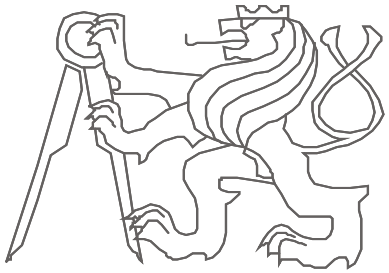
Architektury počítačů

MZ-APO a I/O operace

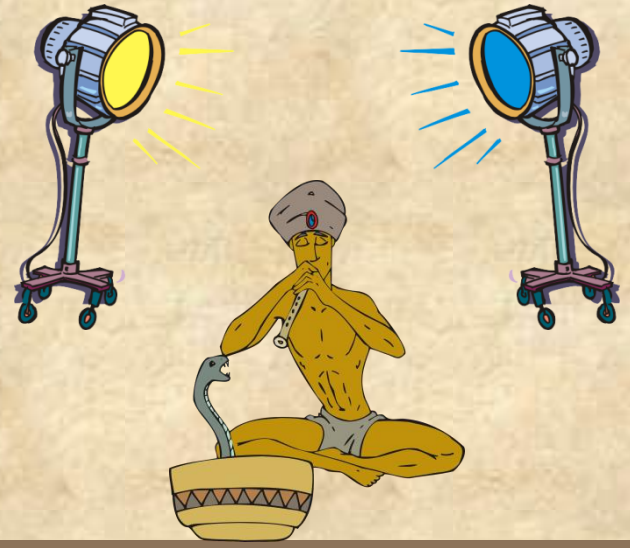


České vysoké učení technické, Fakulta elektrotechnická

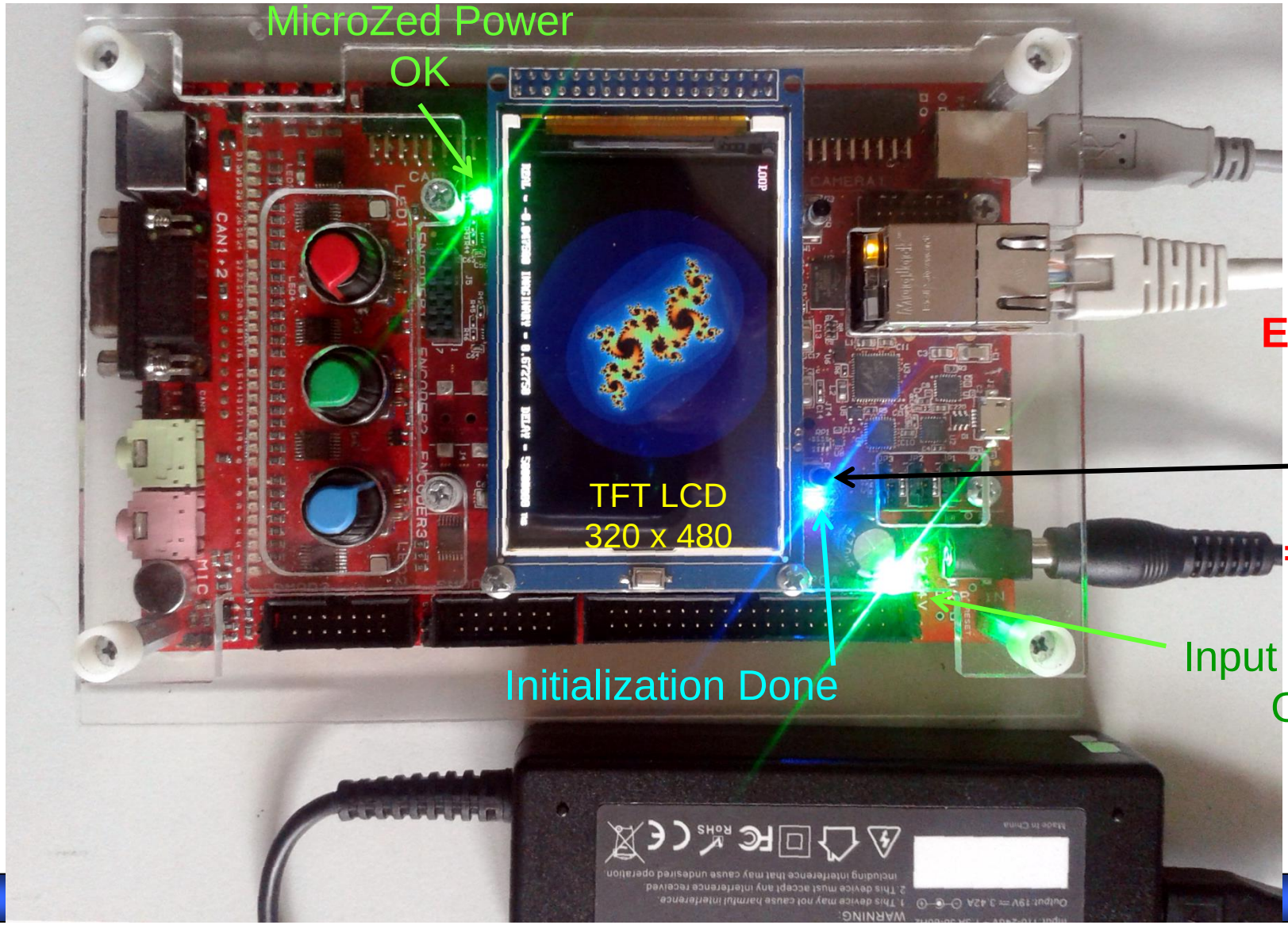
Zadání úlohy

Naprogramujte řídicí jednotku MicroZed na ovládací prvek dvou RGB reflektorů.

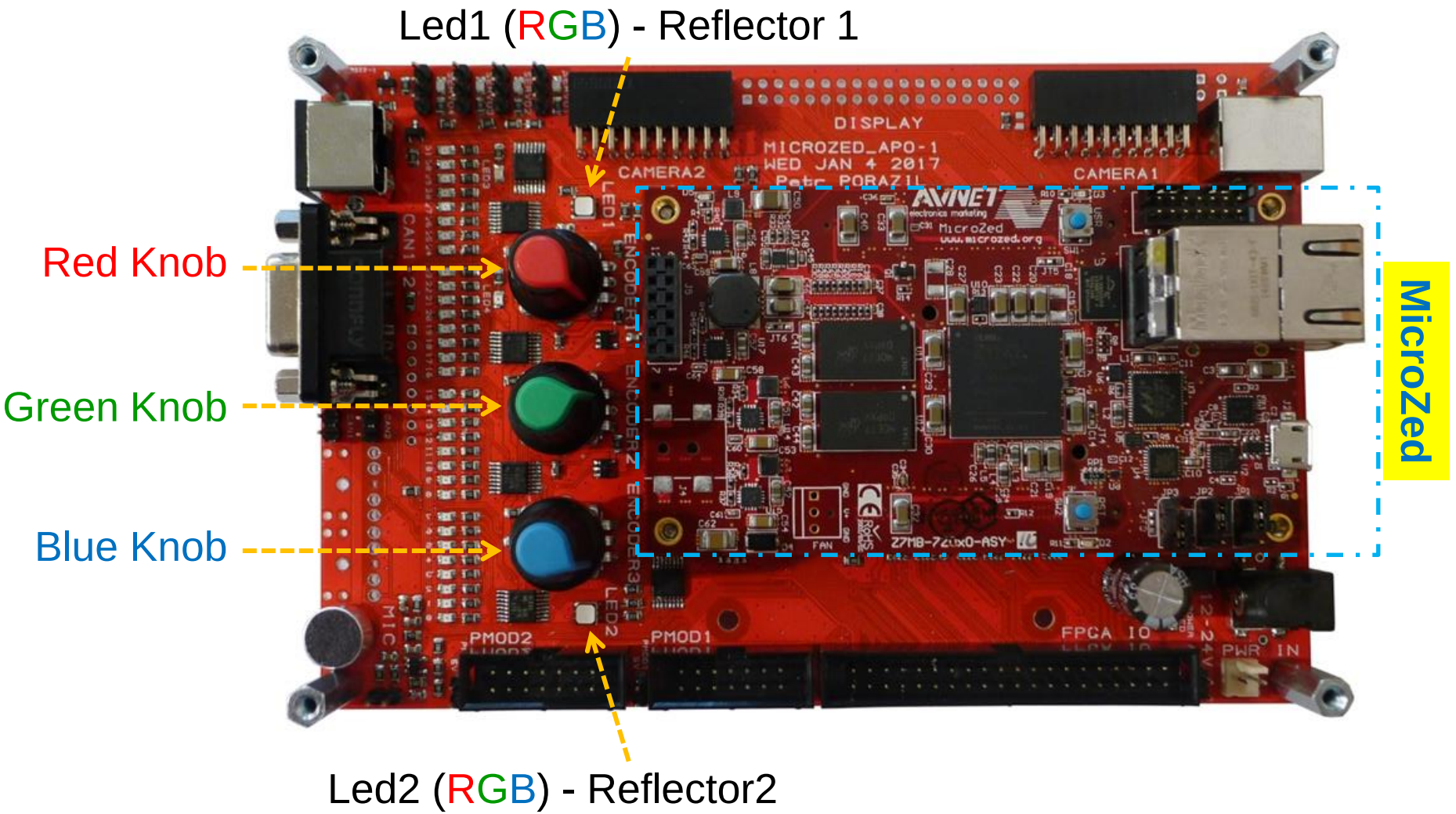
Volba odstínu barvy světla se zadává v barevném modelu HSV/HSB.



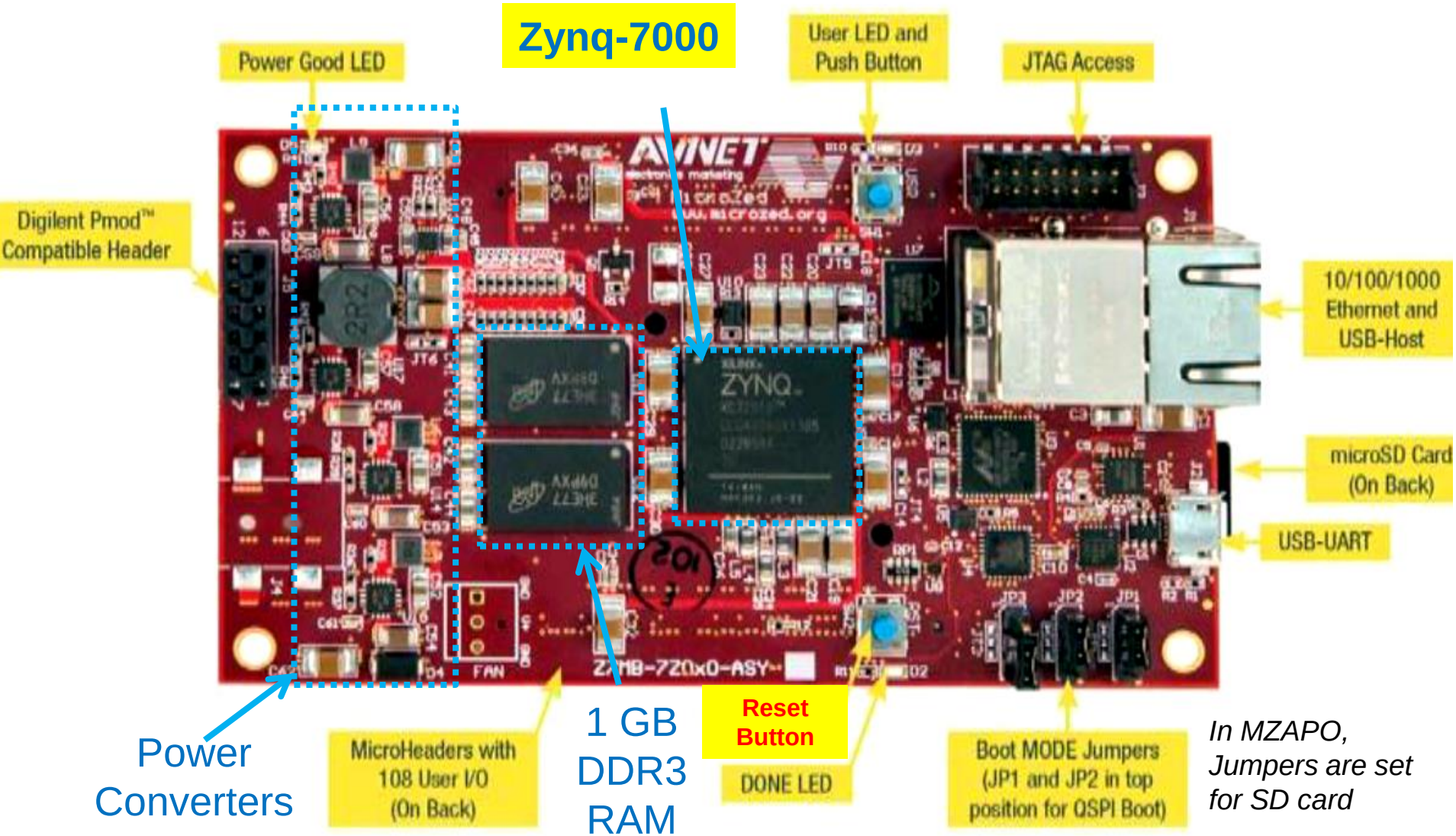
MZAPO - MicroZed_APO board



Demounting LCD -> MicroZed_APO on Carry card

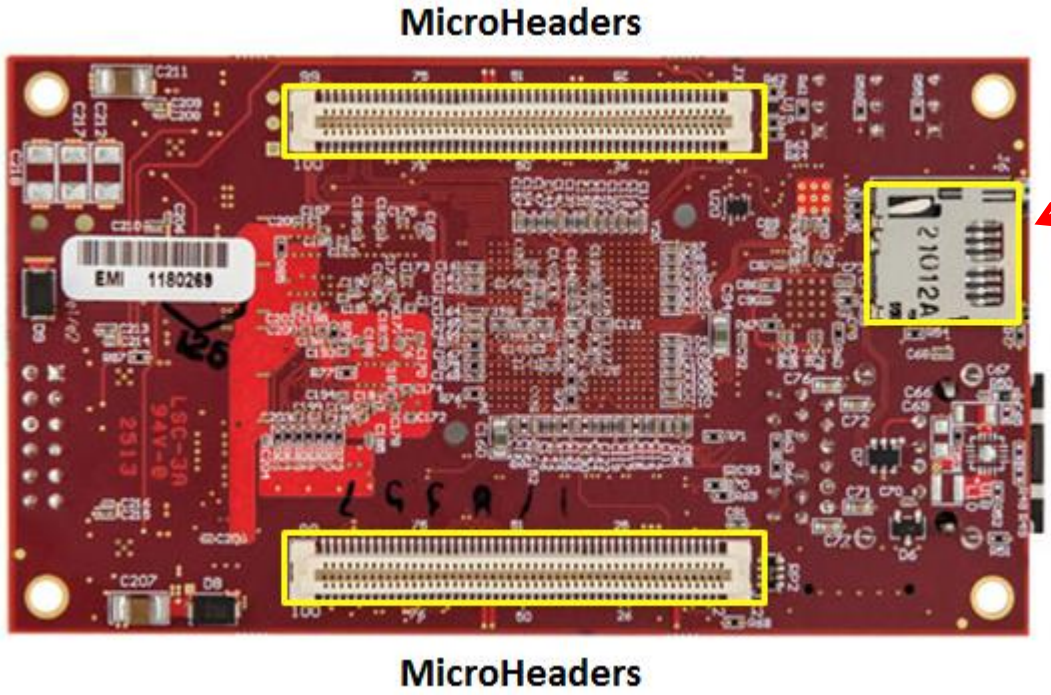


MicroZed - Top View



MicroZed - Bottom View

Microzed Evaluation Kit - ADSAES-Z7MB-7Z010-G



Micro SD Card with initilization program

108-pin micro header connectors allowing mount MicroZed™ Evaluation Kit to a carrier card.

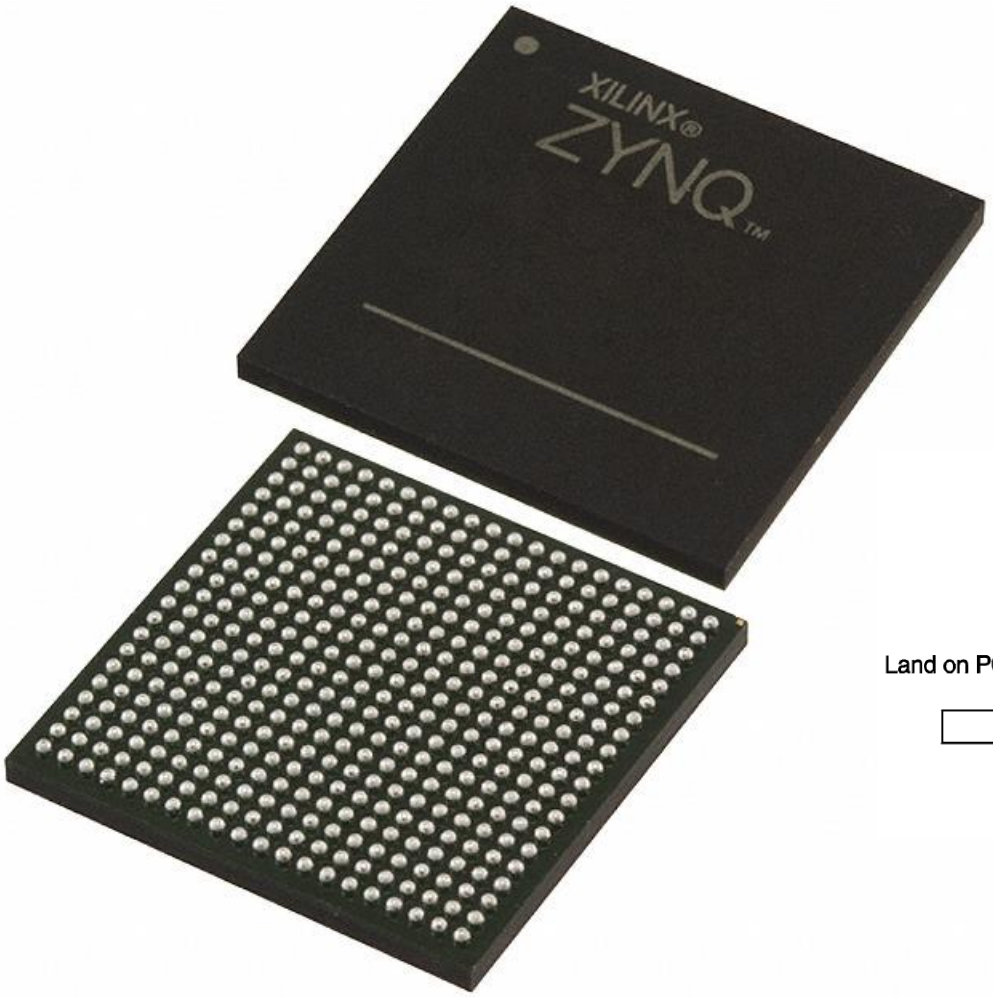
Price of 1 pcs of used Zynq: ~ $45 **,** *price of MicroZed: ~ $180 (April 2019)*

Data sheet of MicroZed

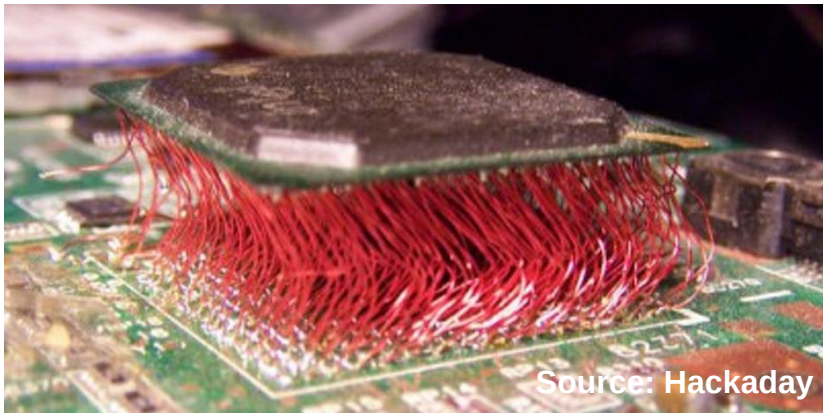
- **FPGA chip** – **Zynq™-7000** AP SoC (XC7Z010-CLG400-1)
  - CPU: Dual **ARM® Cortex™-A9** MPCore™ @ **866 MHz**
  - fast internal static memory 256 kB
  - 4400 slices - *each slice is small configurable logic circuit.*
    It can create up to 8 flip-flops and 4 logic functions with 6-inputs.
    User can freely configure them and mutually interconnect.
- External dynamic memory – **1 GB DDR3**
- Communication – 10/100/1000 **Ethernet**
- MicroSD card **4 GB**. *In APO board, it contains the loader of Linux system for Ethernet network.*
- **USB** Host 2.0 and USB-UART
- Quad-SPI Flash 128 Mb for power-up initialization.
  In APO, it is not used.

