Computer Labs: Lab5
Video Card in Graphics Mode

2º LEIC

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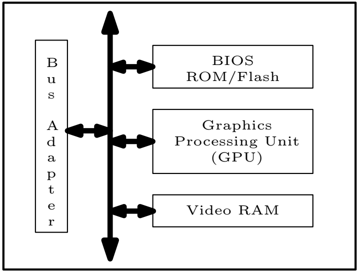
Contents

Graphics Adapter/Video Card



GPU Earlier known as the Graphics Controller:

- Controls the display hardware (CRT vs. LCD)
- Performs 2D and 3D rendering algorithms, offloading the CPU and accelerating graphics applications

BIOS ROM/Flash ROM/Flash Memory with firmware. Includes code that performs some standardized basic video I/O operations, such as the Video BIOS Extension (VBE)

Video RAM Stores the data that is rendered on the screen.

- It is acessible also by the CPU (at least part of it)

Video Modes

Text Mode

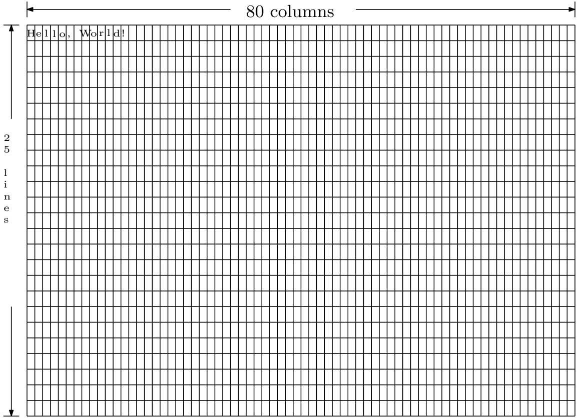
- Mode used by Minix 3 by default

Graphics Mode

- Mode you will use in Lab 5

PC's Graphics Adapter Text Modes

- Used to render mostly text
- Abstracts the screen as a matrix of characters (row x cols)
  - E.g. **25x80**, 25x40, 50x80, 25x132
  - Black and white vs color (16 colors)



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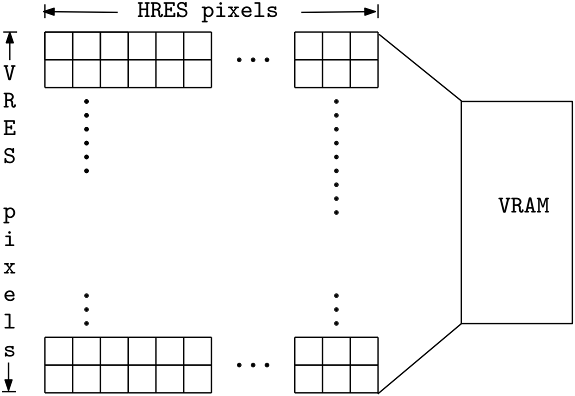
Video Card in Graphics Mode

- The screen is abstracted as a matrix of points, or **pixels**
  - With `HRES` pixels per line
  - With `VRES` pixels per column
- For each pixel, the VRAM holds its color



How Are Colors Encoded? (1/2)

- Most electronic display devices use the RGB color model
  - A color is obtained by adding 3 primary colors – red, green, blue – each of which with its own intensity
  - This model is related to the physiology of the human eye
- One way to represent a color is to use a triple, with a given intensity per primary color
  - Depending on the number of bits used to represent the intensity of each primary color, we have a different number of colors
  - E.g., if we use 8 bits per primary color, we are able to represent $2^{24} = 16777216$ colors

How Are Colors Encoded? (2/2)

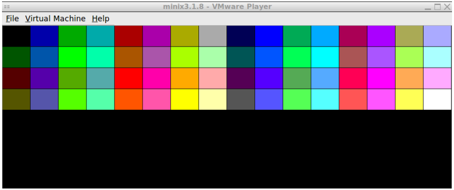
Direct-color mode Store the color of each pixel in the VRAM

- For 8 bits per primary color, if we use a resolution of 1024×768 we need 3 MB (assuming 4 bytes per pixel)

Indexed color Rather than storing the color per pixel, it stores an index into a table – the **palette/color map** – with the definition, i.e. the intensity of the 3 primary colors, of each color

