

# VU Operating Systems

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IAIK – Graz University of Technology



Organizational Details

SWEB

Assignment 1

Booting SWEB

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SWEB

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Booting SWEB

# Teaching assistants

- Will help you with all your problems
- Interactive Programming units
- Student Debates
- Design reviews
- Question hours
- Review meetings (Abgabegespräche)

- Website: <https://iaik.tugraz.at/os>

# Channels

- Website: <https://iaik.tugraz.at/os>
- Discord
- studo
- Email: [os@iaik.tugraz.at](mailto:os@iaik.tugraz.at)
- Consultation hour: send us an email
- *During the question days: less activity on all channels ;)*

## What we expect from you

- Knowledge from earlier lectures
  - ESP, OOP1(!), SLP(!!), CON, ...



## What we expect from you

- Knowledge from earlier lectures
  - ESP, OOP1(!), SLP(!!), CON, ...
- Reasonable C/C++ experience
- Team work + Time management

## What we expect from you

Check whether you are prepared:

- “If I would do ESP/OOP1/SLP/CON again I would get a **1** on my own, without any help, without any problems, and without investing much time.”
- Self assess for which of those 4 courses this statement fits you.
- Hint: ask a colleague whether he agrees with your self-assessment ;)



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- 1 out of 4: You are seriously unprepared. Even with a huge time investment it's very unsure whether you can make it.
- 0 out of 4: Don't waste your time. Consider doing this course at a later point in your studies when you are prepared and have the required knowledge to start with this course.



## How much effort is it?

- Depends significantly on your knowledge and experience ...

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### **Note to students**

While we have made an effort to simplify these projects for you, most Duke students find these projects sufficiently difficult to dominate their lives during the one-semester course.

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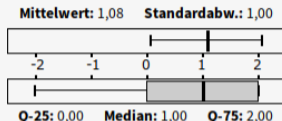
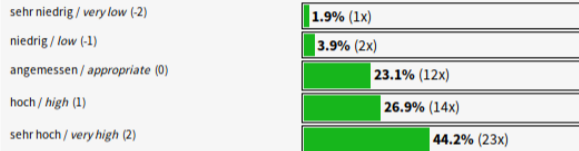
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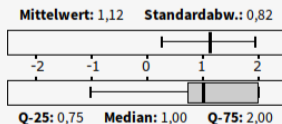
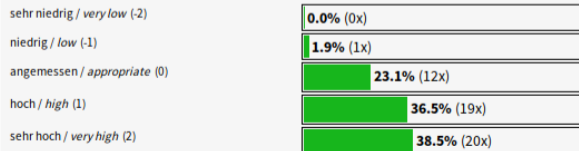
While we have made an effort to simplify these projects for you, most Duke students find these projects sufficiently difficult to dominate their lives during the one-semester course. A common misconception from earlier semesters is that we are sadistic individuals who enjoy seeing students suffer. Actually, this is not the case. We enjoy seeing students who are proud of what they have accomplished and excited by the power that flows from a relatively small set of simple abstractions in an operating system, even a toy one like Nachos.

# From our evaluations

**Wie beurteilen Sie Ihren für diese LV nötigen Arbeitsaufwand - gemessen an den ECTS-Punkten, die Sie erhalten? /**  
**How would you rate the workload for this course - measured against the ECTS credit points you received?** (52 x beantwortet)



**Wie beurteilen Sie die inhaltlichen Anforderungen (Schwierigkeit) dieser LV? /**  
**How would you rate the content requirements (difficulty) of this course?** (52 x beantwortet)





# From our evaluations

## Wie zufrieden sind Sie mit der LV insgesamt? /

*How satisfied are you with this course in general?* (52 x beantwortet)

sehr unzufrieden / *highly dissatisfied* (1)

1.9% (1x)

(2)

1.9% (1x)

(3)

5.8% (3x)

(4)

15.4% (8x)

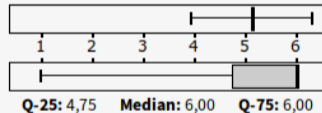
(5)

21.2% (11x)

sehr zufrieden / *highly satisfied* (6)

53.9% (28x)

Mittelwert: 5,13    Standardabw.: 1,18



# From our evaluations

Wie stark trifft die folgende Aussage Ihrer Meinung nach auf die LV zu?:

"In dieser LV werden alle Studierenden gleichermaßen fair behandelt (unabhängig von Lerntyp, Geschlecht, Ethnie)" /

*How well does the following statement describe this course, in your opinion?*

*"On this course, all students are treated fairly and equally (regardless of their learning style, gender and ethnicity)."* (52 x beantwortet)

trifft überhaupt nicht zu / *not at all well* (1)

0.0% (0x)

(2)

0.0% (0x)

(3)

1.9% (1x)

(4)

1.9% (1x)

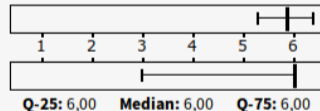
(5)

5.8% (3x)

trifft völlig zu / *very well* (6)

90.4% (47x)

Mittelwert: 5,85 Standardabw.: 0,53



## uSTL hilfreich?

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## Iteratoren verlieren die Gültigkeit, wo sie es nicht sollten

Check the standard!

```
iterator erase (iterator position);
```

```
iterator erase (iterator first, iterator last);
```

erase verwenden ohne den iterator upzudaten geht mit der GNU C++ STL *meistens...*

→ gefährlich sich anzugewöhnen den iterator zu ignorieren



[http://baptiste-wicht.com/posts/2012/12/  
cpp-benchmark-vector-list-deque.html](http://baptiste-wicht.com/posts/2012/12/cpp-benchmark-vector-list-deque.html)

## From this course's evaluations

Was gefällt Ihnen an dieser LV besonders gut? 28 Antwort(en) vorhanden.