Zynq™-7000 in FBGA Package

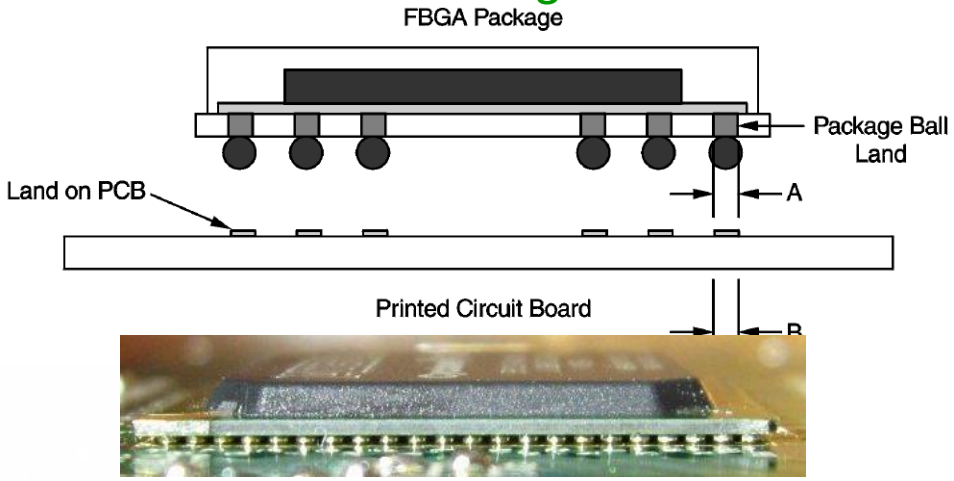
FBGA = Fine-Pitch Ball Grid Array



Clumsy method of FBGA soldering ☹

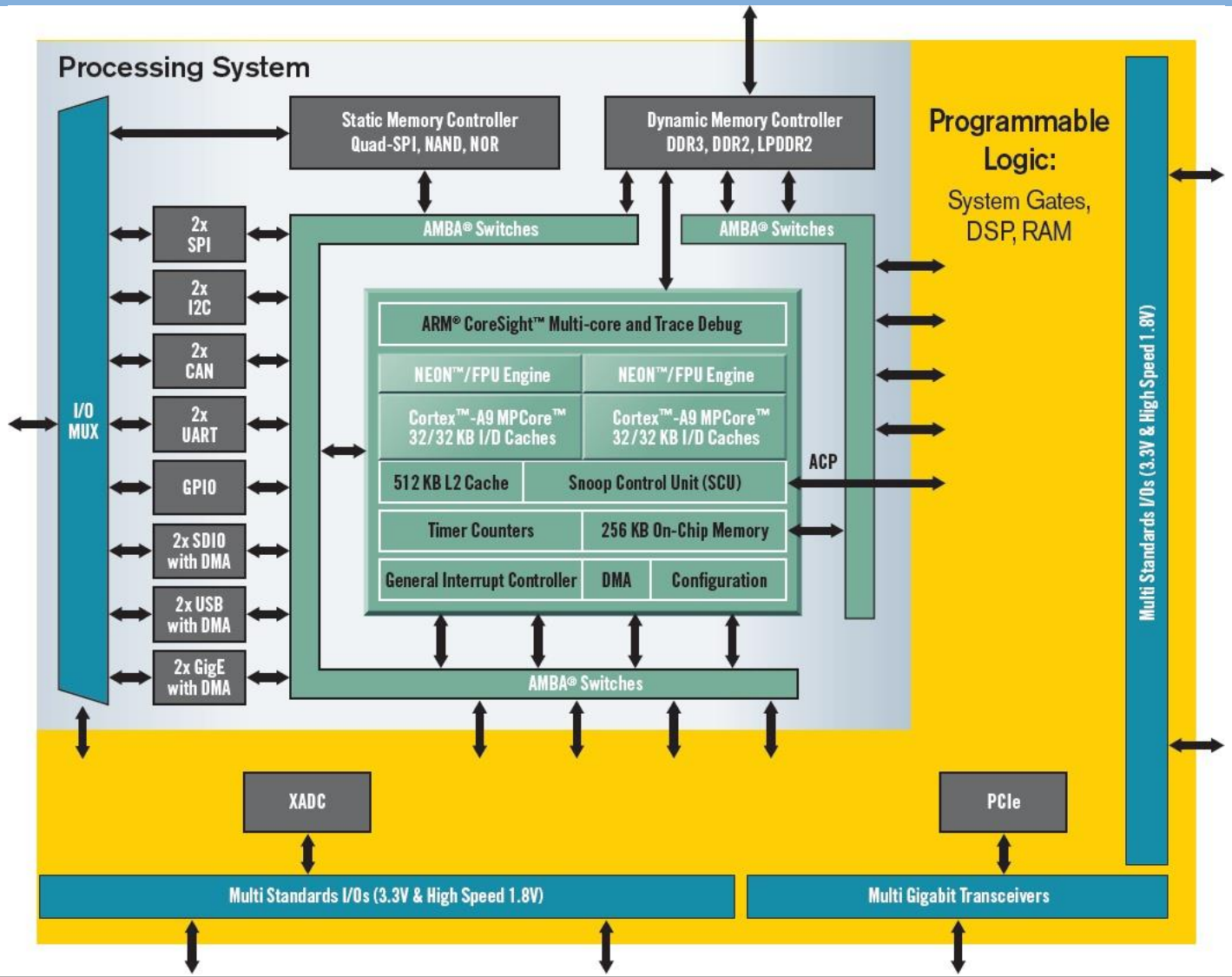


Intended soldering ☺

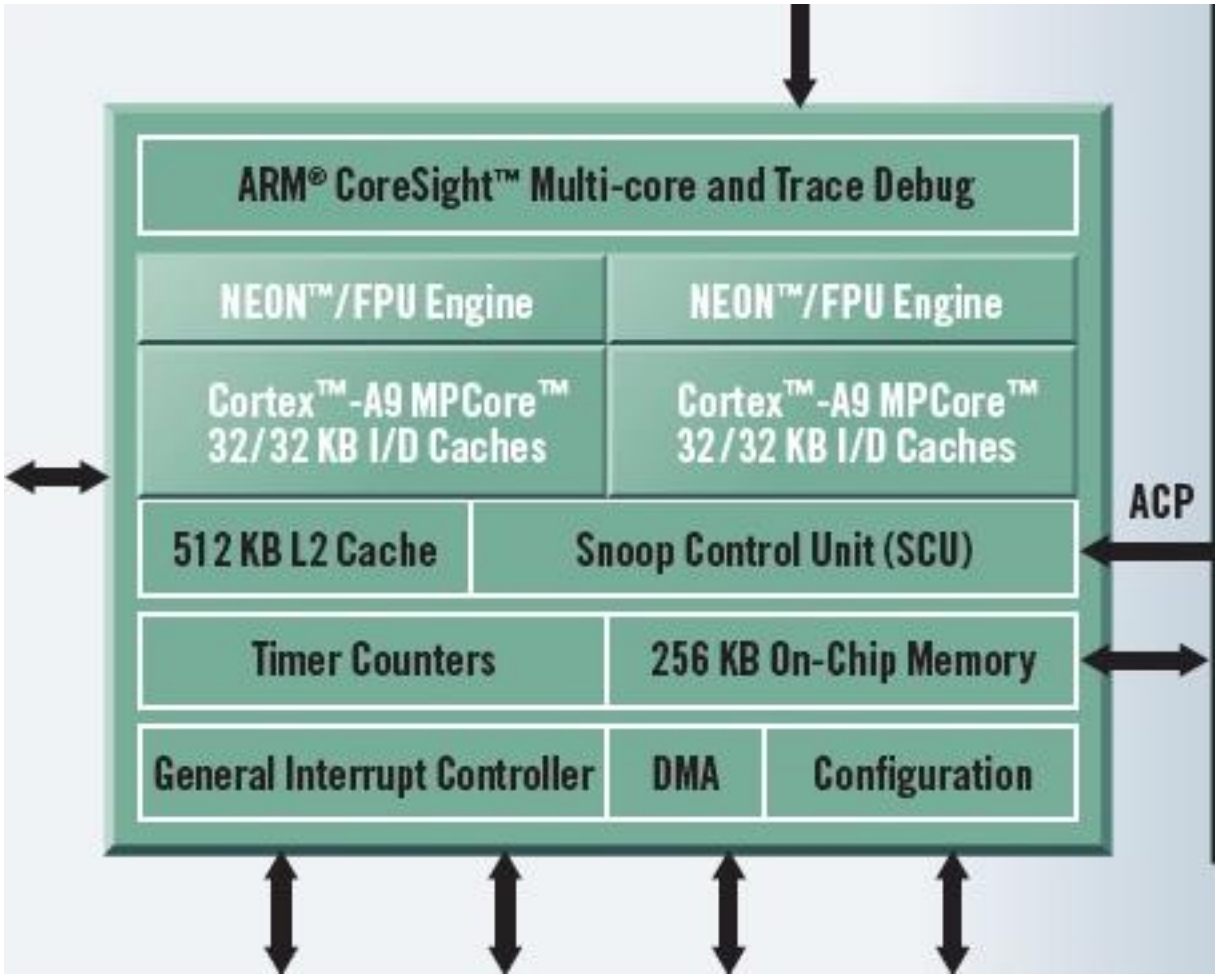


Source: Fairchild Semiconductors

Inside of **Xilinx Zynq™-7000**



Enlarged Zynq Processor Cores



We have already discussed in the lectures:

1. FPU Engine
2. Processor core
3. L1 Instruction/Data caches
4. L2 cache
5. Snoop Control Unit (cache coherency)
6. On-Chip Memory (static RAM)
7. DMA (direct memory access control)

Where is Cortex-A9 used? Some samples

Asus Transformer Pad Infinity (TF700T)
https://en.wikipedia.org/wiki/Asus_Transformer_Pad_Infinity

Apple A5 (iPhone 4S, iPad 2, iPad mini)
http://en.wikipedia.org/wiki/Iphone_4s

NVIDIA Tegra 2 (Motorola Xoom, Droid X2)
http://en.wikipedia.org/wiki/Motorola_Xoom

Full list see: https://en.wikipedia.org/wiki/ARM_Cortex-A9#Implementations

CortexA9 Microarchitecture

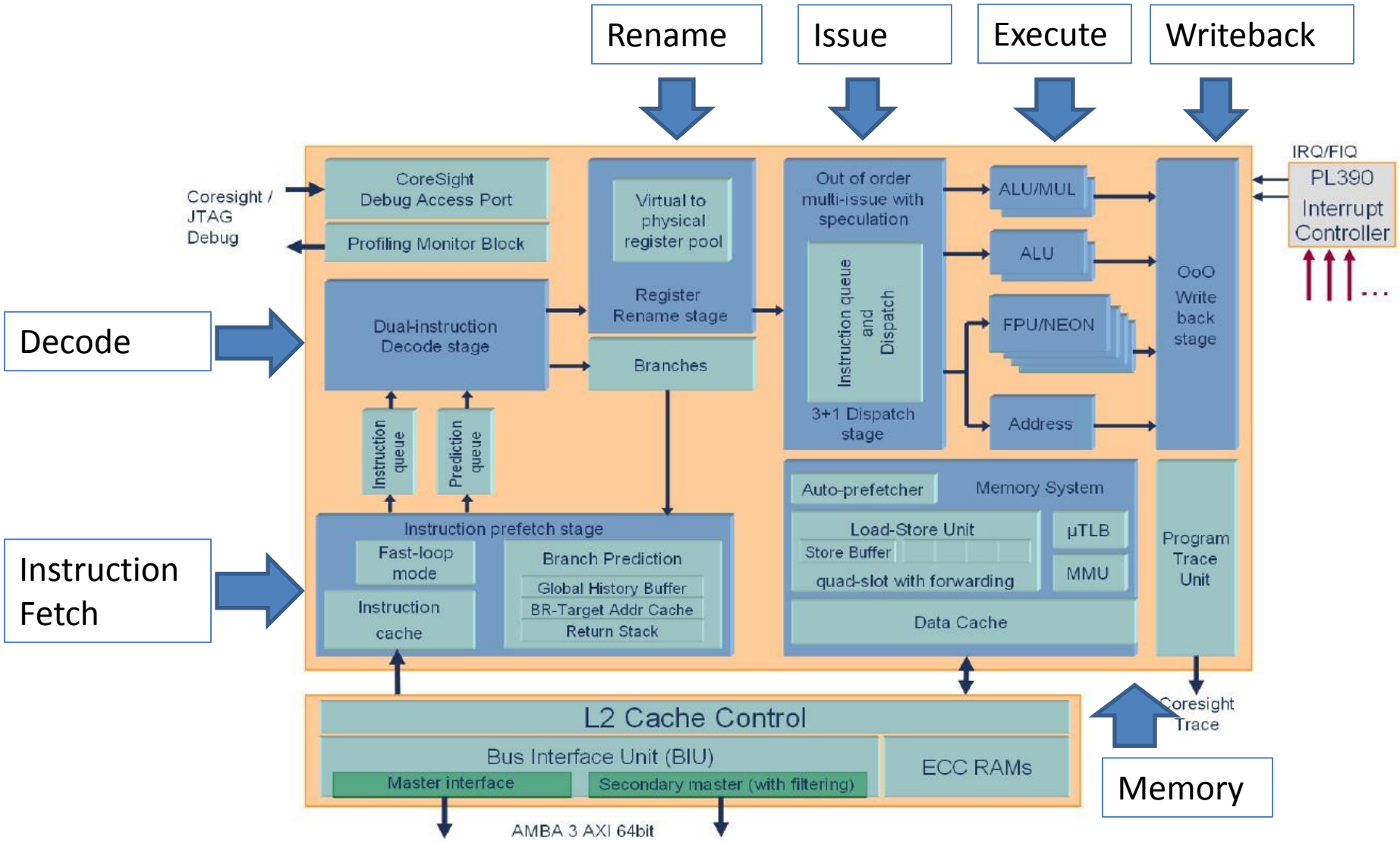


Fig. 1 Cortex-A9 microarchitecture structure and the single core interfaces.

Source: www.arm.com

Our Cortex A9 MP Core properties

- **32 bit RISC Little Endian**, 16 registers integer
- 2.5 DMIPS/MHz
  - -> 866 MHz *2.5 DMIPS/MHz = **2165 DMIPS**

  Note: DMIPS is the result of Dhrystone synthetic computing benchmark intended to represent integer programming.
- Most Integer Instructions finish within 1 cycle, integer multiply needs 4 ~ 5 cycles.
- Float point instruction last on ALU from 4 cycles addition, subtraction (FADD, FSUB), 5 cycles multiply FMUL, 15 cycles divide FDIV (3times longer than multiply!), 17 cycle square root FSQRT.
- Branch prediction
  - 4 K entries table of 2 bit predictors.
- **Virtual memory with 2 level paging tables**

L1 and L2 Caches

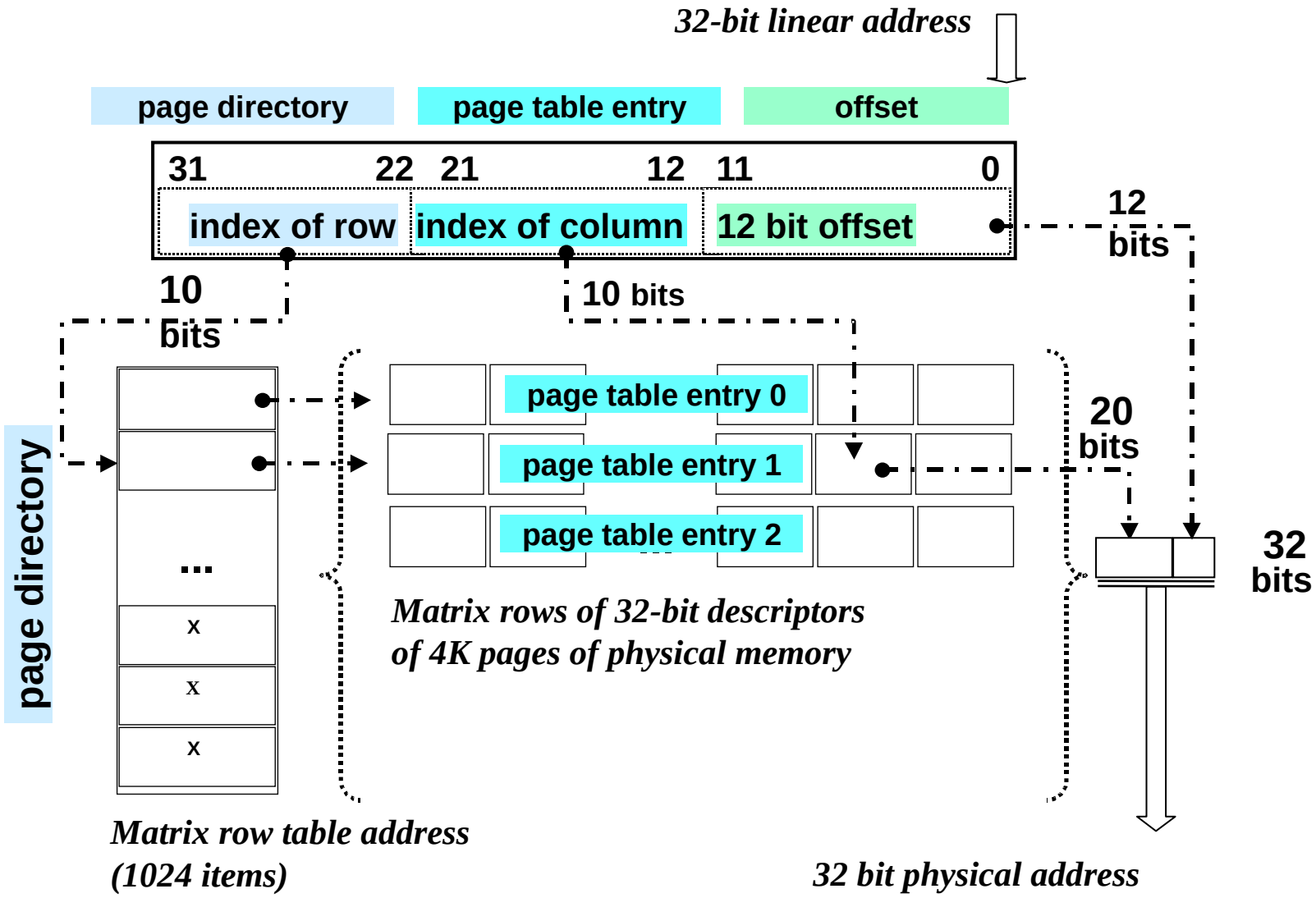
2 separate L1 caches, for I-cache instructions and D-cache for data.
Both L1 have properties:

- **32 kB size**,
- 4-way set associative,
- 32 byte block length,
- replacement policy is pseudo-random or pseudo round-robin.
- **D-Cache** only supports write-back/write-allocate policy.

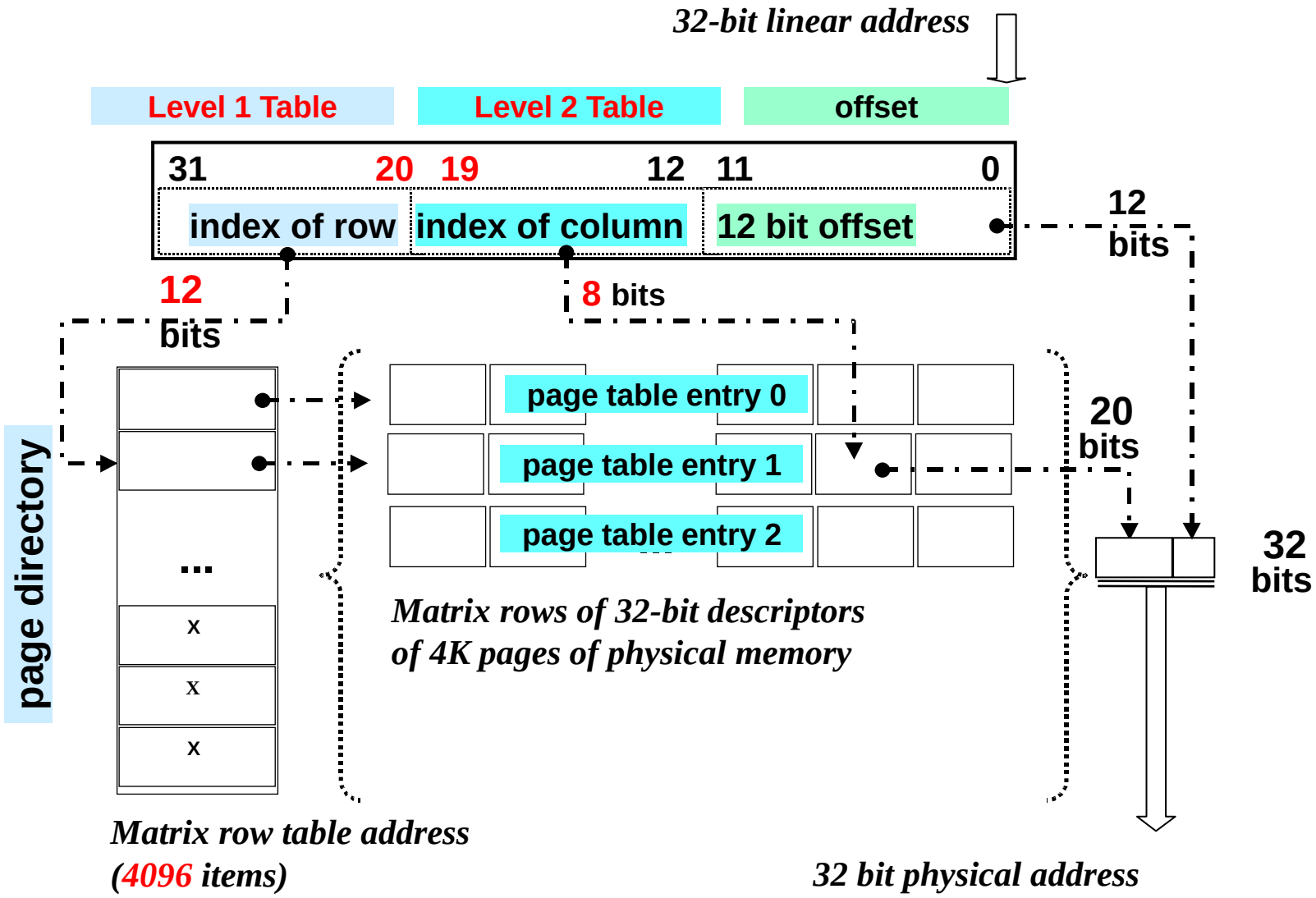
L2 cache is shared by dual Cortex-A9 cores. Its properties:

- **512 KB size,**
- 8-way set-associative,
- 32 byte block (line) length,
- replacement policy is pseudo-random,
- supports Write-back,
  and Write-through with Read allocate, Write allocate.

