Linux Kernel Exploration

Development Environment & Debugging Tips

March 9, 2021

SNU Operating Systems

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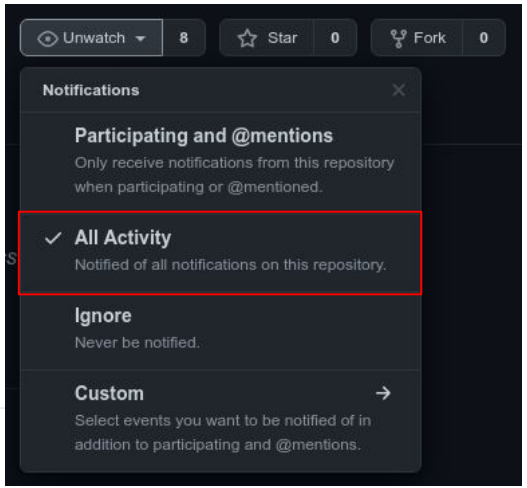
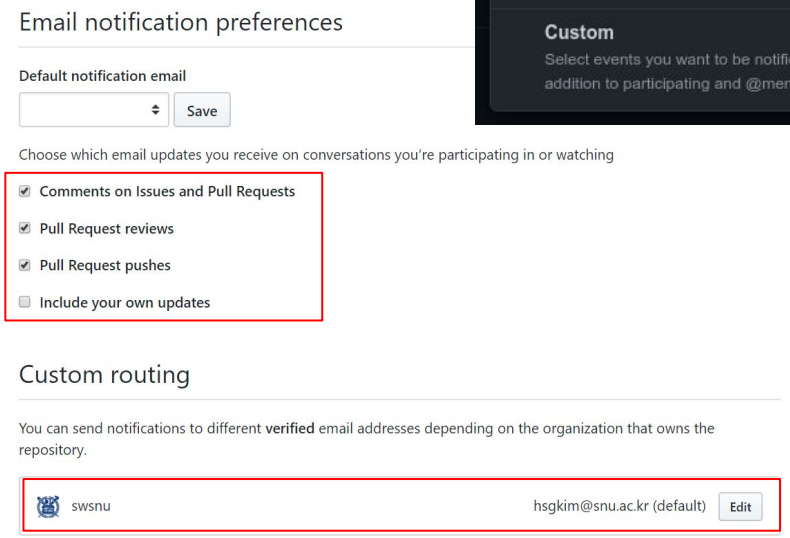
Learning Platforms

1. eTL: Lecture slides and Zoom links
2. Class Github repository: Q&A, docs, and notices
3. Github Classroom: Assignment distribution

Notification Settings

- https://github.com/swsnu/osspr2021
- https://github.com/settings/emails
- https://github.com/settings/notifications





Issue Board

- https://github.com/swsnu/osspr2021/issues
- All questions and announcements go to the issue board
- Active participation is highly encouraged
- Do NOT close your issue!

Host OS

- **Use Ubuntu 18.04 or 20.04.**
  - Arch Linux works, too
  - You must compile QEMU from source on Ubuntu 18.04
- Virtual machines should work, but they might be slow and difficult to configure
- We heard that WSL has dependency problems
- It is up to the students to setup their own project machine

Project Hardware

- We won’t use Raspberry Pi 3 this year
- We’ll use the QEMU full-system emulator throughout the course
- Just in case you want to run your kernel on a real device
  - Tizen OS makes it easy for us to flash devices and run the kernel
  - (Ideally) develop using QEMU and test on RPi3 (much faster since it’s real hardware)
  - https://docs.tizen.org/platform/developing/flashing-rpi/

Building and Booting the Kernel

- Build: `./build-rpi3.sh`
- Setup image files: `./setup-images.sh`
- Boot up QEMU: `./qemu.sh`
- Make sure you read and understand the scripts that we provide

Configuring the Coding Environment

- Dealing with kernel code only with vanilla vim is *extremely* painful
- Quality-of-life features for kernel development
  - jump to definition/declaration
  - find and list references
  - code completion as you type
- You can find guides for ctags or cscope everywhere
  - not much merit
- Language Servers - What we'll learn today!

