NTNU
Kunnskap for en bedre verden

Department of Computer Science

TDT4186 - Operating Systems

Lab 1

Processes & Schedulings

Handout: 16.01.2026
Deadline: 05.02.2026, 22:00

Introduction

Hello, and welcome to the first lab. In the labs, you will have the opportunity to practically try out things you learned in the lectures. The labs are compulsory coursework; you need to get at least **27 points from four labs** approved to take the exam. The labs are also subject to NTNU's plagiarism rules. More on that in Section 3.

To help you get started, we encourage you to attend the corresponding exercise lecture. See the detailed schedule on Blackboard. We also offer weekly lab sessions. The lab sessions are not mandatory, but the lab material is relevant for the exam. In those sessions, we encourage you to ask the student assistants questions and to discuss the tasks with other students. The format of these lab sessions generally follows the following structure:

1. In the week a lab is released, part of the lab session is dedicated to group discussions. During this time, you will sit together in groups to talk through what a potential solution might look like. The goal is for you to exchange ideas on how to solve the lab while also developing your ability to plan before implementation.
2. After the design meeting, we expect you to **implement a solution independently**. Please do not copy any code, as this might constitute a violation of NTNU's rules on plagiarism. Nevertheless, we encourage you to discuss and ask questions with other students and TAs.
3. In the lab session after the deadline, we encourage you to review each other's code and give feedback to your colleagues. While this is not mandatory, it is beneficial because you will see different ways of solving the problem.

1 Task Description

In this lab, you will become familiar with XV6, a small Unix-like operating system that we will use as a sample for this course. XV6 has been developed for the course Operating System Engineering at MIT and is based on Unix V6[1]. We will be working with XV6 for the rest of the semester. More specifically, we are working with XV6 for RISC-V. RISC-V is a specific CPU architecture, which we will not delve into further; to execute it, we will use a virtual machine that provides a RISC-V system.

Before we begin the tasks for the first lab, we review the setup required to complete the labs.

1.1 Setup

To compile the operating system and the user-level programs, as well as run them, you will need a few tools installed. You can also use the virtual machine system images provided on Blackboard, which already include all preinstalled tools. If you decide to use a virtual machine, please follow the instructions provided with the images on Blackboard. If you decide to install it locally, you find the steps to set up below[2].

1.1.1 Windows

Refer to the C Programming setup guide on Blackboard to configure the Windows Subsystem for Linux. Subsequently, follow the instructions for Debian/Ubuntu below.

[1] This version was released by Bell Labs in 1975. If you want to know more about Unix and its place in history, see https://unix.org/what_is_unix/history_timeline.html

[2] The setup follows the setup described under https://pdos.csail.mit.edu/6.828/2022/tools.html

1.1.2 MacOS

1. We first need to install the developer tools. For that, we open a terminal and execute the following command:

   ```
   $ xcode-select --install
   ```

2. Next, we need to install Homebrew (if you don't have that already). We use Homebrew to install the dependencies.

   ```
   $ /usr/bin/ruby -e  $(curl -fsSL https://raw.githubusercontent
     .com/Homebrew/install/master/install)
   ```

3. Now we can install the dependencies, which includes the RISC-V compiler toolchain[3].

   ```
   $ brew tap riscv/riscv
   $ brew install riscv-tools
   $ brew install qemu
   ```

   Check if you can execute the installed tools. If not, check where the binaries got installed and add the directory to `$PATH`.

1.1.3 Debian/Ubuntu

Open a terminal and install the toolchain using the following command

```
$ sudo apt update
$ sudo apt upgrade
$ sudo apt install git build-essential gdb-multiarch qemu-system-misc
$ sudo apt install gcc-riscv64-linux-gnu binutils-riscv64-linux-gnu
```

1.1.4 Arch Linux

Similar to Ubuntu, open a terminal and update the packages. Then install the toolchain, using the following command

```
$ sudo pacman -S riscv64-linux-gnu-binutils riscv64-linux-gnu-gcc riscv64-linux
```

