Topic 3: (Part B)

I/O and Peripheral Devices Management

GRAPHICS in the Nintendo DS

Systèmes Embarqués Microprogrammés

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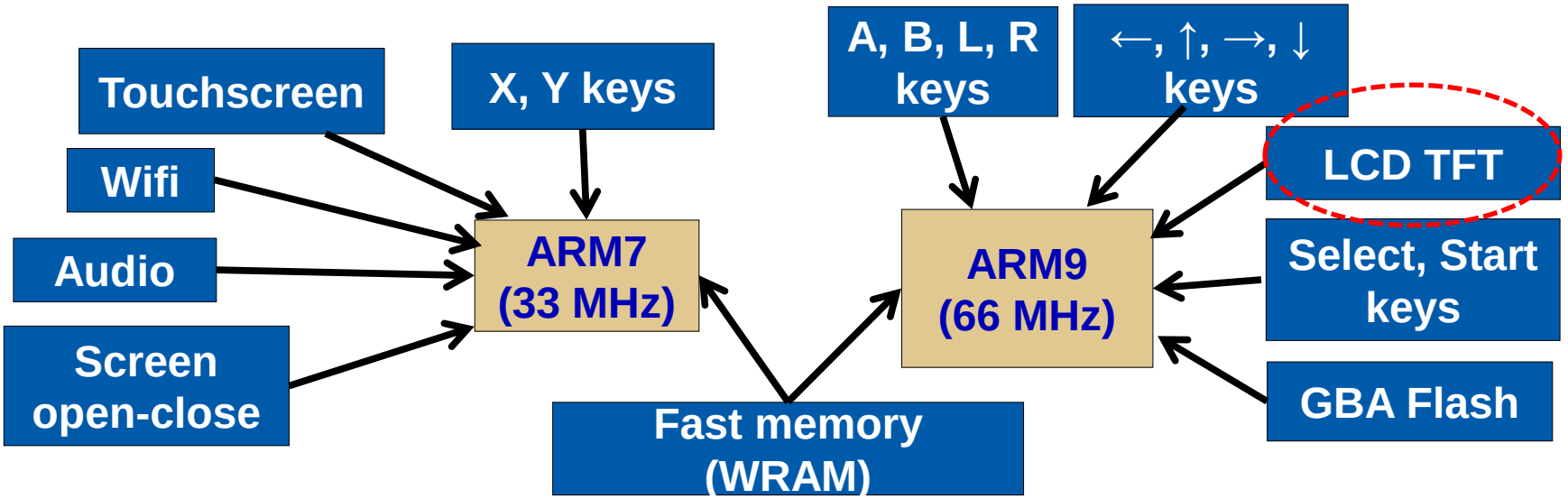
Content of Session

- Fundamental graphics in the NDS
  - Graphics subsystem
  - Concepts: colours and bitmaps
  - NDS video modes
  - Review of the (V)RAM structure

- Drawing graphics in framebuffer mode
  - Implementation of fundamental graphic functions to draw lines and filling colours on areas of the background
  - Drawing basic shapes on the NDS screen (rectangles, lines, triangles) with different colours

Graphics subsystem in the NDS: The screens and the engines

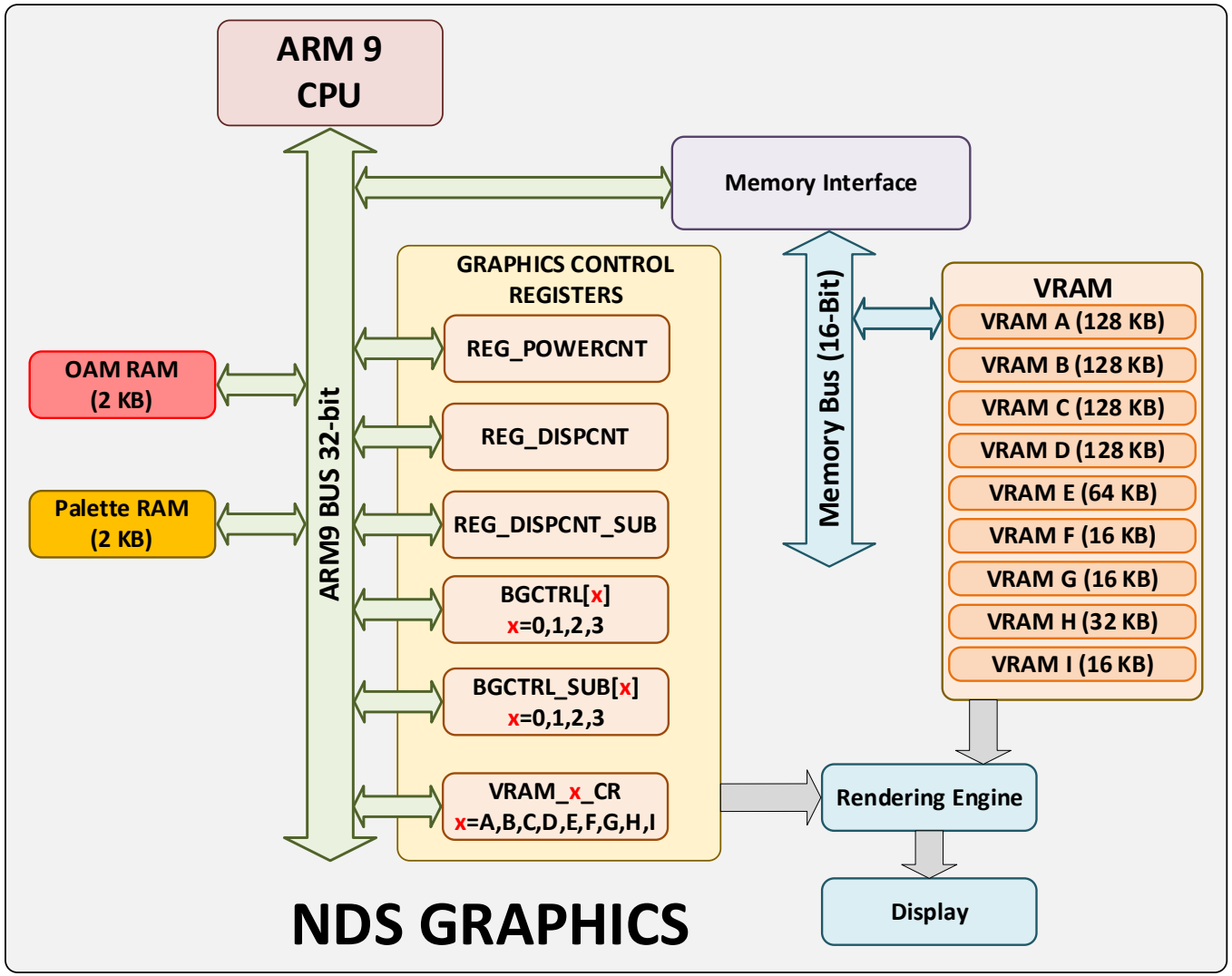
- Two screens on the NDS, both use memory-mapped graphical I/O interface
  - Resolution of 192x256 pixels each screen



