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Introduction

1. Why Should I Take This Module?

Welcome to Number Systems!

- Guess what?
  - This is a 32-bit IPv4 address of a computer in a network: 11000000.10101000.00001010.00001010.
    - It is shown in binary.
    - This is the IPv4 address for the same computer in dotted decimal: 192.168.10.10.
  - Which one would you rather work with?
  - IPv6 addresses are 128 bits!
    - To make these addresses more manageable, IPv6 uses a hexadecimal system of 0-9 and the letters A-F.

- As a network administrator, you must know how to convert binary addresses into dotted decimal and dotted decimal addresses into binary.
  - You will also need to know how to convert dotted decimals into hexadecimal and vice versa.
  - (Hint: You still need your binary conversion skills to make this work.)

- Surprisingly, it is not that hard when you learn a few tricks.
  - This module contains an activity called the Binary Game which will really help you get started.
  - So, why wait?

2. What Will I Learn To Do In This Module?

2A. Module Title

- Number Systems

2B. Module Objective

- Calculate numbers between decimal, binary, and hexadecimal systems.

Topic Title	Topic Objective
Binary Number System	Calculate numbers between decimal and binary systems.
Hexadecimal Number System	Calculate numbers between decimal and hexadecimal systems.

Binary Number System

1. Binary and IPv4 Addresses

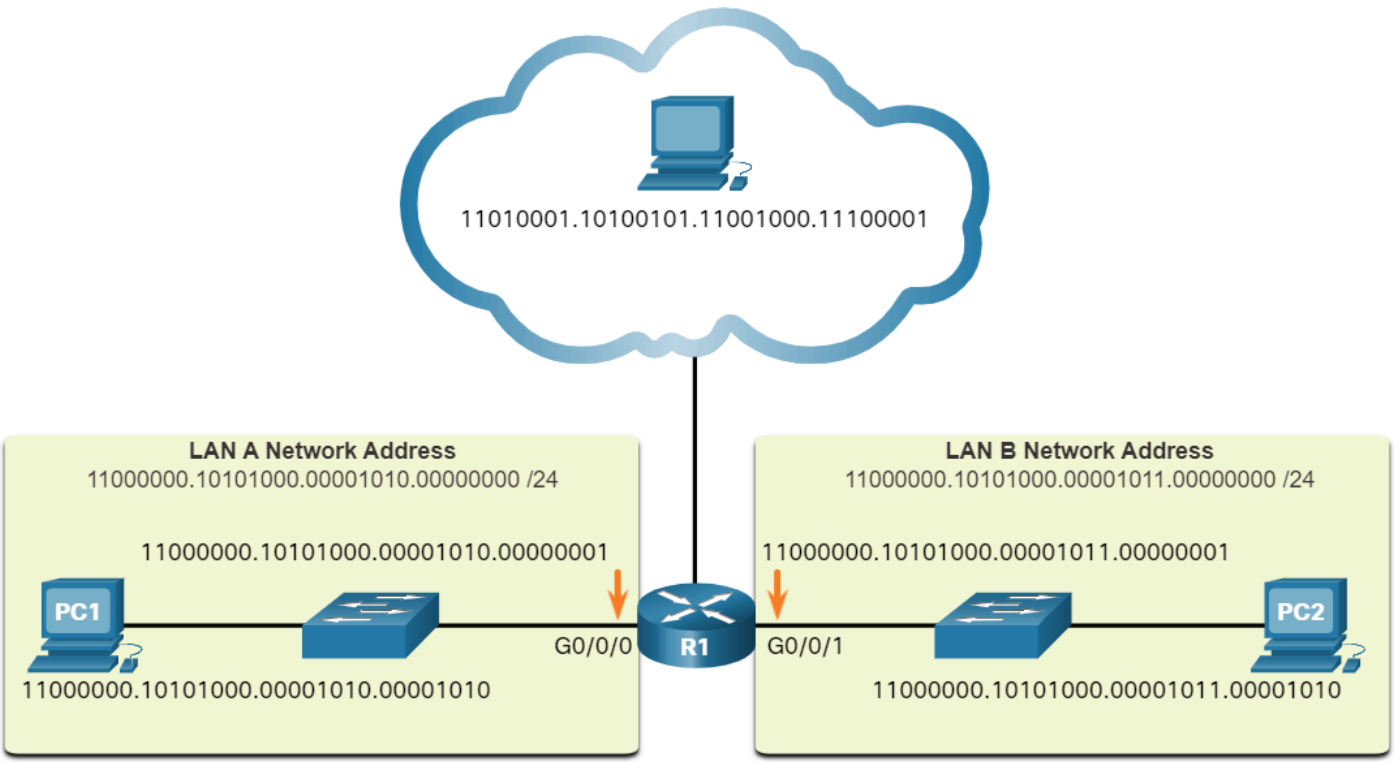
IPv4 addresses **begin as binary**, a series of only **1s** and **0s**. These are **difficult to manage**, so network administrators must **convert them to decimal**. This topic shows you a few ways to do this.

Binary is a **numbering system** that consists of the **digits 0 and 1** called **bits**. In contrast, the **decimal numbering system** consists of **10 digits** consisting of the digits **0 – 9**.

Binary is important for us to understand because **hosts**, **servers**, and **network devices use binary addressing**. Specifically, **they use binary IPv4 addresses**, as shown **in** the **figure**, to identify each other.

There is a central router with two LANs directly connected and one WAN connected to a cloud.

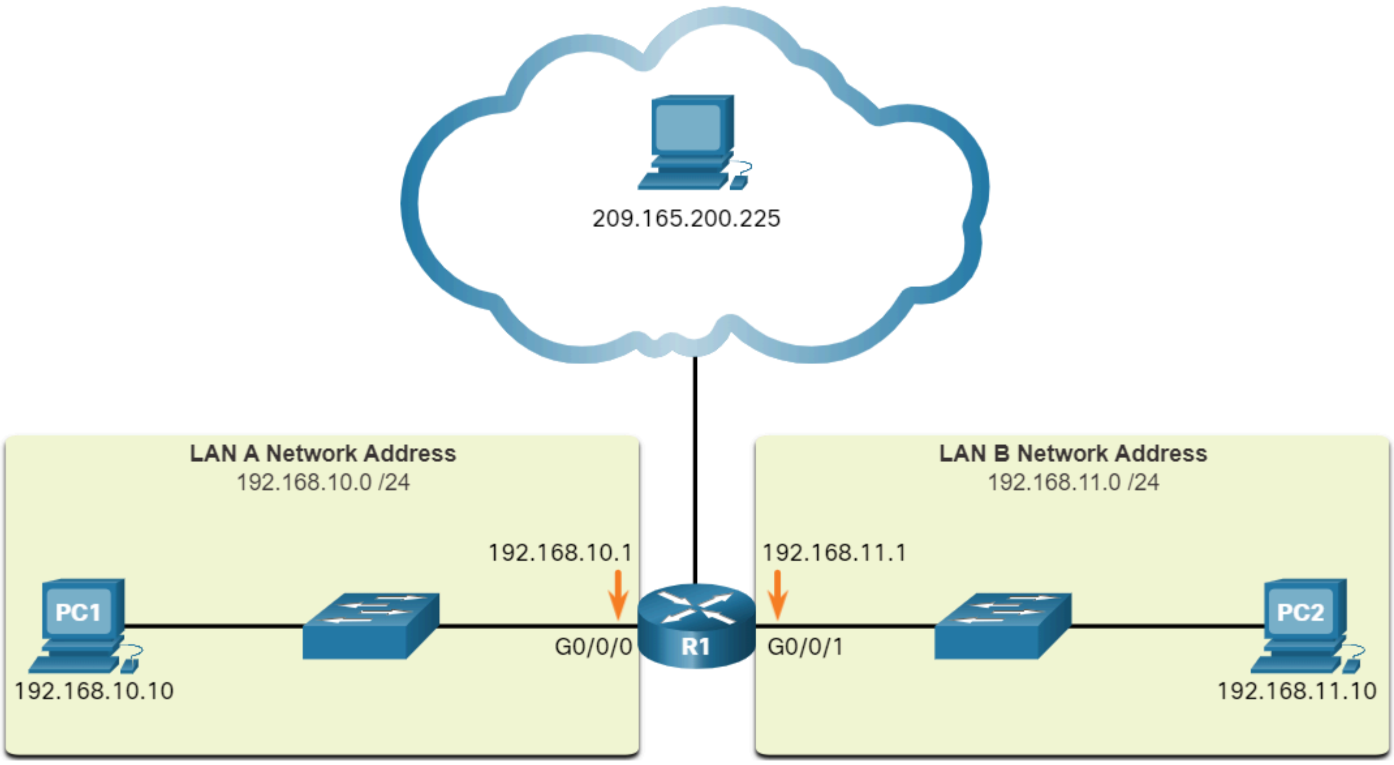
- Each LAN has a switch and a PC.
- The WAN has one PC.
- Each device has an IPv4 address that is in dotted binary notation **instead of 代替** dotted decimal notation.



Each **address** consists of a **string of 32 bits**, divided into **four sections called octets**. **Each octet contains 8 bits** (or **1 byte**) **separated by a dot**. For example, PC1 in the figure is assigned IPv4 address 11000000.10101000.00001010.00001010. Its default gateway address would be that of R1 Gigabit Ethernet interface 11000000.10101000.00001010.00000001.

Binary works well with hosts and network devices. However, it is very **challenging for humans to work with**.

For **ease of use by people**, IPv4 addresses are commonly expressed in **dotted decimal notation**. PC1 is assigned the **IPv4 address 192.168.10.10**, and its default **gateway address is 192.168.10.1**, as shown in the figure.



For a solid understanding of network addressing, it is necessary to know binary addressing and gain practical skills in converting between binary and dotted decimal IPv4 addresses. This section will cover how to convert between base two (binary) and base 10 (decimal) numbering systems.

2. Converting Between Binary and Decimal Numbering Systems

Video: https://www.youtube.com/watch?v=qOMtE6slp-I

2A. Positional Notation - Place Values

Place Value	1,000,000	100,000	10,000	1,000	100	10	1
Number				2	1	6	8

- The table shows the base 10 Decimal Number System.
  - One's Place
  - Ten's Place
  - Hundred's Place
  - Thousand's Place
  - Ten Thousand's Place
  - Hundred Thousand's Place
  - Million Place

- It illustrates how the digits of a number are assigned place values based on their position. Here's the breakdown:
  - 1,000,000: No digit is placed under this column, so the value is 0.
  - 100,000: No digit is placed under this column, so the value is 0.
  - 10,000: No digit is placed under this column, so the value is 0.
  - 1,000: The digit 2 is placed here, representing 2,000.
  - 100: The digit 1 is placed here, representing 100.
  - 10: The digit 6 is placed here, representing 60.
  - 1: The digit 8 is placed here, representing 8.
  - The full number represented by this notation is **2,168**.

2B. Powers Of 10 Review

- When we are talking about the place values in the decimal number system, we are talking about the powers of 10.
  - **The place value is based on powers of 10**.

Powers	10^6	10^5	10^4	10^3	10^2	10^1	10^0
Place Value	1,000,000	100,000	10,000	1,000	100	10	1
Number				2	1	6	8

- The process of converting the decimal number 2168 into its digit components using base 10 (decimal system).
  - Here's a breakdown of the conversion process:
    - Place Values:
      - The number 2168 is broken down into its digits.
      - Each digit is multiplied by the corresponding power of 10 based on its position.

    - Calculation:
      - The digit 2 is in the thousand's place: **2 × 1000 = 2000**
      - The digit 1 is in the hundred's place: **1 × 100 = 100**
      - The digit 6 is in the ten's place: **6 × 10 = 60**
      - The digit 8 is in the unit's place: **8 × 1 = 8**

    - Total Sum:
      - The sum of these products is **2000 + 100 + 60 + 8 = 2168**.
      - This process demonstrates how the decimal number 2168 is constructed using its place values in base 10.

2C. Decimal - Base 10 Numbering Review

- The Decimal System is base 10 which uses 10 digits (0, 1, 2, 3, 4, 5, 6, 7, 8, 9) to represent numbers.

- **Place Value**:
  - The value of each digit in a number depends on its position (or place) within the number. Each position represents a power of 10.
    - The rightmost digit is in the **unit's** place (10^0).
    - The next digit to the left is in the **tens** place (10^1).
    - The digit after that is in the **hundreds** place (10^2), and so on.