- Der "Klick" Moment wenn man endlich verstanden hat worums geht und die Einstellung zur LV von "Sehr abgeneigt" zu "Begeistert" umschwingt. [WS16/17]

## Haben die vielen Assertions geholfen? i

- Assertions sind eine Wunderwaffe beim Debuggen ;)
- wenn man selber welche einfügt, dann sind sie noch hilfreicher ;)
- gegen ende hin waren ca 1/3 der zeilen Asserts - Hat jedoch dem tutor nicht so gut gefallen weil dadurch der code unleserlich war

- We try to improve our support constantly
- Feedback, Evaluations

“We will not lower the bar, but we will do what we can to help you over it.”

## Typical problems

- Bad time management
- Problems with working in a team
- No C/C++ experience
- Not willing to learn and use C/C++

## Student Debates

- Take place before the design deadlines
- You are expected to bring a sketch/summary of your design
- You are expected to have done proof of concept implementations by then



## Student Debates

- Take place before the design deadlines
- You are expected to bring a sketch/summary of your design
- You are expected to have done proof of concept implementations by then
- Prepare to defend your ideas

- Only code! No design document!
- Proof of concept implementation
- You get up to 5 points, depending on the test system score of your submission.

# Git is mandatory

- You have to:
  - push regularly into the provided repository
  - use your real name and email address for commits

## Git is mandatory (2)

- Personal maximum number of points

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- Unlock points:
  - For each commit you unlock 0.5 points
  - For each 10 LoC added you unlock 0.5 points
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## Git is mandatory (2)

- Personal maximum number of points
- Unlock points:
  - For each commit you unlock 0.5 points
  - For each 10 LoC added you unlock 0.5 points
  - Max. 10 points per day can be unlocked
- Average: > 55 points unlocked
- Test system shows your current personal maximum number of points

- We even give you master access to your repository, **but:**

- We even give you master access to your repository, **but:**
  - renaming repo = your group fails the course
  - changing repo path = your group fails the course
  - adding/removing group members = your group fails the course



# Participation

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  - Making coffee,

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  - Making coffee, fetching pizza,

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- We expect **all** members to have a high level overview of design and implementation
- We expect **every** member to be able to read, explain and **change** their own implementation, even if it's the code of another team member
- Otherwise: 0 points



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  - We have automated tests using the POSIX interface

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  - Do not change signatures!
  - We have automated tests using the POSIX interface
- If you implement new functions, try to make signatures POSIX-compatible

# Testing

- Goal: a stable and fault tolerant operating system
- How?

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- How? By writing test programs

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- Goal: a stable and fault tolerant operating system
- How? By writing test programs
- Think of test cases while designing and implementing
- Think of basic test scenarios as well as corner cases

# Testing

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- Test programs are supposed to show whether your implementation works according to the assignment
- You will get points for the test programs



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- Writing **numerous** test programs is unavoidable
- Test programs are supposed to show whether your implementation works according to the assignment
- You will get points for the test programs
- We have our own secret test programs

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- Better: Knowing of a problem but not solving it (probably because time ran out)

# Testing

- Bad: Not knowing of a problem until the review meeting
- Better: Knowing of a problem but not solving it (probably because time ran out)
- Best: Knowing of a problem sufficiently before the deadline and solving it (maybe with the help of a teaching assistant)

## Submissions

- Tag the commit you want to submit: `git tag SubmissionD1 [commit_hash]`

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- Push to repository: `git push / git push --tags`

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- Tag the commit you want to submit: `git tag SubmissionD1 [commit_hash]`
- Push to repository: `git push / git push --tags`
- Read the commit ID:

```
git show SubmissionD1
commit 196bc4a704f37d7f969d27a258b513693e3b30f4
Author: Peter Lipp <peter.lipp@iaik.tugraz.at>
```

Test System will acknowledge your submission!

## Small Fixes after the Deadline

- Small fixes → small deduction
- Do this at the same time:
  - Mail to [os@iaik.tugraz.at](mailto:os@iaik.tugraz.at)!
  - Submit and retag your fixed version!



# Assessment A1

## Reference (=100%)

- Design: 5 points
- Task 1: 20 points
- Task 2: 10 points
- Elective tasks\*: 15 points (or more)

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## Minimum

- Design: 1 point
- Mandatory tasks: 15 points
- And in total: 25 points (=50%)

(\* ) See the list of elective tasks on the Website!

## Assessment A2

### Reference (=100%)

- Design: 5 points
- Mandatory tasks: 40 points
- Elective tasks\*: 5 points (or more)

# Assessment A2

## Reference (=100%)

- Design: 5 points
- Mandatory tasks: 40 points
- Elective tasks\*: 5 points (or more)

## Minimum

- Design: 1 point
- Mandatory tasks: 15 points
- And in total: 25 points (=50%)

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# Assessment of the practicals

## Minimum requirements

- A1: 25 of 50 points
- A2: 25 of 50 points

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## Minimum requirements

- A1: 25 of 50 points
- A2: 25 of 50 points

## Limits

- A1: max. 60 points
  - Unlimited if  $A2 \geq 40$  points
- A2: unlimited points

# Assessment

- mid-term exam: 40%
- the practicals: 60%

## To pass the class, you have to acquire

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- at least 50% of the possible points in the practicals