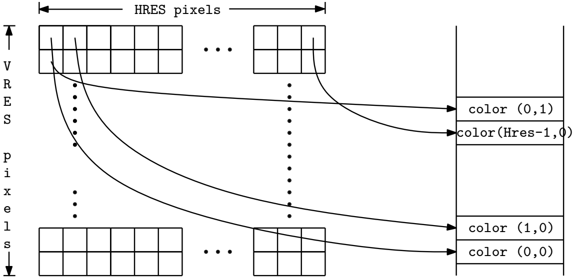
- With an 8 bit index we can represent 256 colors, each of which may have 8 bits per primary color
- By changing the **palette** it is possible to render more than 256 colors

- In the lab you'll use a palette with up to 256 colors, whose default initialization uses only 64 colors



Memory Models

- The memory model determines how video memory is organized, i.e., where the value of each pixel is stored in VRAM
  - Different graphics modes use different memory models
- The simplest mode, and the one that will be used in the lab, is **linear mode**:



All we need to know is:

- The base address of the **frame buffer**
- The coordinates of the pixel
- The number of bytes used to encode the color

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Lab5: Video Card in Graphics Mode - Part 1

- Write a set of functions:

```
void video_test_init(unsigned short mode,
                     unsigned short delay)
int video_test_rectangle(uint16_t mode, uint16_t x,
                         uint16_t y, ...)
int video_test_pattern(uint16_t mode, uint16_t no_rectangles,
                       uint32_t first)
```

  to set the screen to graphics mode and to display on the screen what is requested
- Essentially you have to:
  1. Configure the video card for the desired graphics mode
     - Minix 3 boots in text mode, not in graphics mode
  2. Write to VRAM to display on the screen what is requested
     - Map VRAM to the process' address space
  3. Reset the video card to the text mode used by Minix
     - You need only to call a function that we provide you

Video Card Configuration (`video_test_init()`)

Problem How do you configure the desired graphics mode?

NO Solution Read/write directly the GPU registers

- GPU manufacturers usually do not provide the details necessary for that level of programming

Solution Use the VESA Video Bios Extension (VBE)

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PC BIOS

- Basic Input-Output System is:
  1. A firmware interface for accessing PC HW resources
  2. The implementation of this interface
  3. The non-volatile memory (ROM, more recently flash-RAM) containing that implementation
- It is used mostly when a PC starts up
  - It is 16-bits: even IA-32 processors start in real-mode
  - It is used essentially to load the OS (or part of it)
  - Once the OS is loaded, it usually uses its own code to access the HW not the BIOS
- Nowadays, most PCs use the "Unified Extensible Firmware Interface" (UEFI)

BIOS Calls

- Access to BIOS services is via the SW interrupt instruction `INT xx`
  - The `xx` is 8 bit and specifies the service.
  - Any arguments required are passed via the processor registers
- Standard BIOS services:

Interrupt vector (`xx`)	Service
`10h`	video card
`11h`	PC configuration
`12h`	memory configuration
`16h`	keyboard

BIOS Call: Example

- Set Video Mode: `INT 10h`, function `00h`

```
; set video mode

MOV AH, 0        ; function (set video mode)
MOV AL, 3        ; text, 25 lines X 80 columns, 16 colors
INT 10h
```

How to make a BIOS Call in Minix 3.1.x?

Problem

- The previous example is in real address mode
- Minix 3 uses protected mode with 32-bit

Solution

- Use Minix 3 kernel call `SYS_INT86`

  > "Make a real-mode BIOS call on behalf of a user-space device driver. This temporarily switches from 32-bit protected mode to 16-bit real-mode to access the BIOS calls."

How to make a BIOS Call in Minix 3.4.x?

Problem

- Kernel call `SYS_INT86` was droped in Minix 3.2

Solution

- Pedro Silva has added this kernel call to Minix 3.4.0rc6, by porting `libx86emu`, a small library that emulates some key x86 instructions.
  - Essentially, we can use `sys_int86` in Minix 3.4.x, as we did in Minix 3.1.8.
  - The implementation though is at user level.

BIOS Call in Minix 3: Example

```
#include <machine/int86.h> // /usr/src/include/arch/i386
int vg_exit() {
  reg86_t reg86;

  reg86.intno = 0x10;
  reg86.ah = 0x00;
  reg86.al = 0x03;

  if( sys_int86(&reg86) != OK ) {
    printf("vg_exit(): sys_int86() failed \n");
    return 1;
  }
  return 0;
}
```

- `reg86_t` is a struct with a union of anonymous structs that allow access the IA32 registers as
  - 8-bit registers
  - 16-bit registers
  - 32-bit registers
- The names of the members of the structs are the standard names of IA-32 registers.