- **Positional Notation**:
  - The value of a number is determined by multiplying each digit by the power of 10 corresponding to its position and then summing these values.
  - For example, in the number 9168:
    - The digit 9 is in the thousand's place, so it represents **9 × 1000 = 9000**.
    - The digit 1 is in the hundred's place, so it represents **1 × 100 = 100**.
    - The digit 6 is in the ten's place, so it represents **6 × 10 = 60**.
    - The digit 8 is in the unit's place, so it represents **8 × 1 = 8**.
    - Adding these values gives **9000 + 100 + 60 + 8 9168**.

Powers	10^6	10^5	10^4	10^3	10^2	10^1	10^0
Place Value	1,000,000	100,000	10,000	1,000	100	10	1
Number				9	1	6	8

2D. Binary-Base 2 Numbering Review

- If we consider binary and look at it in the same light as decimal, **binary is a base 2 number system**.
  - There are only 2 characters, or two numbers, **zero and one**.
  - **Place Values**: Each digit in a binary number represents a power of 2, starting from 2^0 on the right.
  - Notice that I extended the table to 8 place values due to **8 bits** are an important grouping of numbers.
    - 8 bits make a byte in computer processing. Now I have the place value for essentially eight bits.

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value								
Number	128	64	32	16	8	4	2	1

- **For Example:**
  - If want to write the number 168 in Binary. I just have to find the corresponding place values and plug in either a one or a zero.

  - **Calculations**:
    - The leftmost digit (1) corresponds to 2^7 = **128**.
      - I will go to the 128's place and ask myself, do I need 128 to reach 168?
      - Yes, I do.
      - So, I will put one there.

    - The next digit (0) corresponds to 2^6 = **64**, but since it's 0, it adds nothing.
      - Do I need a 64? I already have a 128, if I add 64, I would get 192.
      - So, the answer is no, put a zero.

    - The next digit (1) corresponds to 2^5 =**32**.
      - I still have 128 now, do I need a 32?
      - 128 + 32 = 160, so yes.
      - Put a one.

    - The next digit (0) corresponds to 2^4 = **16**, but since it's 0, it adds nothing.
      - Now I have 160, do I need a 16?
      - No, that would make 176, which would go over my target number of 168.
      - I will put a zero.

- The next digit (1) corresponds to 2^3 **= 8**.
  - What about an 8?
  - If I add an 8, I will hit the number perfectly. (128 + 32 + 8 = 168)
  - I will put a one.

- The remaining digits (000) correspond to 2^2, 2^1, and 2^0, but since they are all 0, they add nothing.

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value	1	0	1	0	1	0	0	0
Number	128	64	32	16	8	4	2	1

- Summing the Values:
  - 1 × 128 = 128
  - 1 × 32 = 32
  - 1 × 8 = 8
  - **Total Sum**: 128 + 32 + 8 = 168

- This process demonstrates how the binary number 10101000_2 represents the decimal number 168 when the binary digits are multiplied by their respective powers of 2 and then summed.

2E. Convert Binary To Decimal

- You can see now that I'm now charged with converting the number **01101101** to decimal.
  - If I want to go the opposite way and convert this binary number to decimal. All I need to do is plug it into the place values.

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value								

- All I need to do is plug it into the place values.

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value	0	1	1	0	1	1	0	1

- And then add it up.
  - I have a 64, 32, 8, 4 + 1.
  - 64 + 32 + 8 + 4 + 1 = 109.
  - This number 01101101 converted to decimal is the number 109.

2F. Convert Full IP Address In Binary To Decimal Numbering

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value								

11000000 . 10101000 . 00000001 . 01100101

11000000	10101000	00000001	01100101

- I now have a 32-bit IP Address, 4 Octets, or 32-bit totals.
  - If I want to convert this Binary IP Address (11000000.10101000.00000001.01100101) to decimal, all I need to do is count up each individual octet.

- First Octet: **11000000**
  - 128 + 64 = 192

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

11000000	10101000	00000001	01100101
192			

- Second Octet: **10101000**
    - 128 + 32 + 8 = 168

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**

11000000	10101000	00000001	01100101
192	168		

- Third Octet: **00000001**
    - 1 = 1

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**

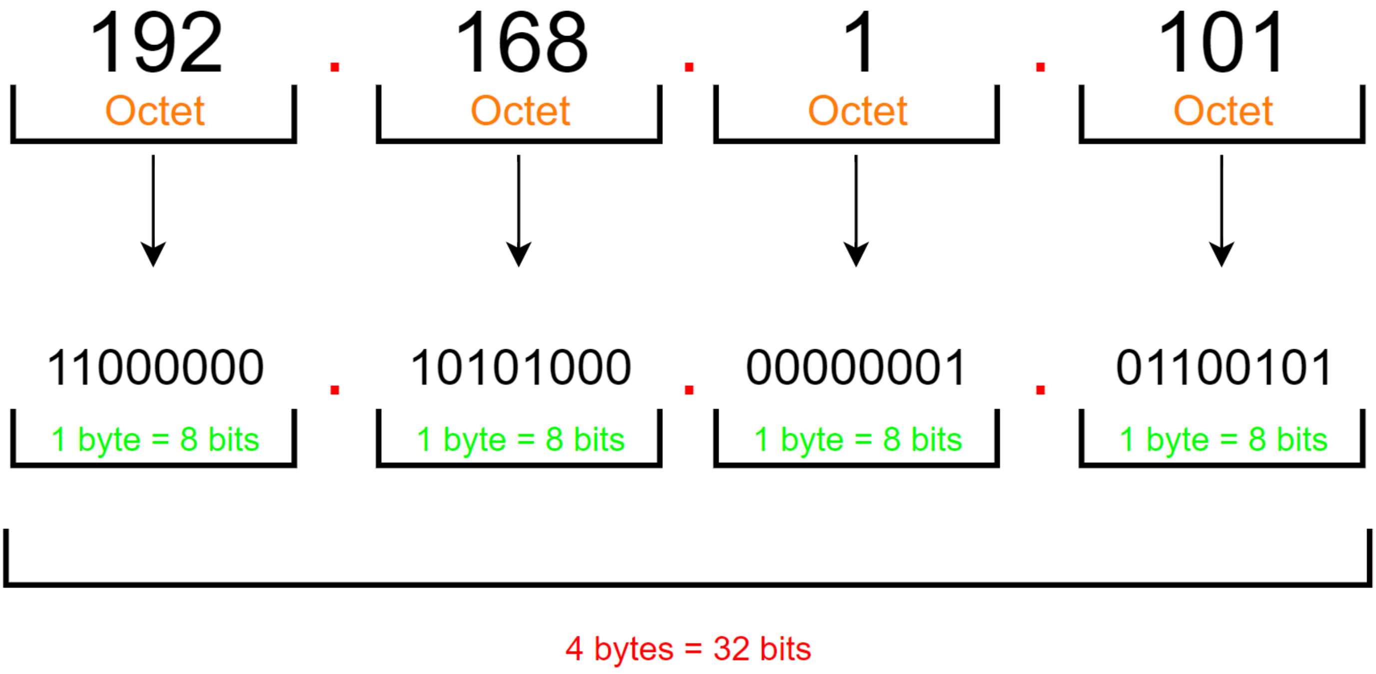
11000000	10101000	00000001	01100101
192	168	1	

- Fouth Octet: **01100101**
    - 64 + 32 + 4 + 1 = 101

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**1**

11000000	**10101000**	**00000001**	**01100101**
192	168	1	101

- The conversion of this Binary IP Address to decimal is 192.168.1.101



3. Binary Positional Notation

Learning to convert binary to decimal requires an understanding of positional notation. Positional notation means that a digit represents different values depending on the “position” the digit occupies in the sequence of numbers. You already know the most common numbering system, the decimal (base 10) notation system.

3A. Decimal Positional Notation System

The decimal positional notation system operates as described in the table.

Radix	10	10	10	10
Position in Number	3	2	1	0
Calculate	(10^3)	(10^2)	(10^1)	(10^0)
Position Value	1000	100	10	1

The following bullets describe each row of the table.

- Row 1, Radix is the number base.
  - Decimal notation is based on 10, therefore the radix is 10.

- Row 2, Position in number considers the position of the decimal number starting with, from right to left, 0 (1st position), 1 (2nd position), 2 (3rd position), 3 (4th position).
  - These numbers also represent the exponential value use to calculate the positional value in the 4th row.

- Row 3 calculates the positional value by taking the radix and raising it by the exponential value of its position in row 2.

- Note: n^0 is = 1.

- Row 4 positional value represents units of thousands, hundreds, tens, and ones.

3B. How Positional Notation Is Used

To use the positional system, match a given number to its positional value. The example in the table illustrates how positional notation is used with the decimal number 1234.

	Thousands	**Hundreds**	**Tens**	**Ones**
Positional Value	1000	100	10	1
Decimal Number (1234)	1	2	3	4
Calculate	1 x 1000	2 x 100	3 x 10	4 x 1
Add them up…	1000	+200	+30	+4
Result	**1,234**			

3C. Binary Positional Notation

In contrast, the binary positional notation operates as described in the table.

Radix	2	2	2	2	2	2	2	2
Position in Number	7	6	5	4	3	2	1	0
Calculate	(2^7)	(2^6)	(2^5)	(2^4)	(2^3)	(2^2)	(2^1)	(2^0)
Position Value	128	64	32	16	8	4	2	1

Each bit in the binary number represents a power of 2, starting from 2^7 (128) on the left to 2^0 (1) on the right. The value of each bit is either 1 or 0, and the decimal value is obtained by summing up the products of these bits and their corresponding positional values.

- **Meanings of the terms Radix, Position in Number, Calculate, and Position Value**:
  - **Radix**:
    - In this context, radix refers to the base of the number system. For binary numbers, the radix is 2, because there are only two possible digits: 0 and 1.
  - **Position in Number**:
    - This indicates the position of each bit in an 8-bit binary number, starting from 7 (leftmost bit) down to 0 (rightmost bit).
  - **Calculate**:
    - This column shows the mathematical calculation for each bit's value. Each position corresponds to a power of 2:
      - $2^7 = 128$
      - $2^6 = 64$
      - $2^5 = 32$
      - $2^4 = 16$
      - $2^3 = 8$
      - $2^2 = 4$
      - $2^1 = 2$
      - $2^0 = 1$

- **Position Value**:
  - This column lists the value that each bit position represents.
  - When a bit is set to 1, its value contributes to the total sum representing the decimal number:
    - Position 7 (2^7): 128
    - Position 6 (2^6): 64
    - Position 5 (2^5): 32
    - Position 4 (2^4): 16
    - Position 3 (2^3): 8
    - Position 2 (2^2): 4
    - Position 1 (2^1): 2
    - Position 0 (2^0): 1

- **Example for Better Understanding**:
  - If we consider the binary number 11000000 (which is 192 in decimal):
    - The bit positions are: $1_7\ 1_6\ 0_5\ 0_4\ 0_3\ 0_2\ 0_1\ 0_0$
  - Using the table:
    - Position 7 (2^7) is 1: **1×128=128**
    - Position 6 (2^6) is 1: **1×64=64**
    - Positions 5 through 0 are 0: **Their contributions are 0**

Positional Value	128	64	32	16	8	4	2	1
Binary Number (11000000)	1	1	0	0	0	0	0	0
Calculate	1 x 128	1 x 64	0 x 32	0 x 16	0 x 8	0 x 4	0 x 2	0 x 1
Add Them Up..	128	+64	+0	+0	+0	+0	+0	+0
Result	**192**							

  - Adding these values together: 128 + 64 + 0 + 0 + 0 + 0 + 0 + 0 = 192

4. Check Your Understanding - Binary Number System

Question 1: Which is the binary equivalent to the 192.168.11.10 IP address?

(a) 11000000.11000000.00001011.00001010

(b) 11000000.10101000.00001011.00001010

(c) 11000000.10101000.00001010.00001011

(d) 11000000.10101000.00001011.00010010

Answer: **(b) 11000000.10101000.00001011.00001010**

Calculation Tool:

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value								

Question 2: Which of the following is the binary equivalent to the 172.16.31.30 IP address?

(a) 11000000.00010000.00011111.00011110

(b) 10101000.00010000.00011111.00011110

(c) 10101100.00010000.00011110.00011110

(d) 10101100.00010000.00011111.00011110

Answer: **(d) 10101100.00010000.00011111.00011110**

5. Convert Binary to Decimal

To convert a binary IPv4 address to its dotted decimal equivalent, divide the IPv4 address into four 8-bit octets. Next, apply the binary positional value to the first octet binary number and calculate accordingly.

For example, consider that 11000000.10101000.00001011.00001010 is the binary IPv4 address of a host. To convert the binary address to decimal, start with the first octet, as shown in the table.

Enter the 8-bit binary number under the positional value of row 1 and then calculate to produce the decimal number 192. This number goes into the first octet of the dotted decimal notation.

