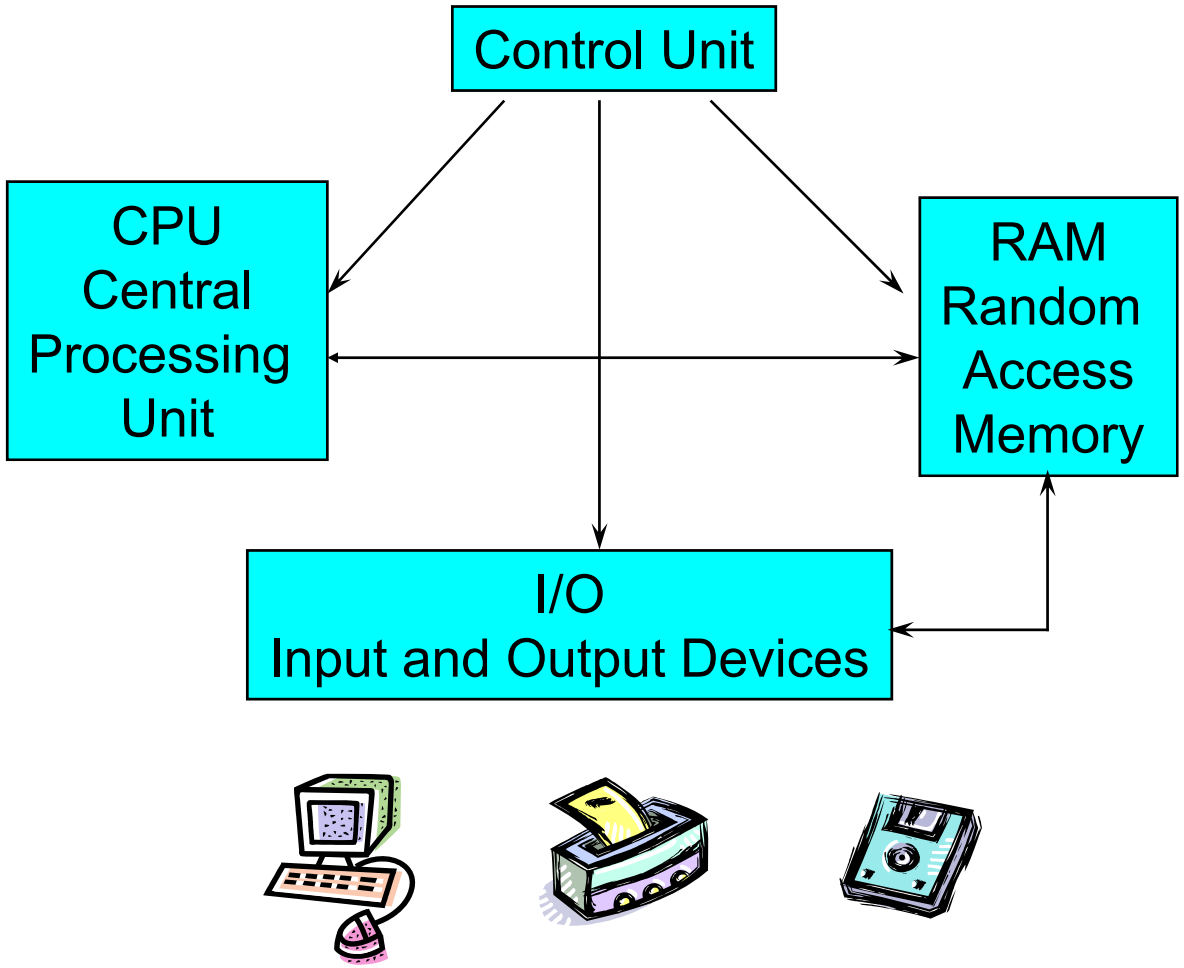
Representation of Information within a computer (digital information)

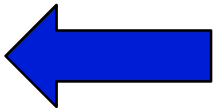
Basic components of a computer



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 with 0s and 1s, i.e. in “binary notation”