Recall Virtual Pages from 6th Lecture



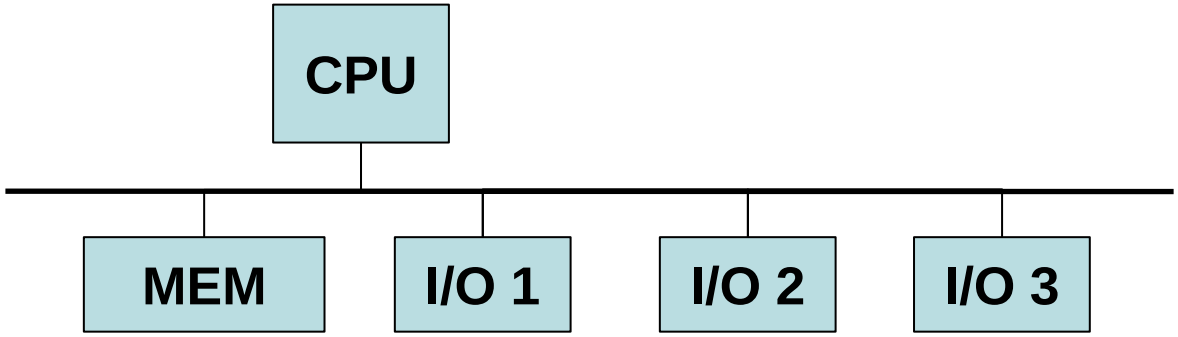
Cortex A9


32-bit linear address
Level 1 Table
Level 2 Table
offset
31
20
19
12
11
0
index of row
index of column
12 bit offset
12 bits
8 bits
12 bits
page directory
...
x
x
x
page table entry 0
page table entry 1
page table entry 2
20 bits
32 bits
Matrix rows of 32-bit descriptors of 4K pages of physical memory
Matrix row table address (4096 items)
32 bit physical address

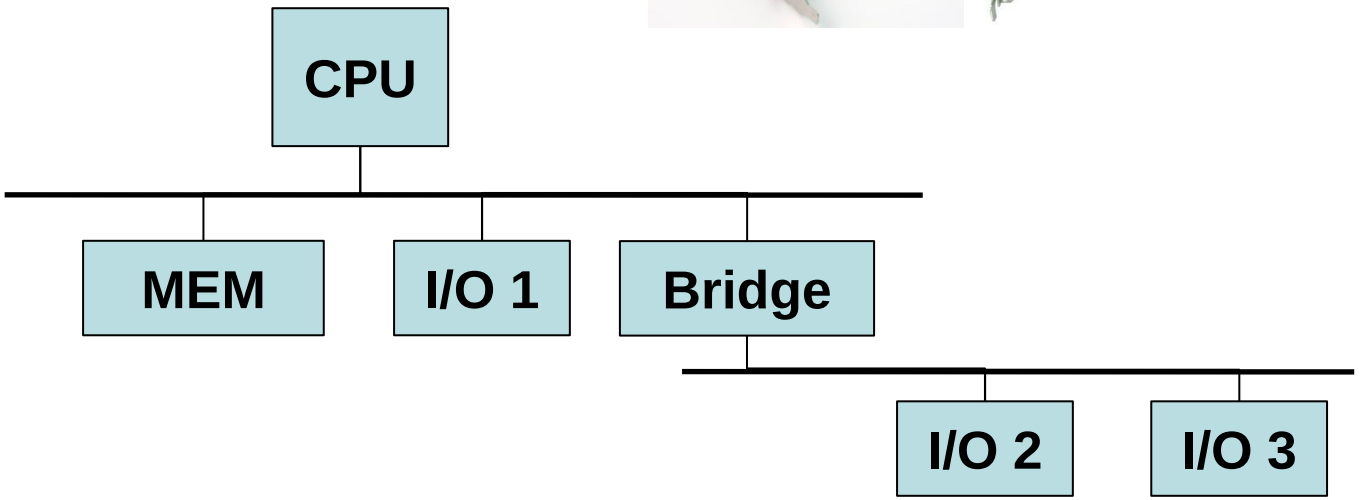
*I/O Pheripherials

Dekodér adres - idea

- Logická struktura: (iluze)

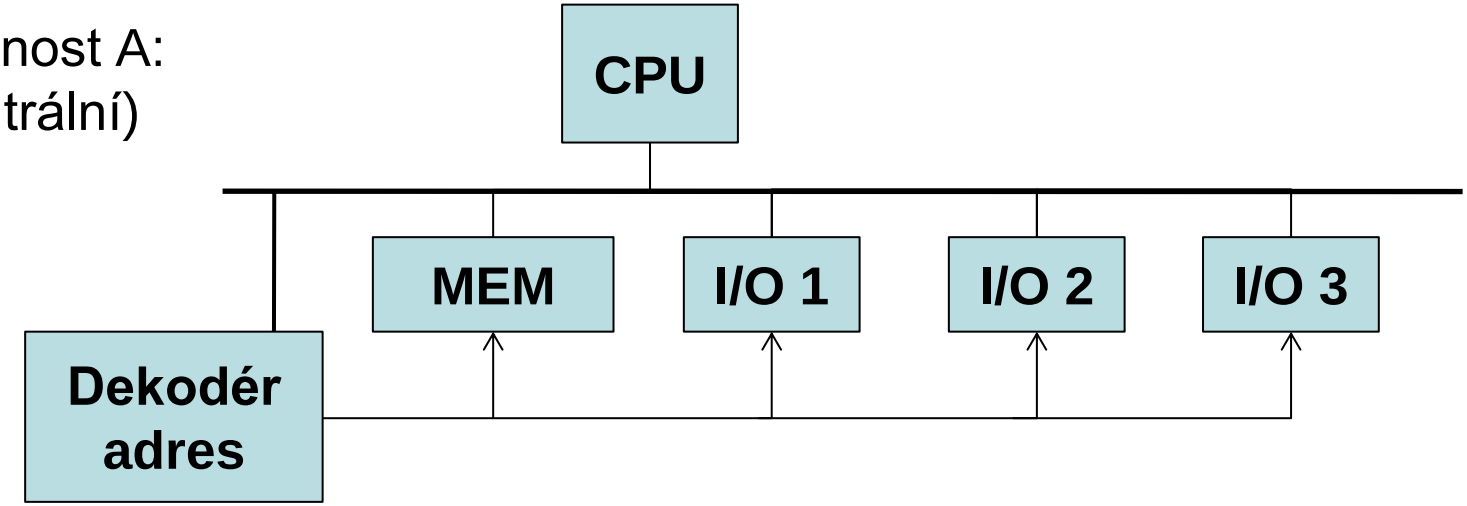


- Možné fyzické uspořádání:

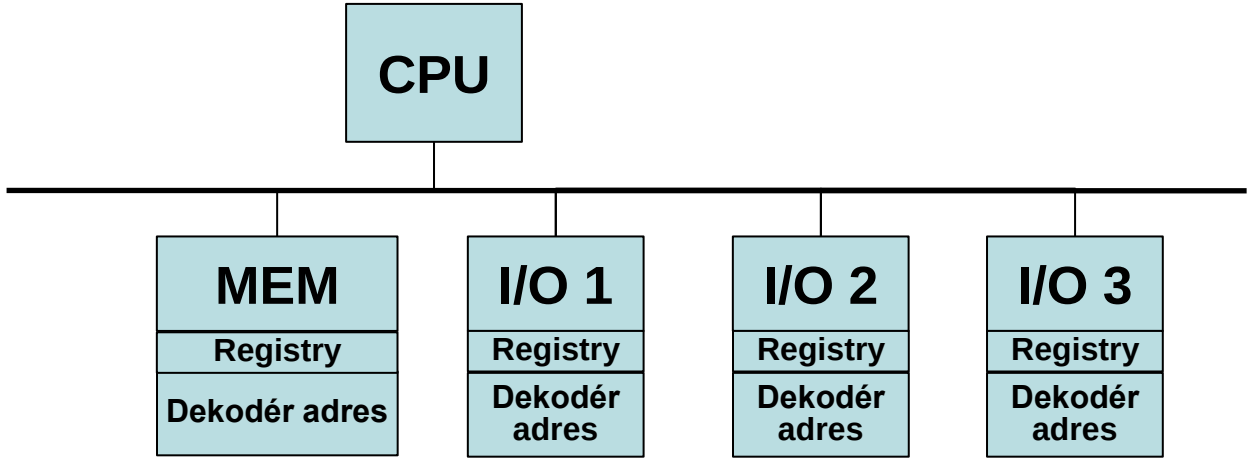


Dekodér adres - idea

- Možnost A: (centrální)



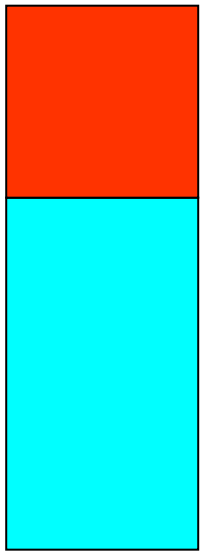
- Možnost B: (autonomní)



Paměťově mapované I/O

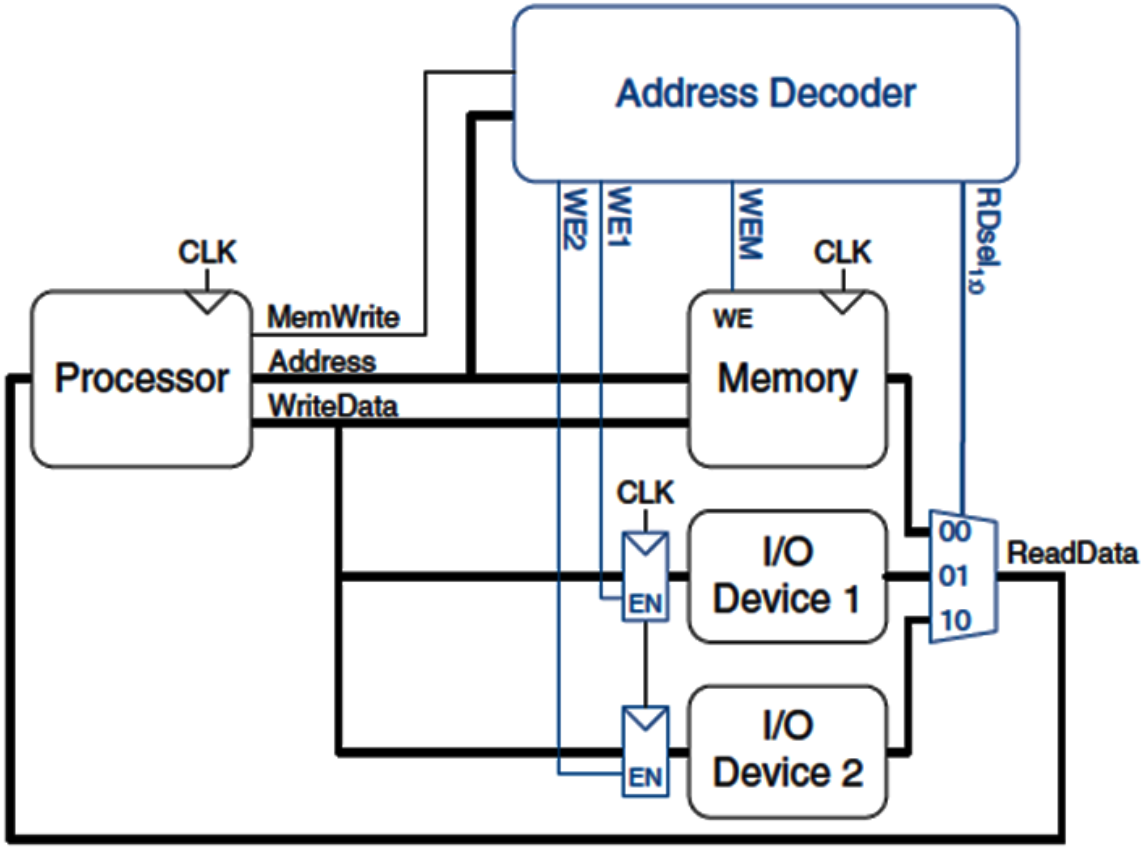
- Idea: K tomu abychom komunikovali s vstupně/výstupními periferiemi (klávesnice, monitor, tiskárna) můžeme použít stejné rozhraní jako pro komunikaci s pamětí (MIPS: instrukce lw, sw).

Společný adresní prostor pro I/O a paměť

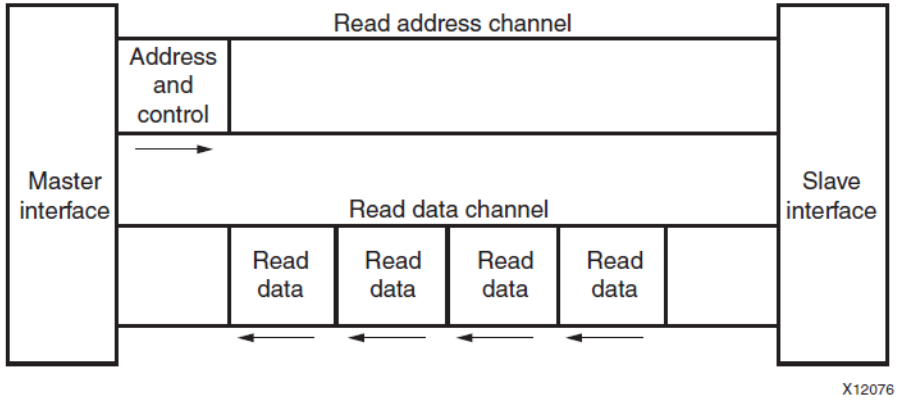


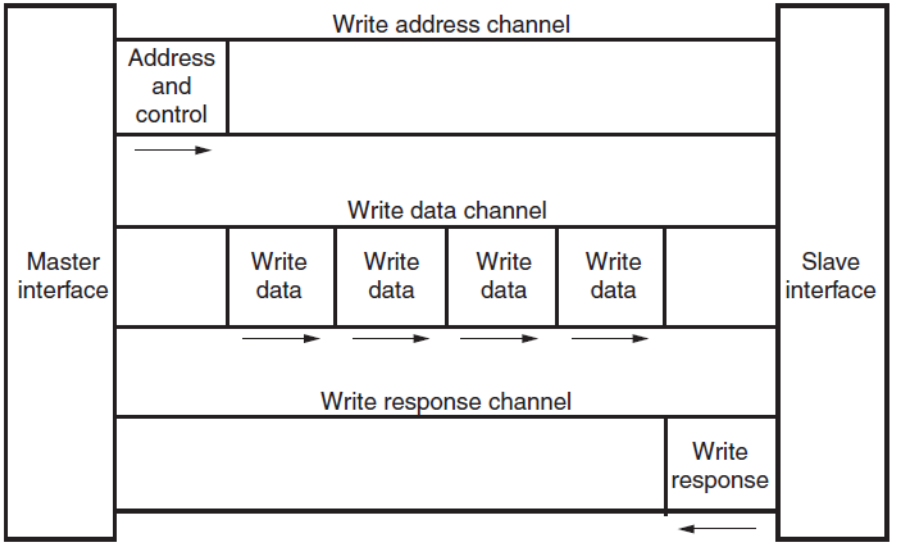
V/V brány jsou mapované do paměti

paměť



MicroZed uses on-chip bus AXI !





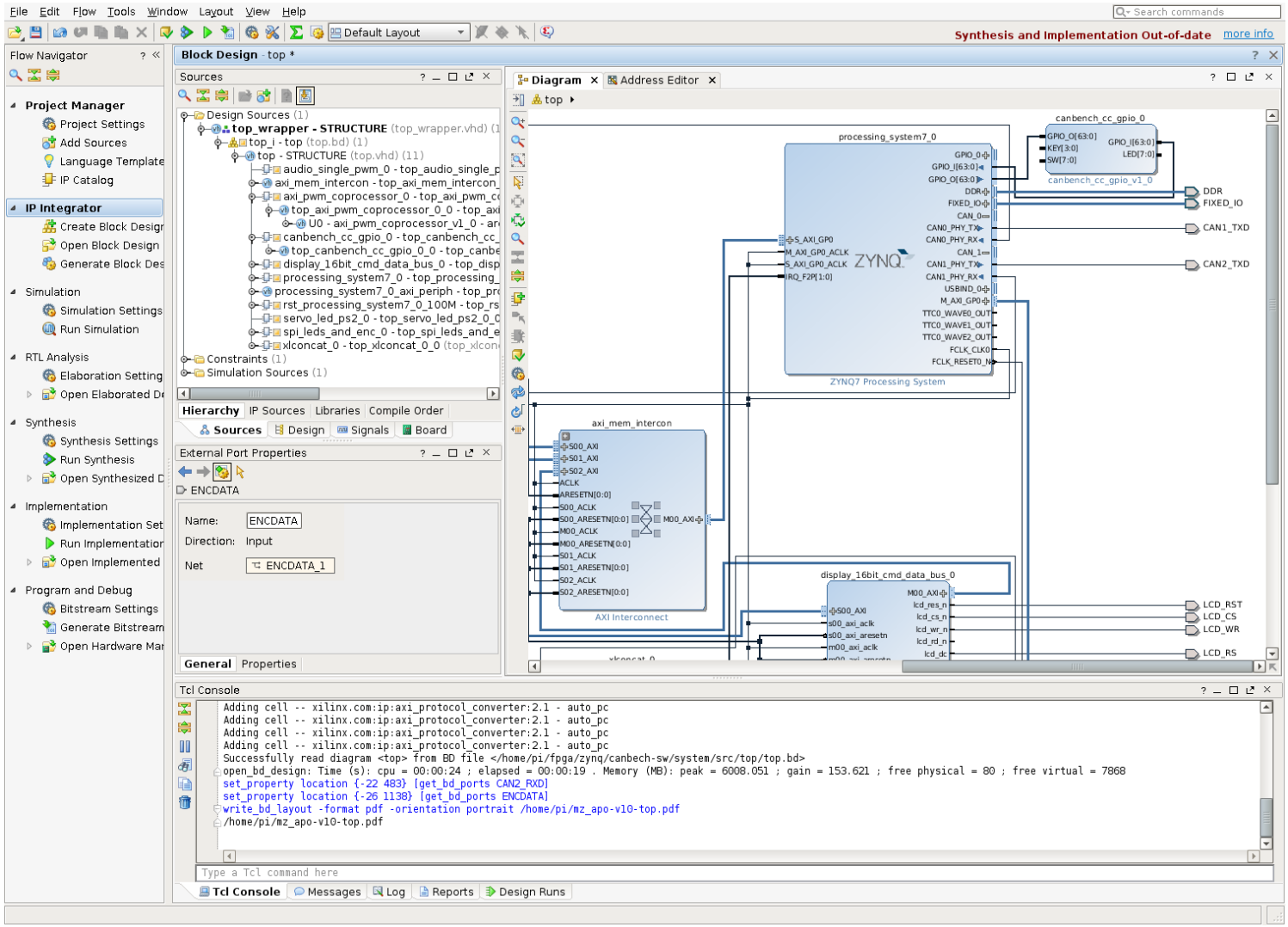
Advanced e**X**tensible **I**nterface (AXI) consists of five different channels:

- Read Address Channel
- Read Data Channel
- Write Address Channel
- Write Data Channel
- Write Response Channel

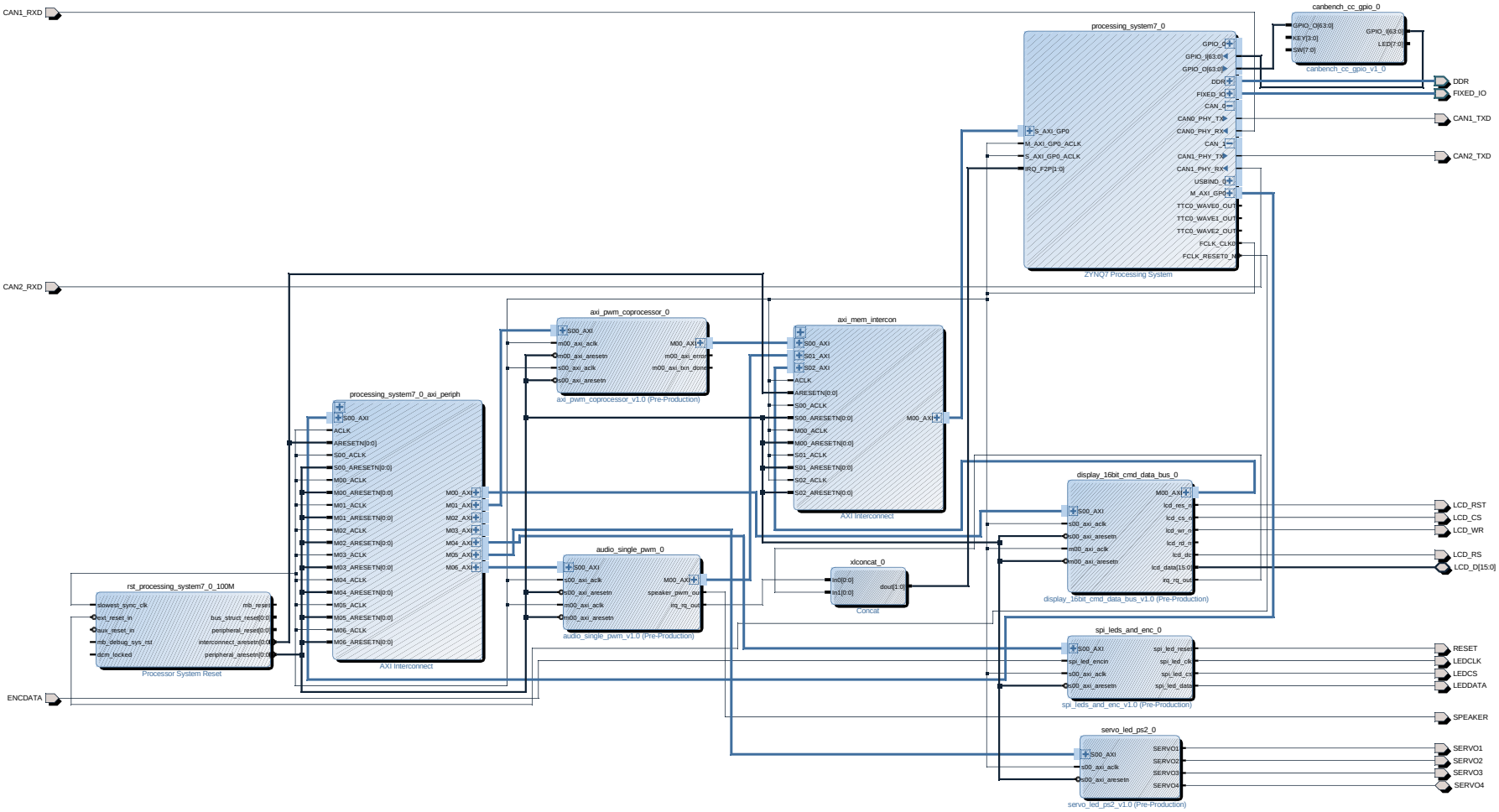
On-chip buses are used only inside integrated circuits and utilize switching multiplexors that allow simultaneous reading and writing operations. They will be described by LSP course (the next semester).