Positional Value	128	64	32	16	8	4	2	1
Binary Number (11000000)	1	1	0	0	0	0	0	0
Calculate	1 x 128	1 x 64	0 x 32	0 x 16	0 x 8	0 x 4	0 x 2	0 x 1
Add Them Up..	128	+64	+0	+0	+0	+0	+0	+0
Result	**192**							

Next, convert the second octet of 10101000 as shown in the table. The resulting decimal value is 168, and it goes into the second octet.

Positional Value	128	64	32	16	8	4	2	1
Binary Number (10101000)	1	0	1	0	1	0	0	0
Calculate	128	64	32	16	8	4	2	1
Add Them Up..	128	+0	+32	+0	+8	+0	+0	+0
Result	**168**							

Convert the third octet of 00001011 as shown in the table.

Positional Value	128	64	32	16	8	4	2	1
Binary Number (00001011)	0	0	0	0	1	0	1	1
Calculate	128	64	32	16	8	4	2	1
Add Them Up..	+0	+0	+0	+0	+8	+0	+2	+1
Result	**11**							

Convert the fourth octet of 00001010 as shown in the table. This completes the IP address and produces 192.168.11.10.

Positional Value	128	64	32	16	8	4	2	1
Binary Number (00001010)	0	0	0	0	1	0	1	0
Calculate	128	64	32	16	8	4	2	1
Add Them Up..	+0	+0	+0	+0	+8	+0	+2	+0
Result	**10**							

6. Activity - Binary to Decimal Conversions

Question 1:

- This activity allows you to practice 8-bit binary to decimal conversion as much as necessary. We recommend that you work with this tool until you can do the conversion without error. Convert the binary number shown in the octet to its decimal value.

Decimal Value	?							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**

- What is the Decimal Value?

Answer: **7**

Question 2:

- This activity allows you to practice 8-bit binary to decimal conversion as much as necessary. We recommend that you work with this tool until you can do the conversion without error. Convert the binary number shown in the octet to its decimal value.

Decimal Value	?							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**

- What is the Decimal Value?

Answer: **105**

Question 3:

- This activity allows you to practice 8-bit binary to decimal conversion as much as necessary. We recommend that you work with this tool until you can do the conversion without error. Convert the binary number shown in the octet to its decimal value.

Decimal Value	?							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**1**

- What is the Decimal Value?

Answer: **209**

Question 4:

- This activity allows you to practice 8-bit binary to decimal conversion as much as necessary. We recommend that you work with this tool until you can do the conversion without error. Convert the binary number shown in the octet to its decimal value.

Decimal Value	?							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**

- What is the Decimal Value?

Answer: **144**

Question 5:

- This activity allows you to practice 8-bit binary to decimal conversion as much as necessary. We recommend that you work with this tool until you can do the conversion without error. Convert the binary number shown in the octet to its decimal value.

Decimal Value	?							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

- What is the Decimal Value?

Answer: **128**

Question 6:

- This activity allows you to practice 8-bit binary to decimal conversion as much as necessary. We recommend that you work with this tool until you can do the conversion without error. Convert the binary number shown in the octet to its decimal value.

Decimal Value	?							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

- What is the Decimal Value?

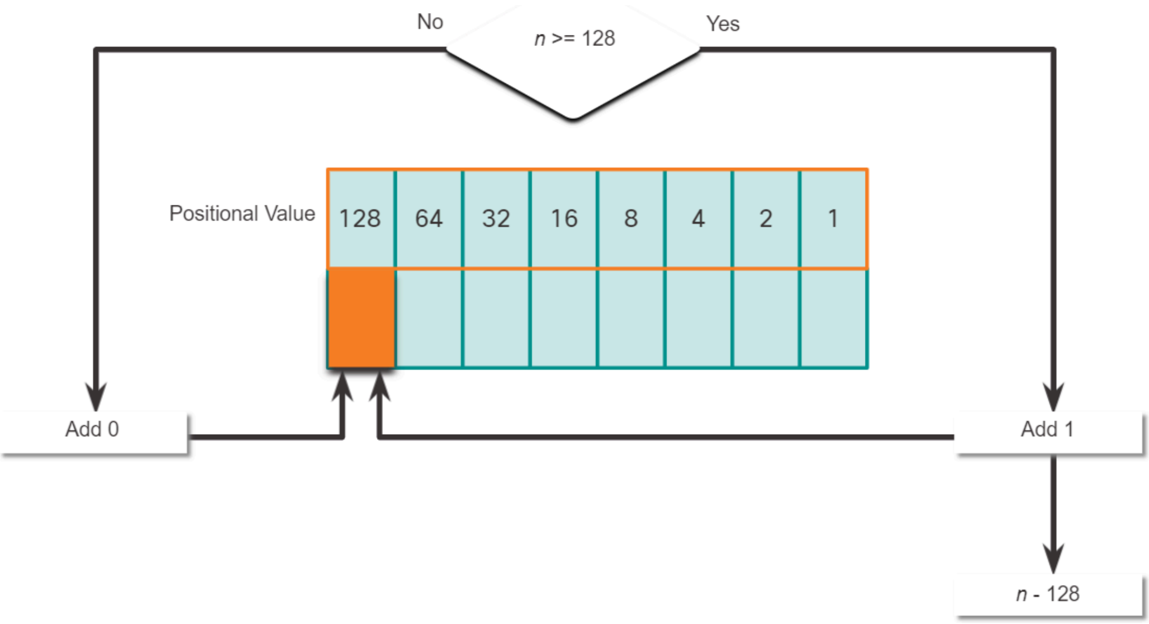
Answer: **255**

7. Decimal to Binary Conversion

- It is also necessary to understand how to convert a dotted decimal IPv4 address to binary. A useful tool is the binary positional value table.
- Below are discussion of each position starting at 128 and working your way from top to bottom to the 1 position.

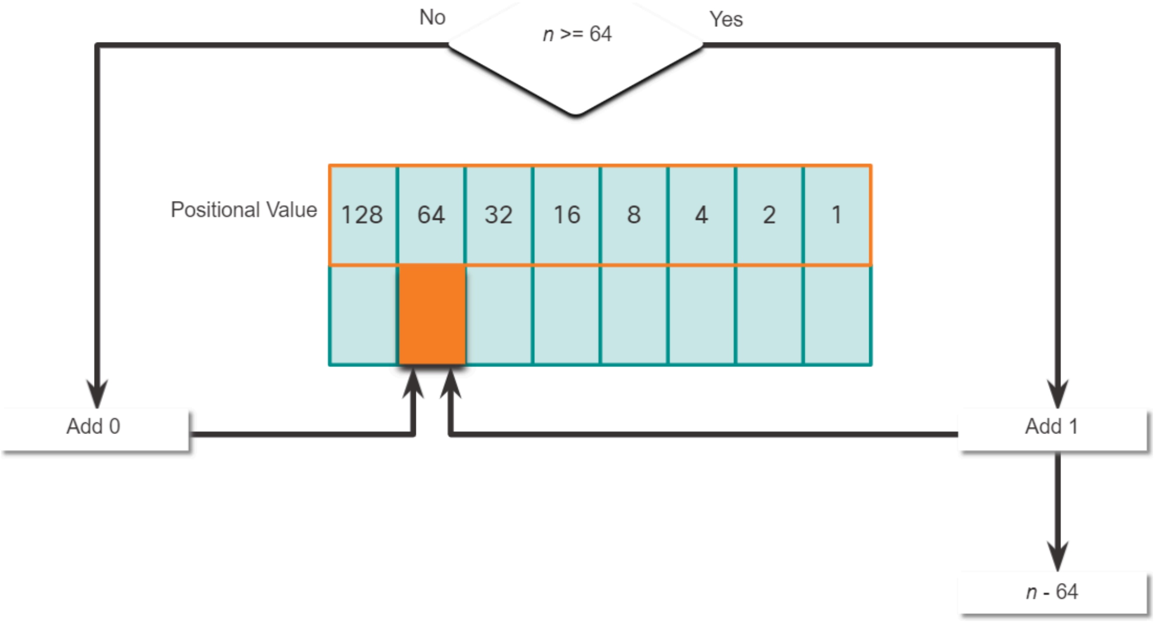
1. 128

- Is the decimal number of the octet (n) equal to or greater than the most significant bit (**128**)?
  - If no, then enter binary **0** in the **128** positional value.
  - If yes, then add a binary **1** in the **128** positional value and subtract **128** from the decimal number.



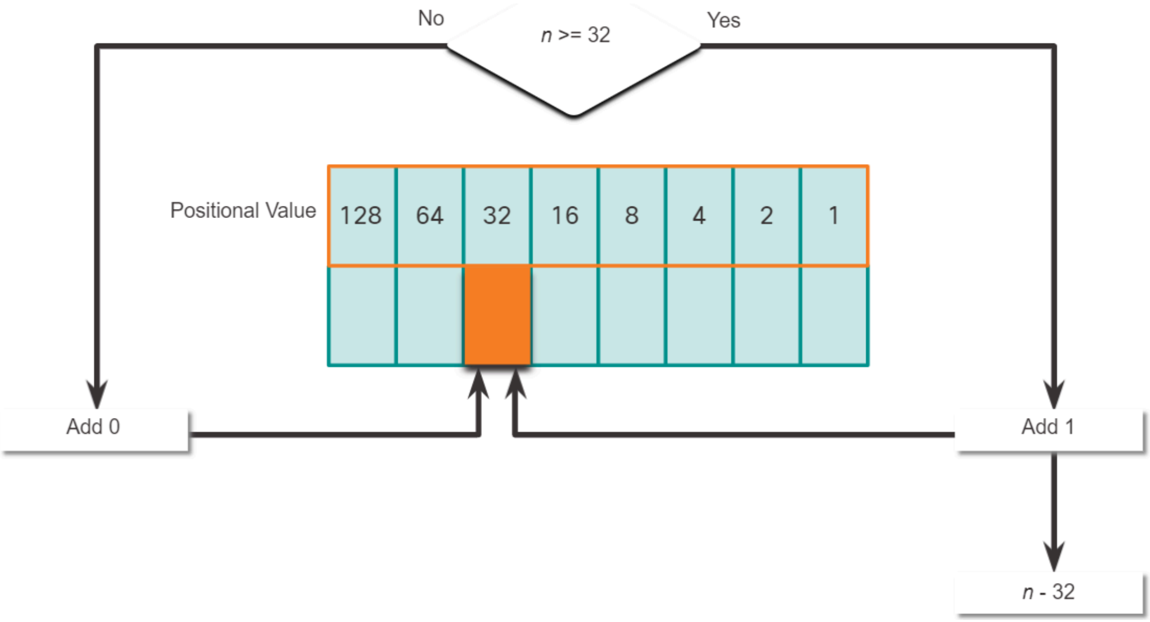
2. 64

- Is the decimal number of the octet (n) equal to or greater than the next most significant bit (**64**)?
    - If no, then enter binary **0** in the **64** positional value.
    - If yes, then add a binary **1** in the **64** positional value and subtract **64** from the decimal number.



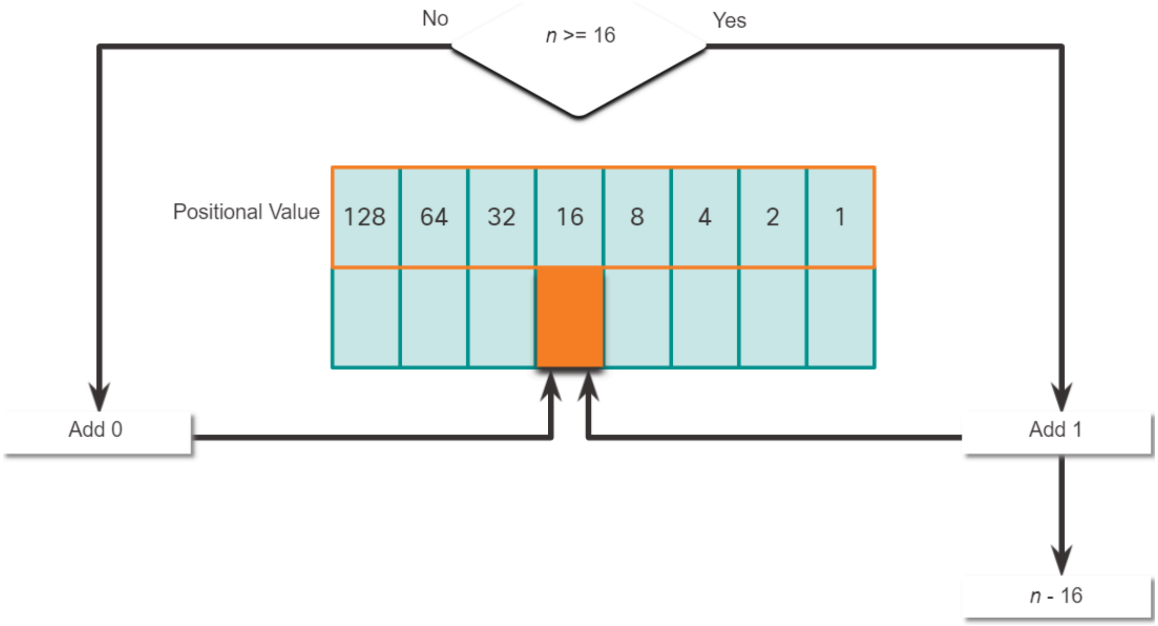
3. 32

- Is the decimal number of the octet (n) equal to or greater than the next most-significant bit (**32**)?
    - If no, then enter binary **0** in the **32** positional value.
    - If yes, then add a binary **1** in the **32** positional value and subtract **32** from the decimal number.



