CS120: Computer Networks

Lecture 21. Data Presentation

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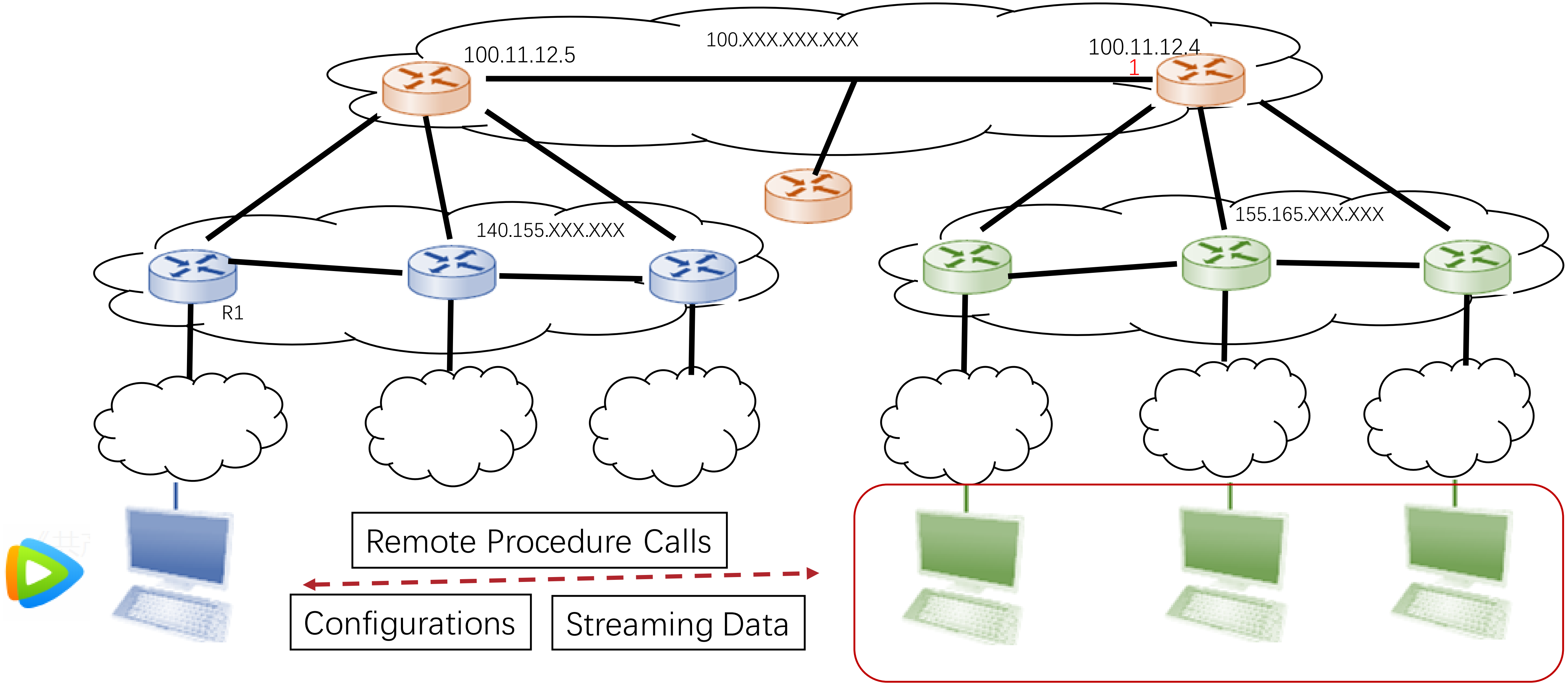
Slides adopted from Zhice Yang

Data in End-to-End Connections

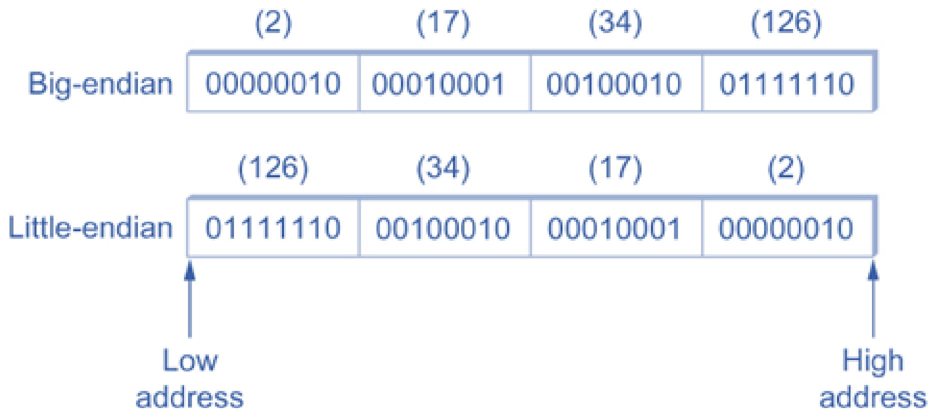


Data in End-to-End Connections

- Presentation Formatting
- Data Compression
  - Lossless Compression
  - Multimedia Compression

Presentation Formatting

- Challenges
  - Different Host Architecture: 16bit, 32bit, 64bit
    - eg. long
  - Different Compilers
    - Different layout/padding of structures
    - eg. struct BitField { unsigned char : 2; unsigned int : 2; }
  - Different base type representation
    - eg. X-endian for 34,677,374.
    - 0000 0010 0001 0001 0010 0010 0111 1110



Presentation Formatting

- Solution
  - Marshalling (encoding) application data into messages
  - Unmarshalling (decoding) messages into application data

Presentation Formatting

- Solution
  - Conversion Strategy
    - Canonical intermediate form
    - Receiver-makes-right
  - Base types (e.g., ints, floats) => Convert
  - Flat types (e.g., structures, arrays) => Pack to base types
  - Complex types (e.g., pointers) => Serialization

Presentation Formatting: Examples

- eXternal Data Representation (XDR)
  - Used in SunRPC
  - Canonical intermediate form
  - Defined in RFC1014
    - C-type
    - big-endian
    - Step in 4-bytes
    - etc.

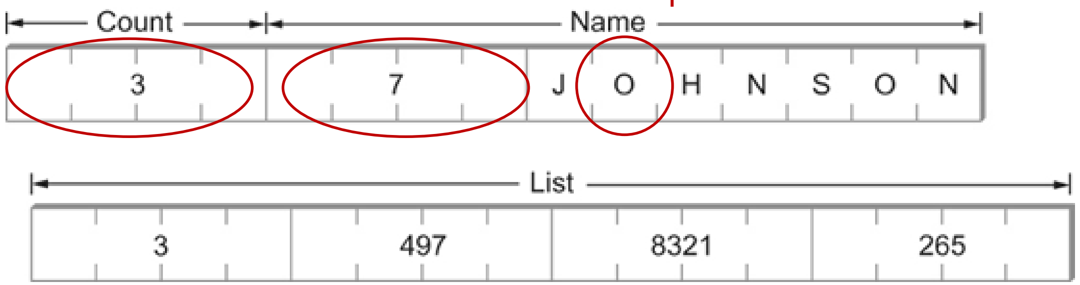
Presentation Formatting: Examples

- eXternal Data Representation (XDR) Steps:
  - Define bytes to be serialized in struct
  - Compile in client and server
  - Stub helps to encode and decode

```
#define MAXNAME 256;
#define MAXLIST 100;
struct item {
 int count;
 char name[MAXNAME];
 int list[MAXLIST];
};
```

