Welcome

Summer School

Digital Tools for Humanists

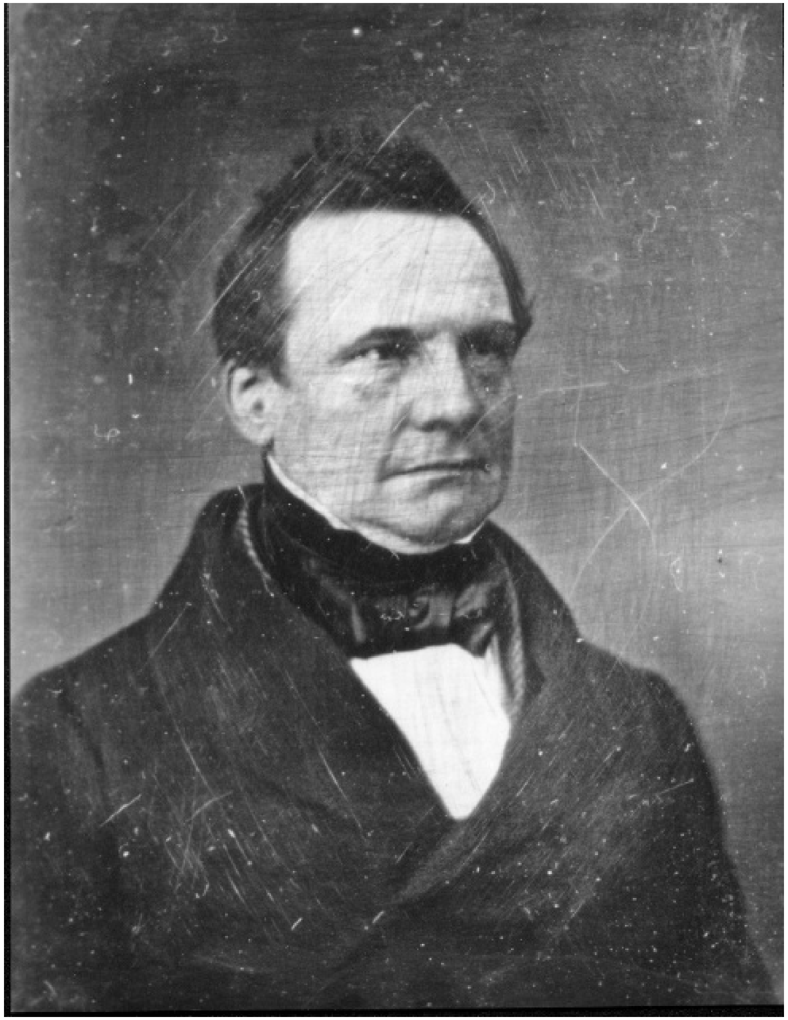
Pisa – June 16-27 2025

Refresher

Refresher on Computer Fundamentals and Networking

- History of computers
- Architecture of a computer
- Data representation within a computer
- Computer networks and the Internet
- The Semantic Web

Early visions



Charles Babbage
1791-1871

Professor of Mathematics, Cambridge University, 1827-1839

Babbage’s engines

- *Difference Engine* 1823
- *Analytic Engine* 1833
  - The forerunner of modern digital computer

Technology

- mechanical gears, Jacquard’s loom (1801), simple calculators

Programming

- Ada Lovelace

Application

- Mathematical Tables – Astronomy
- Nautical Tables – Navy

Use of punched paper tape

The organ grinder

Early experiments
100 years later

- Z1 machine (Konrad Zuse, , private entrepreneur, 1936-1941)
- ABC (Atanasoff-Berry Computer, Iowa State University, 1937-1942)
- Mark I (Howard Aiken, MIT, 1937-1941)

1942 Second World War

Harvard Mark I

- Built in 1944 in IBM Endicott laboratories
  - Howard Aiken – Professor of Physics at Harvard
  - Essentially mechanical but had some electro-magnetically controlled relays and gears
  - Weighed *5 tons* and had *750,000* components
  - A synchronizing clock that beat every *0.015* seconds (66KHz)

Performance:

0.3 seconds for addition
6 seconds for multiplication
1 minute for a sine calculation

WW-2 Effort

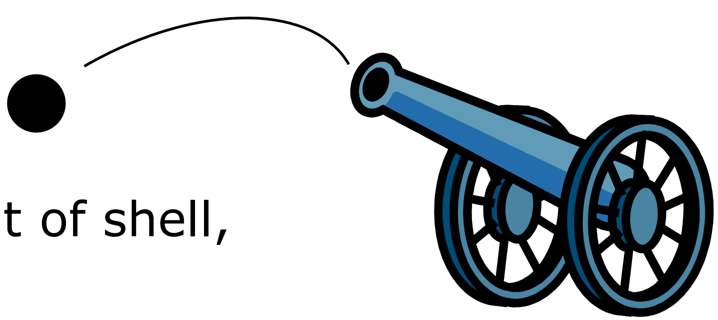
Broke down once a week!

ENIAC

- Inspired by Atanasoff and Berry, Eckert and Mauchly designed and built ENIAC (1943-45) at the University of Pennsylvania
- The first, completely electronic, operational, general-purpose analytical calculator!
  - 30 tons, 72 square meters, 200KW
- Performance
  - Read in 120 cards per minute
  - Addition took 200 μs, Division 6 ms
  - 1000 times faster than Mark I
- Not very reliable!

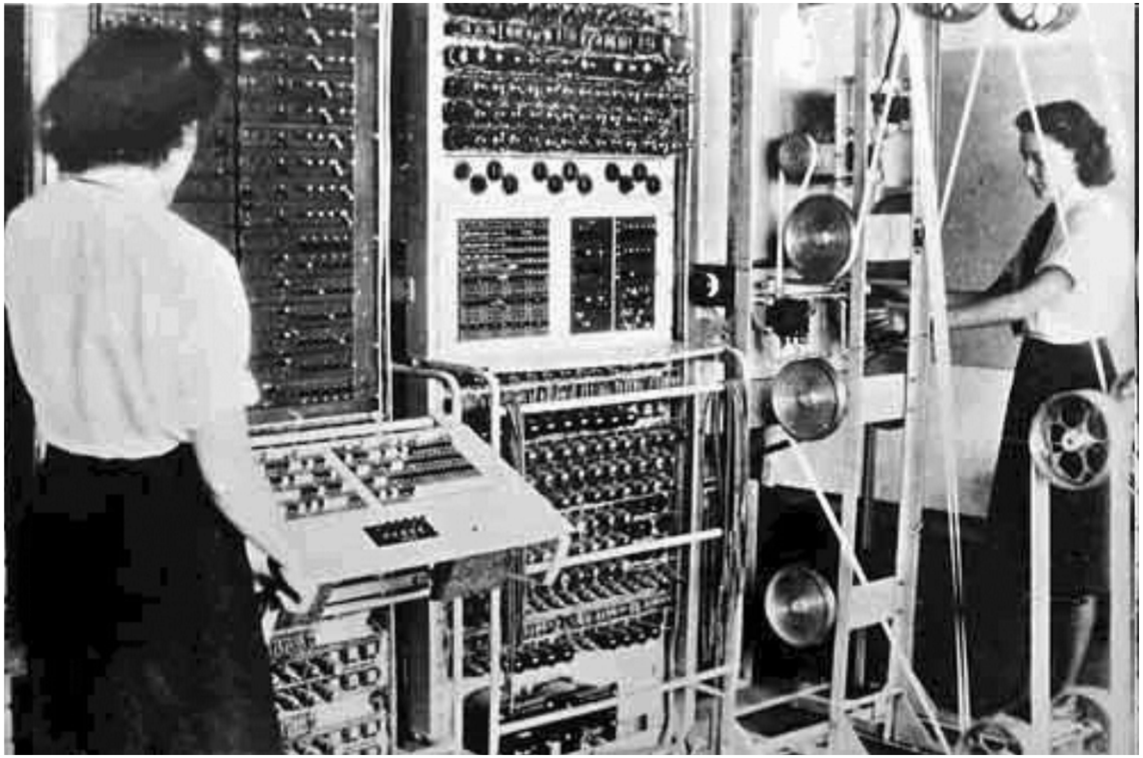
WW-2 Effort

Application: Ballistic calculations



angle = f (location, tail wind, cross wind,
air density, temperature, weight of shell,
propellant charge, ...)

Colossus



Colossus (derived in 1943 from Mark1 and Mark2) was used in London during the second World War to decipher encrypted German messages (Enigma machine)

EDVAC - Electronic Discrete Variable Automatic Computer

- ENIAC's programming system was external
  - Sequences of instructions were executed independently of the results of the calculation
  - Human intervention required to take instructions "out of order"
- Eckert, Mauchly, John von Neumann and others designed EDVAC (1944-1945) to solve this problem
  - Solution was the *stored program computer*

    ⇒ *"program can be manipulated as data"*
- *First Draft of a report on EDVAC* was published in 1945, but just had von Neumann's signature
- In 1973 the court of Minneapolis attributed the honor of *inventing the computer* to John Atanasoff

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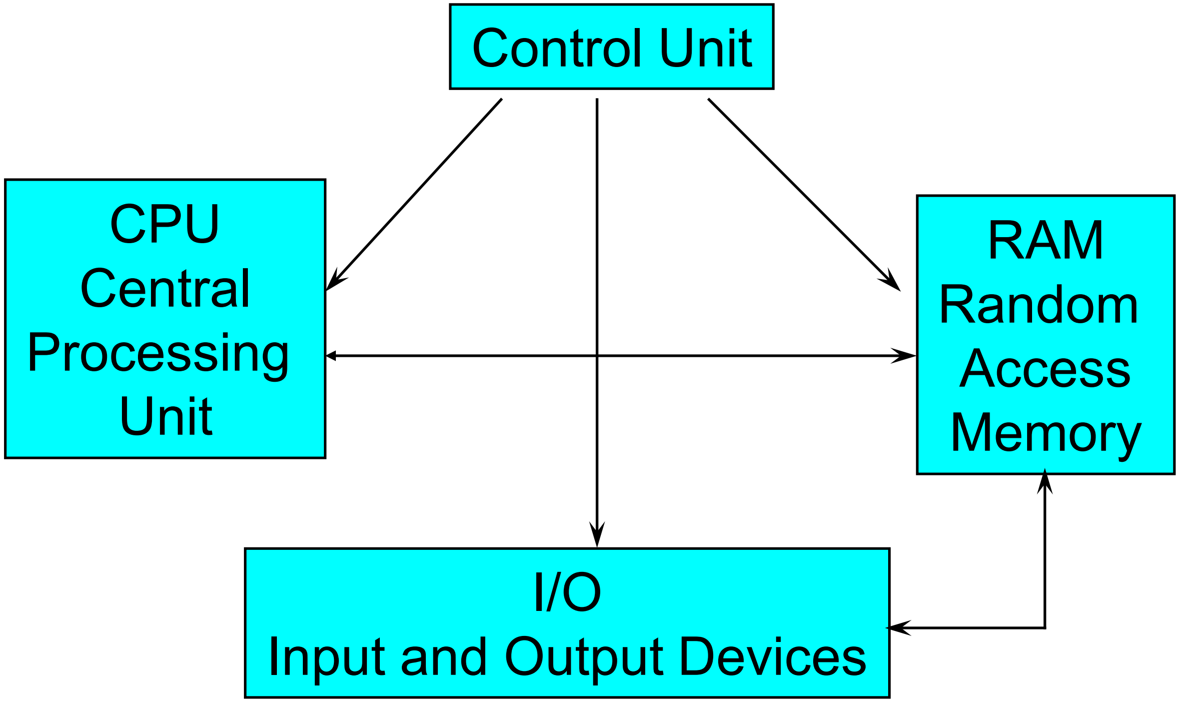
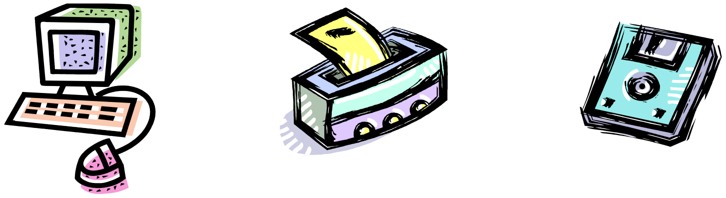
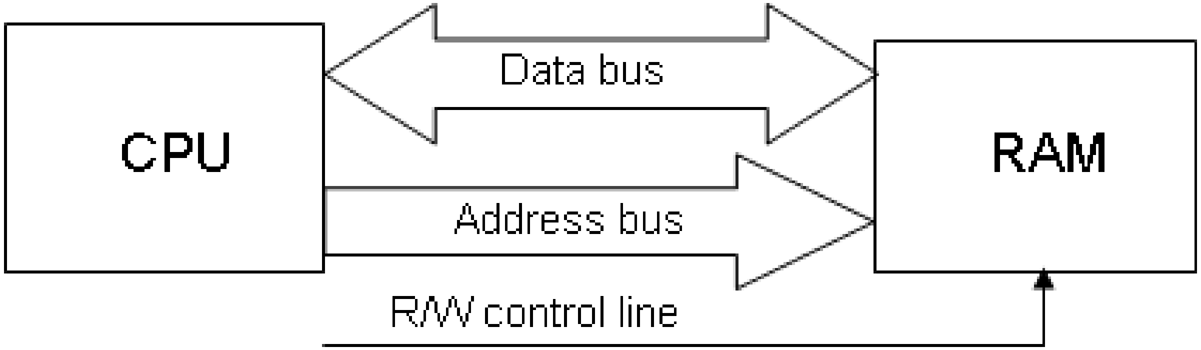
Von Neuman architecture





