1 4 Information and Information Technology

- Definition of Information
- Boole functions
- Multivalued Logic
- Signal processing of biological neurons
- Requirements of logic devices
- Physical limits of computation

1 4.1 Definition and Processing of Information

Reading: „Big Blue Book“, General Introduction

Smallest, irreducible elements of a language are **characters**

Type of Information	Basic Set of Characters (alphabet)	Number of Basic Characters
Morse code	○ – space	3
written English language	letters a b … z A B … Z digits 0 1 … 9 punctuation , . ! ? …	111 printable ASCII characters
CJK-Ideograms (Chinese, Japanese, Korean)	*examples* 金 鉄 家 道 …	27.496 (Unicode v. 3.0)
decimal numbers	0 1 2 3 4 5 6 7 8 9	10

binary numbers	0 1 *alternatively* false true *other alternatives*	2
hexadecimal numbers	0 1 2 3 4 5 6 7 8 9 A B C D E F	16
genetic DNA code	base groups A(denine) C(ytosine) G(uanine) T(hymine)	4
classical music	Frequencies 12 notes per octave 6 octaves Amplitudes 5 levels Duration 6 values	12 x 6 5 6
general sound	any frequency in the range 20 Hz to 20 kHz any amplitude from 0 dB to 120 dB	continuous
printed images	pixel (size depending on print technique) color	discrete or
smells	chemial compounds ❍ volatile ❍ excitable to olfactory nerve cells	$> 10^5$

Alphabet (Code) = Basic set of characters of a language

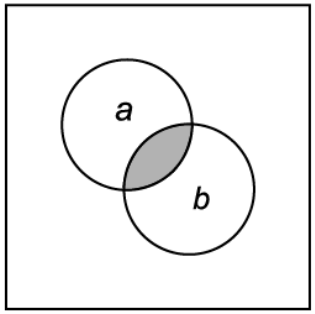
Information

$$I = -k \ln p$$

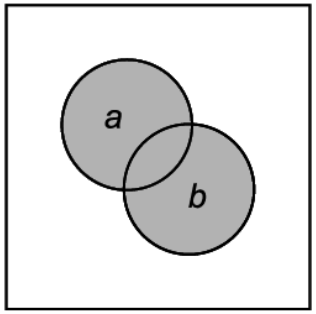
$$\Omega = N^m$$

$$p = \frac{1}{N^m}$$

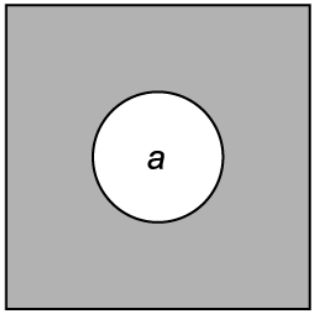
Algebra of sets



intersection
$a \cap b$

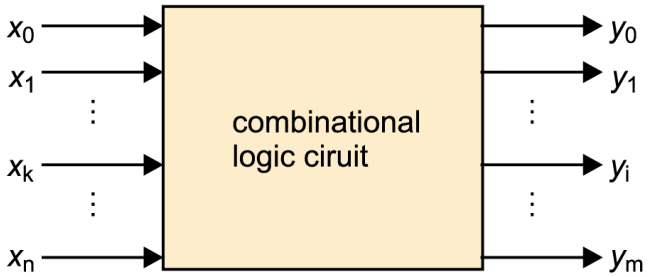


union
$a \cup b$



complement
$\bar{a}$

Basic circuits

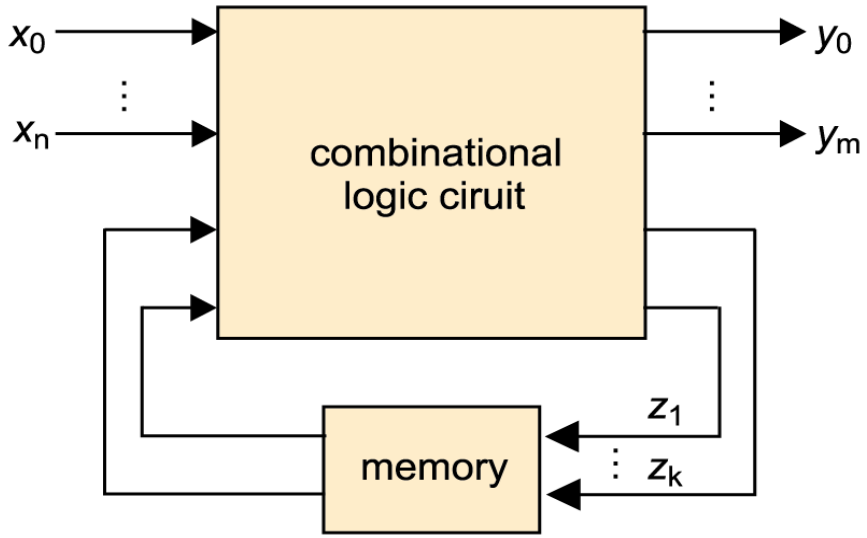


Boole´s Function with two Input Variables

x_0 a	0	0	1	1	realized
x_1 b	0	1	0	1	by
f_0	0	0	0	0	0
f_1	0	0	0	1	$x_0 \bullet x_1$
f_2	0	0	1	0	$x_0 \bullet \overline{x}_1$
f_3	0	0	1	1	x_0
f_4	0	1	0	0	$\overline{x}_0 \bullet x_1$
f_5	0	1	0	1	x_1
f_6	0	1	1	0	$x_0 \bullet \overline{x}_1 + \overline{x}_0 \bullet x_1$
f_7	0	1	1	1	$x_0 + x_1$
f_8	1	0	0	0	$\overline{x}_0 \bullet \overline{x}_1$
f_9	1	0	0	1	$x_0 \bullet x_1 + \overline{x}_0 \bullet \overline{x}_1$
f_{10}	1	0	1	0	$\overline{x}_1$
f_{11}	1	0	1	1	$\overline{x}_1 + x_0$
f_{12}	1	1	0	0	$\overline{x}_0$
f_{13}	1	1	0	1	$\overline{x}_0 + x_1$
f_{14}	1	1	1	0	$\overline{x}_0 + \overline{x}_1$
f_{15}	1	1	1	1	1

Further reading: „Big Blue Book“, General Introduction

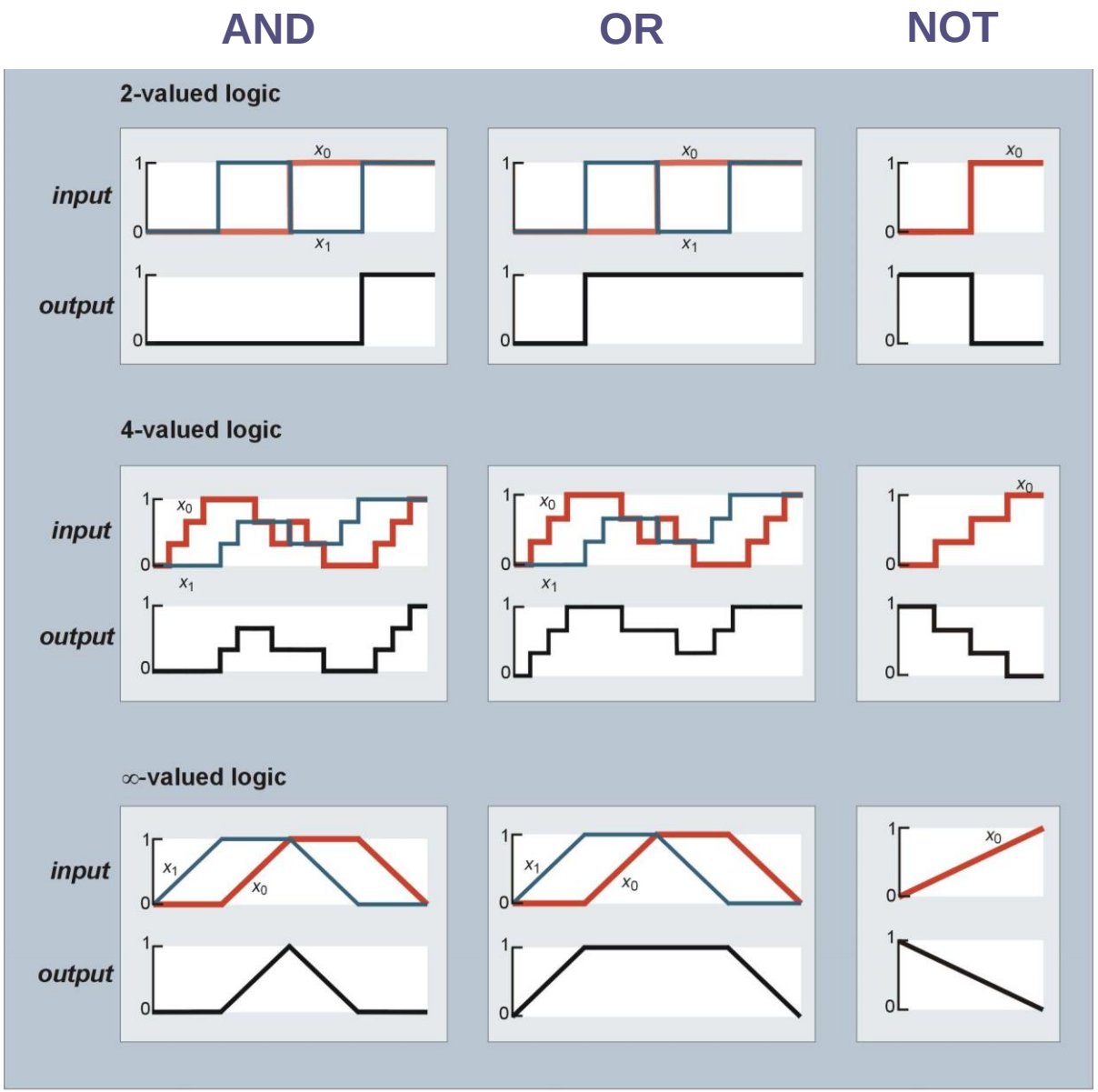
Basic circuits (cont.)



