ET0730

Chapter 9
IPv6

Singapore Polytechnic
School of Electrical & Electronic Engineering

Objectives

- Understand the limitation of IPv4 Addressing.
- Understand the IPv6 Addressing representation.
- Describe various types of IPv6 Unicast Addresses and their uses.
- Describe how IPv4 and IPv6 co-exist in the network.

Outline

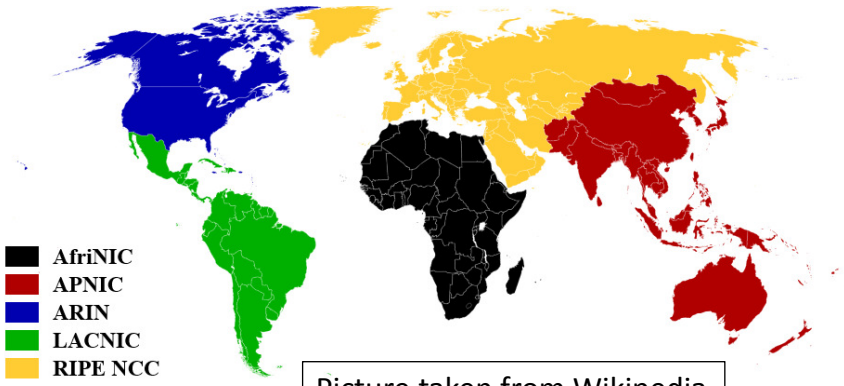
- Depletion of IPv4 Public Addresses
- IPv6 Addressing
- IPv6 Unicast Addresses
- Configure IPv6 Address on Windows Computers
- IPv4 and IPv6 “Co-existence”
  - Dual-stack
  - Tunnelling
  - Translation

Limitation of IPv4 Addressing

- Available IPv4 addresses (Classes A, B and C) ≈ 3.7 billions.
  - Insufficient for anticipated growth in the number of internet users and connected devices (e.g. Internet of Things, IoT).
- Temporary solution: Sharing of IP Addresses.
  - Example: Network Address Translation (NAT)
- Long term solution is IPv6.

Depletion of IPv4 Public Addresses (1)

- IP addresses are assigned by IANA, through the Regional Internet Registries (RIRs).
  - IANA = Internet Assigned Numbers Authority
- There are 5 RIRs world-wide:
  - AfriNIC
  - APNIC
  - ARIN
  - LACNIC
  - RIPE NCC



Picture taken from Wikipedia

Depletion of IPv4 Public Addresses (2)

- Depletion of IPv4 address space has been the main reason for moving to IPv6.
- It is anticipated that all five RIRs will run out of IPv4 addresses between 2015 and 2020.

IPv6 Addressing

- IPv6 addresses use 128 bits.
- 128 bits give 2^{128} = 3.4×10^{38} IPv6 addresses.
  - 340 undecillions
- IPv6 addresses are too long to be expressed in dotted-decimal format.
  - 123.123.123.123.123.123.123.123.123.123.123.123.123.123.123.123
- Solution: Use Hexadecimal Numbering System + simplification + compression.

Revision:

Jump to "Appendix"

- Hexadecimal Numbering System
- Conversion between Decimal and Hexadecimal Numbering Systems

You may skip this if you are already familiar with the conversion among decimal, binary and hexadecimal numbering systems.

IPv6 Address Representation (1)

- IPv6 addresses use hexadecimal numbering system.
- Example: 2001:0000:0000:008F:0003:5005:CAA1:0001
- IPv6 addresses are written in groups of 16-bit sections (called “hextet”) separated by colon.
- Each hextet represents 16 binary bits:
  - 0x2001 = 0010 0000 0000 0001
  - 0x0000 = 0000 0000 0000 0000
  - 0x0000 = 0000 0000 0000 0000
  - 0x008F = 0000 0000 1000 1111
  - 0x0003 = 0000 0000 0000 0011
  - 0x5005 = 0101 0000 0000 0101
  - 0xCAA1= 1100 1010 1010 0001
  - 0x0001 = 0000 0000 0000 0001

IPv6 Address Representation (2)

- IPv6 can be written in both uppercase or lowercase.
- Example: The two IPv6 addresses below are same.
  - 2001:CAFE:0000:BEEF:0003:57FE:CAA1:0001
  - 2001:cafe:0000:beef:0003:57fe:caa1:0001

How to make IPv6 Addresses "Shorter"? (1)

- Even in hexadecimal format the IPv6 addresses are too long to be written (let alone to be remembered).
- IPv6 addresses can be represented in a shorter format, following three rules:
  1. Any leading '0's (zeros) in any 16-bit section or hextet can be omitted.
  2. A double colon (::) can replace any single, contiguous string of one or more 16-bit segments (hextets) consisting of all 0's.
  3. Double colon (::) can only be used once within an address otherwise the address will be ambiguous.

