# Lab2 traps

This lab explores how system calls are implemented using traps. You will first do a warm-up exercises with stacks and then you will implement an example of user-level trap handling.

## Switch to trap branch

```
# in the project directory
git fetch
git checkout traps
make clean
```

## RISC-V assembly

> It will be important to understand a bit of RISC-V assembly. There is a file `user/call.c` in your xv6 repo. make `fs.img` compiles it and also produces a readable assembly version of the program in `user/call.asm`.
> Read the code in call.asm for the functions `g`, `f`, and `main`. The instruction manual for RISC-V is on the reference page. Here are some questions that you should answer (store the answers in a file report.txt):

- Which registers contain arguments to functions? For example, which register holds 13 in main's call to `printf` ?
- Where is the call to function `f` in the assembly code for main? Where is the call to `g`? (Hint: the compiler may inline functions.)
- At what address is the function `printf` located?
- What value is in the register `ra` just after the `jalr` to `printf` in main?
- In the following code, what is going to be printed after `y=`? (note: the answer is not a specific value.) Why does this happen?

```
printf("x=%d y=%d", 3);
```

# Lab Task

## Backtrace

> For debugging it is often useful to have a backtrace: a list of the function calls on the stack above the point at which the error occurred. To help with backtraces, the compiler generates machine code that maintains a stack frame on the stack corresponding to each function in the current call chain. Each stack frame consists of the return address and a "frame pointer" to the caller's stack frame. Register s0 contains a pointer to the current stack frame (it actually points to the the address of the saved return address on the stack plus 8). Your backtrace should use the frame pointers to walk up the stack and print the saved return address in each stack frame.

- Implement a `backtrace()` function in `kernel/printf.c`. Insert a call to this function in `sys_sleep`, and then run `bttest`, which calls `sys_sleep`. Your output should be a list of

return addresses with this form (but the numbers will likely be different):

```
backtrace:
0x0000000080002cda
0x0000000080002bb6
0x0000000080002898
```

- After `bttest` exit qemu. In a terminal window: run `addr2line -e kernel/kernel` (or `riscv64-unknown-elf-addr2line -e kernel/kernel`) and cut-and-paste the addresses from your backtrace, like this:

```
$ addr2line -e kernel/kernel
0x0000000080002de2
0x0000000080002f4a
0x0000000080002bfc
Ctrl-D
```

- You should see something like this:

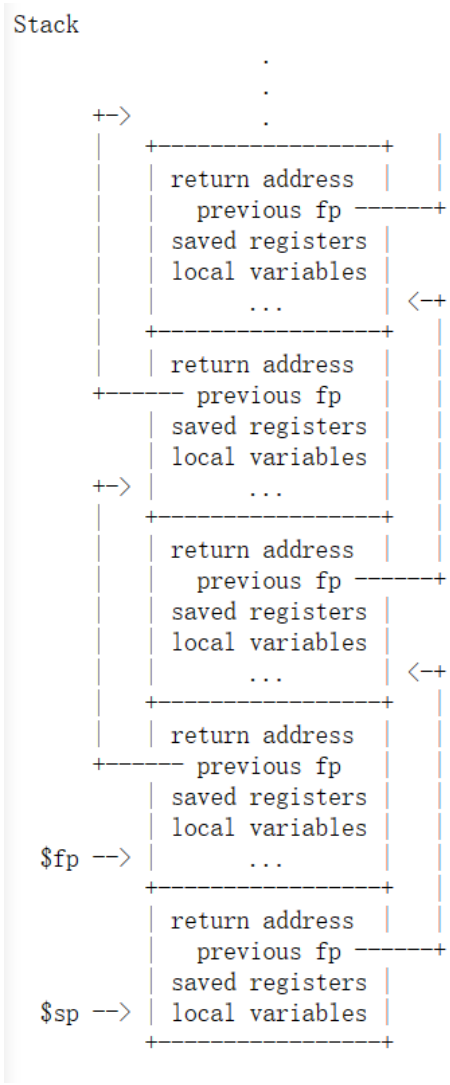
```
kernel/sysproc.c:74
kernel/syscall.c:224
kernel/trap.c:85
```

Some hints:

- Add the prototype for your `backtrace()` to `kernel/defs.h` so that you can invoke `backtrace` in `sys_sleep`
- The GCC compiler stores the frame pointer of the currently executing function in the register `s0`. Add the following function to `kernel/riscv.h`:

```
static inline uint64
r_fp()
{
  uint64 x;
  asm volatile("mv %0, s0" : "=r" (x) );
  return x;
}
```

- and call this function in backtrace to read the current frame pointer. `r_fp()` uses in-line assembly to read s0.
- Figure below is a picture of the layout of stack frames. Note that the return address lives at a fixed offset (-8) from the frame pointer of a stackframe, and that the saved frame pointer lives at fixed offset (-16) from the frame pointer.
- Your `backtrace()` will need a way to recognize that it has seen the last stack frame, and should stop. A useful fact is that the memory allocated for each kernel stack consists of a single page-aligned page, so that all the stack frames for a given stack are on the same page. You can use `PGROUNDDOWN(fp)` (see `kernel/riscv.h`) to identify the page that a frame pointer refers to.




Once your backtrace is working, call it from panic in `kernel/printf.c` so that you see the kernel's backtrace when it panics.