## Assessment: Getting a grade

### Marks

- genügend: 55-66
- befriedigend: 67-78
- gut: 79-89
- sehr gut: 90+

# Review meetings (Abgabegespräche)

## As a group

- You explain what you implemented and how you tested it
- Together with the teaching assistant you determine the points of your group

## As a group member

- You are able to read, explain and change the code
- You can implement small new features or extend existing ones
- Otherwise you will get less points

# Plagiarism

- Discussions with other teams are appreciated
- But: **no collaboration!**

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- But: **no collaboration!**
- We check for plagiarism
- Similarities → teams are questioned
- Both teams: 0 points in either case
- At least one team: “Ungültig/Täuschung” (with all its consequences)

# Plagiarism

- Do not provide your source code to other teams



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  - Your own code (not exactly the same team)  
→ not allowed
  - Your own code (exactly the same team)  
→ allowed, probably not the best idea ;)

Questions so far?

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**SWEB**

Assignment 1

Booting SWEB

## History and the others

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- VU Amsterdam: Minix (1987), Minix3 (2005)
- Berkeley: Nachos (1992)
- Stanford: Pintos (2004)
- Graz
  - Nachos until 2006
  - Now: SWEB

# History of SWEB

- BS KU 2004/2005

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- Many subsequent projects
- BS KU: since 2007 SWEB only

## Base Line SWEB

- Minimalistic operating system kernel
- Runs on x86-32, x86-64, ARM
- Emulated using qemu

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- Minimalistic operating system kernel
- Runs on x86-32, x86-64, ARM
- Emulated using qemu
- Important features are missing
- Your task: Make your SWEB a beautiful, feature-rich kernel



# What is possible in SWEB

- Mouse driver

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- Mouse driver
- Window manager

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- Mouse driver
- Window manager
- Network driver

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- Mouse driver
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- Network driver
- Soundblaster driver

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## What is possible in SWEB

- Mouse driver
- Window manager
- Network driver
- Soundblaster driver
- Gameboy emulator
- 3D game engine
- Running it on a small ARM board with only 256KB RAM

# First steps

- Try out the tutorials on <http://iaik.tugraz.at/os>
  - Set up development environment
  - Implement your first syscall



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- Get acquainted with the source code: Try out implementing things in SWEB

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- Get acquainted with the source code: Try out implementing things in SWEB
- Start with the practicals **NOW!** (or rather already a week ago)

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## Task 1: Multithreading

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- What do we have to change?

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- Each thread has its own instances of some resources
  - id, stack, registers, status, ...

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  - id, stack, registers, status, ...
- Other resources are shared among all threads
  - memory, files, ...



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- Which ones?
- You decide - but function names and arguments have to be POSIX-compatible!
- Minimum requirements:

`pthread_create`

`pthread_exit`

`pthread_cancel`

`pthread_join`

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- User programs?
- System calls provide a “safe” interface
- Control flow is transmitted to kernel code
- Typical syscalls: `fork()`, `read()`, `write()`, `execve()`, `wait()`, `exit()`
- You will step through a syscall in the tutorial this week!

## Task 2: fork

- `fork()` creates a new process by duplicating the calling process
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- The new process (=the child), is an exact duplicate of the calling process (=the parent)
- Interesting in combination with multithreading!

## Additional Task: exec

- Replaces the current process image with a new process image

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## Additional Task: exec

- Replaces the current process image with a new process image
- `exec` with arguments → more points
- `fork()/exec()` combination often used

## Additional Task: sleep/clock

- `sleep()` sets a thread asleep for a given number of seconds



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- `sleep()` sets a thread asleep for a given number of seconds
- `clock` returns how much cpu time the current process consumed

## Additional Task: exit

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- Already implemented, but ...
- ... you will break the current implementation with multithreading

## Additional Task: I/O syscalls

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- I/O syscalls are already implemented, but ...
- ... they use global (not process specific) file descriptors
- Why is that a problem?

## Additional Task: Synchronization

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- Kernel has mutexes and condition variables
- We want: mutexes, condition variables and semaphores, both in kernelspace and userspace
- Pure userspace implementation (except for initialization and for going to sleep)
- Implement test programs (Readers-Writers-Problem, Sleeping Barber, etc.)

## Additional Task: Your own ideas

- Own ideas are the most fun!

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Assignment 2 tasks will **only** be counted in Assignment 2 assessment

## Tutors Point List

- We use this for grading and we are legally expected to put this online.
- No explanation. No details on how much you have to do for which point.
- Not suitable to choose tasks.
- Not suitable to estimate your points (points vary a lot!).