- Two 2D graphics engines in the NDS
  - Main: it can display both video memory content or bitmaps of 256 colours
    - Also it can use the proprietary 3D graphics engine for backgrounds
  - Sub: secondary display that can only use the video memory content

Graphics subsystem in the NDS: Registers and Memories

- Graphics Control Registers and VRAM memory banks



Configuration Sequence of Framebuffer Mode

1. Power Manager configuration (REG_POWERCNT)
   - Performed with default settings in system boot-up

2. Graphical engines configuration (REG_DISPCNT)
   - Configure mode.

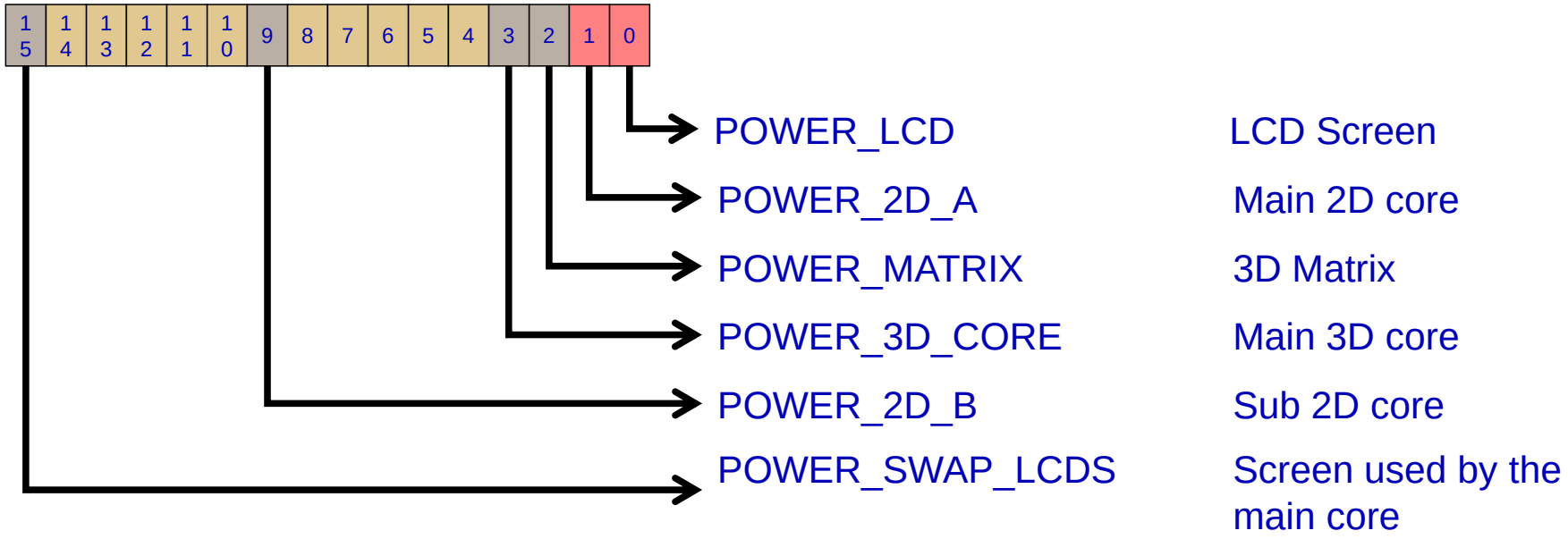
3. VRAM configuration (VRAM_x_CR)
   - Activate banks and configure them (depending on used framebuffer mode)

Ready to filling the screen canvas with graphics!

Graphics subsystem in the NDS: Activating screens and graphic coprocessors

- Control register for powering up I/O NDS devices: REG_POWERCNT
  - It is mapped on the memory address: 0x4000304

REG_POWERCNT



- In libnds, activating the LCD and engines can be done with macros:

REG_POWERCNT = POWER_LCD | POWER_2D_A;

Pixels, colours and bitmaps

- Pixels: the basic screen drawing elements
  - Each pixel has an RGB (Red-Green-Blue) representation of 16 bits
    - 5 bits to show the intensity of each colour (0: none, 31: maximum value)
    - 1 bit for transparency (0: pixel is transparent, 1: pixel is opaque)
  - In libnds, macros *ARGB16() and RGB15()* can create each pixel:

```
static uint16 shape_color = ARGB16(1, 31, 0, 0);
static uint16 shape_color = RGB15(31, 0, 0);
```

Libnds: RGB15	Colour
RGB15(31,0,0)	Red
RGB15(0,31,0)	Green
RGB15(0,0,31)	Blue
RGB15(0,0,0)	Black

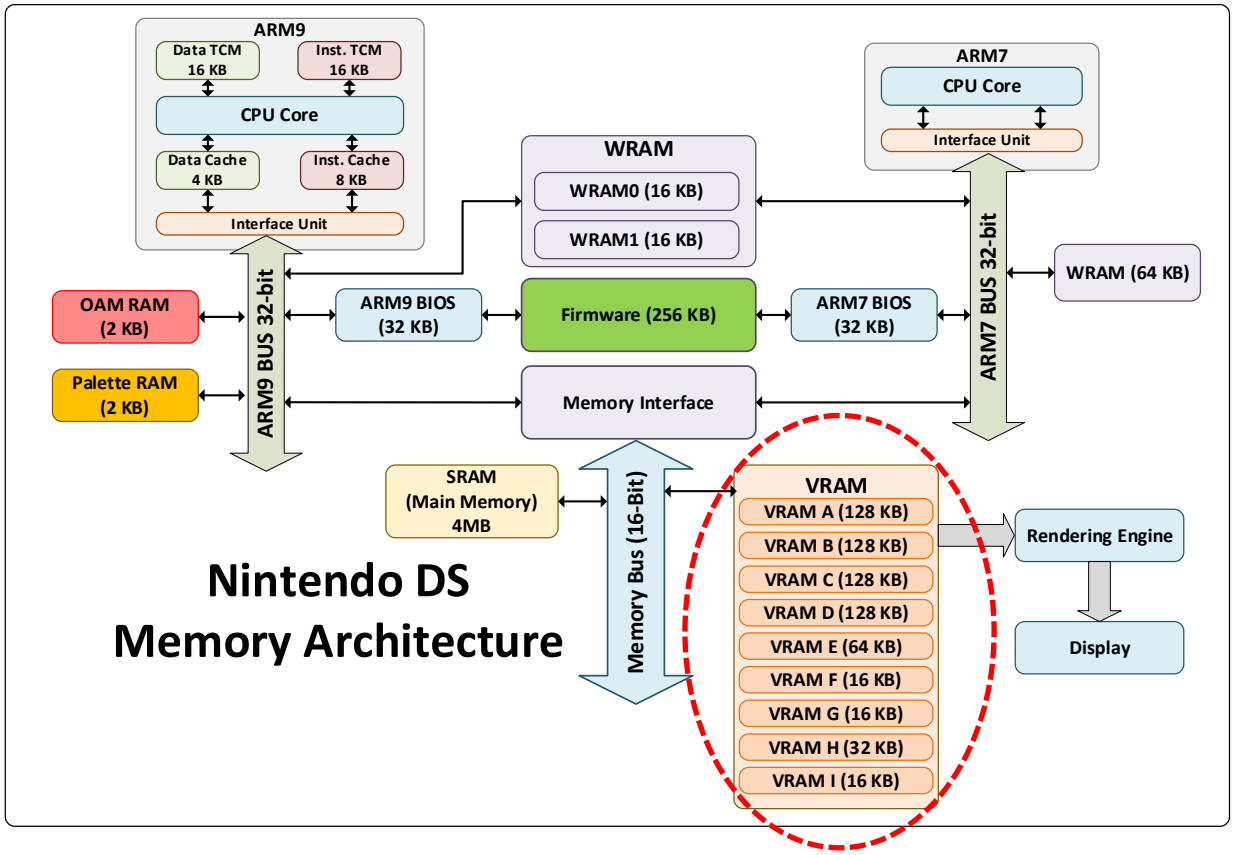
- Resolution relates to draw (render) raster graphic bitmaps: matrix of pixels
  - 49152 pixels: 192 rows of 256 points each
  - The screen draws sequentially each point from left to right and up to down
    - Two interrupts occurs from the screen drawing
  - When do we change the bitmap content to draw?
    - In the interval between VBLANK and start redrawing again from the top-left pixel