## Alarm

> In this exercise you'll add a feature to xv6 that periodically alerts a process as it uses CPU time. This might be useful for compute-bound processes that want to limit how much CPU time they chew up, or for processes that want to compute but also want to take some periodic action. More generally, you'll be implementing a primitive form of user-level interrupt/fault handlers; you could use something similar to handle page faults in the application, for example. Your solution is correct if it passes alarmtest and 'usertests -q'

- You should add a new `sigalarm(interval, handler)` system call. If an application calls `sigalarm(n, fn)`, then after every `n` "ticks" of CPU time that the program consumes, the kernel should cause application function `fn` to be called. When fn returns, the application should resume where it left off. A tick is a fairly arbitrary unit of time in xv6, determined by how often a hardware timer generates interrupts. If an application calls `sigalarm(0, 0)`, the kernel should stop generating periodic alarm calls.
- You'll find a file `user/alarmtest.c` in your xv6 repository. Add it to the Makefile. It won't compile correctly until you've added `sigalarm` and `sigreturn` system calls (see below).

- `alarmtest` calls `sigalarm(2, periodic)` in `test0` to ask the kernel to force a call to `periodic()` every 2 ticks, and then spins for a while. You can see the assembly code for alarmtest in `user/alarmtest.asm`, which may be handy for debugging. Your solution is correct when `alarmtest` produces output like this and `usertests -q` also runs correctly:

```
$ alarmtest
test0 start
........alarm!
test0 passed
test1 start
...alarm!
..alarm!
...alarm!
..alarm!
...alarm!
..alarm!
...alarm!
..alarm!
...alarm!
..alarm!
test1 passed
test2 start
................alarm!
test2 passed
test3 start
test3 passed
$ usertest -q
...
ALL TESTS PASSED
$
```

- When you're done, your solution will be only a few lines of code, but it may be tricky to get it right. We'll test your code with the version of `alarmtest.c` in the original repository. You can modify alarmtest.c to help you debug, but make sure the original alarmtest says that all the tests pass.

**test0: invoke handler**

Get started by modifying the kernel to jump to the alarm handler in user space, which will cause test0 to print "alarm!". Don't worry yet what happens after the "alarm!" output; it's OK for now if your program crashes after printing "alarm!". Here are some hints:

- You'll need to modify the Makefile to cause `alarmtest.c` to be compiled as an xv6 user program
- The right declarations to put in `user/user.h` are:

```
int sigalarm(int ticks, void (*handler)());
int sigreturn(void);
```

- Update `user/usys.pl` (which generates `user/usys.S`), `kernel/syscall.h`, and `kernel/syscall.c` to allow `alarmtest` to invoke the `sigalarm` and `sigreturn` system calls.

- For now, your `sys_sigreturn` should just return zero
- Your `sys_sigalarm()` should store the alarm interval and the pointer to the handler function in new fields in the `proc` structure (in `kernel/proc.h`)
- You'll need to keep track of how many ticks have passed since the last call (or are left until the next call) to a process's alarm handler; you'll need a new field in `struct proc` for this too. You can initialize proc fields in `allocproc()` in `proc.c`
- Every tick, the hardware clock forces an interrupt, which is handled in `usertrap()` in `kernel/trap.c`
- You only want to manipulate a process's alarm ticks if there's a timer interrupt; you want something like

  ```
  if (which_dev == 2) ...
  ```

- Only invoke the alarm function if the process has a timer outstanding. Note that the address of the user's alarm function might be 0 (e.g., in `user/alarmtest.asm`, periodic is at address 0)
- You'll need to modify `usertrap()` so that when a process's alarm interval expires, the user process executes the handler function. When a trap on the RISC-V returns to user space, what determines the instruction address at which user-space code resumes execution?
- It will be easier to look at traps with gdb if you tell qemu to use only one CPU, which you can do by running

  ```
  make CPUS=1 qemu-gdb
  ```

- You've succeeded if alarmtest prints "alarm!"

**test1/test2()/test3(): resume interrupted code**

Chances are that alarmtest crashes in test0 or test1 after it prints "alarm!", or that alarmtest (eventually) prints "test1 failed", or that alarmtest exits without printing "test1 passed". To fix this, you must ensure that, when the alarm handler is done, control returns to the instruction at which the user program was originally interrupted by the timer interrupt. You must ensure that the register contents are restored to the values they held at the time of the interrupt, so that the user program can continue undisturbed after the alarm. Finally, you should "re-arm" the alarm counter after each time it goes off, so that the handler is called periodically.

As a starting point, we've made a design decision for you: user alarm handlers are required to call the `sigreturn` system call when they have finished. Have a look at `periodic` in `alarmtest.c` for an example. This means that you can add code to `usertrap` and `sys_sigreturn` that cooperate to cause the user process to resume properly after it has handled the alarm.

Some hints:

- Your solution will require you to save and restore registers---what registers do you need to save and restore to resume the interrupted code correctly? (Hint: it will be many)
- Have `usertrap` save enough state in `struct proc` when the timer goes off so that `sigreturn` can correctly return to the interrupted user code

- Prevent re-entrant calls to the handler----if a handler hasn't returned yet, the kernel shouldn't call it again. `test2` tests this
- Make sure to restore `a0`. `sigreturn` is a system call, and its return value is stored in `a0`

Once you pass `test0`, `test1`, `test2`, and `test3` run `usertests -q` to make sure you didn't break any other parts of the kernel

# Submit the Lab

## Report

Put your report about this lab in a new file `report.txt`. You can write down the errors you met when doing the lab, or some techniques you found that helps you to finish the lab better. You can use both **English** and **Chinese**.

Don't forget to `git add` and `git commit` the file.

## Time spent

Create a new file, `time.txt`, and put in it a single integer, the number of hours you spent on the lab. Don't forget to `git add` and `git commit` the file.

## Check

- Please run `make grade` to ensure that your code passes all of the tests
- Commit any modified source code before running `make tarball`

## Submit

Run `make tarball`, you should see a new file in the root directory called `lab-traps-handin.tar.gz`. Upload this file here.