Random Access Memory

- The RAM is a linear array of "cells", usually called "words". The words are numbered from 0 to N, and this number is the "address" of the word
- In order to read/write a word from/into a memory cell, the CPU has to provide its address on the "address bus"
- A "control line" tells the memory whether it is a read or write operation
- In a read operation the memory will provide on the "data bus" the content of the memory cell at the address provided on the "address bus"
- In a write operation the memory will store the data provided on the "data bus" into the memory cell at the address provided on the "address bus", overwriting previous content



Program execution

- The RAM contains both the program (machine instructions) and the data
- The basic model is “sequential execution”
  - each instruction is extracted from memory (in sequence) and executed
- Basic execution cycle
  - Fetch instruction (from memory) at location indicated by LC
  - Increment Location Counter (to point to the next instruction)
  - Bring instruction to CPU
  - Execute instruction
    - Fetch operand from memory (if needed)
    - Execute operation
    - Store result
      - in “registers” (temporary memory)
      - in memory (RAM)

Data within a computer

- The Control Unit, the RAM, the CPU and all the physical components in a computer act on electrical signals and on devices that (basically) can be in only one of two possible states
- The two states are conventionally indicated as “zero” and “one” (0 and 1), and usually correspond to two voltage levels
- The consequence is that all the data within a computer (or in order to be processed by a computer) has to be represented in binary notation, i.e. with a sequence of 0s and 1s, called bits

Evolution of computer technology

- First Generation
  mechanical/electromechanical
- Second Generation
  vacuum tubes
- Third Generation
  discrete transistors (solid state devices)
  SSI, MSI, LSI integrated circuits
- Fourth Generation
  VLSI integrated circuits

VLSI = Very Large Scale Integration

Evolution of computer components

- Computer technology
  - CPU on integrated chips
    - From KHz to MHz to GHz
  - Random Access Memories
    - RAM – from KB to GB
  - External memories
    - Tapes, hard disks, floppy disks
    - Memory sticks
    - CDs
    - DVDs
    - from MB to GB to TB to PB to EB

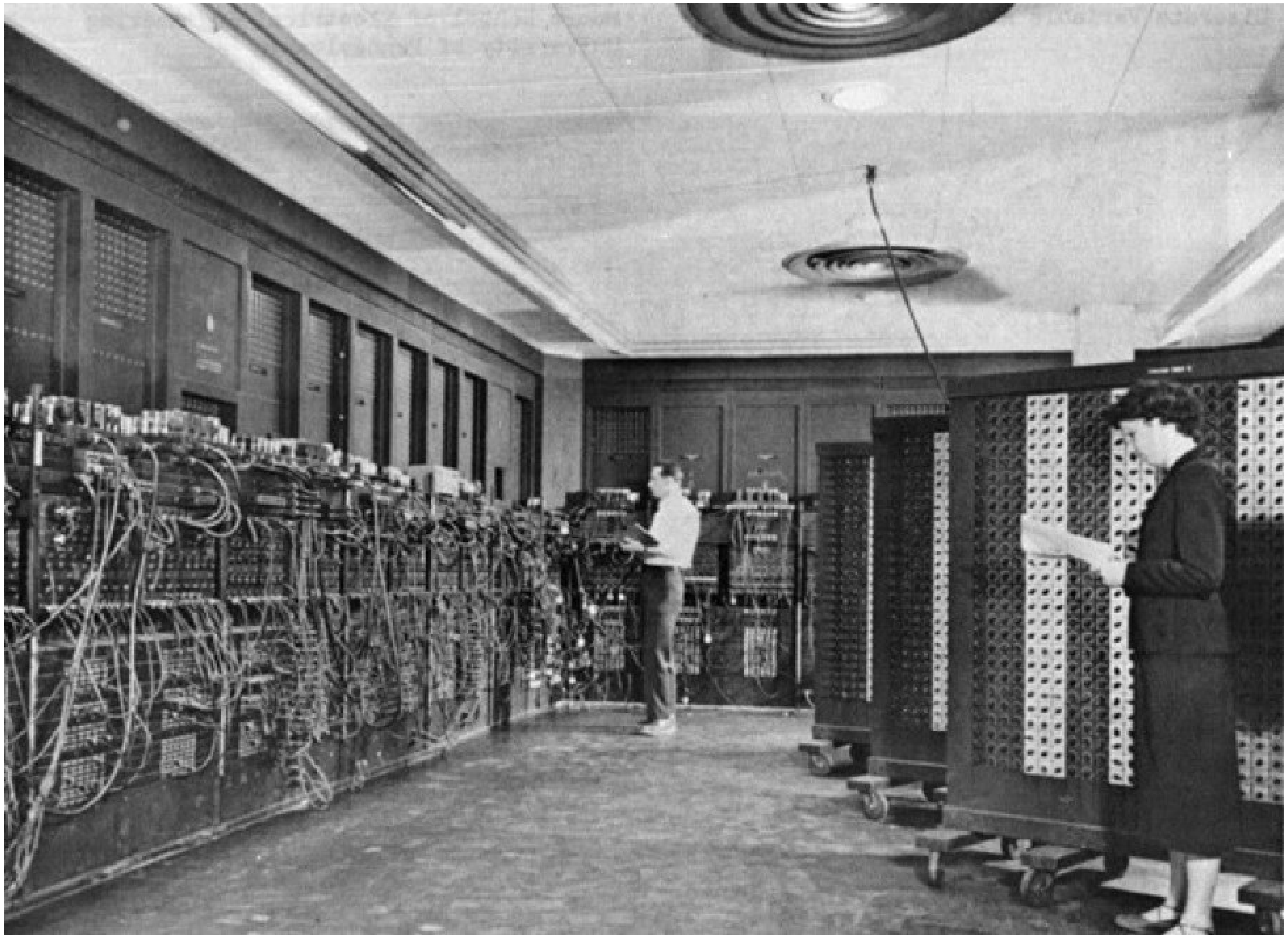
Size of digital information

1000	k	kilo
1000^2	M	mega
1000^3	G	giga
1000^4	T	tera
1000^5	P	peta
1000^6	E	exa
1000^7	Z	zetta
1000^8	Y	yotta

Evolution of computer market

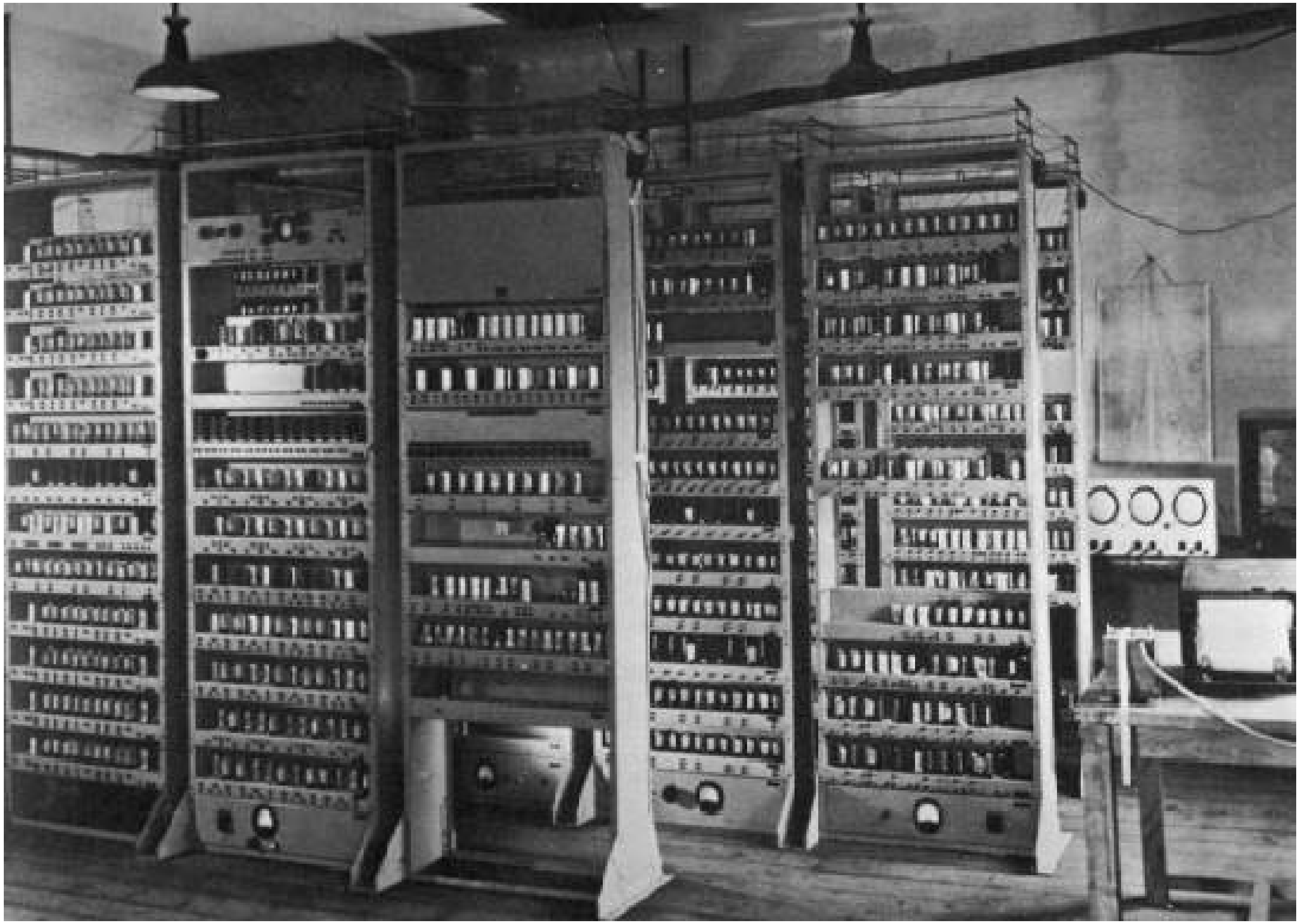
- Military applications in early 40s
- Scientific/research applications in late 40s
- Commercial applications appear in early 50s
- Monopoly of IBM starts with 650, 701, 702
- Monopoly of IBM continues with 7070, 7090 and the 360 series, starting the “mainframe era” (in the 60s)
- Arrival of the “minicomputers” in the 70s
- Arrival of the PC in the 80s
- Arrival of the Internet in the 90s
- Arrival of the Web in the 90s

ENIAC - Electronic Numerical Integrator And Computer (1945)



EDSAC - Electronic Delay Storage Automatic Calculator

EDSAC, University of Cambridge, UK, 1949



A “mainframe” in the 60’

A “mainframe” in the 70’

Minicomputers (in the '70)

Early PCs (in the ‘80)

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Representation of information within a computer

- Numbers ⬅
- Text (characters and ideograms)
- Images
- Video and Audio

Positional notation base 10

Positional notation in base 10

Ten different symbols are needed for the digits (0,1,2,3,4,5,6,7,8,9)

The “weight” of each digit is a power of 10 (the base) and depends on its position in the number

$10^0=1$

$10^1=10$

$10^2=100$

$10^3=1000$

$10^4=10000$

3	4	7

$$3\times10^2 + 4\times10^1 + 7\times10^0 = 347$$

Positional notation base 8

Positional notation in base 8

Eight different symbols are needed for the digits (0,1,2,3,4,5,6,7)

The “weight” of each digit is a power of 8 (the base) and depends on its position in the number

$8^0=1$

$8^1=8$

$8^2=64$

$8^3=512$

$8^4=4096$

3	4	7

$3x8^2 + 4x8^1 + 7x8^0$

$192 + 32 + 7 = 231$

Positional notation base 16

Positional notation in base 16

Sixteen different symbols are needed for the digits (0,1,2,3,4,5,6,7, 8,9,A,B,C,D,E,F)

The "weight" of each digit is a power of 16 (the base) and depends on its position in the number

$16^0=1$

$16^1=16$

$16^2=256$

$16^3=4096$

$16^4=65536$

3	B	F

$3x16^2 + Bx16^1 + Fx16^0$

$3x256 + 11x16 + 15x1$

$768 + 176 + 15 = 959$

Positional notation base 2

Positional notation in base 2

Two different symbols are needed for the digits (0,1)

The “weight” of each digit is a power of 2 (the base) and depends on its position in the number

$2^0=1$

$2^1=2$

$2^2=4$

$2^3=8$

$2^4=16$

$2^5=32$

$2^6=64$

$2^7=128$

$2^8=256$

1	0	1	1

$1x2^3 + 0x2^2 + 1x2^1 + 1x2^0$

$1x8 + 0x4 + 1x2 + 1x1$

$8 + 0 + 2 + 1 = 11$

Powers of 2

$2^0=1$
$2^1=2$
$2^2=4$
$2^3=8$
$2^4=16$
$2^5=32$
$2^6=64$
$2^7=128$
$2^8=256$

$2^9=512$			
$2^{10}=1024$	**1K**		
$2^{11}=2048$	2K		
$2^{12}=4096$	4K		
$2^{13}=8192$	8K		
$2^{14}=16384$	16K		
$2^{15}=32768$	32K		
$2^{16}=65356$	**64K**		
. . . . . .			
$2^{20}=1.048.576$		**1024K**	**1M**
$2^{30}=1.073.741.824$		**1024M**	**1G**
$2^{32}=4.271.406.736$		**4096M**	**4G**