Representation of information within a computer

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

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

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

$8 + 0 + 2 + 1 = 11$

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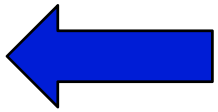
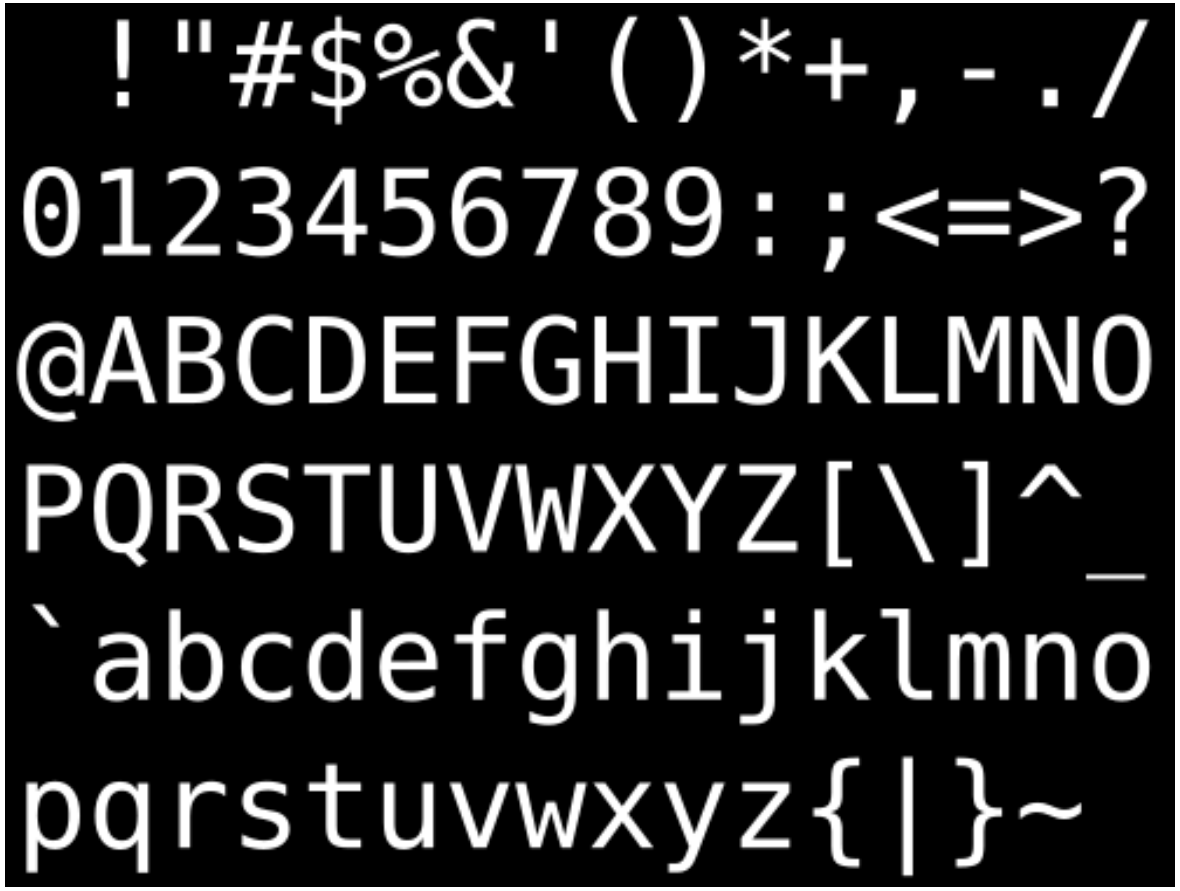


The ASCII characters



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	□

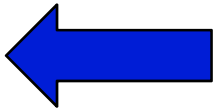
Representation standards

- 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; 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

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, most often one byte)
  - 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

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

Welcome

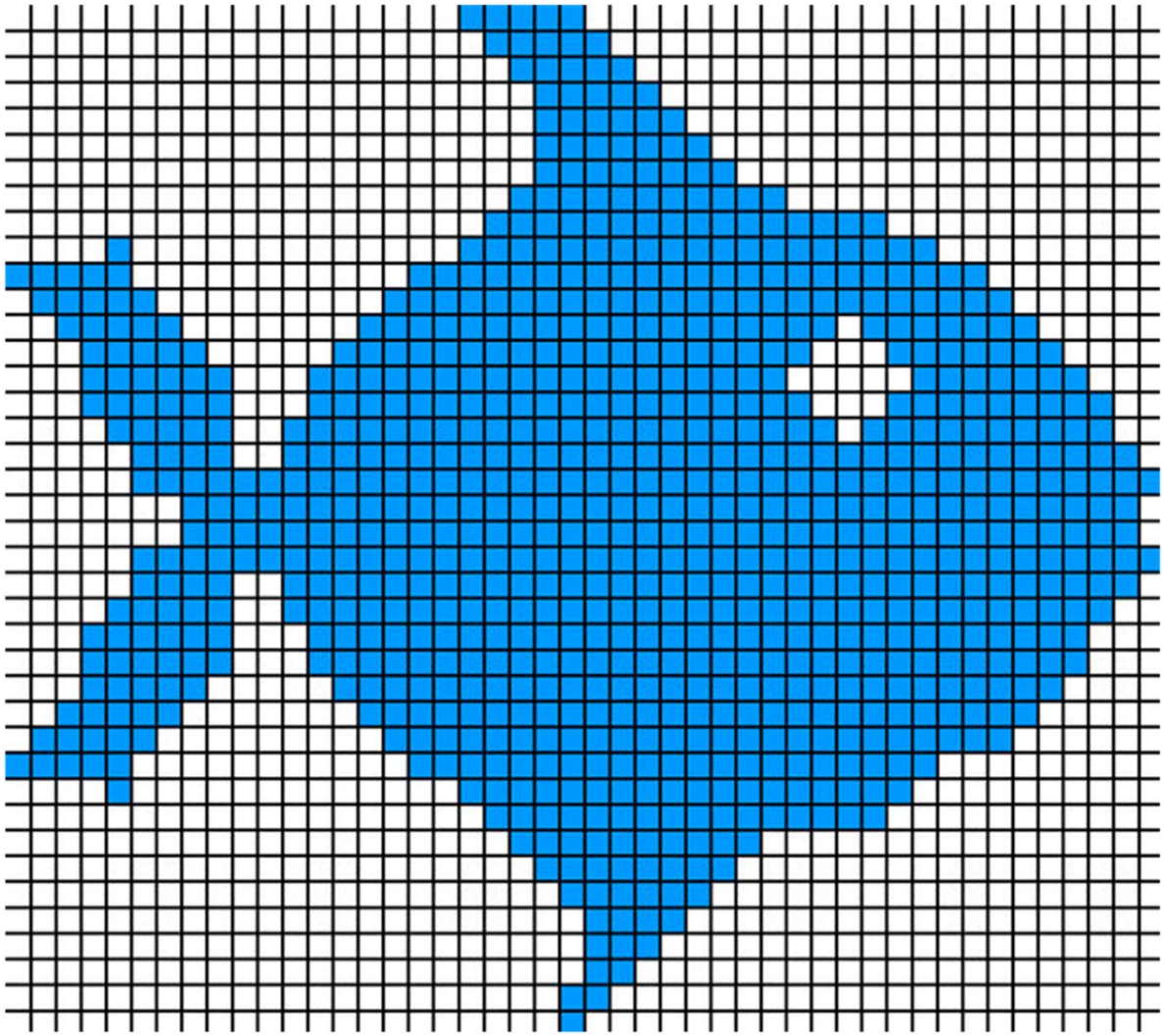
Welcome to image representation and compression