Libnds: IRQ_MASK	Description
IRQ_VBLANK	Vertical blank
IRQ_HBLANK	Horizontal blank

But where are the pixels stored?

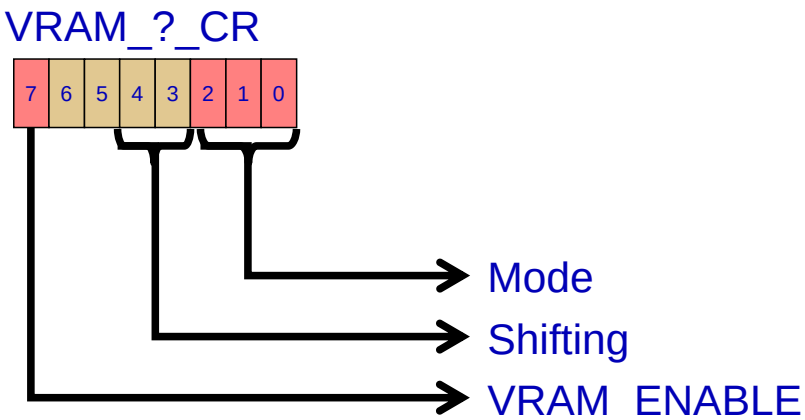
Nintendo DS memory range: Video memory or VRAM

- The bitmaps are stored in a fast RAM memory: VRAM
  - ARM9: **0x06000000** - **0x068A0000** (656KB);
- Divided in 9 banks
  - Different uses/modes
  - Backgrounds or layers
  - Different bank sizes



Accessing the video memory (VRAM)

- Control register for each bank: control select and activate: **VRAM_?_ CR**
  - VRAM_A (128KiB)
  - VRAM_B (128KiB)
  - VRAM_C (128KiB)
  - VRAM_D (128KiB)
  - VRAM_E (64KiB)
  - VRAM_F (16KiB)
  - VRAM_G (16KiB)
  - VRAM_H (32KiB)
  - VRAM_I (16KiB)



- Example: activate bank A and map it to the 2D background representation with the main 2D core

```
VRAM_A_CR = VRAM_ENABLE | VRAM_A_LCD;
```

- Set functions are also available: */opt/devkitPro/libnds/include/nds/arm9/video.h*
  - Example: VRAM_A bank mapped to main 2D core background

```
vramSetBankA(VRAM_A_LCD);
```

NDS screen modes: 2D engines configuration

- Each engine has four backgrounds (or layers): BG0, BG1, BG2 and BG3
  - Final view on the screen will be their combination based on used graphic mode
- Each 2D engine has different sets of four possible modes:
  - Tiled
  - Rotation or rotoscale
  - Extended rotation
  - Framebuffer (special rendering mode, without backgrounds)

- Main engine
  - 7 modes and framebuffer

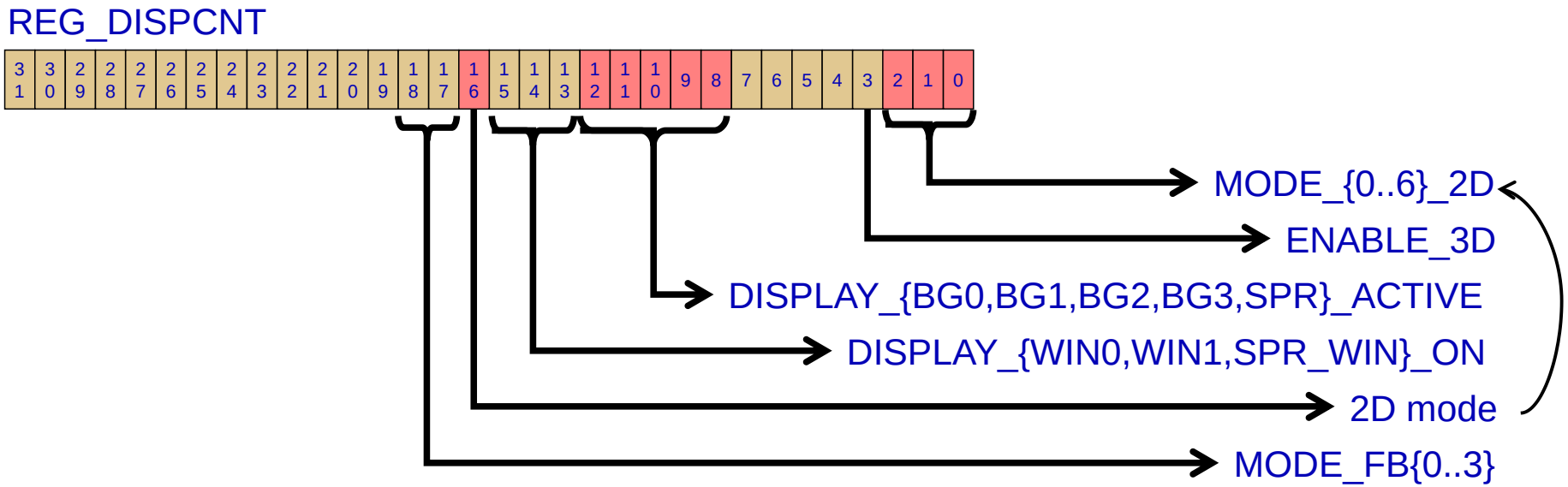
Mode	BG0	BG1	BG2	BG3
0	Tiled/3D	Tiled	Tiled	Tiled
1	Tiled/3D	Tiled	Tiled	Rotoscale
2	Tiled/3D	Tiled	Rotoscale	Rotoscale
3	Tiled/3D	Tiled	Tiled	Ext. Rotoscale
4	Tiled/3D	Tiled	Rotoscale	Ext. Rotoscale
5	Tiled/3D	Tiled	Ext. Rotoscale	Ext. Rotoscale
6	3D	N/A	Large Bitmap	N/A
FrameBuf.	Direct VRAM display as a bitmap			

