TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Informatik Institut für Systemarchitektur, Professur für Betriebssysteme

OPERATING-SYSTEM CONSTRUCTION

Material based on slides by Olaf Spinczyk, Universität Osnabrück

Exercise 1: C++ (1), CGA Programming

https://tud.de/inf/os/studium/vorlesungen/betriebssystembau

HORST SCHIRMEIER

Overview

- **Development Environment**
- C++ crash course (Part 1)
- CGA programming

- … and next week:
- C++ crash course (Part 2)
- Keyboard programming

OSC Complex Lab

- Tasks every ~2 weeks (task description on OSC website, template code in Git repository), **in total 7 tasks**
  - Work on Lab tasks in groups of 2–3 students with technical support
  - Hand in + discuss your solutions **+ demonstration on real PC**
    (goal: maintain a working code base that doesn't break later in the semester)
  - Development **at home** possible
    (**Linux**, or **Linux VM** with ready-to-use VirtualBox image from OSC website, or possibly soon via **remote login** to a specific ZIH server)
- **Contest:** Task #7 – an own (free-style) OOStuBS application

Overview

- Development Environment
- **C++ crash course (Part 1)**
- CGA programming

- … and next week:
- C++ crash course (Part 2)
- Keyboard programming

OSC: Introduction to C++

- Basis for Complex Lab

- Prerequisite:
  - **Programming experience** in another object-oriented programming language (e.g., Java)

- Focus on **differences between Java and C++**
  - … and a few of the peculiarities you need to watch out for when using C++ for systems programming …

Literature

- There are a LOT of books and tutorials on C++ ...
- Good **introduction**:
  - Stanley B. Lippman: **C++ Primer** (also in German)
- **Advanced** material:
  - Scott Meyers: **Effective Modern C++** (also in German)
- “Best Practices”:
  https://github.com/isocpp/CppCoreGuidelines
- and “Von Java nach C++” (Müller/Weichert, TU Dortmund)
  - Basis for these slides
  - Book chapter: https://doi.org/10.1007/978-3-658-16141-5_13

C++

- As usual: “Hello, World” in C++

```
#include <iostream>
int main() {
   std::cout << "Hello, world" << std::endl;
   return 0;
}
```

- Java version:

```
import whatever.u.like.*;
class Test {
  public static void main(String[] argv) {
    System.out.println("Hello, world");
  }
}
```

A Few C++ Concepts

- Control structures and variable types in C++
- Complex data types (structs)
- Pointers and references
- Operator overloading

- Source-code organization
- Inheritance and multiple inheritance
- Virtual functions

Control Structures and Variable Types

- Conditional statements, loops, compound statements (blocks)
  - are identical in C++ and Java! (ignoring variants in recent C++ versions)
- C++ allows “global” functions, while in Java methods must be part of a class.
  - In particular, C++ allows calling “normal” C and assembler functions
  - ... and you can make C++ functions callable from C and assembler via **`extern "C"`**
  - One example for an important global function is **`main()`** :-)

Control Structures and Variable Types

- Array definition in C++:

```
int a[4]; // ... or with initialization:
int a[] = { 1, 2, 3 };
```

- Not necessarily placed on the heap (like in Java)
  - also stack / data / BSS
- No runtime checks for array boundaries! (like in Java)
  - **Potential security risk:** “Buffer overflows”, during which values beyond an array’s boundaries get overwritten (e.g. other variables, return addresses on the stack).
- Variables do **not have default values**, must explicitly be initialized (compiler warnings may give a hint of the problem, if you notice them)
- **Memory management** must be done by the programmer (no garbage collector like in Java)

Type Casting

- Like in Java, we can explicitly cast one type into another:
  - **`(type)expression`**, e.g.:

```
int a = 3;
double b = (double) a / 2; // b==1.5
```

- Another way to do it in C++:
  - **`type(expression)`**, e.g.:

```
int a = 3;
double b = double(a) / 2; // b==1.5
```

Value Ranges

- C++: signed and unsigned ("un-signed", i.e. without a sign) types (char, short, int, long), e.g.:
  - int from -2^{31} to $2^{31}-1$
  - unsigned int from 0 to $2^{32}-1$
- **Potential security risk:** No runtime check for overflows/underflows on arithmetic operations

```
unsigned int i=0;
i = i - 1;
// i==4294967295
```