sequential logic ciruit

Further reading: „Big Blue Book“,
General Introduction

Multivalued logic



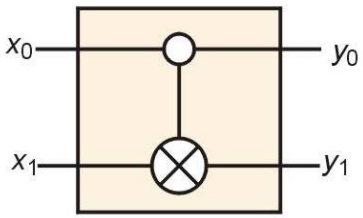
Reversible logic gates

- Irreversible logic gates:
  indispensible loss of information
- Reversible logic gates:
  no loss of information
  -> no loss of energy (ideal case)

Simplest example: NOT gate

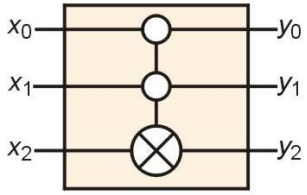
NOT	output states 0	1
input states 0	0	1
1	1	0

C-NOT gate



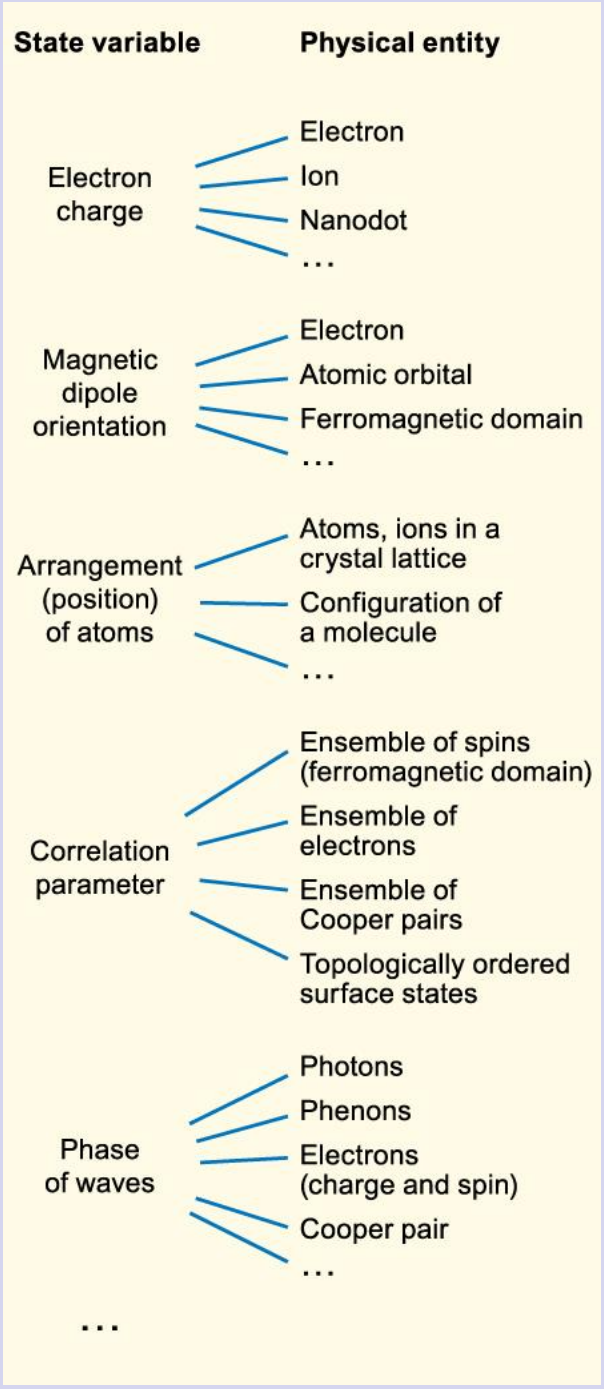
C-NOT	output states y_0y_1 00	01	10	11
input states x_0x_1 00	1	0	0	0
01	0	1	0	0
10	0	0	0	1
11	0	0	1	0

CC-NOT

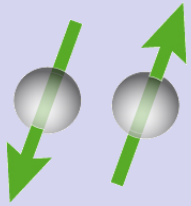


CC-NOT	output states $y_0y_1y_2$ 000	001	010	011	100	101	110	111
input states $x_0x_1x_2$ 000	1	0	0	0	0	0	0	0
001	0	1	0	0	0	0	0	0
010	0	0	1	0	0	0	0	0
011	0	0	0	1	0	0	0	0
100	0	0	0	0	1	0	0	0
101	0	0	0	0	0	1	0	0
110	0	0	0	0	0	0	0	1
111	0	0	0	0	0	0	1	0