Binary and hexadecimal numbers

$2^0=1$
$2^1=2$
$2^2=4$
$2^3=8$
$2^4=16$
$2^5=32$
$2^6=64$
$2^7=128$
$2^8=256$

0000=0	1000=8
0001=1	1001=9
0010=2	1010=10 A
0011=3	1011=11 B
0100=4	1100=12 C
0101=5	1101=13 D
0110=6	1110=14 E
0111=7	1111=15 F
	10000=16 10

decimal and exadecimal
decimal
hexadecimal

01011011 can be represented in hexadecimal as 5B

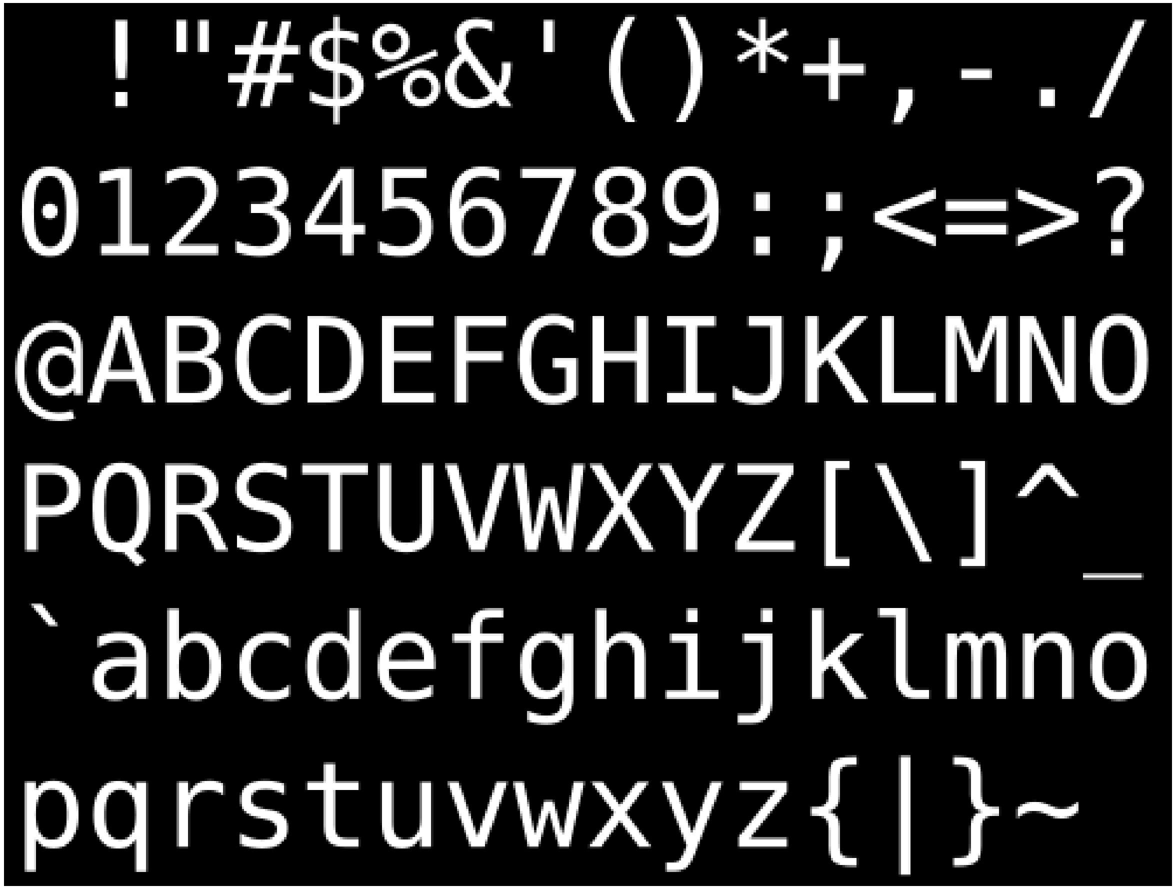
Representation of information within a computer

- Numbers
- Text (characters and ideograms)
- Images
- Video and Audio

Representation of characters

- The most simple way to represent (alphanumeric) characters (and symbols) within a computer is to associate a character (a symbol) with a number, defining a “coding table”
- How many bits are needed to represent the Latin alphabet ?

The ASCII table (7 bits)



The 95 printable ASCII characters, numbered from 32 to 126 (decimal)

33 control characters

ASCII table (7 bits)

Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
0	00	Null	32	20	Space	64	40	@	96	60	`
1	01	Start of heading	33	21	!	65	41	A	97	61	a
2	02	Start of text	34	22	"	66	42	B	98	62	b
3	03	End of text	35	23	#	67	43	C	99	63	c
4	04	End of transmit	36	24	$	68	44	D	100	64	d
5	05	Enquiry	37	25	%	69	45	E	101	65	e
6	06	Acknowledge	38	26	&	70	46	F	102	66	f
7	07	Audible bell	39	27	'	71	47	G	103	67	g
8	08	Backspace	40	28	(	72	48	H	104	68	h
9	09	Horizontal tab	41	29	)	73	49	I	105	69	i
10	0A	Line feed	42	2A	*	74	4A	J	106	6A	j
11	0B	Vertical tab	43	2B	+	75	4B	K	107	6B	k
12	0C	Form feed	44	2C	,	76	4C	L	108	6C	l
13	0D	Carriage return	45	2D	–	77	4D	M	109	6D	m
14	0E	Shift out	46	2E	.	78	4E	N	110	6E	n
15	0F	Shift in	47	2F	/	79	4F	O	111	6F	o
16	10	Data link escape	48	30	0	80	50	P	112	70	p
17	11	Device control 1	49	31	1	81	51	Q	113	71	q
18	12	Device control 2	50	32	2	82	52	R	114	72	r
19	13	Device control 3	51	33	3	83	53	S	115	73	s
20	14	Device control 4	52	34	4	84	54	T	116	74	t
21	15	Neg. acknowledge	53	35	5	85	55	U	117	75	u
22	16	Synchronous idle	54	36	6	86	56	V	118	76	v
23	17	End trans. block	55	37	7	87	57	W	119	77	w
24	18	Cancel	56	38	8	88	58	X	120	78	x
25	19	End of medium	57	39	9	89	59	Y	121	79	y
26	1A	Substitution	58	3A	:	90	5A	Z	122	7A	z
27	1B	Escape	59	3B	;	91	5B	[	123	7B	{
28	1C	File separator	60	3C	<	92	5C	\	124	7C	|
29	1D	Group separator	61	3D	=	93	5D	]	125	7D	}
30	1E	Record separator	62	3E	>	94	5E	^	126	7E	~
31	1F	Unit separator	63	3F	?	95	5F	_	127	7F	□

ASCII 7-bits character set

Last 4 bits

ASCII Code Chart

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL	BS	HT	LF	VT	FF	CR	SO	SI
1	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB	CAN	EM	SUB	ESC	FS	GS	RS	US
2		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
3	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
4	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
6	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
7	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	DEL

First 3 bits

Representation standards

- ASCII 7 bits (late fifties)
  - American Standard Code for Information Interchange
  - 7 bits for 128 characters (Latin alphabet, numbers, punctuation, control characters)
- EBCDIC (early sixties)
  - Extended Binary Code Decimal Interchange Code
  - 8 bits; defined by IBM in early sixties, still used and supported on many computers
- ASCII 8 bits (ISO 8859-xx) extends original ASCII to 8 bits to include accented letters and non Latin alphabets (e.g. Greek, Russian)
- UNICODE or ISO-10646 (1993)
  - Merged efforts of the Unicode Consortium and ISO
  - UNIversal CODE still evolving
  - It incorporates all(?) the pre-existing representation standards
  - Basic rule: round trip compatibility
    - Side effect is multiple representations for the same character

ISO-8859-xx (ASCII 8-bits)

- Developed by ISO (International Organization for Standardization)
- There are 16 different tables coding characters with 8 bit
- Each table includes ASCII (7 bits) in the lower part and other characters in the upper part for a total of 191 characters and 32 control codes
- It is also known as ISO-Latin–xx (includes all the characters of the “Latin alphabet”)

ISO-8859-xx code pages

8859-1	Latin-1	Western European languages
8859-2	Latin-2	Central European languages
8859-3	Latin-3	South European languages
8859-4	Latin-4	North European languages
8859-5	Latin/Cyrillic	Slavic languages
8859-6	Latin/Arabic	Arabic language
8859-7	Latin/Greek	modern Greek alphabet
8859-8	Latin/Hebrew	modern Hebrew alphabet
8859-9	Latin-5	Turkish language (similar to 8859-1)
8859-10	Latin-6	Nordic languages (rearrangement of Latin-4)
8859-11	Latin/Thai	Thai language
8859-12	Latin/Devanagari	Devanagari language (abandoned in 1997)
8859-13	Latin-7	Baltic Rim languages
8859-14	Latin-8	Celtic languages
8859-15	Latin-9	Revision of 8859-1
8859-16	Latin-10	South-Eastern European languages

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UNICODE

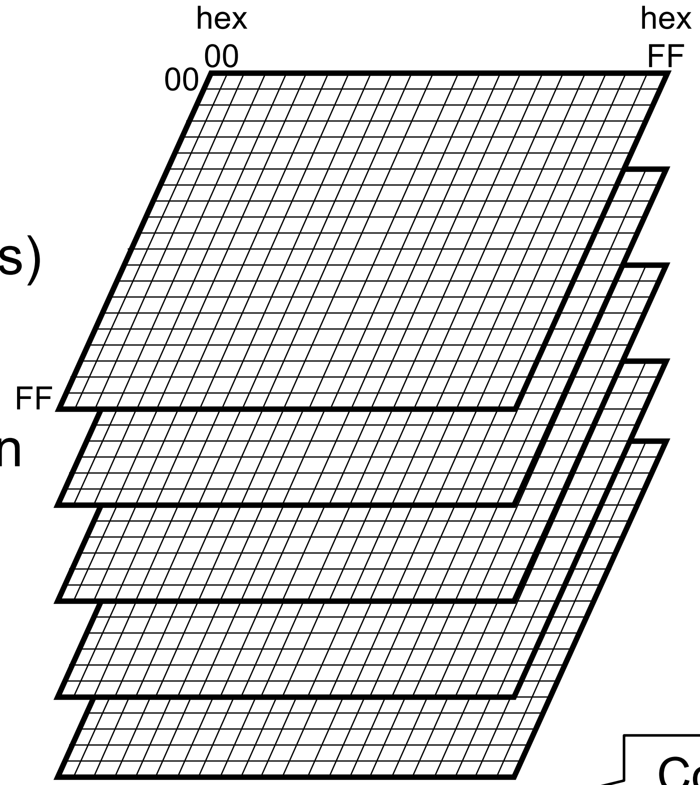
- In Unicode, the word “character” refers to the notion of the abstract form of a “letter”, in a very broad sense
  - a letter of an alphabet
  - a mark on a page
  - a symbol (in a language)
- A “glyph” is a particular rendition of a character (or composite character). The same Unicode character can be rendered by many glyphs
  - Character “a” in 12-point Helvetica, or
  - Character “a” in 16-point Times
- In Unicode each “character” has a name and a numeric value (called “code point”), indicated by U+hex value.
  For example, the letter “G” has:
  - Unicode name: “LATIN CAPITAL LETTER G”
  - Unicode value: U+0047 (see ASCII codes)

Unicode representation

- The Unicode standard has specified (and assigned values to) about 96.000 characters
- Representing Unicode characters (code points) in binary
  - 32 bits in ISO-10646
  - 21 bits in the Unicode Consortium
- In the 21 bit address space, we can take the last 16 bits to address a "plane" of 64K characters (256 rows by 256 columns)
- The first five bits can then identify one of the 32 possible planes
- Only 6 planes defined as of today, of which only 4 are actually "filled"
- Plane 0, the Basic Multingual Plane, contains most of the characters used (as of today) by most of the languages present in the Web

The planes of Unicode

256 columns (last 8 bits)



256 rows (8 bits)

Each plane can contain 64 K characters

There are 32 planes, identified by the first 5 bits

Plane | Row | Column

5 bits	8 bits	8 bits

= 21 bits for a symbol

Beginning of BMP

in this table each “column” represents 16 characters

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
00	C0 Controls		Basic Latin						C1 Controls		Latin 1 Supplement					
01	Latin Extended-A								Latin Extended-B							
02	Latin Extended-B					IPA Extensions						Spacing Modifiers				
03	Combining Diacritics							Greek								
04	Cyrillic															
05	Cyrillic Sup.			Armenian						Hebrew						
06	Arabic															
07	Syriac					Arabic Sup.			Thaana				N'Ko			
08	(Samaritan)				(Mandaic)		???	???	???	???	¿Arabic Extended-A?					
09	Devanagari								Bengali							
0A	Gurmukhi								Gujarati							
0B	Oriya								Tamil							
0C	Telugu								Kannada							
0D	Malayalam								Sinhala							
0E	Thai								Lao							
0F	Tibetan															
10	Myanmar										Georgian					

Unicode encoding

- UTF-32 (fixed length, four bytes)
  - UTF stands for “UCS Transformation Format” (UCS stands for “Unicode Character Set”)
  - UTF-32BE and UTF-32LE have a “byte order mark” to indicate “endianness”
- UTF-16 (variable length, two bytes or four bytes)
  - All characters in the BMP represented by two bytes
  - The 21 bits of the characters outside of the BMP are divided in two parts of 11 and 10 bits; to each part is added an offset to bring it in the “surrogate zone” of the BMP (low surrogate at D800 and high surrogate at DC800)
  - in other words, they are represented as two characters in the BMP
  - UTF-16BE and UTF-16LE to indicate “endianness”
- UTF-8 (variable length, 1 to 4 bytes)
  - Characters in the 7-bit ASCII represented by one byte
  - Variable length encoding (2, 3 or 4 bytes) for all other characters

UTF-8

Table 4.3 Encoding the Unicode character set as UTF-8.