Representation of images

- Vector formats (geometric description)
  - Postscript
  - PDF
  - SVG (Scalable Vector Graphics)
  - SWF (ShockWave Flash)
    - from FutureWave Software to Macromedia to Adobe
    - vector-based images, plus audio, video and interactivity
    - can be played by Adobe Flash Player (browser plug-in or stand-alone)

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

Picture elements (pixels)

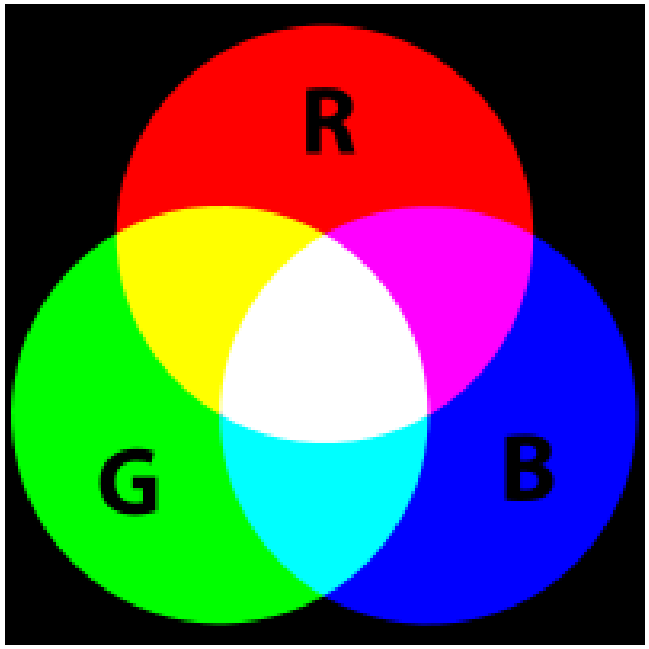


A pixel must be small enough so that its color can be considered uniform for the whole pixel.
Inside the computer, a pixel is represented with a number representing its color.

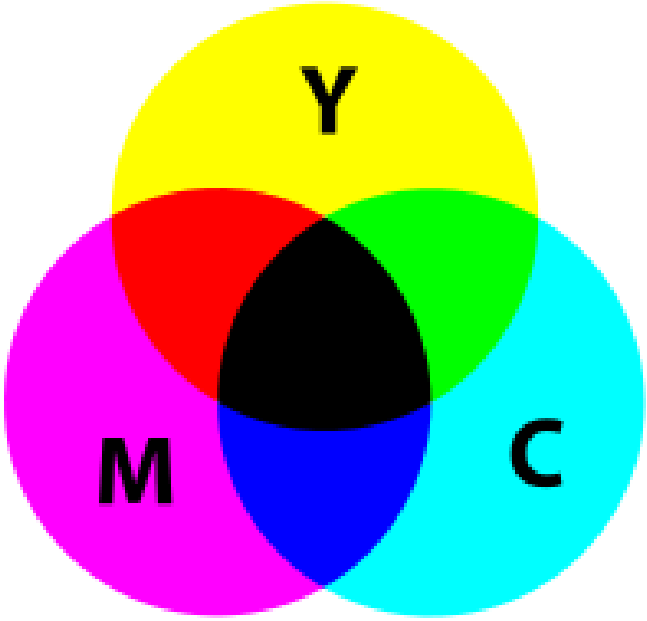
Raster format

- In raster format an image (picture) is represented by a matrix of “pixels”
- Colors are represented by three numbers, one for each “color component”
- The quality of a picture is determined by:
  - The number of rows and columns in the matrix
    - Very often it is expressed as “dots per inch” (dpi)
    - 200-4800 dpi (most common ranges)
  - The number of bits representing one pixel (called depth)
    - 1 bit for black and white
    - 8-16 bits for gray scale (most common ranges)
    - 12-48 bits for color images (most common ranges)
- 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