External PC buses *(ISA, PCI, SATA, PCIe)* ***have different operation!*** *We will deal with them in a future lecture.*

Design of Peripherals in Xilinx Vivado



Vivado Design of Peripherals for APO



Compete design sources: https://cw.fel.cvut.cz/b182/courses/b35apo/documentation/mz_apo/start

MicroZed Physical Memory

Address start	Length	
0x0000 0000	1 GB	DRAM
0x4000 0000	1 GB	AXI bus port 0 to FPGA
0x43c00000	16 bytes	APOZed - LCD display
0x43c40000	48 bytes	APOZed - Peripherals
0x8000 0000	1 GB	AXI bus port 1 to FPGA
0xE000 0000		Reserved for system
0xFFFC 0000	256 kB	On chip static memory

But Cortex A9 runs with GNU/Linux OS that is configured for paging, thus, we cannot use directly physical addresses!

Mapping Hardware in Linux

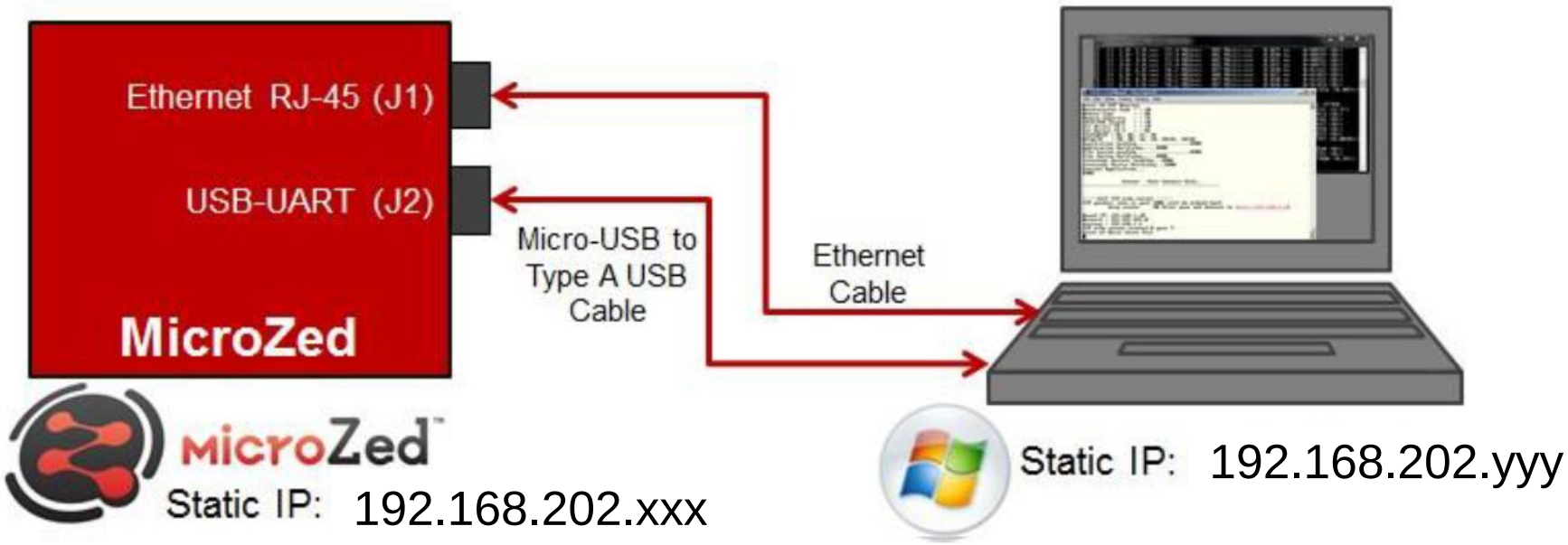
It is simplified part of the code that you use in your semester project

```
int fd = open("/dev/mem",  /* we ask for physical memory addresses */
              O_RDWR /* with read and write access */
              | O_SYNC /* and non-cached for /dev/mem */
              );
unsigned char *mem = (unsigned char *) mmap(
              NULL, /* kernel selects virtual address */
              0x4000 /* our required size = MicroZed physical mem view */,
              PROT_READ | PROT_WRITE, /* allow read and write*/
              MAP_SHARED, /* visible to other processes*/
              fd,  /* handle of an already opened file */
              0x43c40000 /* offset in file, here I/O physical base address*/  );
```

Note: For simplification, we have supposed that the size and offset are already align to page size.
Full template: https://gitlab.fel.cvut.cz/b35apo/mzapo_template

Connecting to the board

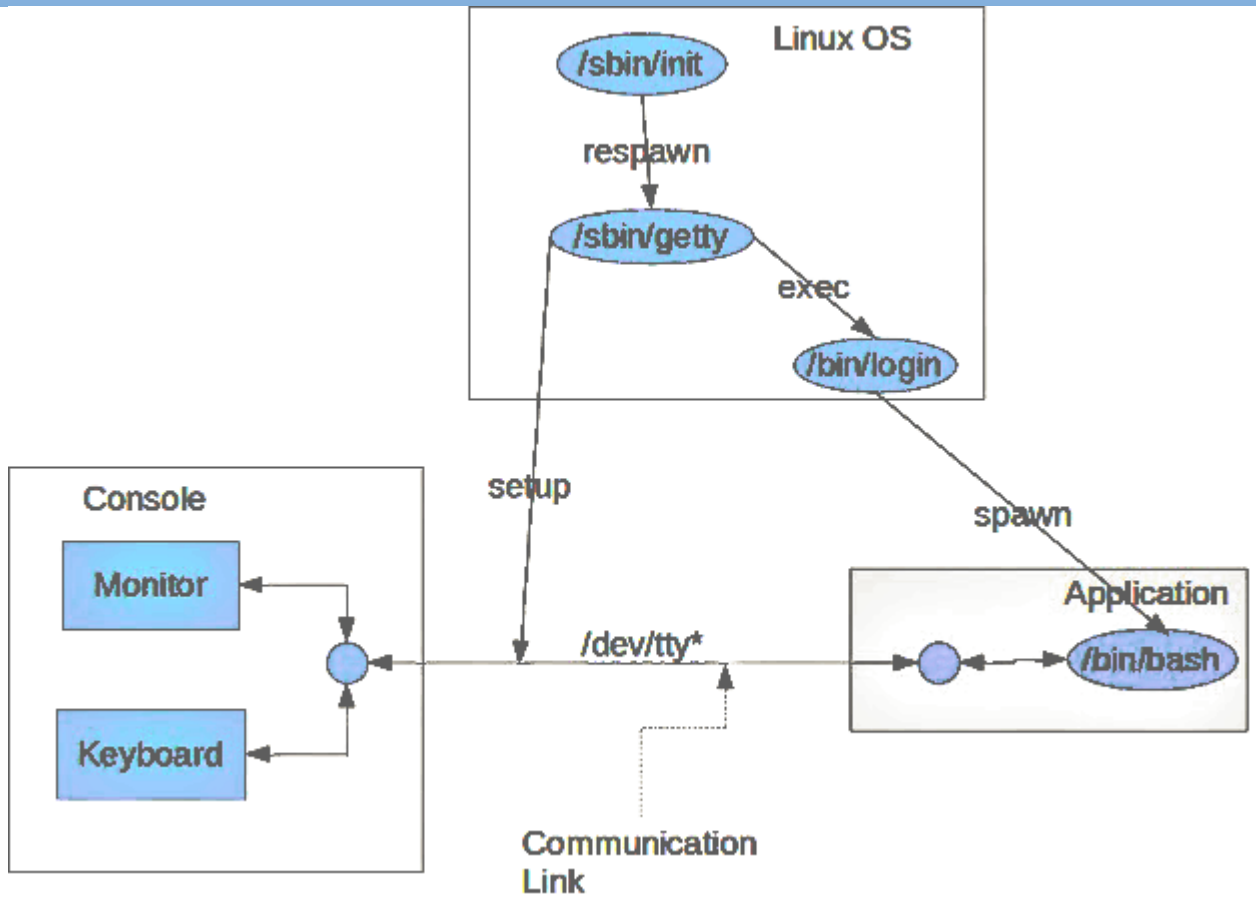
Connection to Board



Notes:

1. *Micro USB is replaced by more robust USB type B on our carry board.*
2. *In Linux,*
   - *GtkTerm allows USB connection*
   - *SSH utilizes Ethernet*

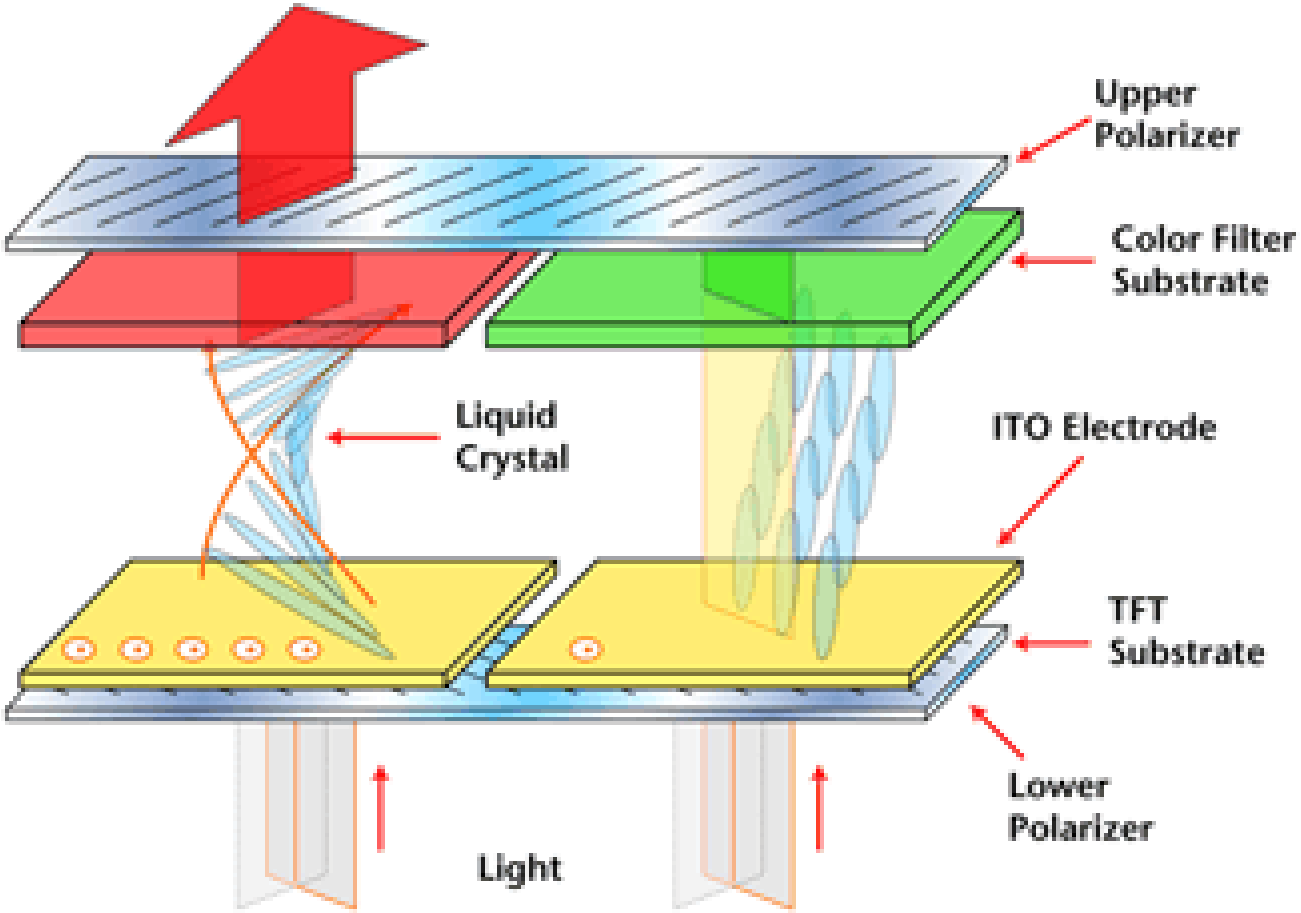
Linux Console Concept



- GtkTerm uses /**dev/ttyUSB0**
- SSH connect through Ethernet and uses **/dev/ttyp****

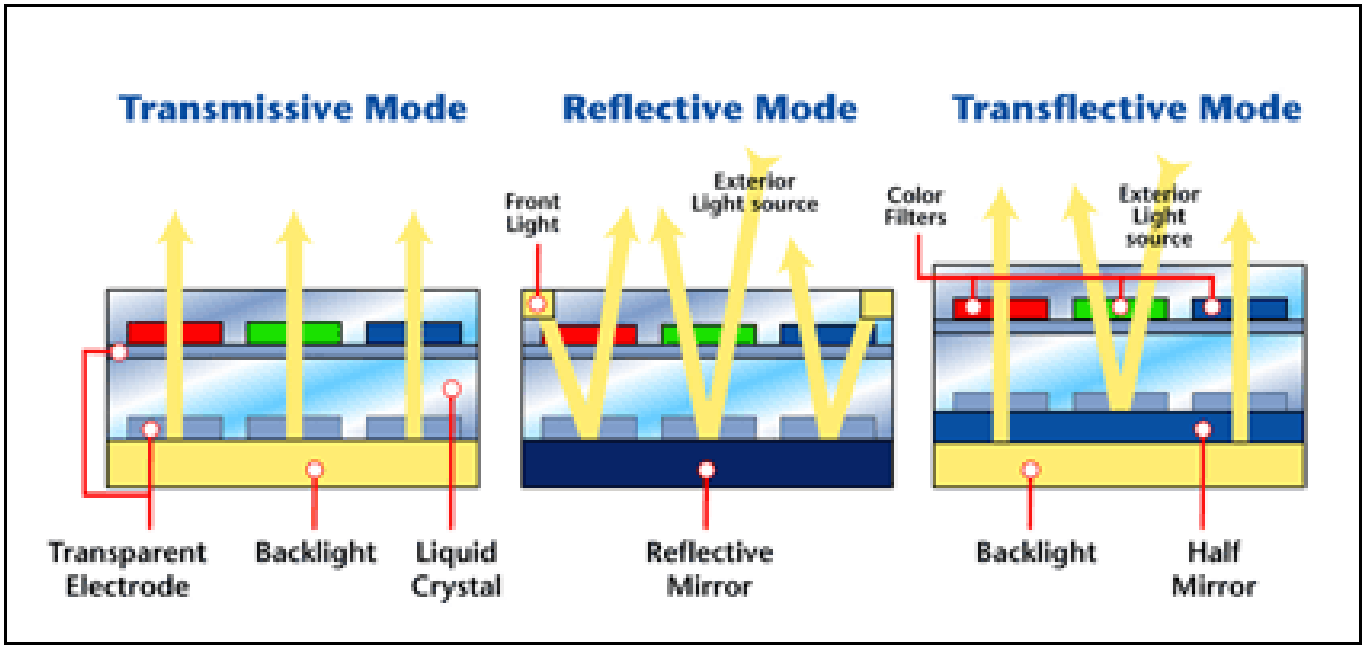
*LCD display

LCD Lighting Theory



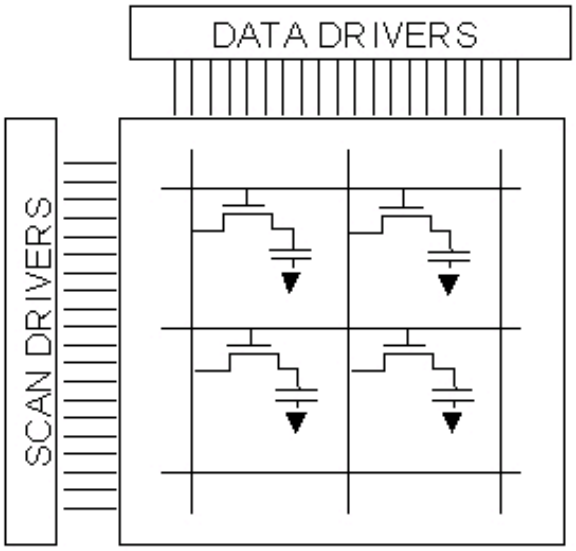
Source: Matrix

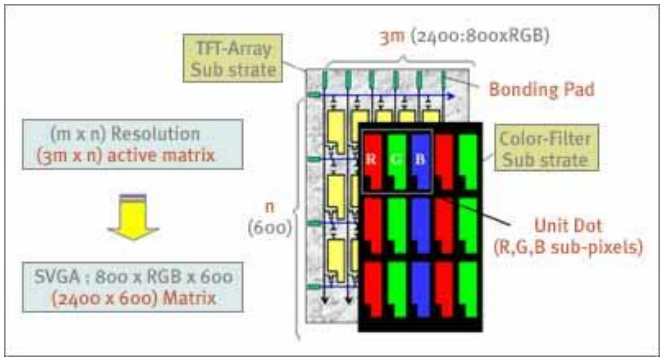
LCD Lighting Theory

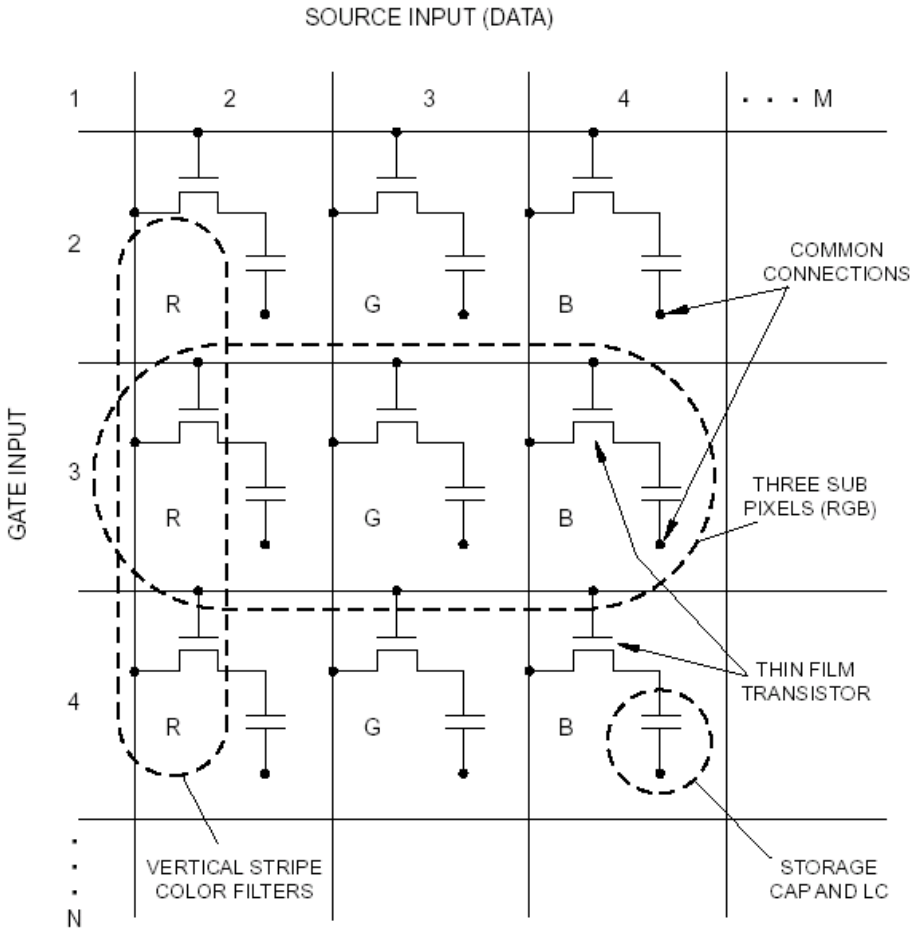


Source: Matrix

TFT with Active Matrix

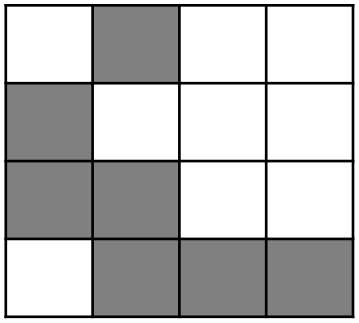






Source:

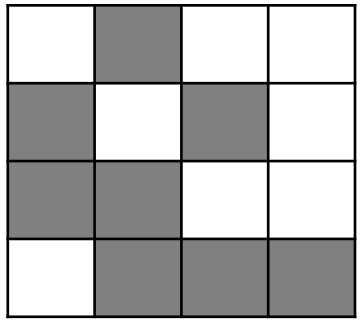
Compare with Memory Matrix from 4th lecture



TFT display only writes and usually selects only 1 pixel !