Unicode value	21-bit binary code	UTF-8 code			
U+00000000 – U+0000007F	00000000000000wwwwwww	0wwwwwww			
U+00000080 – U+000007FF	0000000000wwwwwxxxxxx	110wwwww	10xxxxxx		
U+00000800 – U+0000FFFF	00000wwwwxxxxxxyyyyyy	1110wwww	10xxxxxx	10yyyyyy	
U+00010000 – U+001FFFFF	wwwxxxxxxyyyyyyzzzzzz	11110www	10xxxxxx	10yyyyyy	10zzzzzz

Representation of information within a computer

- Numbers
- Text (characters and ideograms)
- Images ←
- Video and Audio

Welcome

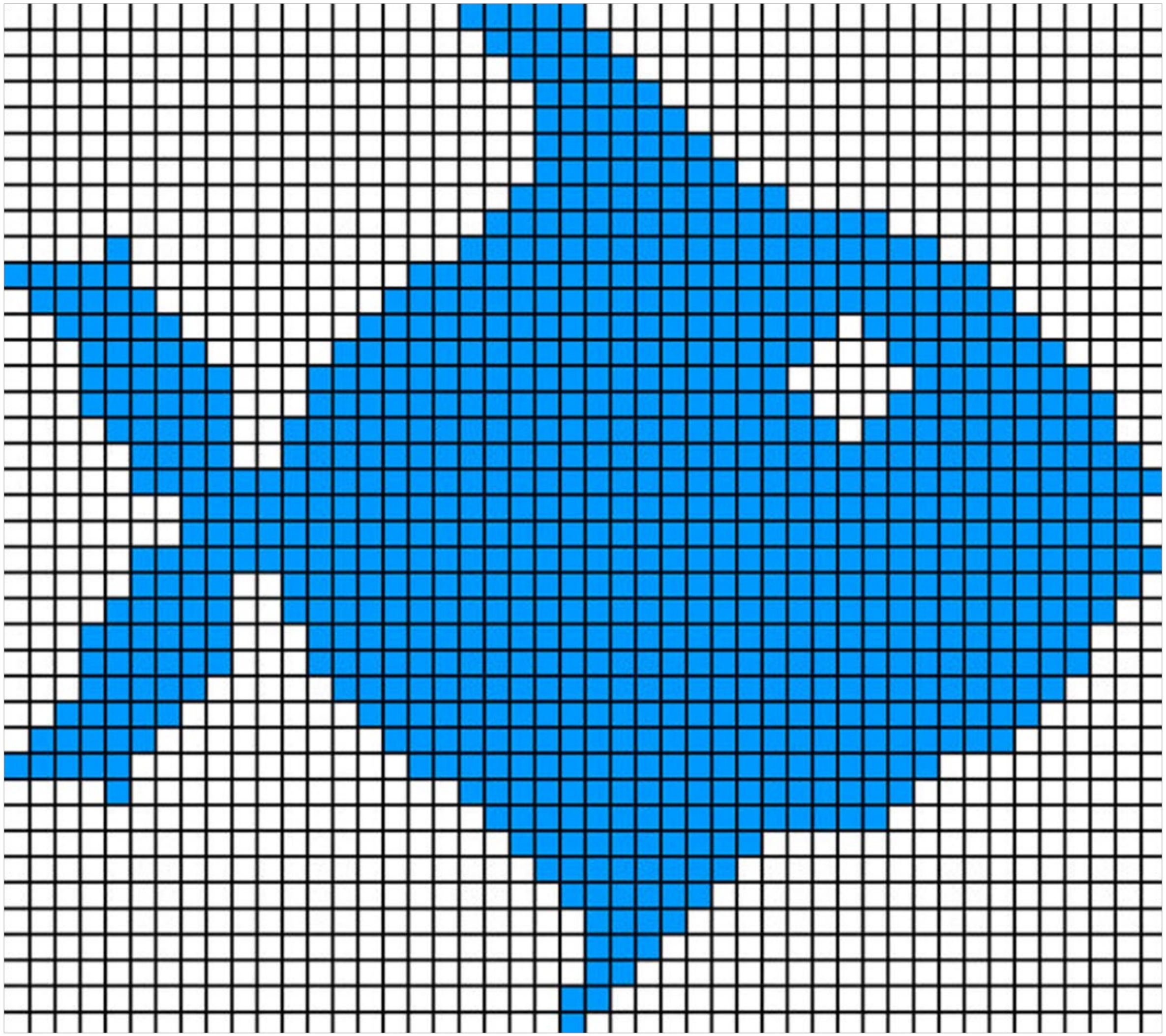
Welcome to image representation and compression

Representation of images

- Vector formats (geometric description)
  - Main advantage is scalability
    - Postscript
    - PDF
    - SVG (Scalable Vector Graphics)
    - SWF (ShockWave Flash)
      - vector-based images, plus audio, video and interactivity
      - Flash player obsolete since end of 2020

- Raster formats (array of “picture elements”, called “pixels”)

Picture elements (pixels)



A pixel must be small enough so that its color can be considered uniform for the whole pixel. Inside the computer, a pixel is represented with a number representing its color.

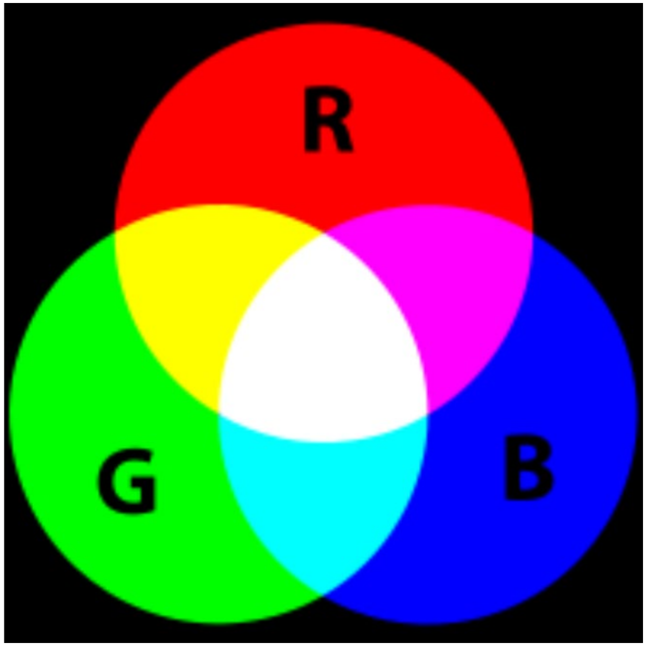
Raster format

- In raster format an image (picture) is represented by a matrix of “pixels”
- A first measure of the quality of a picture is given by the number of pixels, which can be measured in different ways
- Total number of pixels, as in digital cameras and phones
  - from 3-5 MegaPixels to 30-50 MegaPixels
- Number of rows and columns of the matrix, like in TV or PC screens (columns by rows)
  - HDTV 1920x1080, 4K TV 3840 x 2160,
  - PC screen 1024x768, 1280x1024, 1920x1080
- Number of pixels in 1 inch (2,54 cm), called “dpi” (dots per inch), in scanners and printers
  - 200-4800 dpi most common ranges

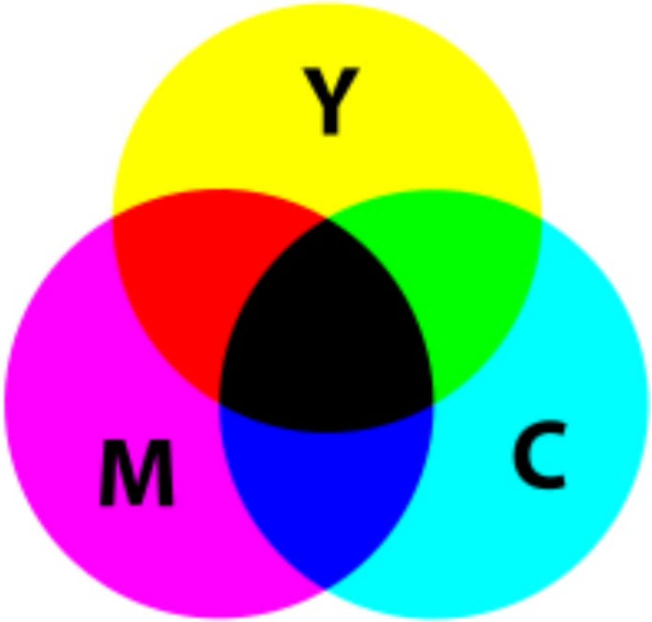
Raster format

- In raster format an image (picture) is represented by a matrix of “pixels”
- The quality of a picture is determined also by the number of bits used to represent one pixel (called depth)
  - 1 bit for black and white
  - 8-16 bits for grey scale (most common ranges)
  - 12-48 bits for color images (most common ranges)
- Colors are represented by three numbers, one for each “color component”
- Big file sizes for (uncompressed color) pictures
  - For example, one color page scanned at 600 dpi is about 100 MB

RGB and CMY color components



Additive color mixing



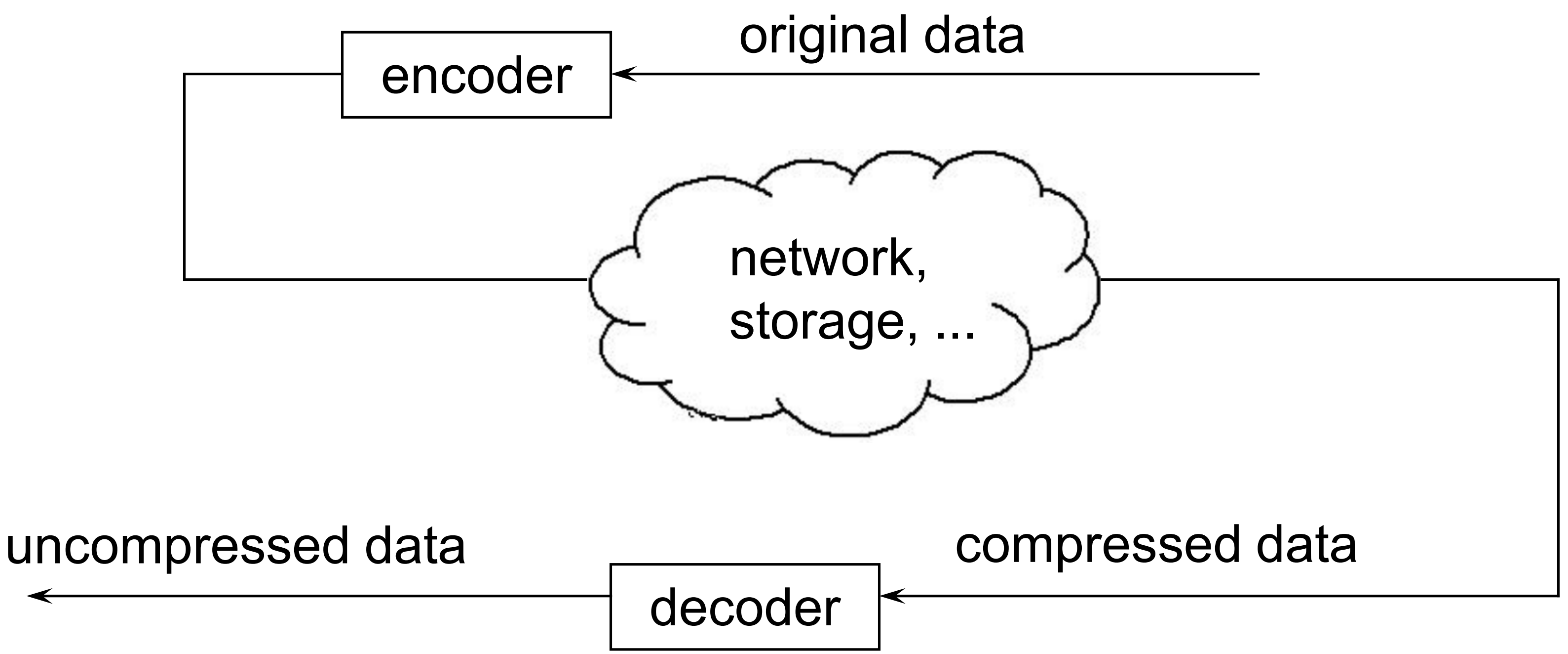
Subtractive color mixing

Common raster image file formats

Big file sizes for raw pictures - Compression is needed

- Lossless compression
  - G3, G4, JBIG (fax)
  - GIF, PNG (simple graphics)
- Lossy compression
  - JPEG (all kind of images)
- BMP, RAW (sensor output), DNG (Digital Negative), etc.
- Tagged Image File Format (image container)
  - TIFF
- International Image Interoperability Framework
  - IIIF

Compression of information



lossless compression: the uncompressed data is identical (bit by bit) to the original data (Huffman, ZIP)

lossy compression: the uncompressed data contains less “information” than the original data (JPEG)

Lossless compression techniques (symbol-wise)

- There are two main classes of lossless data compression methods
  - Symbol-wise encoding (Huffman)
  - Dictionary encoding (LZV)
- Symbolwise encoding
  - The basic idea is that the most frequent symbols can be coded with fewer bits (short codewords) than the less frequent symbols (long codewords)
  - Coders work by taking one symbol at the time from the input string, and coding it with a codeword whose length depends on the frequency (probability) of the symbol in the given alphabet
  - One of the most common symbol encoders is the Huffman coding
- Dictionary coding
  - The basic idea is to replace a sequence of symbols in the input string with an “index” in a dictionary (list) of “phrases”
  - .zip, .rar, .tar, etc

Frequency distribution of the English letters

A	0.0856
B	0.0139
C	0.0279
D	0.0378
E	0.1304
F	0.0289
G	0.0199
H	0.0528
I	0.0627
J	0.0013
K	0.0042
L	0.0339
M	0.0249
N	0.0707
O	0.0797
P	0.0199
Q	0.0012
R	0.0677
S	0.0607
T	0.1045
U	0.0249
V	0.0092
W	0.0149
X	0.0017
Y	0.0199
Z	0.0008

0.1304	E	.
0.1045	T	-
0.0856	A	.-
0.0797	O	---
0.0707	N	-.
0.0677	R	.-.
0.0627	I	..
0.0607	S	...
0.0528	H	....
0.0378	D	-..
0.0339	L	.-..
0.0289	F	..-.
0.0279	C	-.-.
0.0249	M	--
0.0249	U	..-
0.0199	G	--.
0.0199	Y	-.--
0.0199	P	.--.
0.0149	W	.--
0.0139	B	-...
0.0092	V	...-
0.0042	K	-.-
0.0017	X	-..-
0.0013	J	.---
0.0012	Q	--.-
0.0008	Z	--..