Video BIOS Extension (VBE)

- The BIOS specification supports only VGA graphics modes
  - VGA stands for Video Graphics Adapter
  - Specifies very low resolution: 640x480 @ 16 colors and 320x240 @ 256 colors
- The Video Electronics Standards Association (VESA) developed the Video BIOS Extension (VBE) standards in order to make programming with higher resolutions portable
- Early VBE versions specify only a real-mode interface
- Later versions added a protected-mode interface, but:
  - In version 2, only for some time-critical functions;
  - In version 3, supports more functions, but they are optional.
- Unfortunately, VirtualBox does not support the protected mode interface

VBE `INT 0x10` Interface

- VBE still uses `INT 0x10`, but to distinguish it from basic video BIOS services
  - `AH = 4Fh` - BIOS uses `AH` for the function
  - `AL = function`
- VBE graphics mode 105h, 1024x768@256, **linear** mode:

```
reg86_t r;
r.ax = 0x4F02; // VBE call, function 02 -- set VBE mode
r.bx = 1<<14|0x105; // set bit 14: linear framebuffer
r.intno = 0x10;
if( sys_int86(&r) != OK ) {
    printf("set_vbe_mode: sys_int86() failed \n");
    return 1;
}
```

You should use symbolic constants.

video_test_rectangle()

- Draw a rectangle on the screen in the desired mode

```
int video_test_rectangle(uint16_t mode, uint16_t x, uint16_t y,
                         uint16_t width, uint16_t height, uint32_t color)
```

- The LCF can test your code for different graphical modes, i.e. different:

  Resolution both horizontal and vertical

  Bits per pixel and color models

  Indexed color modes also called packed-pixel by VBE, appear to have only 8 bits per pixel

  Direct color modes May use a different number of bits per pixel

  - And sometimes, the number of bits per component may be different, even if the number of bits per pixel is the same.

- These affect the offset, with respect to the frame-buffer base address, of the memory location with the color value of a pixel, or of one of its RGB components.
- The goal is that your code be parametric, so that it can easily handle these differences

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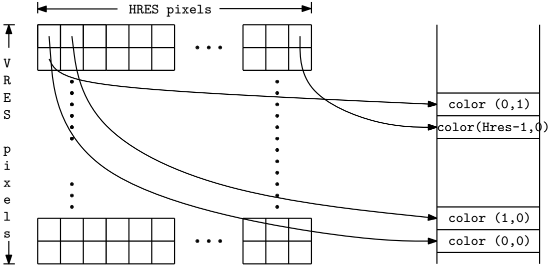
Mapping the Linear Frame Buffer

- Before you can write to the frame buffer.



1. Obtain the physical memory address
   1.1 Use `vbe_get_mode_info()` that **we provide as part of the LCF**
      - This function retrieves information about the input VBE mode, including the physical address of the frame buffer

   1.2 ~~Should provide your own implementation, using VBE function `0x01` Return VBE Mode Information, once everything else has been completed.~~
2. Map the physical memory region into the process' (virtual) address space

```
int vbe_get_mode_info(uint16_t mode, vbe_mode_info_t *vmi_p)
```

- Returns information on the input VBE mode, including screen dimensions, color depth and VRAM physical address.
- Initializes packed `vbe_mode_info_t` structure passed as an address with the VBE information on the input mode, by calling VBE function 0x01, Return VBE Mode Information, and copying the ModeInfoBlock struct returned by that function.

Arguments

`mode` VBE mode whose information should be returned, e.g. `0x105`

`vmi_p` address of a `vbe_mode_info_t` struct that will be initialized by `vbe_get_mode_info()`. All you need is just:

- Declare a variable of that type
- Use its address as argument

Return Value 0 on success, non-zero, otherwise

vbe_mode_info_t

```
#pragma pack(1)

typedef struct {
   uint16_t ModeAttributes;
   [...]
   uint16_t XResolution;
   uint16_t YResolution;
   [...]
   uint8_t BitsPerPixel;
   [...]
   uint8_t RedMaskSize;
   uint8_t RedFieldPosition;
   [...]
   uint8_t RsvdMaskSize;
   uint8_t RsvdFieldPosition;
   [...]
   uint32_t  PhysBasePtr;
   [...]
}  vbe_mode_info_t;

#pragma options align = reset
```

Implementation Notes

- You should call `vbe_get_mode_info()` only once and store its information somewhere
  - It must allocate a struct in the first 1 Mbyte of the physical address space every time it is invoked, and this piece of Minix code does not appear very reliable
    - If `vbe_get_mode_info()` fails, you can retry a couple of times
    - But sometimes, just rebooting Minix is faster

