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

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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)
- **Contest:** Task #7 – an own (free-style) OOStuBS application

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OSC: Introduction to C++

- Basis for lab tasks

- 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

```
int_pointer = &a;
```

- Dereferencing operator **`*`**
  - Yields the value that is stored **at the address the pointer "points to"** (its "content")

```
*int_pointer = 42;
```

Pointers: Example

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

Cast of a constant address to a pointer

```c
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

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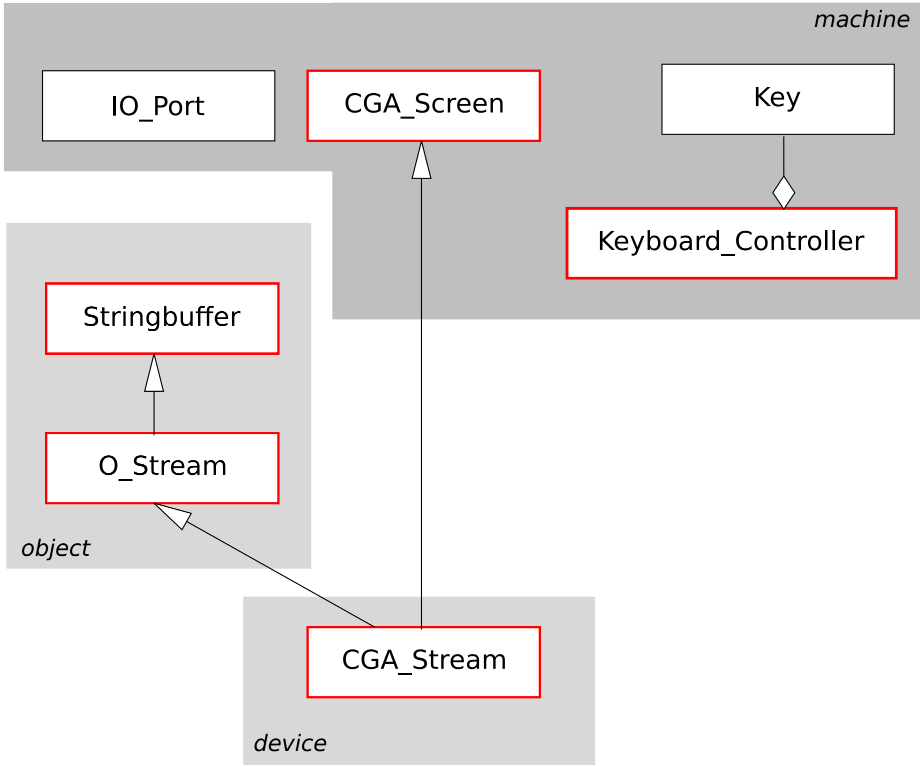
Output Stream

- 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)

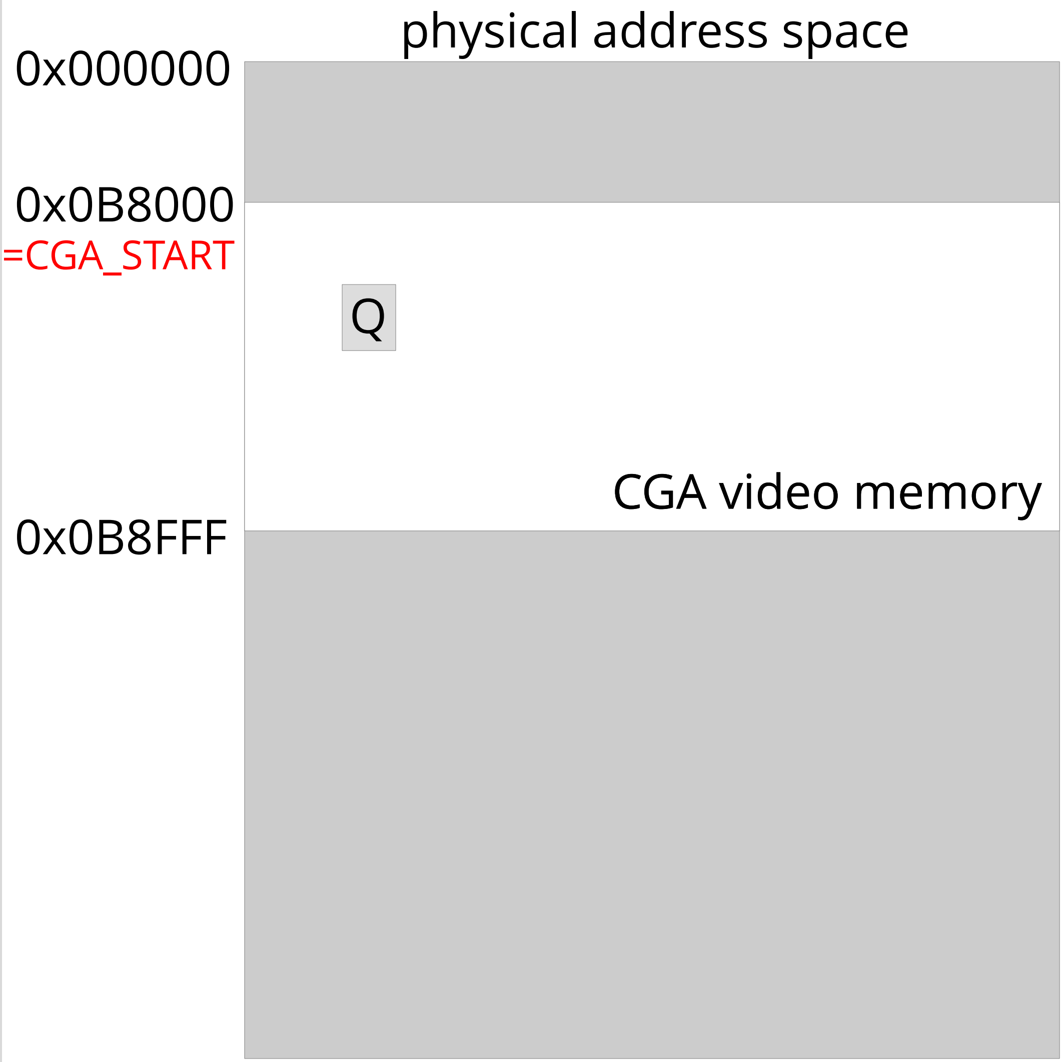
- used by **`CGA_Stream`** during **`flush()`**
- **`show(x,y,c,attrib)`**
  - Character c with attribute attrib at position x/y
  - Code from the C++ crash course:

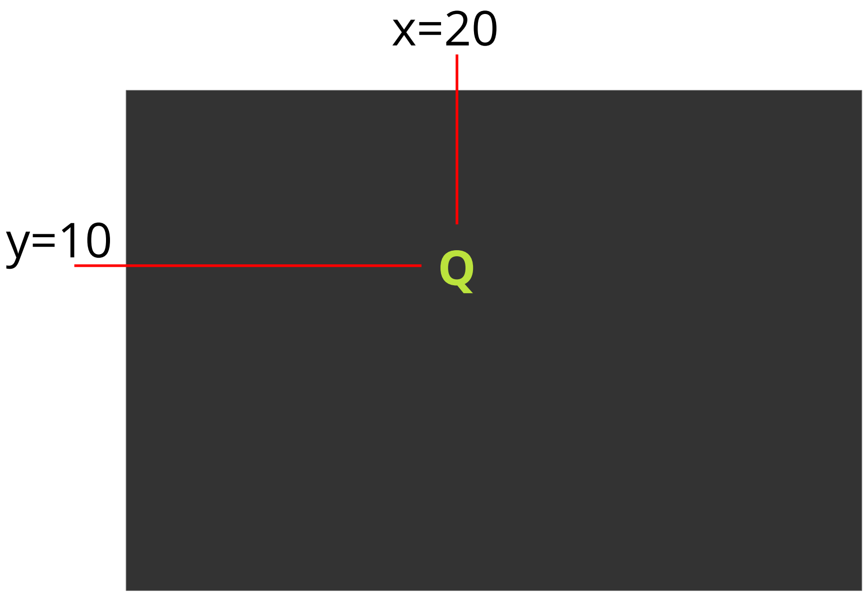
```
char *CGA_START = (char *)0xb8000;
char *pos;
int x = 20, y = 20;

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

Index	Register	Meaning
14	Cursor (high)	Character offset of the cursor position
15	Cursor (low)	

CGA_Screen (6)

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