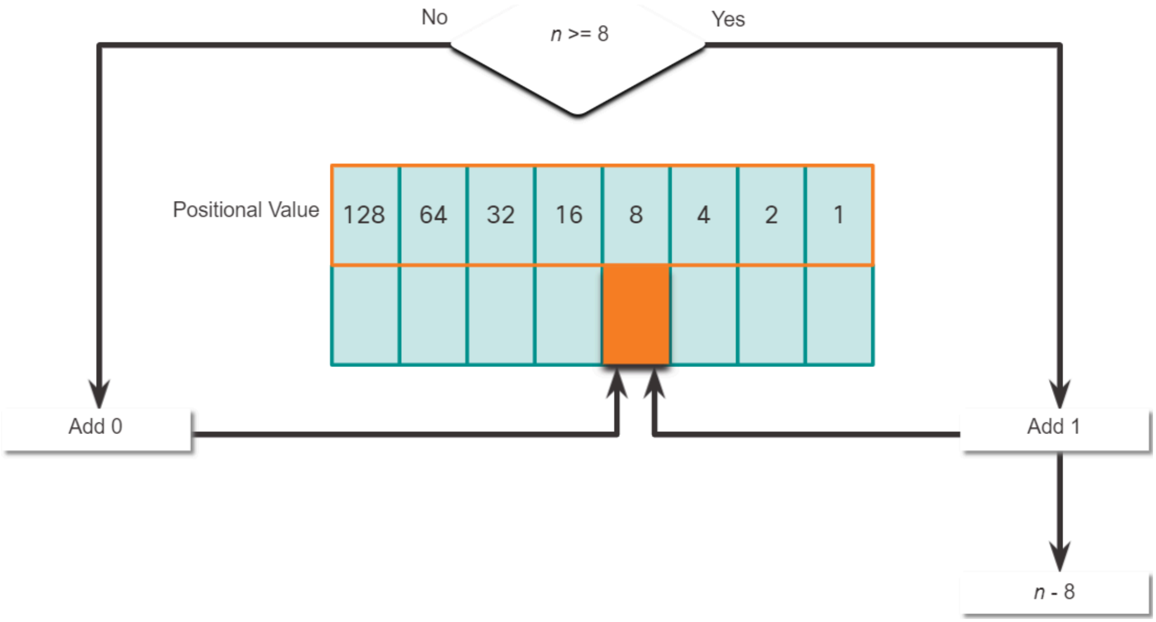
4. 16

- Is the decimal number of the octet (n) equal to or greater than the next most-significant bit (**16**)?
  - If no, then enter binary **0** in the **16** positional value.
  - If yes, then add a binary **1** in the **16** positional value and subtract **16** from the decimal number.



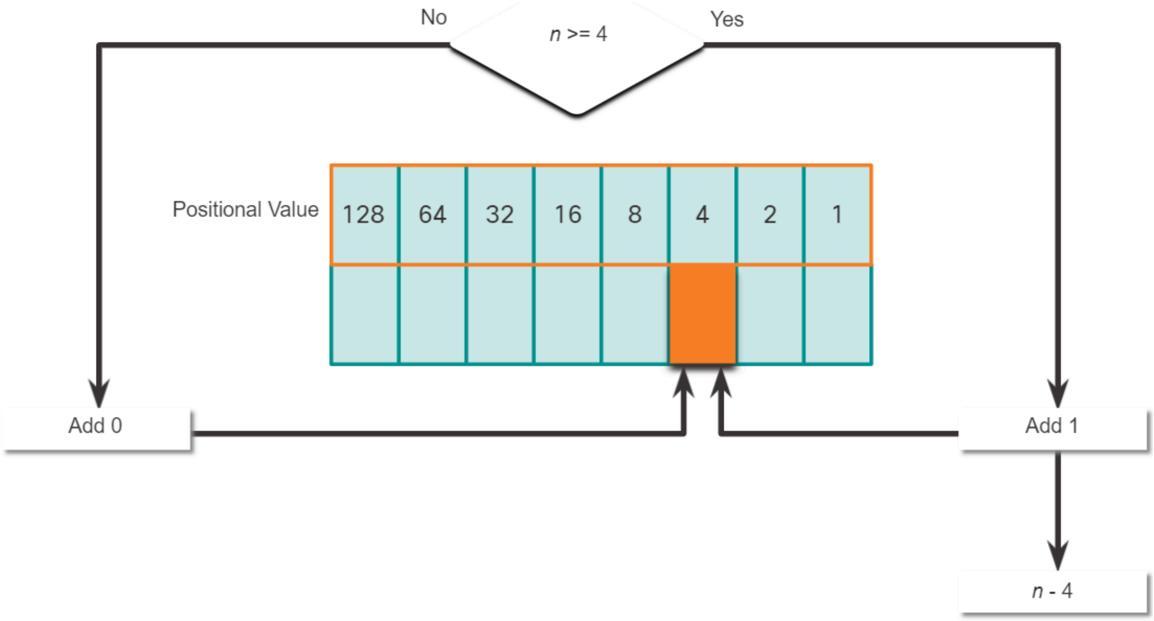
5. 8

- Is the decimal number of the octet (n) equal to or greater than the next most-significant bit (**8**)?
  - If no, then enter binary **0** in the **8** positional value.
  - If yes, then add a binary **1** in the **8** positional value and subtract **8** from the decimal number.



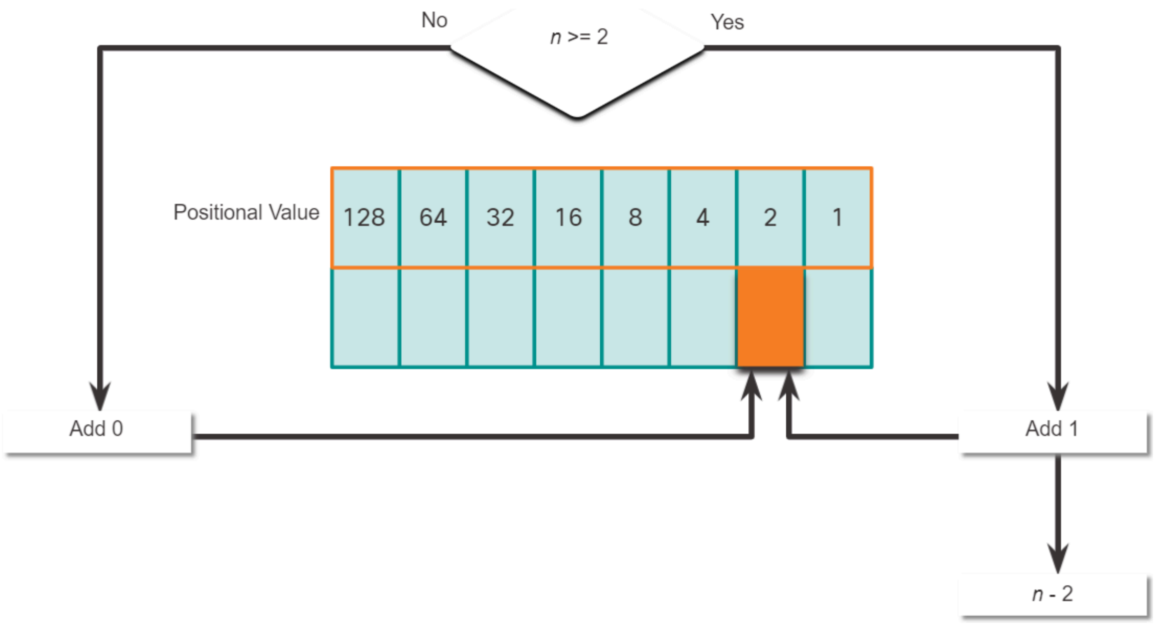
6. 4

- Is the decimal number of the octet (n) equal to or greater than the next most-significant bit (**4**)?
  - If no, then enter binary **0** in the **4** positional value.
  - If yes, then add a binary **1** in the **4** positional value and subtract **4** from the decimal number.



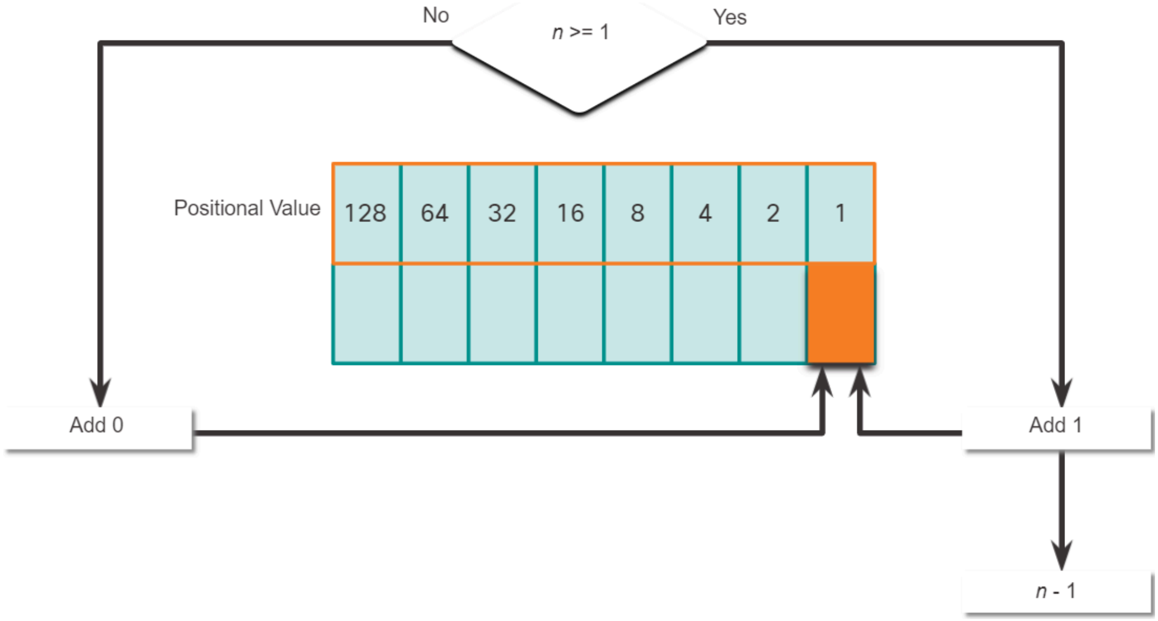
7. 2

- Is the decimal number of the octet (n) equal to or greater than the next most-significant bit (**2**)?
  - If not, insert binary **0** into positional value **2**.
  - If it is, add a binary **1** into positional value **2** and subtract **2** from the decimal number.



8. 1

- Is the decimal number of the octet (n) equal to or greater than the last most significant bit (**1**)?
  - If no, then enter binary **0** in the **1** positional value.
  - If yes, then add a binary **1** in the **1** positional value and subtract **1** from the last decimal number.



8. Decimal to Binary Conversion Example

- To help understand the process, consider the IP address 192.168.10.11.

- The first octet number 192 is converted to binary using the previously explained positional notation process.

- It is possible to bypass the process of subtraction with easier or smaller decimal numbers.
  - For instance, notice that it is fairly easy to calculate the third octet converted to a binary number without actually going through the subtraction process (8 + 2 = 10).
  - The binary value of the third octet is 00001010.

