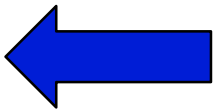
Welcome

Summer School
Digital Tools for Humanists

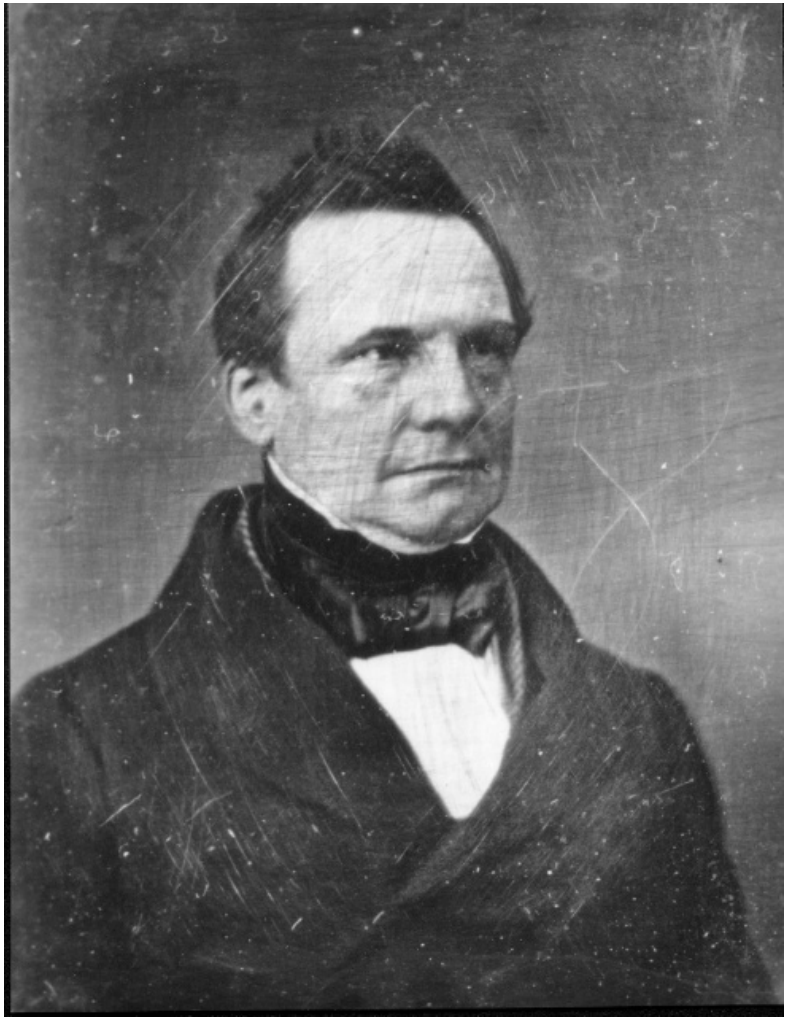
Pisa – May 25-30 2026

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

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 (1944)

- 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!

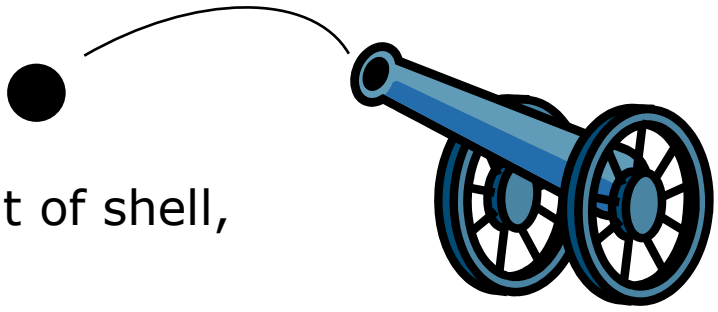
ENIAC (1943-1945)

- 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!

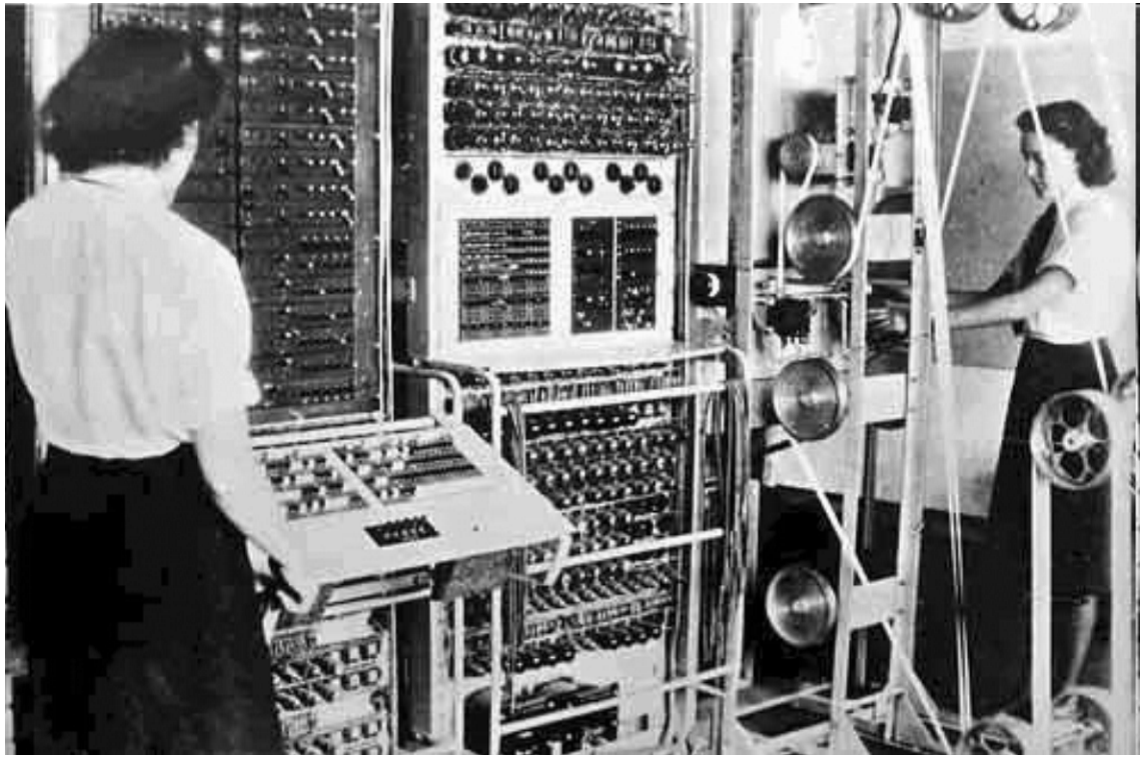
WW-2 Effort

Application: Ballistic calculations

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



Colossus (1943-1945)



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 (1944-1945)

- 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 (Electronic Discrete Variable Automatic Computer) to solve this problem
  - Solution was the ***stored program computer***