- Value ranges are machine / architecture / compiler specific
  - e.g., **long** can have 32 or 64 bits
- With `typedef` we can define new types based on existing ones:

```
typedef int Index;
Index a = 3;
```

Complex Data Types

- enums: Enumeration types

```
enum { caps_lock = 4, num_lock = 2, scroll_lock = 1 };
```

Often used as an alternative to **`#define`**

- structs: User-defined compound data types

```
struct Rectangle {
  int xp, yp;
  int width, height;
  int color;
  ...
};
```

- Usage:

```
Rectangle r;
r.xp = 100; r.yp = 200; r.width = 20; r.height = 40;
```

Classes in C++

- A class in C++ consists of
  - a **declaration** in a header file (e.g. **`keyctrl.h`**)

```
class Keyboard_Controller {
  ...
};
```

  - and an **implementation** file (**`keyctrl.cc`**)

```
#include "machine/keyctrl.h"
...
```

  - (The file names and the name of the class do not *have* to match. It helps keeping the chaos level lower if they do, though.)

Header-File Structure

- **keyctrl.h** excerpt:

```
class Keyboard_Controller {
private:
  unsigned char code;       // Attributes
  unsigned char prefix;
  ...
public:
  Keyboard_Controller ();  // Constructor
  ~Keyboard_Controller (); // Destructor

  Key key_hit ();     // Methods
  void reboot ();
  void set_repeat_rate (int speed, int delay);
  ...
};
```

Header-File Structure

- Class definition starts with the keyword **`class`**
- Classes are always “public” (unlike in Java)
- Attributes
  - (Instance) variables may be initialized at declaration (since C++11)
- Constructors/destructors
  - Constructors: Called on object instantiation
  - Destructors: Called on object deletion
- Method declarations
- ***Class definition ends with a semicolon!***

Implementation-File Structure

- **`#include`** the corresponding header file
- **Class name plus scope operator "`::`"** tell the compiler which class a method (or constructor/destructor) belongs to:

```
#include "keyctrl.h"

Keyboard_Controller::Keyboard_Controller () {
    ...
}

Keyboard_Controller::~Keyboard_Controller () {}

void Keyboard_Controller::reboot () {
    ...
}
```

Pointers

- Every byte in memory assigned to an object (variable) has a unique address
  - In bare-metal / OS development, this can also be an address where a specific hardware device's internal memory or control registers are mapped to – for example **video memory**.
- **Pointer:** variable whose value is **the memory address** of a variable, of a data structure or of an object
  - Pointers have a type, e.g. "pointer to int"
  - Denoted by the ***** symbol, e.g.:

```
int a; // not a pointer
int *int_pointer; // pointer to an int variable
// Hint: Read right-to-left!
```

Pointers

- **Pointer content:**

  Value stored at the memory address the pointer points to

- **Content size (in bytes):**

  Depends on the assigned data type

  - e.g. 1 byte for **`char`**, 2 bytes for **`short`** etc.
  - **Again:** Sizes are architecture and compiler specific in C/C++ and not portable!

Pointers

Two pointer-specific operators:

- Address operator **&**
  - Yields the address belonging to a variable
- Dereferencing operator *
  - Yields the value that is stored **at the address the pointer "points to"** (its "content")

```
int_pointer = &a;
```

```
*int_pointer = 42;
```

Pointers: Example

Declaration (+definition) of a **pointer variable** CGA_START (pointer to char)

Cast of a constant address to a pointer

```
char *CGA_START = (char *)0xb8000;
char *pos;
int x=20, y=20;
pos = CGA_START + 2*(x + y*80);
*pos = 'Q';
```

Dereferencing: The character at position (x, y) gets overwritten by the letter ‘Q’

Pointer arithmetic: 'pos' now points to the memory address that stores the character code for the character at position (x, y)

References as Parameters

- **References:** Similar to pointers, often used for function parameters that can affect arguments at the call site

```
int& max(int& a, int& b) {
  if (a>b) return a; else return b;
}
```