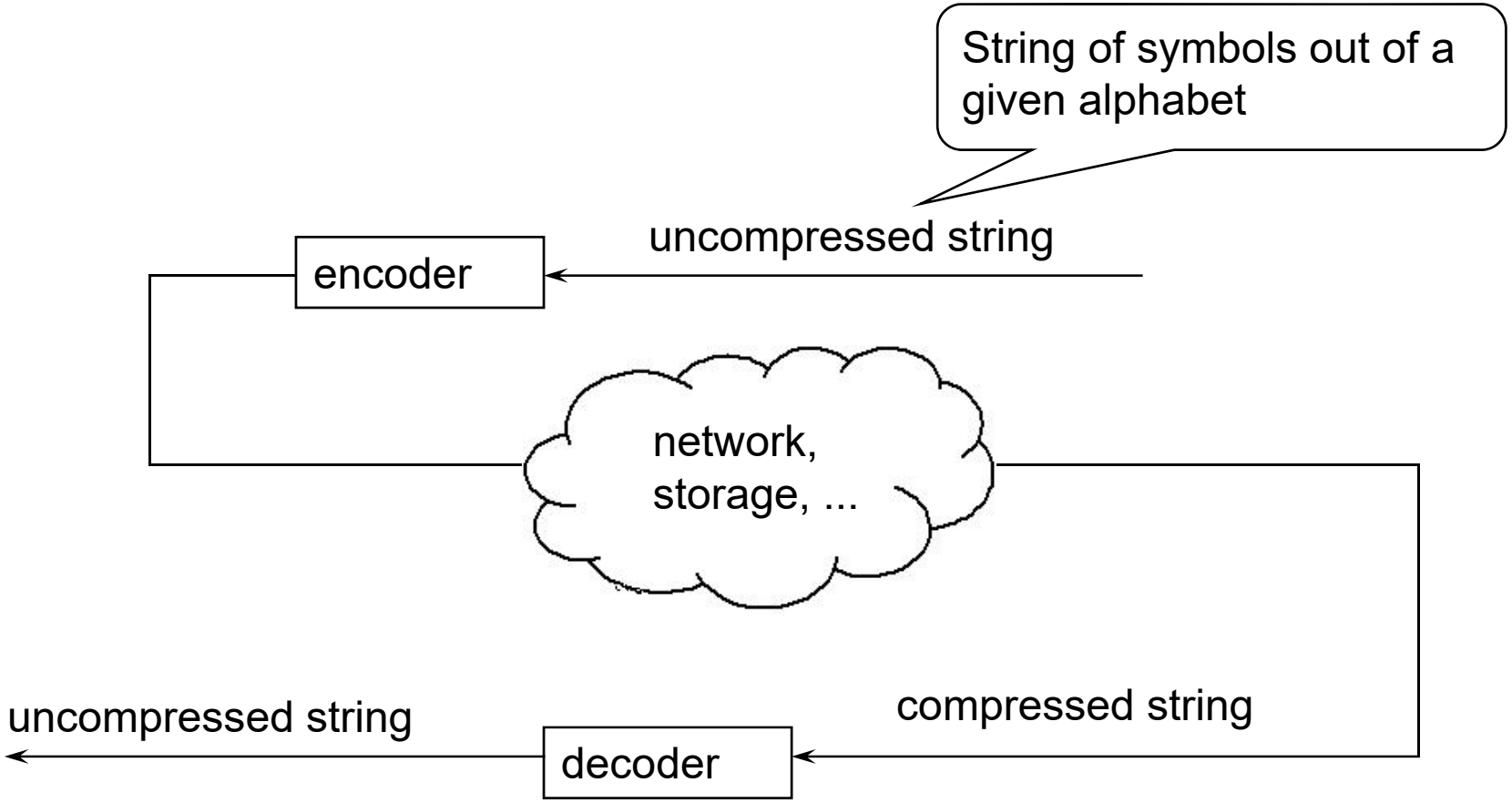


Subtractive color mixing

Common raster image file formats

- Big file sizes for (uncompressed color) pictures. Compression is needed
- Lossless compression
  - G3, G4, JBIG
  - GIF, PNG
- Lossy compression
  - JPEG
- Image containers
  - TIFF
- BMP, RAW (sensor output), DNG (Digital Negative), etc.

Compression process



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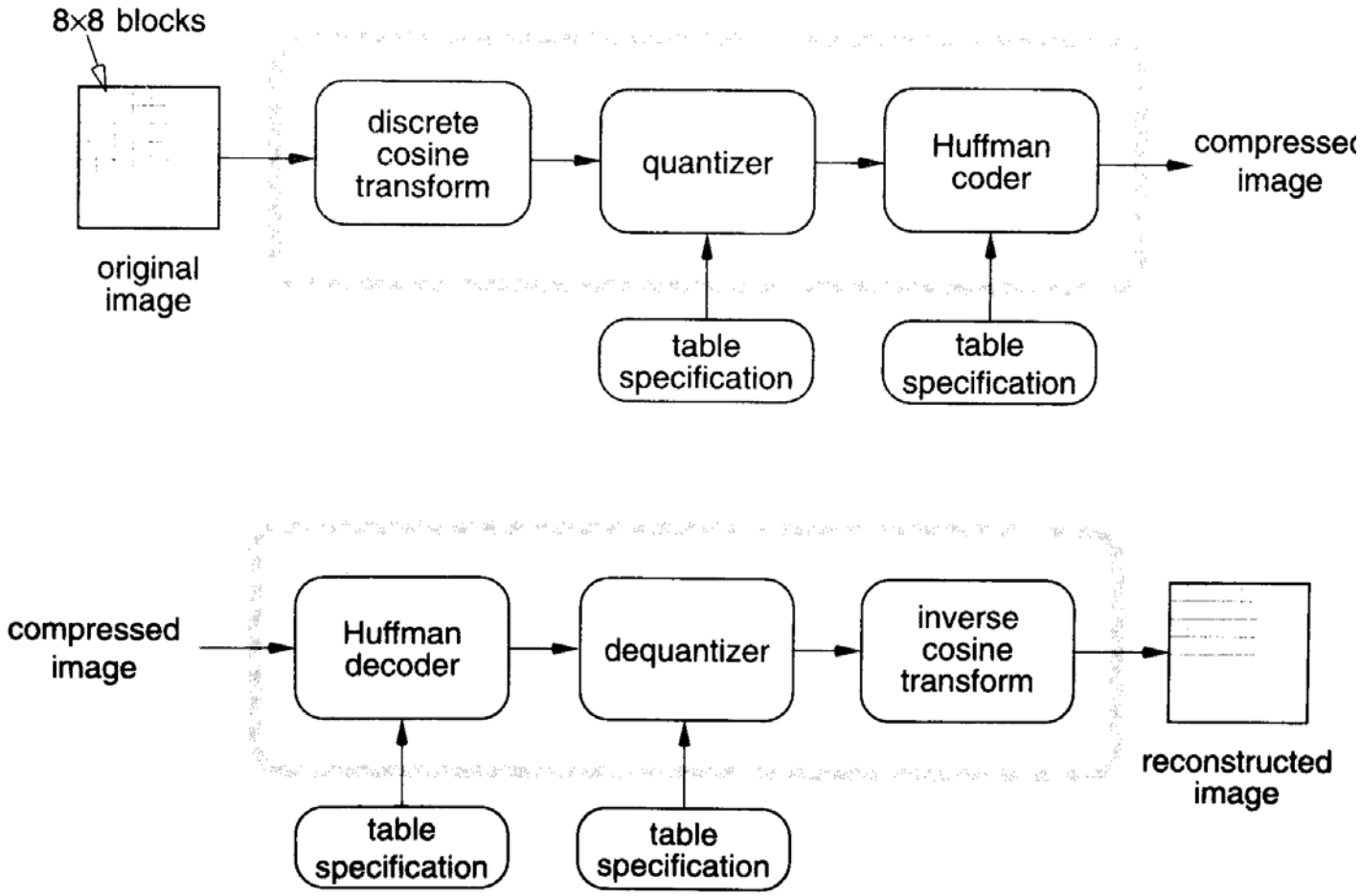
JPEG