How to make IPv6 Addresses "Shorter"? (2)

- **Rule #1**: Any leading 0's (zeros) in any hextet can be omitted.
- Example:
  2001:0000:0000:008F:0003:5005:CAA1:0001

  can be simplified to:

  2001:0:0:8F:3:5005:CAA1:1

How to make IPv6 Addresses "Shorter"? (3)

Rule #1:
Any leading 0's (zeros) in any hextet can be omitted.

2001:0000:0000:008F:0003:5005:CAA1:0001

2001: 0 : 0 : 8F : 3 :5005:CAA1: 1

2001:0:0:8F:3:5005:CAA1:1

Exercise on Rule #1

- Simplify this IPv6 address using Rule #1:
  2002:F000:0400:0008:0CE3:0000:CAA1:0081
- **Answer:**
- Those leading zeros (underlined) can be omitted.
  2002:F000:0400:0008:0CE3:0000:CAA1:0081
- Therefore, answer is
  2002:F000:400:8:CE3:0:CAA1:81

How to make IPv6 Addresses "Shorter"? (4)

- **Rule #2**: A double colon (::) can replace any single, contiguous string of one or more 16-bit segments (hextets) consisting of all 0's.
- This step is known as "Compression".
- Example:
  - 2001:0000:0000:0000:0000:5555:0000:0001
    can be simplified to 2001:0:0:0:0:5555:0:1 first.
  - Then it can be "compressed" to 2001::5555:0:1, where the double colon :: represents the 4 "0000" hextets.

How to make IPv6 Addresses "Shorter"? (5)

Rule #2:
A double colon (::) can replace any single, contiguous string of one or more 16-bit segments (hextets) consisting of all 0's.

2001:0000:0000:0000:0000:5555:0000:0001

↓ Rule #1: Simplification

2001: 0 : 0 : 0 : 0 :5555: 0 : 1

↓ Rule #2: Compression

2001: :5555: 0 : 1

↓

2001::5555:0:1

Exercise on Rule #2

- Rewrite this IPv6 address in the compressed format:

  2055:8888:0000:0000:0000:0070:0000:0033

- Answer:
  - Step 1: Simplification
    - 2055:8888:0:0:0:70:0:33
  - Step 2: Compression
    - 2055:8888::70:0:33

Exercise on Rule #2

- Rewrite this IPv6 address in the compressed format:

  FE80:0000:0000:0000:0000:0000:0000:0001

- Answer:
  - Step 1: Simplification
    - FE80:0:0:0:0:0:0:1
  - Step 2: Compression
    - FE80::1

Exercise on Rule #2

- Rewrite this IPv6 address in the compressed format:

  0000:0000:0000:0000:0000:0000:0000:0001

- Answer: ::1

- Re-write the IPv6 address with all 0's in the compressed format.

- Answer: ::

How to make IPv6 Addresses "Shorter"? (6)

- **Rule #3:** Double colon (::) can only be used **once** within an address, otherwise the address will be ambiguous.
- Example: 2001:0000:0000:3333:0000:0000:4444:5555

  can be simplified to:

  2001::3333:0:0:4444:5555 or

  2001:0:0:3333::4444:5555

But 2001::3333::4444:5555 is **not** allowed.

Reason: No way to tell the original content of each double-colon.

Exercise

- Re-write the compressed IPv6 address in its original 8-hextet format (i.e. no simplification, no compression).

  2222:3333::1

- Answer:
- "2222", "3333" and "1" are three hextets. Since there are 8 hextets in IPv6 addresses, the double-colon represents the other 5 hextets of "0000".
- Therefore, the original IPv6 address is

  2222:3333:0000:0000:0000:0000:0000:0001

Exercise

- Re-write the compressed IPv6 address in its original 8-hextet format.