Size of each element is a multiple of 4 bytes

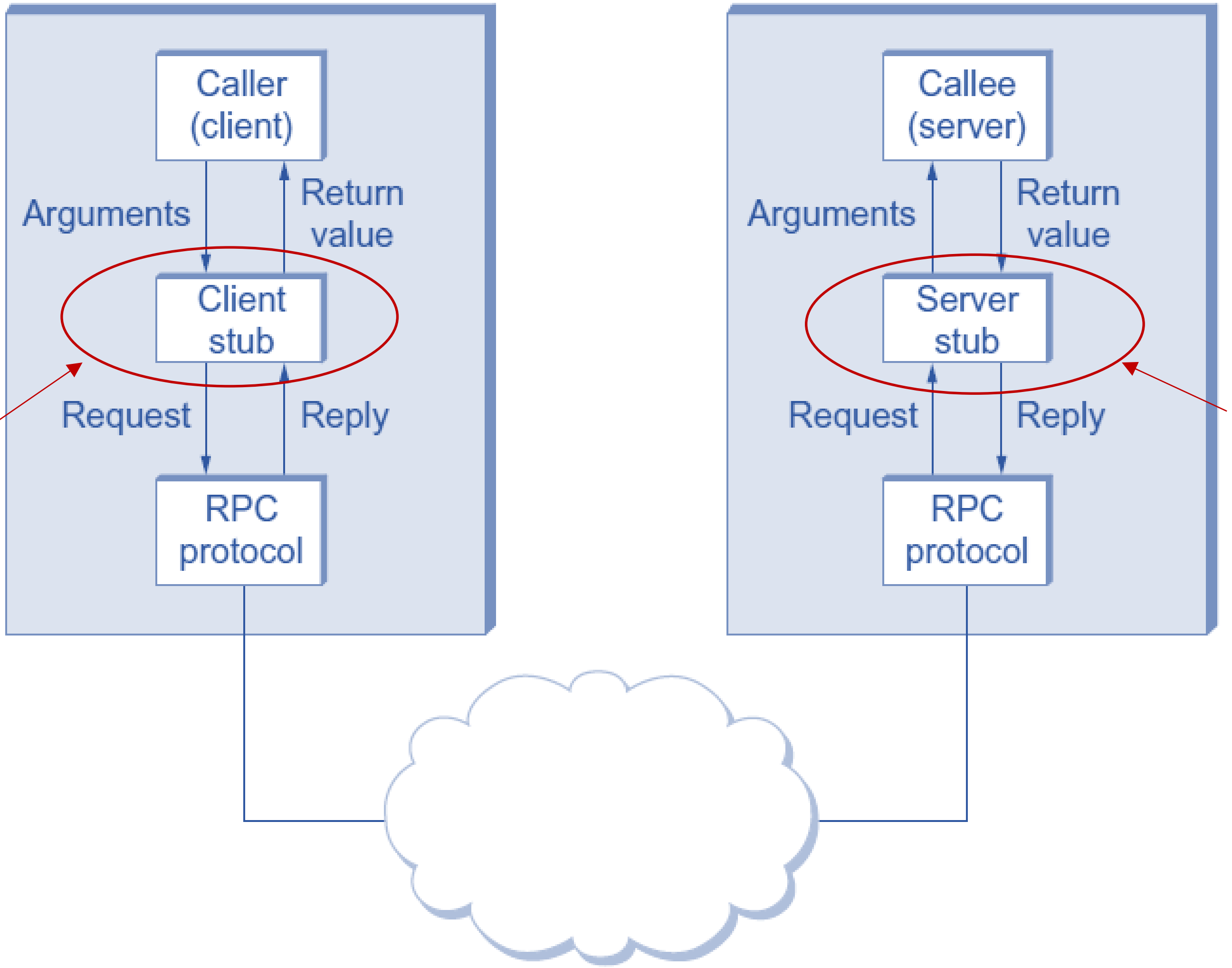
Except chars



RPC Mechanism

Stub is like a proxy to translates procedure calls between network transmissions

Marshals parameters and calls the server

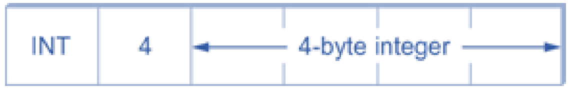


Unmarshals parameters and calls the local function

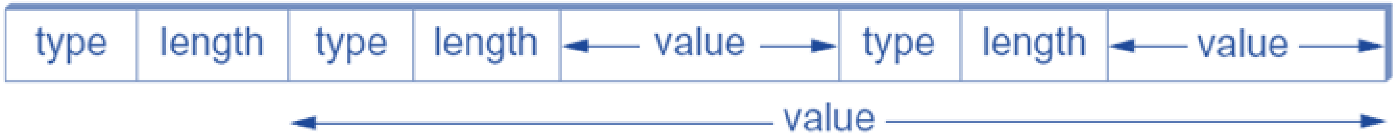
Presentation Formatting: Examples

- Abstract Syntax Notation One (ASN.1)
  - ISO Standard, used in SNMP
  - Canonical intermediate form
  - Based on tag: <tag, length, value>
  - Format can be interpreted, but of low efficiency
    - Overhead: marshaling processing, byte boundary, additional space for length, etc.

Integer:



Compound types:

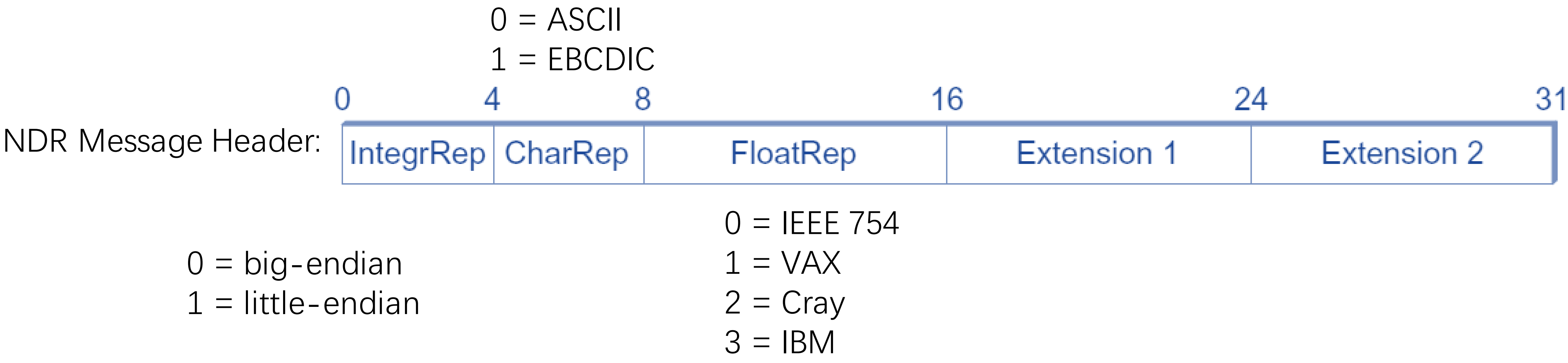


Length Field for >127:

Length Field for <= 127:

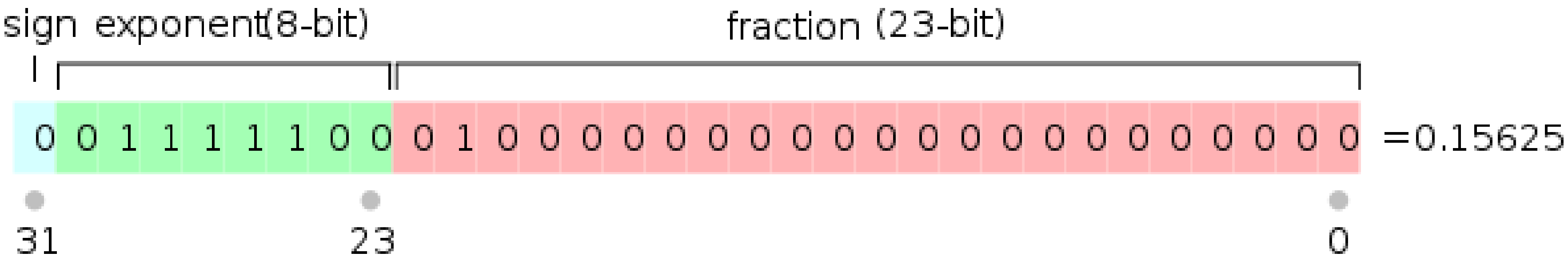
Presentation Formatting: Examples

- Network Data Representation (NDR)
  - Used in DCE
  - Receiver-makes-right
  - Architecture tag at the front of each message

