VU Operating Systems

Daniel Gruss

2020-10-01

IAIK – Graz University of Technology

Organizational Details

SWEB

Assignment 1

Booting SWEB

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SWEB

Assignment 1

Booting SWEB

Teaching assistants

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

Channels

- Wiki: `https://teaching.iaik.tugraz.at/bs`

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- Newsgroup
  - Organizational: tu-graz.lv.bs
  - SWEB specific: tu-graz.lv.bs.sweb

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- IRC: `irc://irc.freenode.net/sweb`

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  - SWEB specific: tu-graz.lv.bs.sweb
- IRC: `irc://irc.freenode.net/sweb`
- Email: bs-helpline@iaik.tugraz.at
- Consultation hour: send us an email
- *During the question days: less activity on all channels ;)*

05.10.-09.10. Interactive Programming

Timeline Assignment 1

05.10.-09.10. Interactive Programming

07.10. Assignment A1 Tutorial

Timeline Assignment 1

05.10.-09.10. Interactive Programming
07.10. Assignment A1 Tutorial
12.10.-16.10. Interactive Virtual Memory Tutorial
19.10.-23.10. Design Discussions A1
30.10. 18:00 Deadline Design-PoC A1

Timeline Assignment 1

05.10.-09.10. Interactive Programming
07.10. Assignment A1 Tutorial
12.10.-16.10. Interactive Virtual Memory Tutorial
19.10.-23.10. Design Discussions A1
30.10. 18:00 Deadline Design-PoC A1
02.11.-06.11. Review Design-PoC A1
16.11.-20.11. Question Days A1
20.11. 18:00 Deadline Implementation A1
23.11.-27.11. Review Meetings A1

Timeline Assignment 2

25.11. Assignment A2 Tutorial
30.11.-04.12. Design Discussions A2
11.12. 18:00 Deadline Design-PoC A2

25.11. Assignment A2 Tutorial
30.11.-04.12. Design Discussions A2
11.12. 18:00 Deadline Design-PoC A2
14.12.-18.12. Review Design-PoC A2
11.01.-15.01. Question Days A2
15.01. 18:00 Deadline Implementation A2 - **Friday!**
18.01.-22.01. Review Meetings A2

What we expect from you

- Knowledge from earlier lectures
  - Rechnerorganisation(!), SNP(!!), ...

What we expect from you

- Knowledge from earlier lectures
  - Rechnerorganisation(!), SNP(!!), ...
- 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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- 4 out of 4: Congratulations, you are well prepared!

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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.

What we expect from you

- 4 out of 4: Congratulations, you are well prepared!
- 3 out of 4: You are not well prepared, but you can catch up with some additional time investment.
- 2 out of 4: You are not prepared for the course. It will be a huge time investment to get any positive grade at all.
- 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 ...

How much effort is it?

- Depends significantly on your knowledge and experience ...
- ... and on your team members.

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- Short good solutions add around 4000 lines of code $\rightarrow$ 1000 lines of code per member

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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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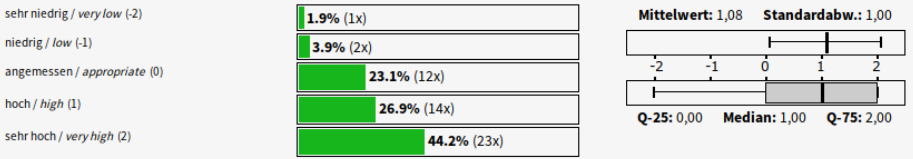
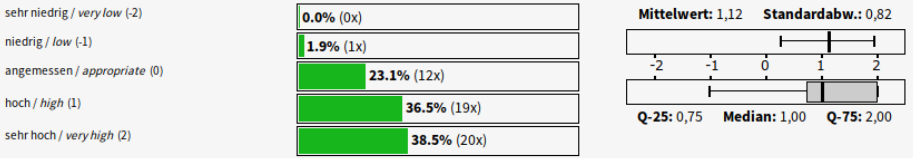
From our evaluations