- **Call by reference:** We’re passing a reference to each variable, and the function returns a reference, too.

```
int a=5, b=7;
max(a,b)++; // increases b by 1!
```

Operator Overloading

- Operators behave depending on the data type they operate on (not in Java)
- **Example:** Operator “+”
  - **int, float, double variables:** the usual arithmetic “add”
  - **std::string objects:** string concatenation
  - **3D vectors:** vector addition
- **In OOStuBS:** Operator “<<”
  - **int values:** Stored number gets “shifted left” by n bits
    (e.g. 2 << 3 == 16)
  - Overloaded for output streams (cf. “Hello World”):

    ```
    cout << "Hello" << endl;
    ```

    (Similarly: Operator “>>” for input streams)

Operator Overloading

- Only possible for operators **defined in the language**
  (no completely new operators)
- Supported:
  - Unary operators:
    ```
    +   -   *   &   ~   !   ++   --   ->   ->*
    ```
  - Binary operators:
    ```
    +   -   *   /   %   ^   &   |   <<  >>
    +=  -=  *=  /=  %=  ^=  &=  |=  <<= >>=
    <   <=   >   >=   ==   !=   &&   ||
    ,   []   ()
    new   new[]   delete   delete[]
    ```

Operator Overloading: Example

- Adding integers to a date:

```
class tDate {
public:
        // ....
        void operator+=(int days);
};

void tDate::operator+=(int days) {
        // [… date calculation …]
}
```

The += operator updates the date object, accepting an int at the “right-hand side”. Calculating today in two weeks:

```
tDate today;
today += 14;
```

Systems Programming in C++

- No runtime environment available
  - If you need one, you have to build one ...
- Consequence: No dynamic object instantiation
  - No “new”, no “delete”
  - ... because there’s no memory management (yet)
- For experts ... that’s unavailable, too:
  - Exceptions, assertions, runtime type information (RTTI)
- A wrong / uninitialized / corrupted pointer can be the end ...
  - The machine freezes and that’s it.
  - No “segmentation violation”, no core dump

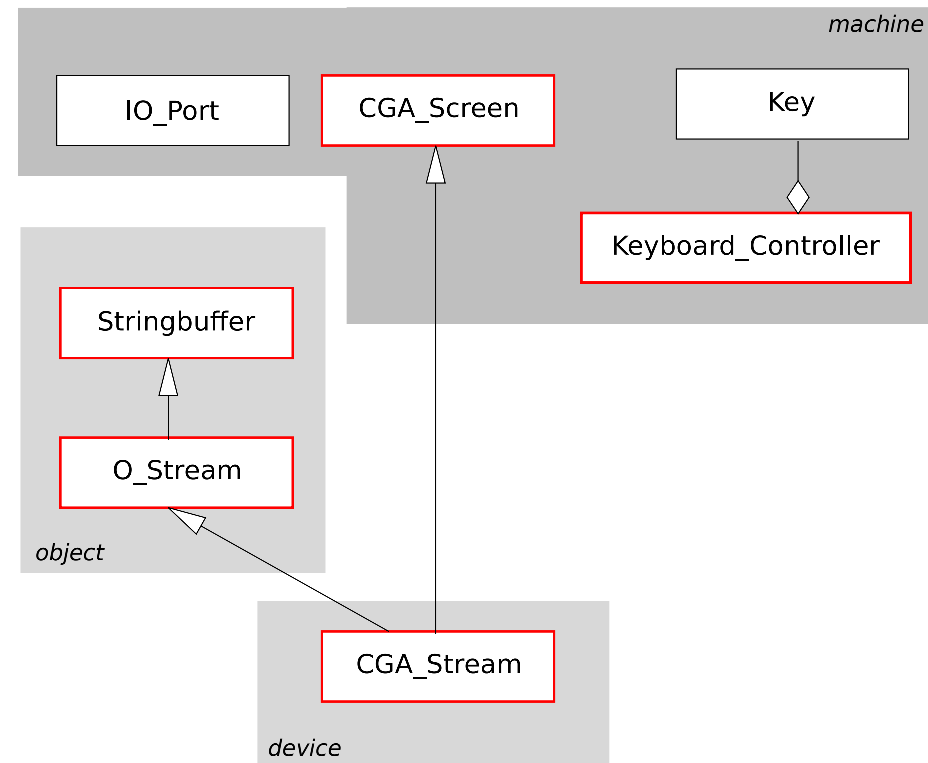
Overview

- Development Environment
- C++ crash course (Part 1)
- **CGA programming**

- ... and next week:
- C++ crash course (Part 2)
- Keyboard programming

Output Stream

- Stringbuffer: `put(c)`, *`flush()`*
  - Why buffer? Reasonable buffer size?
- `O_Stream`: similar to C++ `std::ostream`
  - Formatting, number output
  - uses `Stringbuffer::put(c)`
- `CGA_Stream::flush()`