1.1.5 Fedora/RHEL/CentOS

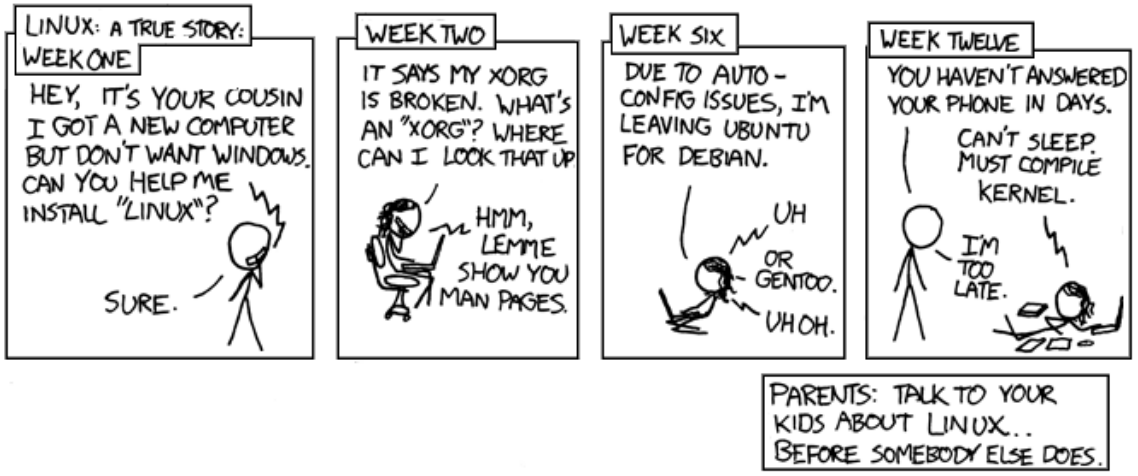
In Fedora, many tools are not available in the package repositories. This leaves you with two possibilities: either you compile the entire pipeline from source, which we cannot support. The other option is to use distrobox[4] to get a Debian shell running.

To install distrobox under Fedora, you can run the following commands (see https://distrobox.it/#installation for more information):

```
$ sudo dnf install distrobox docker
$ sudo systemctl enable docker
$ usermod -aG docker $USER
$ distrobox create -i ubuntu:22.04 --name  <NAME_CHOSEN_BY_YOU>
$ distrobox enter <NAME_CHOSEN_BY_YOU>
```

[3] https://github.com/riscv-software-src/homebrew-riscv
[4] https://distrobox.it/

You can now follow the instructions for Debian/Ubuntu in Section 1.1.3.



"This really is a true story, and she doesn't know I put it in my comic because her wifi hasn't worked for weeks."
Source: Cautionary by Randall Munroe / CC BY-NC 2.5 DEED

1.1.6 Testing the Installation

Download the handout code for this Lab from Blackboard. Move it to the folder you want to work in and unpack its content by running the following command.

```
$ tar -xvf lab-l1-handout.tar.gz
```

This will give you the following:

- Folder: kernel
- Folder: mkfs
- Folder: user
- File: `gradelib.py`
- File: LICENSE
- File: Makefile
- File: ReadMe
- File: test-lab-l1

Then run

```
$ make qemu
init: starting sh
$
```

This should start a shell within xv6. If not, please verify the versions of the installed QEMU and GCC, and confirm whether RISC-V versions are available.

If the shell prompt (`$`) appears, you can try xv6. To exit the virtual machine and XV6, press `Ctrl` and `A` together, then release and press `X`. This will shut down the virtual machine.

1.1.7 Debugging Kernel and Userspace

Debugging an operating system is generally difficult, especially at the beginning of development, when few options are available. We often resort to print statements, which are considered a "poor man's" debugger.