New value = 1

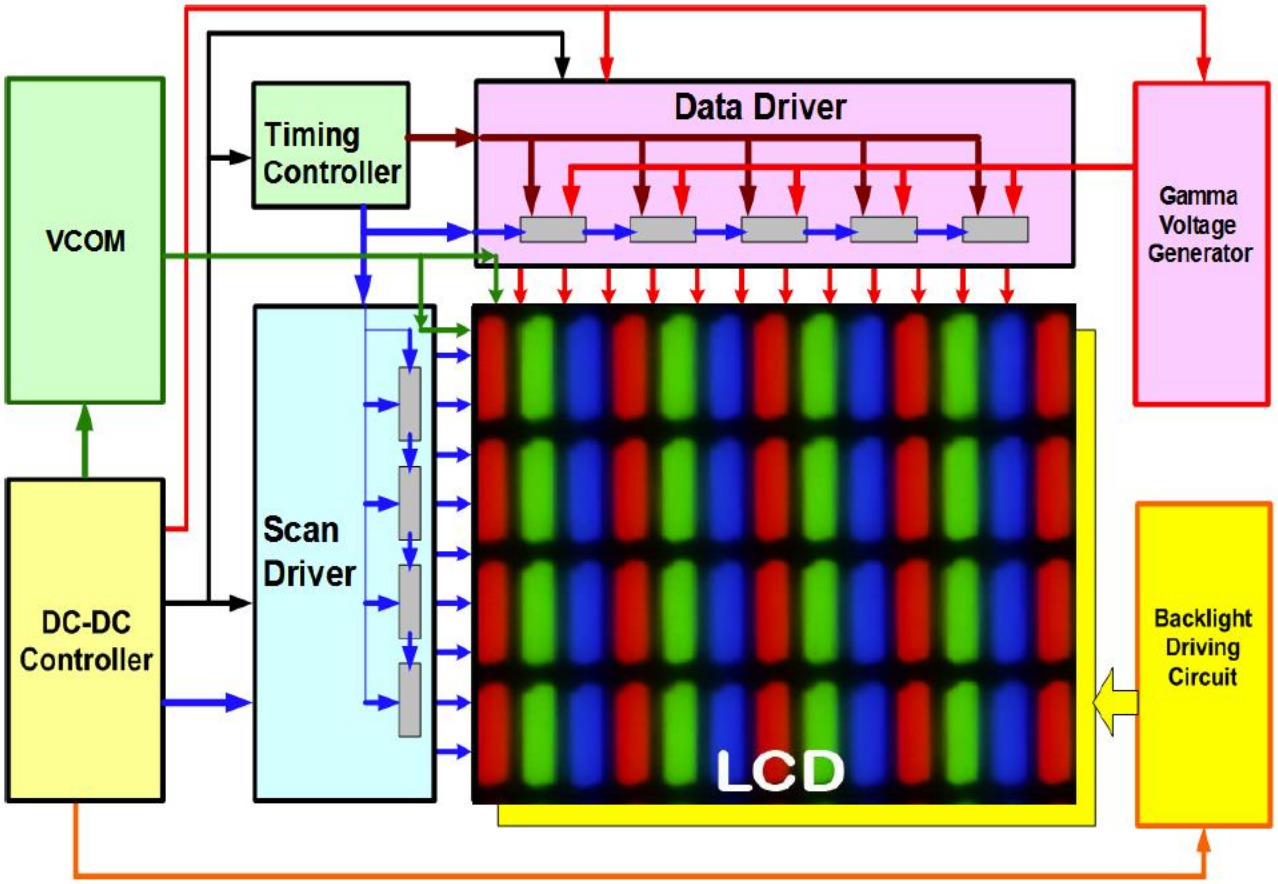
Compare with Memory matrix 4th lecture



TFT display only writes and select 1 pixel !

New value = 0

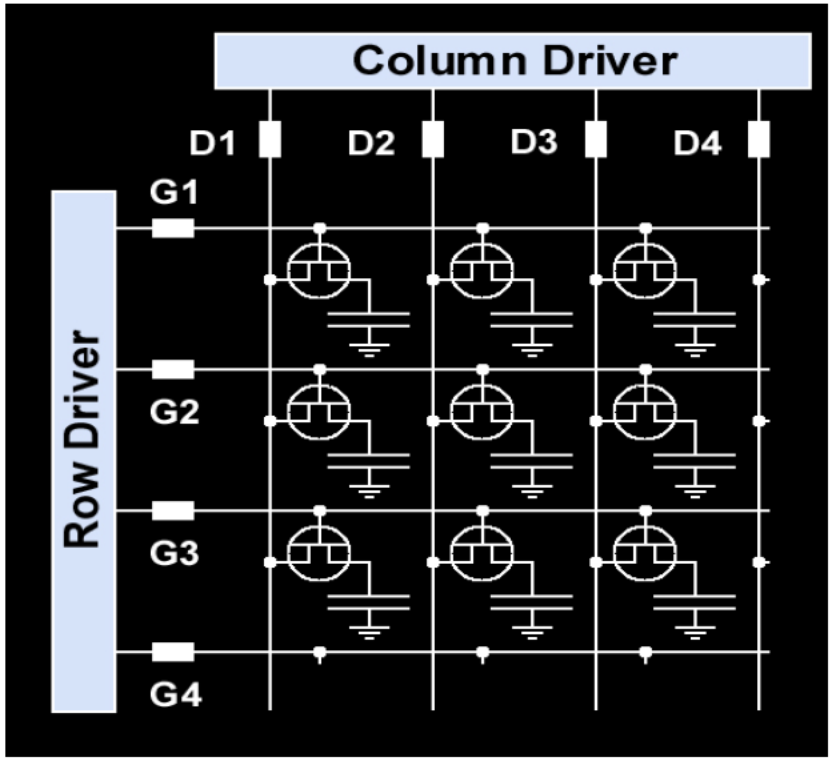
LCD Control



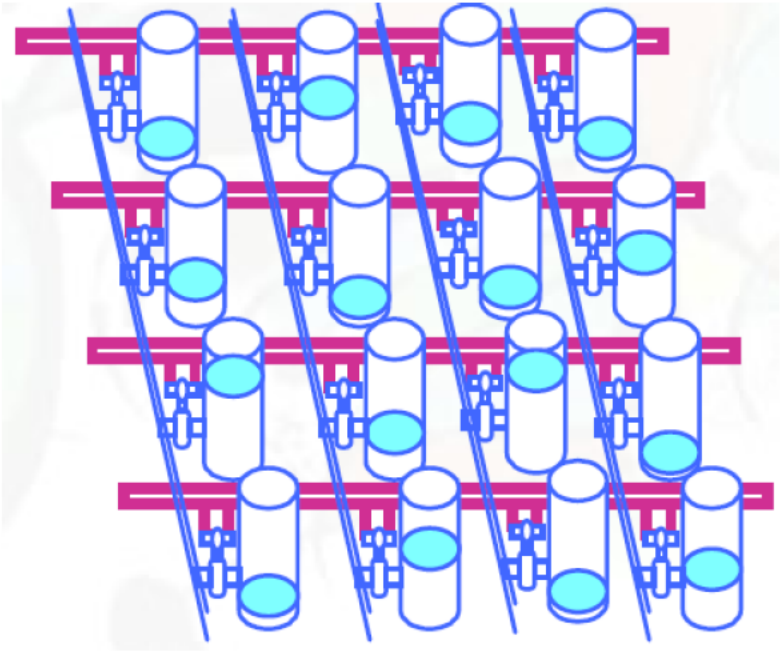
Source: Dr. Zhibing Ge, College of Optics and Photonics

LCD Pixel has More Levels !

TFT (switch) + LC cell (capacity)

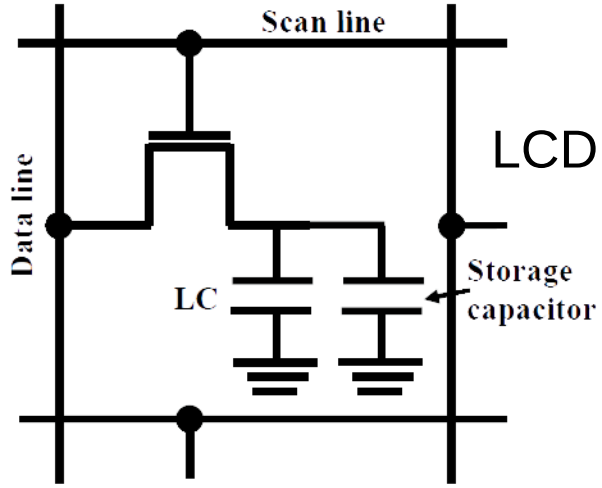


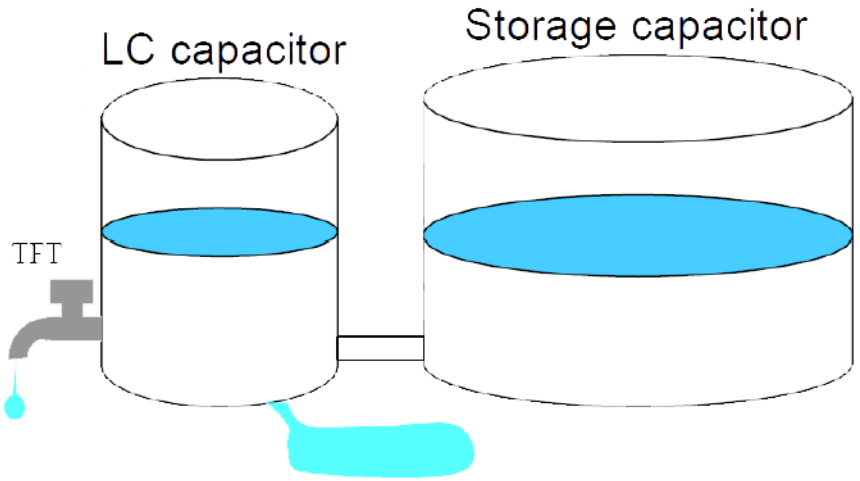
Hydrant (switch)+ Bucket (capacity)

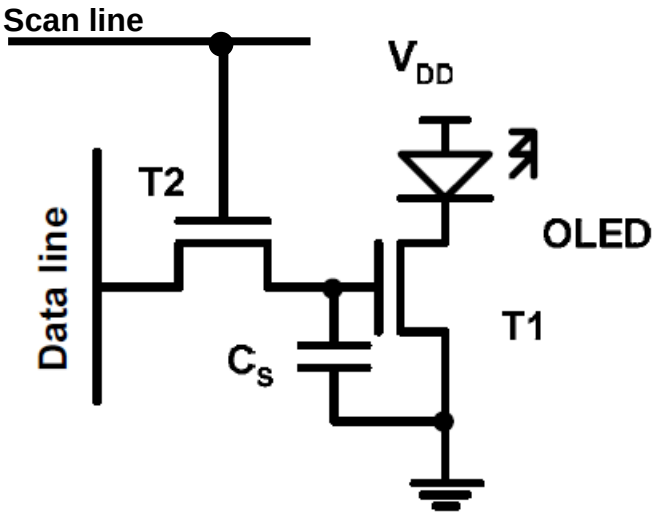


Source: Dr. Zhibing Ge, College of Optics and Photonics

LCD Refreshing







LCD display needs periodic refresh as DRAM, but in slower rate.
Typical values of C_s are from 100 fF (=0.1pF) to 2000 fF (=2pF), in DRAM from 10 to 50 fF.

LCD read/write

Our program contains assembler instruction of compiled C code

register1 = * address;

or

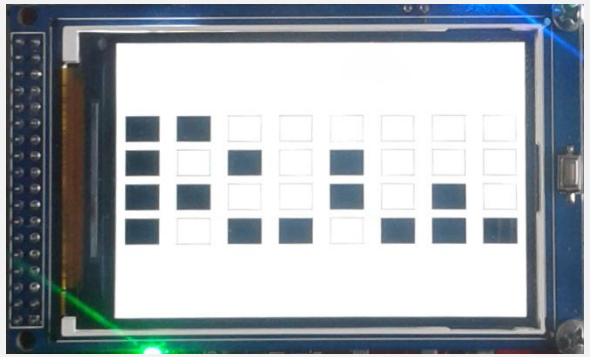
*** address = register2;**

Program in DDR3

rd/wr virtual address

APO MicroZed

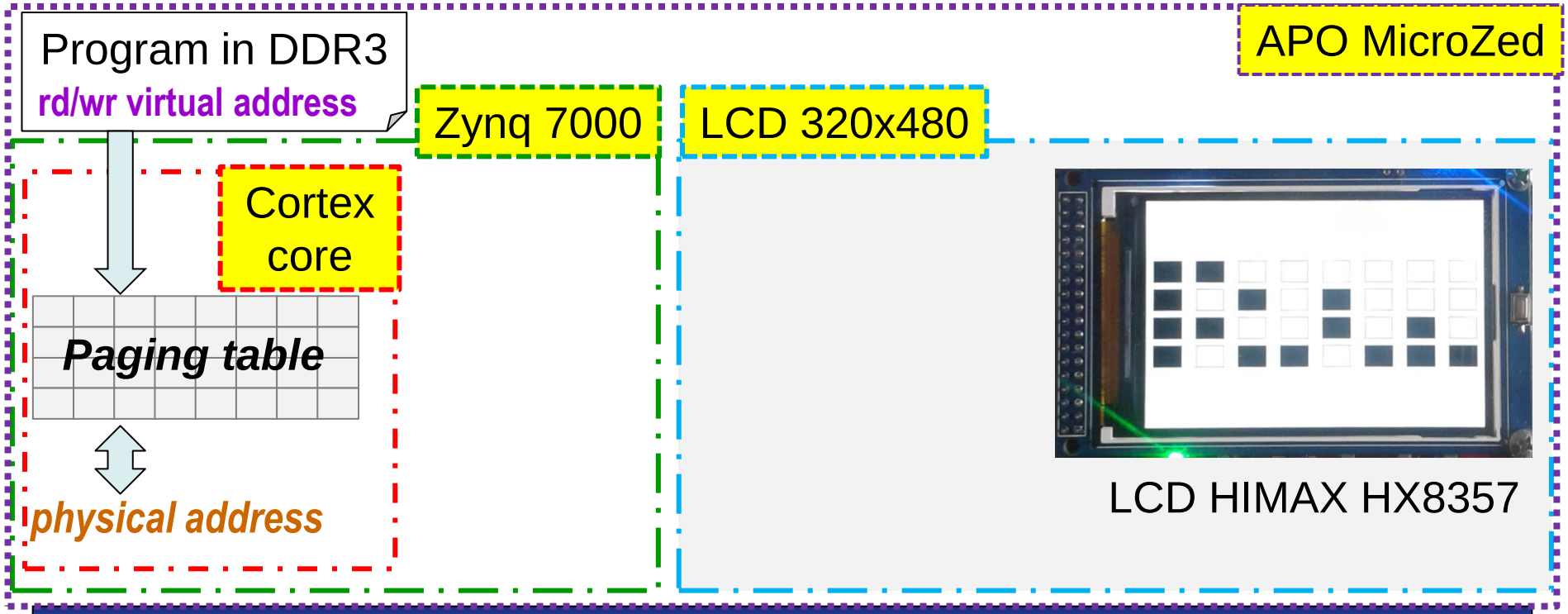
LCD 320x480



LCD HIMAX HX8357

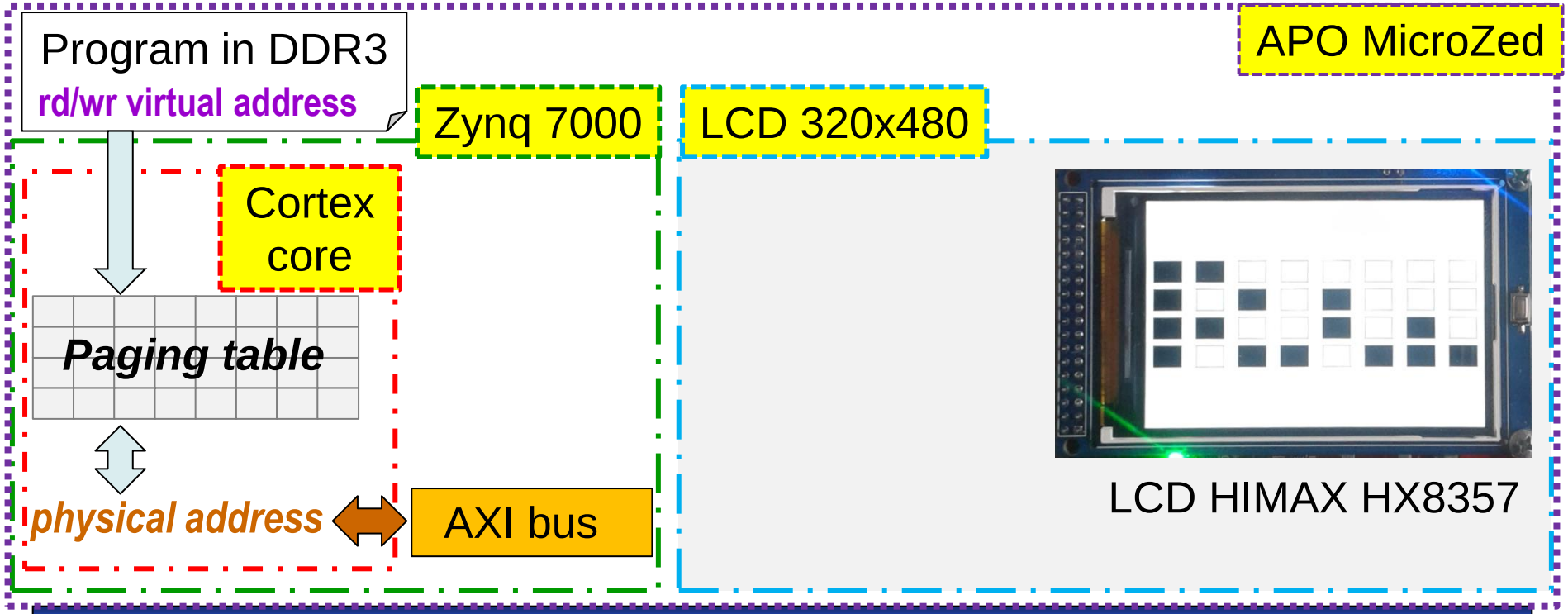
LCD read/write

Virtual address is transformed to physical address during FETCH phase of pipeline



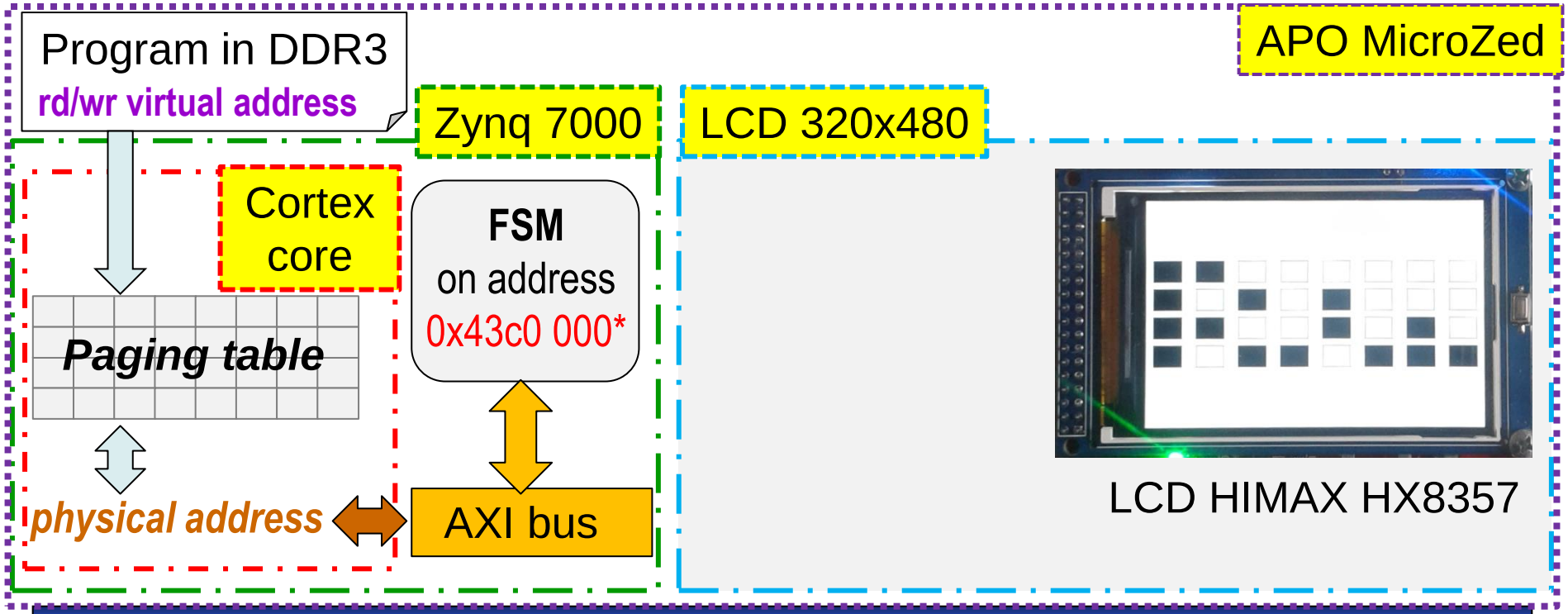
LCD read/write

Physical address and data are send to AXI bus



LCD read/write

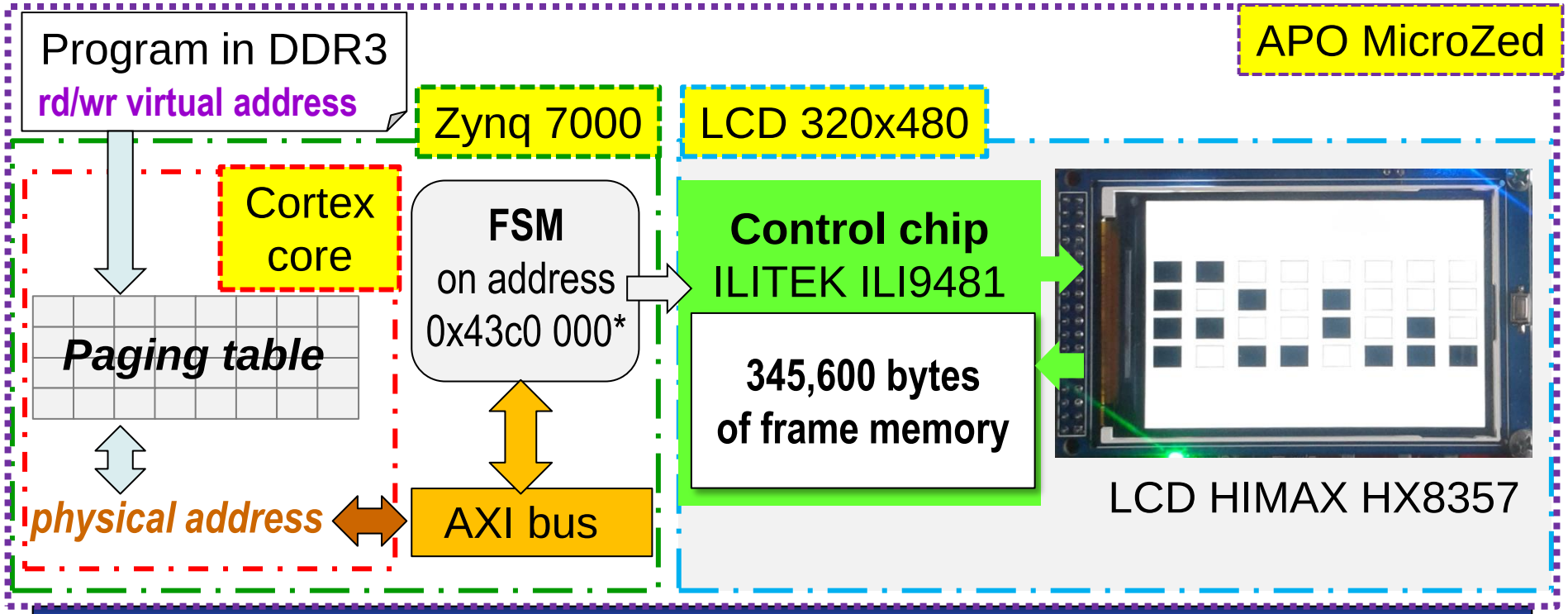
FSM (Finite State Machine, cz: konečný automat) compares addresses on AXI bus.
If some address is in range 0x43c0 0000 to 0x43c0 000F then it accepts corresponding data for LCD.