    $\Rightarrow$ *"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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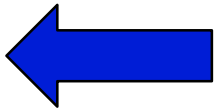
- Architecture of a computer 
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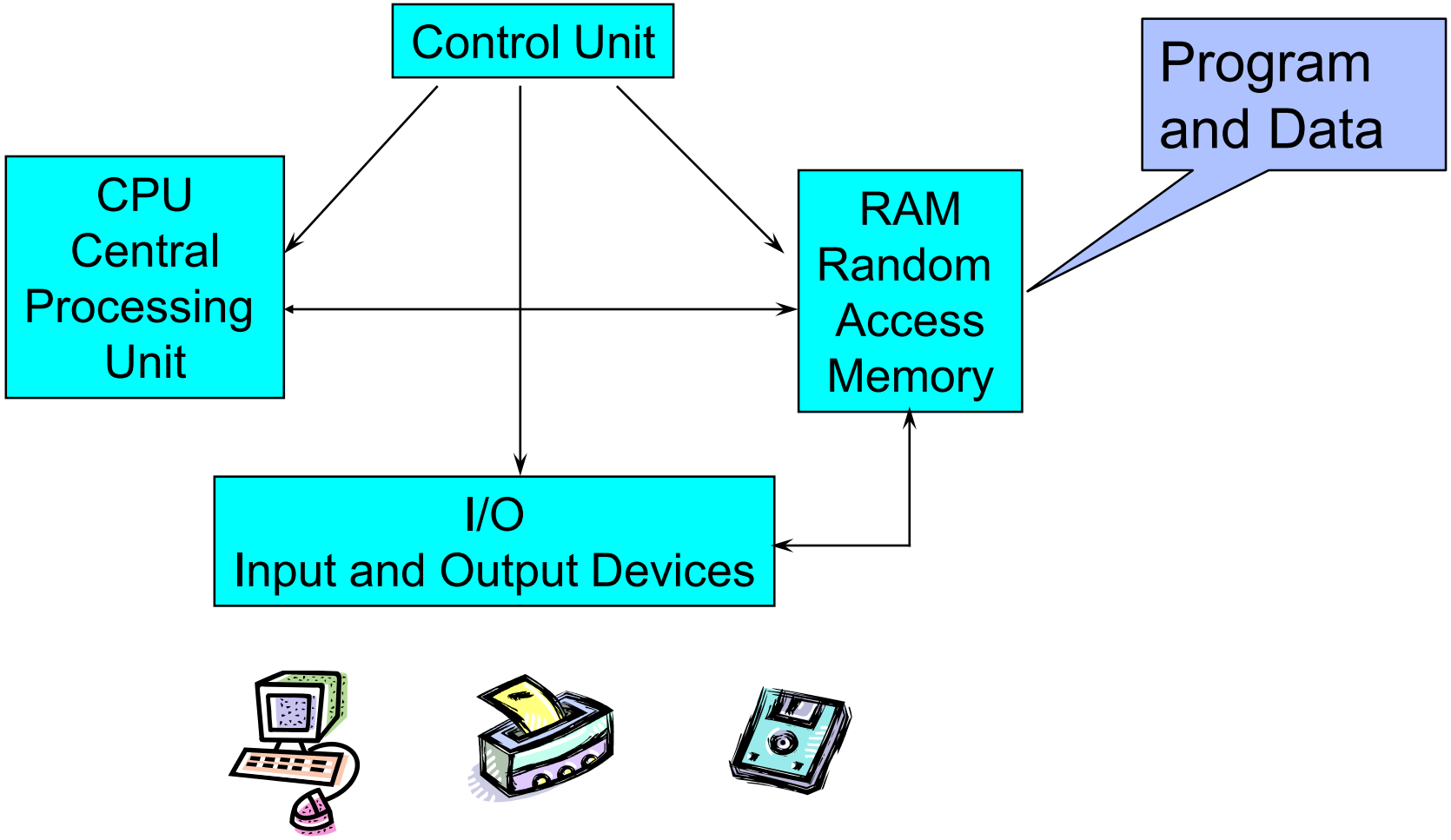
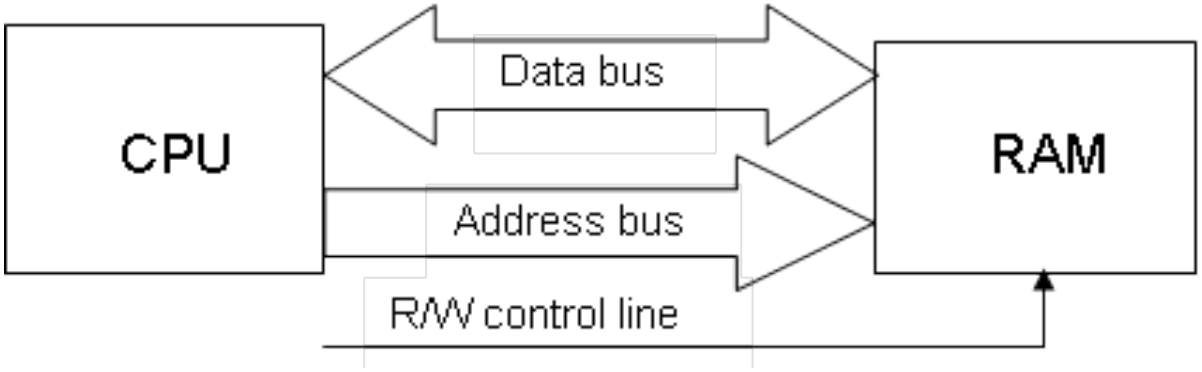
Von Neuman architecture



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



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

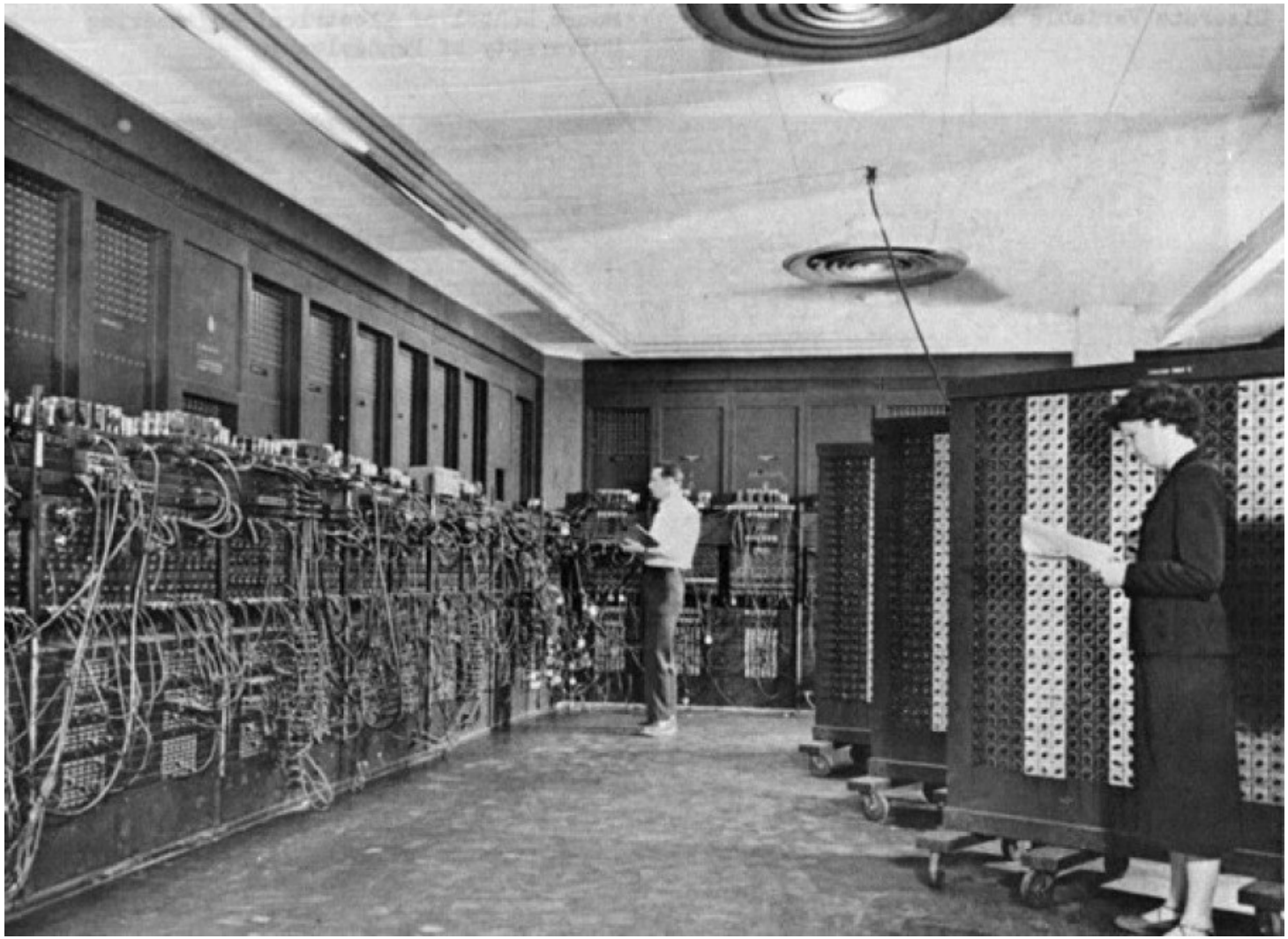
1000	k	kilo
1000^2	M	mega
1000^3	G	giga
1000^4	T	tera
1000^5	P	peta
1000^6	E	exa
1000^7	Z	zetta
1000^8	Y	yotta