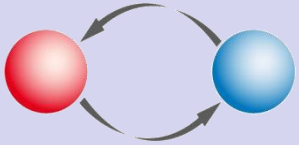
1 4.2 Fundamentals of Logic Devices



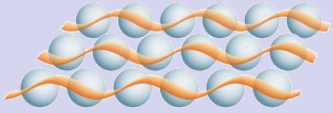
electron charge



electron spin



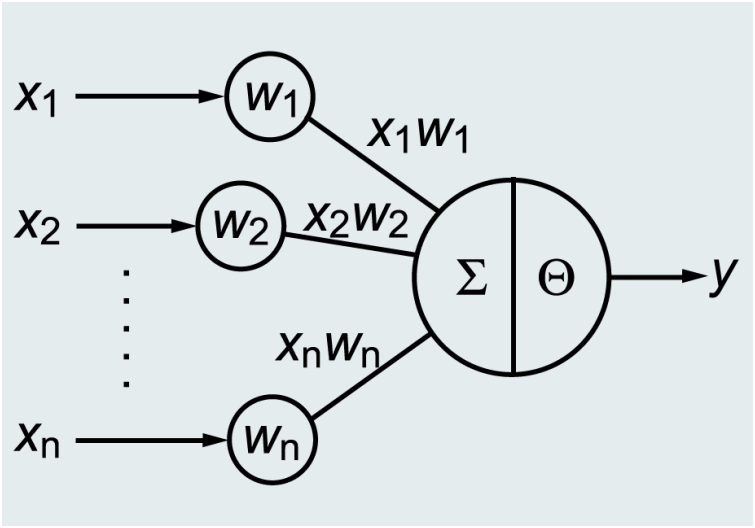
redox ion



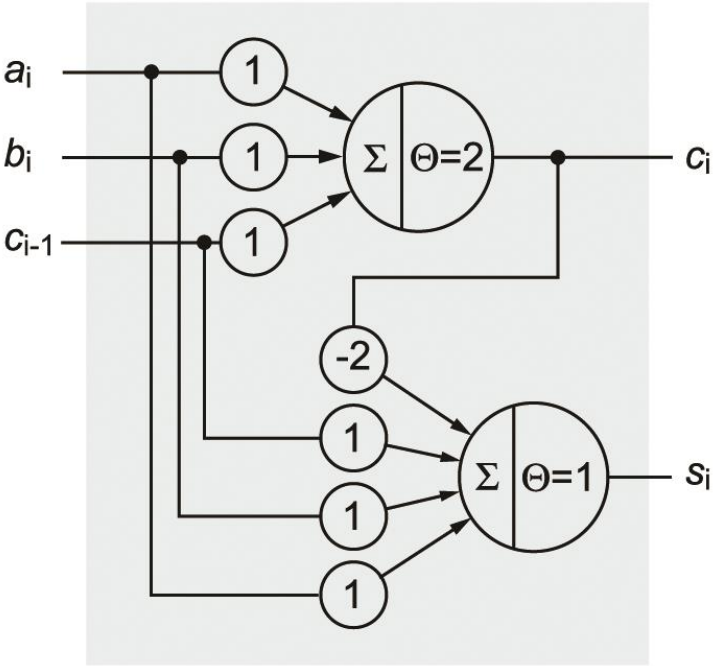
correlation

Reading: „Big Blue Book“, Introduction to Part III

Multivalued logic processing by threshold gates



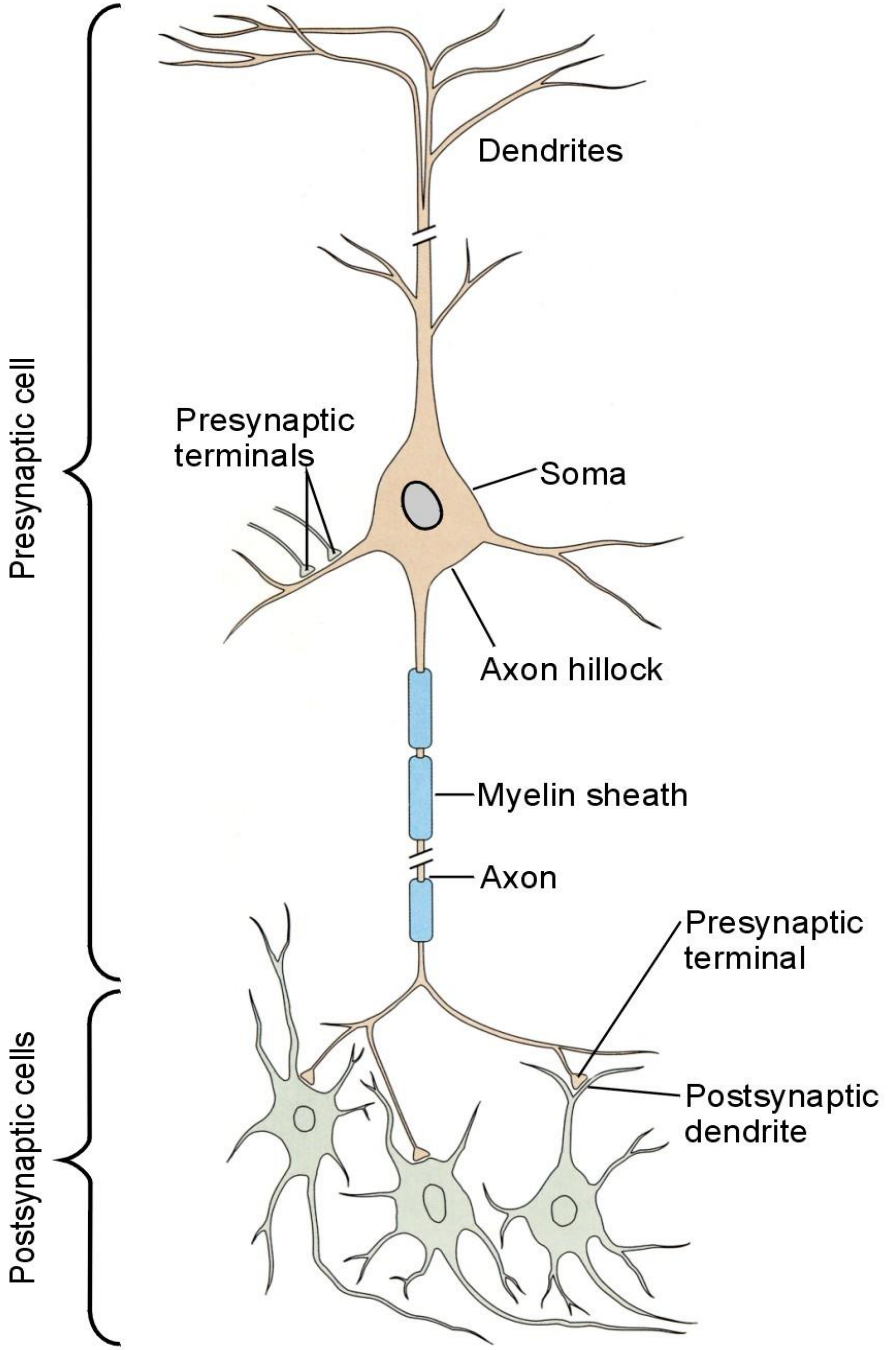
Example:
Full adder



Reading: „Big Blue Book“,
Introduction to Part III

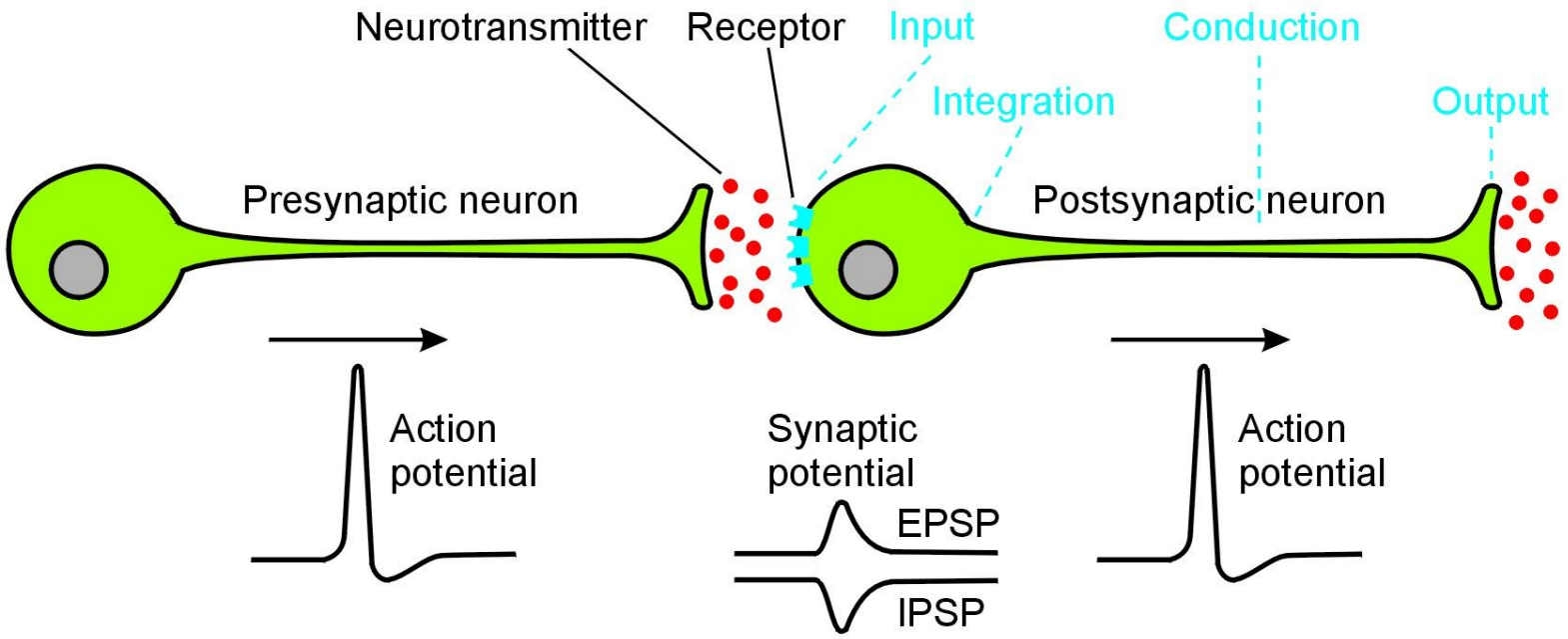
Example:

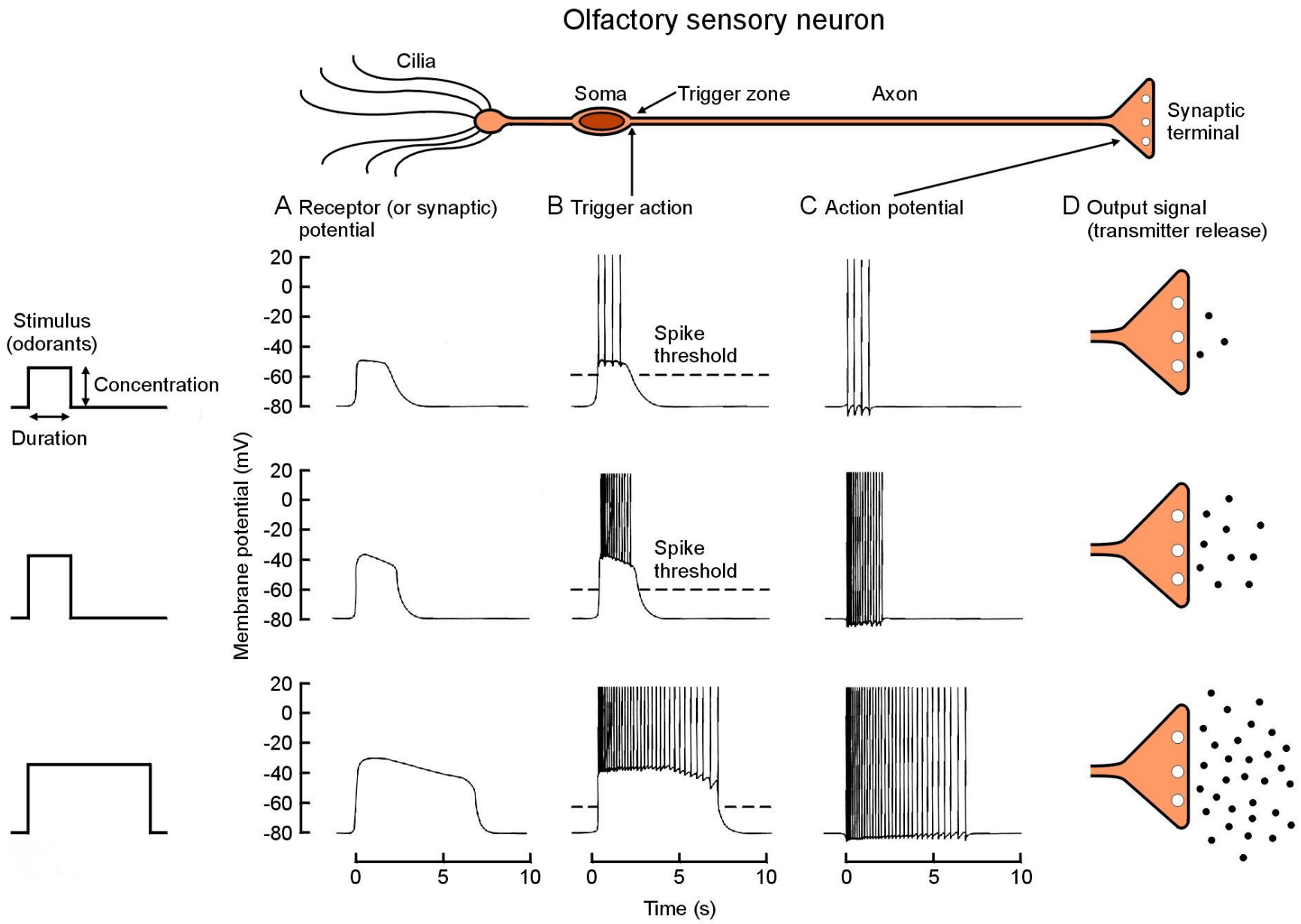
Information processing by biological neurons



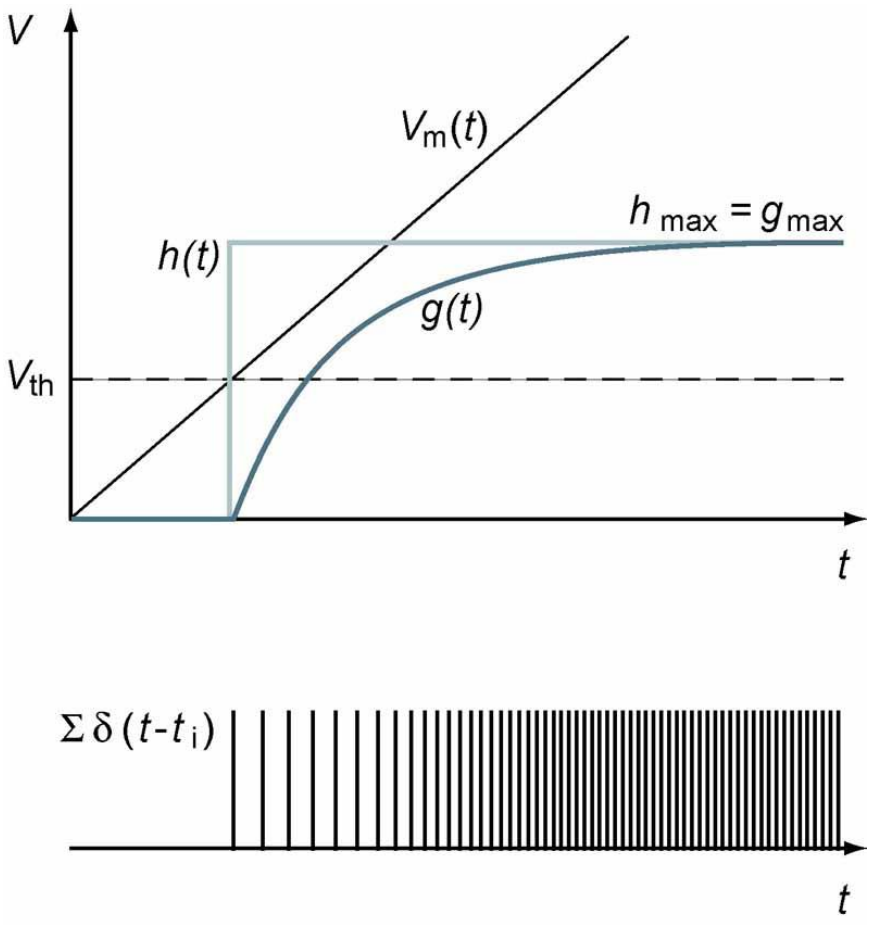
Further reading: „Big Blue Book“, Chapter 6