LCD read/write

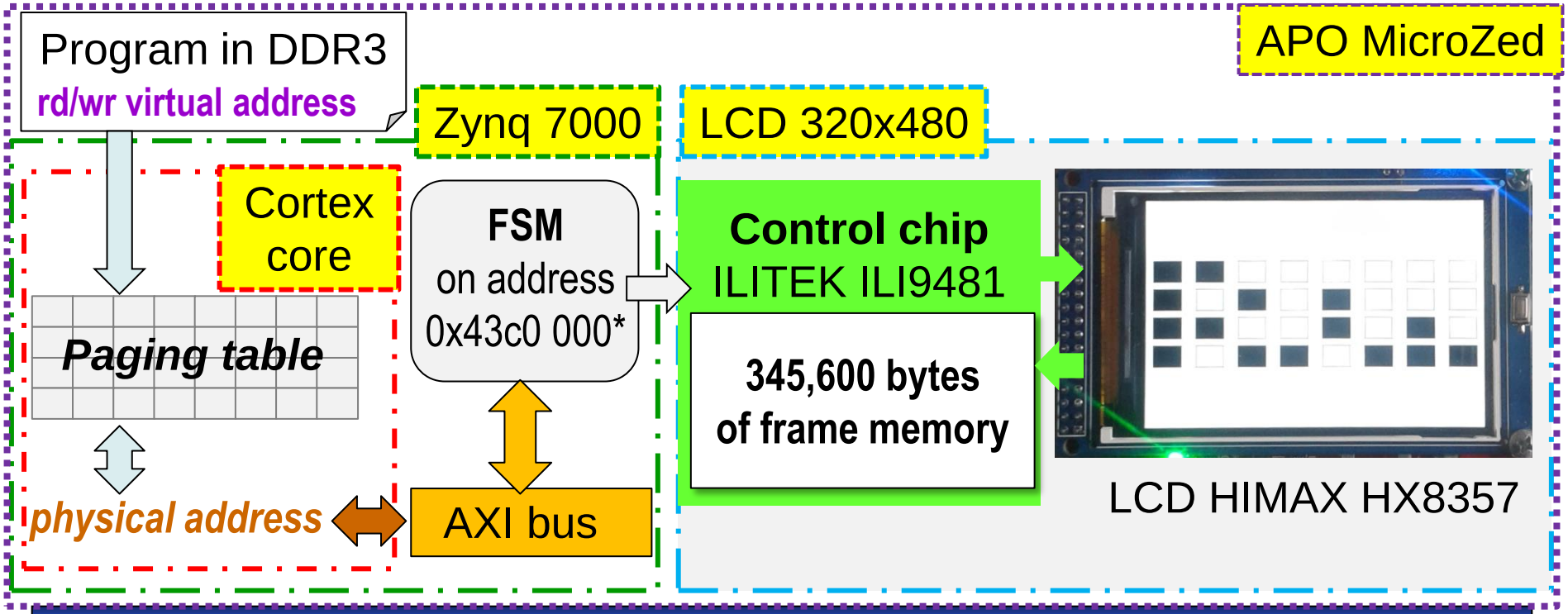
FSM transmit data to LCD by generating appropriate signals for LCD control chip that periodically refreshes TFT-LCD display.

If a new request appears before the previous is done, FSM is sending WAIT to AXI bus until it can accept next data/command.



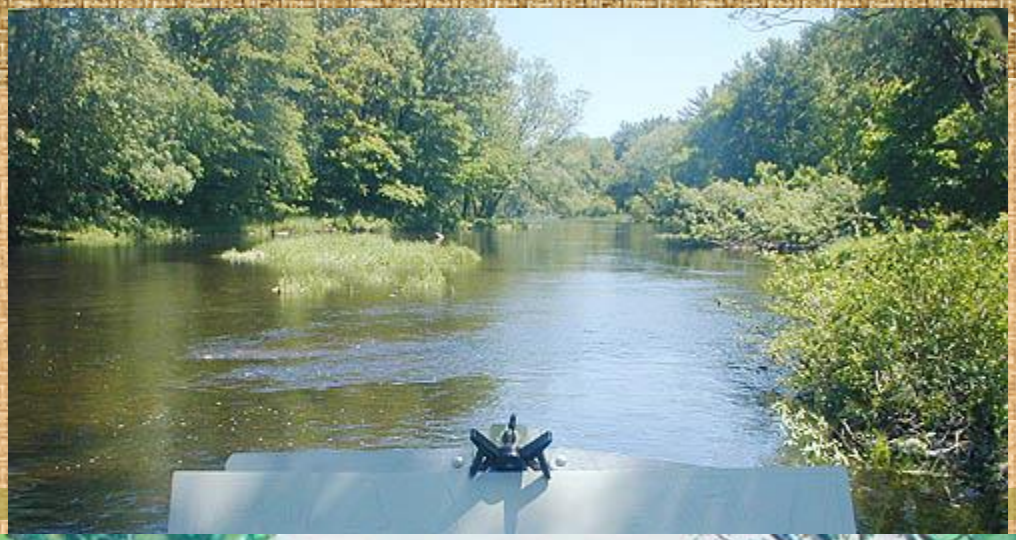
LCD read/write

Virtual Base Address	Data Type	Control Chip Operation
+0	uint16_t	0x1 - reset LCD, bit0 == 0 - no function
+8	uint16_t	LCD control command
0xC	uint16_t	write 16 bit color pixel (bits 15..0) to frame memory
0xC	uint32_t	write 2 following pixels: bits 15..0 | bits 31..0 to mem.



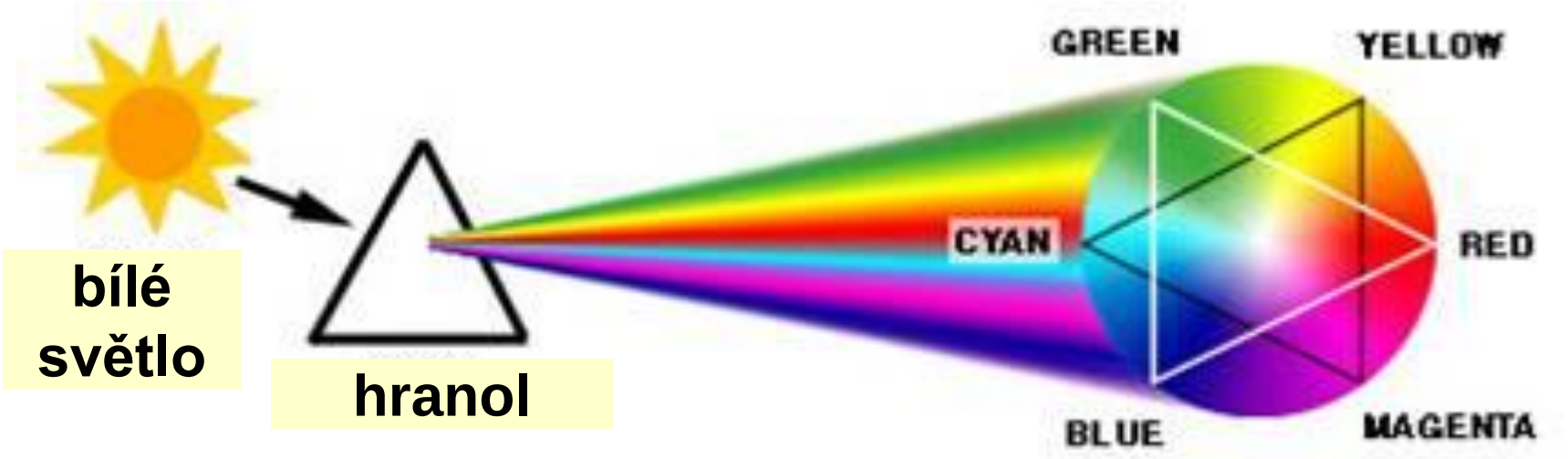
Co je to HSV ?

realita versus paleta

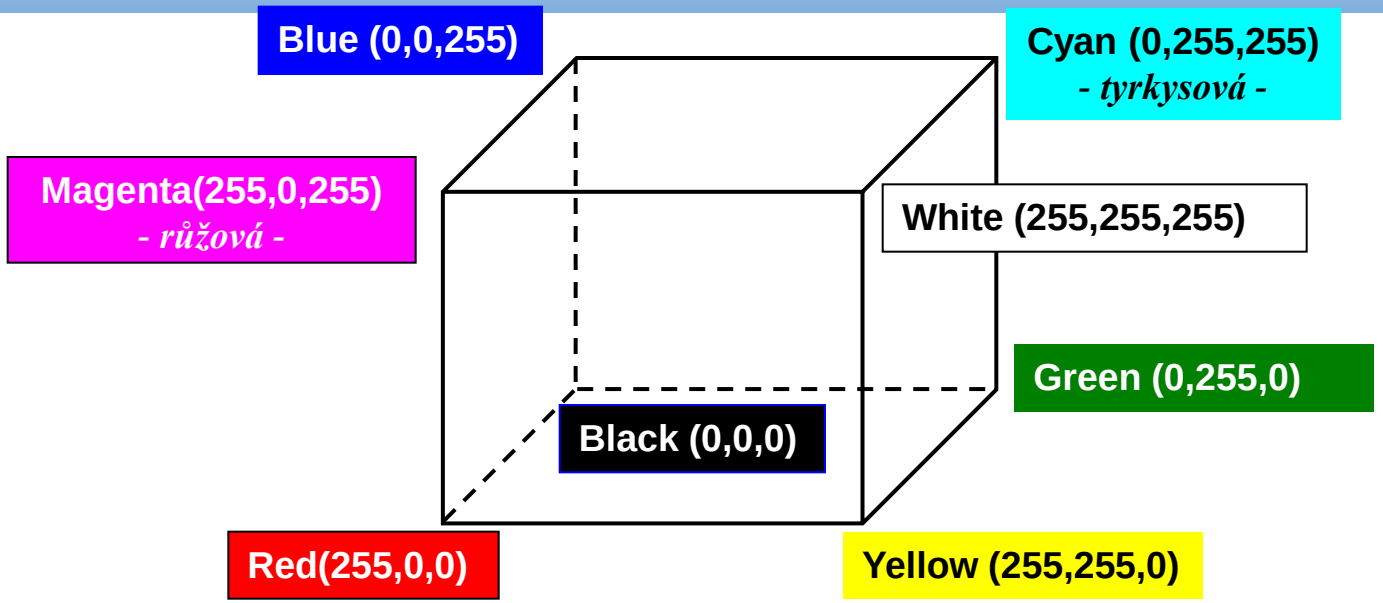


[www.realcolorwheel.com]

Aditivní míšení barev

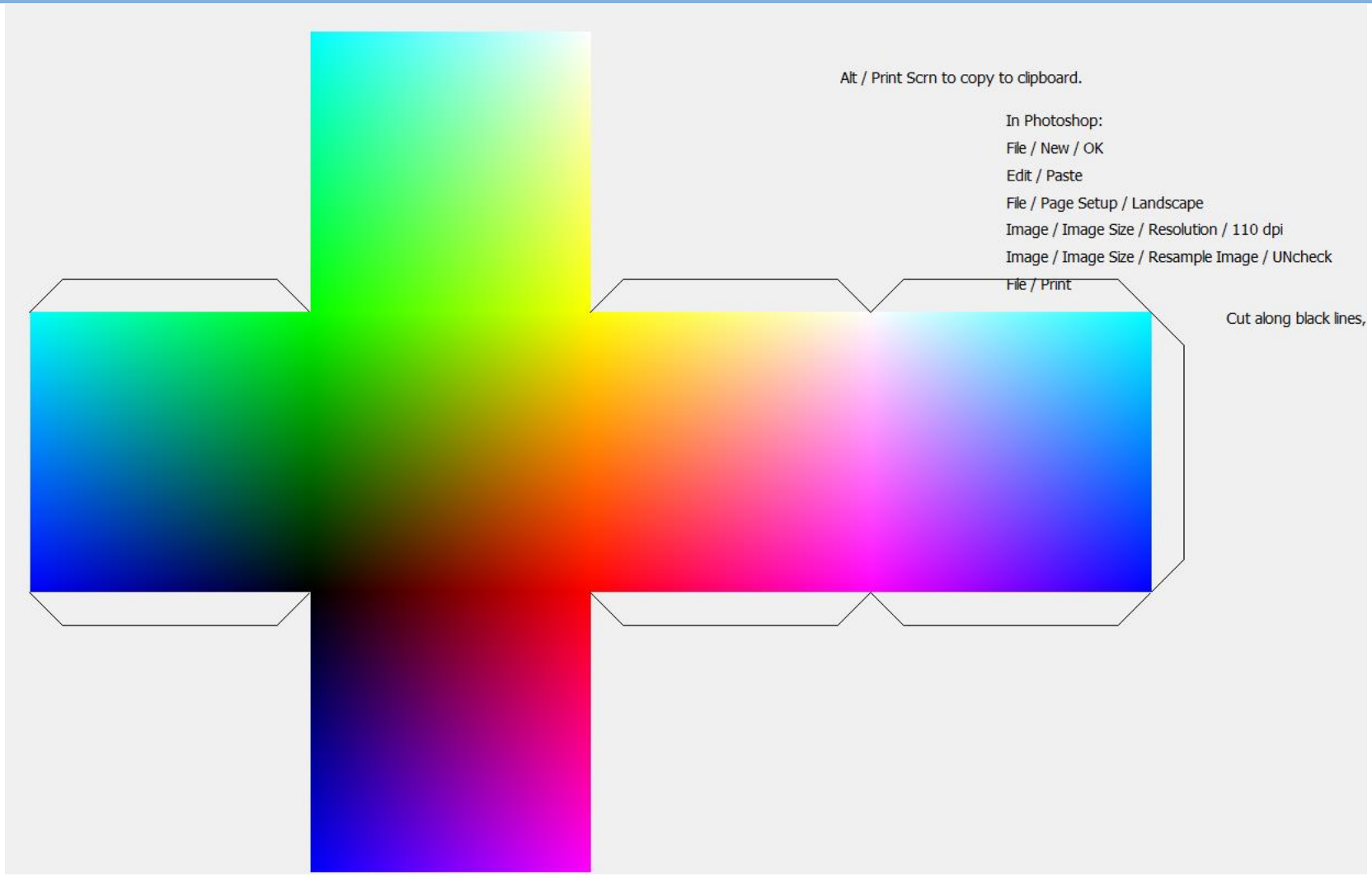


RGB barevná krychle



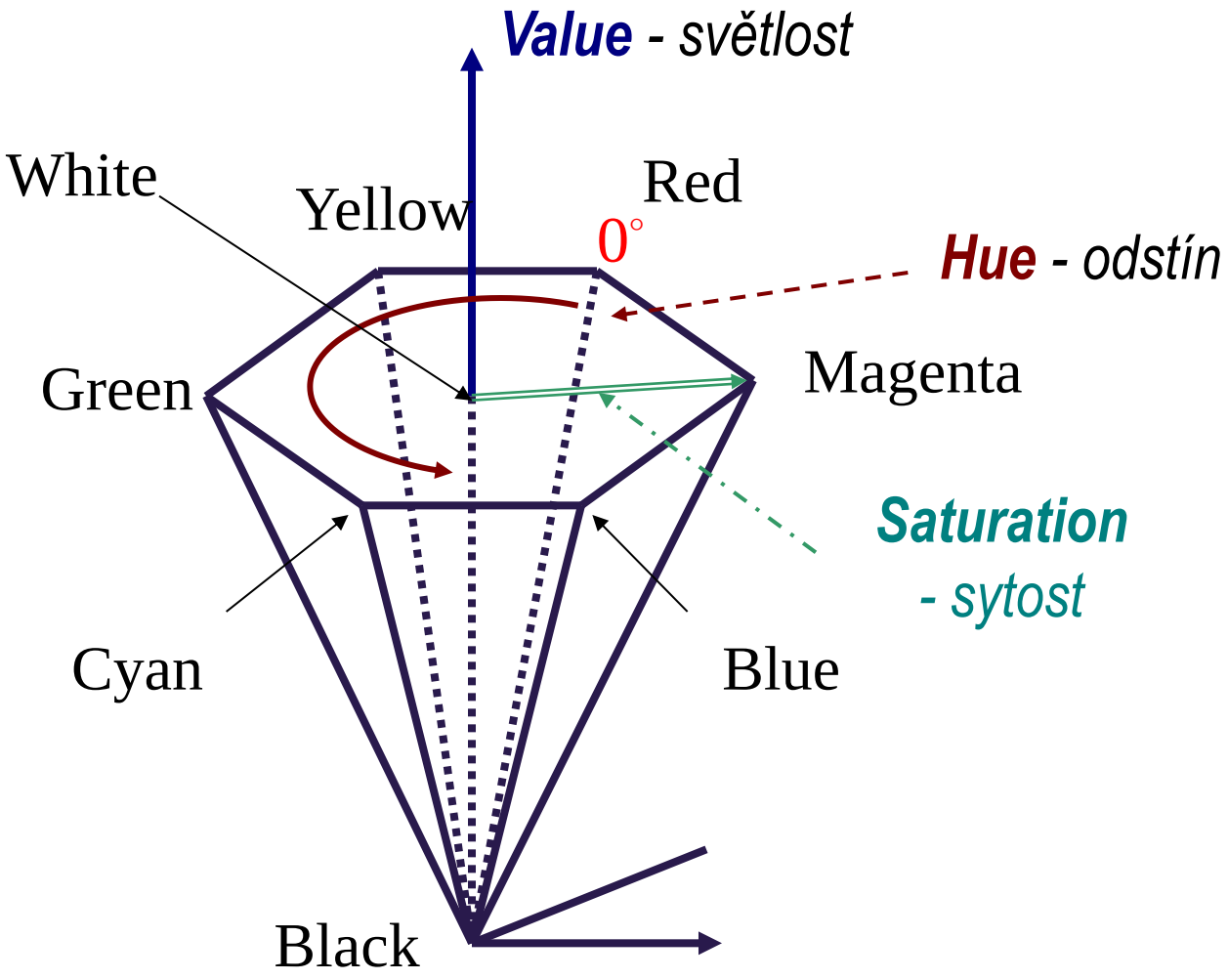
- *Aditivní míchání barev se používá například na monitorech, vlivy jednotlivých barev se sčítají, neboť každá složka se chová jako zdroj světla.*

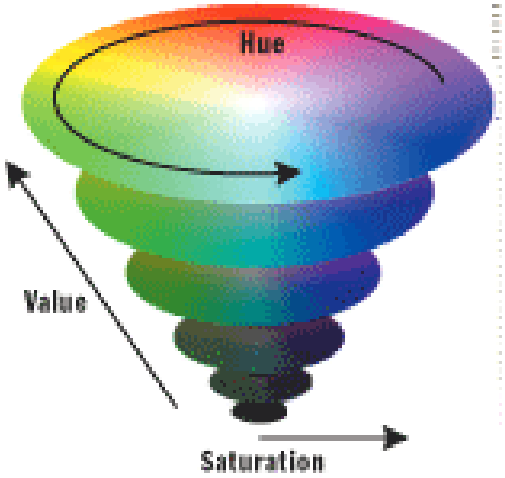
RGB Cube with Unintuitive Distribution of Color