The Morse alphabet (1840)

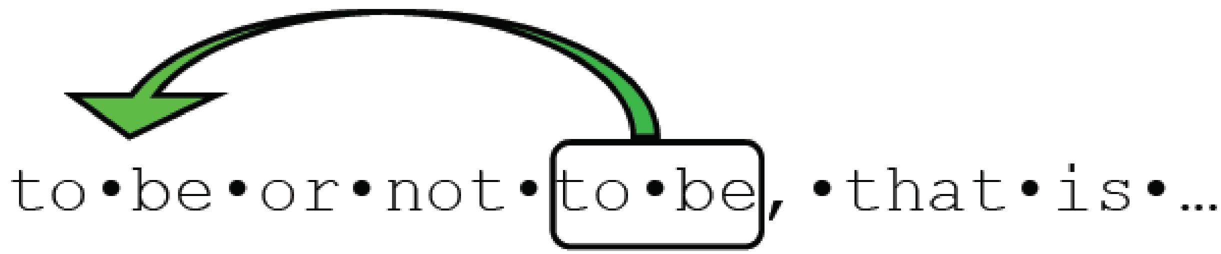
Lossless compression techniques (dictionary coding)

- There are two main classes of lossless data compression methods
  - Symbol-wise encoding
  - Dictionary encoding
- Symbolwise encoding
  - The basic idea is that the most frequent symbols can be coded with less bits (short codewords) than the less frequent symbols (long codewords)
  - Symbol coders work by taking one symbol at the time from the input string, and coding it with a codeword whose length depends on the frequency (probability) of the symbol in the given alphabet
  - One of the most common symbol encoders is the Huffman coding
- Dictionary coding
  - The basic idea is to replace a sequence of symbols in the input string with an “index” in a dictionary (list) of “phrases”
  - .zip
  - .rar
  - .tar

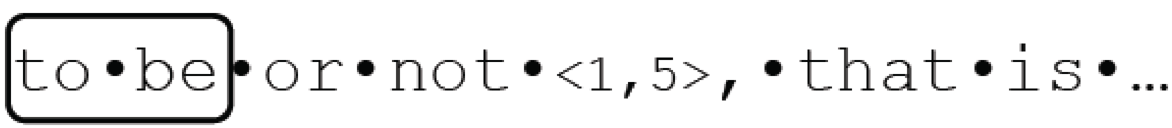
Lempel Ziv 77 coding (1/4)

Repeat occurrences of character sequences?

— replace them with a pointer back to the first occurrence



Pointer is <position,length>



In both are <256, pointer fits in 2 bytes

Lempel Ziv 77 coding (2/4)

The more regulare the input, the better the compression

Encoder input

aaaaaaaaaaaaaaaaarrrrrrrr
rrrrrggggggggghhhhh

Encoder output

Dictionary built while encoding and decoding

phrase 0 = NUL
phrase 1 = SOH
phrase 2 = STX
phrase 3 = ETX
phrase 4 = EOT
phrase 5 = ENQ
phrase 6 = ACK
phrase 7 = BEL
phrase 8 = BS
phrase 9 = HT
phrase 10 = LF
phrase 11 = VT
phrase 12 = FF
phrase 13 = CR
. . . . . .

Initial vocabulary

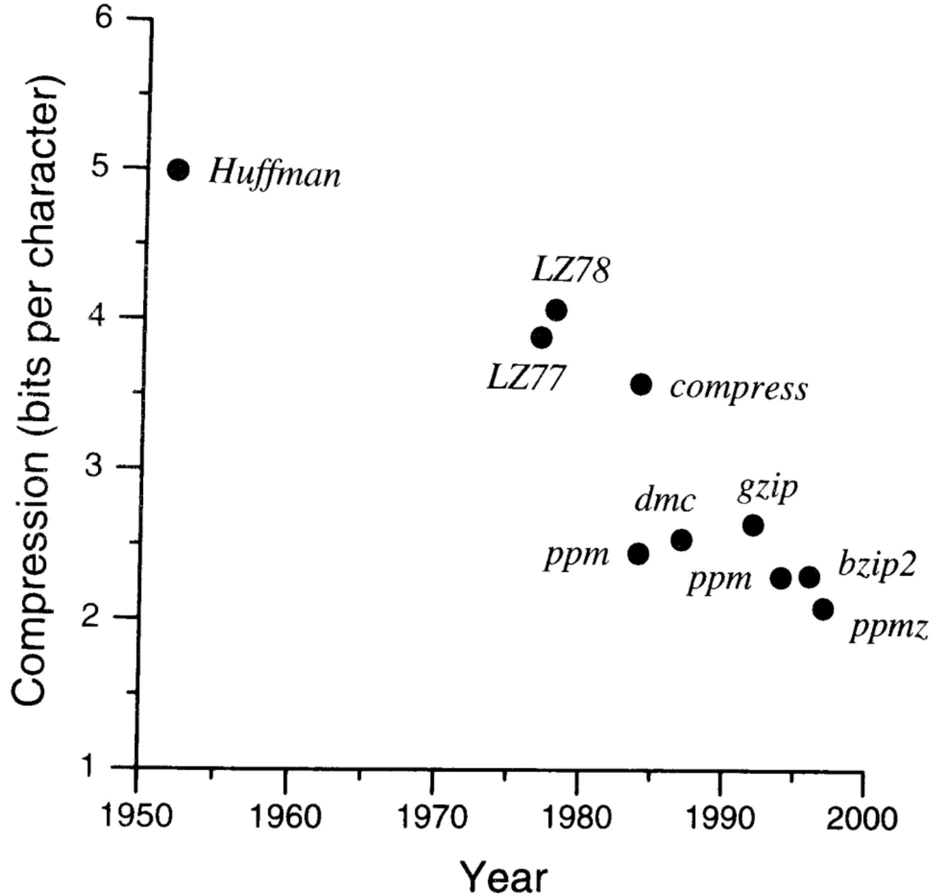
. . . . . .
phrase 97= a
phrase 98 = b
phrase 99 = c
phrase 100 = d
phrase 101 = e
phrase 102 = f
. . . . . .
phrase 123 = {
phrase 124 = |
phrase 125 = }
phrase 126 = ~
phrase 127 = DEL

. . . . . .
phrase 128 = ab
phrase 129 = ba
phrase 130 = aa
phrase 131 = aba
phrase 132 = abb
phrase 133 = baa
phrase 134 = abaa
. . . . . .

new phrases added as the string is being encoded

Encoder input	a b a ab ab ba aba abaa
Encoder output	97 98 97 128 128 129 131 134

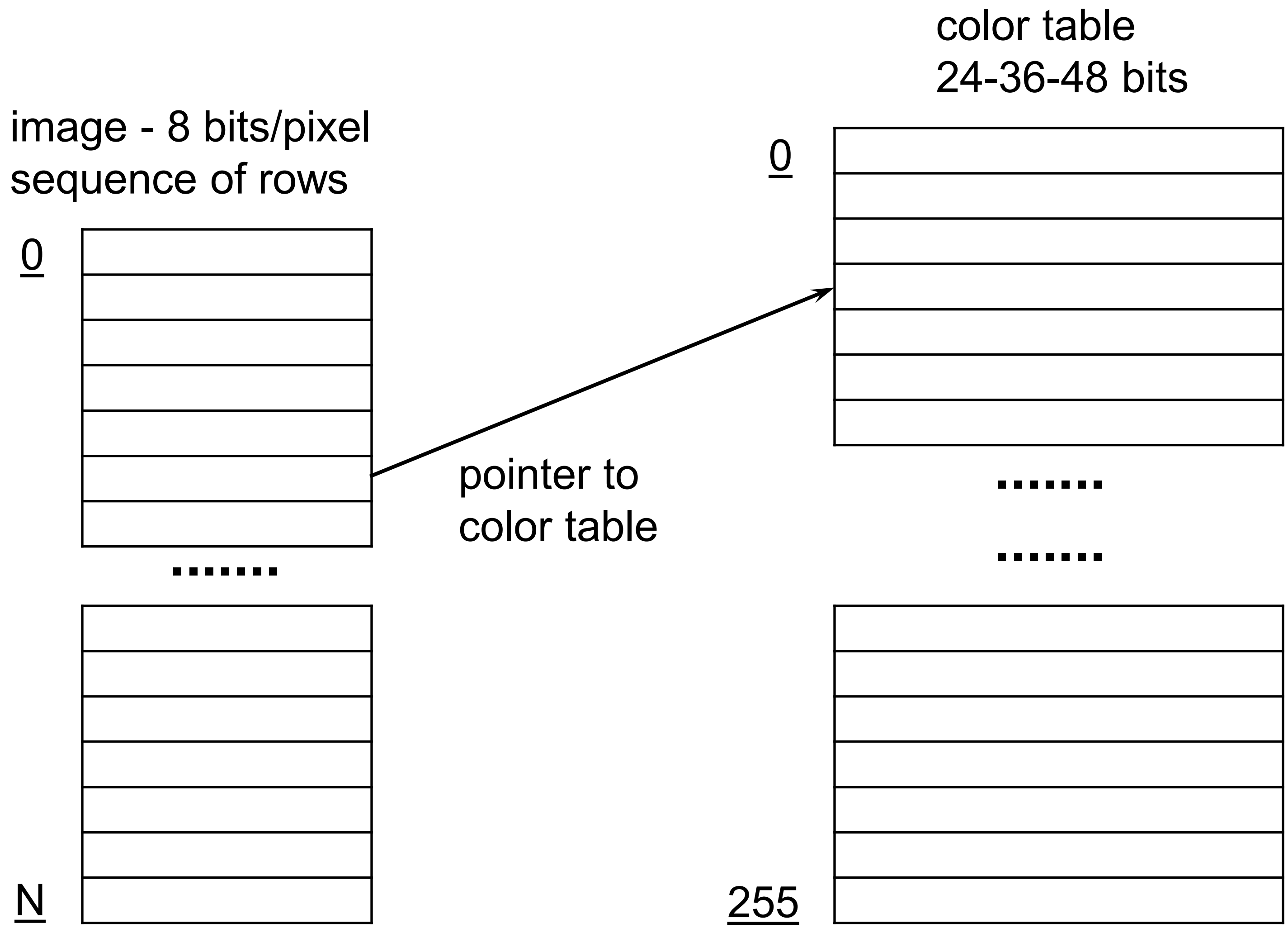
Comparison of lossless compression methods