Information processing and transfer: Generation of action potential spikes



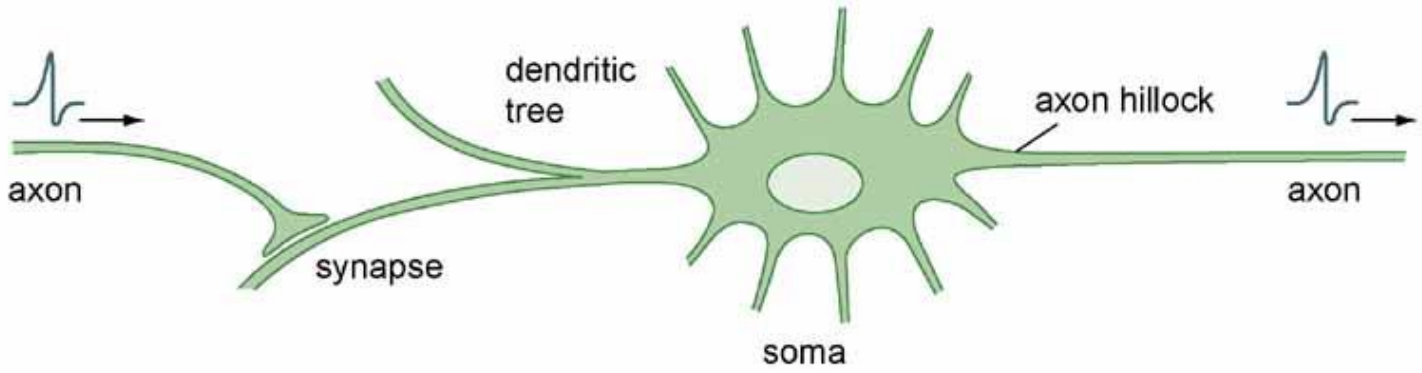

Olfactory sensory neuron
Cilia
Soma
Trigger zone
Axon
Synaptic terminal
A Receptor (or synaptic) potential
B Trigger action
C Action potential
D Output signal (transmitter release)
Stimulus (odorants)
Concentration
Duration
Membrane potential (mV)
20
0
-20
-40
-60
-80
Spike threshold
Spike threshold
0
5
10
Time (s)

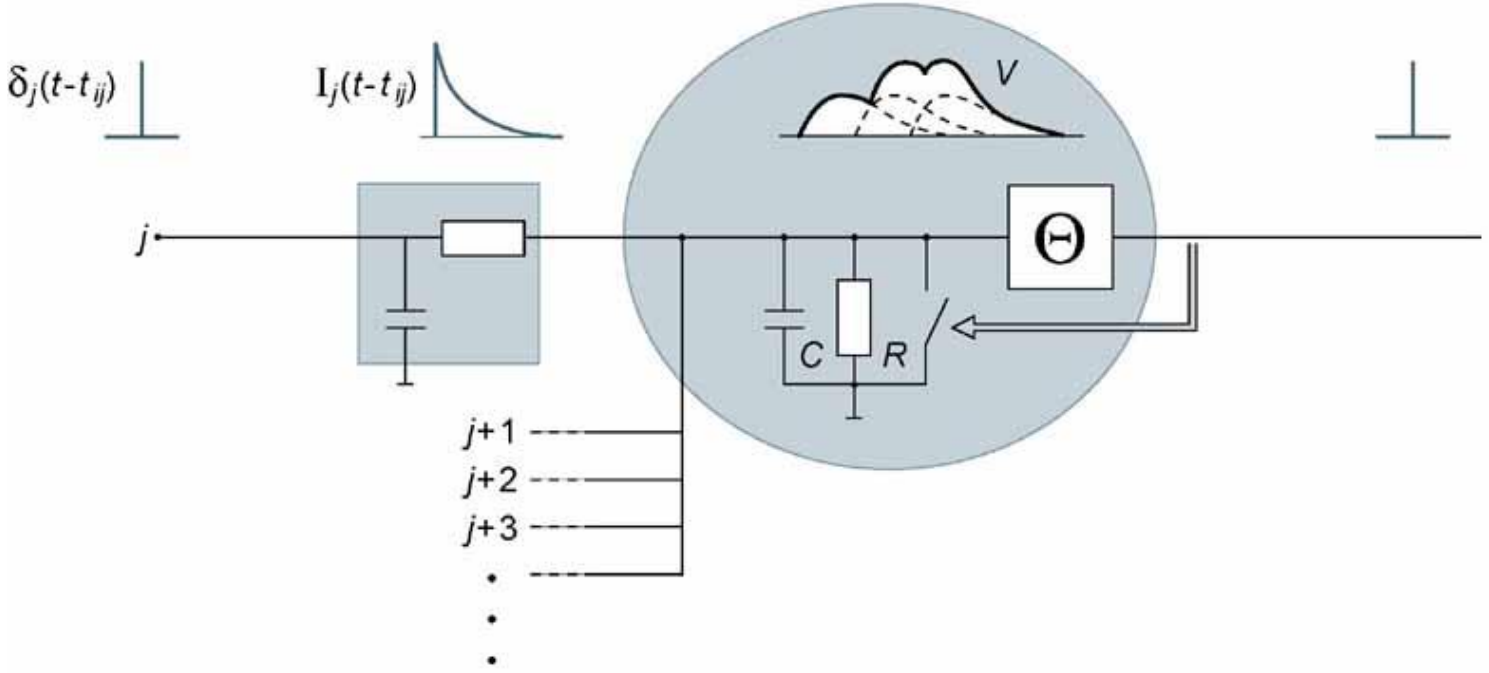
Transfer function at the axon hillock



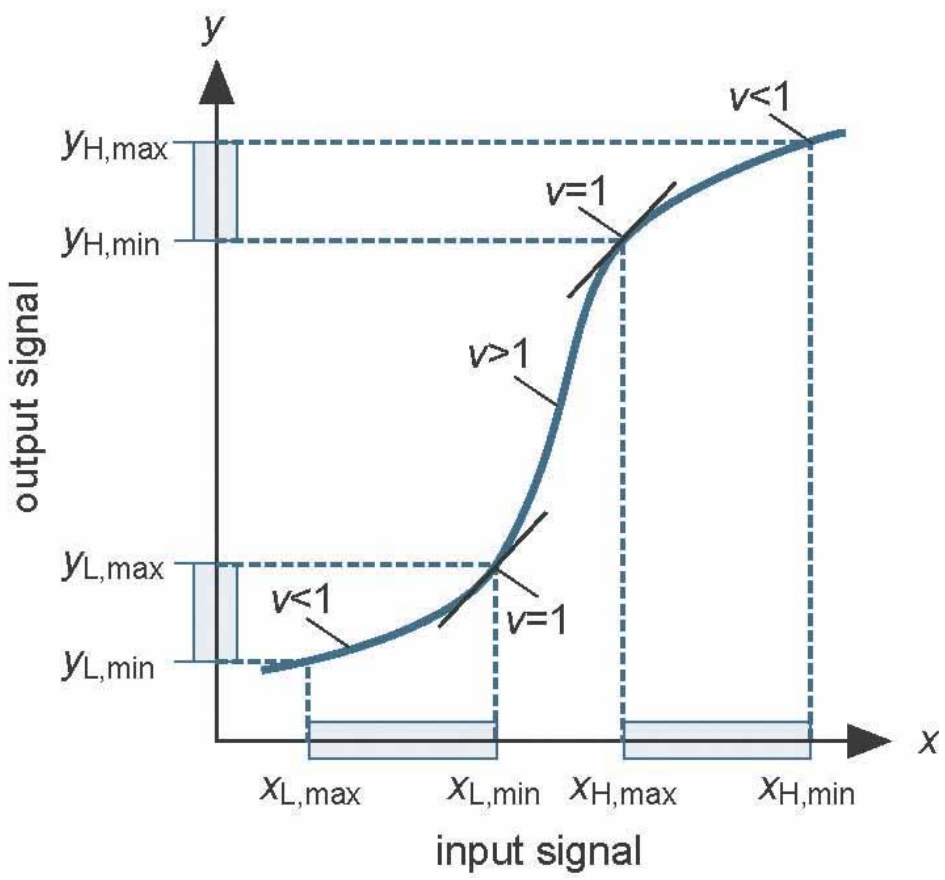
h(t) – binary step-like threshold function

g(t) – refined function


dendritic
tree
axon hillock
axon
axon
synapse
soma


$\delta_j(t-t_{ij})$
$I_j(t-t_{ij})$
V
j
Θ
C
R
j+1
j+2
j+3

Generic requirements of logic devices



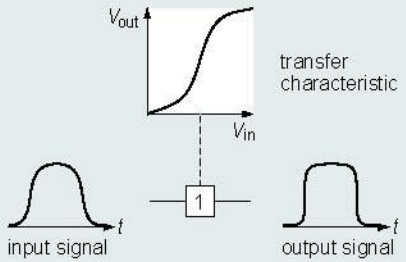
Transfer characteristics of a logic gate (here: unity gate) showing the non-linear characteristics

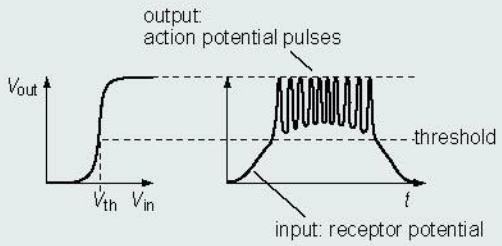
Reading: „Big Blue Book“, Introduction to Part III