  2001:D8B::44:2:1

- Answer:

2001:0D8B:0000::0000:0000:0044:0002:0001

IPv6 Prefix Length

- IPv6 addresses are also divided into Network Portion and Host Portion.
- The indication of the Network and Host portion does not use the subnet mask.
- IPv6 addresses use Prefix Length to indicate their network portion.
- Example: For an IPv6 address with 64 bits in the Network Portion, the Prefix Length is /64.
- Example: 2001:CAFE:3::1/64

Exercise

- What is the Network Portion of the IPv6 address 2001:CAFE:3::5555:1/64?

- Answer:
- Expand into original IPv6 address

  2001:CAFE:0003:0000:0000:0000:5555:0001
- Since the prefix length is /64, the first 64 bits (64/16 = 4 hextets) belong to the Network Portion.
- Answer: 2001:CAFE:0003:0000

Exercise

- What is the Network Portion of the IPv6 address 2001::CAFE:4:3:2:1/64?

- Answer:
- Expand into original IPv6 address

  2001:0000:0000:CAFE:0004:0003:0002:0001
- Since the prefix length is /64, the first 64 bits (64/16 = 4 hextets) belong to the Network Portion.
- Answer: 2001:0000:0000:CAFE

Exercise

- What is the Network Portion of the IPv6 address 2001:3456:CAFE::2/48?

- Answer:
- Expand into original IPv6 address

2001:3456:CAFE:0000:0000:0000:0000:0002
- Since the prefix length is /48, the first 48 bits (48/16 = 3 hextets) belong to the Network Portion.
- Answer: 2001:3456:CAFE

Types of IPv6 Addresses

- There are 3 types of IPv6 addresses:
  - Unicast
  - Multicast
  - Anycast
- Note: IPv6 does not have broadcast addresses.
- This module will only cover IPv6 Unicast Addresses.

IPv6 Unicast Addresses

- There are 6 types of IPv6 Unicast addresses:
  - Global Unicast
  - Link-Local
  - Loopback
  - Unspecified Address
  - Unique Local
  - Embedded IPv4
- In this module, we will only discuss the first 4 types.

Types of IPv6 Addresses

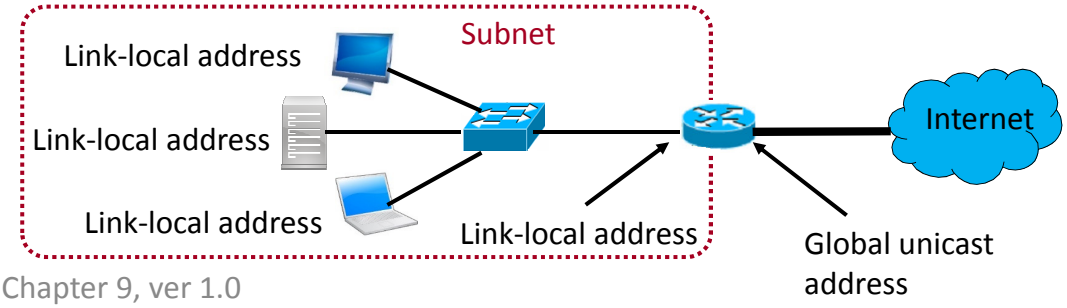
Global Unicast Address

- Similar to a public IPv4 address, which is internet-routable.
- Globally unique, no two devices should have identical global unicast address.
- Can be static (manual) or dynamic (e.g. DHCPv6).
- ICANN allocates IPv6 address blocks to the 5 RIRs.
- Currently, only global unicast addresses with the first three bits of 001 are being assigned.
  - The first hextet is 0010 or 0011
  - IPv6 address is 2000::/3.

Types of IPv6 Addresses

Link-Local Unicast Address

- For communication with other devices on the same subnet (subnet" is also referred to as "link" in IPv6).
- Link-Local Unicast Address is confined to a subnet, not routable beyond the subnet.
- Link-local addresses are FE80::/10.
- Every IPv6-enabled network interface is required to have a link-local address.