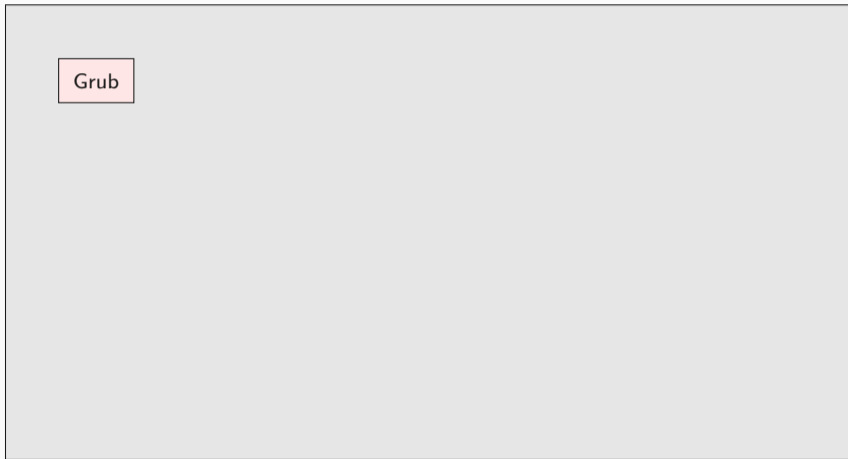
Organizational Details

SWEB

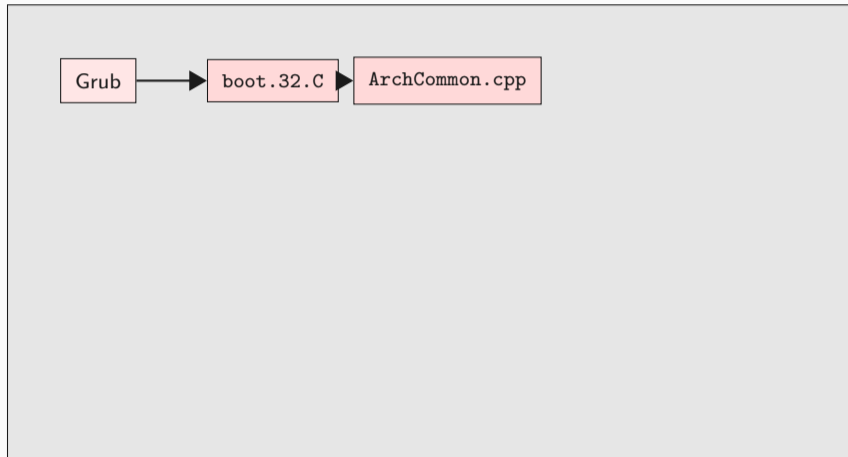
Assignment 1

Booting SWEB

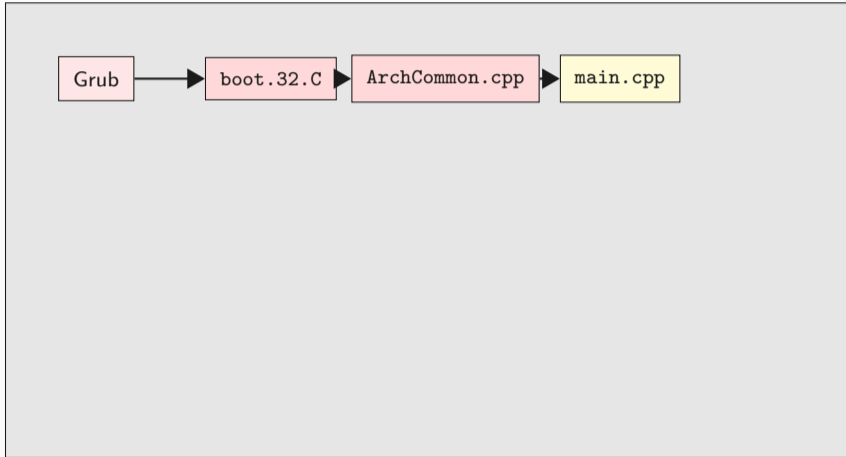
# Overview



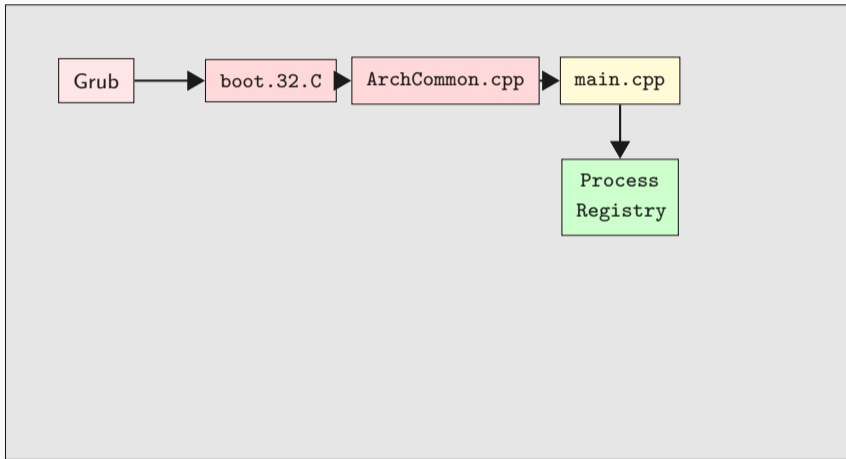