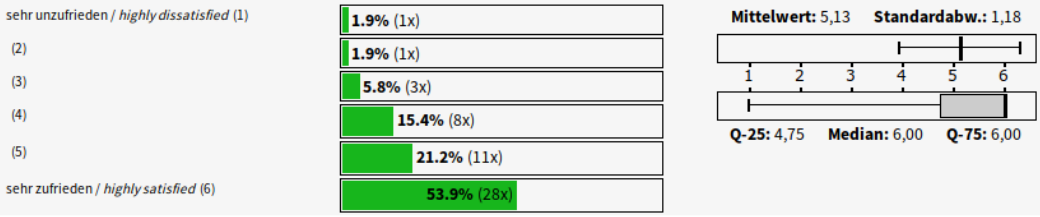
Wie beurteilen Sie Ihren für diese LV nötigen Arbeitsaufwand - gemessen an den ECTS-Punkten, die Sie erhalten? /
How would you rate the workload for this course - measured against the ECTS credit points you received? (52 x beantwortet)



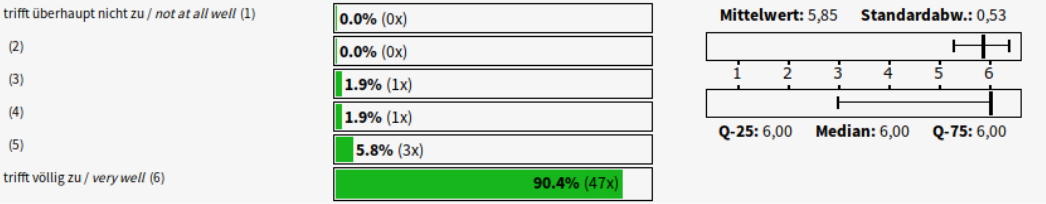
Wie beurteilen Sie die inhaltlichen Anforderungen (Schwierigkeit) dieser LV? /
How would you rate the content requirements (difficulty) of this course? (52 x beantwortet)



Wie zufrieden sind Sie mit der LV insgesamt? /
How satisfied are you with this course in general? (52 x beantwortet)



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)



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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

Effizienz?

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

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

Feedback

- 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++

Design discussions

- 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

Design discussions

- 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

- Personal maximum number of points

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

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

- Every team member has to participate:

- Every team member has to participate:
  - Making coffee,

- Every team member has to participate:
  - Making coffee,fetching pizza,

- Every team member has to participate:
  - Making coffee,fetching pizza,etc.

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  - Making coffee,fetching pizza,etc. is not enough

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- Otherwise: 0 points

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  - Do not change signatures!
  - 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

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

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- How? By writing test programs

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- How? By writing test programs
- Think of test cases while designing and implementing
- Think of basic test scenarios as well as corner cases

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- You will get points for the test programs

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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
- 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)

- 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)

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

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

Submissions

- 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 $\rightarrow$ small deduction
- Do this at the same time:
  - Mail to helpline!
  - Submit and retag your fixed version!

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 in the Wiki!

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Plagiarism

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

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- We check for plagiarism
- Similarities $\rightarrow$ teams are questioned

Plagiarism

- Discussions with other teams are appreciated
- 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)

- Do not provide your source code to other teams

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

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

Minimum requirements

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

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

- two written exams: 20% each
- 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

Marks

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

Questions so far?

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Assignment 1

Booting SWEB

- VU Amsterdam: Minix (1987), Minix3 (2005)

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- Stanford: Pintos (2004)
- Graz
  - Nachos until 2006
  - Now: SWEB

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- Runs on x86-32, x86-64, ARM
- Emulated using qemu

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

- Mouse driver

What is possible in SWEB

- 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
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- 3D game engine

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

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  - Set up development environment
  - Implement your first syscall

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- Start with the practicals NOW! (or rather already a week ago)

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- We want: multiple threads per user process

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- What do we have to change?

- 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, ...

- How to “use” multithreading?

Task 1: Multithreading

- How to “use” multithreading?
- Syscalls!
- Which ones?

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- Syscalls!
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- Minimum requirements:

```
pthread_create
pthread_exit
pthread_cancel
pthread_join
```

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Syscalls (system calls)

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- By definiton: Operating system is written by people who know what they do
- 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!

- `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!

- Replaces the current process image with a new process image

Additional Task: exec

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- exec with arguments $\rightarrow$ more points

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- 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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- `clock` returns how much cpu time the current process consumed

- `exit()` terminates the current process

Additional Task: exit

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- Already implemented, but ...