- Sub engine
  - 6 modes, without 3D or framebuffer

Mode	BG0	BG1	BG2	BG3
0	Tiled	Tiled	Tiled	Tiled
1	Tiled	Tiled	Tiled	Rotoscale
2	Tiled	Tiled	Rotoscale	Rotoscale
3	Tiled	Tiled	Tiled	Ext. Rotoscale
4	Tiled	Tiled	Rotoscale	Ext. Rotoscale
5	Tiled	Tiled	Ext. Rotoscale	Ext. Rotoscale

NDS screen mode control

- REG_DISPCNT: display register to control mode and active backgrounds



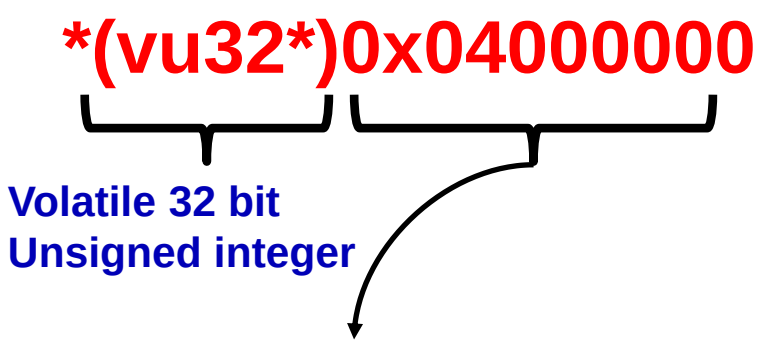
- Example: activate mode 0 and background 1 (BG1)

REG_DISPCNT = MODE_0_2D | DISPLAY_BG1_ACTIVE;

Configuring Memory-Mapped I/O Peripheral Registers

- LibNDS library under /opt/devkitPro defines the registers ID

#define REG_DISPCNT *(vu32*)0x04000000

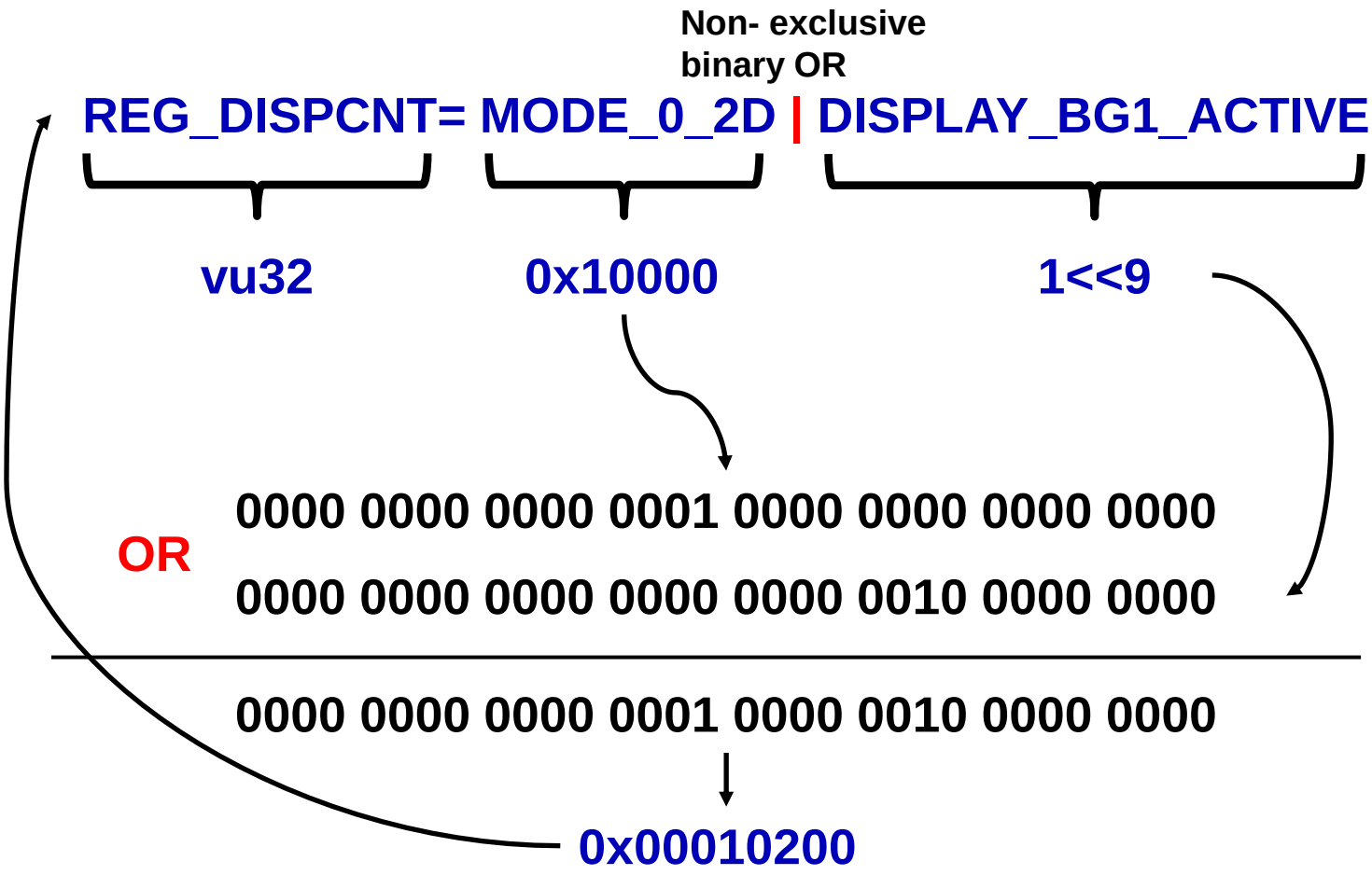


- Hint: Use the following command in the virtual image terminal to find any macro's value:

  $: grep –rnw '/opt/devkitPro/libnds/include/nds' –e 'MACRO_NAME'

Example: Enabling and Assigning VRAM Block A to Main Screen in Mode 0

- C language operation meaning:



The framebuffer mode

- Framebuffer mode: drawing the map of pixels directly
  - Screen mapped to a portion of memory: bitmap or matrix of pixels (192 x 256)
  - Writing data to this memory results in data represented onto the screen

- Four different framebuffers: FB0.. FB3
  - Mapped to the 128KiB VRAM banks
  - Support for *double buffering*:
    hiding changes in the pixels content
    - One buffer is being read to write on the screen, while another one is being written in memory
    - Exchange during VBLANK interrupt