# Overview



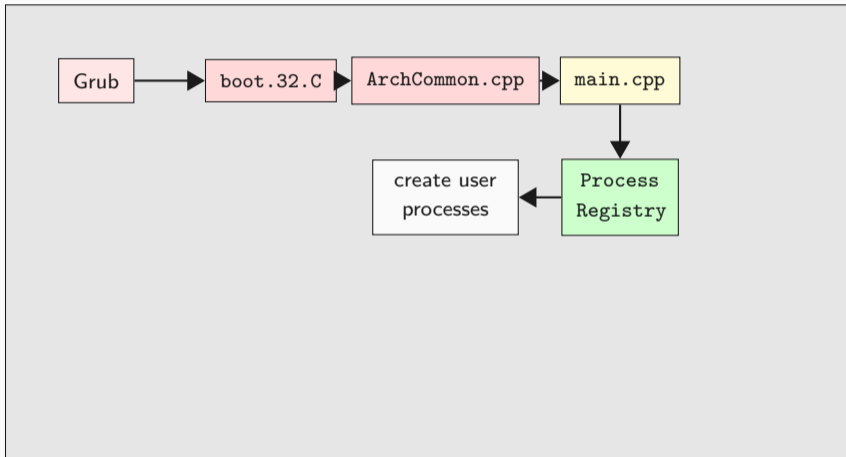
# Overview



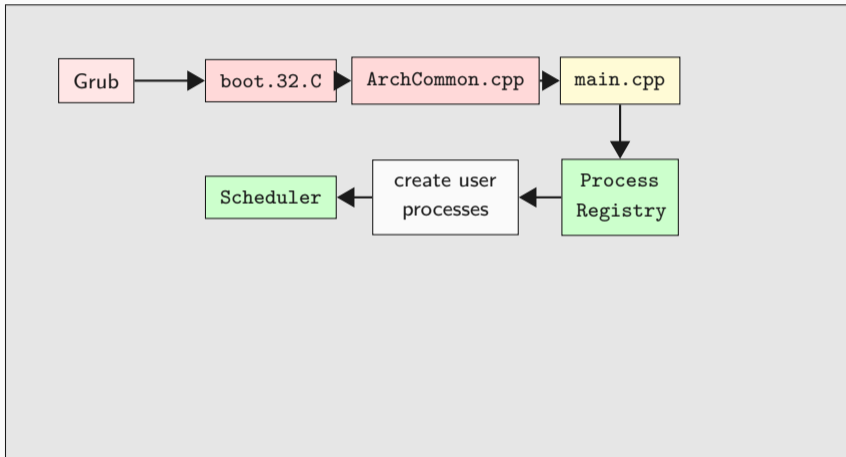
# Overview



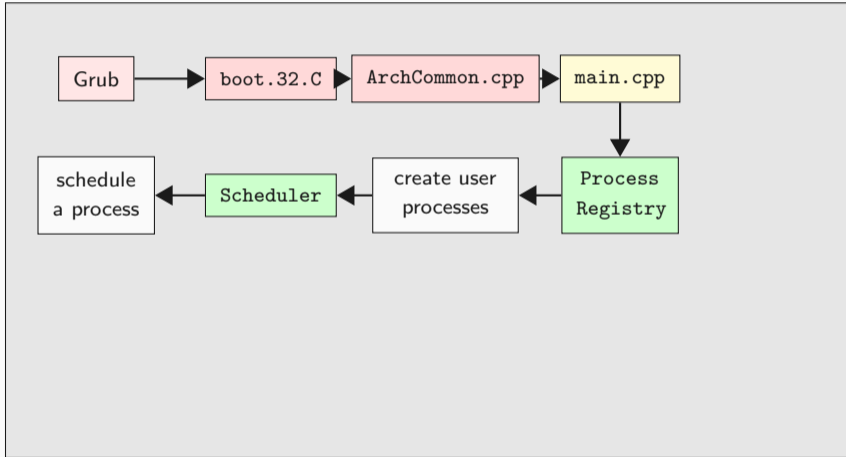
# Overview



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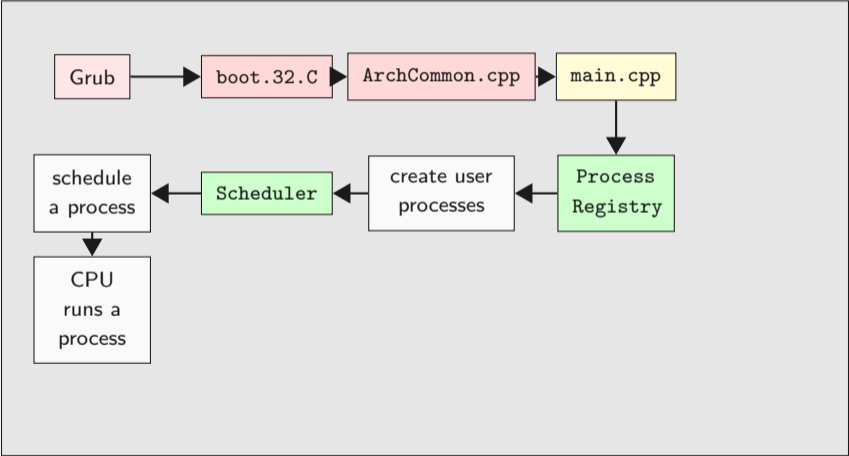