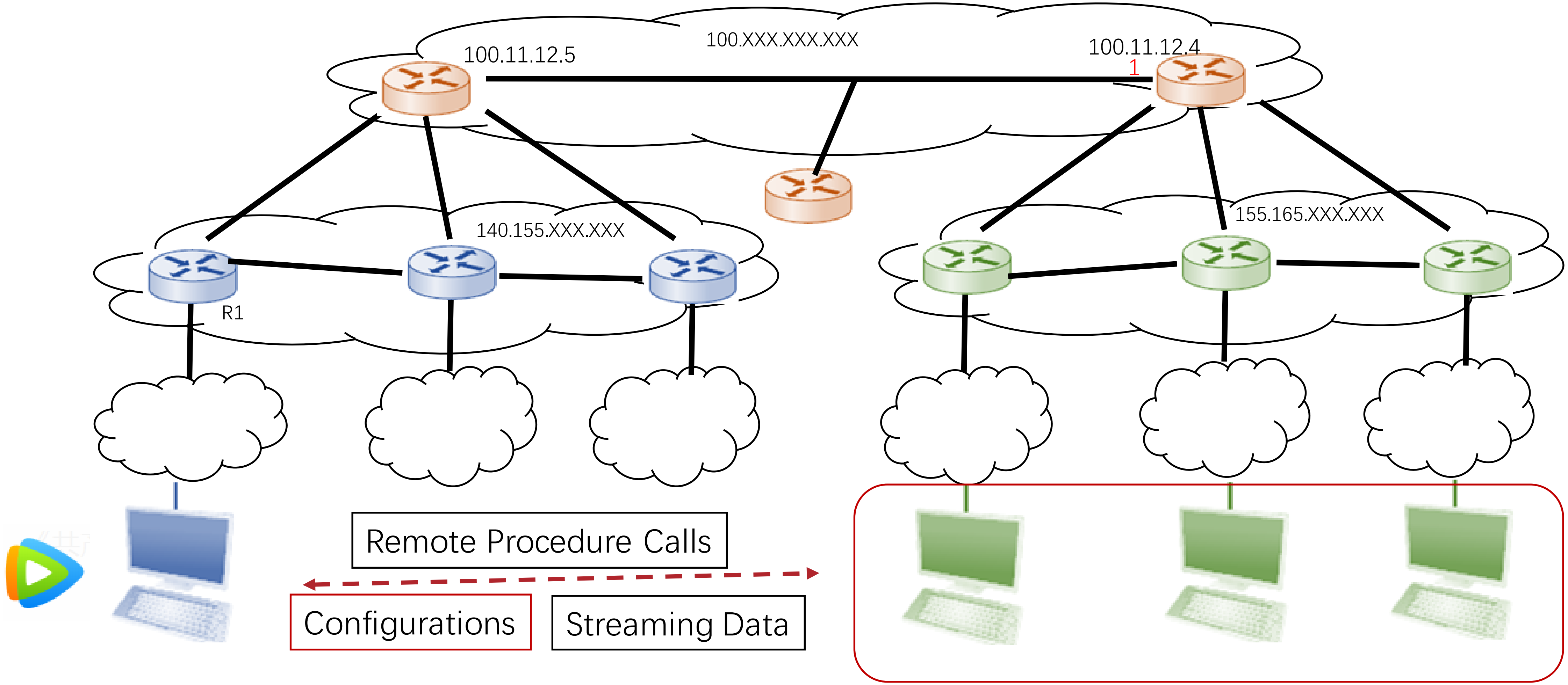


IEEE 754

- https://www.h-schmidt.net/FloatConverter/IEEE754.html



Data in End-to-End Connections



Markup Languages

- Examples: XML and HTML
- Approach
  - Data is represented as text
    - Readable for human
    - Can reuse XML parsers
  - Text tags (markup) are used to express information about the data.

```xml
<?xml version="1.0"?>
<employee>
        <name>John Doe</name>
        <title>Head Bottle Washer</title>
        <id>123456789</id>
        <hiredate>
                <day>5</day>
                <month>June</month>
                <year>1986</year>
        </hiredate>
</employee>
```

Markup

Nested structure

Extensible Markup Language (XML)

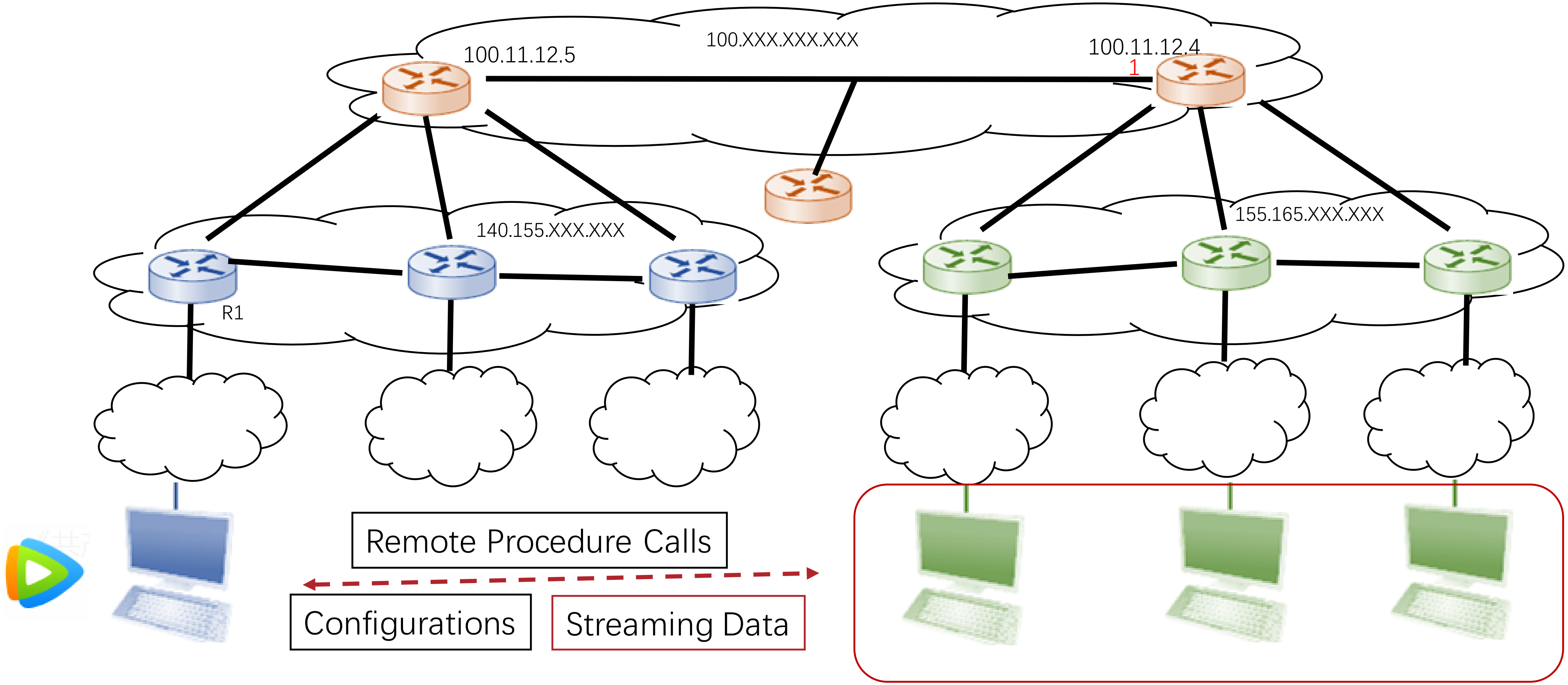
- XML Schema
  - Define XML

```
<?xml version="1.0"?>
<schema xmlns="http://www.w3.org/2001/XMLSchema">
   <element name="employee">
       <complexType>
           <sequence>
              <element name="name" type="string"/>
              <element name="title" type="string"/>
              <element name="id" type="string"/>
                 <element name="hiredate">
                    <complexType>
                        <sequence>
                           <element name="day" type="integer"/>
                           <element name="month" type="string"/>
                           <element name="year" type="integer"/>
                        </sequence>
…
```

Extensible Markup Language (XML)

- XML Namespace
  - Use Uniform Resource Identifier (URL) to identify a unique namespace
  - Define an XML namespace
    - `xmlns:emp="http://www.example.com/employee">`
  - Identifier with namespace
    - `<emp:title>Head Bottle Washer</emp:title>`

Data in End-to-End Connections



Traffic of a Full Size Video Stream

- Resolution: 1920*1080
- Framerate: 30fps
- Color per pixel: 3
- Color depth: 8 bits
- Required Throughput: 1920*1080*3*8*30 bps = 1.5Gbps

Data in End-to-End Connections

- Data Presentation

➢ Data Compression
  - Lossless Compression
  - Multimedia Compression

gzip

- GNU zip
- A widely-used lossless compression method
- Main Algorithms
  - LZ Algorithm
  - Huffman Coding