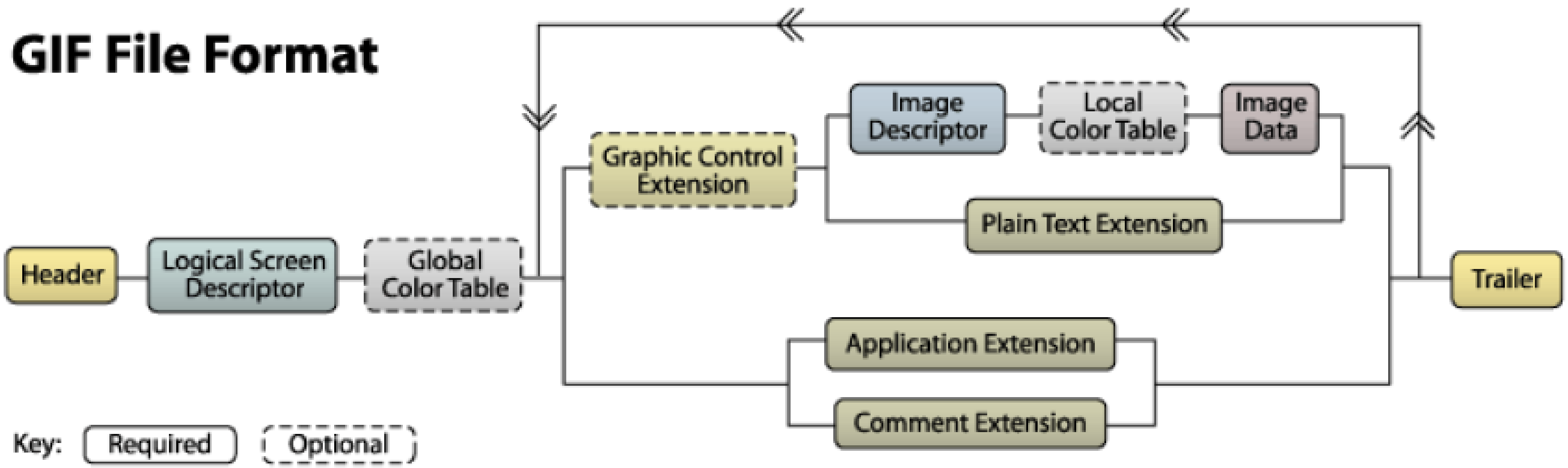
Common raster image file formats

- Lossless compression
  - G3, G4, JBIG (fax)
  - GIF, PNG (simple graphics)
- Lossy compression
  - JPEG (all kind of images)
- BMP, RAW (sensor output), DNG (Digital Negative), etc.
- Tagged Image File Format (image container)
  - TIFF
- International Image Interoperability Framework
  - IIIF

Pixel representation in GIF



GIF format


GIF File Format
Header
Logical Screen Descriptor
Global Color Table
Graphic Control Extension
Image Descriptor
Local Color Table
Image Data
Plain Text Extension
Application Extension
Comment Extension
Trailer
Key:
Required
Optional

GIF and PNG

- GIF – Graphics Interchange Format, is probably the most used “lossless” compression format for images (late eighties)
- Each file may contain several images (it supports animation)
- In an image, each pixel is represented by 8 bits (or less), and the value is an index in a color table, which can be included in the file (if not included, a standard color table is used)
- The color table has 256 entries, therefore a GIF image can have a “palette” of at most 256 colors (which is much less than the colors actually in the picture)
- The pixel index values are compressed using the LZW (zip) method
- The LZW coded information is divided in blocks, preceded by a header with a byte count, so it is possible to skip over images without decompressing them
- PNG (Portable Network Graphics) is essentially the same, and was defined some years later to avoid the use of the “proprietary” LZW compression algorithm
  - PNG uses “public domain” *gzip* or *deflate* methods
  - It incorporates also several improvements over GIF

Common raster image file formats

- Lossless compression
  - G3, G4, JBIG
  - GIF, PNG
- Lossy compression
  - JPEG
- BMP, RAW (sensor output), DNG (Digital Negative), etc.
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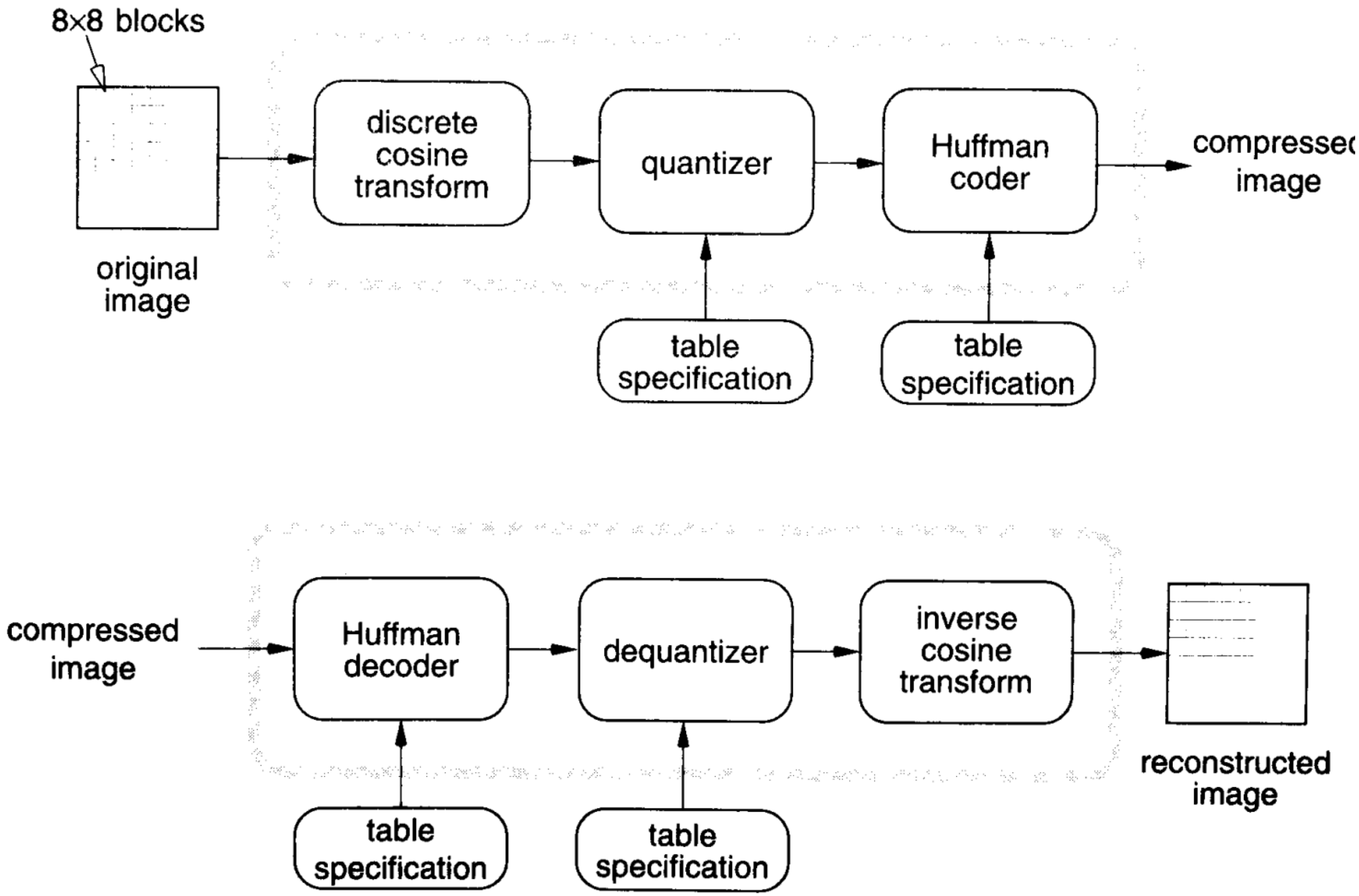
JPEG

- For grayscale and color images, lossless compression still results in “too many bits”
- Lossy compression methods take advantage from the fact that the human eye is less sensitive to small greyscale or color variation in an image
- JPEG - Joint Photographic Experts Group and Joint Binary Image Group, part of CCITT and ISO
- JPEG can compress down to about one bit per pixel (starting with 8-48 bits per pixel) still having excellent image quality
  - Not very good for fax-like images
  - Not very good for sharp edges and sharp changes in color
- The encoding and decoding process is done on an 8x8 block of pixels (separately for each color component)

JPEG encoding and decoding



Discrete Cosine Transform

pixel values

154	123	123	123	123	123	123	136
192	180	136	154	154	154	136	110
254	198	154	154	180	154	123	123
239	180	136	180	180	166	123	123
180	154	136	167	166	149	136	136
128	136	123	136	154	180	198	154
123	105	110	149	136	136	180	166
110	136	123	123	123	136	154	136

DCT coefficients

162.3	40.6	20.0	72.3	30.3	12.5	–19.7	–11.5
30.5	108.4	10.5	32.3	27.7	–15.5	18.4	–2.0
–94.1	–60.1	12.3	–43.4	–31.3	6.1	–3.3	7.1
–38.6	–83.4	–5.4	–22.2	–13.5	15.5	–1.3	3.5
–31.3	17.9	–5.5	–12.4	14.3	–6.0	11.5	–6.0
–0.9	–11.8	12.8	0.2	28.1	12.6	8.4	2.9
4.6	–2.4	12.2	6.6	–18.7	–12.8	7.7	12.0
–10.0	11.2	7.8	–16.3	21.5	0.0	5.9	10.7

Discrete Cosine Transform

The “lossy step”

162.3	40.6	20.0	72.3	30.3	12.5	–19.7	–11.5
30.5	108.4	10.5	32.3	27.7	–15.5	18.4	–2.0
–94.1	–60.1	12.3	–43.4	–31.3	6.1	–3.3	7.1
–38.6	–83.4	–5.4	–22.2	–13.5	15.5	–1.3	3.5
–31.3	17.9	–5.5	–12.4	14.3	–6.0	11.5	–6.0
–0.9	–11.8	12.8	0.2	28.1	12.6	8.4	2.9
4.6	–2.4	12.2	6.6	–18.7	–12.8	7.7	12.0
–10.0	11.2	7.8	–16.3	21.5	0.0	5.9	10.7

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

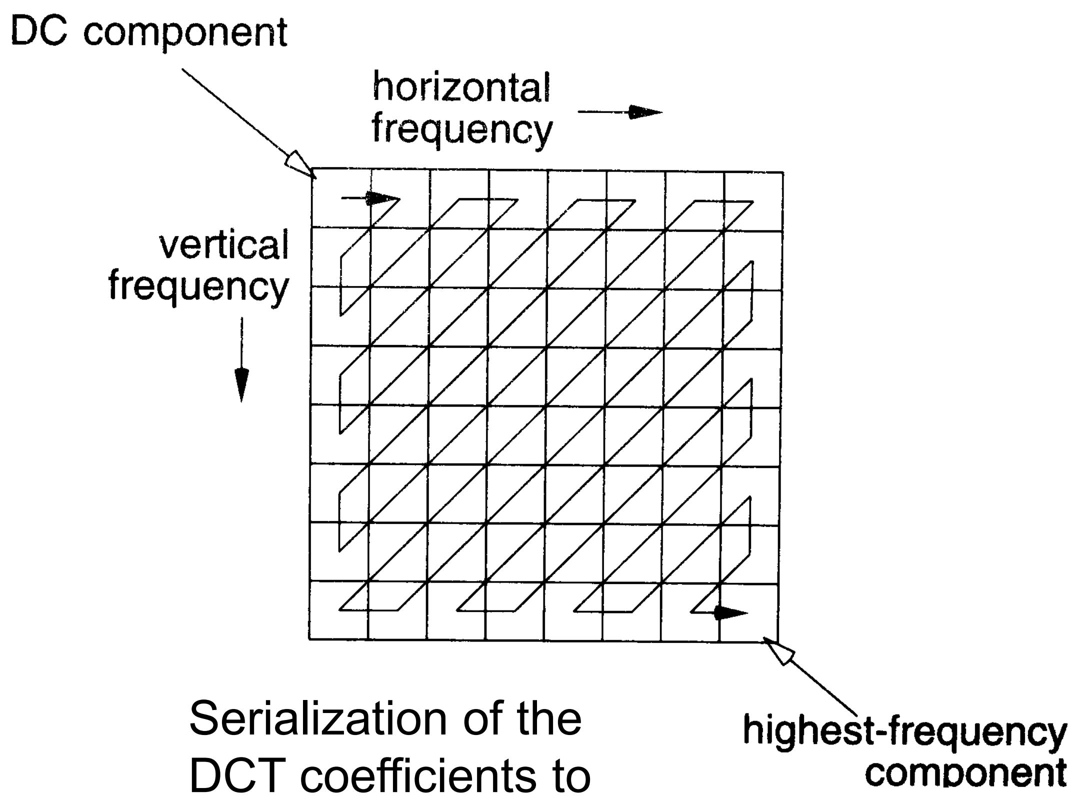
divide DCT coefficients by Q_{50} quantization matrix, round to nearest integer and get this result

10	4	2	5	1	0	0	0
3	9	1	2	1	0	0	0
–7	–5	1	–2	–1	0	0	0
–3	–5	0	–1	0	0	0	0
–2	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Quantization and coding

10	4	2	5	1	0	0	0
3	9	1	2	1	0	0	0
–7	–5	1	–2	–1	0	0	0
–3	–5	0	–1	0	0	0	0
–2	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

DCT coefficients after quantization Q_{50}
The DCT coefficients have been divided by the quantization matrix and then rounded to nearest integer



Serialization of the DCT coefficients to maximize run-lengths of zeros and therefore take advantage of Huffman coding

JPEG dequantization

10	4	2	5	1	0	0	0
3	9	1	2	1	0	0	0
–7	–5	1	–2	–1	0	0	0
–3	–5	0	–1	0	0	0	0
–2	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

160	44	20	80	24	0	0	0
36	108	14	38	26	0	0	0
–98	–65	16	–48	–40	0	0	0
–42	–85	0	–29	0	0	0	0
–36	22	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

DCT coefficients after quantization Q_{50}

In between there is the Huffman coding and decoding

DCT coefficients dequantized (multiplied by Q_{50})

Inverse DCT

160	44	20	80	24	0	0	0
36	108	14	38	26	0	0	0
–98	–65	16	–48	–40	0	0	0
–42	–85	0	–29	0	0	0	0
–36	22	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

149	134	119	116	121	126	127	128
204	168	140	144	155	150	135	125
253	195	155	166	183	165	131	111
245	185	148	166	184	160	124	107
188	149	132	155	172	159	141	136
132	123	125	143	160	166	168	171
109	119	126	128	139	158	168	166
111	127	127	114	118	141	147	135