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

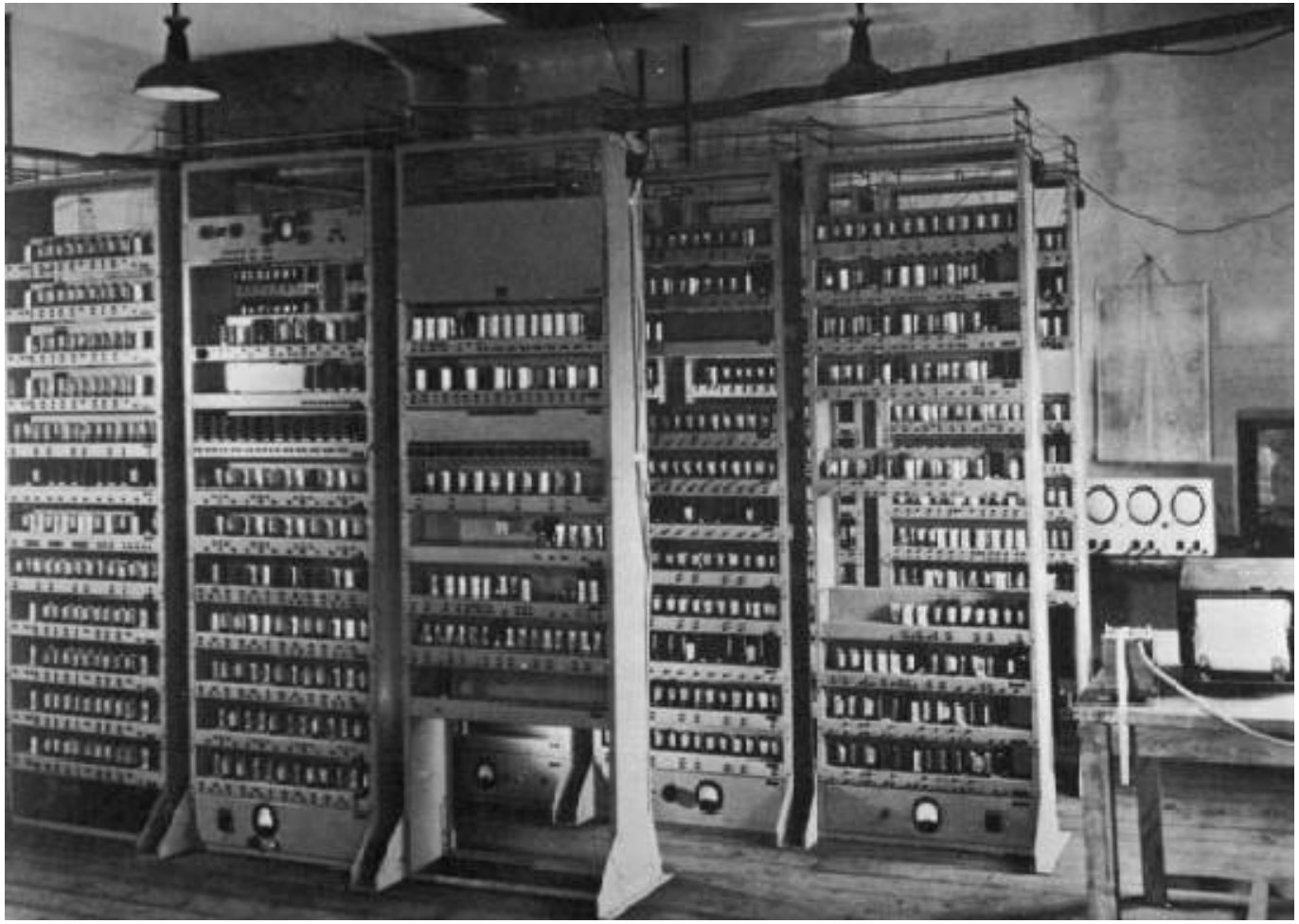
Harvard Mark I, 1943

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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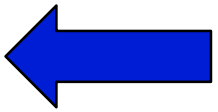
- Data representation within a computer 
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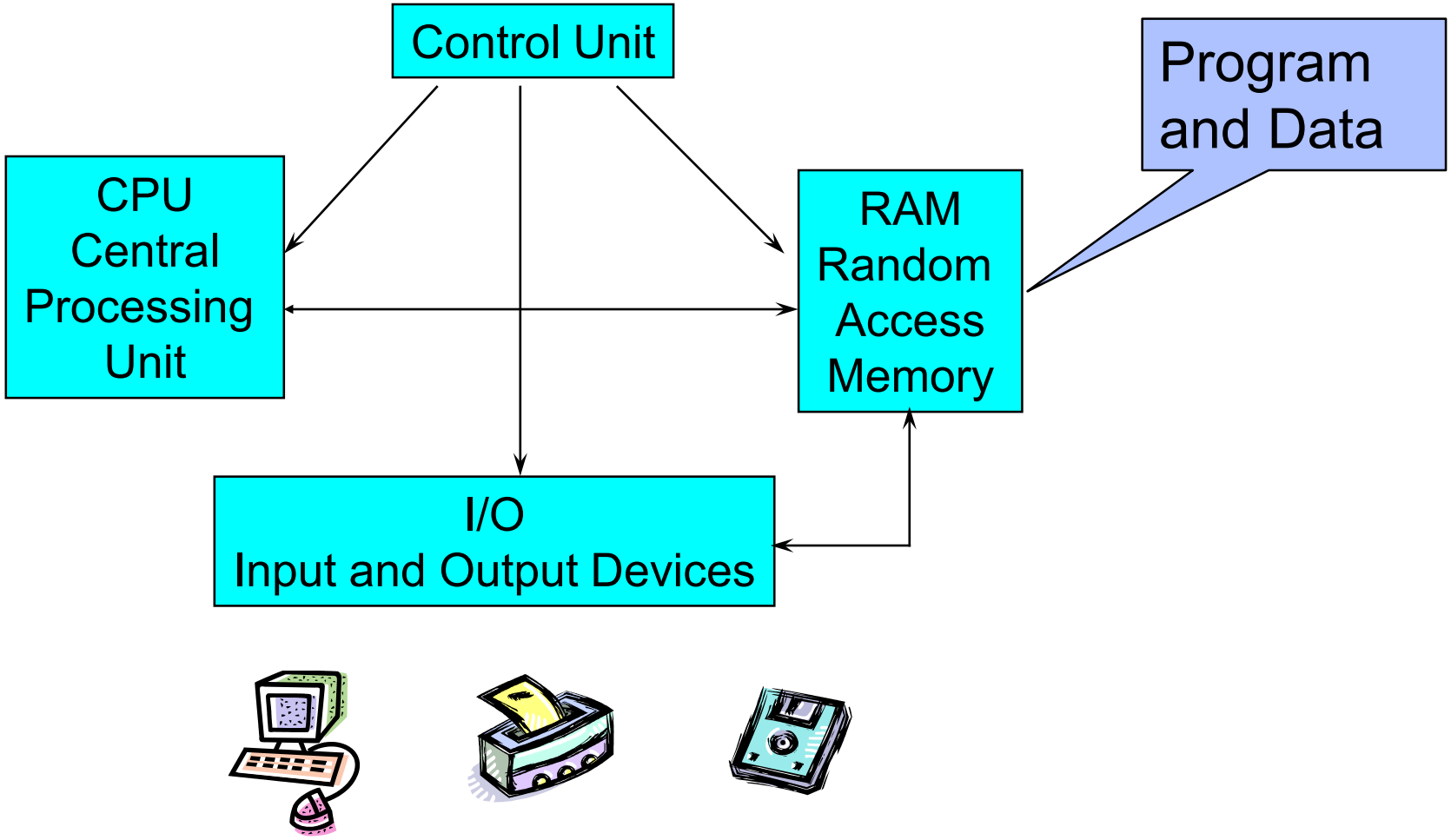
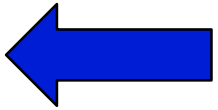
Von Neuman architecture