Run Length Encoding

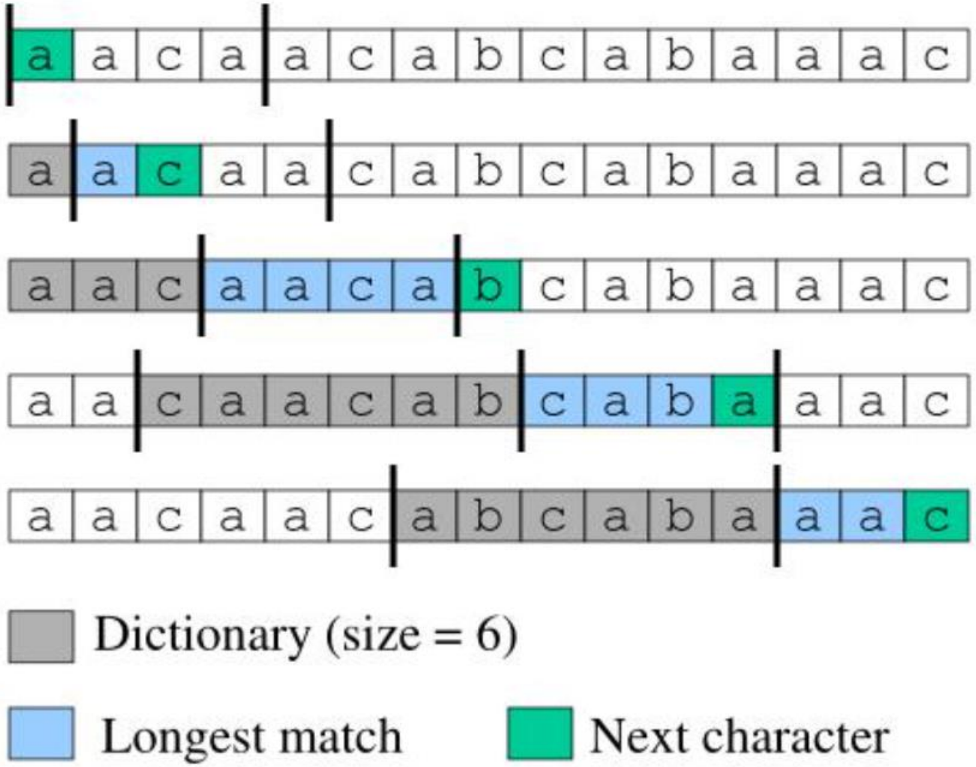
- Basic idea:
  - Replace consecutive occurrences of a given symbol with only one copy of the symbol
  - Plus a count of how many times that symbol occurs
  - eg.: AAABBCDDDD => 3A2B1C4D

LZ Algorithm

- Dictionary-Based Compression
- Method
  - Construct dictionary: find repeated strings
  - Repeated strings are represented by its index in dictionary
    - eg. Repeated strings are simplified to <distance, length> pair
      - blah blah b! => blah [D=5, L=6]!

LZ77

- Encoding



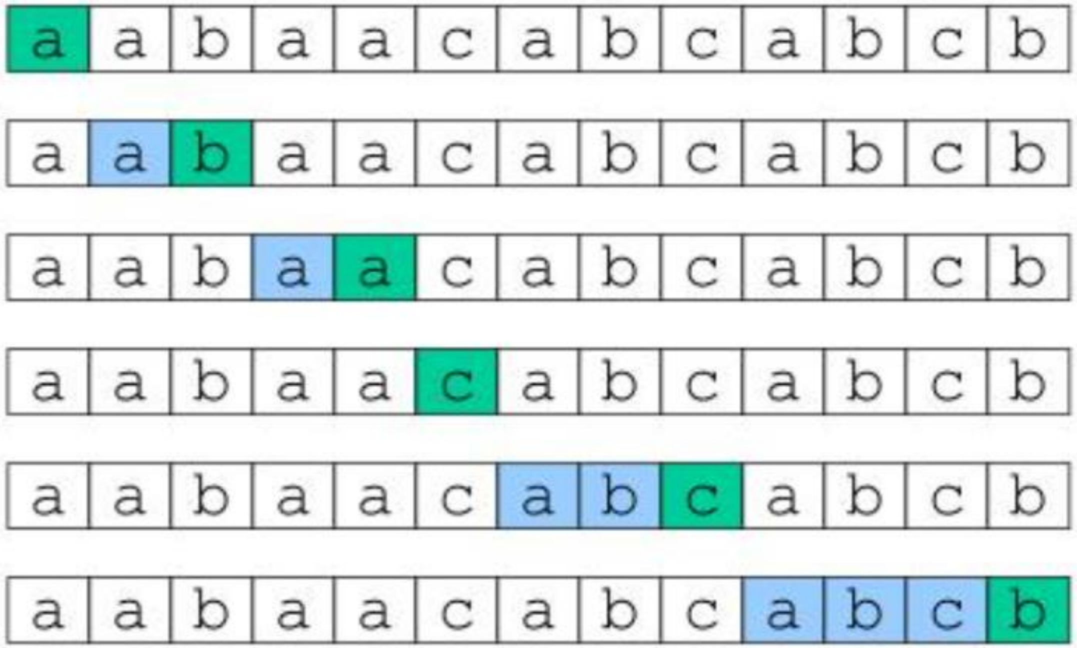
Output

(0,0,a)
(1,1,c)
(3,4,b)
(3,3,a)
(1,2,c)

https://www.slideserve.com/shalin/data-compression

LZ78

- Encoding



Output

Output	Dict.
(0,a)	1 = a
(1,b)	2 = ab
(1,a)	3 = aa
(0,c)	4 = c
(2,c)	5 = abc
(5,b)	6 = abcb

https://www.slideserve.com/shalin/data-compression

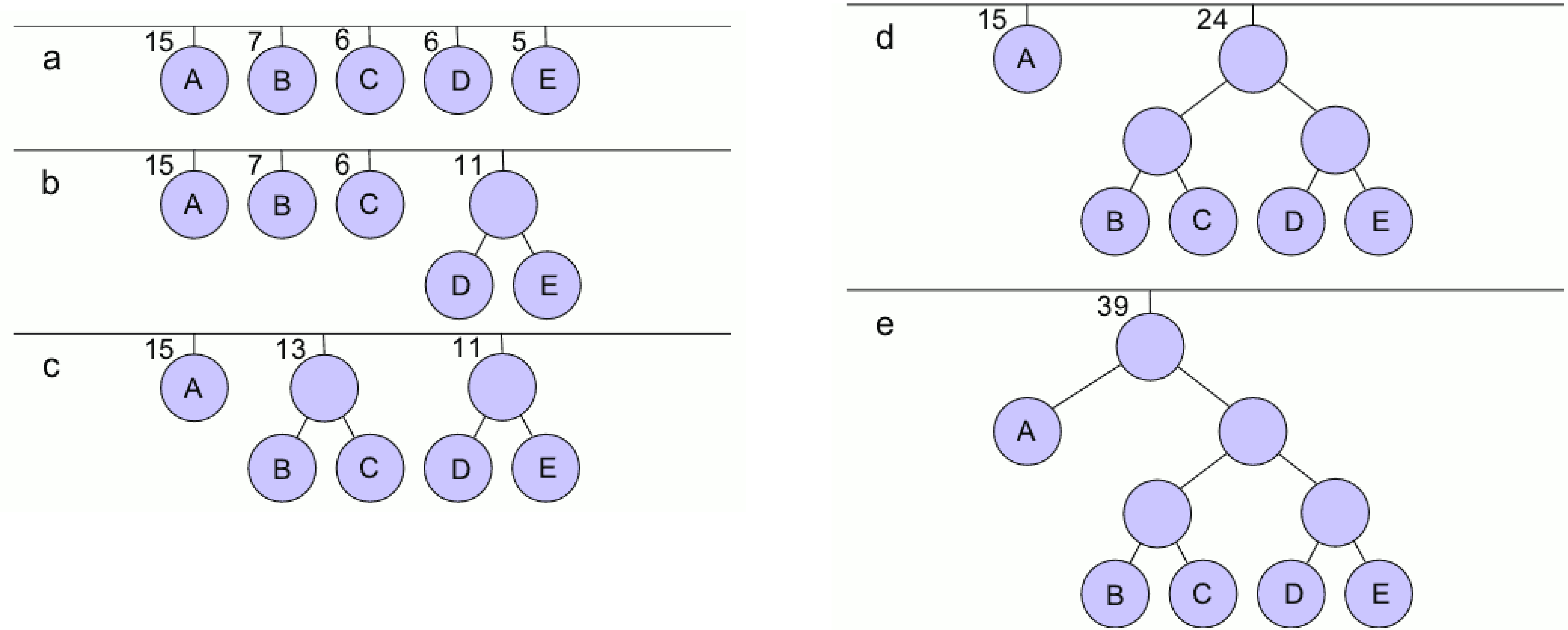
Huffman Coding

- Intuition: Higher frequency characters => less bit to representation
- A:90%, B:5%, C:5%
  - A: 1
  - B: 01
  - C: 00

Huffman Coding

- Create a leaf node for each symbol and add it to the priority queue.
- While there is more than one node in the queue:
  - Remove the two nodes of highest priority (lowest probability) from the queue
  - Create a new internal node with these two nodes as children and with probability equal to the sum of the two nodes' probabilities.
  - Add the new node to the queue.
- The remaining node is the root node and the tree is complete.

