "-"

Binary Numbers

| sign $2^{2120}$ |  |
| :---: | :---: |
| $\downarrow!\downarrow$ |  |
| 000 | 0 |
| 001 | 1 |
| 010 | 2 |
| 011 | 3 |
| 100 |  |
| 101 |  |
| 110 |  |
| 111 |  |

3-bit signed binary number

Binary Numbers

| $\operatorname{sign} 2120$ |  |  |
| :--- | :--- | :--- |
| $!!!$ |  |  |
| 000 | 0 |  |
| 001 | 1 |  |
| 010 | 2 |  |
| 011 | 3 |  |
| 100 | -0 | $? ? ?$ |
| 101 | -1 |  |
| 110 | -2 |  |
| 111 | -3 |  |

3-bit signed binary number

Binary Numbers (two's complement)
I. start with an unsigned 4-bit binary number where leftmost bit is 0

- $0110=6$

Binary Numbers (two's complement)
I. start with an unsigned 4-bit binary number where leftmost bit is 0

- $0110=6$

2. complement your binary number (flip bits)

- 1001

Binary Numbers (two's complement)
I. start with an unsigned 4-bit binary number where leftmost bit is 0

- $0110=6$

2. complement your binary number (flip bits)

- 1001

3. add one to your binary number

- $1010=-6$

Binary Numbers (two's complement)

| positive | complement | +1 |
| :---: | :---: | :---: |
| 0 | 000 |  |
| 1 | 001 | 0 |
| 2 | 010 | -1 |
| 3 | 011 | -2 |
|  |  | -3 |

3-bit signed binary number

Binary Numbers (two's complement)

| positive | complement |  | +1 | negzitive |
| :--- | :--- | :--- | :--- | :---: |
| 0 | 000 |  |  | 0 |
| 1 | 001 | $\longrightarrow 110$ | $\longrightarrow 111$ | -1 |
| 2 | 010 |  |  | -2 |
| 3 | 011 |  |  | -3 |

3-bit signed binary number

Binary Numbers (two's complement)

| positive | complement | ${ }^{+1}$ | negzative <br> 0 | 000 |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | 0 |  |
| 1 | 001 | $\longrightarrow 110$ | $\longrightarrow 111$ | -1 |
| 2 | 010 | $\longrightarrow 101$ | $\longrightarrow 110$ | -2 |
| 3 | 011 |  |  | -3 |

3-bit signed binary number

Binary Numbers (two's complement)

| positive | complement | ${ }^{+1}$ | negative <br> 0 | 000 |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 0 |  |  |
| 1 | 001 | $\longrightarrow 110$ | $\longrightarrow 111$ | -1 |
| 2 | 010 | $\longrightarrow 101$ | $\longrightarrow 110$ | -2 |
| 3 | 011 | $\longrightarrow 100$ | $\longrightarrow 101$ | -3 |

3-bit signed binary number

Binary Numbers (two's complement)

| ositive |  | complement | +1 |  |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 000 | $\longrightarrow 111$ | $\longrightarrow$ | 0 |
| 1 | 001 | $\longrightarrow 110$ | $\longrightarrow 111$ | -1 |
| 2 | 010 | $\rightarrow 101$ | $\longrightarrow 110$ | -2 |
| 3 | 011 | $\longrightarrow 100$ | 101 | -3 |

3-bit signed binary number

Binary Numbers (two's complement)

| positive | complement | ${ }^{+1}$ | negative |  |
| :--- | :---: | :---: | :---: | :---: |
| 0 | 000 | $\longrightarrow 111$ | $\longrightarrow 000$ | 0 |
| 1 | 001 | $\longrightarrow 110$ | $\longrightarrow 111$ | -1 |
| 2 | 010 | $\longrightarrow 101$ | $\longrightarrow 110$ | -2 |
| 3 | 011 | $\longrightarrow 100$ | $\longrightarrow 101$ | -3 |

3-bit signed binary number

Binary Numbers (two's complement)

| positive | complement | ${ }^{+\prime}$ | negative |  |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 000 | $\longrightarrow 111$ | $\longrightarrow 000$ | 0 |
| 1 | 001 | $\longrightarrow 110$ | $\longrightarrow 111$ | -1 |
| 2 | 010 | $\longrightarrow 101$ | $\longrightarrow 110$ | -2 |
| 3 | 011 | $\longrightarrow 100$ | $\longrightarrow 101$ | -3 |

we lost a number?