Language Server Protocol (LSP)[1]

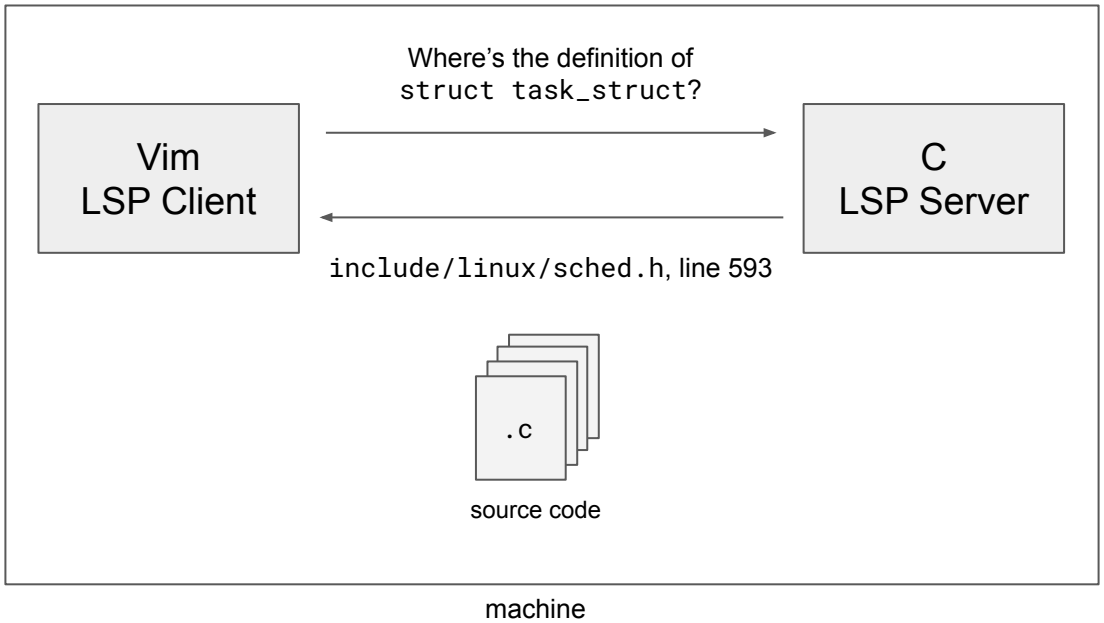
- Without LSP: each editor implements custom support for each language

	C/C++	Python	Rust
Vim	`ronakg/quickr-cscope`	`davidhalter/jedi-vim`	`rust-lang/rust.vim`
VSCode	`C/C++ plugin from marketplace`	`Python plugin from marketplace`	`Rust plugin from marketplace`
Sublime Text	`...`	`...`	`...`

1. Language Server Protocol, Microsoft. https://microsoft.github.io/language-server-protocol/

Language Server Protocol (LSP)

- LSP: The editor asks the language server about the source code



Language Server Protocol (LSP)

- With LSP: Editor and language decoupled via the server-client architecture!

	LSP Client Impl.
Vim	`prabirshrestha/vim-lsp`
Neovim	`built-in`
VSCode	`built-in`

	LSP Server Impl.
C/C++	`ccls, clangd`
Python	`pyls, pyls_ms`
Rust	`rls, rust-analyzer`

Setting up LSP for Kernel Development

- We'll use the `ccls` language server for C/C++/ObjC
  - https://github.com/MaskRay/ccls
- We'll use Neovim since it has an LSP client built-in
  - https://github.com/neovim/neovim
  - Version >= 0.5 (nightly) required for built-in LSP client

Setting up ccls for Linux Kernel Development

- Installation
  - ```
    # ccls and neovim
    apt-get update
    apt-get install curl rsync git ccls -y  # 18.04: snap install ccls --classic
    mkdir -p ~/.local
    curl -LO
    https://github.com/neovim/neovim/releases/download/nightly/nvim-linux64.tar.gz
    tar xzf nvim-linux64.tar.gz
    rsync -a nvim-linux64/* ~/.local
    export PATH="$HOME/.local/bin:$PATH"
    ```
  - ```
    # vim-plug for neovim plugin management
    curl -fLo ~/.local/share/nvim/site/autoload/plug.vim --create-dirs \
    https://raw.githubusercontent.com/junegunn/vim-plug/master/plug.vim
    ```