Huffman Coding



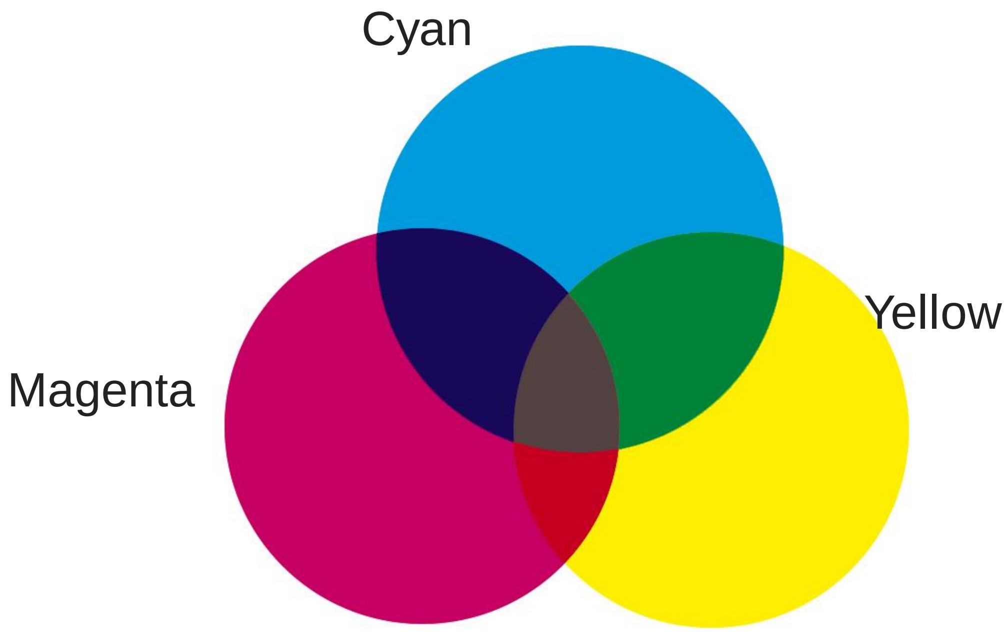
ref: https://en.wikipedia.org/wiki/Huffman_coding

End-to-End Data

- Data Presentation
- Data Compression
  - Lossless Compression
  - ➢ Multimedia Compression

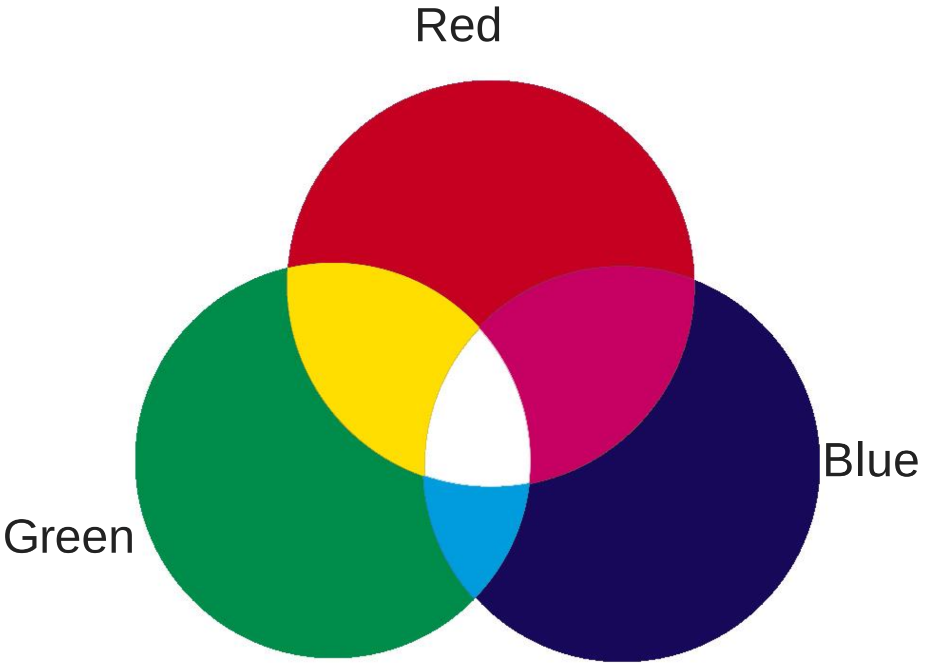
Color and Display

- Color Model



Subtractive color (CMYK)

for printing

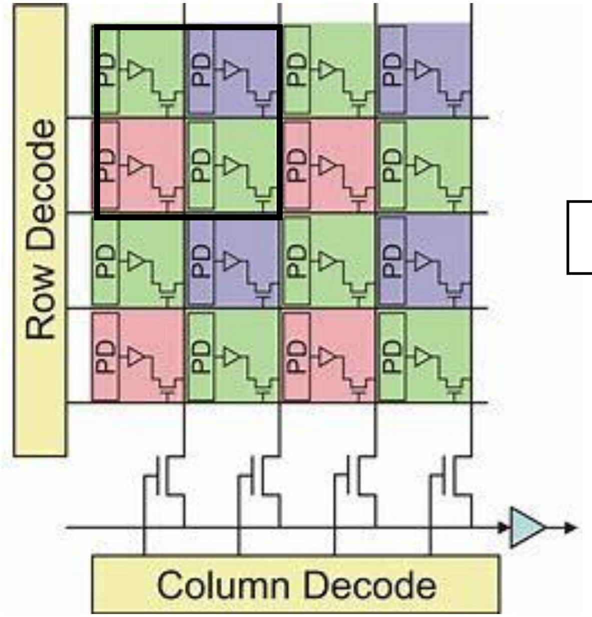


Additive Color (RGB)

for display

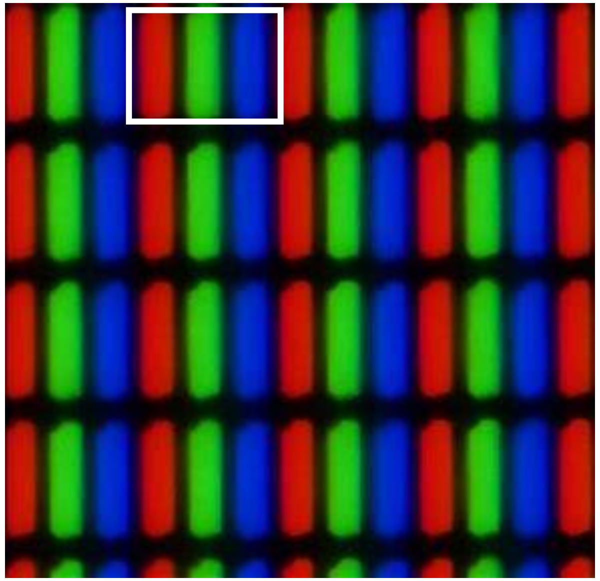
Color and Display

- Imaging and Display



RGBs

RGBs



CMOS

Display

Color and Display

- Digital Image

$$= \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{pmatrix}_{n \times m}$$

Size = 1080*1920*8*3 = 50Mb !

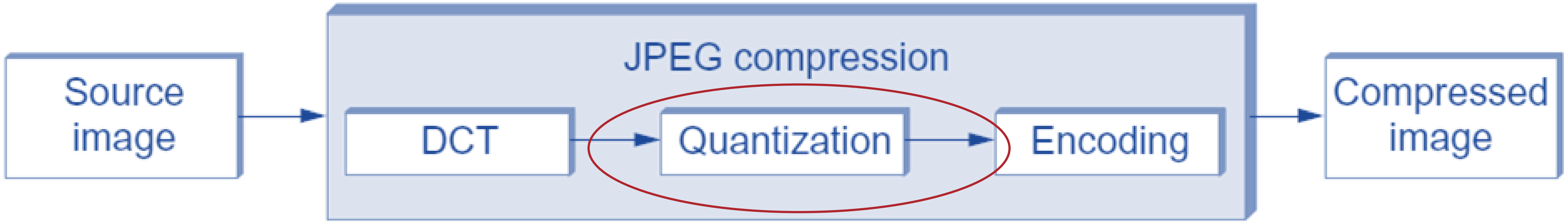
GIF – Image Compression

- Filename Extension: `.gif`
- Simple Lossy Compression
- 3*8 bit => 256 colors

JPEG – Image Compression

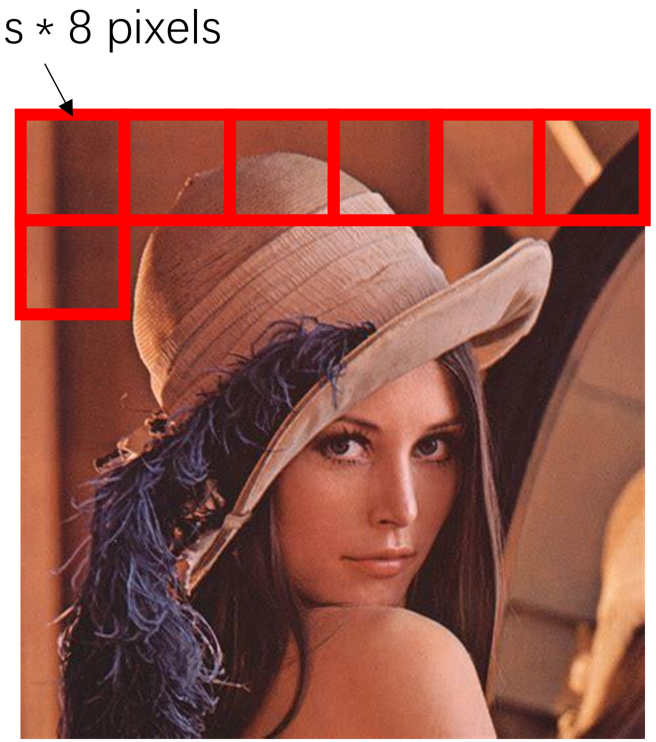
- Filename Extension: `.jpg, .jpeg`
- Joint Photographic Experts Group
- Intuition
  - Human eyes are sensitive to intensity changes, but less sensitive to chromatic changes
  - Human eyes are sensitive to low frequency changes, but less sensitive to high frequency changes