Additional Task: exit

- `exit()` terminates the current process
- Already implemented, but ...
- ... you will break the current implementation with multithreading

- I/O syscalls are already implemented, but ...

Additional Task: I/O syscalls

- 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

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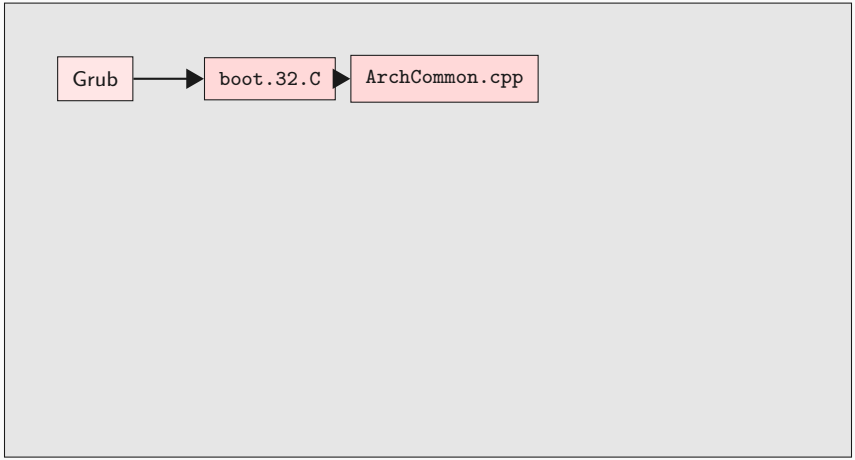
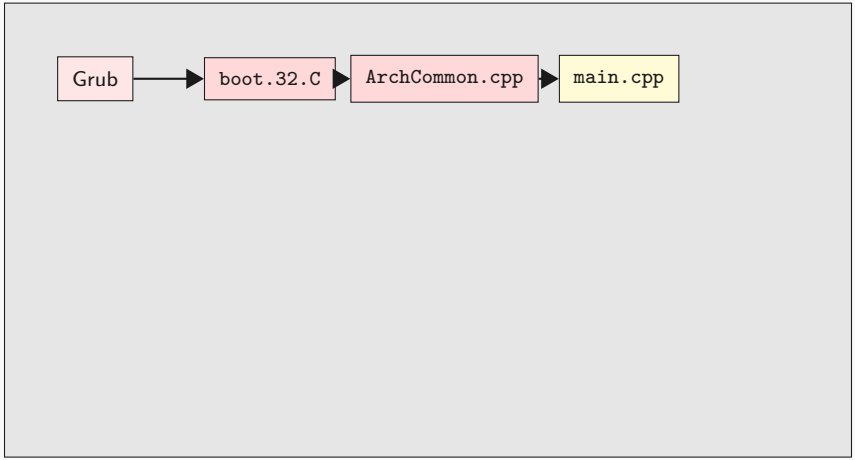
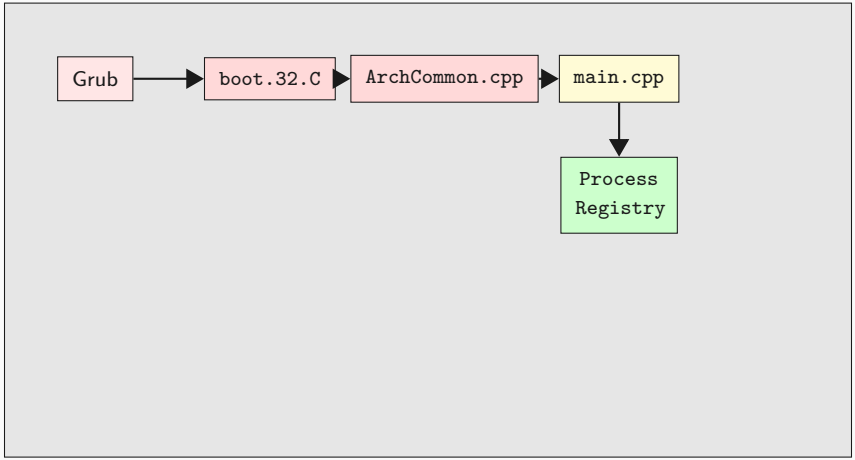
  Assignment 2 tasks will only be counted in Assignment 2 assessment