A better option is to use either JTAG or a remote debugger. Regardless of the option we choose, we must first implement the corresponding stubs. However, because we are working with a more mature operating system in this course, a remote debugger is already available. To debug the OS and any user-space program contained in the image, execute `make qemu-gdb`. This launches a debugger stub, opens a port to which we can connect with GDB, and writes a configuration file to the current directory. When starting GDB (e.g. `gdb-multiarch`) from within the project directory, it should use the config file and automatically connect to the port. If GDB warns that auto-loading has been declined, see https://sourceware.org/gdb/onlinedocs/gdb/Auto_002dloading-safe-path.html#Auto_002dloading-safe-path on how to solve the problem.[5]

To debug in the kernel space, you can start debugging right away. If you want to debug a user-space program, you must first load it. See the sequence of commands below for an example.

```
(gdb) file user/_ls
    Reading symbols from user/_ls...
(gdb) b fmtname
    Breakpoint 1 at 0x0: file user/ls.c, line 8.
(gdb) c
    Continuing.
```

From there on, it behaves as a normal GDB, so you can set breakpoints, check values and state of the program as you know it from a normal debugger.

1.2 Hello World

The first task in the first lab is to write a small user-space program that takes one optional parameter. This program should output the string `Hello World` if no argument has been supplied and `Hello [argument], nice to meet you!`, where `[argument]` should be replaced with the argument the user of the program provided. The `hello` program should only read the first argument and ignore any additional arguments.

Sample in/output:

```
$ hello
  Hello World
$ hello Roman
  Hello Roman, nice to meet you!
$ hello Roman Brunner
  Hello Roman, nice to meet you!
```

A word of caution: The C standard library has not been ported to XV6 (which is very common for small/research operating systems). Thus, you cannot assume that the C standard headers exist. If you need specific functionality, you a) can check back with the existing code if something similar has already been programmed (e.g. `printf` exists - do you find out which header file you have to include?) or b) have to write the code yourself (e.g. if you require a particular data type).

Below are a few questions that you should be able to answer after completing this task:

- What do you have to do in order to compile a user-space program on XV6?
- Which header defines the user-space `printf`?

[5] If you want to learn more about the GDB init file, see https://www.cse.unsw.edu.au/~learn/debugging/modules/gdb_init_file/

A few additional questions that you might be able to answer after completing the Hello World task are:

- Where is `printf` implemented? What is the call stack from your call to `printf` in your program to the printf implementation?
- Which syscall is required to print something to the screen? How is a syscall called in XV6?
- How is the output represented? How would we change it if we want to output something to stderr instead of stdout? Would that be possible in its current state?

Files that you might want to take a look at for this task:

`user/user.h`: That file contains all available user library functions. You might find some of them useful.

`user/ulib.c`: You might find it interesting to look at the implementation of the user library functions to know what they do.

`user/ls.c`: If you solved exercise 1 on C programming, this program should look somewhat familiar. You can review it for inspiration on implementing user-space programs in XV6.

`Makefile`: We need to add our newly added program to the makefile in order for it to be compiled. Examine other samples of user-space programs (e.g., `ls`) and add your program in a similar manner.

1.3 Process Management

For this task, we want you to write a small tool that helps us monitor the currently running processes. In order to achieve that, it should list all processes that the OS is currently aware of in the following format: `proc_name(proc_id): proc_state`, one process per line. Implement all required parts and think about what should go in the kernel space and the user space.

Sample input/output of the program:

```
$ ps
  init (1): 2
  sh (2): 2
  sh (8): 2
  sh (9): 2
  ps (10): 4
```

If you find it difficult to start with the task, see the optional tasks. Some of them might help you to break down the problem into more manageable pieces.

1.3.1 Optional Tasks

For some tasks, we provide a list of optional tasks, some of which are easier than the original and some of which are harder. The easier ones are intended to help you begin designing and implementing the main task, while the harder ones are provided for those who seek additional challenge. We indicate the difficulty of the different tasks at the beginning. You don't have to do either of those tasks, as long as you complete the main task described above.

EASIER: Implement a "Hello World" syscall that just prints a simple message when invoked from a user-level process. Have a look at other syscalls that are already implemented as a sample.

Files that you want to take a look at for the implementation of the syscall:

`kernel/syscall.h`: This file contains the syscall number definitions.

`kernel/syscall.c`: This file contains the syscall number mapping to the kernel function[6]. Additionally, you find some helper functions that are used to pass arguments to the syscalls.

`kernel/sysfile.c`: Contains samples for syscalls that handle filesystem operations.