CGA_Screen (1)

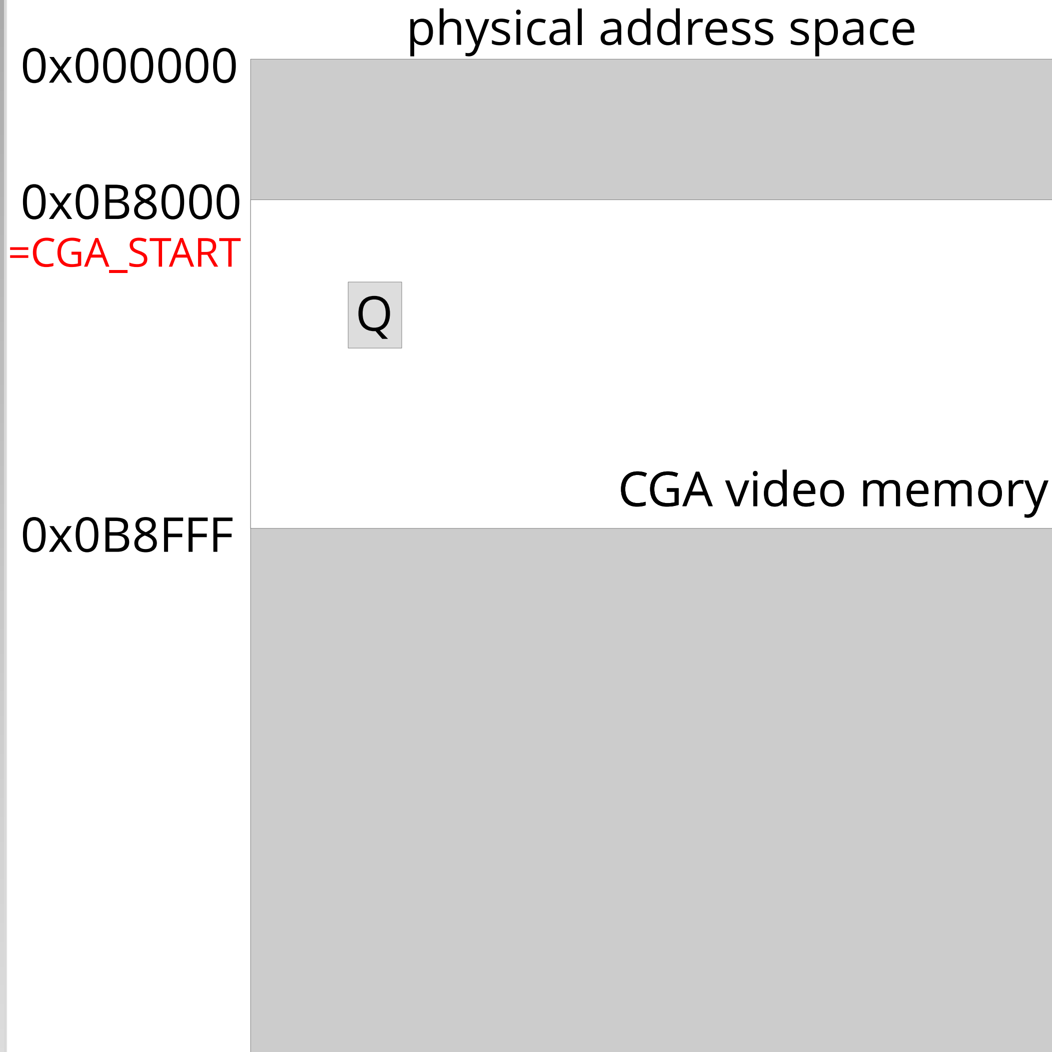
- used by **`CGA_Stream`** during **`flush()`**
- **`show(x,y,c,attrib)`**
  - Character c with attribute attrib at position x/y
  - Code from the C++ crash course:

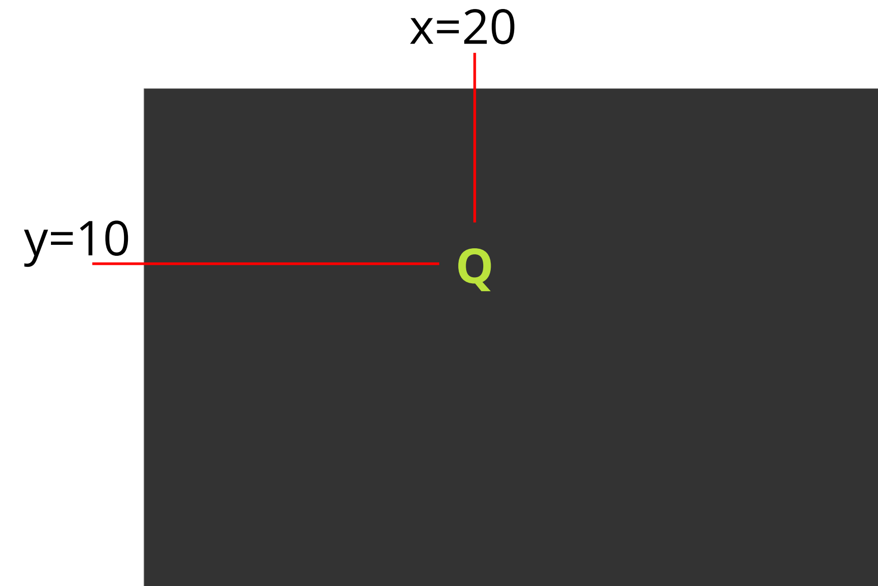
```
char *CGA_START = (char *)0xb8000;
char *pos;
int x = 20, y = 20;

pos = CGA_START + 2*(x + y*80);
*pos = 'Q';
```

  - **What’s missing here?**

CGA_Screen (2)






```
char *CGA_START = (char *)0xb8000;
char *pos;
int x = 20, y = 20;

pos = CGA_START + 2*(x + y*80);
*pos = 'Q';
```

CGA_Screen (3)

- *Two* bytes per coordinate in video memory!
- Even addresses: ASCII code
- Odd addresses: Attribute byte

```
char *CGA_START = (char *)0xb8000;
char *pos;
int x = 20, y = 20;

pos = CGA_START + 2*(x + y*80);
*pos = 'Q';
*(pos + 1) = 0x0f;    // white on black
```

- ... what happens without this line?

CGA_Screen (4)

- **`setpos/getpos`**
  - Change internal state of **`CGA_Screen`**
    - Current position needed in **`print()`**!
  - Position the CGA cursor
- In general: Access to PC devices
  - **Two address spaces:** Memory address space, I/O address space
  - **Memory:** addressable directly via pointers (video memory)
  - **I/O:** via CPU instructions **`in/out`** (**`inb/inw/inl`**; **`outb/outw/outl`**)
    - OOStuBS: encapsulated in class **`IO_Port`**
  - Some devices use both (e.g. CGA)

CGA_Screen (5)

- CGA: Memory *and* I/O address spaces
  - **Video memory** mapped into memory address space
  - **CGA registers** mapped to I/O address space
- but: More registers than I/O addresses
  - **Multiplexing** via index/data ports

Port	Register	Access mode
0x3d4	Index register	Write only
0x3d5	Data register	Read and write

<table>
<tr><th>Index</th><th>Register</th><th>Meaning</th></tr>
<tr><td>14</td><td>Cursor (high)</td><td rowspan="2">Character offset of the cursor position</td></tr>
<tr><td>15</td><td>Cursor (low)</td></tr>
</table>

CGA_Screen (6)

- **`print(char *text, int length, unsigned char attrib)`**
  - Uses **`show()`** and **`setpos()`**
  - Arrived at screen bottom? Scrolling! (How?)