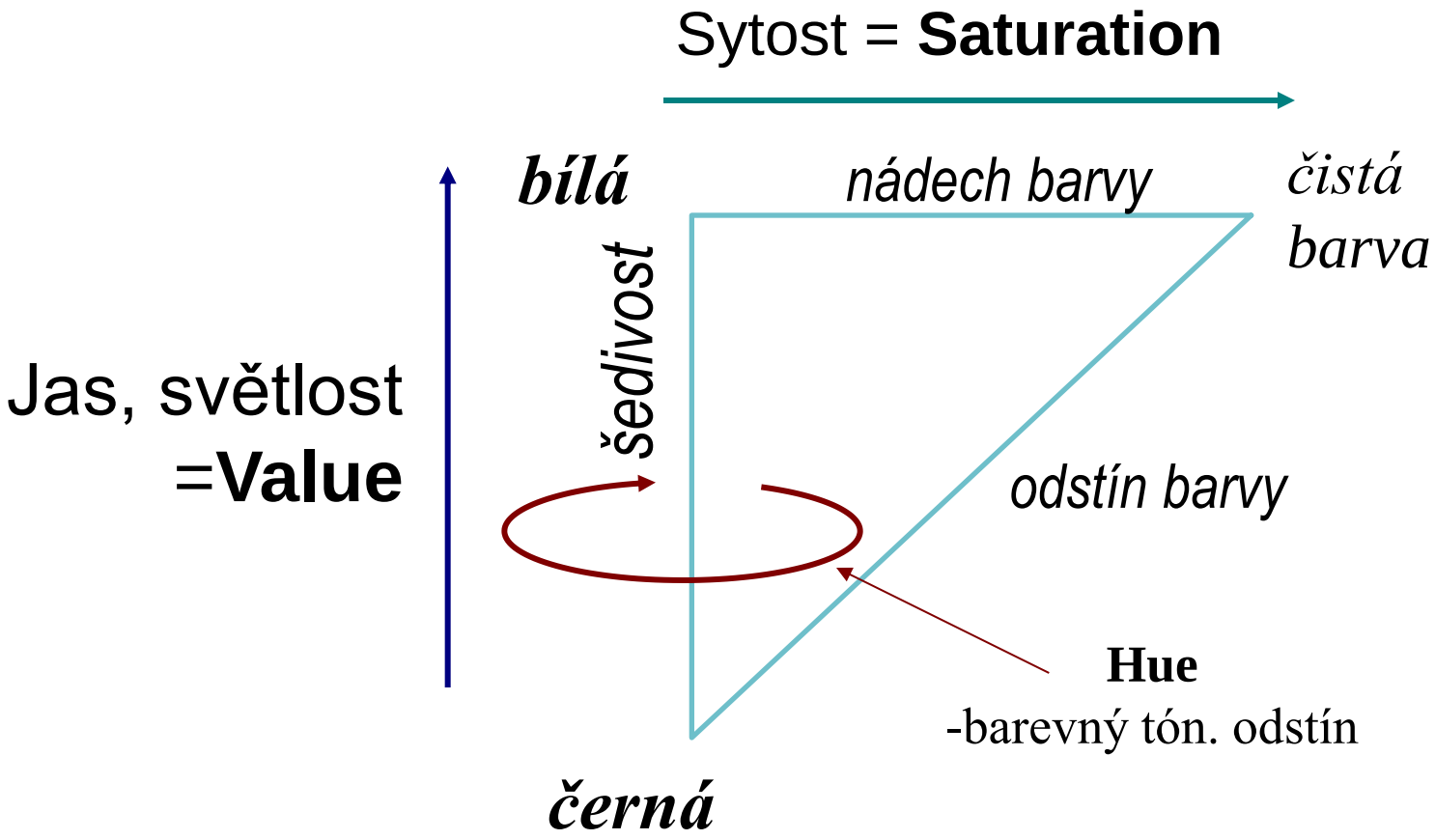
Source: http://people.duke.edu/~ng46/borland/graphics.htm

HSV sytém pro intuitivní tvorbu barev



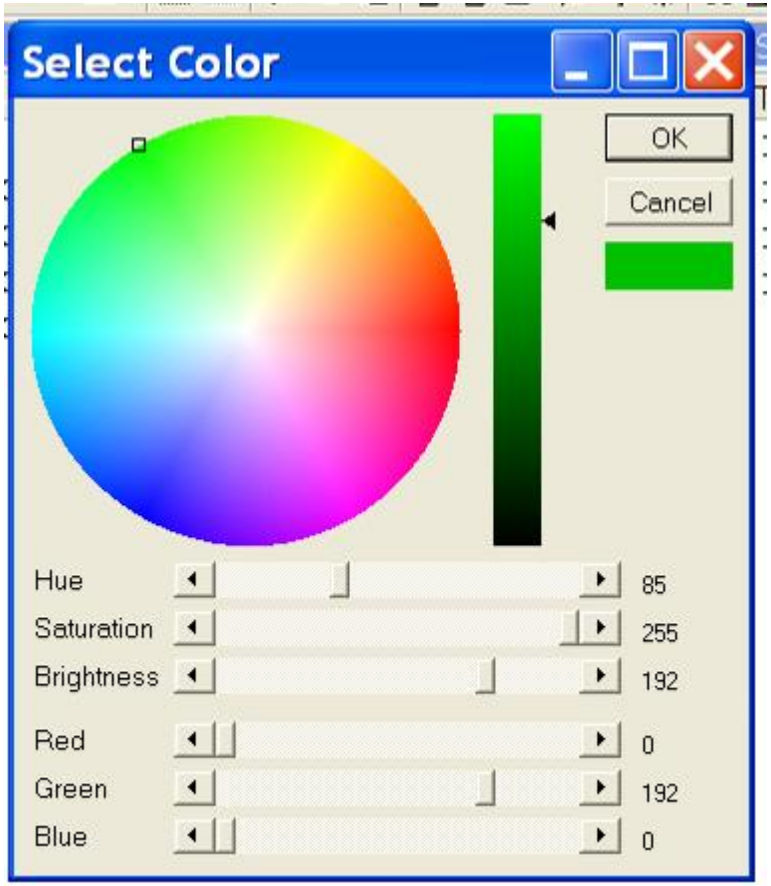


Význam parametrů HSV



Example of HSV Color Picker

Převod mezi RGB a HSV je poměrně složitý, ale existují C kódy na webu.



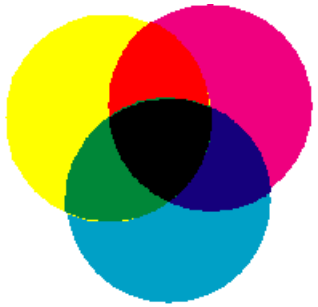
Pro srovnání CMYK

- *Subtraktivní míchání barev se projevuje při tisku - vlivy jednotlivých barvy se odečítají, jelikož každá složka se chová jako filtr bílého světla.*

- *CMY barevnou krychli dostaneme prohozením protilehlých vrcholů RGB krychle, tj- černá↔bílá, žlutá↔modrá, apod.*

$$\begin{matrix}\text{Cyan}\\ \text{Magenta}\\ \text{Yellow}\end{matrix}\begin{bmatrix}C\\M\\Y\end{bmatrix} = \begin{bmatrix}255\\255\\255\end{bmatrix} - \begin{bmatrix}R\\G\\B\end{bmatrix}$$

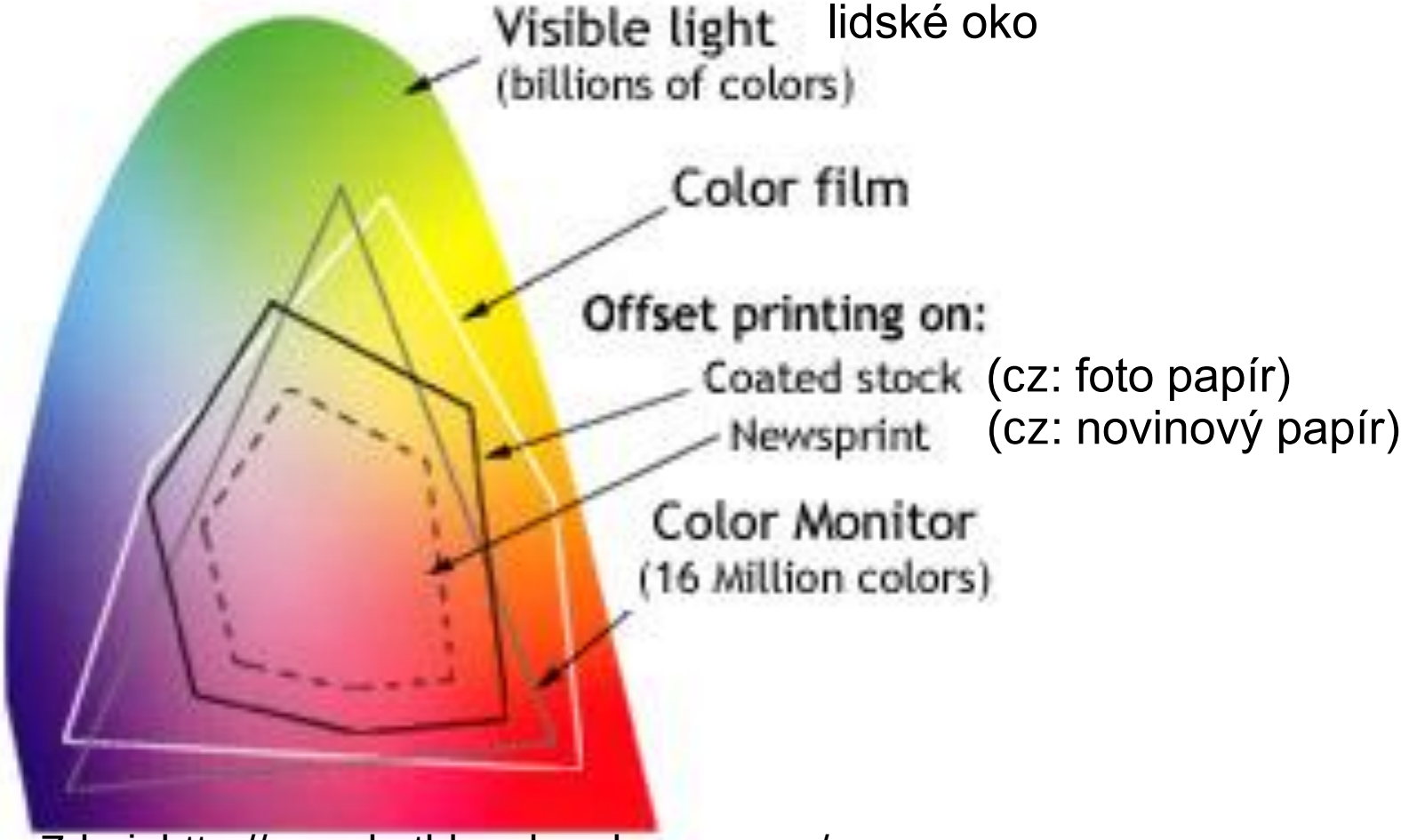
RGB



CMYK

- *Přidáním blacK dostaneme CMYK:*
  K = min(C,M,Y); C=C-K; M=M-K; Y=Y-K;

Získáme ale stejný gamut?



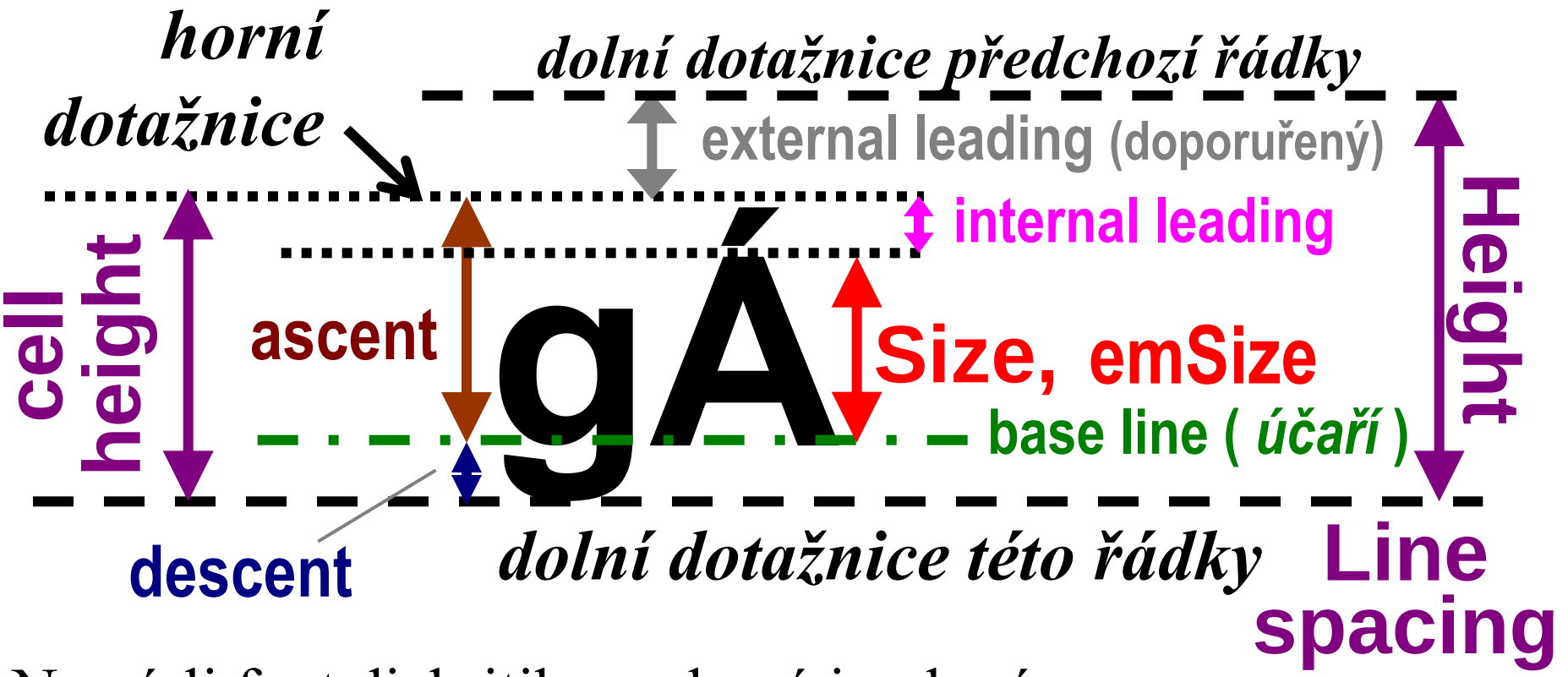
Zdroj: http://www.kathleenhmahoney.com/

gamut = rozsah barev zařízení

Text to Pixels ?

LCD has no character generator
and MicroZed does not contains any graphic card!

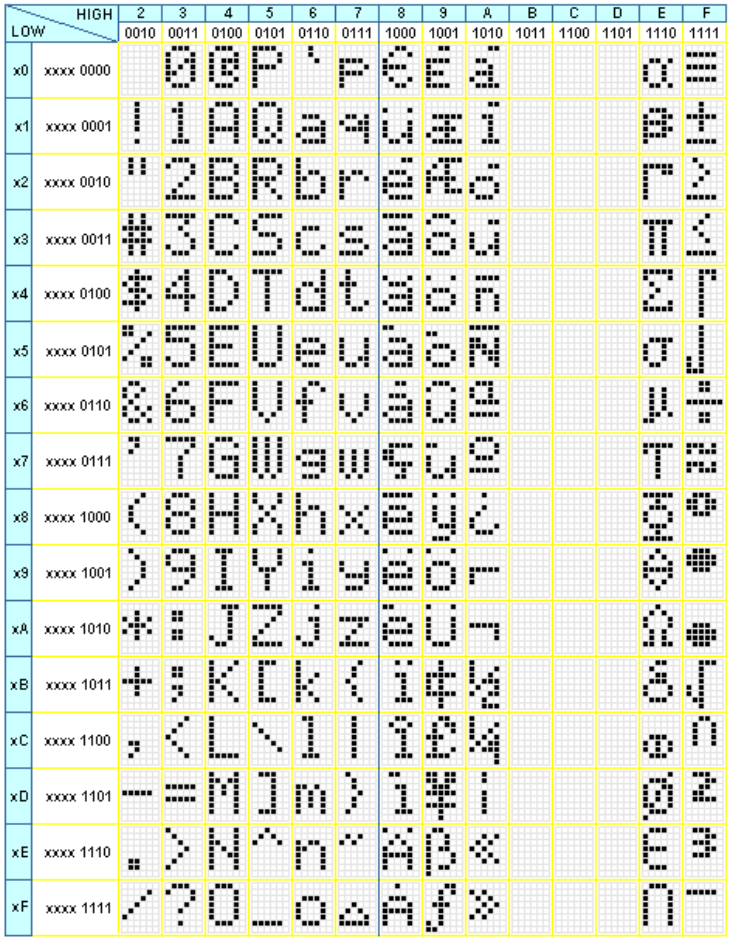
Velikost fontu



- Nemá-li font diakritiku, pak má i nulový internal leading a jeho ascent odpovídá emSize

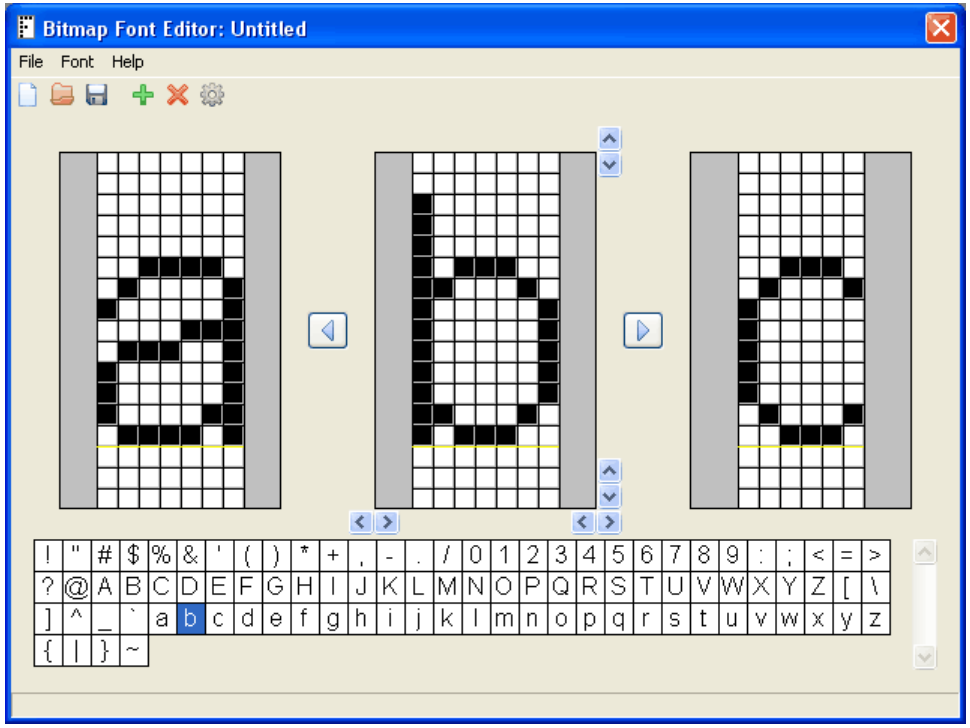
Bitmap Fonts

Bitmaps font are **faster and easier to use** and therefore suitable for low cost computer systems.



http://growboxbox.org/doku.php/lcd

http://mobilefonts.sourceforge.net/



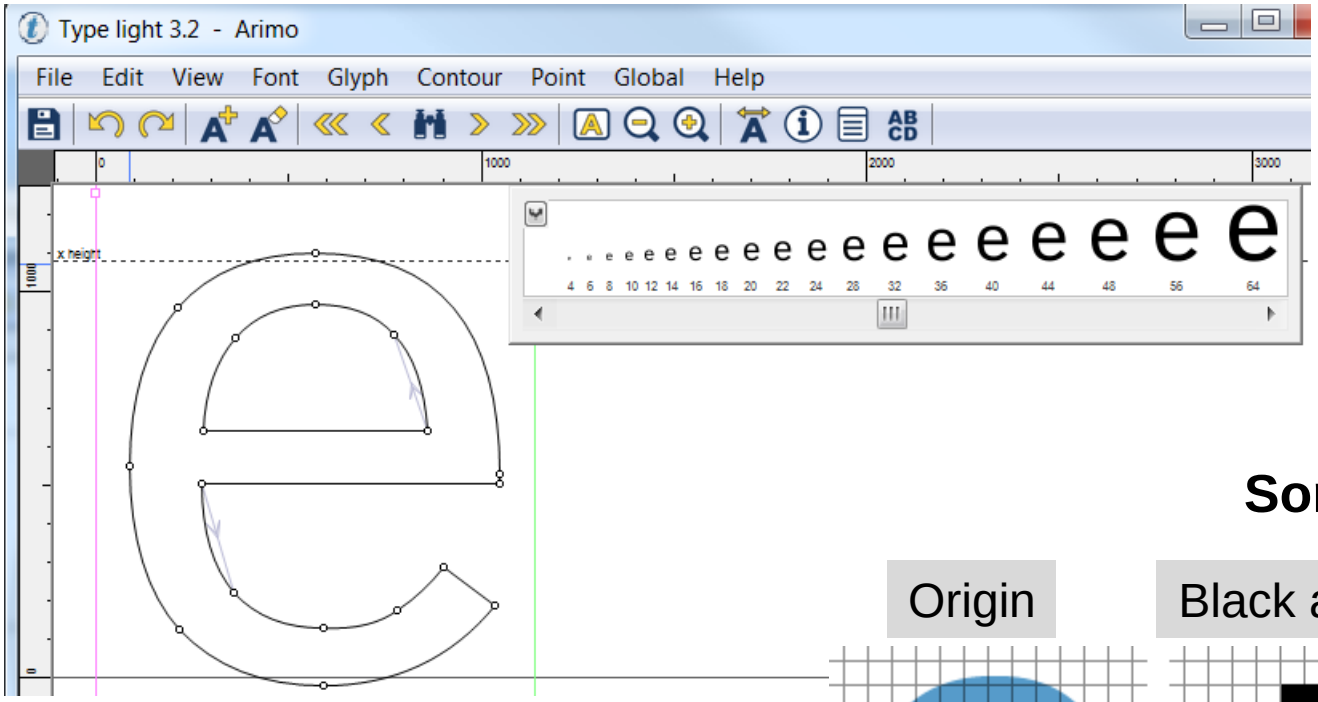
Note: In 1968 ,the first bitmap font was created by German inventor Rudolf Hell for his Digiset typesetting machine .

The Scalable Font Wars

- Apple and Microsoft developed (1980) the **TrueType** methodology that is a system of scalable outline fonts, and can draw characters at low resolution.
- Adobe **PostScript** (1984) is another method of describing an image in terms of ***mathematical constructs*** (Bézier curves), so it is used not only to describe the individual characters of a font but also to describe entire illustrations and whole pages of text.
- **Open Type** (1996) digital font format was developed jointly by Apple and Microsoft to put an end to the PostScript/TrueType war. Like TrueType, a single file contains all the outline and bitmap data for an OpenType font, but it also contains either PostScript data or additional TrueType data within the font, which in the PostScript case, makes the font truly scalable and exacting.