JPEG Compression Flow



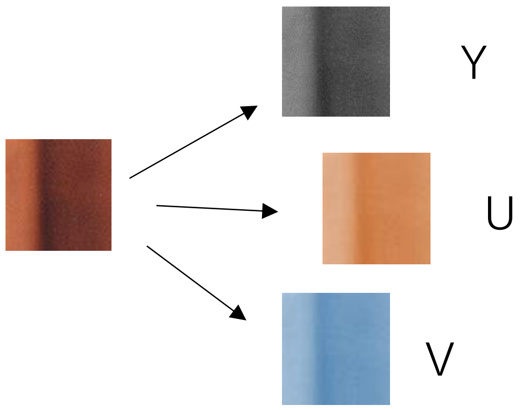
Information Loss

JPEG Compression: Splitting



JPEG Compression: RGB -> YUV

- YUV Space
  - Y -> luminance
    - Sensitive
  - U, V -> chrominance



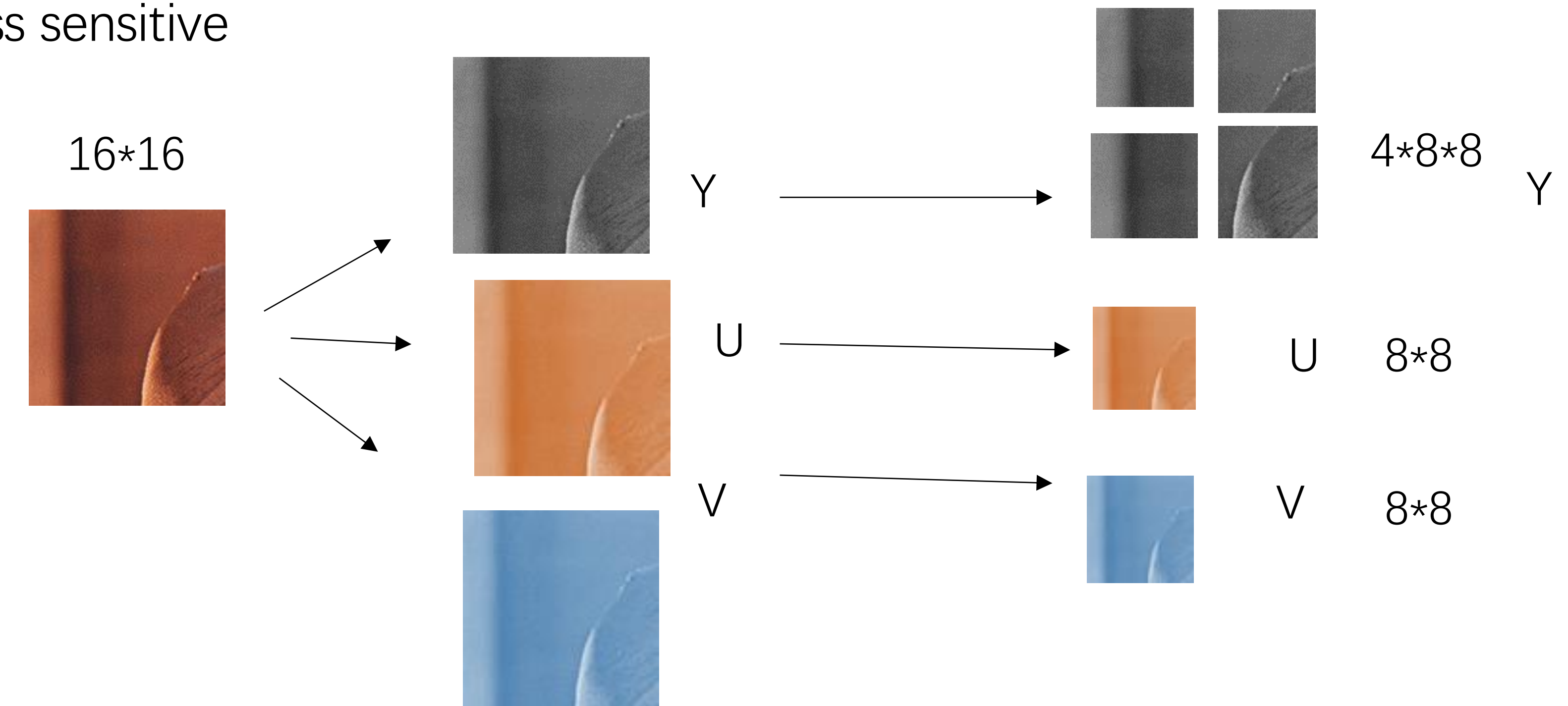
$$Y = 0.299R + 0.587G + 0.114B$$

$$U = (B - Y) \times 0.565$$

$$V = (R - Y) \times 0.713$$

JPEG Compression: Subsampling UV

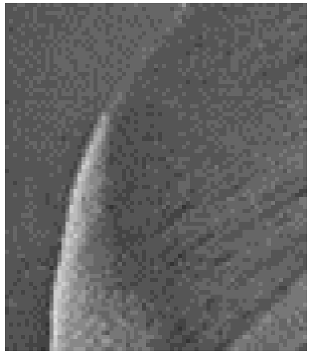
- YUV Space
  - Y -> luminance
    - Sensitive
  - U, V -> chrominance
    - Less sensitive

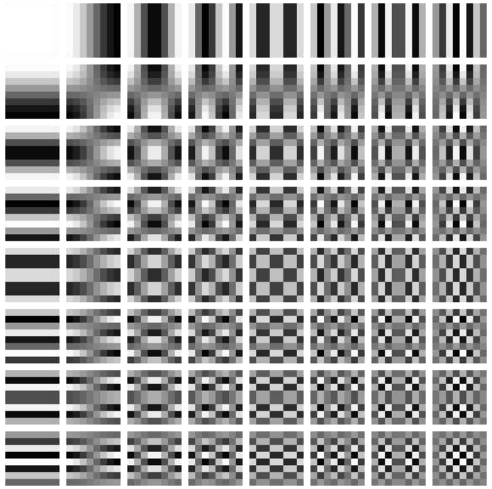


JPEG Compression: DCT

Discrete Cosine Transform: convert an 8x8 block into a bunch of 8x8 cosine waves.