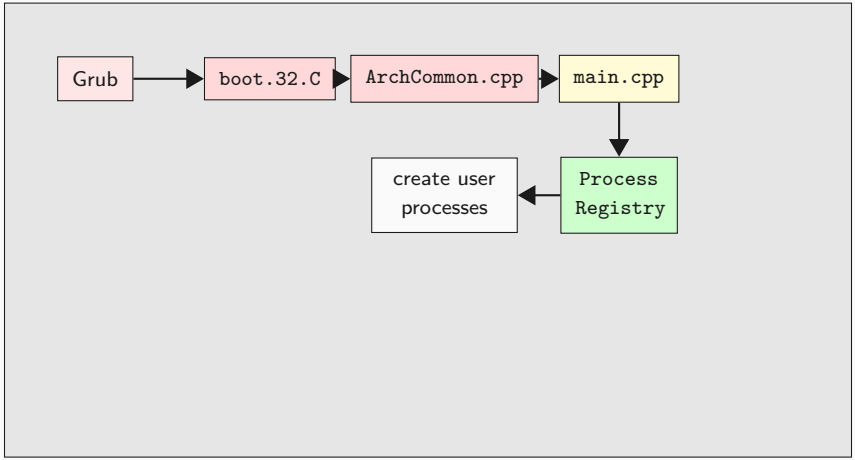
- We use this for grading and we are legally expected to put this online.
- No explanation. No details on how much you have to do for which point.
- Not suitable to choose tasks.
- Not suitable to estimate your points (points vary a lot!).