Source: wordpress.com

Rendering of Fonts



Upper picture: program [Type Light](#) V3.2

Some rasterizations

Origin | Black and white | Grayscale

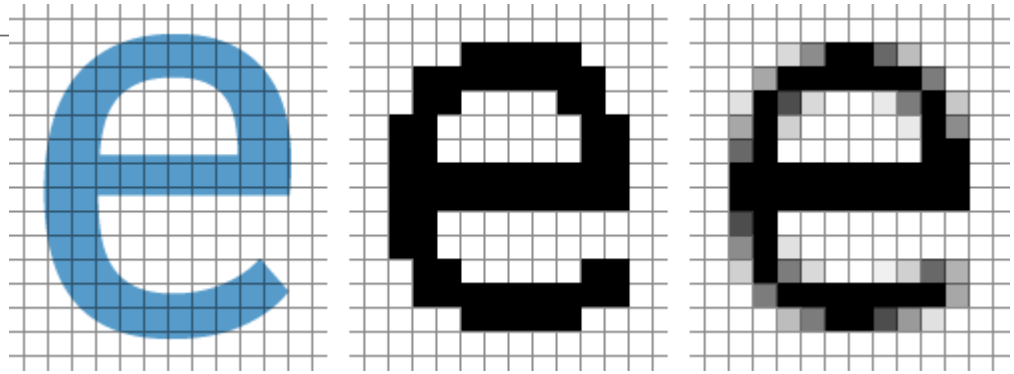


Image source: https://www.smashingmagazine.com/

Any scalable font must be finally rendered (rasterized) to pixels of display !

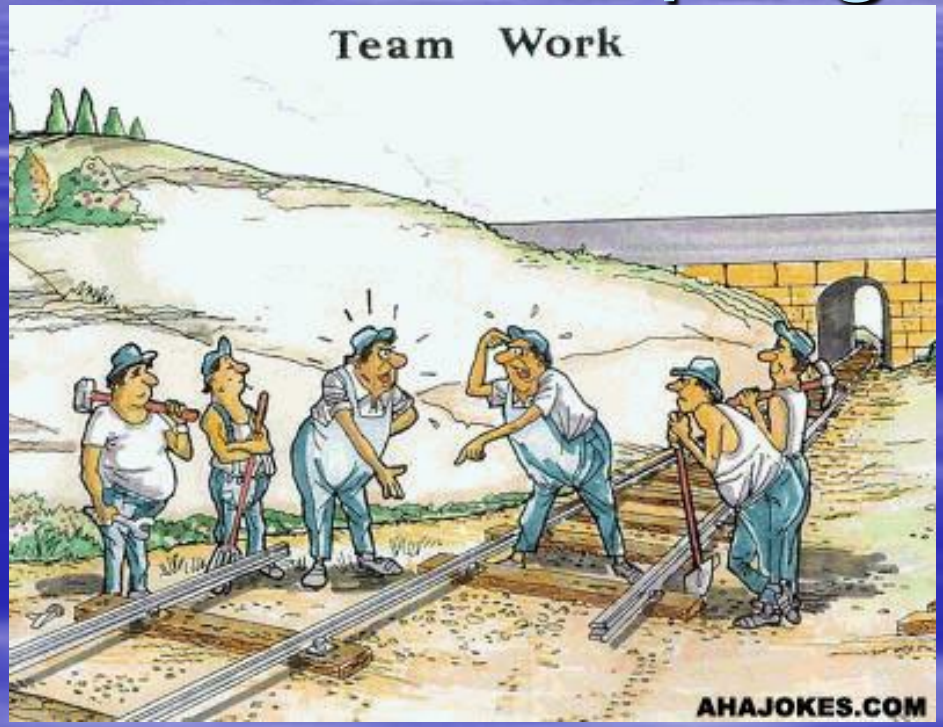
Black and White Rastered Fonts

```
static font_bits_t rom8x16_bits[] = { ...
/* Character e (0x65):   ht=16, width=8
   +--------+
   |        |
   |        |
   |        |
   |        |
   |        |
   | *****  |
   |**   **  |
   |**   **  |
   |*******  |
   |**       |
   |**   **  |
   | *****  |
   |        |
   |        |
   |        |
   |        |
      +--------+ */
0x0000,0x0000,0x0000,0x0000,
0x0000,
0x7c00,
0xc600,
0xc600,
0xfe00,
0xc000,
0xc600,
0x7c00,
0x0000,0x0000,0x0000,0x0000,
```

File: font_rom8x16.c / .h

		x-column								
		+0	+1	+2	+3	+4	+5	+6	+7	y-row
0x00	0000 0000...									+0
0x00	0000 0000...									+1
0x00	0000 0000...									+2
0x00	0000 0000...									+3
0x00	0000 0000...									+4
0x7c	0111 1100...		■	■	■	■	■			+5
0xc6	1100 0110...	■	■				■	■		+6
0xc6	1100 0110...	■	■				■	■		+7
0xfe	1111 1110...	■	■	■	■	■	■			+8
0xc0	1100 0000...	■	■							+9
0xc6	1100 0110...	■	■				■	■		+10
0x7c	0111 1100...		■	■	■	■	■			+11

Jak sestavit řídicí program ?



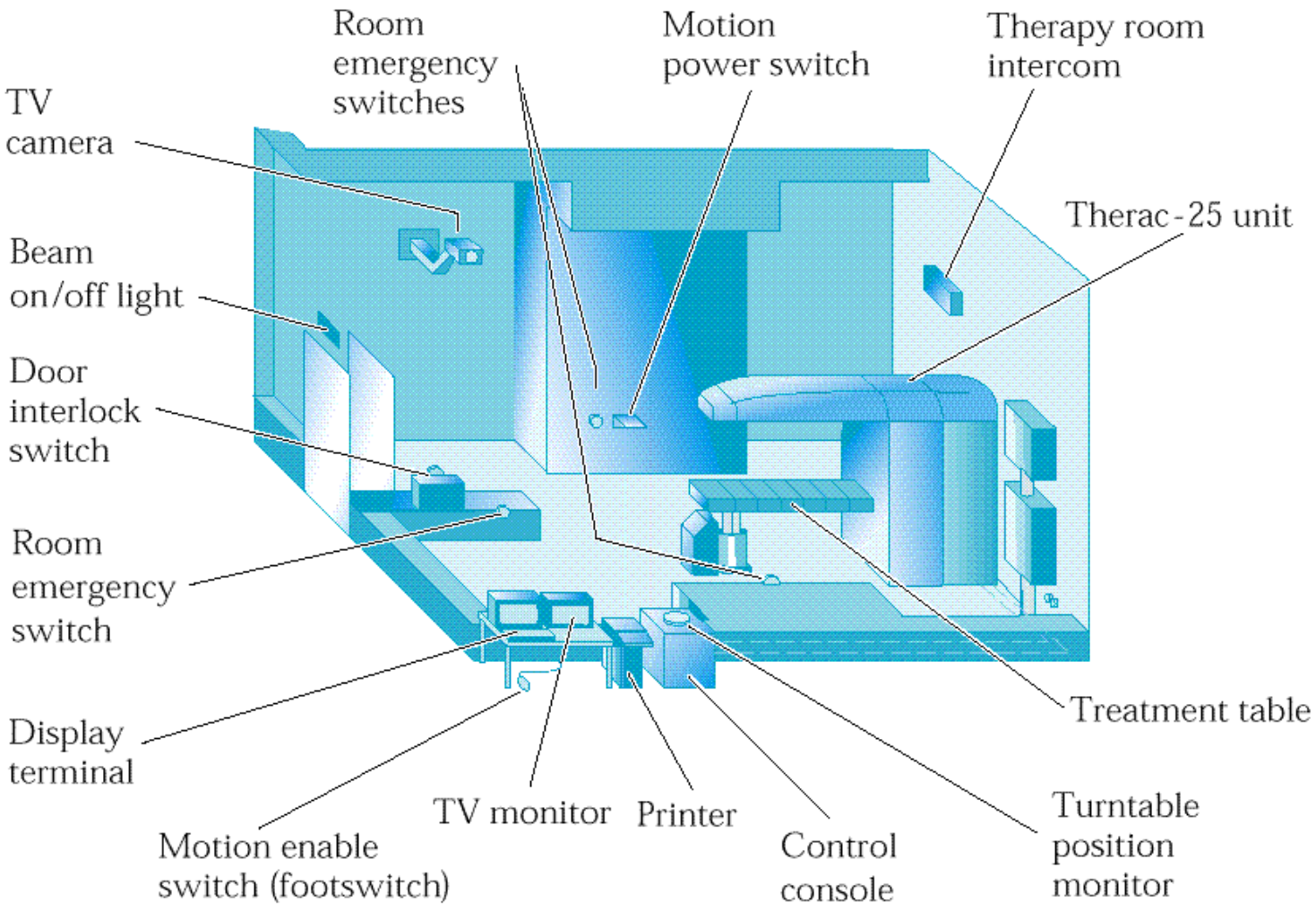
aneb pozor na paralelní úkony !

The Millennium Bridge London

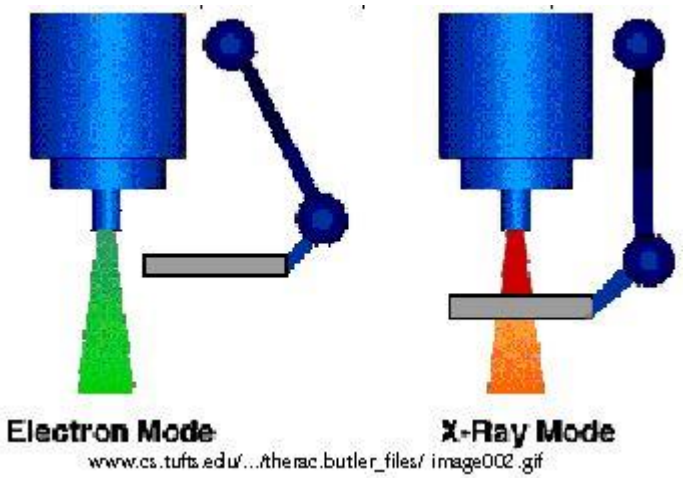
Slavnostně otevřen
v sobotu
10.6.2001
Rychle zavřený
v pondělí
12.6.2001

Přímo učebnicový příklad chyby v návrhu

Therac 25 – fatální chyba v programu



Mask of Therac 25



2 deadly errors escaped detection

- *during 2 years testing by the manufacture*
  - *during 2 deep inspections*
- *during deep inspection perform by US government*

even if all knew what they should look for

Operator sidebar

PATIENT NAME : TEST A 1

TREATMENT MODE: FIX BEAM TYPE: X ENERGY (KeV): 25

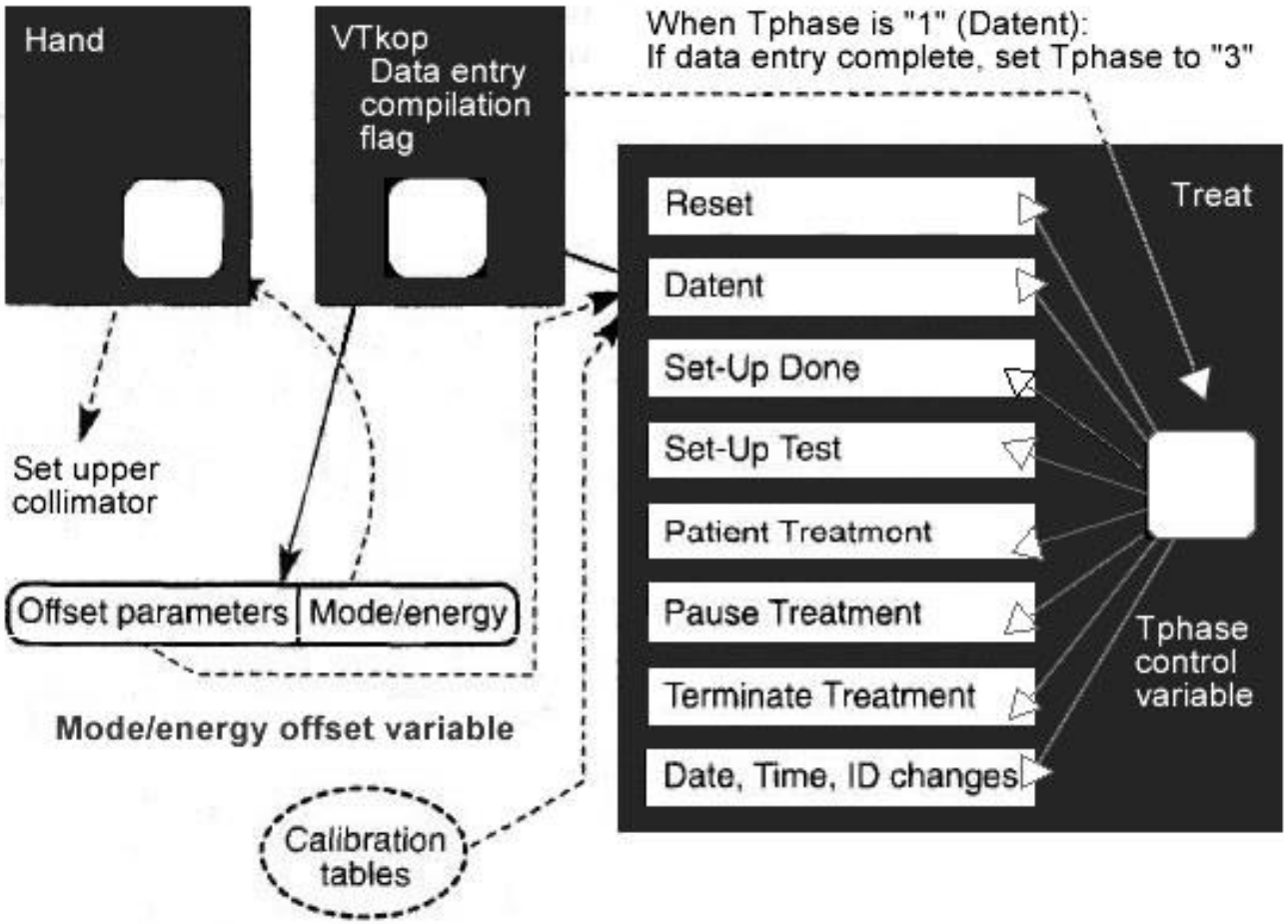
	ACTUAL	PRESCRIBED	
UNIT RATE/MINUTE	0	200	
MONITOR UNITS	50 50	200	
TIME (MIN)	0.27	1.00	
GANTRY ROTATION (DEG)	0.0	0	VERIFIED
COLLIMATOR ROTATION (DEG)	359.2	359	VERIFIED
COLLIMATOR X (CM)	14.2	14.3	VERIFIED
COLLIMATOR Y (CM)	27.2	27.3	VERIFIED
WEDGE NUMBER	1	1	VERIFIED
ACCESSORY NUMBER	0	0	VERIFIED

DATE : 84-OCT-26 SYSTEM: BEAM READY OP.MODE: TREAT AUTO

TIME : 12:55. 8 TREAT : TREAT PAUSE X-RAY 173777

OPR ID: T25VO2-RO3 REASON: OPERATOR COMMAND:

Structure of code



[source: Nancy G. Leveson, Clark S. Turner, An Investigation of the Therac-25 Accidents]

1 of 2 errors

Error is clear only if you know its exact location

Magnet:

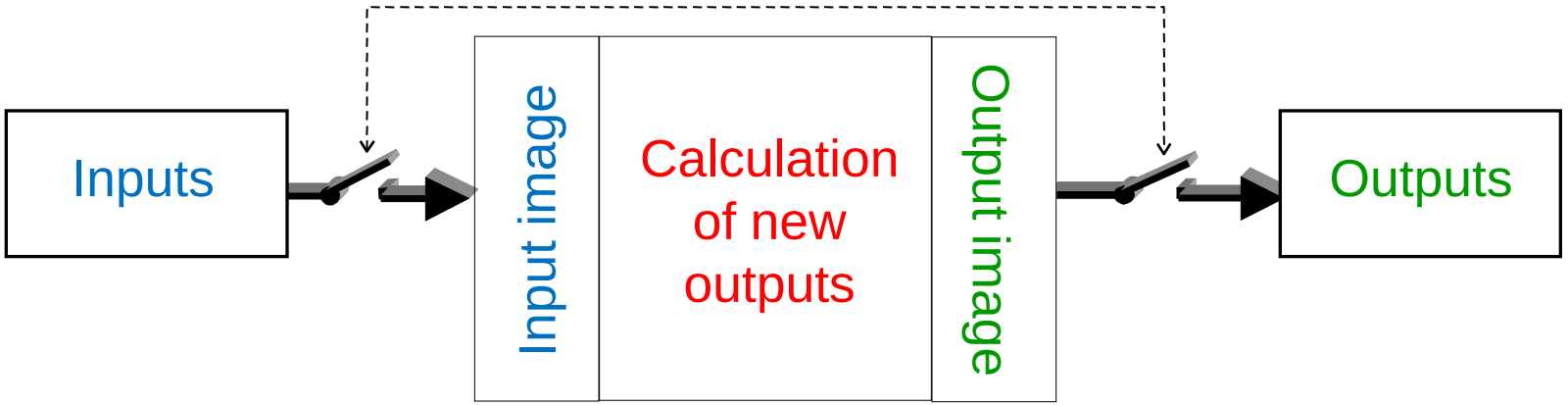
```
Set bending magnet flag          // ..but the flag is reset after 1st call of Ptime
repeat  Set next magnet
        Call Ptime
        if mode/energy has changed, then exit
until all magnets are set        // it takes 8 s to adjust magnets!!!
return
```

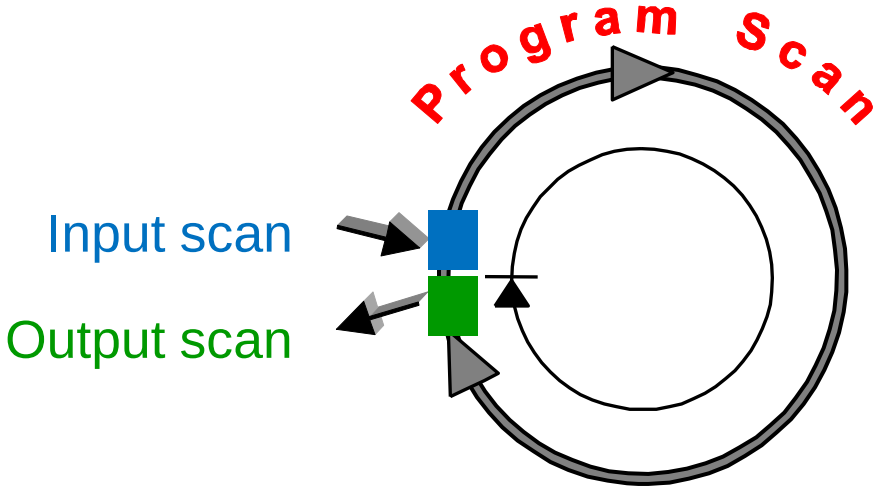
Ptime:

```
repeat
  if bending magnet flag is set then
    if editing taking place then  // it is tested only if bending magnet flag is set
      if mode/energy has changed then exit
until hysteresis delay has expired
Clear bending magnet flag return
```

2nd more complex error appeared when an operator pressed key in the same moment when a byte circular counter overflowed

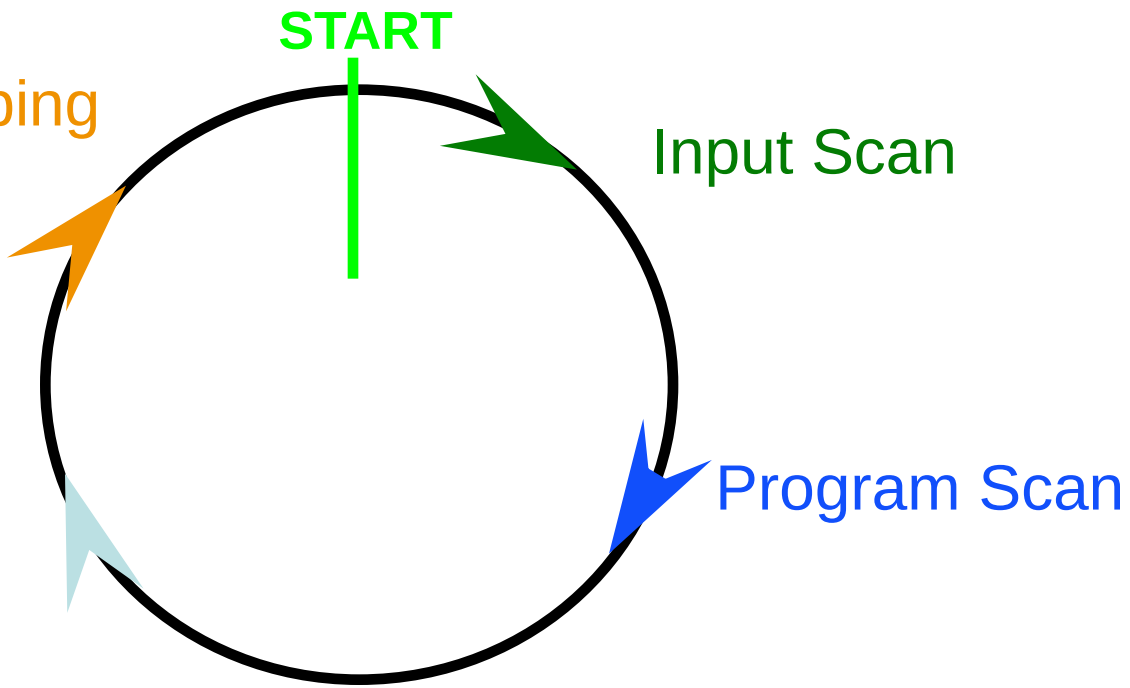
Industrial Control System






```
do
{  ReadInputs();
   CalculateOutputs();
   WriteOutputs();
}
 while(IsRunOn);
```

Přesněji Program Scan



Housekeeping tasks are special tasks that have to perform to get ready for the next scan of the program

Klasický řídicí program

- Program se vykonává periodicky. Nepřistupuje se v něm k vstupům a výstupům přímo, ale pracuje s obrazy jejich dat, uložených ve dvou pamětech - v obraze vstupů a v obrazu výstupů. Vzniká tak periodický cyklus složený ze tří kroků:
  - **Vzorkování vstupů - scan vstupů** (*input scan*) - načtení hodnot vstupů ze vstupních modulů do paměti zvané obraz vstupů (*input image*).
  - **Výpočet programu - scan programu** (*program scan*) - vykonání celého programu, výpočet nových hodnot výstupů a jejich uložení do paměti zvané obraz výstupů (*output image*).
  - **Zápis výstupů - scan výstupů** (*output scan*) - zápis obrazu výstupů do výstupních modulů.