Mode	VRAM bank
FB0	VRAM_A
FB1	VRAM_B
FB2	VRAM_C
FB3	VRAM_D

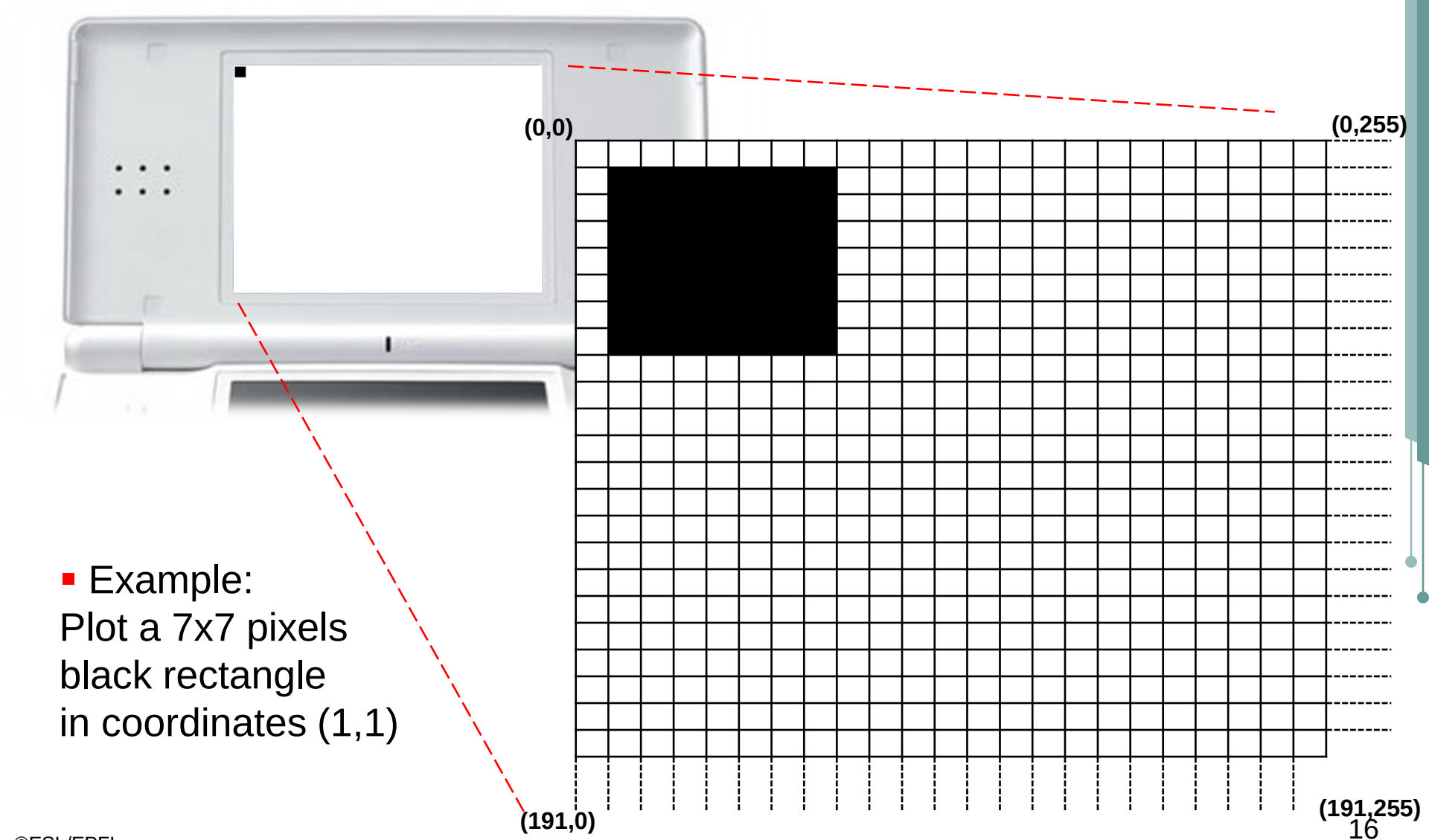
- Example of use: Use of FB0, so two steps:
  1. Framebuffer configured in VRAM bank A (VRAM_A)
  2. VRAM_A activated and configured to work with the LCD screen

```
REG_DISPCNT = MODE_FB0;
VRAM_A_CR = VRAM_ENABLE | VRAM_A_LCD;
```

Display format in framebuffer mode

- A framebuffer is characterized by three elements:
  - The memory portion where it is mapped to
    - FB0 in VRAM_A, FB1 in VRAM_B, ...
  - The line length
    - In the NDS it is of 256 pixels per line
  - The pixel format:
    - RGB15(r,g,b)
      - R, G, B: 5 bits per channel (0..31)
      - Most significant bit (Bit15) is not used: pixels are always opaque

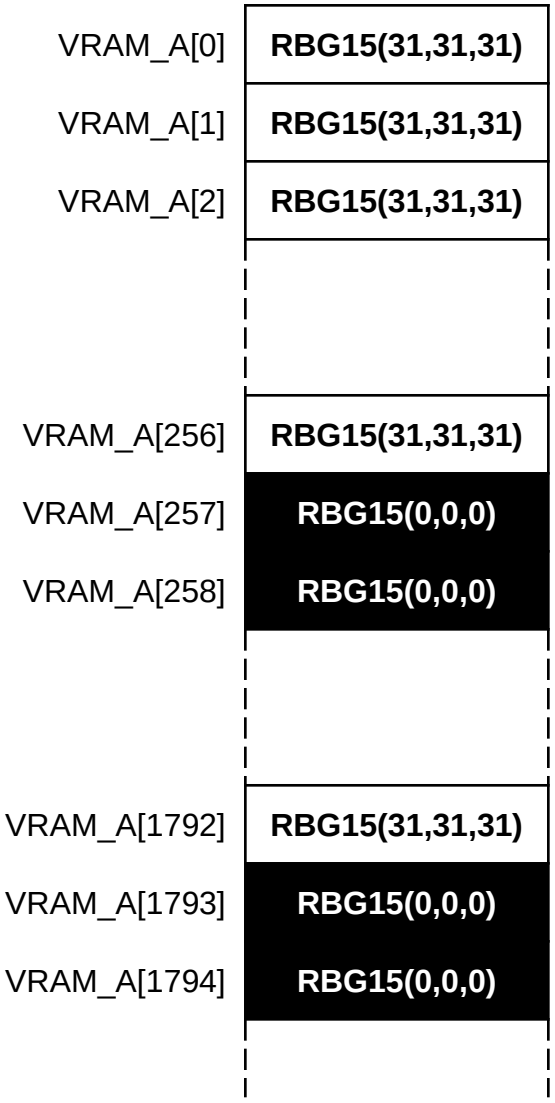
Practical Work 6: Graphics (Part 1): Framebuffer Mode