Binary Numbers (two's complement)

| postive |  | complement | +1 | regative |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 000 | $\rightarrow 111$ | -000 | 0 |
| 1 | 001 | $\longrightarrow 110$ | -111 | -1 |
| 2 | 010 | $\longrightarrow 101$ | $\rightarrow 110$ | -2 |
| 3 | 011 | $\longrightarrow 100$ | -101 | -3 |
|  |  |  | 100 |  |

we lost a number?

Binary Numbers (two's complement)

Binary Numbers (two's complement)

| complement | 100 | 010 |
| :---: | :---: | :---: |
|  |  | 011 |
| 011 |  | 100 |
|  |  | 101 |
|  |  | 110 |

Binary Numbers (two's complement)

## complement

$100 \longleftarrow 011 \longleftarrow 100$

Binary Numbers (two's complement)

## complement

$4100 \longleftarrow 011 \longleftarrow 100$00

Binary Numbers (two's complement)

| positive |  | complement | +1 |  |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 000 | $\longrightarrow 111$ | 000 | 0 |
| 1 | 001 | $\longrightarrow 110$ | $\rightarrow 111$ | -1 |
| 2 | 010 | $\longrightarrow 101$ | $\longrightarrow 110$ | -2 |
| 3 | 011 | $\longrightarrow 100$ | $\longrightarrow 101$ | -3 |
|  |  |  | 100 | -4 |

n-bit unsigned binary numbers: 0...2n-1

Binary Numbers (two's complement)

| ositio |  | mplement | +1 | 1egrave |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 000 | $\longrightarrow 111$ | $\bigcirc 00$ | 0 |
| 1 | 001 | $\longrightarrow 110$ | -111 | -1 |
| 2 | 010 | $\longrightarrow 101$ | -110 | -2 |
| 3 | 011 | $\longrightarrow 100$ | -101 | -3 |
|  |  |  | 100 | -4 |

n-bit signed binary numbers: -2n-1... $2^{n-1}-1$

Binary Numbers (two's complement)

| 0010 | 2 |
| ---: | ---: |
| 0010 | 2 |
| +--- | + |
| 0100 | 4 |

summing unsigned binary numbers is easy

Binary Numbers (two's complement)

| 0010 | 2 |
| ---: | ---: |
| 1010 | -2 |
| +--- | + |
| 1100 | 0 |$?$

Binary Numbers (two's complement)

| 0011 | 3 |
| ---: | ---: |
| 1011 | -3 |
| +--- | +- |
| 1110 | 0 |$?$

Binary Numbers (two's complement)

summing signed (2's complement) binary numbers

Binary Numbers (two's complement)

summing signed (2's complement) binary numbers

Binary Numbers (two's complement)

summing signed (2's complement) binary numbers

Binary Numbers (two's complement)

summing signed (2's complement) binary numbers

Binary Numbers (decoding two's complement)

$$
0111=?
$$

4-bit signed (two's complement) binary number

Binary Numbers (decoding two's complement)

$$
0111=7
$$

4-bit signed (two's complement) binary number

Binary Numbers (decoding two's complement)

$$
1011=?
$$

4-bit signed (two's complement) binary number

Binary Numbers (decoding two's complement)

$$
1011 \quad 1010
$$

4-bit signed (two's complement) binary number

Binary Numbers (decoding two's complement)

101110100101

4-bit signed (two's complement) binary number

Binary Numbers (decoding two's complement)

|  | subtract I | complement |  |
| :--- | :--- | :--- | :--- |
| 1011 | 1010 | 0101 | 5 |

4-bit signed (two's complement) binary number

Binary Numbers (decoding two's complement)

$$
1011=-5
$$

4-bit signed (two's complement) binary number

Binary Numbers
How do we encode fractional numbers?
How do we encode fractional numbers?
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How do we encode fractional numbers?