Setting up ccls for Linux Kernel Development

- Setup Neovim (`~/.config/nvim/init.vim`)
  - ```
    call plug#begin()
    Plug 'neovim/nvim-lspconfig'
    Plug 'nvim-lua/completion-nvim'
    Plug 'nvim-lua/popup.nvim'
    Plug 'nvim-lua/plenary.nvim'
    Plug 'nvim-telescope/telescope.nvim'
    call plug#end()

    set omnifunc=v:lua.vim.lsp.omnifunc
    set completeopt=menuone,noinsert,noselect
    set shortmess+=c
    set signcolumn=yes

    nnoremap gd <cmd>lua vim.lsp.buf.definition()<CR>
    nnoremap gr <cmd>Telescope lsp_references<CR>
    nnoremap gw <cmd>Telescope lsp_workspace_symbols<CR>
    imap <Tab> <Plug>(completion_smart_tab)
    imap <S-Tab> <Plug>(completion_smart_s_tab)
    ```
    ```

Setting up ccls for Linux Kernel Development

- Setup Neovim (`~/.config/nvim/init.vim`) - continued
  - ```
    lua << END
    local lspconfig = require'lspconfig'
    lspconfig.ccls.setup{
      on_attach = require'completion'.on_attach,
      init_options = {
        client = { snippetSupport = false }
      }
    }
    END
    ```
- Generate `compile_commands.json` (I already did this for you)
  - ```
    pip install compiledb
    compiledb make ARCH=arm64 CROSS_COMPILE=aarch64-linux-gnu- -j$(nproc)
    ```
- Index the entire kernel (optional)
  - ```
    ccls --index .
    ```
    ```

Use `printk` for kernel messaging

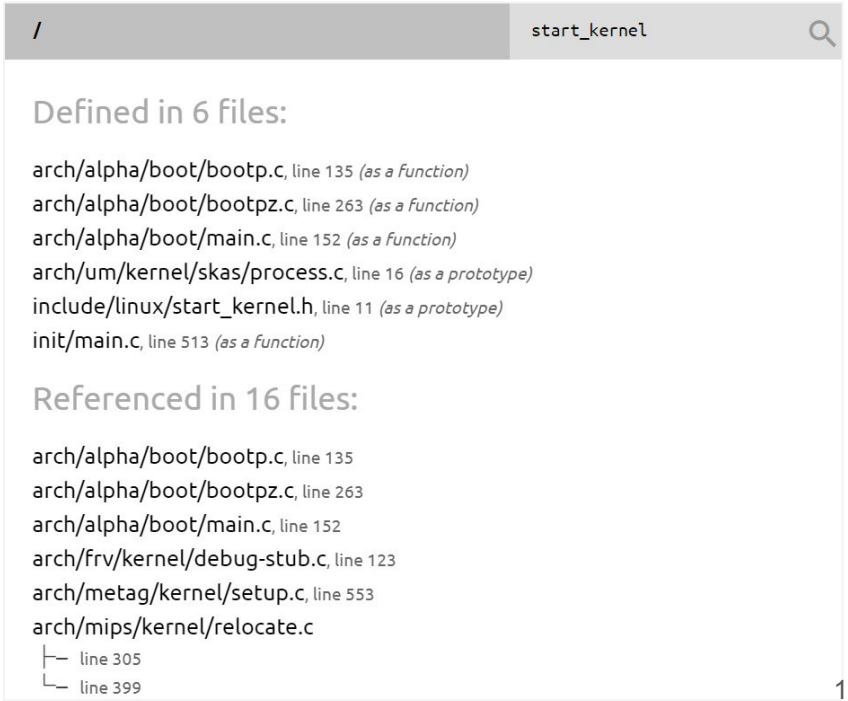
- `printf` does not work inside the linux kernel
- `printk` syntax
  - `printk(<loglevel> "message", <arguments>);`
  - No comma between log level and message!
- You can use `printk` instead for feeding kernel messages
  - Declared in `include/linux/kernel.h`
  - Mostly compatible with ANSI C `printf` function
  - Can give priority by concatenating pre-defined string constants
    - e.g. `printk(KERN_INFO "this syscall is called!\n");`
    - `KERN_INFO` is what you want for most cases
- You can read kernel messages using `dmesg`
  - `dmesg -w`: wait for new messages
  - `dmesg | tail`: only show last few messages