Example CMOS Logic

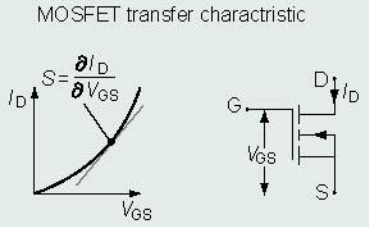
Example Biological Neuron

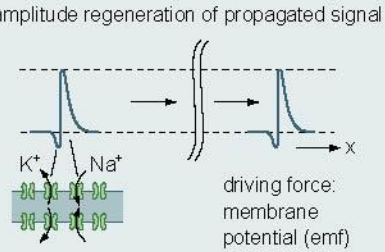
Non-Linearity



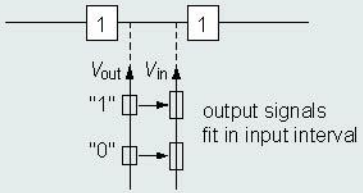


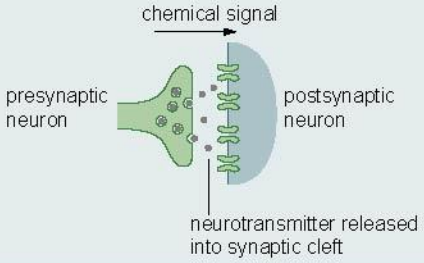
Power Amplification



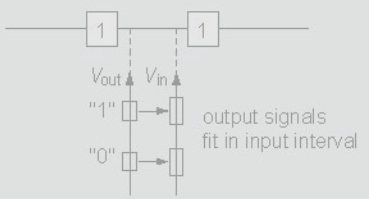


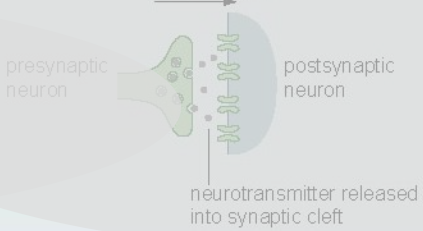
Concatenability



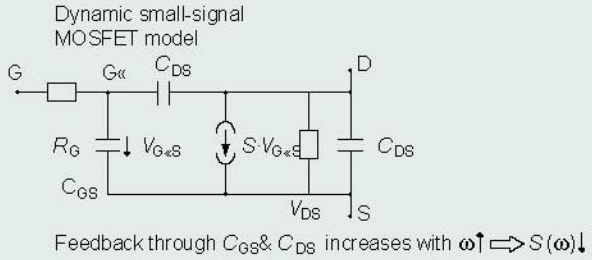


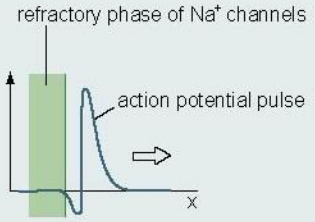
Feedback Supression



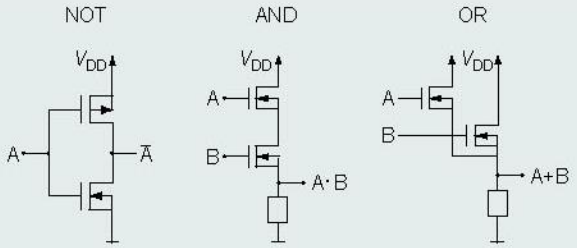


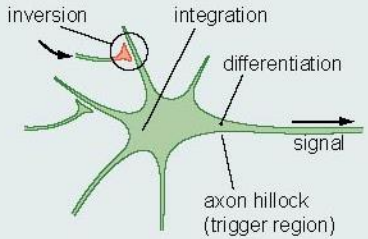
Feedback Supression





Basic Logic Functions





⅃ 4.3 Physical limits of computation

Thermodynamical limit

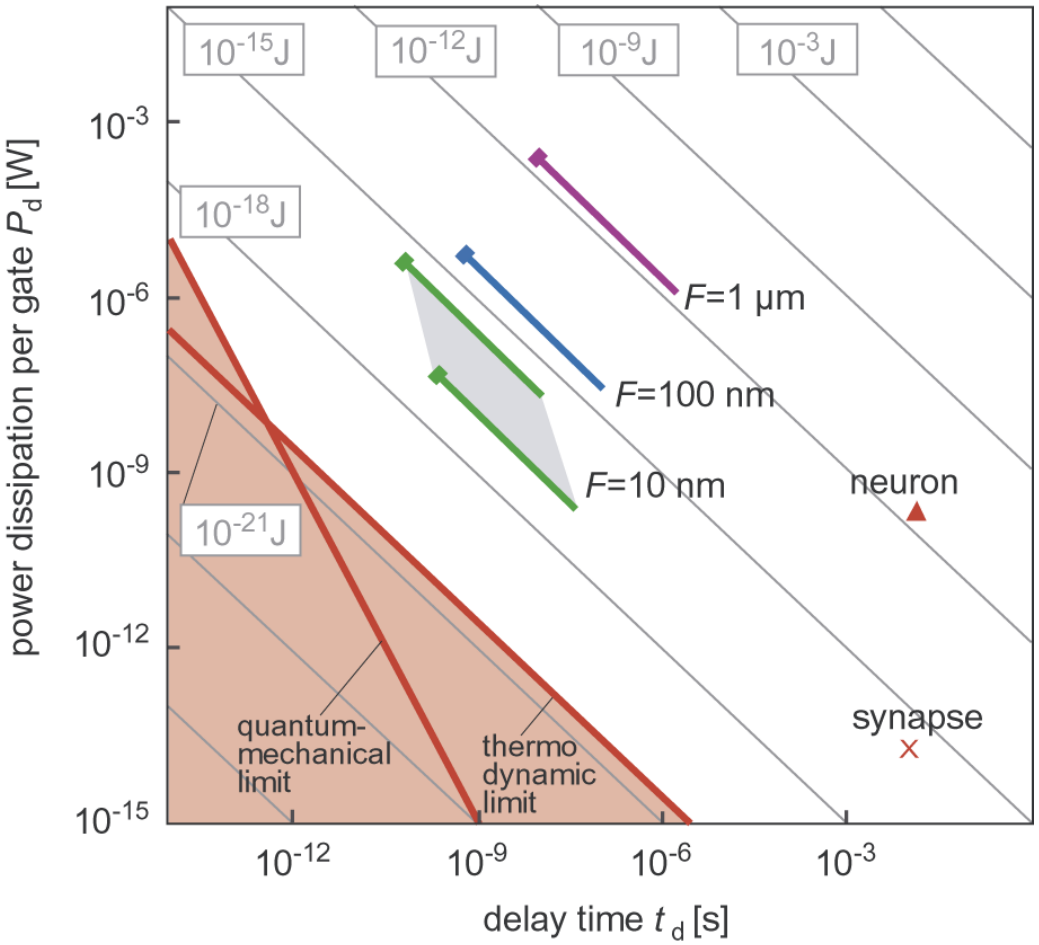
$$W_{\mathrm{TD,min}} = k_{\mathrm{B}} T \ln 2 \approx 3 \cdot 10^{-21}\ \mathrm{J/bOp}$$

Quantum physics limit

$$W_{\mathrm{QM,min}} \equiv \Delta W \geq h/\Delta t$$

Average dissipated power per gate P_d vs. transition delay time t_d for T = 300K.
Lines of equal energy dissipated during a logic operation:

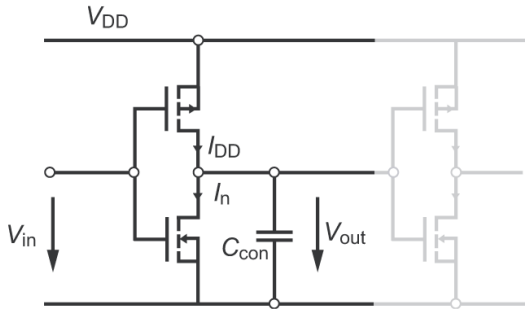
$$W_{\mathrm{d}} = P_{\mathrm{d}} \cdot t_{\mathrm{d}}$$