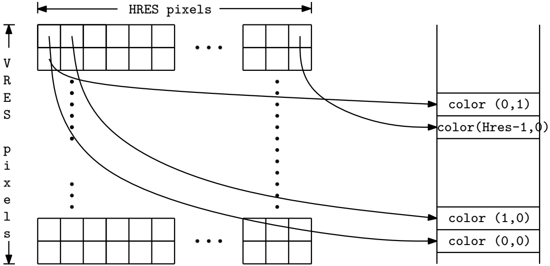
      Always use the shell command **`poweroff`**
- As suggested in the handout, you can use static global variables:

```
static uint16_t hres; /* XResolution */
static uint16_t vres; /* YResolution */
```

- Although you should avoid global variables, this use is akin to the use of static member variables in C++
- You can define `get()` methods, if you want to access these variables from outside of the file where they are declared.
  - For example, `get_hres()`

Mapping the Linear Frame Buffer

- Before you can write to the frame buffer.



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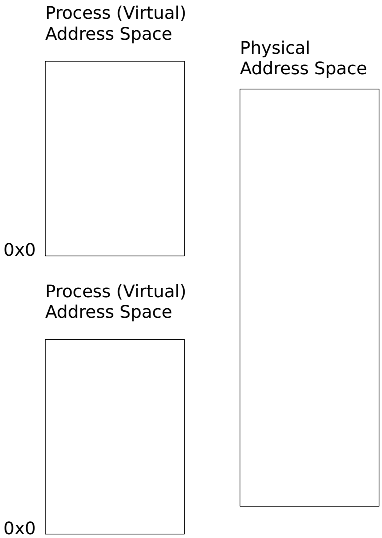
2. Map the physical memory region into the process' (virtual) address space

Virtual and Physical Address Spaces

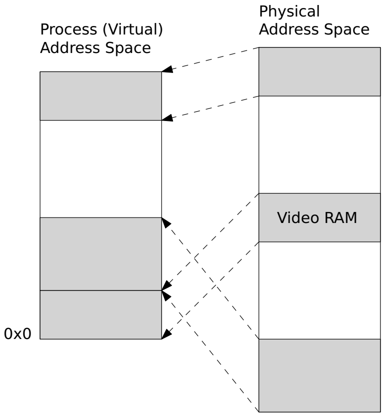
Issue Most computer architectures support a **virtual address space** that is decoupled from the **physical address space**

- Processes can access (physical) memory using a **logical** address that is independent of the physical address (determined by the address bus decoding circuitry)
- Most modern operating systems, including Minix, take advantage of this feature to simplify memory management.



Mapping Physical Memory to Virtual Address Space

- Each process has its own virtual address space, whose size is usually determined by the processor architecture (32-bit for IA-32)
- The operating system maps regions of the physical memory in the computer to the virtual address spaces of the different processes
  - The details of how this is done were presented in the Operating Systems course.
- In Lab 5, you have to map the Video RAM to the virtual address space



Mapping VRAM in Minix (1/2)

```
int r;
struct minix_mem_range mr; /* physical memory range */
unsigned int vram_base;   /* VRAM's physical addresss */
unsigned int vram_size;   /* VRAM's size, but you can use
                             the frame-buffer size, instead */
void *video_mem;          /* frame-buffer VM address */

/* Allow memory mapping */

mr.mr_base = (phys_bytes) vram_base;
mr.mr_limit = mr.mr_base + vram_size;

if( OK != (r = sys_privctl(SELF, SYS_PRIV_ADD_MEM, &mr)))
   panic("sys_privctl (ADD_MEM) failed: %d\n", r);

/* Map memory */

video_mem = vm_map_phys(SELF, (void *)mr.mr_base, vram_size);

if(video_mem == MAP_FAILED)
   panic("couldn't map video memory");
```

Mapping VRAM in Minix (2/2)

Question What is the following code about?

```
/* Allow memory mapping */

mr.mr_base = (phys_bytes) vram_base;
mr.mr_limit = mr.mr_base + vram_size;

if( OK != (r = sys_privctl(SELF, SYS_PRIV_ADD_MEM, &mr)))
   panic("sys_privctl (ADD_MEM) failed: %d\n", r);
```

Answer In modern operating systems, **user-level processes** cannot access **directly** HW resources, including physical memory and VRAM

- Minix 3 handles this by allowing to grant **privileged** user-level processes the permissions they require to perform their tasks

Lab 5 - Part 1: Key Programming Issue

Issue Given a virtual address, how can a program access the physical memory mapped to that virtual address?

Solution Use C pointers

- Pay attention to the size of a pixel.