- 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
- The encoding and decoding process is done on an 8x8 block of pixels (separately for each color component)
- Compression rates
  - 0.25–0.5 bit/pixel: moderate to good quality, sufficient for some applications
  - 0.5–0.75 bit/pixel: good to very good quality, sufficient for many applications
  - 0.75–1.5 bit/pixel: excellent quality, sufficient for most applications
  - 1.5–2 bits/pixel: usually indistinguishable from the original, sufficient for the most demanding applications

JPEG encoding and decoding



JPEG – Final comments

- Arithmetic coding instead of Huffman coding (10% improvement in compression)
- JPEG-2000 - Use of wavelets instead of DCT (20% improvement in compression, better quality for images with sharp edges)
- JPEG-LS – state of the art lossless compression
  - For each pixel, what is coded is the difference between the actual pixel value and a prediction of pixel value based on the pixel context
- Compression rates
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  - 0.5–0.75 bit/pixel: good to very good quality, sufficient for many applications
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Common raster image file formats

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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

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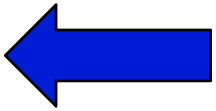
- Video 
- Audio

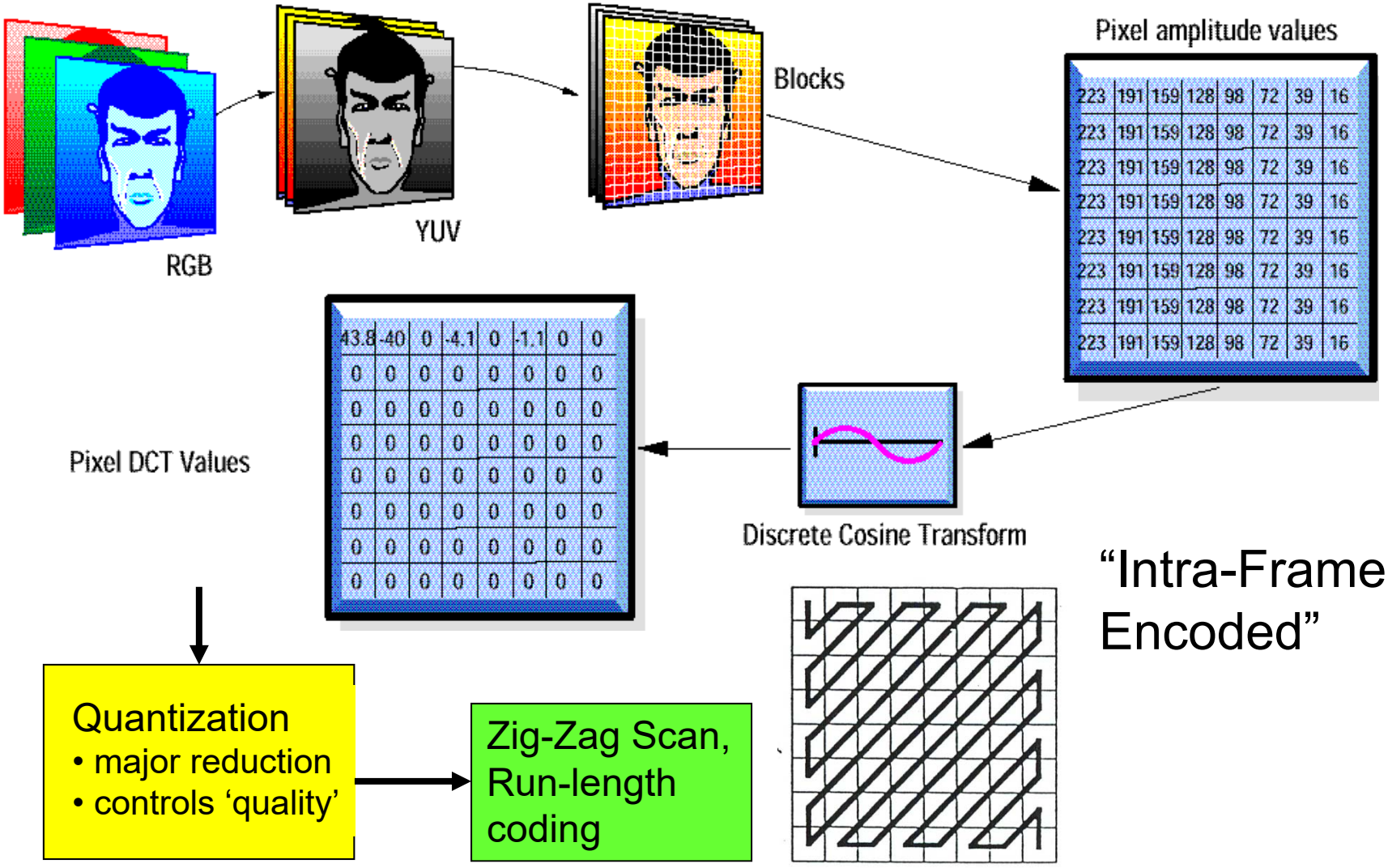
Representing video

- 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. 1920x1080x24x30 = ~ 1,5 GB/sec
- It is possible to obtain very high compression rates
  - Spatial redundancy (within each frame, JPEG-like)
  - Temporal redundancy (across frames)

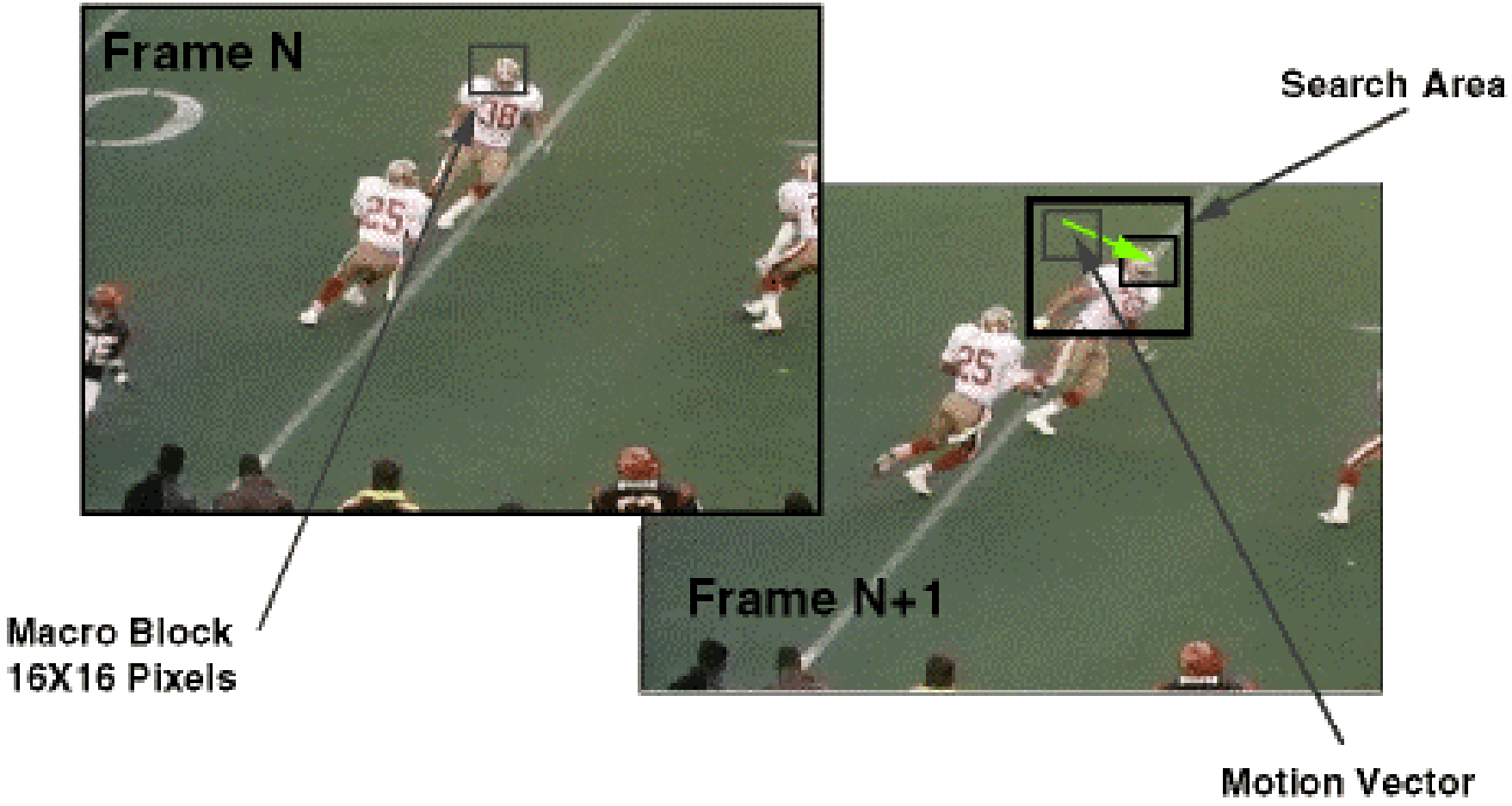
MPEG

- MPEG - Motion Picture Experts Group established in 1988 as a committee of ISO to develop an open standard for digital TV format (CD-ROM)
- Business motivations
  - Two types of application for videos:
    - Asymmetric (encoded once, decoded many times)
      - Broadcasting, CD's
  - Video games, Video on Demand
    - Symmetric (encoded once, decoded once)
      - Video phone, video mail …
- Design point for MPEG-1
  - Video at about 1.5 Mbits/sec
  - Audio at about 64-192 kbits/channel