Types of IPv6 Addresses

Loopback

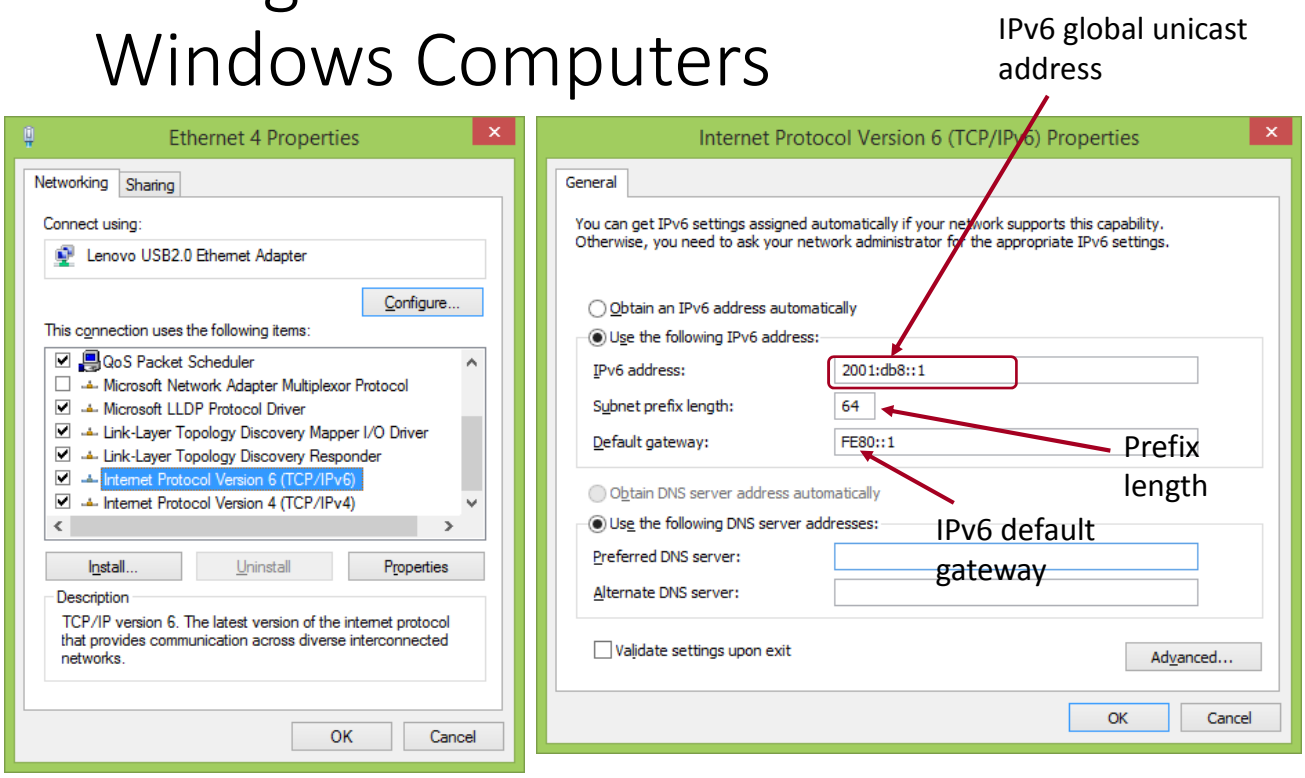
- Used by a host to send a packet to itself.
- Ping an IPv6 loopback address to test the configuration of TCP/IP on the local host.
- Cannot be assigned to a physical interface.
- The loopback address is all-0s except for the last bit, represented as ::1/128 or just ::1.