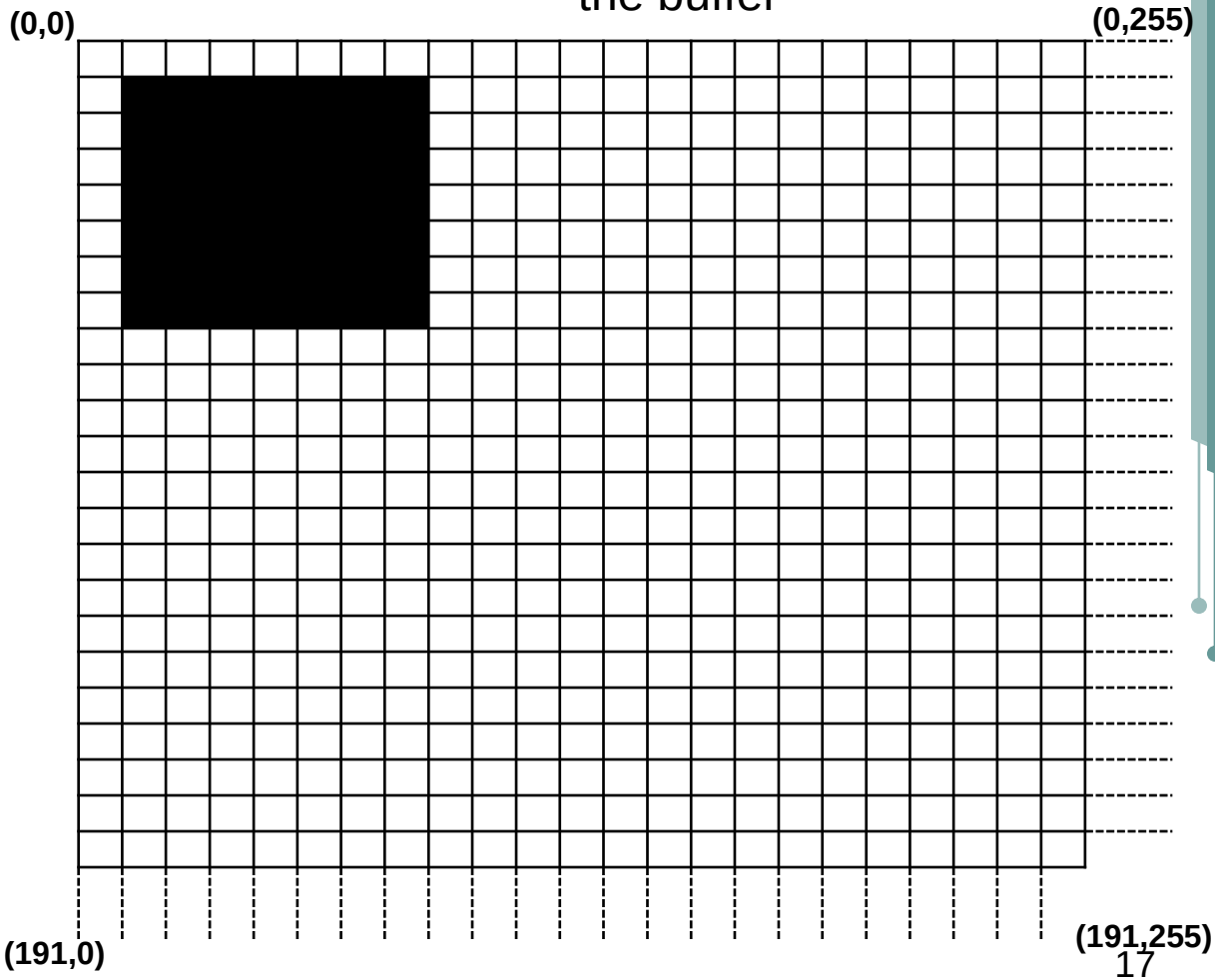
- Example:

Plot a 7x7 pixels black rectangle in coordinates (1,1)

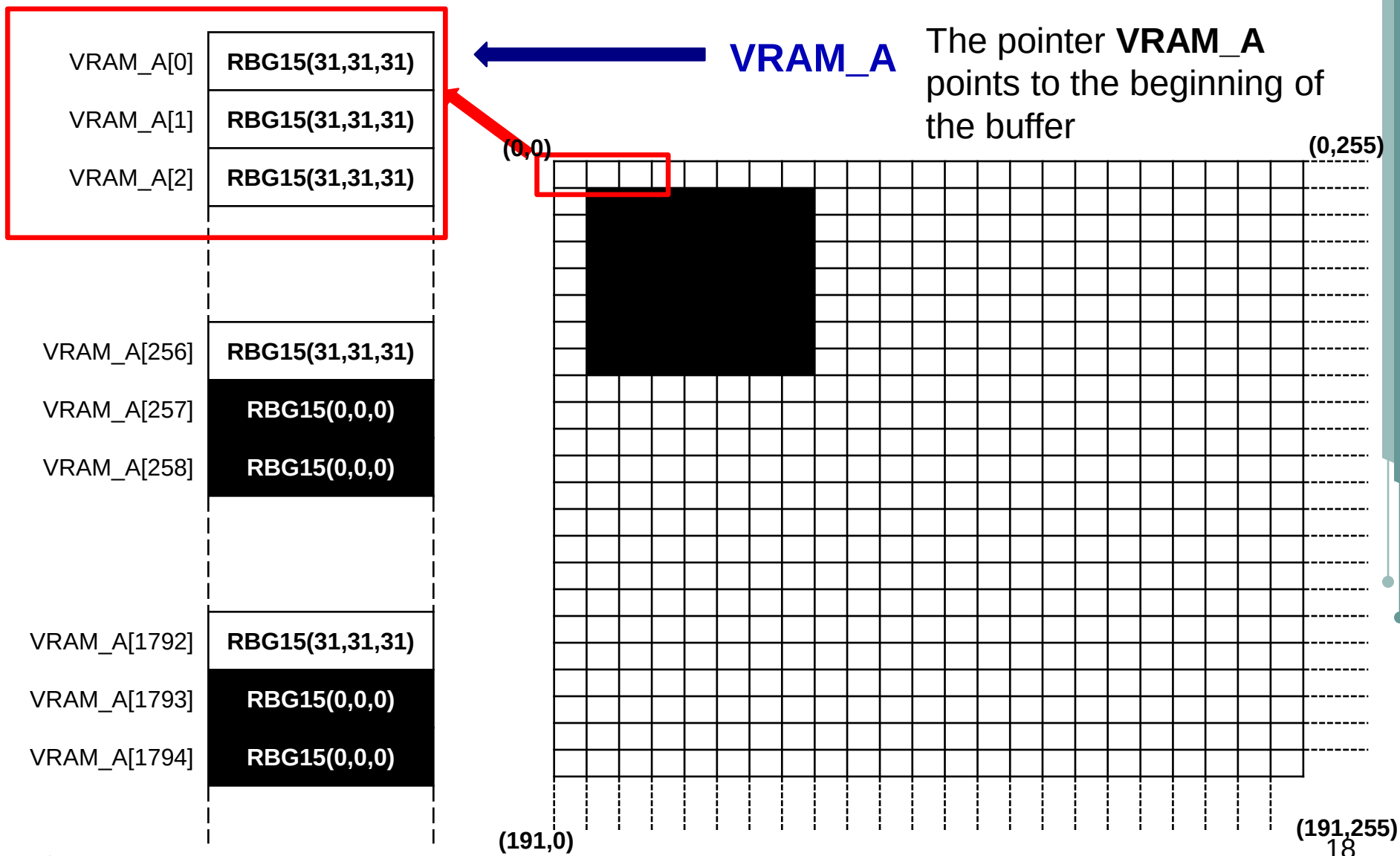
Practical Work 6: Graphics (Part 1): Framebuffer Mode