Spatial Redundancy Reduction (DCT)



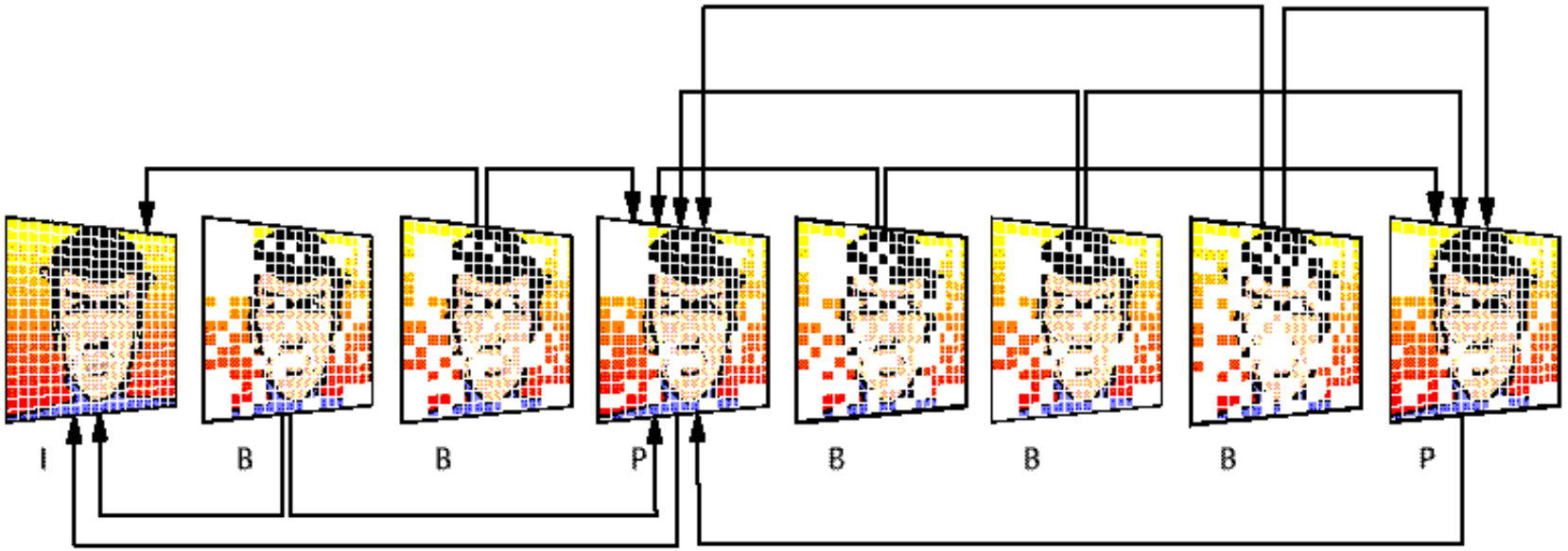
Temporal Redundancy Reduction (motion vectors)



Types of frames in compression

- MPEG uses three types of frames for video coding (compressing)
  - I frames: intra-frame coding
    - Coded without reference to other frames
    - Moderate compression (DCT, JPEG-like)
    - Access points for random access
  - P frames: predictive-coded frames
    - Coded with reference to previous I or P frames
  - B frames: bi-directionally predictive coded
    - Coded with reference to previous and future I and P frames
    - Highest compression rates

Temporal Redundancy Reduction



- *I* frames are independently encoded
- *P* frames are based on previous I and P frames
- *B* frames are based on previous and following I and P frames

Sequence of frames

Frame number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	...
Frame type	I	B	B	P	B	B	P	B	B	P	B	B	I	B	B	P	B	B	...

12-unit cycle

(a)

Encoded frame order	1	4	2	3	7	5	6	10	8	9	13	11	12	16	...
Frame type	I	P	B	B	P	B	B	P	B	B	I	B	B	P	...

(b)