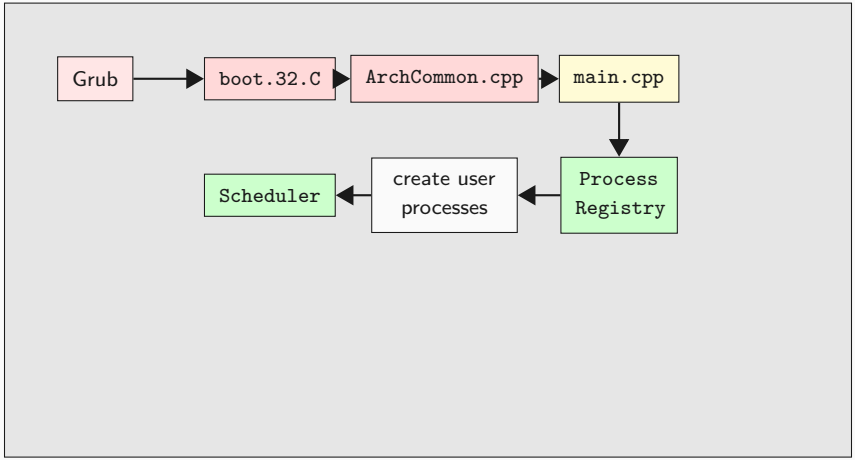

Grub

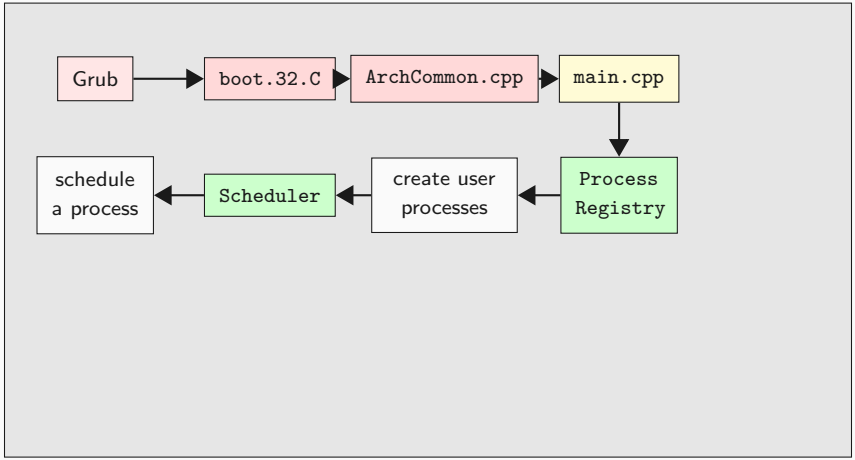

Grub
boot.32.C
ArchCommon.cpp

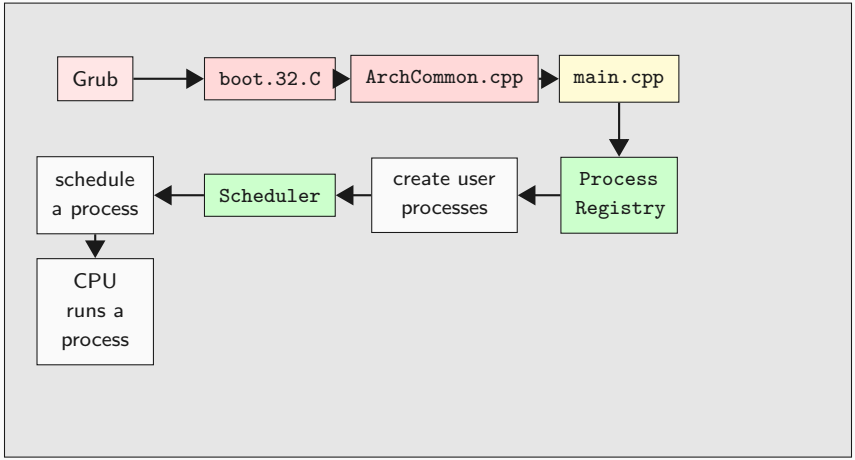

Grub
boot.32.C
ArchCommon.cpp
main.cpp

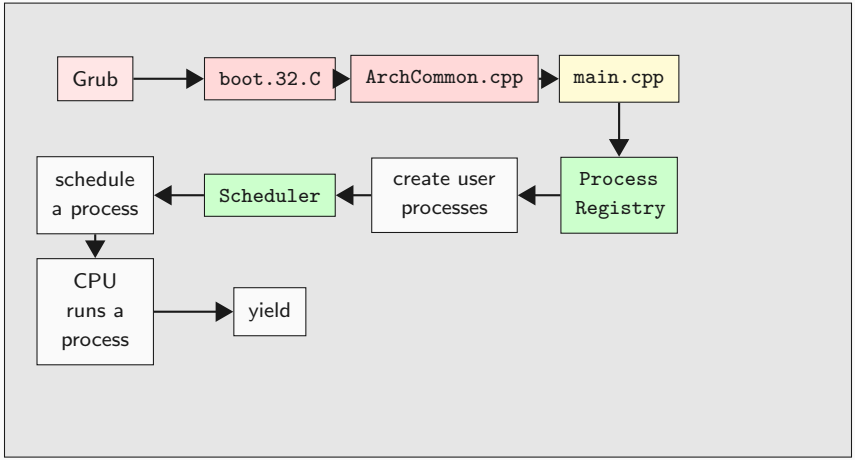

Grub
boot.32.C
ArchCommon.cpp
main.cpp
Process
Registry

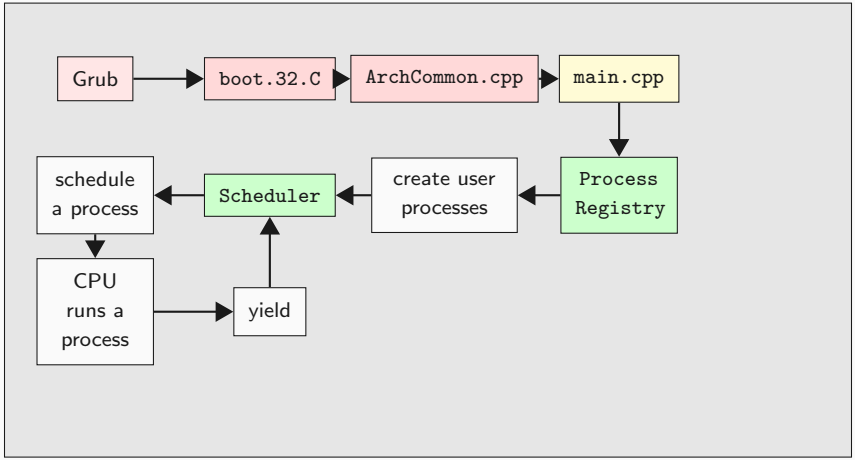

Grub
boot.32.C
ArchCommon.cpp
main.cpp
Process Registry
create user processes


Grub
boot.32.C
ArchCommon.cpp
main.cpp
Process Registry
create user processes
Scheduler