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\(\pm\) mantissa \(\times\) base \(\pm\) exponent

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\(\pm\) mantissa \(\times\) base \(\pm\) exponent
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\(\pm\) mantissa \(\times\) base \(\pm\) exponent
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\(x^{2}\)
\(\qquad\)
\[
\begin{align*}
& \text { Boolean Logic (variables) } \\
& \qquad \begin{array}{l}
1=\text { True } \\
0=\text { False }
\end{array}
\end{align*}
\]
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Boolean Logic (truth tables)
\(\mathbf{a}\) and \(\mathbf{b}\) \(\mathbf{a}\) and \(\mathbf{b}\) \(\square\)


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\begin{tabular}{|c|c|c|}
\hline \(\mathbf{a}\) & \(\mathbf{b}\) & \(\mathbf{a}\) and \(\mathbf{b}\) \\
\hline I & I & I \\
\hline I & 0 & 0 \\
\hline 0 & I & 0 \\
\hline 0 & 0 & 0 \\
\hline
\end{tabular}

Boolean Logic (truth tables)\(\square\)
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Boolean Logic (truth tables)

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\hline \(\mathbf{a}\) & not \(\mathbf{a}\) \\
\hline 1 & 0 \\
\hline 0 & 1 \\
\hline
\end{tabular}
\begin{tabular}{|c|c|}
\hline a & not a \\
\hline 1 & 0 \\
\hline 0 & 1 \\
\hline
\end{tabular}
\begin{tabular}{|l|l|l|}
\hline \(\mathbf{a}\) & not \(\mathbf{a}\) \\
\hline 1 & 0 \\
\hline 0 & 1 \\
\hline
\end{tabular}
\begin{tabular}{|l|l|l|}
\hline \(\mathbf{a}\) & not \(\mathbf{a}\) \\
\hline 1 & 0 \\
\hline 0 & 1 \\
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\end{tabular}

\begin{tabular}{|l|l|l|}
\hline \(\mathbf{a}\) & not \(\mathbf{a}\) \\
\hline 1 & 0 \\
\hline 0 & 1 \\
\hline
\end{tabular}
 \begin{tabular}{|c|c|c|}
\hline a & not a \\
\hline & 0 & 1 \\
\hline & 0 \\
\hline
\end{tabular}

2
\begin{tabular}{|c|c|}
\hline \(\mathbf{a}\) & not \(\mathbf{a}\) \\
\hline I & 0 \\
\hline 0 & I \\
\hline
\end{tabular}
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Boolean Logic (truth tables)
\[
\begin{array}{cc}
\text { input } & \text { output } \\
\text { (boolean variable) } & \text { (boolean variable) }
\end{array}
\]
\(\mathbf{a}, \mathbf{b} \quad \mathbf{a}\) and \(\mathbf{b}\)
\(\mathbf{a}\) or \(\mathbf{b}\)
not a

Gates
\begin{tabular}{|c|c|c|}
\hline \(\mathbf{a}\) & \(\mathbf{b}\) & \(\mathbf{a}\) and \(\mathbf{b}\) \\
\hline \(\mathbf{I}\) & l & I \\
\hline \(\mathbf{I}\) & 0 & 0 \\
\hline 0 & I & 0 \\
\hline \(\mathbf{0}\) & 0 & 0 \\
\hline
\end{tabular}



Gates
\begin{tabular}{|c|c|c|}
\hline \(\mathbf{a}\) & \(\mathbf{b}\) & \(\mathbf{a}\) or \(\mathbf{b}\) \\
\hline I & I & I \\
\hline I & 0 & I \\
\hline 0 & \(I\) & I \\
\hline 0 & 0 & 0 \\
\hline
\end{tabular}
\(a \rightarrow+=-a\) or \(b\)
    \(++\mathbf{a}\) or \(\mathbf{b}\)


\[
\pi+2-a
\]

Gates
 \begin{tabular}{|c|c|c|c|}
\hline \(\mathbf{a}\) & \(\mathbf{b}\) & \(\mathbf{a}\) or \(\mathbf{b}\) \\
\hline & & & \\
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\hline \(\mathbf{a}\) & not \(\mathbf{a}\) \\
\hline \(\mathbf{I}\) & 0 \\
\hline 0 & \(I\) \\
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Gates

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- not a \(\mathfrak{a}\)
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\hline 1 & 0 \\
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Building Gates (transistors)

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Building Gates (transistors) \(0^{2}+2\)
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