Low frequency



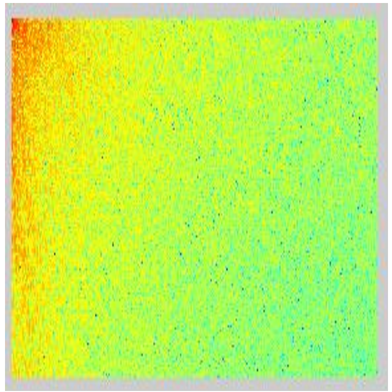


$$
\begin{bmatrix}
-415 & -33 & -58 & 35 & 58 & -51 & -15 & -12 \\
5 & -34 & 49 & 18 & 27 & 1 & -5 & 3 \\
-46 & 14 & 80 & -35 & -50 & 19 & 7 & -18 \\
-53 & 21 & 34 & -20 & 2 & 34 & 36 & 12 \\
9 & -2 & 9 & -5 & -32 & -15 & 45 & 37 \\
-8 & 15 & -16 & 7 & -8 & 11 & 4 & 7 \\
19 & -28 & -2 & -26 & -2 & 7 & -44 & -21 \\
18 & 25 & -12 & -44 & 35 & 48 & -37 & -3
\end{bmatrix}
$$

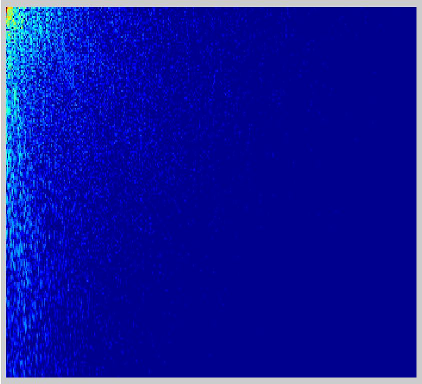
High frequency

ref: https://yasoob.me/posts/understanding-and-writing-jpeg-decoder-in-python/

JPEG Compression: Quantization



Round (DCT(i,j)/Quantum(i,j))



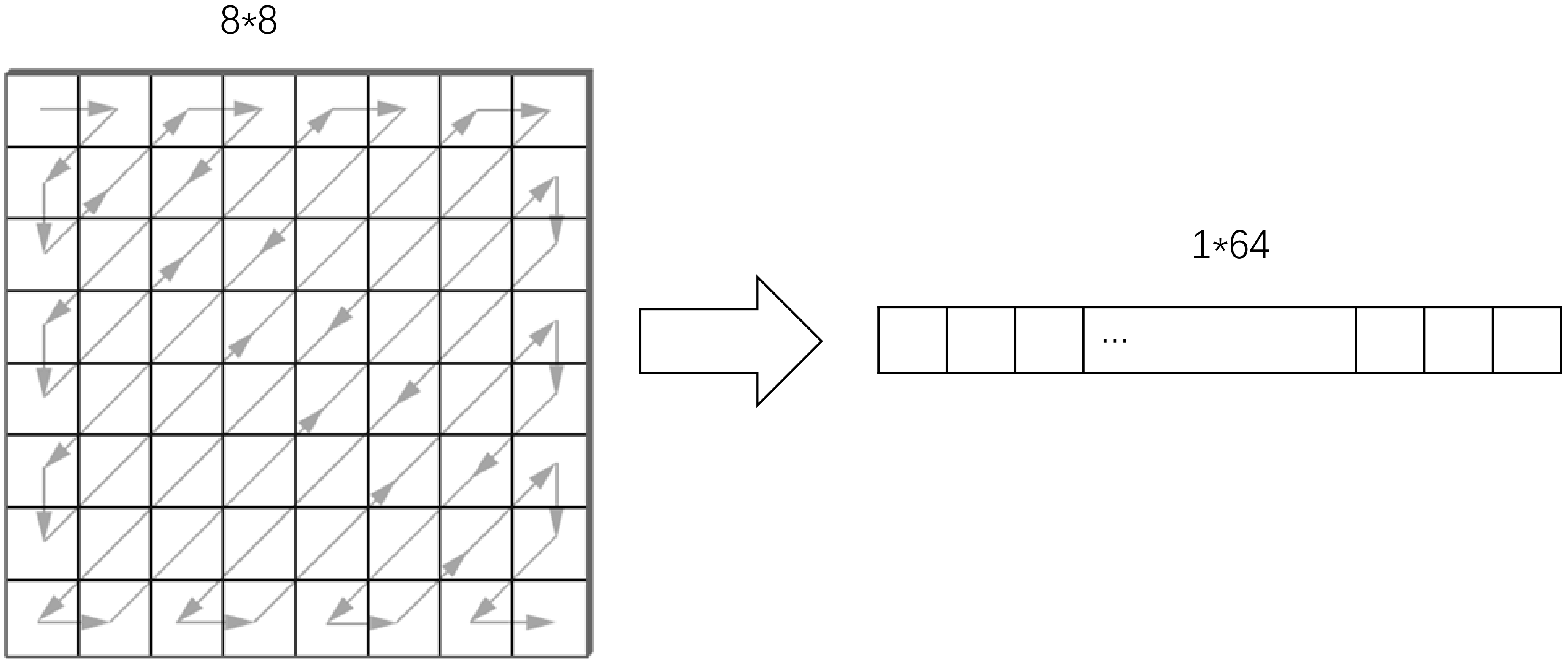
$$\text{Quantum} = \begin{bmatrix} 3 & 5 & 7 & 9 & 11 & 13 & 15 & 17 \\ 5 & 7 & 9 & 11 & 13 & 15 & 17 & 19 \\ 7 & 9 & 11 & 13 & 15 & 17 & 19 & 21 \\ 9 & 11 & 13 & 15 & 17 & 19 & 21 & 23 \\ 11 & 13 & 15 & 17 & 19 & 21 & 23 & 25 \\ 13 & 15 & 17 & 19 & 21 & 23 & 25 & 27 \\ 15 & 17 & 19 & 21 & 23 & 25 & 27 & 29 \\ 17 & 19 & 21 & 23 & 25 & 27 & 29 & 31 \end{bmatrix}$$

Determine the How Much Information is dropped

JPEG Compression: Quantization

- Quantization is a lossy process
  - Recovered DCT(i,j) = QuantizedValue(i,j)*Quantum(i,j)
  - Rounding in Quantization is lossy

JPEG Compression: Zig-Zag



JPEG Compression: DC Component

- DC Components are large and normally non-zero
- Nearby DC Components are closed

➢Differential Pulse Code Modulation (DPCM)

  - 14, 12, 13, 12, 15 => 14, -2, 1, -1, 3

1	14			…				
2	12			…				
3	13			…				
4	12			…				
	…			…				

JPEG Compression: DC Component

- DC Component can be expressed in integer
  - eg. in one's complement
    - 3 => 0011
    - -3 => 1100
    - 4 => 0100
    - -4 => 1011
- Problem
  - If expressing integer in fix-length bits
    - padding zeros waste space
  - If expressing integer in dynamic length bits
    - how to split the bit stream ?

JPEG Compression

- DC Component can be expressed as (size, amplitude)
  - Size: number of bits to express amplitude
  - Amplitude: DPCM value in ones complement
  - Examples:
    - 0 => (0,-)
    - 1 => (1,1)
    - -1 => (1,0) bitwise inverse for negative value
    - 2 => (2, 10)
    - -2 => (2, 01)
    - 3 => (2,11)
    - -3 => (2,00)

JPEG Compression: Huffman Coding

- DC Component can be expressed as (size, amplitude)
  - Size: number of bits to express amplitude, Huffman coded
    - The coding table is included in the JPEG file
  - Amplitude: DPCM value in ones complement
  - Examples:
    - 0 => (0,-) => 0
    - 1 => (1,1) => 101 1
    - -1 => (1,0) => 101 0
    - 2 => (2, 10) => 011 10
    - -2 => (2, 01) => 011 01
    - 3 => (2,11) => 011 11
    - -3 => (2,00) => 011 00

Length	Code	Size
3 bits	000 001 010 011 100 101 110	04 05 03 02 06 01 00 (End of Block)
4 bits	1110	07
5 bits	1111 0	08
6 bits	1111 10	09
7 bits	1111 110	0A
8 bits	1111 1110	0B

table ref: https://www.impulseadventure.com/photo/jpeg-huffman-coding.html

JPEG Compression: AC Component

- AC Components are small and normally zero

➢ Run Length Encoding (RLE)

  - 000002000010000210000 => (5,2)(4,1)(4,2)(0,1)(0,0)

JPEG Problem

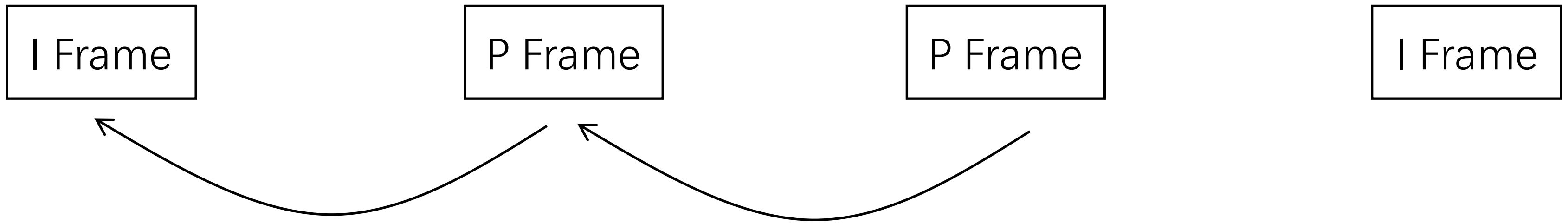
- Compression Granularity is in Unit of 8*8

MPEG – Video Compression

- Filename Extension: MPEG-4 `.mp4`
- Moving Pictures Experts Group
- Intuition
  - Adjacent frames are similar and changes are due to foreground motion