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

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

$3x10^2 + 4x10^1 + 7x10^0 = 347$

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

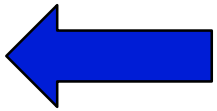
$1x2^3 + 0x2^2 + 1x2^1 + 1x2^0$

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

$8 + 0 + 2 + 1 = 11$

Representation of information within a computer

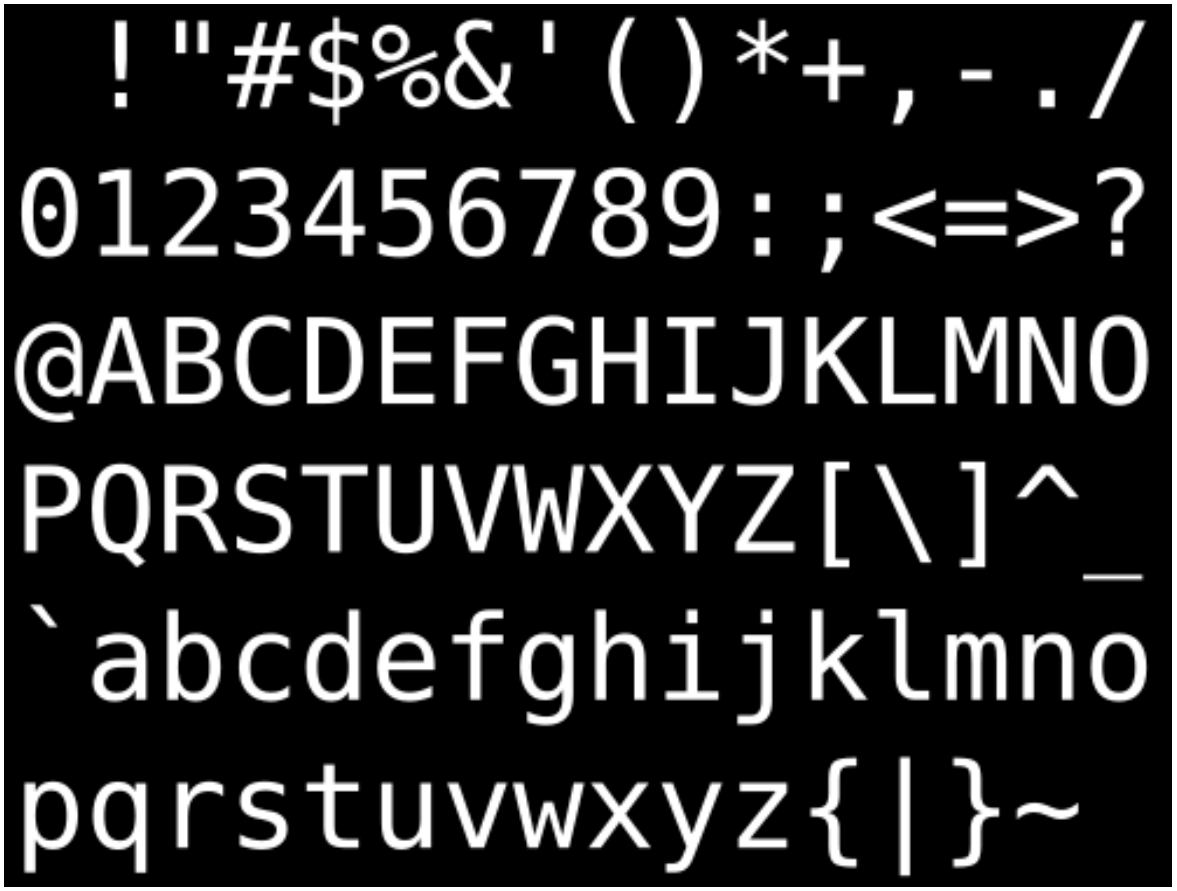
- Numbers
- Text (characters and ideograms)
- Images
- Video and Audio



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	□

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 (one byte); 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 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: U+hex value) 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