Types of IPv6 Addresses

Unspecified Address

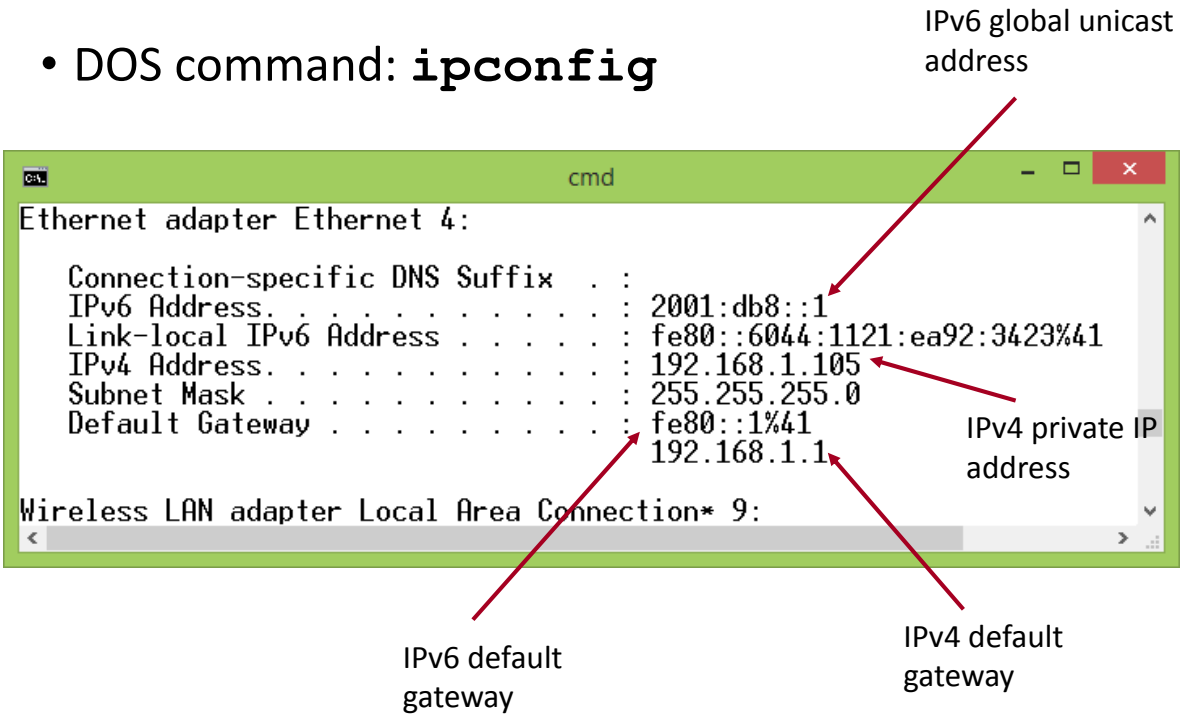
- Unspecified Address is all-0's address represented as ::/128 or just :: .
- Cannot be assigned to an interface.
- Can only used as a source address, when
  - the device does not yet have a permanent IPv6 address, or
  - the source of the packet is irrelevant to the destination.

Configure IPv6 Address on Windows Computers



Verify IPv6 Configuration on Windows Computers

- DOS command: **`ipconfig`**



IPv4 and IPv6 "Co-existence"

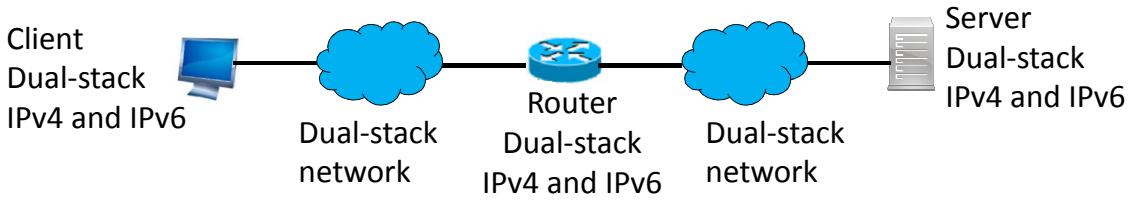
- There are billions of existing devices that only support IPv4.
- IPv4 and IPv6 are NOT compatible.
- Migration to IPv6 should still allow IPv4-only devices to be usable – "co-existence".
- Three categories of migration techniques:
  - Dual-stack
  - Tunnelling
  - Translation

IPv6 Migration Technique (1)

Dual-stack

- Allows IPv4 and IPv6 to co-exist on the same network.
- Devices run both IPv4 and IPv6 protocol stacks simultaneously.