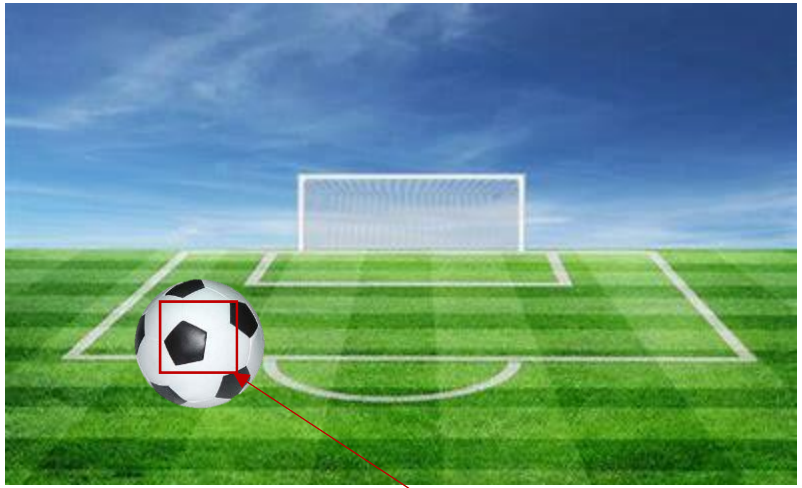
MPEG Compression: I Frame and P Frame

- I (intra) Frame
  - Independent frames
  - Coded without reference to other frames (JPEC Compressed)
- P (predictive) Frame
  - Not Independent frames
  - Predicted from a past frame (I or P)



Forward prediction

MPEG Compression: Forward Prediction



current motion vector

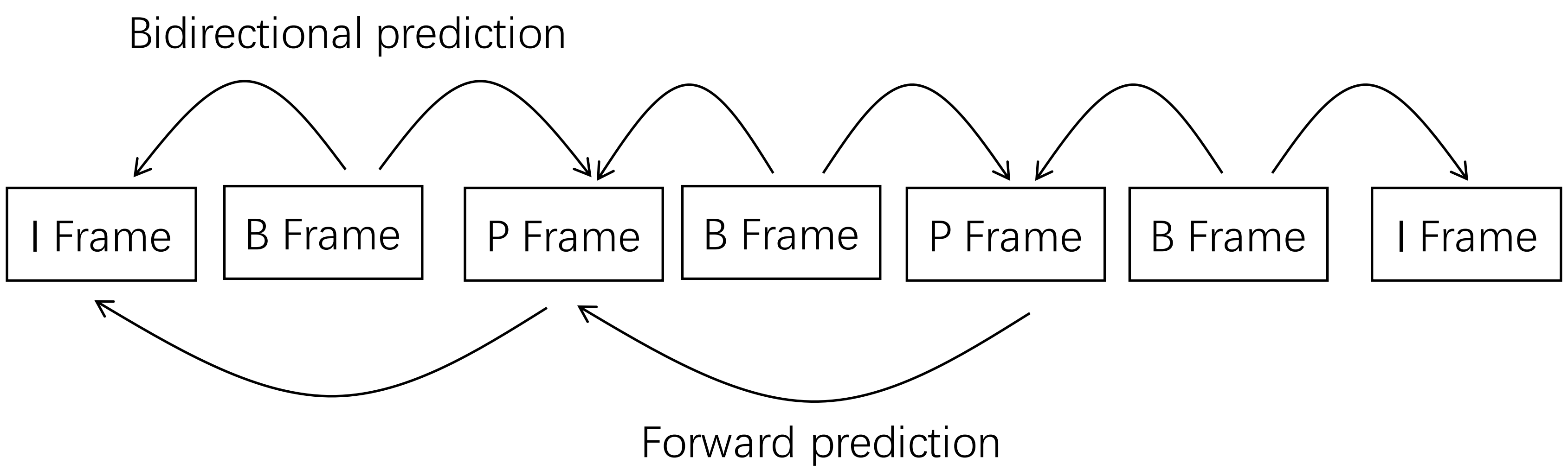
past location vector

16*16

Difference is encoded similar to JPEG

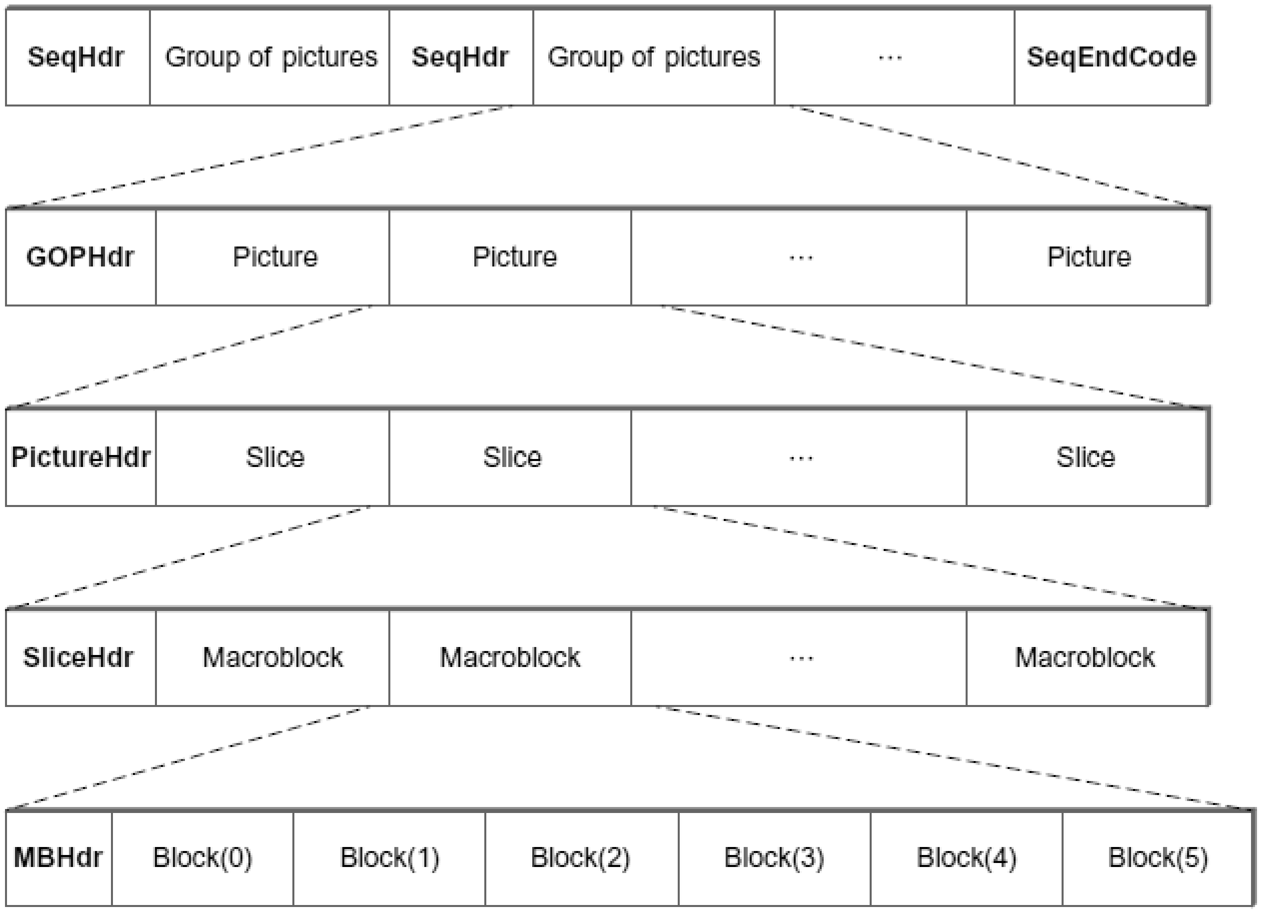
MPEG Compression: B Frame

- B (Bidirectional) Frame
  - Not independent frames
  - Reason: enhance forward prediction
    - The forward I frame might not contain similar information as the B frame
  - Coded with reference to both previous and future frames (I or P)



MPEG over a Network

- A Video Stream



MPEG over a Network

Delay transmitting B frame until the subsequent I or P frame is available.

- Target Seq: IBBBBPBBBBI
- Transmitting Seq: IPBBBBIBBBB
  - Large Delay
- For Interactive Videos
  - Only use I and P frames or pure I frames

MP3 – Audio Compression

- Filename Extension: `.mp3`
- A part of MPEG
  - MP3 is introduced in MPEG-1 to encode audio
- Intuition
  - Human ear are less sensitive to high frequency sound
  - Divide audio signal into subbands
  - Compressing subband by allocating different numbers of bits

Reference

- Textbook 7.1 7.2