Inverse of Discrete Cosine Transform

Comparison with original values

149	134	119	116	121	126	127	128
204	168	140	144	155	150	135	125
253	195	155	166	183	165	131	111
245	185	148	166	184	160	124	107
188	149	132	155	172	159	141	136
132	123	125	143	160	166	168	171
109	119	126	128	139	158	168	166
111	127	127	114	118	141	147	135

pixel values after Inverse Cosine Transform

154	123	123	123	123	123	123	136
192	180	136	154	154	154	136	110
254	198	154	154	180	154	123	123
239	180	136	180	180	166	123	123
180	154	136	167	166	149	136	136
128	136	123	136	154	180	198	154
123	105	110	149	136	136	180	166
110	136	123	123	123	136	154	136

original pixel values

Common raster image file formats

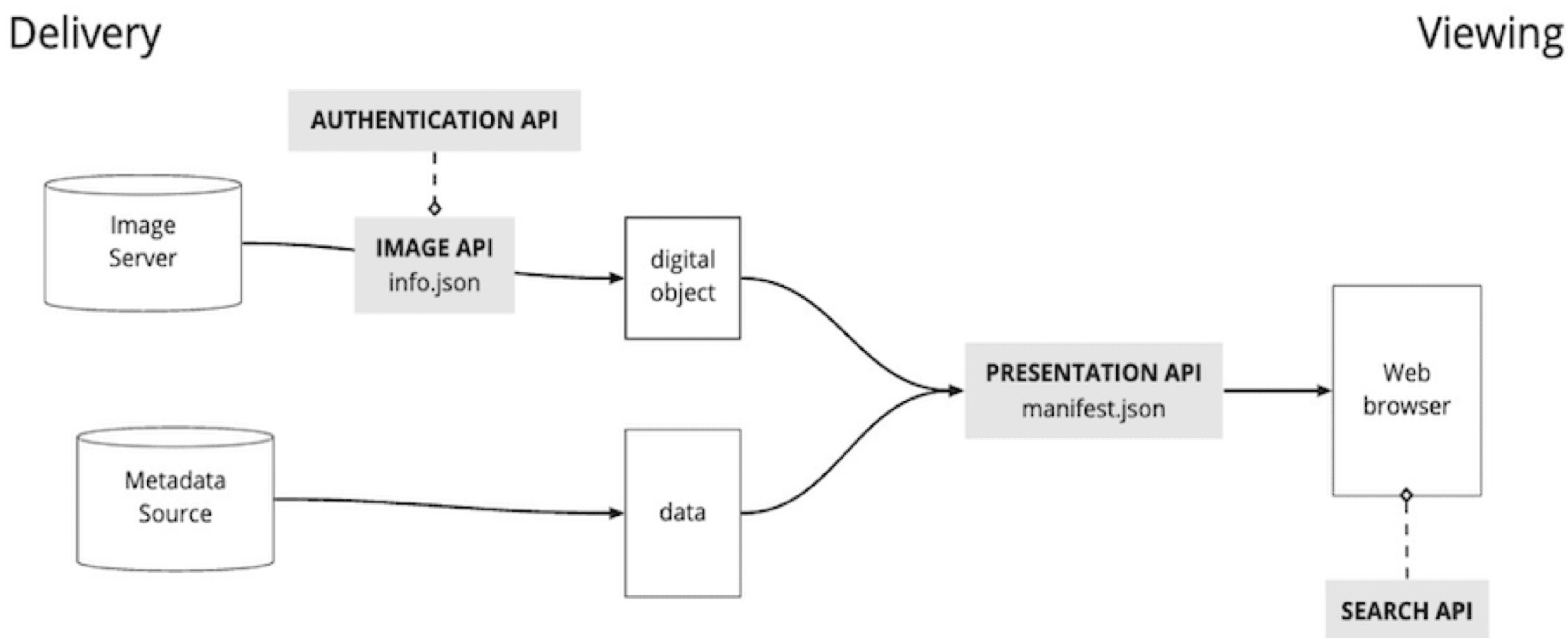
- Lossless compression
  - G3, G4, JBIG
  - GIF, PNG
- Lossy compression
  - JPEG
- BMP, RAW (sensor output), DNG (Digital Negative), etc.
- Tagged Image File Format (image container)
  - TIFF
- International Image Interoperability Framework
  - IIIF

TIFF

- Tagged Image File Format – file format that includes extensive facilities for descriptive metadata
  - note that TIFF tags are not the same thing as XML tags
- Owned by Adobe, but public domain (no licensing)
- Large number of options
  - Problems of backward compatibility
  - Problems of interoperability (Thousands of Incompatible File Formats 🙂)
- Can include (and describe) four types of images
  - bilevel (black and white), greyscale, palette-color, full-color
- Support of different color spaces
- Support of different compression methods
- Much used in digital libraries and archiving

IIIF (pronounced "Triple-Eye-Eff")

International Image Interoperability Framework



Just an example: https://digi.vatlib.it/

IIIF Framework (based on JSON)

- The Image API defines how image servers deliver image pixels to a viewer
- The Presentation API attaches basic metadata and structure to digital objects, to be shown by IIIF-compliant viewers
- The Authentication API defines where or by who your objects can be viewed
- The Search API allows users to search within any text associated with an object
- The Content State API provides a way of linking directly to a particular region and zoom level of a IIIF resource
- The Change Discovery API is a tool to describe the new publication of and updates to digital objects

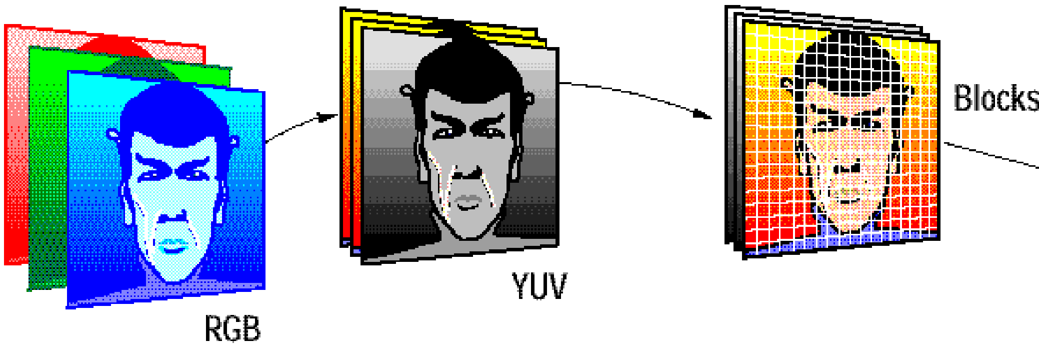
Representation of information within a computer

- Numbers
- Text (characters and ideograms)
- Images
- Video and Audio

Representing video

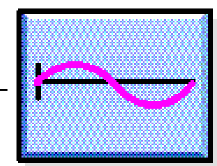
- Sequence of *frames* (still images) displayed with a given frequency
  – NTSC 30 f/s, PAL 25 f/s, HDTV 60 f/s
- Resolution of each frame depend on quality and video standard
  – 720x480 NTSC, 768x576 PAL, 1920x1080 HDTV, 3840×2160 UltraHD, 4096×2160 4K
- Uncompressed video requires “lots of bits”
  – e.g. 1920x1080x30x24 = ~ 1,5 GB/sec
- It is possible to obtain very high compression rates
  – Spatial redundancy (within each frame, JPEG-like)
  – Temporal redundancy (across frames)

Spatial Redundancy Reduction (DCT)



Pixel amplitude values

223	191	159	128	98	72	39	16
223	191	159	128	98	72	39	16
223	191	159	128	98	72	39	16
223	191	159	128	98	72	39	16
223	191	159	128	98	72	39	16
223	191	159	128	98	72	39	16
223	191	159	128	98	72	39	16
223	191	159	128	98	72	39	16



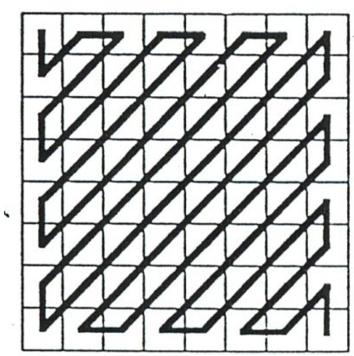
Discrete Cosine Transform

Pixel DCT Values

43.8	-40	0	-4.1	0	-1.1	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

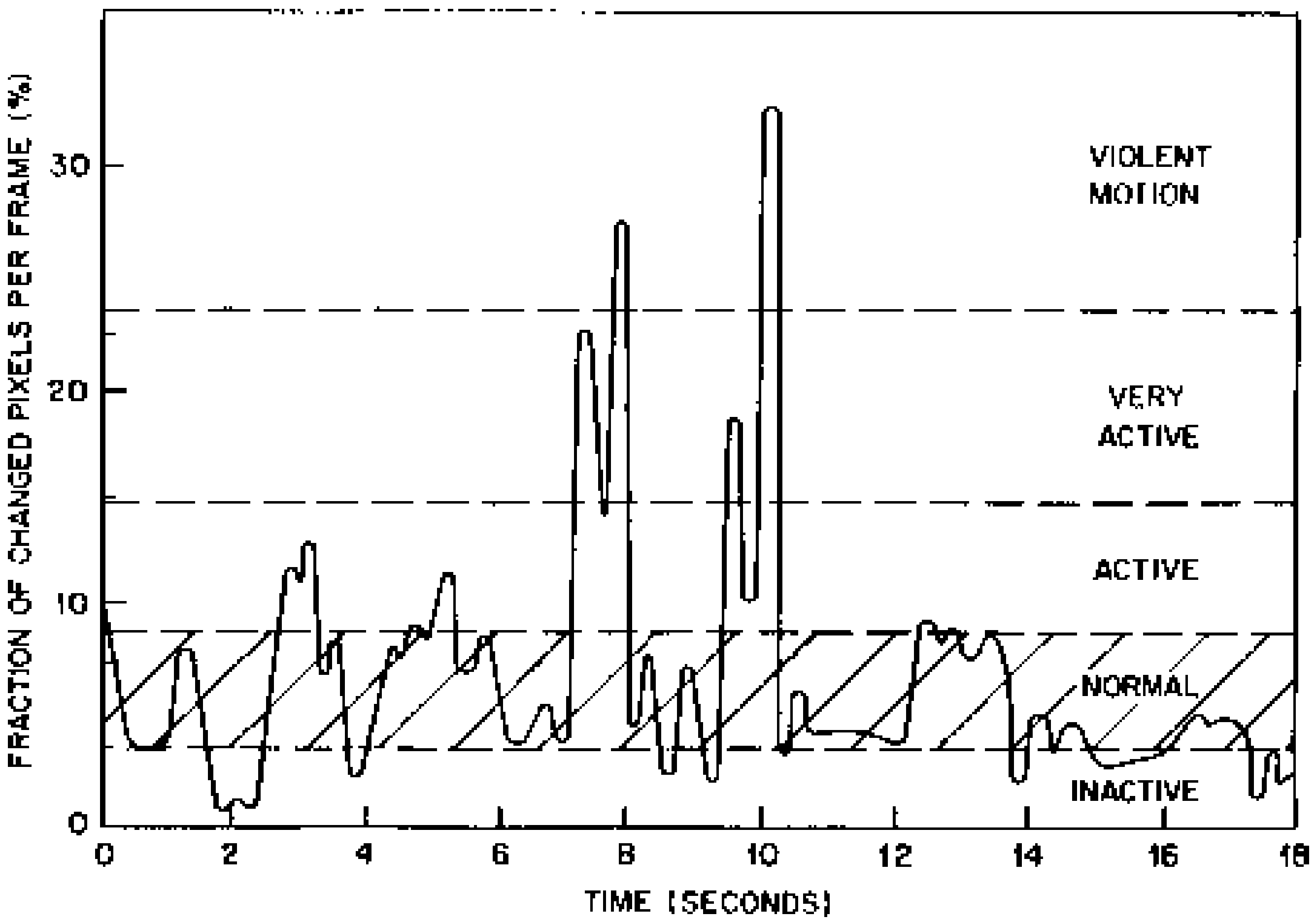
Quantization
- major reduction
- controls 'quality'