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

Representation of information within a computer

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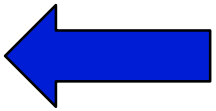
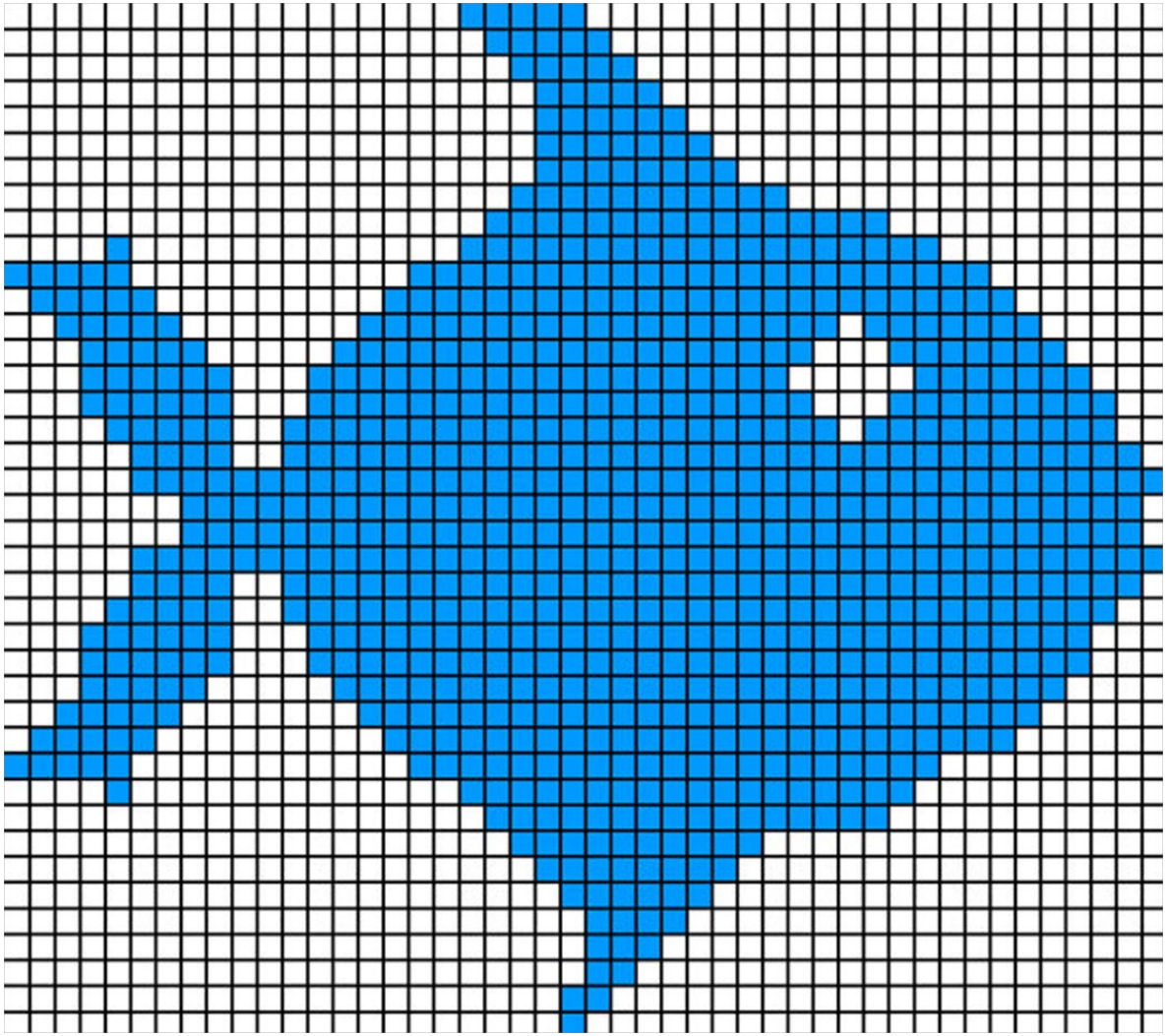
- Text (characters and ideograms)
- Images 
- Video and Audio

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.

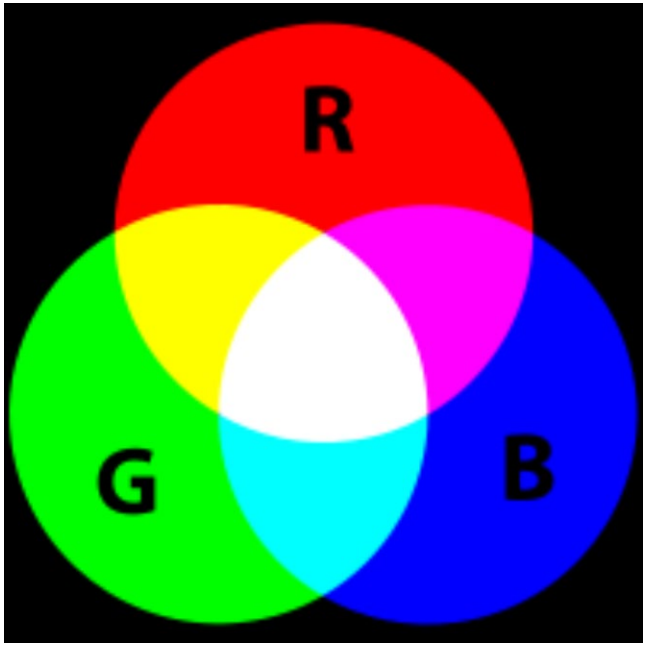
Raster format

- 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

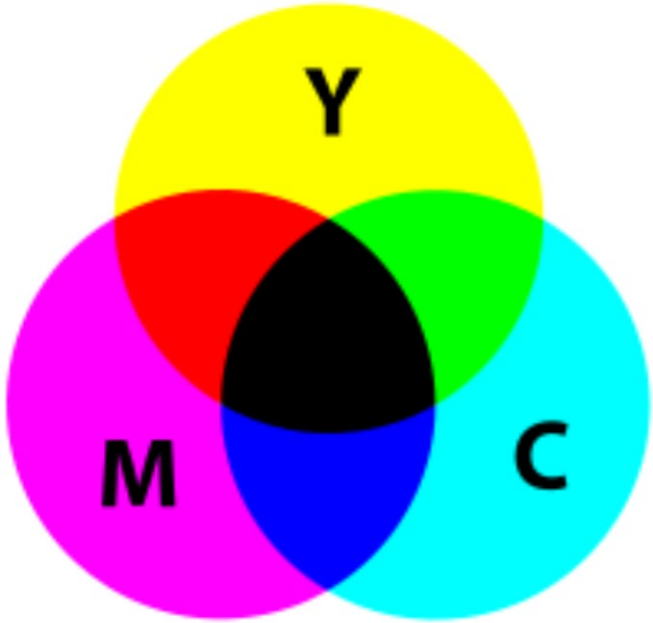
Raster format

- 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)
  - 24-48 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