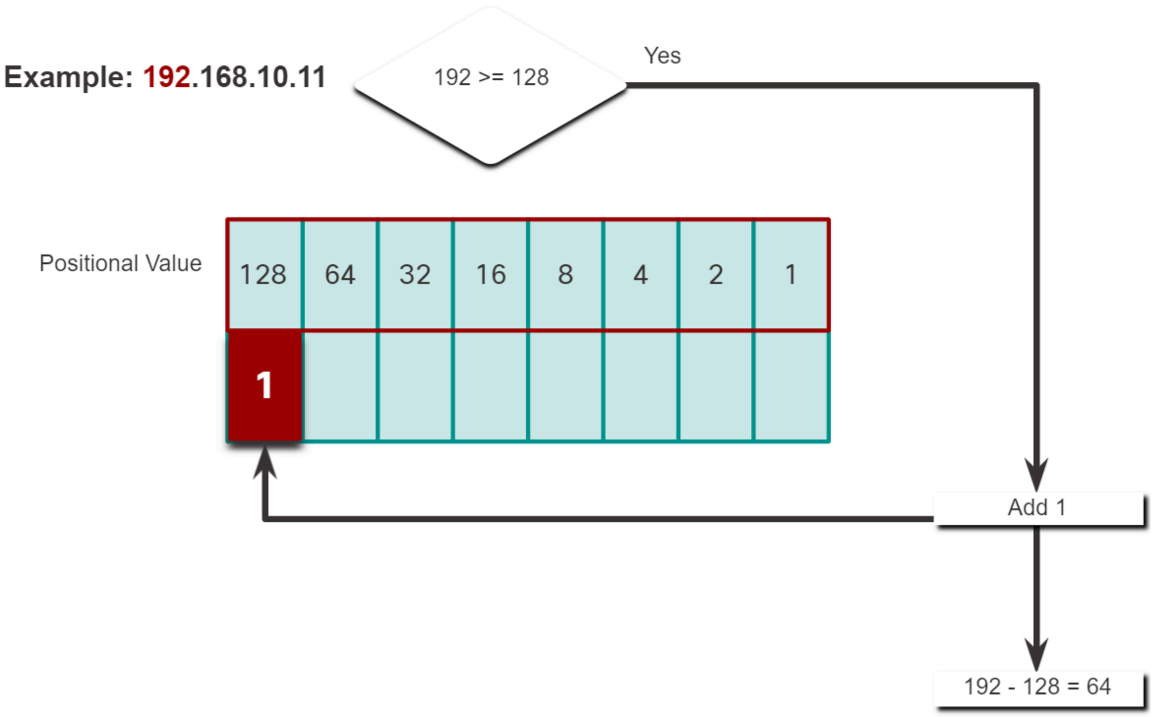
- The fourth octet is 11 (8 + 2 + 1). The binary value of the fourth octet is 00001011.

- Converting between binary and decimal may seem challenging at first, but with practice, it should become easier over time.

- Below is a describe each step to see the conversion of the IP address of **192.168.10.11** into binary.

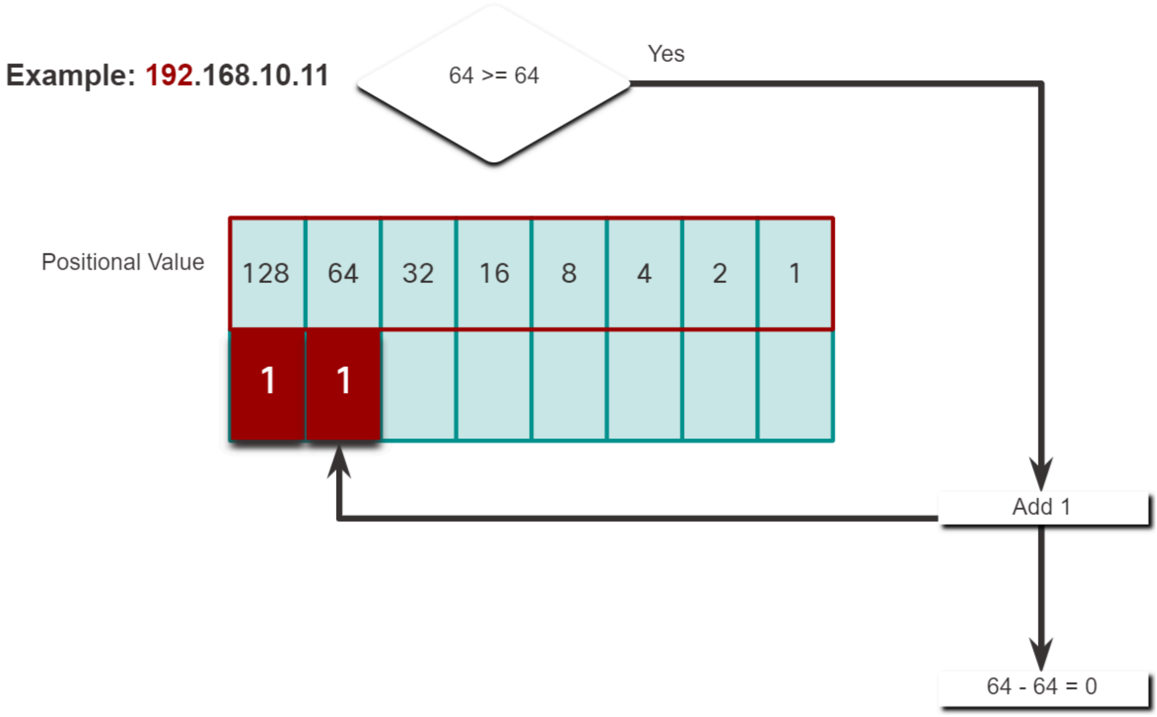
Step 1:

- Is the first octet number **192** equal to or greater than the high-order bit **128**?
  - Yes, it is, therefore add a **1** to the high-order positional value to represent **128**.
  - Subtract **128** from **192** to produce a remainder of **64**.



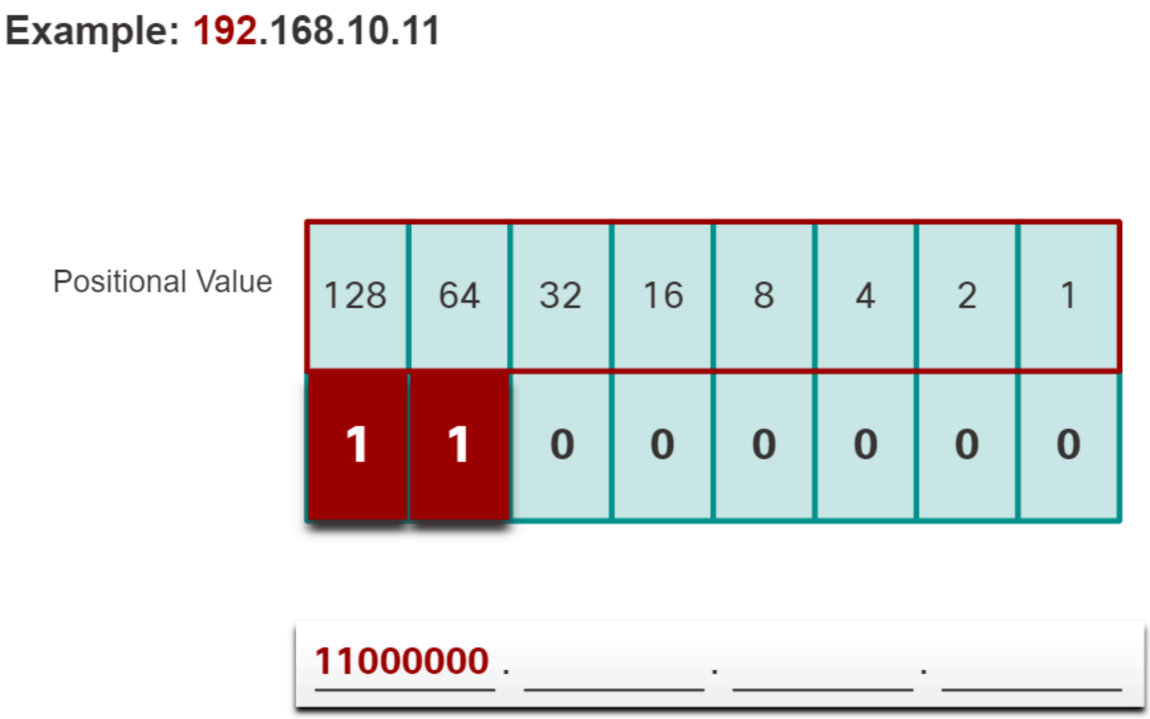
Step 2:

- Is the remainder **64** equal to or greater than the next high-order bit **64**?
  - It is equal, therefore add a **1** to the next high-order positional value.



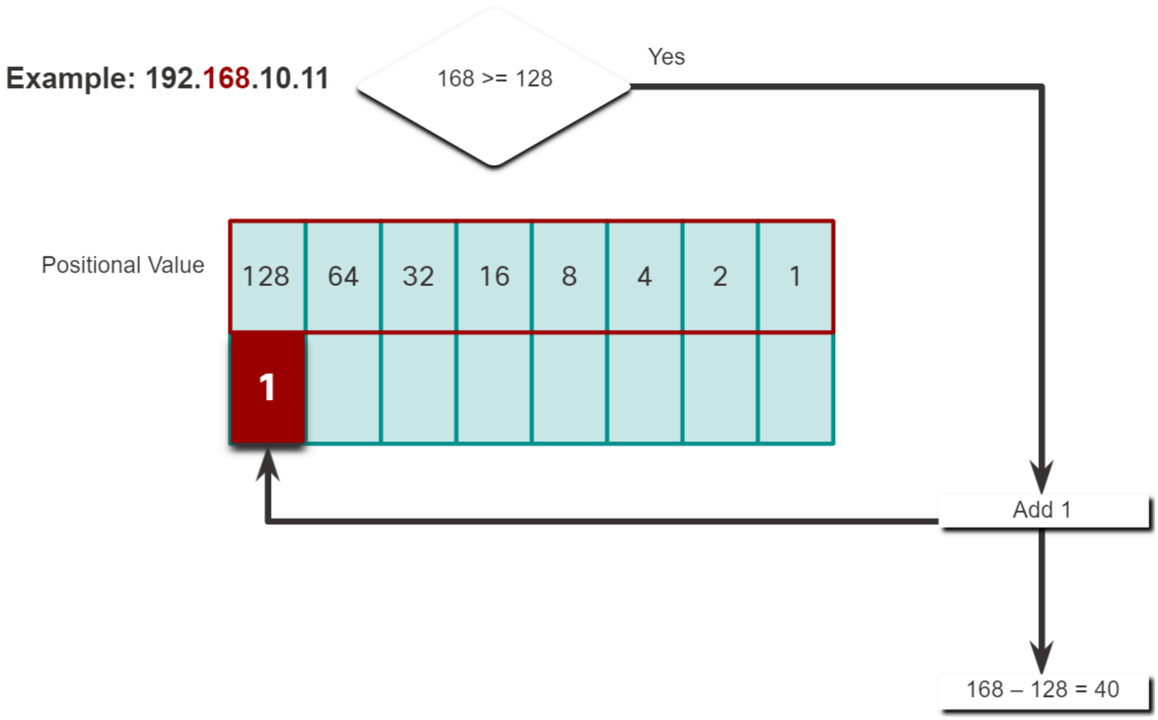
Step 3:

- Since there is no remainder, enter binary **0** in the remaining positional values.
  - The binary value of the first octet is **11000000**.



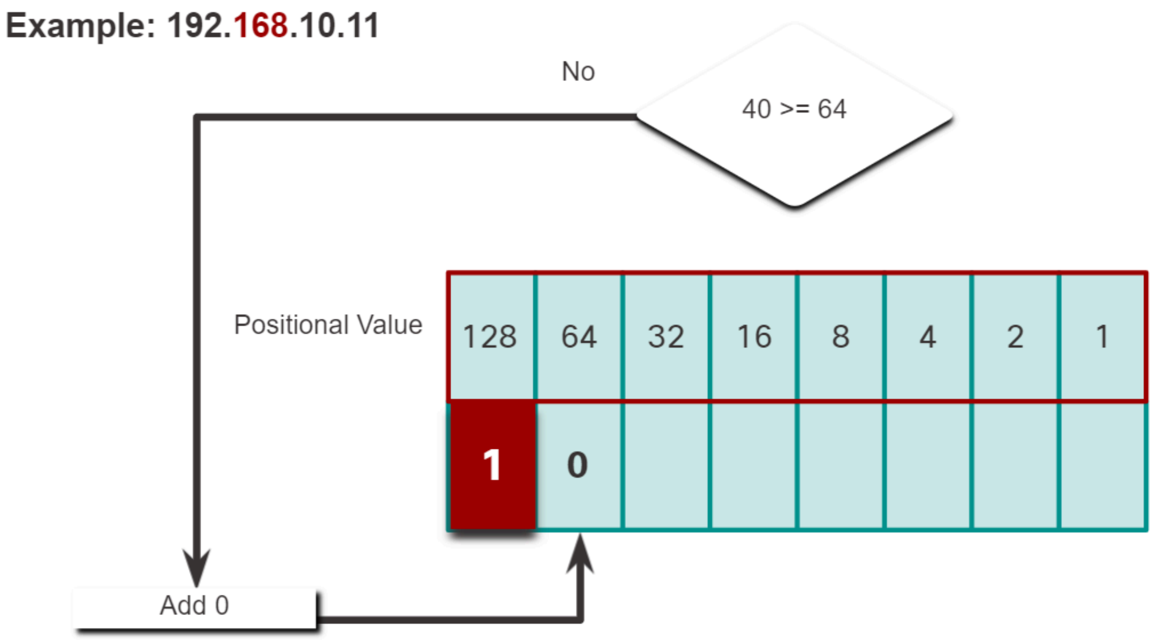
Step 4:

- Is the second octet number **168** equal to or greater than the high-order bit **128**?
  - Yes, it is, therefore add a **1** to the high-order positional value to represent **128**.
  - Subtract **128** from **168** to produce a remainder of **40**.