Zig-Zag Scan, Run-length coding



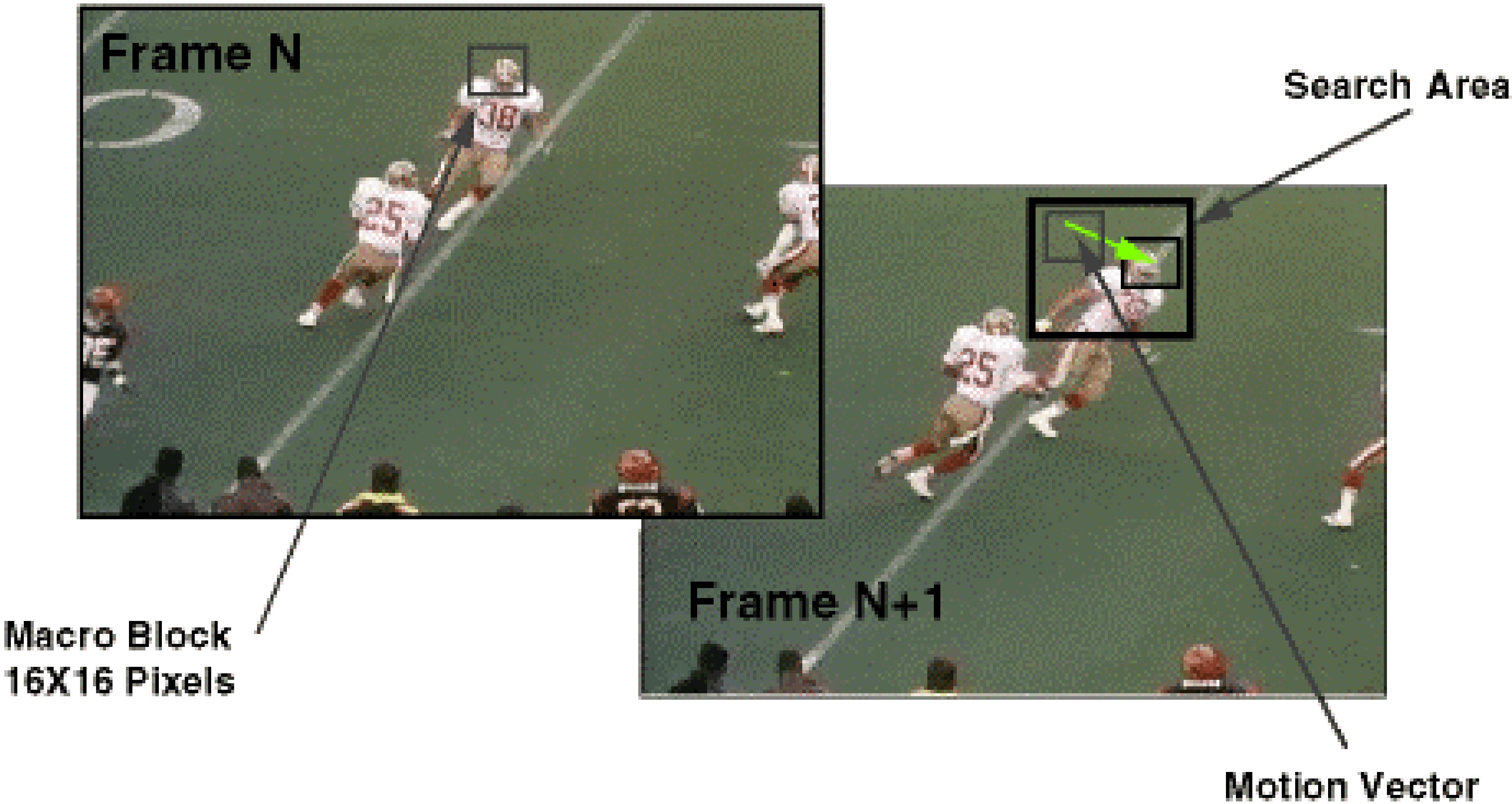
"Intra-Frame Encoded"

Temporal Activity

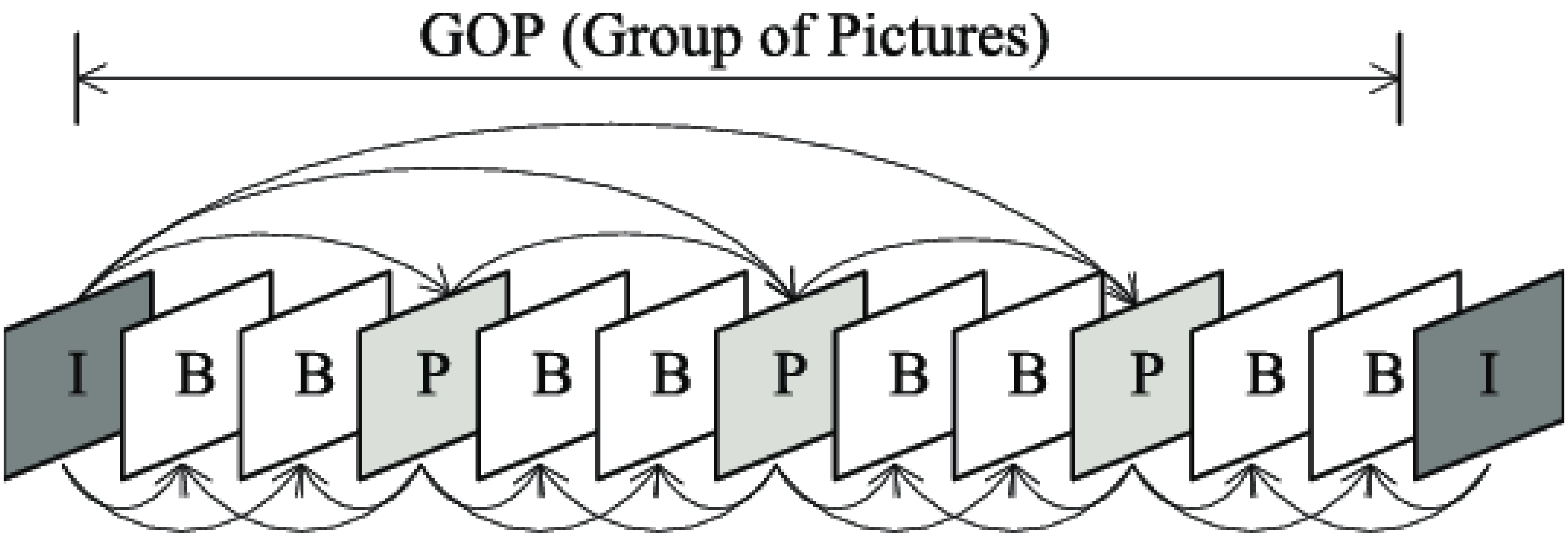


“Talking Head”

Temporal Redundancy Reduction (motion vectors)



Temporal Redundancy Reduction

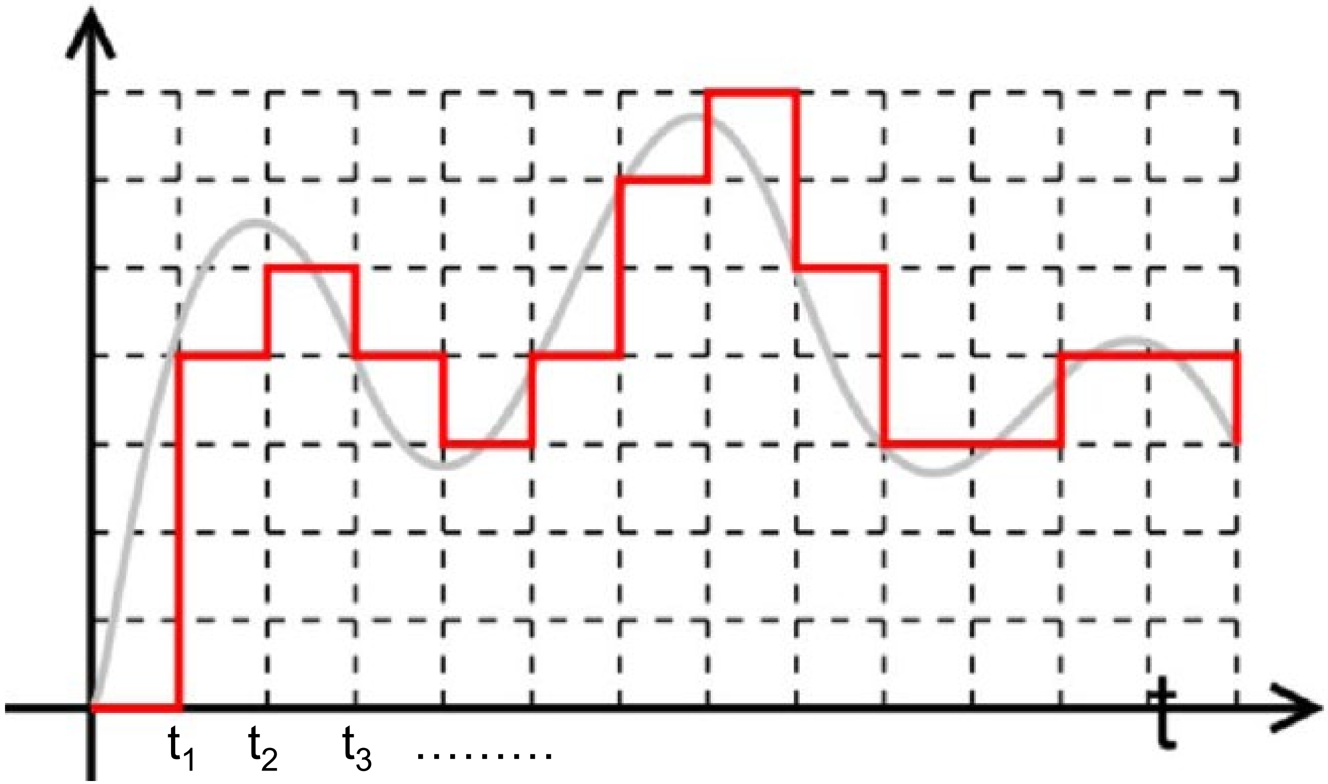


- *I* frames are independently encoded (JPEG like)
- *P* frames are based on previous I and P frames
- *B* frames are based on previous and following I and P frames

Typical Compression Performance

Type	Size	Compression
I	18 KB	7:1
P	6 KB	20:1
B	2.5 KB	50:1
Avg	4.8 KB	27:1

Digitization of audio (analog) signals



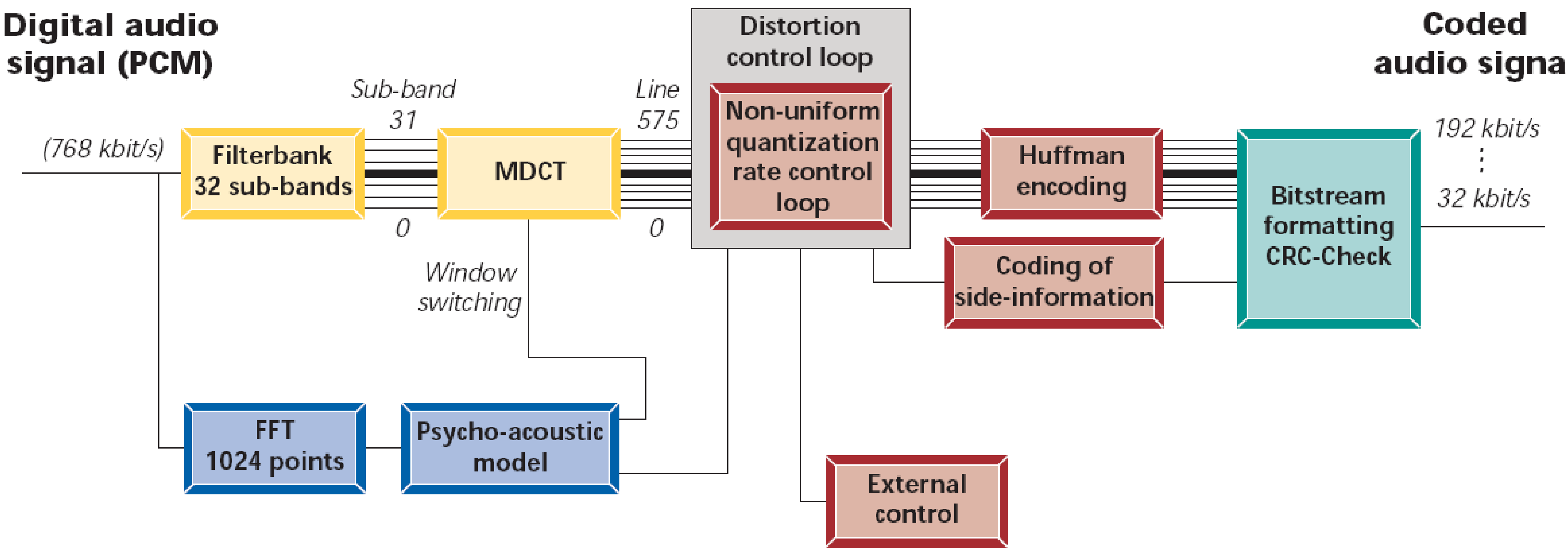
The signal is sampled (the intensity is measured) at fixed time intervals and the “curve” is replaced by a sequence of numbers

Digitization of audio (analog) signals

- The audio signal is a vibration that hits the human ear
- The (audio) signal can be considered as the sum of a series of sinusoidal signals, each with increasing frequency (Fourier theorem)
- The human ear can hear “vibrations” that go from 15-20 times per second (Hertz) to 20000 Hertz (20 KHz)
- Sampling rate should be at least the double of the highest frequency in the signal that we want to maintain (Shannon theorem)
- Sampling at 44 KHz will “keep” all the frequencies up to 20 KHz
- Transforming the “sequence of samples” back into an audio signal, the human ear will not detect that this signal has “lost” the higher frequencies

Representing audio

- MPEG-1 defines three different schemes (called *layers*) for compressing audio
- All layers support sampling rates of 32, 44.1 and 48 kHz
- Each sample 8-16 bits
- MP3 is MPEG-1 Layer 3



Multimedia file formats

- A muxer (abbreviation of multiplexer) is a “container” file that can contain several video and audio streams, compressed with codecs
  - Common file formats are AVI, DIVx, FLV, MKV, MOV, MP4, OGG, VOB, WMV, 3GPP
- A codec (abbreviation of coder/decoder) is a “system” (a series of algorithms) to compress video and audio streams
  - Common video codecs are HuffyYUV, FLV1, HEVC, Mpeg2, xvid4, x264, H264, H265
  - Common audio codecs are AAC, AC3, MP3, PCM, Vorbis