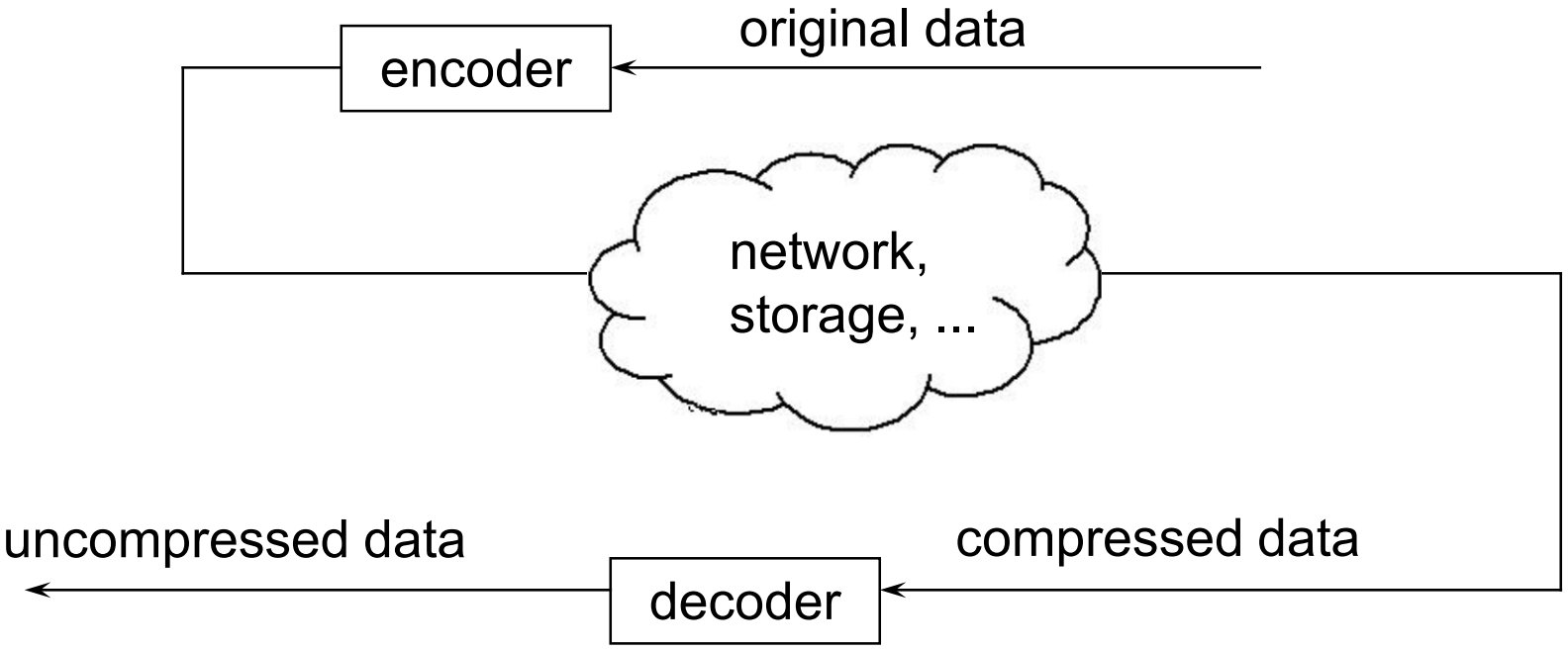
Subtractive color mixing

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

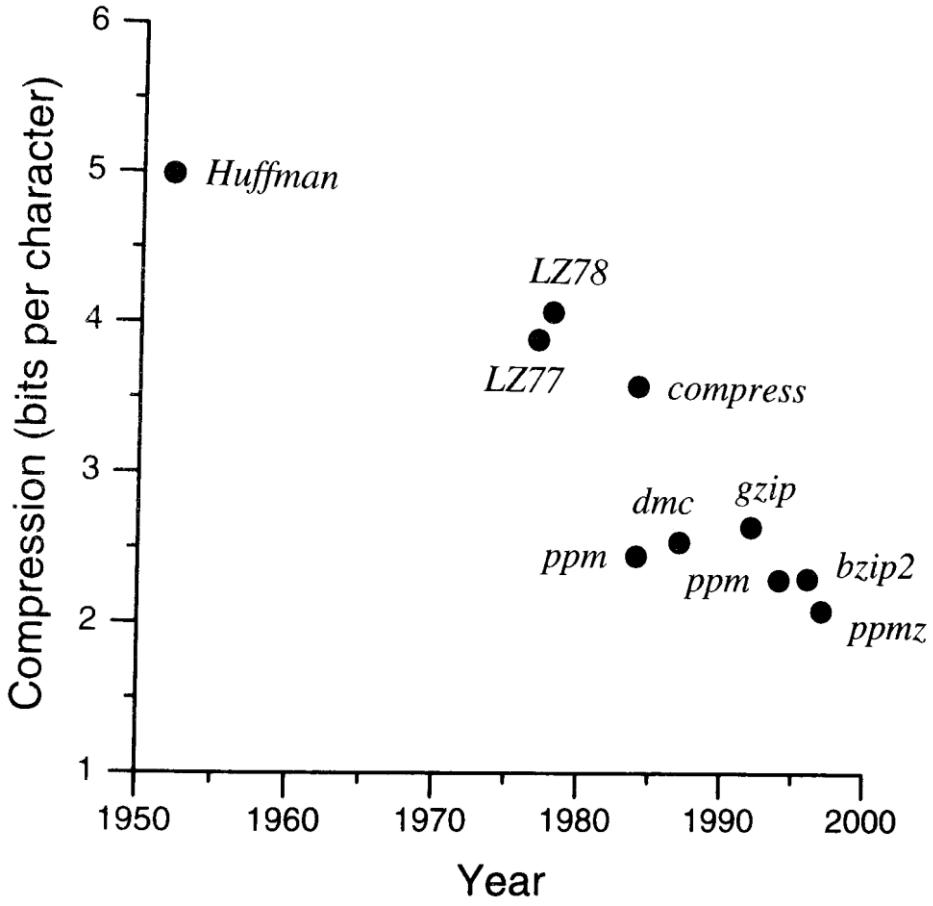
Compression of information



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)

Comparison of lossless compression methods



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  - GIF, PNG (simple graphics)
- Lossy compression
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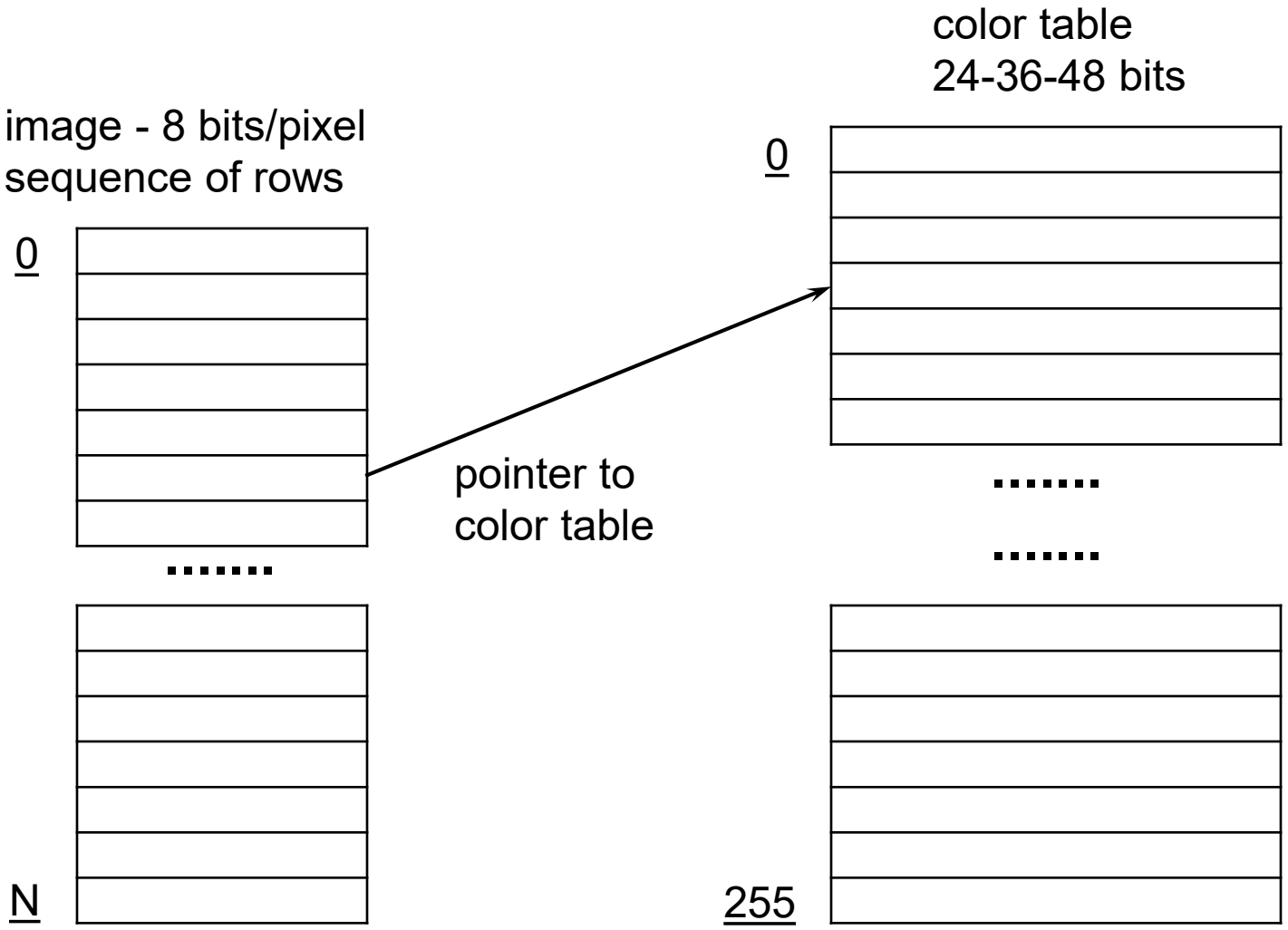
  - IIIF