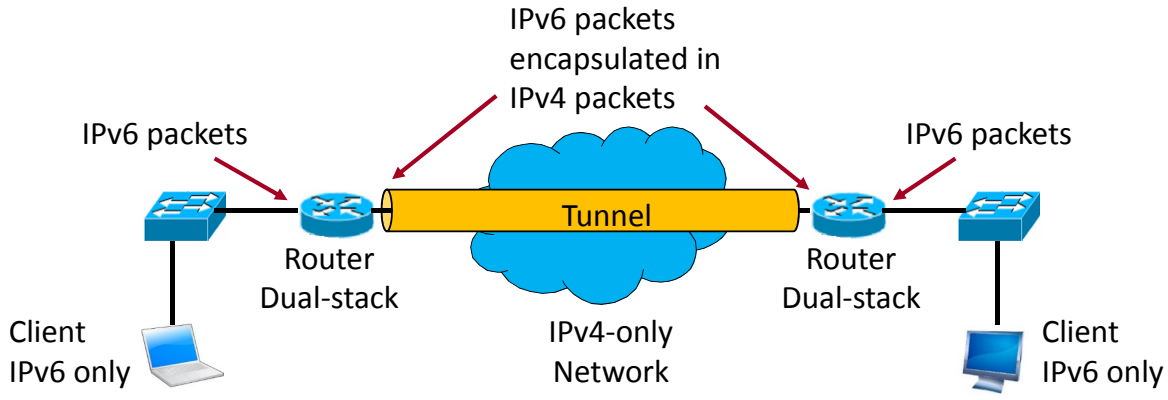
	IPv4-only server	IPv6-only server	Dual-stack server
IPv4-only server	√	x	√
IPv6-only server	x	√	√
Dual-stack server	√	√	√



IPv6 Migration Technique (2)

Tunnelling

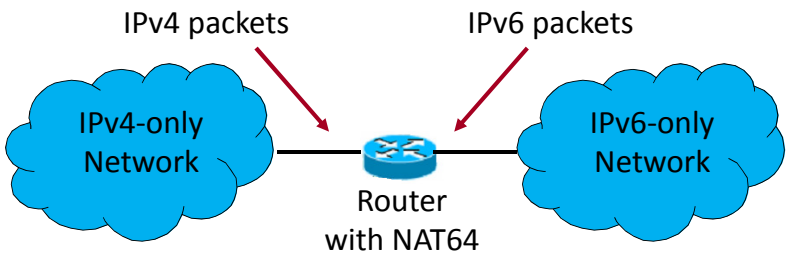
- A method of transporting an IPv6 packet over an IPv4 network.
- The IPv6 packet is encapsulated inside an IPv4 packet.



IPv6 Migration Technique (3)

Translation

- IPv6 packets are translated to IPv4 packets, and vice versa using NAT64 (Network Address Translation 64).
- Through the translation technique, IPv6-only devices can communicate with IPv4-only devices.



Questions & Answers

Appendix

- Hexadecimal Numbering System
- Conversion between Decimal and Hexadecimal Numbering Systems

Appendix

Decimal Numbering System (1)

- Before learning **Hexadecimal Numbering System**, let's re-visit the **Decimal Numbering System** that you are very familiar with.
- Decimal Numbering System is a base-10 system.
- Base-10 system uses 0 to 9.

Decimal Numbering System			
$x10^3$ = 1000	$x10^2$ = 100	$x10^1$ = 10	$x10^0$ = 1
0	0	0	0
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9

Appendix

Decimal Numbering System (2)

- Example: 365 = $(3x10^2)+ (6x10^1) + (5x10^0)$

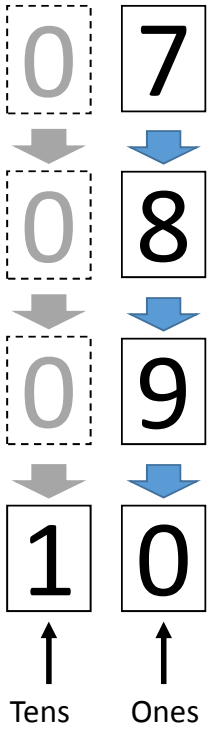
  = 300 + 60 + 5

Decimal Numbering System		
$x10^2$ = 100	$x10^1$ = 10	$X10^0$ = 1
0	0	0
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9

Appendix

Decimal Numbering System (3)

- When we count from 0 to 9, we have 0, 1, 2, 3, …, 7, 8, 9.
- After counting to "9", we all know that the next number is "10".
- But, why should the number after "9" be "10"? (We take things for granted…)
- Answer:
  - Since "9" is the maximum digit in base-10 system, to go beyond "9", we will roll back to "0", and +1 to the digit with next higher power (i.e. tens).