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

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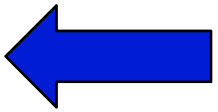
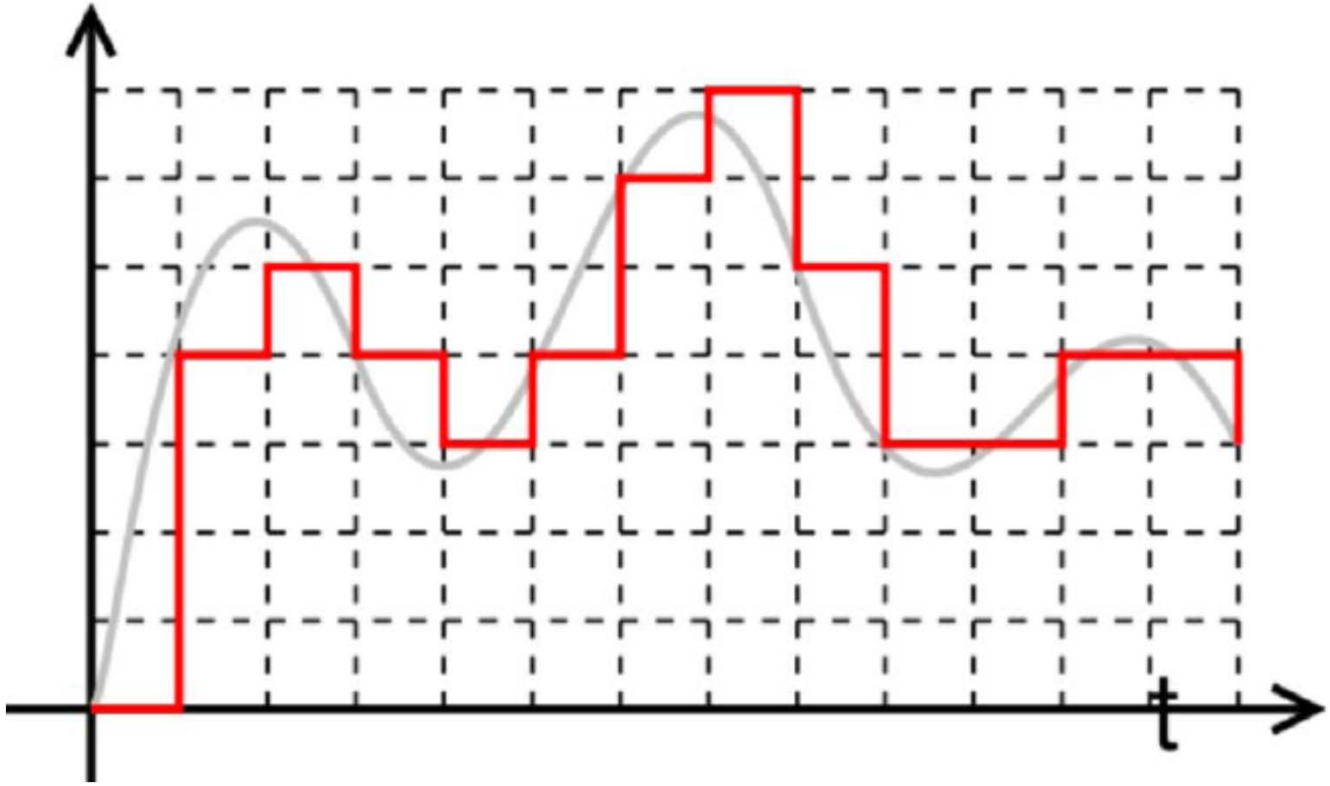
- Audio 

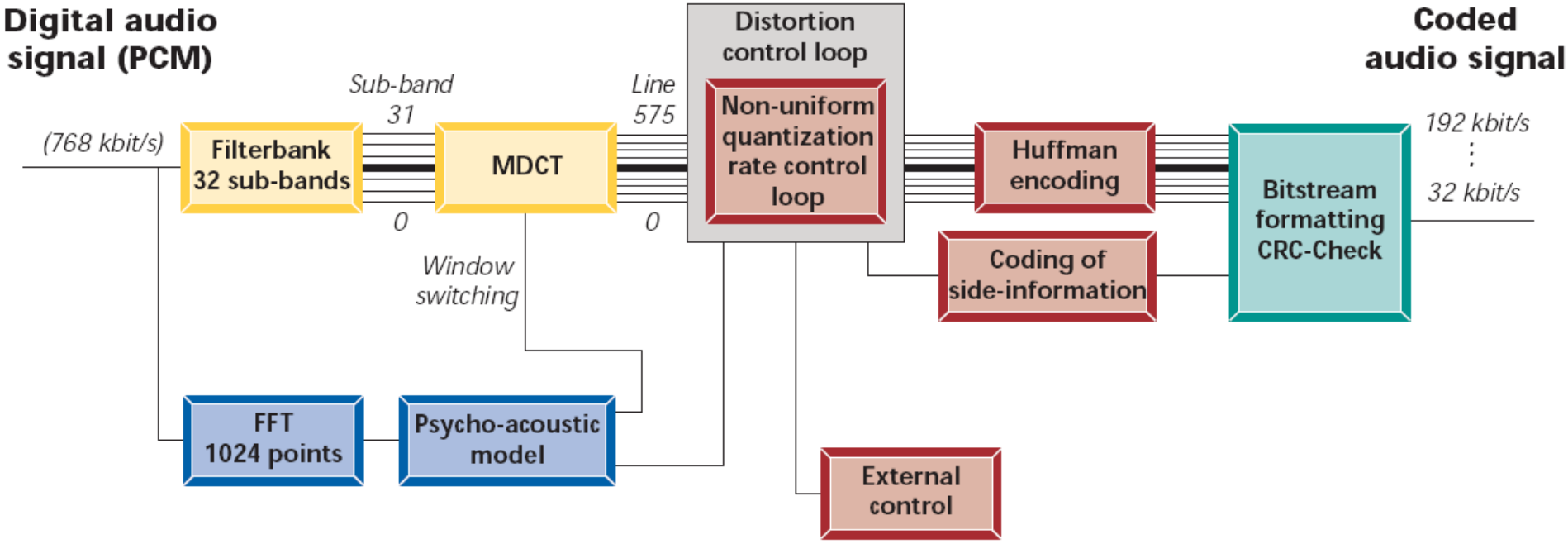
Digitization of audio (analog) signals



• sampling rate should be at least the double of the highest frequency in the signal (Shannn theorem)
•8-16 bit per sample

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
- 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