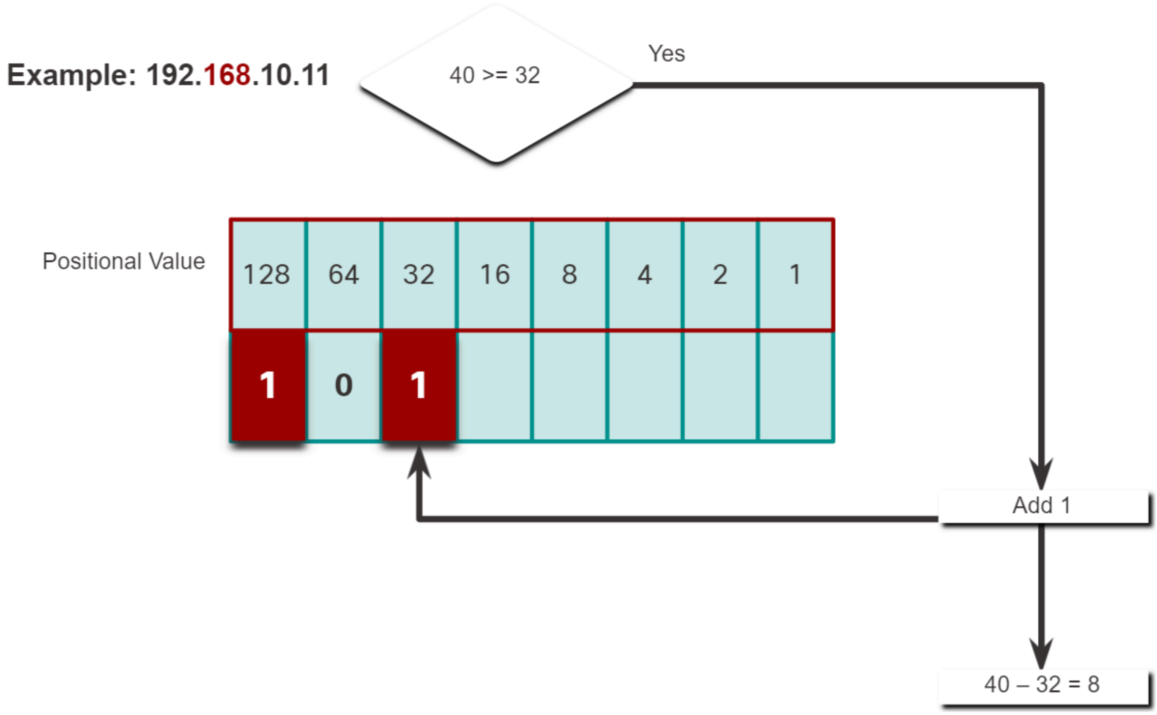
Step 5:

- Is the remainder **40** equal to or greater than the next high-order bit **64**?
  - No, it is not, therefore, enter a binary **0** in the positional value.



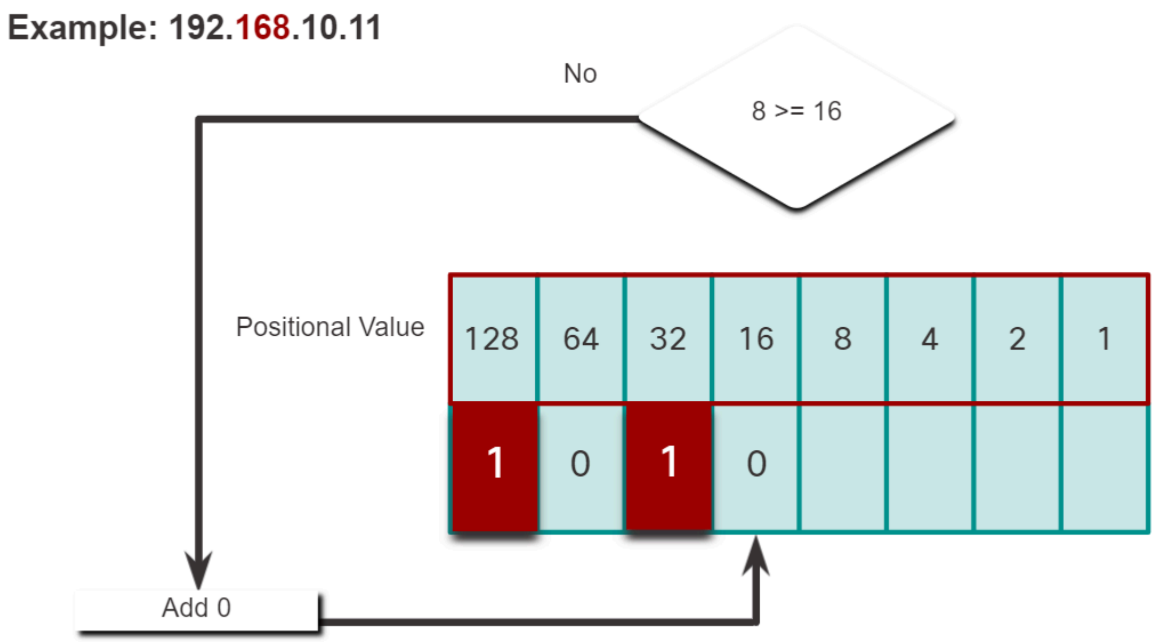
Step 6:

- Is the remainder **40** equal to or greater than the next high-order bit **32**?
  - Yes, it is, therefore add a **1** to the high-order positional value to represent **32**.
  - Subtract **32** from **40** to produce a remainder of 8.



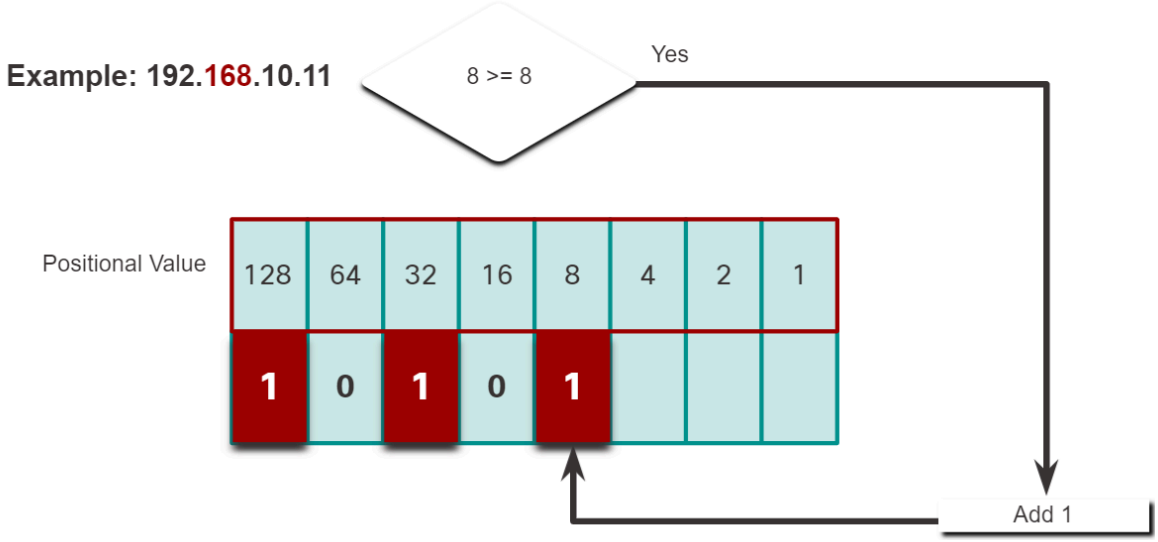
Step 7:

- Is the remainder **8** equal to or greater than the next high-order bit **16**?
  - No, it is not, therefore, enter a binary **0** in the positional value.



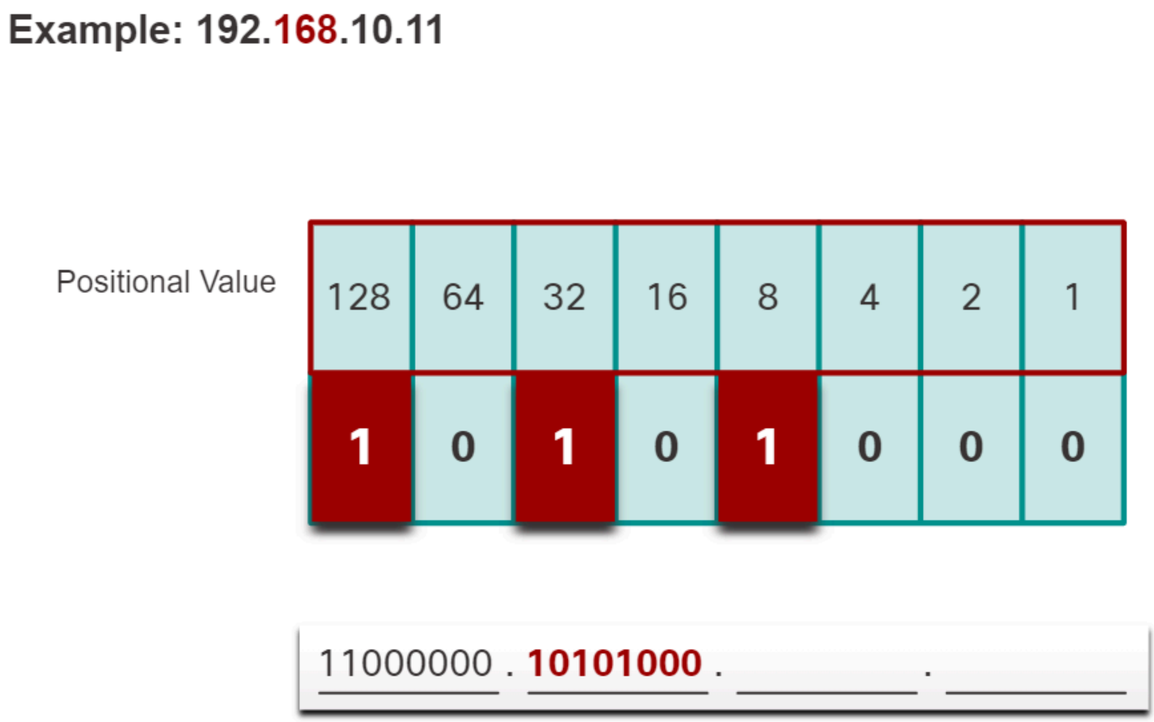
Step 8:

- Is the remainder **8** equal to or greater than the next high-order bit **8**?
  - It is equal, therefore add a **1** to the next high-order positional value.



Step 9:

- Since there is no remainder, enter binary **0** in the remaining positional values.
  - The binary value of the second octet is **10101000**.



Step 10:

- The binary value of the third octet is **00001010**.

Example: 192.168.10.11

Positional Value	128	64	32	16	8	4	2	1
	0	0	0	0	**1**	0	**1**	0

11000000 . 10101000 . **00001010** . ________

Step 11:

- The binary value of the fourth octet is **00001011**.

Example: 192.168.10.11

Positional Value	128	64	32	16	8	4	2	1
	0	0	0	0	**1**	0	**1**	**1**

11000000 . 10101000 . 00001010 . **00001011**

9. Activity - Decimal to Binary Conversions

Question 1:

- This activity allows you to practice decimal conversions to 8-bit binary values. We recommend that you work with this tool until you can do the conversion without error. Convert the decimal number shown in the Decimal Value row to its binary bits.

Decimal Value	110							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit								

- What is the Bit?

Answer: **01101110**

Question 2:

- This activity allows you to practice decimal conversions to 8-bit binary values. We recommend that you work with this tool until you can do the conversion without error. Convert the decimal number shown in the Decimal Value row to its binary bits.

Decimal Value	18							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit								

- What is the Bit?