Use `printk` for kernel messaging

- You should be aware that...
  - The internal buffer size of `printk` is limited to 1kB
  - Too many kernel messages will make the system slow or even hang completely
  - Make sure to add a line separator at the end of each message
- Good read: https://www.kernel.bz/boardPost/118679/17
  - Log levels (e.g. `KERN_INFO`, `KERN_ALERT`), and how to adjust how much to print in system
- Use KERN_ALERT to print a message directly to the console
  - `printk(KERN_ALERT "hello world\n");`
- Where was this called?
  - `printk(KERN_INFO "%s: %s (%d)\n", __FILE__, __FUNCTION__, __LINE__);`

Linux Cross Reference (LXR)

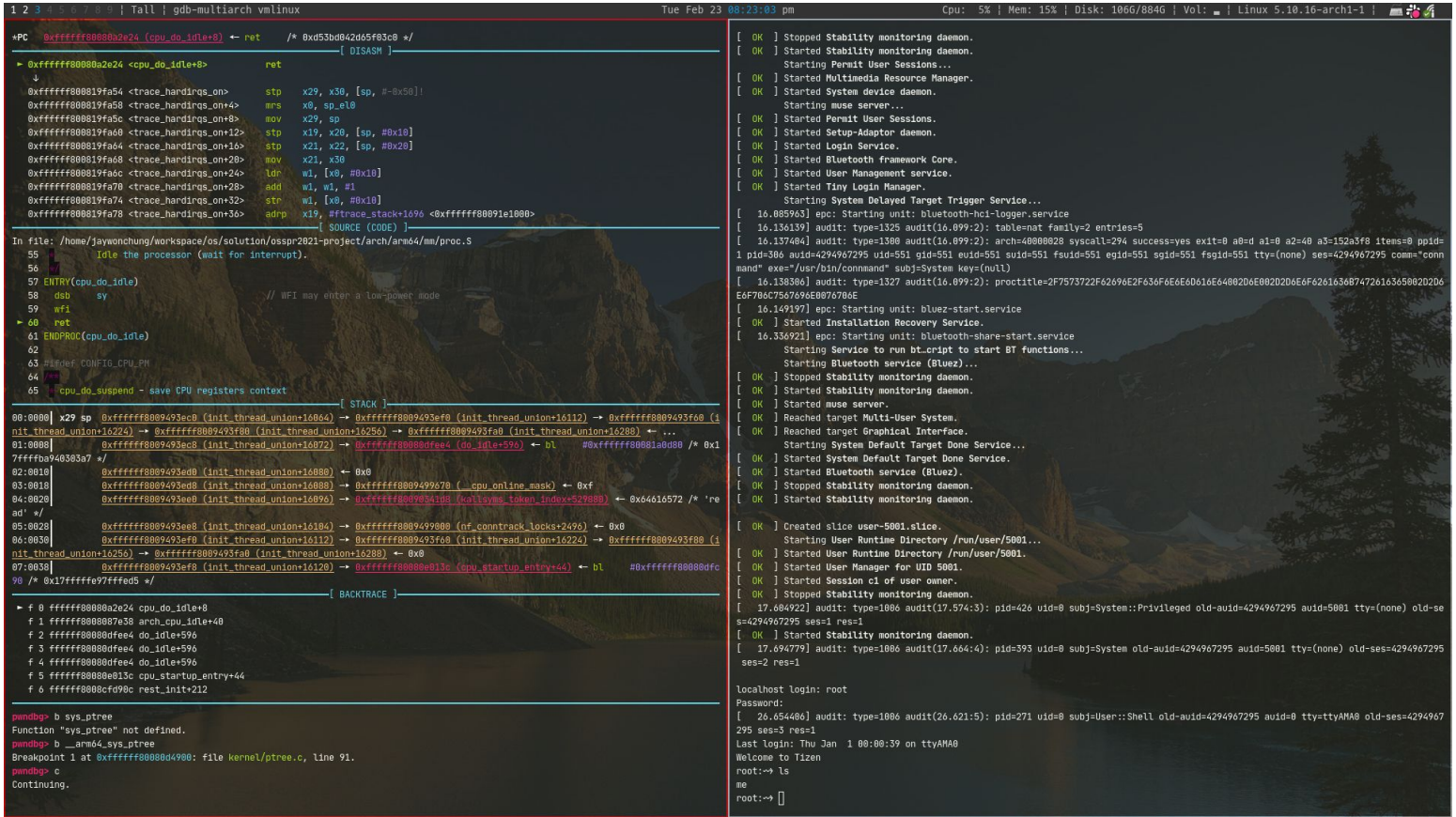
- https://elixir.bootlin.com/linux/v4.19.49/source
- Find functions/symbols in Linux kernel
- You won't need this if you setup `ccls`