Reading: „Big Blue Book“, Introduction to Part III

Power dissipation of CMOS cirucits

CMOS inverter



$$C_L = C_{out} + C_{con} + C_{in}$$

$$P_{dyn,\,CL} = \sigma f C_L V_{DD}^2$$

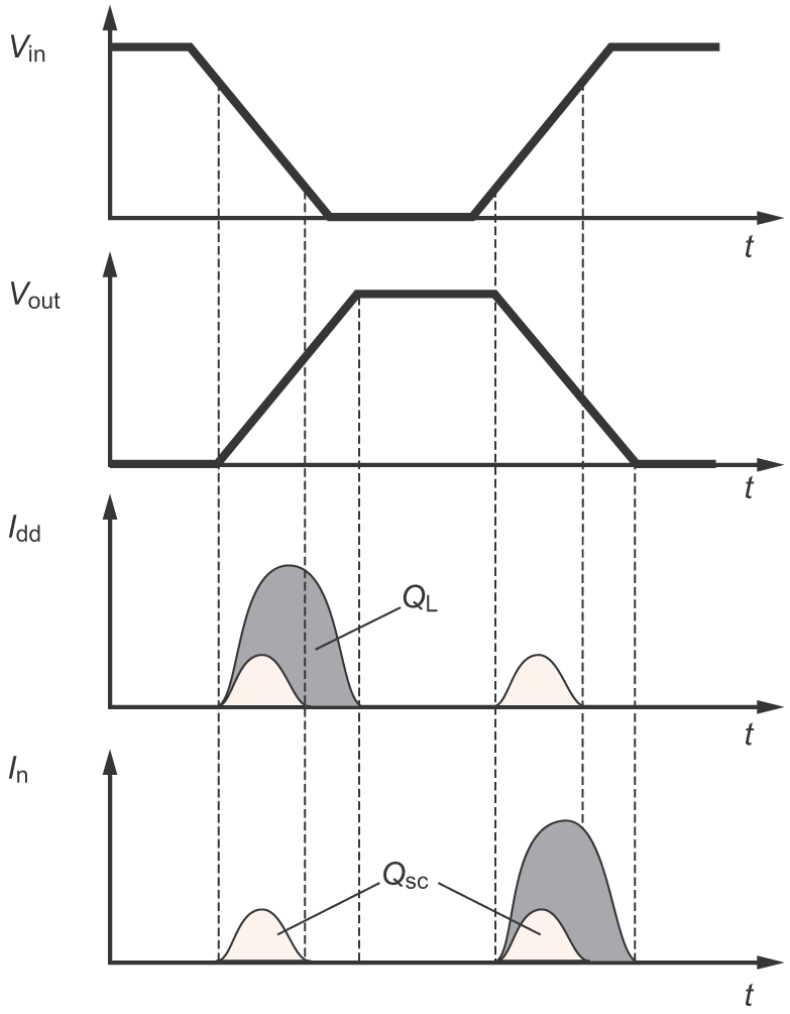
$$P_d = P_{dyn,\,CL} + P_{dyn,\,SC} + P_{stat}$$