Answer: **00010010**

Question 3:

- This activity allows you to practice decimal conversions to 8-bit binary values. We recommend that you work with this tool until you can do the conversion without error. Convert the decimal number shown in the Decimal Value row to its binary bits.

Decimal Value	106							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit								

- What is the Bit?

Answer: **01101010**

Question 4:

- This activity allows you to practice decimal conversions to 8-bit binary values. We recommend that you work with this tool until you can do the conversion without error. Convert the decimal number shown in the Decimal Value row to its binary bits.

Decimal Value	94							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit								

- What is the Bit?

Answer: **01011110**

Question 5:

- This activity allows you to practice decimal conversions to 8-bit binary values. We recommend that you work with this tool until you can do the conversion without error. Convert the decimal number shown in the Decimal Value row to its binary bits.

Decimal Value	214							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit								

- What is the Bit?

Answer: **11010110**

Question 6:

- This activity allows you to practice decimal conversions to 8-bit binary values. We recommend that you work with this tool until you can do the conversion without error. Convert the decimal number shown in the Decimal Value row to its binary bits.

Decimal Value	63							
Base	2	2	2	2	2	2	2	2
Exponent	7	6	5	4	3	2	1	0
Position	128	64	32	16	8	4	2	1
Bit								

- What is the Bit?

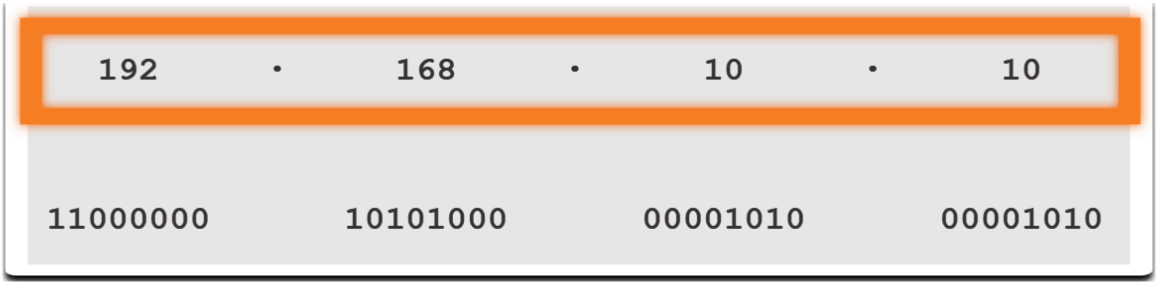
Answer: **00111111**

10. IPv4 Addresses

- As mentioned at the beginning of this topic, routers and computers only understand binary, while humans work in decimals.
  - You need to gain a thorough understanding of these two numbering systems and how they are used in networking.

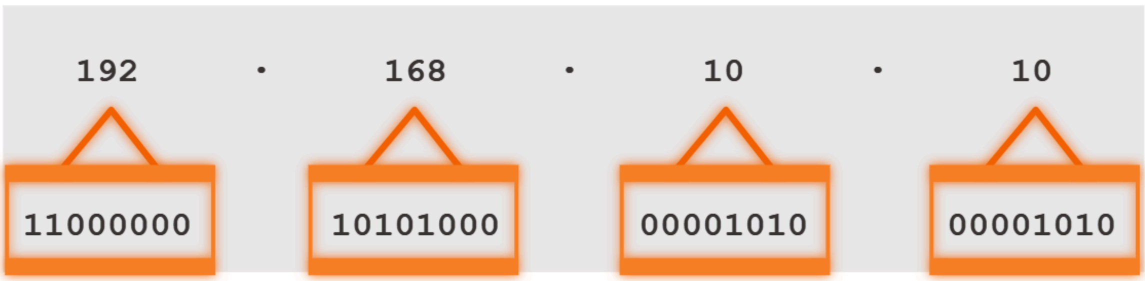
10A. Dotted Decimal Address

- 192.168.10.10 is an IP address that is assigned to a computer.



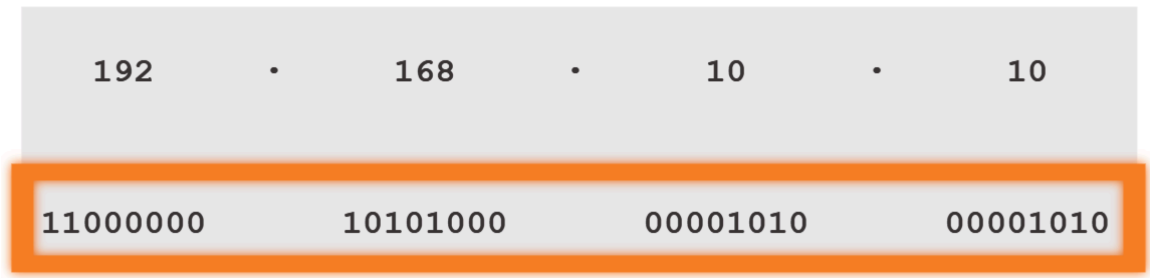
10B. Octets

- This address is made up of four different octets.



10C. 32-bit Address

- The computer stores the address as the entire 32-bit data stream.



Hexadecimal Number System

1. Hexadecimal and IPv6 Addresses

- Now you know how to convert binary to decimal and decimal to binary.
  - You need that skill to understand IPv4 addressing in your network.
  - However, you are just as likely to be using IPv6 addresses in your network.
  - To understand IPv6 addresses, you must be able to convert hexadecimal to decimal and vice versa.

- Just as decimal is a base ten number system, hexadecimal is a base sixteen system.
  - The base sixteen number system uses the digits 0 to 9 and the letters A to F.
  - The figure shows the equivalent decimal and hexadecimal values for binary 0000 to 1111.

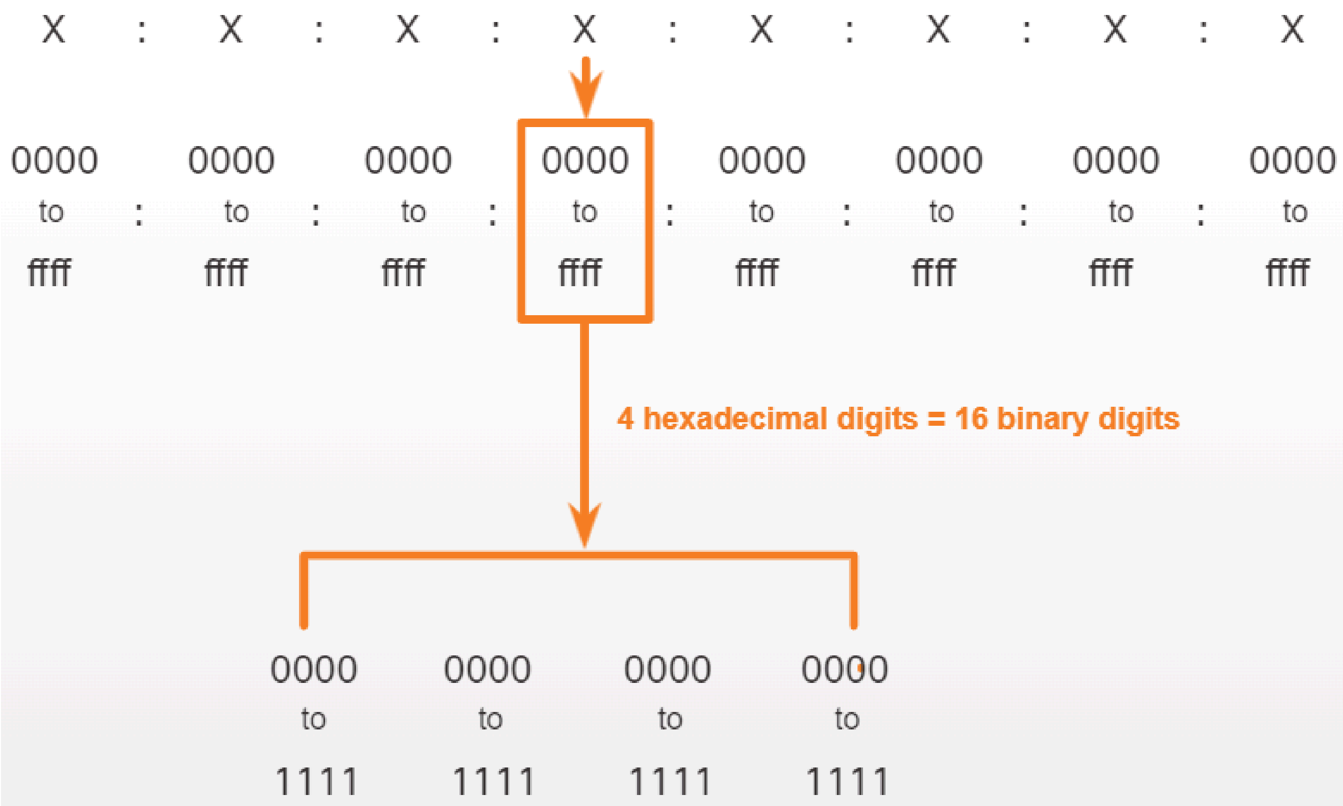
Decimal	Binary	Hexadecimal
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

- Binary and hexadecimal work well together because it is easier to express a value as a single hexadecimal digit than as four binary bits.

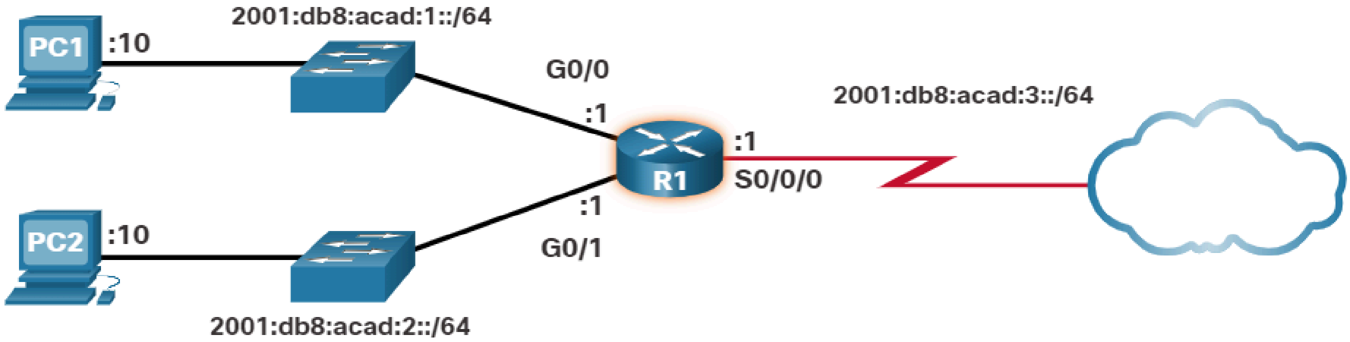
- The hexadecimal numbering system is used in networking to represent IP Version 6 addresses and Ethernet MAC addresses.

- IPv6 addresses are 128 bits in length and every 4 bits is represented by a single hexadecimal digit; for a total of 32 hexadecimal values.
  - IPv6 addresses are not case-sensitive and can be written in either lowercase or uppercase.

- As shown in the figure, the preferred format for writing an IPv6 address is x:x:x:x:x:x:x:x, with each "x" consisting of four hexadecimal values.
  - When referring to 8 bits of an IPv4 address we use the term octet.
  - In IPv6, a *hextet* is the unofficial term used to refer to a segment of 16 bits or four hexadecimal values.
  - Each "x" is a single hextet, 16 bits, or four hexadecimal digits.



● The sample topology in the figure displays IPv6 hexadecimal addresses.



2. Converting Between Hexadecimal and Decimal Numbering Systems

Video: https://youtu.be/yexYGtu5rCE

2A. Characteristics of the Hexadecimal System

If we follow the same procedure used for converting binary to decimal, we can write out the place values or positional notation for the hexadecimal number system.

- Base 16 Number System
- 16 Symbols (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F)
- Powers of 16

Powers	16^3	16^2	16^1	16^0
Number	4096	256	16	1

i. Hexadecimal, Decimal, and Binary Equivalents

The table shows the relationship between three different numbering systems: hexadecimal, decimal, and binary. Here's what each column and the text mean:

- **Hexadecimal (Hex)**: This is a base-16 numbering system, meaning it uses 16 symbols. The symbols include the numbers 0-9 and the letters A-F, where A represents 10, B represents 11, up to F, which represents 15.
- **Decimal**: This is the standard base-10 numbering system that we use in everyday life, with digits ranging from 0 to 9.
- **Binary**: This is a base-2 numbering system that uses only two symbols: 0 and 1. Each digit in a binary number is called a bit.

Key Points:

- **Each hex symbol represents a 4-bit binary number**: For example, the hex symbol "A" corresponds to the decimal number 10, which is represented in binary as 1010.
- **An 8-bit binary number can be expressed using two hex symbols**: This means if you have a binary number with 8 bits (like 11001100), you can split it into two 4-bit segments and convert each to its hexadecimal equivalent.