Pixel representation in GIF



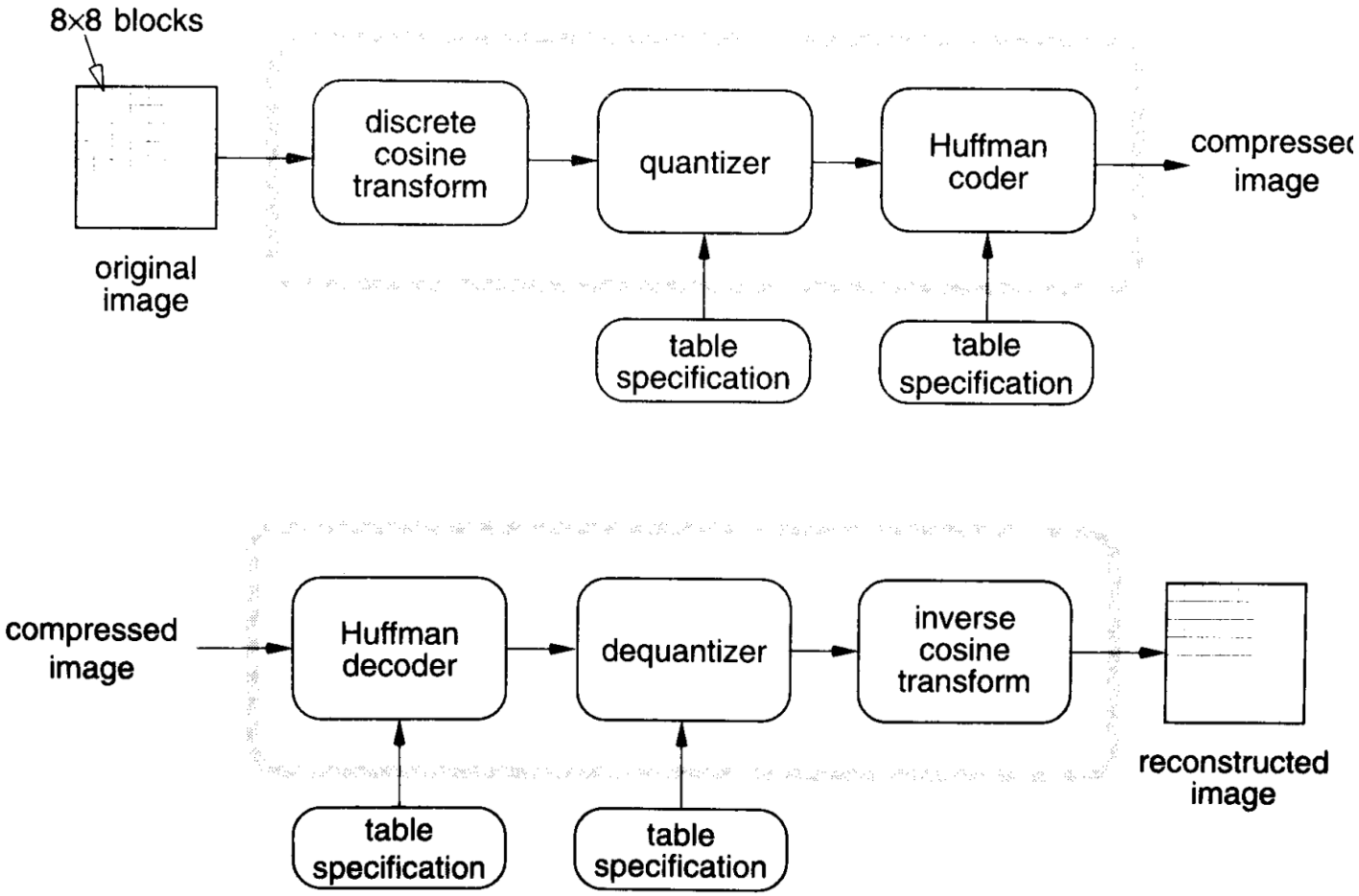
Common raster image file formats

- 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

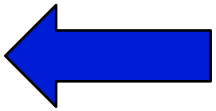
JPEG

- 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



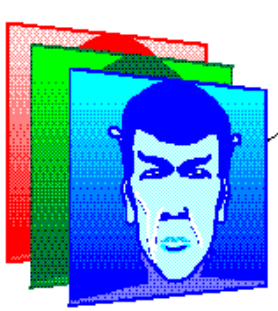
Representation of information within a computer

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

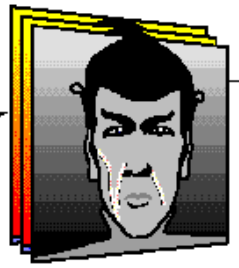
Representing video

- 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)



RGB



YUV

Blocks

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

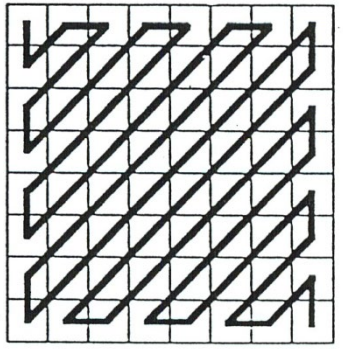
Discrete Cosine Transform

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

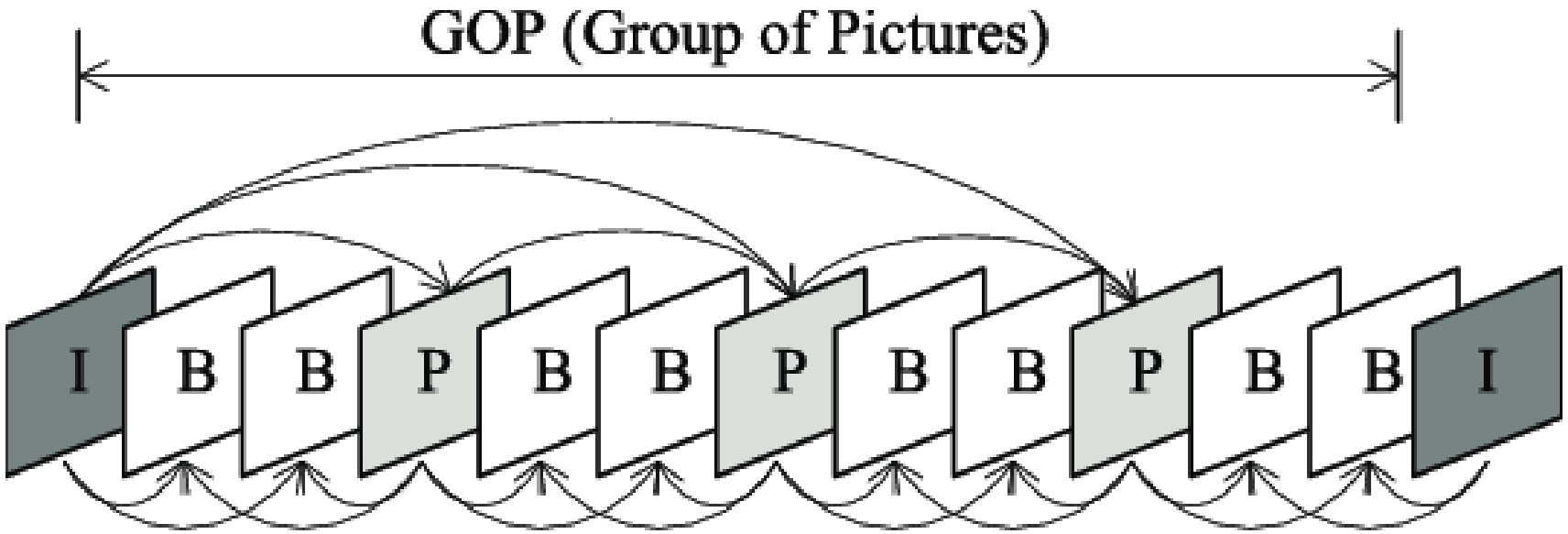
Quantization
- major reduction
- controls ‘quality’