# Overview

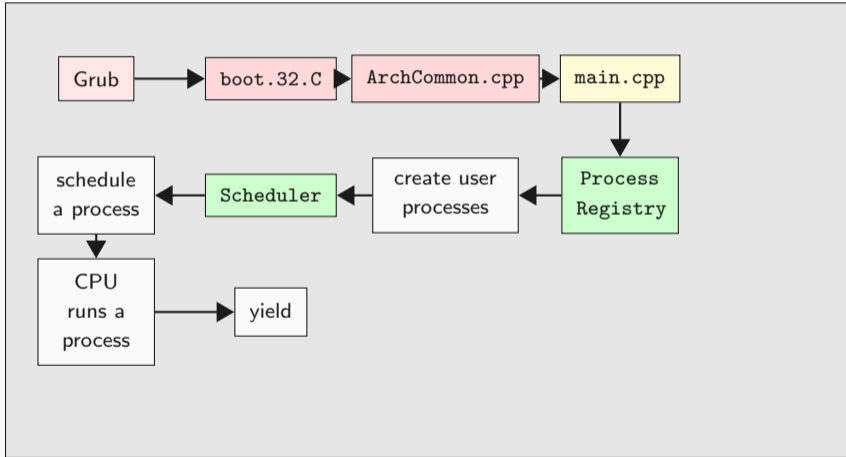




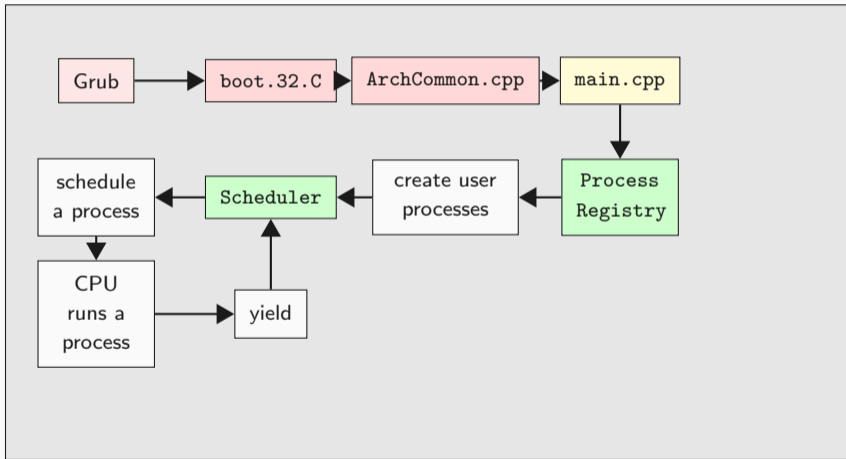
# Overview



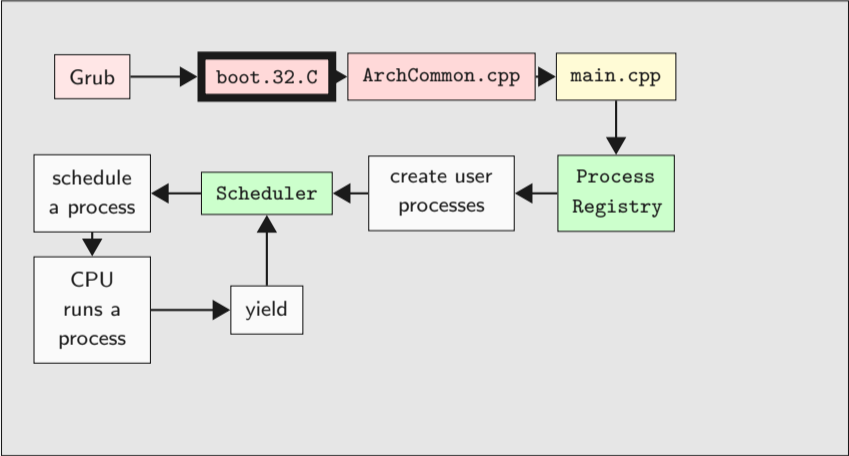
# Overview



# Overview



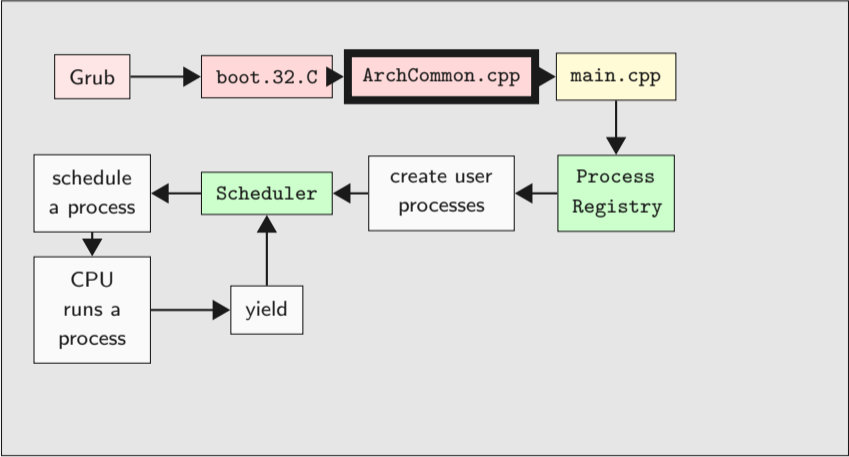
# Overview



```
extern "C" void entry()
{
    PRINT("Booting...\n");
    // ...
    PRINT("Initialize Kernel Paging Structs\n");
    // ...
    PRINT("Enable Paging...\n");
    // ...
    PRINT("Calling entry64()...\n");
    asm("ljmp %[cs], $entry64-BASE\n" : : [cs]"i"(KERNEL_CS));
}
```

- 32 bit
- Works on physical addresses
- Setup hardware
- Setup paging
- Jump into sane, virtual C world

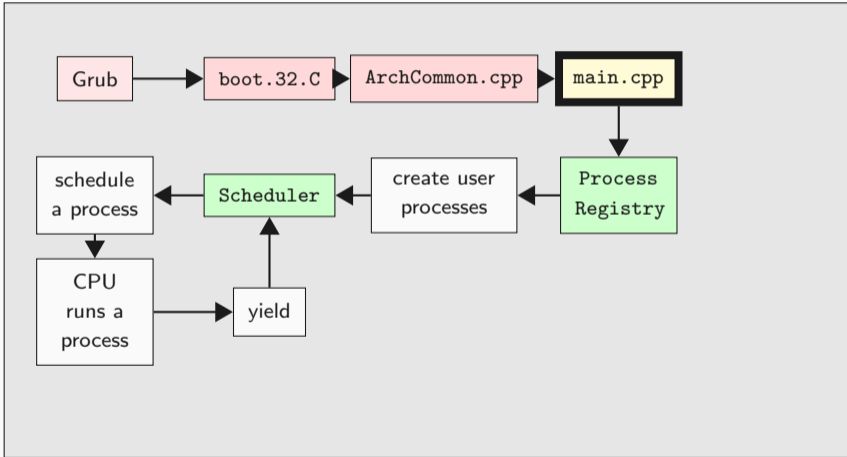
# Overview



```
extern "C" void entry64()
{
    // ...
    PRINT("Switch to our own stack...\n");
    asm("mov %[stack], %%rsp\n"
        "mov %[stack], %%rbp\n" : : [stack]"i"(boot_stack + 0x4000));
    PRINT("Loading Long Mode Segments...\n");
    // ...
    PRINT("Calling startup()...\n");
    asm("jmp *%[startup]" : : [startup]"r"(startup));
}
```