This table is useful for understanding how different numbering systems relate to each other, particularly in computer science where hexadecimal and binary are often used for low-level programming and memory addressing.

Hexadecimal		Decimal		Binary
0	**Equal to**	0	**Equal to**	0000
1	**Equal to**	1	**Equal to**	0001
2	**Equal to**	2	**Equal to**	0010
3	**Equal to**	3	**Equal to**	0011
4	**Equal to**	4	**Equal to**	0100
5	**Equal to**	5	**Equal to**	0101
6	**Equal to**	6	**Equal to**	0110
7	**Equal to**	7	**Equal to**	0111
8	**Equal to**	8	**Equal to**	1000
9	**Equal to**	9	**Equal to**	1001
A	**Equal to**	10	**Equal to**	1010
B	**Equal to**	11	**Equal to**	1011
C	**Equal to**	12	**Equal to**	1100
D	**Equal to**	13	**Equal to**	1101
E	**Equal to**	14	**Equal to**	1110
F	**Equal to**	15	**Equal to**	1111

2B. Convert from Hexadecimal to Decimal

i. Example 1: Convert Hex 2A To Decimal

Steps:

1. Write Out Positional Notation: (For The First Two Powers Of 16)

- The hexadecimal number 2A is made up of two digits: "2" and "A".
- The first digit (2) is in the 16^1 (16 to the power of 1) place.
- The second digit (A) is in the 16^0 (16 to the power of 0) place.

2. Multiply Each Hex Symbol by Its Place Value:

- The value of "2" in hexadecimal is 2 in decimal.
- The value of "A" in hexadecimal is 10 in decimal (as seen in the previous table).
- Multiply the value of each digit by its corresponding power of 16:
  - $2 \times 16^1 = 2 \times 16 = 32$
  - $A \times 16^0 = 10 \times 1 = 10$

3. Add the Results Together:

- Add the results from the multiplication step:
  - 32 + 10 = 42

4. So, the hexadecimal number **2A** converts to **42** in decimal.

Powers	16^1	16^0
Number	16	1
Hex Symbols	**2**	**A**

ii. Example 2: Convert Hex 9F To Decimal

Steps for Conversion:

1. Convert each hex digit to its 4-bit binary equivalent:

- Hex 9 converts to binary 1001.
- Hex F (which is 15 in decimal) converts to binary 1111.

Powers	2^3	2^2	2^1	2^0
Number	8	4	2	1
Place Value	**1**	**0**	**0**	**1**
Result	**Hex 9**			
Decimal	**8 + 0 + 0 + 1 = 9**			

Powers	2^3	2^2	2^1	2^0
Number	8	4	2	1
Place Value	**1**	**1**	**1**	**1**
Result	**Hex F**			
Decimal	**8 + 4 + 2 + 1 = 15**			

2. Combine the binary equivalents into one 8-bit binary number:

- Combine 1001 (for 9) and 1111 (for F) to get 10011111.

3. **Convert the 8-bit binary number to a decimal number**:

- The 8-bit binary 10011111 is converted by calculating the sum of the powers of 2 for each bit:
  - $1*2^7$ (128) + $0*2^6$ (0) + $0*2^5$ (0) + $1*2^4$ (16) + $1*2^3$ (8) + $1*2^2$ (4) + $1*2^1$ (2) + $1*2^0$ (1).
- Adding these values: 128 + 16 + 8 + 4 + 2 + 1 = 159.

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**
Result	**128 + 16 + 8 + 4 + 2 + 1 = 159 Decimal**							

4. Therefore, the hexadecimal number 9F is equivalent to 159 in decimal.

2C. Convert from Decimal to Hexadecimal

i. Example 1: Convert Decimal 197 To Hex

Steps to Convert Decimal 197 to Hexadecimal:

1. Convert Decimal to Binary:

- Start by converting 197 to an 8-bit binary number.
- The table on the top shows the binary place values from 2^7 to 2^0, which correspond to 128, 64, 32, 16, 8, 4, 2, and 1.
- Subtract the largest possible value (starting with 128) from 197 and continue subtracting the largest possible remaining value until you reach 0.
- The result is:
  - 197 − 128 = 69
  - 69 − 64 = 5
  - 5 − 4 = 1
  - 1 − 1 = 0
- This gives you the binary number 11000101.
- So, 197 in decimal is equal to **binary 11000101**. (Decimal 197 = Binary 11000101)

Powers	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Number	128	64	32	16	8	4	2	1
Place Value	1	1	0	0	0	1	0	1

2. **Convert Binary to Hexadecimal**:

- Next, split the 8-bit binary number into two 4-bit sections: 1100 and 0101.
- Convert each section to its decimal equivalent:
  - 1100 (binary) = 8 + 4 = 12 (decimal), which is **C** in hexadecimal.
  - 0101 (binary) = 4 + 1 = 5 (decimal), which is **5** in hexadecimal.
- Combine the results: 197 in decimal is equal to **C5** in hexadecimal.

Powers	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0
Number	8	4	2	1	8	4	2	1
Place Value	1	1	0	0	0	1	0	1
Result	8 + 4 = 12 Hex C				4 + 1 = 5 Hex 5			

3. So, the final answer is **197 decimal = C5 hex** or **0xC5**.

i(a) Further Explanation

The notation "0xC5" is a way to represent a hexadecimal number in programming and digital electronics. Here's a breakdown:

- **"0x"**: This prefix indicates that the number following it is in hexadecimal (base-16) format. It's a common notation used in programming to make it clear that the number is not in the usual decimal (base-10) format.
- **"C5"**: This is the actual hexadecimal number.

Understanding "C5" in Hexadecimal:

- **C**: In hexadecimal, the letter "C" represents the decimal number 12.
- **5**: This is just the number 5, and it remains the same in both hexadecimal and decimal.

Converting "C5" to Decimal:

- The hexadecimal number "C5" can be broken down as follows:
  - C is in the 16^1 place (which is the same as 16).
  - 5 is in the 16^0 place (which is the same as 1).
- To convert it to decimal:
  - $C \times 16^1$ **= 12 × 16 = 192**
  - **5 ×** 16^0 **= 5 × 1 = 5**
- Add them together:
  - 192 + 5 = 197 in decimal.

So, "0xC5" in hexadecimal is equal to 197 in decimal. The "0x" is just a way to signal that the number is in hexadecimal format.

3. Decimal to Hexadecimal Conversions

- Converting decimal numbers to hexadecimal values is straightforward.
  - Follow the steps listed:
    - Convert the decimal number to 8-bit binary strings.
    - Divide the binary strings into groups of four starting from the rightmost position.
    - Convert each of four binary numbers into their equivalent hexadecimal digit.

- The example provides the steps for converting **168** to hexadecimal.

- For example, **168** was converted into hex using the three-step process.
  - **168** in binary is **10101000**.
  - **10101000** in two groups of four binary digits is **1010** and **1000**.
  - **1010** is hex **A** and **1000** is hex **8**.

- **Answer**:
  - **168** is **A8** in hexadecimal.

4. Hexadecimal to Decimal Conversion

- Converting hexadecimal numbers to decimal values is also straightforward.
  - Follow the steps listed:
    - Convert the hexadecimal number to 4-bit binary strings.
    - Create 8-bit binary grouping starting from the rightmost position.
    - Convert each 8-bit binary grouping into their equivalent decimal digit.

- The example provides the steps for converting **D2** to decimal.

- For example, **168** was converted into hex using the three-step process.
  - **D2** in 4-bit binary strings is **1101** and **0010**.
  - **1101** and **0010** is **11010010** in an 8-bit grouping.
  - **11010010** in binary is equivalent to **210** in decimal.

- **Answer**:
  - **D2** in hexadecimal is **210** in decimal.

5. Check Your Understanding - Hexadecimal Number System

- Check your understanding of hexadecimal number system by choosing the correct answer to the following questions.

Question 1: Which is the hexadecimal equivalent of 202?

(a) B10

(b) BA

(c) C10

(d) CA

Answer: **(d) CA**

Question 2: Which is the hexadecimal equivalent of 254?

(a) EA

(b) ED

(c) FA

(d) FE

Answer: **(d) FE**

Question 3: Which is the decimal equivalent of A9?

(a) 168

(b) 169

(c) 170

(d) 171

Answer: **(b) 169**

Question 4: Which of the following is the decimal equivalent of 7D?

(a) 124

(b) 125

(c) 126

(d) 127

Answer: **(b) 125**

Module Practice and Quiz

1. What Did I Learn In This Module?

1A. Binary Number System

- Binary is a numbering system that consists of the numbers 0 and 1 called bits.
  - In contrast, the decimal numbering system consists of 10 digits consisting of the numbers 0 – 9.
  - Binary is important for us to understand because hosts, servers, and network devices use binary addressing, specifically, binary IPv4 addresses, to identify each other.
  - You must know binary addressing and how to convert between binary and dotted decimal IPv4 addresses.
  - This topic presented a few ways to convert decimal to binary and binary to decimal.

1B. Hexadecimal Number System

- Just as decimal is a base ten number system, hexadecimal is a base sixteen system.
  - The base sixteen number system uses the numbers 0 to 9 and the letters A to F.
  - The hexadecimal numbering system is used in networking to represent IPv6 addresses and Ethernet MAC addresses.
  - IPv6 addresses are 128 bits in length and every 4 bits is represented by a single hexadecimal digit; for a total of 32 hexadecimal values.
  - To convert hexadecimal to decimal, you must first convert the hexadecimal to binary, then convert the binary to decimal.
  - To convert decimals to hexadecimals, you must first convert them to binary.

2. Module Quiz - Number Systems

Question 1: What is the binary representation for the decimal number 173?

(a) 10110101

(b) 10100101

(c) 10100111

(d) 10101101

Answer: **(d) 10101101**

Question 2: Given the binary address of 11101100 00010001 00001100 00001010, which address does this represent in dotted decimal format?

(a) 236.17.12.10

(b) 234.16.12.10

(c) 234.17.10.9

(d) 236.17.12.6

Answer: **(a) 236.17.12.10**

Question 3: How many binary bits exist within an IPv6 address?

(a) 64

(b) 128

(c) 32

(d) 256

(e) 48

Answer: **(b) 128**

Question 4: What is the binary equivalent of the decimal number 232?

(a) 11000110

(b) 11110010

(c) 10011000

(d) 11101000

Answer: **(d) 11101000**

Question 5: Which two statements are correct about IPv4 and IPv6 addresses? (Choose two.)

(a) IPv4 addresses are represented by hexadecimal numbers.

(b) IPv6 addresses are 64 bits in length.

(c) IPv6 addresses are 32 bits in length.

(d) IPv4 addresses are 32 bits in length.

(e) IPv4 addresses are 128 bits in length.

(f) IPv6 addresses are represented by hexadecimal numbers.

Answer: **(d & f) IPv4 addresses are 32 bits in length. & IPv6 addresses are represented by hexadecimal numbers.**

Question 6: Which IPv4 address format was created for ease of use by people and is expressed as 201.192.1.14?

(a) dotted decimal

(b) ASCII

(c) binary

(d) hexadecimal

Answer: **(a) dotted decimal**

Question 7: What is the dotted decimal representation of the IPv4 address 11001011.00000000.01110001.11010011?

(a) 192.0.2.199

(b) 203.0.113.211

(c) 198.51.100.201

(d) 209.165.201.223

Answer: **(b) 203.0.113.211**

Question 8: What is the decimal equivalent of the binary number 10010101?

(a) 192

(b) 168

(c) 149

(d) 157

Answer: **(c) 149**

Question 9: What is the decimal equivalent of the hex number 0x3F?

(a) 93

(b) 87

(c) 63

(d) 77

Answer: **(c) 63**

Question 10: What is the dotted decimal representation of the IPv4 address which is represented as the binary string 00001010.01100100.00010101.00000001?

(a) 10.10.20.1

(b) 100.21.10.1

(c) 10.100.21.1

(d) 100.10.11.1

Answer: **(c) 10.100.21.1**

Question 11: What is the decimal equivalent of 0xC9?

(a) 200

(b) 185

(c) 201

(d) 199

Answer: **(c) 201**

Question 12: Which is a valid hexadecimal number?

(a) h

(b) j

(c) f

(d) g

Answer: **(c) f**

Question 13: What is the binary representation of 0xCA?

(a) 11010101

(b) 10111010

(c) 11011010

(d) 11001010

Answer: **(d) 11001010**

Question 14: How many bits are in an IPv4 address?

(a) 32

(b) 256

(c) 64

(d) 128

Answer: **(a) 32**