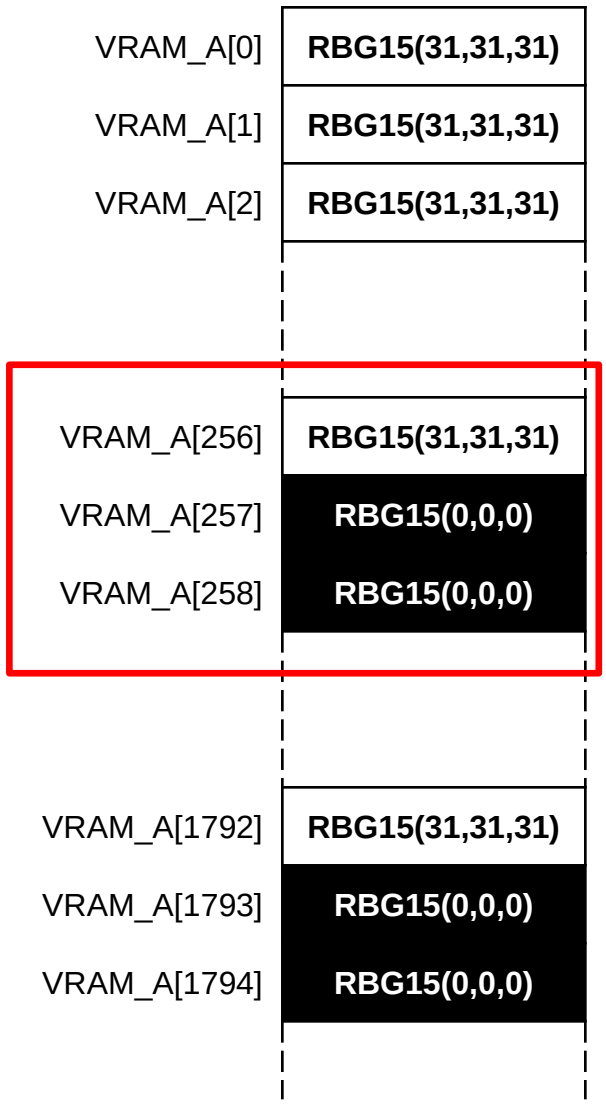
The pointer **VRAM_A** points to the beginning of the buffer



Practical Work 6: Graphics (Part 1): Framebuffer Mode



Practical Work 6: Graphics (Part 1): Framebuffer Mode



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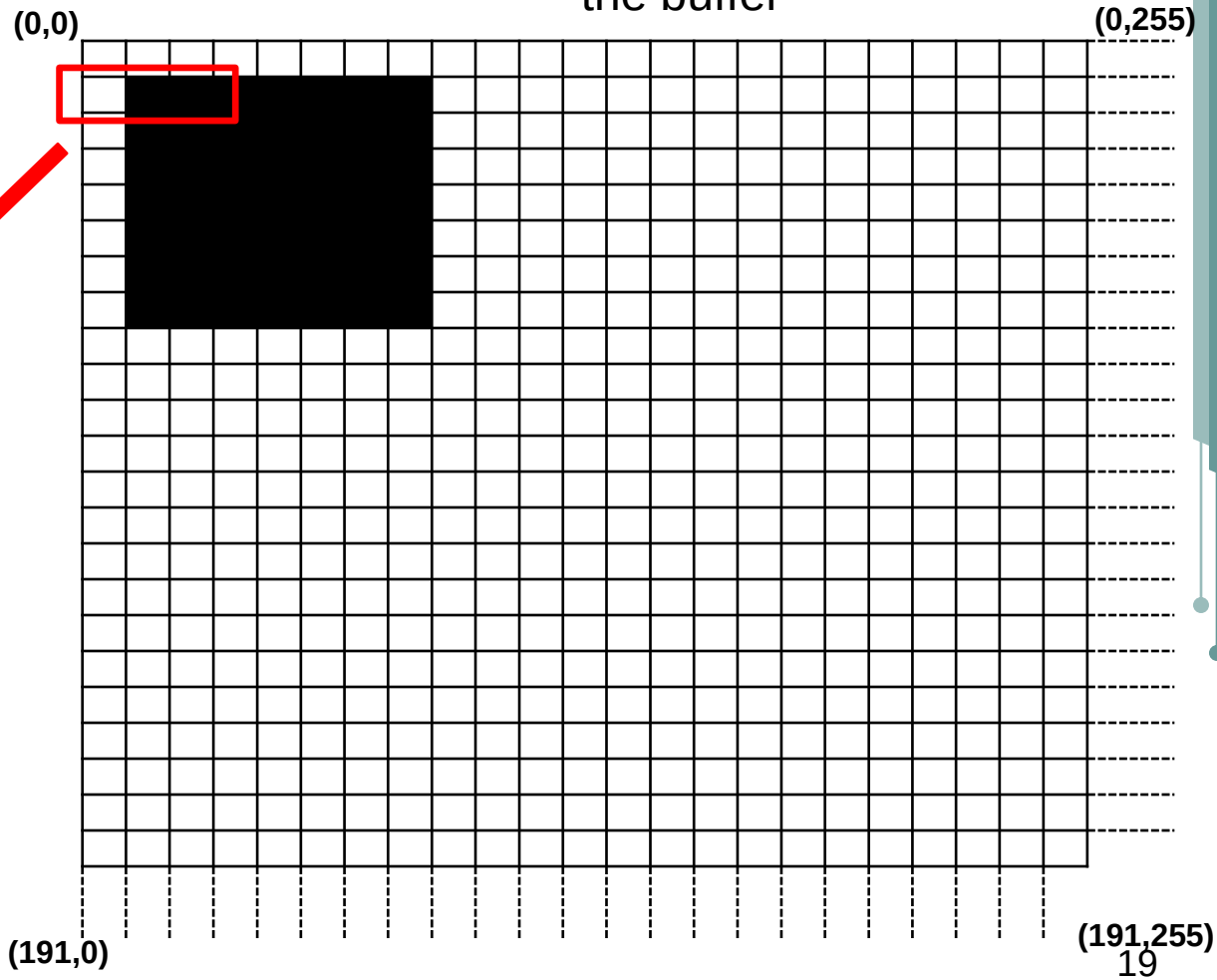
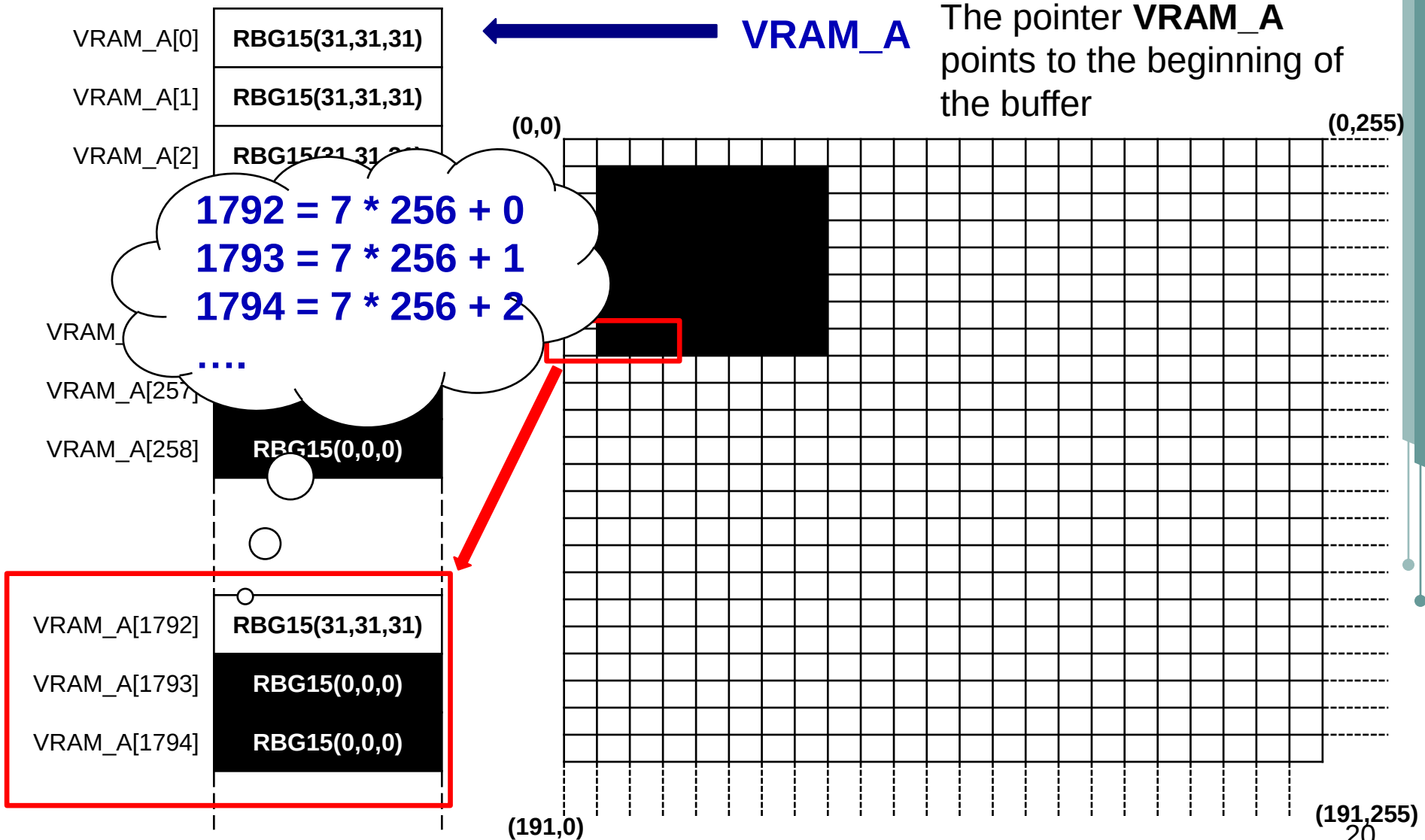