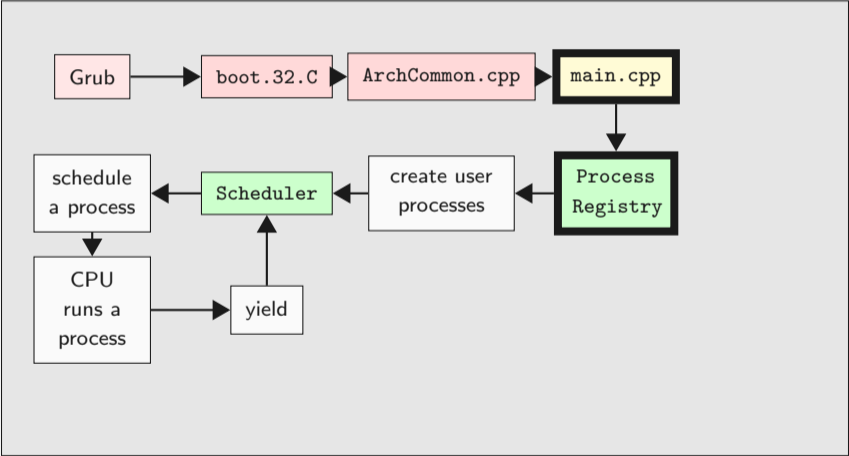
# Overview



```
extern "C" void startup() {
    removeBootTimeIdentMapping();
    system_state = BOOTING;
    PageManager::instance();
    writeLine("PageManager and KernelMemoryManager created\n");
    // ...
    Scheduler::instance()->addNewThread(new ProcessRegistry(...));
    // ...
    system_state = RUNNING;
    ArchInterrupts::enableInterrupts();
    Scheduler::instance()->yield();
    //not reached
```

- Setup kernel objects
- Setup more hardware
- Enable interrupts
- Handover control to Scheduler

# Overview



# ProcessRegistry

```
void ProcessRegistry::Run()
{
    debug(PROCESS_REG, "mounting userprog-partition \n");
    // ...
    vfs_syscall.mount("idea1", "/usr", "minixfs", 0);
    debug(PROCESS_REG, "mount idea1\n");

    for (size_t i = 0; progs_[i]; i++)
    {
        createProcess(progs_[i]);
    }
}
```

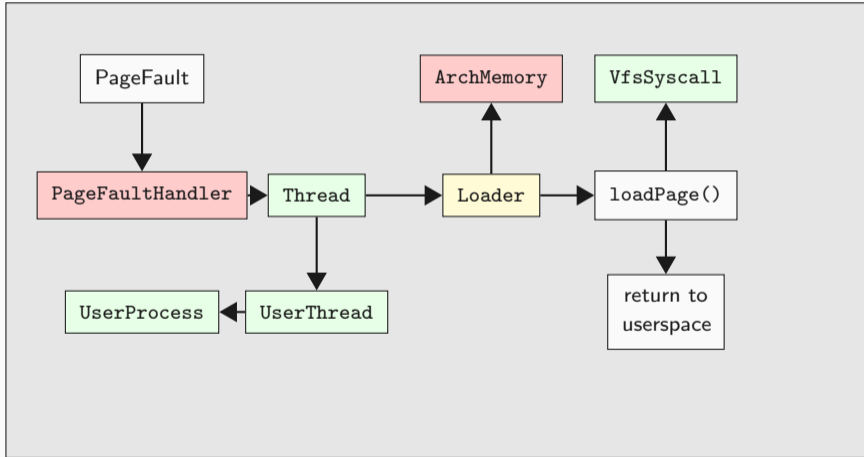
# ProcessRegistry

- Kernel Thread
- Mounts hard disk
- Creates user processes
- Sleeps until last user process died, ...

# ProcessRegistry

- Kernel Thread
- Mounts hard disk
- Creates user processes
- Sleeps until last user process died, ...
- ... and unmounts the hard disk again

# Loading User Processes





Status quo

- Derived from Thread

## Status quo

- Derived from Thread
- Bad design is easier for you to improve ;)

## Status quo

- Derived from Thread
- Bad design is easier for you to improve ;)
- Executes binary code
- Has a virtual address space (Loader → ArchMemory)
- Has a userspace part and a kernel part

# Timer Interrupt

- Every  $54.925439\mu s$
- Implemented in InterruptUtils.cpp

```
extern "C" void irqHandler_0()  
{  
    ArchCommon::drawHeartBeat();  
    Scheduler::instance()->incTicks();  
    Scheduler::instance()->schedule();  
    ArchInterrupts::EndOfInterrupt(0);  
    arch_contextSwitch();  
}
```

# Scheduler

- List of threads
- `schedule()` on IRQ0
- `schedule()` on IRQ65 (yield)
- `void Scheduler::addNewThread(Thread *thread);`
- Contains IdleThread (hlt if idle)
- Contains CleanupThread
  - Calls delete on dead threads

## Scheduling a process

A process is scheduled:

- only if `switch_to_userspace_ == 1`
  - Scheduler loads register values from `ArchThreadRegisters` member variable
- Implicitly sets RIP from `ArchThreadRegisters`
- RIP initially points to binary entry point
  - CPU switches to user mode and continues with given RIP

## Entry point

```
userspace/libc/src/nonstd.c
```

```
extern int main();
```

```
void _start()
```

```
{
```

```
    exit(main());
```

```
}
```

libc is in userspace!