Grub
boot.32.C
ArchCommon.cpp
main.cpp
Process Registry
create user processes
Scheduler
schedule a process


Grub
boot.32.C
ArchCommon.cpp
main.cpp
Process Registry
create user processes
Scheduler
schedule a process
CPU runs a process


Grub
boot.32.C
ArchCommon.cpp
main.cpp
Process Registry
create user processes
Scheduler
schedule a process
CPU runs a process
yield


Grub
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create user processes
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schedule a process
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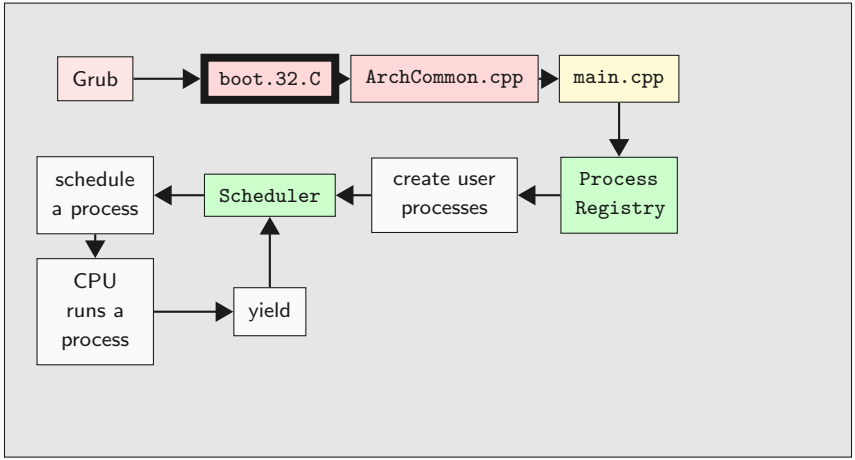
yield


Grub
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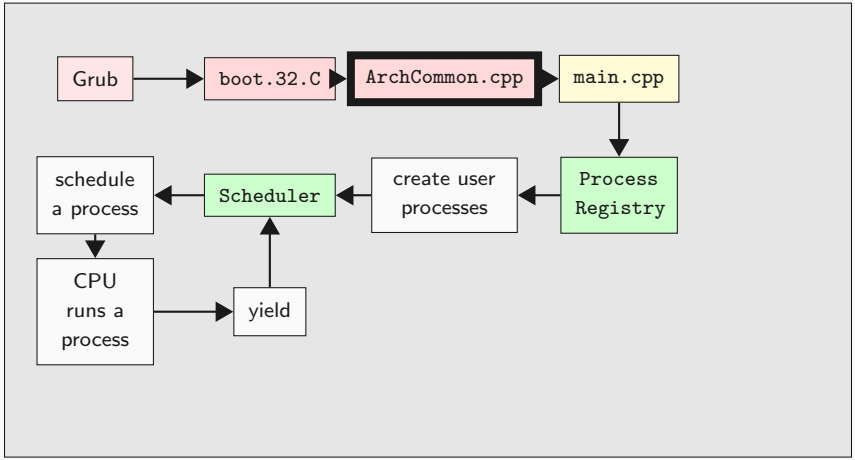
CPU runs a process
yield

```
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


Grub
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create user processes
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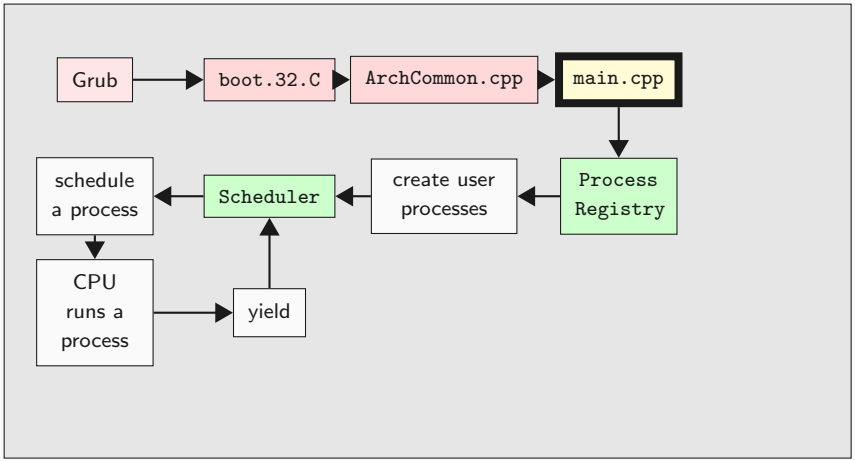
schedule a process
CPU runs a process
yield