Zig-Zag Scan, Run-length coding



“Intra-Frame Encoded”

Temporal Redundancy Reduction

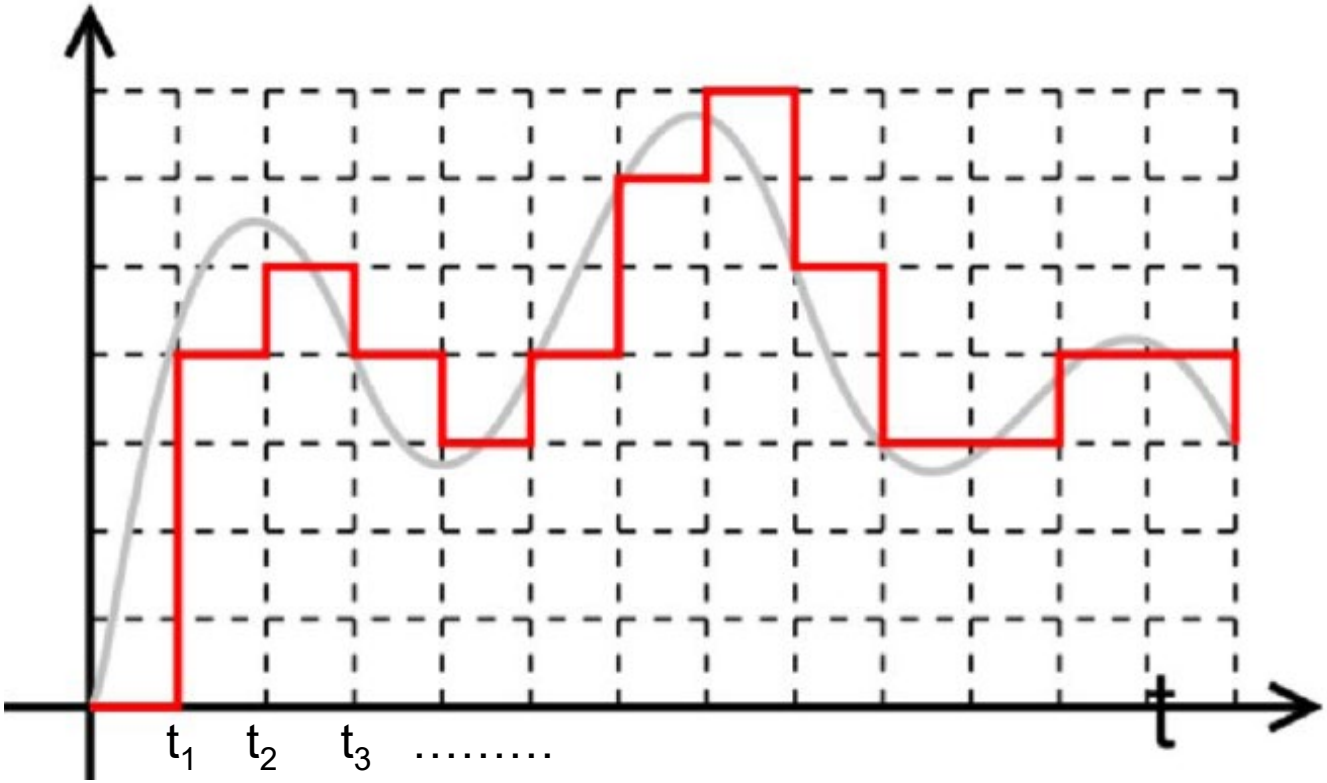


- *I* frames are independently encoded (JPEG like)
- *P* frames are based on previous I and P frames
- *B* frames are based on previous and following I and P frames

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



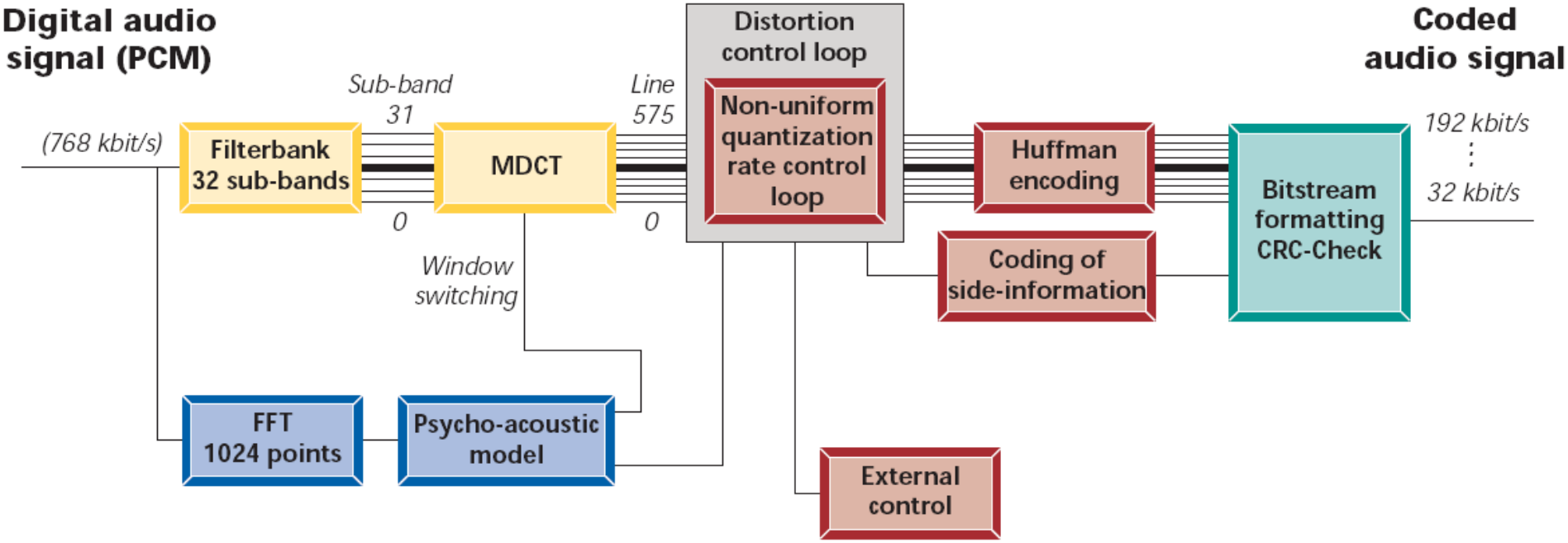
The signal is sampled (the intensity is measured) at fixed time intervals and the “curve” is replaced by a sequence of numbers

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 about 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