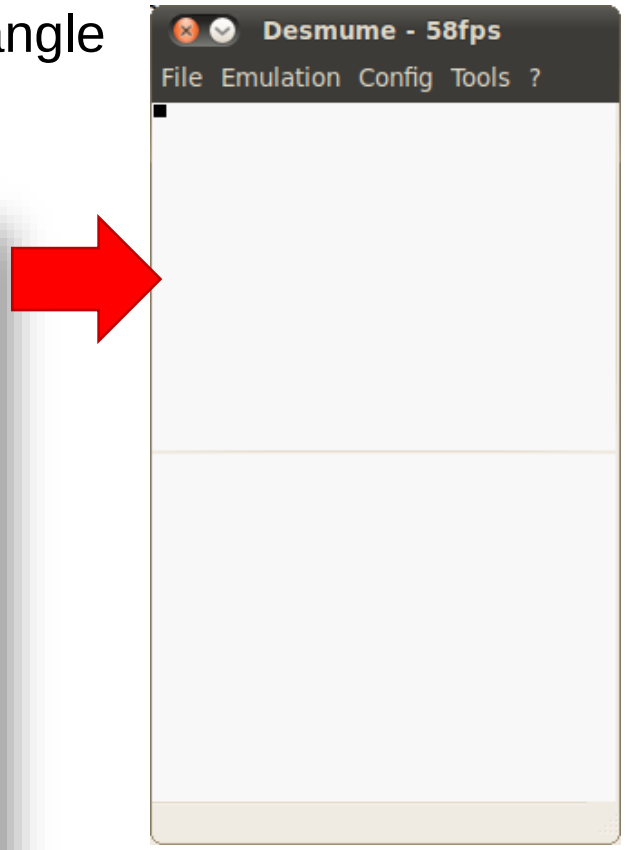
Practical Work 6: Graphics (Part 1): Framebuffer Mode



Practical Work 6: Graphics (Part 1): Framebuffer Mode

- Solution to the example: code that fills the screen with white, and then draws a black-filled rectangle
  - White => RGB15(31,31,31)
  - Black => RGB15(0,0,0)

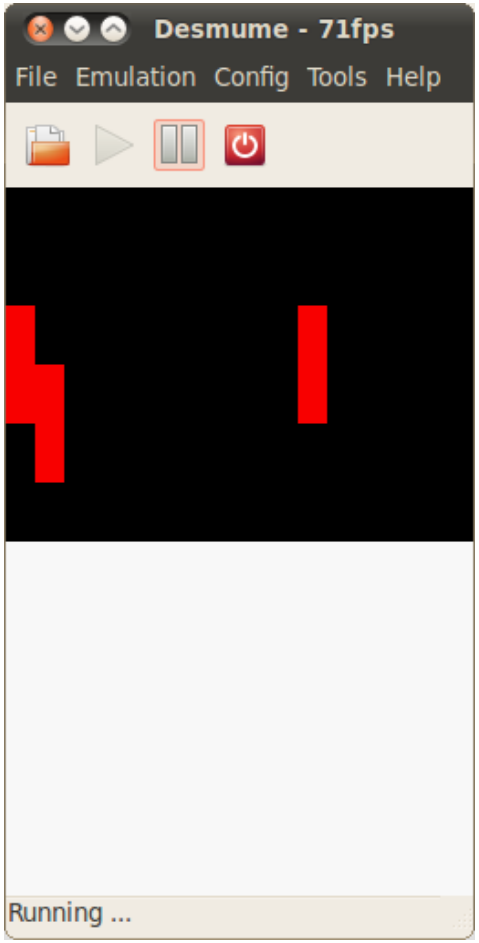
```
//counters for the for loops
int row, column;

//Pointer to the buffer
u16* buff = (u16*) VRAM_A;

//Fill the screen with white
for(row = 0; row < 192; row++)
    for(column = 0; column < 256; column++)
        buff[row * 256 + column] = RGB15(31,31,31);

//Draw the 7x7 pixels rectangle
for(row = 1; row < 8; row++)
    for(column = 1; column < 8; column++)
        buff[row * 256 + column] = RGB15(0,0,0);
```



Practical Work 5: Graphics (Part 1): Framebuffer Mode

- Exercises (and homework)
  - Exercise 1 – Initializing the main graphical engine
  - Exercise 2 – Changing the color of the screen
  - Exercise 3 – Filling a rectangle
  - Exercise 4 – Drawing an horizontal line
  - Exercise 5 – Drawing a vertical line
  - Exercise 6 – Drawing a rectangle - reusing code
  - Exercise 7 – Integrating the code (Tetris tiles)

  - *Exercise 8 – Color degradation
  - *Exercise 9 – Shifting data
  - *Exercise 10 – Grayscale transformation



* Additional exercises

Questions?

Let’s use the screen of the NDS!