```
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));
```


Grub
boot.32.C
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create user processes
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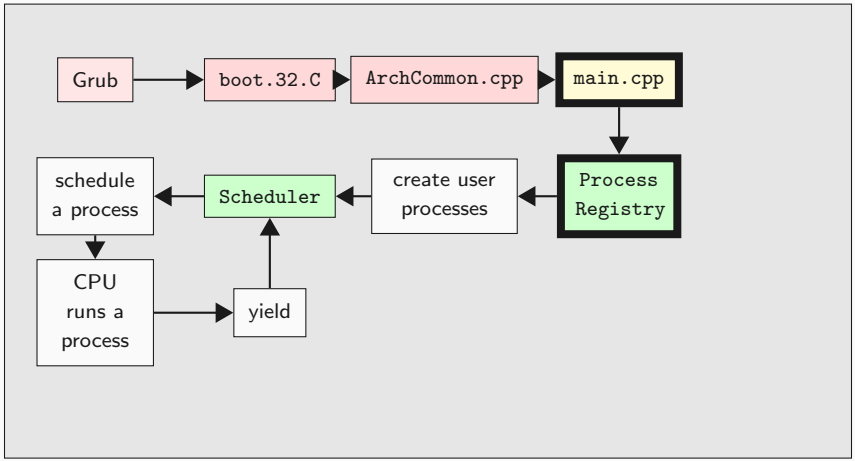
schedule a process
CPU runs a process
yield

```
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`


Grub
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Process Registry
create user processes
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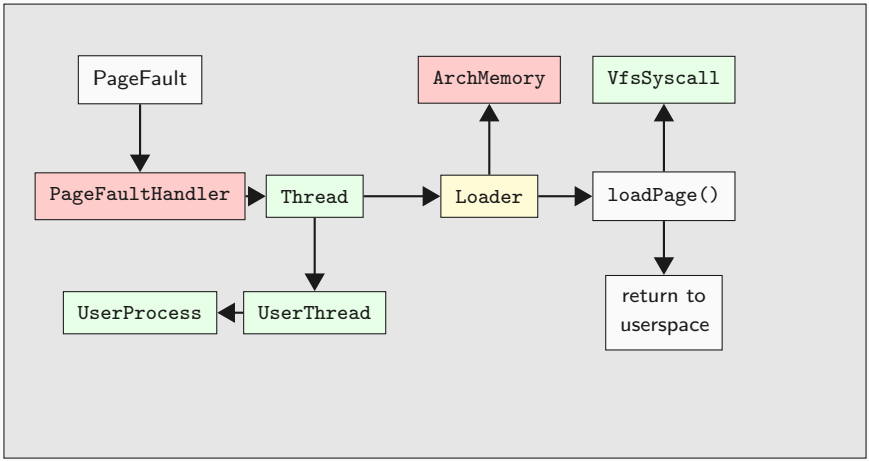
yield

```
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]);
  }
```

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

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


PageFault
ArchMemory
VfsSyscall
PageFaultHandler
Thread
Loader
loadPage()
UserProcess
UserThread
return to
userspace

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

- Every 54.925439μs
- Implemented in `InterruptUtils.cpp`

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

- 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

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!

userspace/tests/helloworld.c

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

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

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`

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`

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.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

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

```
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);
 }
 // ...
```

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!

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

→ Prefer `debug`

```c
#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();
}
```

```
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`

```
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!