Appendix

Hexadecimal Numbering System (1)

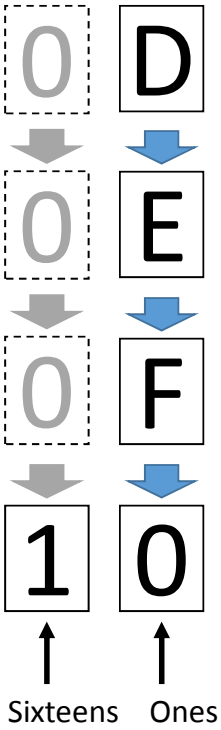
- Hexadecimal is a base-16 system.
- Base-16 Numbering System uses the numbers 0 to 9 and the letters A to F (to represent 10 to 15).
- Counting from 0 to F, we have 0, 1, 2, …, 8, 9, A, B, C, D, E, F.
- After "F", the next number is "10_{16}".

Hexadecimal Numbering System			
$x16^3$ = 4096	$x16^2$ = 256	$x16^1$ = 16	$x16^0$ = 1
0	0	0	0
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
A	A	A	A (10_{10})
B	B	B	B (11_{10})
C	C	C	C (12_{10})
D	D	D	D (13_{10})
E	E	E	E (14_{10})
F	F	F	F (15_{10})

Appendix

Hexadecimal Numbering System (2)

- After counting to "F", the next number is "10_{16}" (pronounced as "*hex one zero*", not "*ten*").
- But, why "10_{16}"?
- Answer:
  - Since "F" is the maximum digit in base-16 system, to go beyond "F", we will roll back to "0", and +1 to the digit with next higher power (i.e. Sixteens).



Appendix

Hexadecimal Numbering System (3)

- To show that 10_{16} ("one zero in hexadecimal") indeed equals to 16_{10} ("sixteen in decimal"), consider the comparison below:

Decimal:
(1x10)+(6x1)
= 16

Decimal Numbering System	
$x10^1 = 10$	$X10^0 = 1$
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9

Hexadecimal:
(1x16)+(0x1)
= 16

Hexadecimal Numbering System	
$x16^1 = 16$	$X16^0 = 1$
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
A	A
B	B
C	C
D	D
E	E
F	F

Same, therefore
$16_{10} = 10_{16}$

Appendix

Exercise: Hexadecimal to Decimal Conversion

- Express 52_{16} in decimal numbering system.
- Answer:
  - $52_{16} = (5x16) + (2x1) = 80 + 2 = 82_{10}$

- Express FB_{16} in decimal numbering system. Hint: F=15, B=11.
- Answer:
  - $FB_{16} = (15x16) + (11x1) = 240 + 11 = 251_{10}$

- Express $CAFE_{16}$ in decimal numbering system.
- Answer:
  - $CAFE_{16} = (13x4096) + (10x256) + (15x16) + (14x1)$
    $= 53248 + 2560 + 240 + 14 = 56062_{10}$

Appendix

Decimal to Hexadecimal Conversion

- It is possible to directly convert decimal to hexadecimal.
  - See YouTube video at https://www.youtube.com/watch?v=QgVc1Tl-JDA
- You may also convert a decimal number into binary, and then hexadecimal:
  1. Convert decimal number to binary number.
  2. Segment the binary number (long string of '1's and '0's) into groups of 4 bits (called "nibble").
  3. Convert each nibble into a single hexadecimal digit.

Appendix

Exercise: Decimal to Hexadecimal Conversion

- Express 37_{10} in hexadecimal numbering system.
- Answer:
  - 37_{10} = 100101
  - 100101 = 0010 0101 (add two '0's in front to form groups of 4 bits)
  - 0010 = 2 and 0101 = 5.
  - Therefore $37_{10} = 25_{16}$.
- Express 200_{10} in hexadecimal numbering system.
- Answer: $C8_{16}$ (Since 200 = 1100 1000)
- Express 583_{10} in hexadecimal numbering system.
- Answer: 247_{16} (Since 583 = 10 0100 0111)

Appendix

Hexadecimal Numbering System (4)

- It is quite clumsy to express hexadecimal numbers in the format involving subscript style, for example, 2001_{16}.
  - Typewriters (if you know what they are and how to operate them) certainly find it very clumsy to produce the text '16' with subscript effect.
  - Even modern word processing finds it tedious.
- More often, we use **0x**2001 to represent 2001_{16}. The **0x** in front of the digits indicates that this is a hexadecimal number, not 2001_{10}.