# Hello World!

```
userspace/tests/helloworld.c
```

```
#include <stdio.h>
int main()
{
    puts("hello, world");
    return 0;
}
```

- Off-the-shelf Hello World Program
- Brian Kernigham, 1974



# puts?

userspace/libc/printf.c

```
int puts(const char *output_string)
{
    // ...
    characters_written = write(STDOUT_FILENO,
                              (void*) output_string, string_length);
    // ...
}
```

- In libc again
- Sanity checks
- Actually only a wrapper for syscall write

## write?

userspace/libc/write.c

```
ssize_t write(int file_descriptor, const void *buffer, size_t count) {  
    return __syscall(sc_write, file_descriptor,  
                    (long) buffer, count, 0, 0);  
}
```

- POSIX!
- fwrite is a simple write wrapper
- Down the rabbit hole: \_\_syscall

# \_\_syscall

```
arch/x86/64/common/userspace/syscalls.c
```

```
void __syscall()  
{  
    asm("int $0x80");  
}
```

- Function call copies arguments to registers
- Issue interrupt 0x80

→ switch to kernel space

# Syscall Dispatching in Kernel

```
arch/x86/64/common/source/arch_interrupts.S
```

```
arch_syscallHandler:
```

```
    pushall
```

```
    movq %rsp,%rdi
```

```
    movq $0,%rsi
```

```
    call arch_saveThreadRegisters
```

```
    call syscallHandler
```

## Syscall dispatching (higher level)

InterruptUtils.cpp

```
extern "C" void syscallHandler() {
    thread->switch_to_userspace_ = 0;
    threadRegisters = thread->kernel_regs_;
    ArchInterrupts::enableInterrupts();
    thread->user_regs_->rax =
        Syscall::syscallException(
            thread->user_regs_->rdi,
            thread->user_regs_->rsi,
            thread->user_regs_->rdx,
            thread->user_regs_->rcx,
            thread->user_regs_->r8,
            thread->user_regs_->r9);
}
```

## Syscall handling

Syscall.cpp

```
size_t Syscall::syscallException(size_t syscall_number, size_t arg1,
    size_t arg2, size_t arg3, size_t arg4, size_t arg5) {
    switch (syscall_number)
    {
        // ...
        case sc_write:
            return_value = write(arg1, arg2, arg3);
            break;
        // ...
    }
}
```

syscallException only calls the right methods with the right number of parameters

## Syscall handling

- `sc_write` constant defined in `Syscall.h`
- `Syscall::write` method is regular in-kernel C++

## Syscall::write

```
size_t Syscall::write(size_t fd, pointer buffer, size_t size)
{
    if (fd == fd_stdout) //stdout
    {
        debug(SYSCALL, "Syscall::write: %.*s\n", (int)size, (char*) buffer);
        kprintf("%.*s", (int)size, (char*) buffer);
    }
    // ...
}
```



# Debug Flags

```
common/include/console/debug.h
const size_t MAIN          =Ansi_Red      | ENABLED;
const size_t THREAD        =Ansi_Magenta | ENABLED;
const size_t USERPROCESS  =Ansi_Cyan     | ENABLED;
const size_t PROCESS_REG  =Ansi_Yellow   | ENABLED;
const size_t BACKTRACE    =Ansi_Red      | ENABLED;
const size_t USERTRACE    =Ansi_Red      | ENABLED;
//group memory management
const size_t PM            =Ansi_Green   | ENABLED;
const size_t KMM          =Ansi_Yellow;
```

Add your own debug tags!

## “This is not the printf you are looking for”

- `kprintf` → SWEB Terminal
  - `kprintfd` → Host
  - Cannot be disabled by flags
- Prefer debug

# Process termination

```
#include <stdio.h>
int main()
{
    puts("hello, world");
    return 0;
}
```

What does return 0; do?

## Process termination (2)

```
userspace/libc/src/nonstd.c
```

```
extern int main();
```

```
void _start()
```

```
{
```

```
    exit(main());
```

```
}
```

**AANNND**



**IT'S GONE**

## Exit Syscall

```
size_t Syscall::syscallException(...) {  
    // ...  
    case sc_exit:  
        exit(arg1);  
        break;  
    // ...  
}  
void Syscall::exit(size_t exit_code) {  
    debug(SYSCALL, "Syscall::EXIT: called, exit_code: %zd\n", exit_code)  
    ;  
    currentThread->kill();  
}
```

## Thread termination

```
void Thread::kill() {
    switch_to_userspace_ = 0;
    state_ = ToBeDestroyed;
    if (currentThread == this) {
        ArchInterrupts::enableInterrupts();
        Scheduler::instance()->yield();
    }
}
```

Recall: Scheduler will call delete on thread if `state_ == ToBeDestroyed`

## Thread deletion

```
UserProcess::~~UserProcess() {
    delete loader_;
    vfs_syscall.close(fd_);
    delete working_dir_;
    process_registry_ ->processExit();
}
Thread::~~Thread() {
    delete user_registers_;
    delete kernel_registers_;
}
```





Get in touch with the source code!