`kernel/sysproc.c`: Contains samples for syscalls that handle process related operations (e.g. fork()).

EASIER: Implement a user-space program that calls the "Hello World" syscall. If either the call on the user-level or something on the kernel-level fails, try debugging it with the remote GDB. You find a description of how to debug XV6 in Section 1.1.7.

Files that you want to take a look at for the user-facing part of a syscall:

`user/usys.pl`: Autogenerates the user space stub for the syscall to be callable from user space programs. Add your syscall entry in the same manner as the other syscalls. This will generate some assembly. We don't introduce assembly in this course; thus, we don't expect you to understand the assembly part of that file.

`user/user.h`: Contains the user space facing syscall function definitions. Make sure that the name matches what you added to `usys.pl`

EASIER: Implement a syscall that returns information about the current process (e.g. its process ID and state). Think about who is responsible for allocating the memory that contains the process information that will be returned, and how it can be freed again after use (if it needs to be freed).

Files that you want to take a look at to access process information:

`kernel/proc.h`: Declarations of process functions and datastructures.

`kernel/proc.c`: Implementation of process functionality and instantiation of relevant datastructures.

SIMILAR: How could one implement a syscall that returns an array or list of arbitrary length? Can you also propose a fixed-length solution for obtaining an arbitrary number of results from a syscall (you can call the syscall multiple times)?

HARDER: The processes in XV6 also store information about the process tree. Can you develop a tool that uses that information and prints the process tree? The binary should be named `proctree` and print a tree in the following format: if a process is a child of another process, it will be prefixed with `|-` and start at the same indentation as its parent process. If you have a look at the sample output below, you see, for example, that the first shell is a child of `init`. **NOTE:** This is a difficult task and not required to pass the lab.

Sample output:

```
$ proctree
  init (1): 2
  |-sh (2): 2
    |-sh (8): 2
      |-sh (9): 2
        |-ps (10): 4
```

[6] Don't forget to add the forward declaration of the syscall function

2 Handing In

Before submitting, we recommend using the command `make test`, which runs your implementation on a small set of test cases. If you want to see the tests in greater detail, you can find the executed commands and the expected output in the file `test-lab-l1`. The test script also tests for some optional tasks, so you don't need to pass all the tests. We marked the test cases for the mandatory tasks with the tag `[MANDATORY]`. Ensure that all mandatory tests pass before submission. You may test your implementation independently using more complex test cases.

After you have tested and potentially debugged and fixed your solution, you can run `make prepare-handin` to create an archive of your solution. The archive will be written in the current directory, and the file is called `lab-l1-handin.tar.gz`. Upload the file to Blackboard on the Lab 1 submission page. You can submit multiple solutions. We will grade the last submission we received before the deadline.

Files to Hand in

- **lab-l1-handin.tar.gz**: The output of the command `make prepare-handin`. Please do not package your code manually, as this command runs tests on your machine and ensures that we can verify that it ran there. Additionally, the format in which it packages it up is the one expected by our automated tests.

Missing Deadlines

We expect you to begin working on the labs early to ensure submission before the deadline. The deadlines are fixed, and we can do little to move them. However, if you encounter a problem and notice that you can't make it in time, don't hesitate to **contact us as soon as you notice**. If you contact us early, we have time to develop a solution.

Last lab: Since we need to hand in a list of people who get to sit in the exam, handing in late for the last lab is not allowed. We need time to grade the labs, and if you submit late, we cannot grade your assignment before the list is submitted to the administration.

3 Plagiarism

You must submit your **own work**. You must write your **own code** and **not copy** it from anywhere else, including your classmates, the internet, and textbooks[7]. Failure to do so may constitute plagiarism. Detailed guidelines on what constitutes plagiarism can be found at: https://innsida.ntnu.no/wiki/-/wiki/English/Cheating+on+exams.

We check all submitted code for similarities to other submissions and online sources. Plagiarism detection tools have been effective in the past at finding similarities. If we suspect that a student has copied code, we will involve the administration to investigate the case.

[7] This is not an exhaustive list. Don't copy code from any source