Max. clock frequency

$$f_{max} = \beta / t_d$$

Transition time of the FET

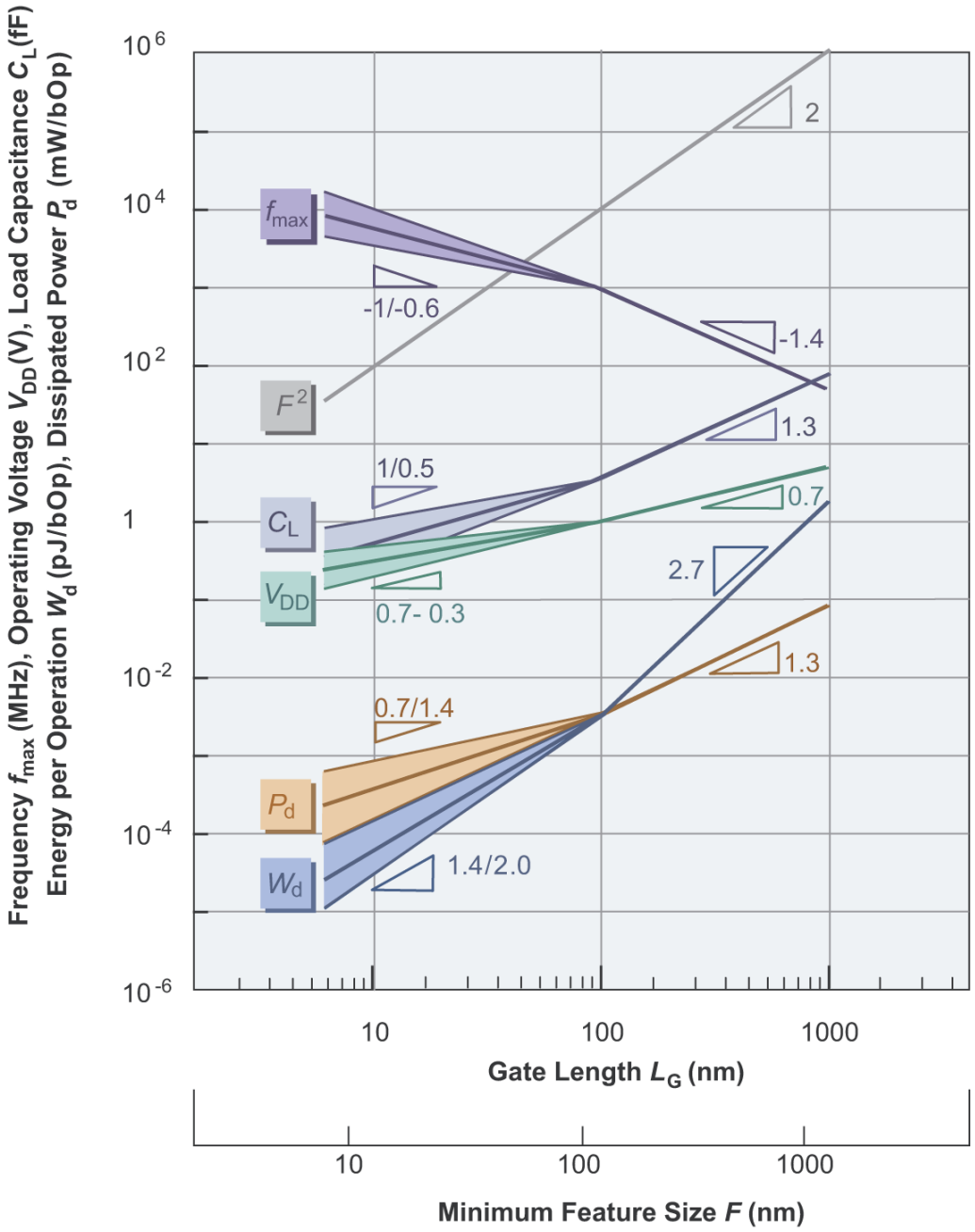
$$t_{d,FET} = L_{ch}/v$$



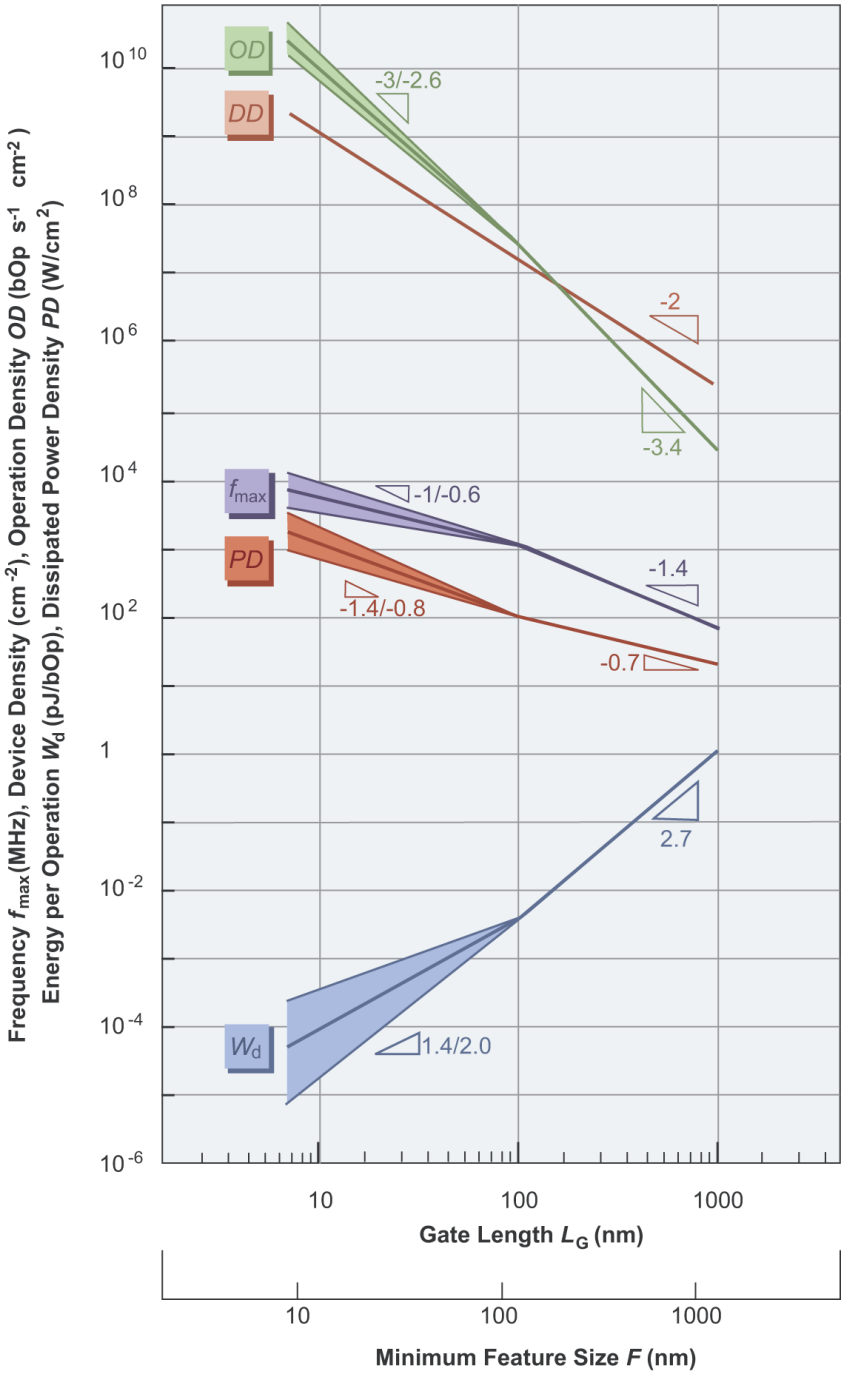
Switching cycle for a CMOS inverter

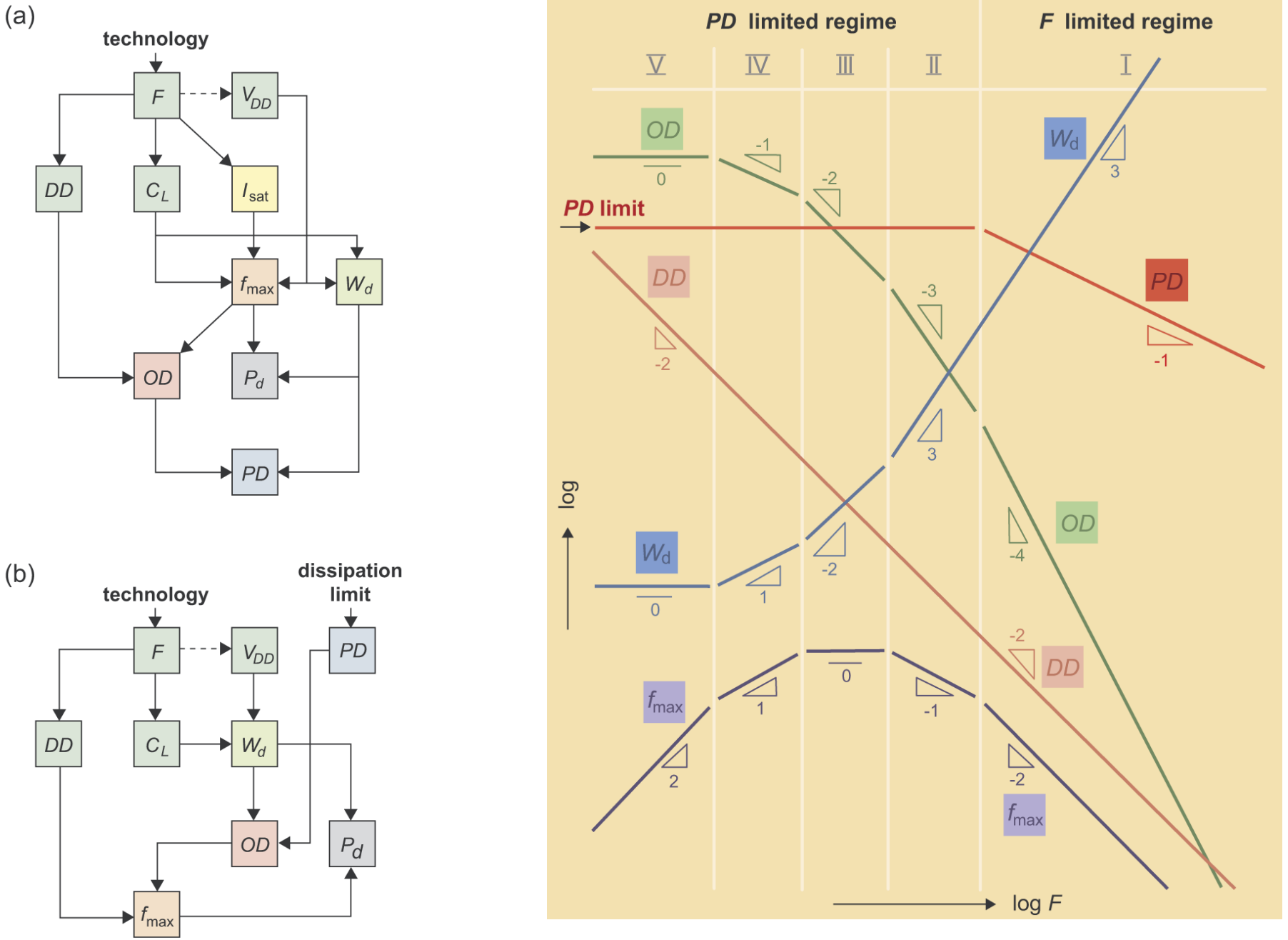
Reading: „Big Blue Book“, Introduction to Part III

Various properties of low power CMOS logic circuits vs. feature size *F* (DRAM ½ pitch)



Device density related properties of low power CMOS logic circuits vs. feature size *F* (DRAM ½ pitch)




(a)
technology
F
V_{DD}
DD
C_L
I_{sat}
f_{max}
W_d
OD
P_d
PD
(b)
technology
dissipation limit
F
V_{DD}
PD
DD
C_L
W_d
OD
P_d
f_{max}
PD limited regime
F limited regime
Ⅴ
Ⅳ
Ⅲ
Ⅱ
Ⅰ
OD
0
-1
-2
PD limit
DD
-2
-3
W_d
3
PD
-1
3
log
W_d
0
1
-2
OD
-4
-2
DD
f_{max}
1
0
-1
2
-2
f_{max}
log F

Summary

- Definition of Information
  alphabet(code) = basic set of
  characters of a language; probability and information (bit)
- Boolean functions
  AND, OR, NOT; algebra of sets; generic functions
- Multivalued Logic
  generalized Boole fcts.;
- State variables of logic functions
  e.g. electron charge, spin, redox state, molecular configuration, phase of a wave
- Signal processing of biological neurons
  threshold gate; model of biological neuron
- Requirements of logic devices
  nonlinearity, power amplication, concatenability, feedback suppression, basic set
- Physical limits of computation
  electron charge
  - ⇨ ideal case: thermodynamic and quantum mech. limit
  - ⇨ real case (CMOS): scenarios as a fct of the minimum feature size F