Kernel Debugging with GDB

- We can attach GDB to the running kernel inside QEMU
  - `target remote :1234` will attach the GDB instance to the kernel
  - Made possible due to the flag `-gdb tcp:1234` given to QEMU
- Installation
  - `sudo apt-get install gdb-multiarch`
- Running GDB (after booting up QEMU)
  - `gdb-multiarch ./vmlinux`
  - Then, inside GDB run: `target remote :1234`

Bonus: gdb-pwndbg



Bonus: gdb-pwndbg

- *“pwndbg is a GDB plugin that makes debugging with GDB suck less”*
  - https://github.com/pwndbg/pwndbg
  - Another similar project: gdb-peda (https://github.com/longld/peda)
- Installation
  - ```
    git clone https://github.com/pwndbg/pwndbg
    cd pwndbg
    ./setup.sh
    ```
    ```

Important Directories

- `arch`
  - Architecture dependent (i.e. x86, arm, mips, …) parts of Linux
  - We're only interested in `arch/arm64`
- `kernel`
  - Common kernel code
- `net`
  - Common network related code
- `drivers`
  - Common driver code for Linux
- `fs`
  - Common file system code for Linux
- `include`
  - Common header files

Our Architecture

- AArch64 kernel
- ARMv7 userland
- This means there are compatibility issues!
  - Example: `sizeof(long)` is different

Kernel Configuration

- Config, then build
  - `make menuconfig`, `make xconfig`, `make gconfig`
  - Creates a file called `.config` in the kernel root
- Using distributed config files
  - Our version: `arch/arm64/configs/tizen_bcmrpi3_defconfig`
  - Applying it:
    - `make ARCH=arm64 CROSS_COMPILE=aarch64-linux-gnu- tizen_bcmrpi3_defconfig`

Things to Keep in Mind...

- No memory protection
  - Corruption in kernel memory space can make the whole machine crash!
- No floating point or MMX operation
  - Dealing with real numbers can be challenging and painful!
    - You unfortunately have to do it for some projects :(
- Rigid stack limit
  - Use extra caution when allocating local arrays or having recursive calls
  - `kmalloc` instead for huge arrays
- Your kernel code will run in a multi-core environment
  - Use proper synchronization mechanisms to avoid race conditions
  - Beware of deadlocks

Q & A

… one more thing!

- We prepared a thorough setup demo for you
  - Ubuntu 18.04: https://asciinema.org/a/jbnD7iyz34f1UoF9UaDYxc5T3
  - Ubuntu 20.04: https://asciinema.org/a/ruGNu9GWwvSuhaFf38vJr6CkQ
- From nothing to running a cross-compiled binary inside QEMU in 20 minutes
- You can copy text directly from the demo and paste it in your command line
- Hope this helps :)