Project2 实验报告

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# 1 实验概述

1.1 实验名称

UNIX Shell Programming & Linux Kernel Module for Task Information

1.2 实验内容

1. 实现简单的Unix shell，完成shell的一些基本的功能
2. 编写一个Linux Kernel Module，根据输入的pid输出对应进程的命令、pid和进程状态

# 2 实验环境

- Ubuntu 18.04.5 LTS
- Linux version 5.4.0-72-generic
- VirtualBox 6.1.18

# 3 实验过程与结果展示

3.1 UNIX Shell Programming

基本思路：使用一个while循环，不断读取用户的命令，并判断用户的命令是否是含有 `exit` 、 `!!` 、 `&` 、 `|` 、 `>` 、 `<` 这些特殊命令。先根据读取的特殊命令进行特殊化处理，再调用 `execvp()` 函数；

参数的声明和初始化

首先对各参数进行声明：

```
#define MAX_LINE 80 /* 80 chars per line, per command */
```

```

    pid_t pid;
    pid_t pipe_pid;
    int parent_wait;
    int history_exist = 0;
    int num_of_args;
    int history_num_of_args;
    char *args[MAX_LINE / 2 + 1]; /* command line (of 80) has max of 40 arguments */
    char history_args[MAX_LINE / 2 + 1][MAX_LINE / 2 + 1];
    char *pipe_args[MAX_LINE / 2 + 1];
    int should_run = 1;
    int input_red, output_red;
    int pipe_created;
    int num_of_pipe_args;
    int filedes[2];
    char input_file[MAX_LINE], output_file[MAX_LINE];
    char buffer[MAX_LINE];
```

在 while(should_run) 循环内，对各参数进行初始化：

```
        memset(buffer, 0, sizeof(buffer));
        input_red = output_red = 0;
        pipe_created = 0;
        num_of_args = 0;
        num_of_pipe_args = 0;
        parent_wait = 1;
        filedes[0] = filedes[1] = 0;
```

读取用户命令

读取用户的命令，并按空格分割，存入 args[] 数组：

```
        fgets(buffer, MAX_LINE, stdin);
        char *token;
        char delim[] = " \n\t";
        for (token = strtok(buffer, delim); token != NULL; token = strtok(NULL, delim))
        {
            args[num_of_args] = token;
            num_of_args++;
        }
        args[num_of_args] = NULL;
```

特殊命令判断

判断是否为 exit，并处理：

```c
        if (strcmp(args[0], "exit") == 0)
        {
            should_run = 0;
            continue;
        }
```

判断是否为 !!，是则用 history_args[] 数组替换当前的 args[] 数组，不是则将当前的 args[] 数组拷贝到 history_args[] 数组中去，以备下次使用:

```c
        if (strcmp(args[0], "!!") == 0)
        {
            if (!history_exist)
            {
                printf("No commands in history.\n");
            }
            else
            {
                for (int i = 0; i < history_num_of_args; ++i)
                {
                    args[i] = history_args[i];
                    printf("%s ", args[i]);
                }
                num_of_args = history_num_of_args;
                printf("\n");
            }
            if (strcmp(args[0], "!!") == 0)
                continue;
        }
        else
        {
            history_exist = 1;
            history_num_of_args = num_of_args;
            for (int i = 0; i < num_of_args; ++i)
            {
                strcpy(history_args[i], args[i]);
            }
        }
```

判断是否为 &，并标记：

```
        if (strcmp(args[num_of_args - 1], "&") == 0)
        {
            parent_wait = 0;
            num_of_args--;
            args[num_of_args] = NULL;
        }
```

判断`<`、`>`、`|`的使用，对是否涉及输入输出重定向和管道通信做好标记；若使用管道通讯，则做好参数的复制工作：

```
        for (int i = 0; i < num_of_args; ++i)
        {
            if (args[i] && strcmp(args[i], "<") == 0)
            {
                input_red = 1;
                strcpy(input_file, args[i + 1]);
                args[i] = args[i + 1] = NULL;
                num_of_args -= 2;
            }
            if (args[i] && strcmp(args[i], ">") == 0)
            {
                output_red = 1;
                strcpy(output_file, args[i + 1]);
                args[i] = args[i + 1] = NULL;
                num_of_args -= 2;
            }
            if (args[i] && strcmp(args[i], "|") == 0)
            {
                pipe_created = 1;
                args[i] = NULL;
                for (int j = i + 1; j < num_of_args; ++j)
                {
                    strcpy(pipe_args[num_of_pipe_args], args[j]);
                    args[j] = NULL;
                    num_of_pipe_args++;
                }
                pipe_args[num_of_pipe_args] = NULL;
                num_of_args -= num_of_pipe_args;
            }
        }
```

命令执行

首先执行 fork()，并对 fork() 失败的情况进行异常处理：

```
        pid = fork();
        if (pid < 0)
        {
            fprintf(stderr, "Fail to fork.\n");
            return -1;
        }
```

对于子进程，分别根据之前的标记处理输入输出重定向和管道通讯，再执行 execvp() 函数：

```
        else if (pid == 0)
        {
            if (input_red)
            {
                int fd;
                fd = open(input_file, O_RDONLY);
                dup2(fd, STDIN_FILENO);
            }
            if (output_red)
            {
                int fd;
                fd = open(output_file, O_CREAT | O_RDWR, S_IRWXU);
                dup2(fd, STDOUT_FILENO);
            }
            if (pipe_created)
            {
                if (pipe(filedes) == -1)
                {
                    fprintf(stderr, "Creating pipe failed.\n");
                    return 1;
                }
                else
                {
                    pipe_pid = fork();
                    if (pipe_pid < 0)
                    {
                        fprintf(stderr, "Fork failed when creating pipe.\n");
                        return 1;
                    }
                    else if (pipe_pid == 0)
                    {
                        close(filedes[0]);
                        dup2(filedes[1], STDOUT_FILENO);
                        execvp(args[0], args);
                        close(filedes[1]);
                        exit(0);
                    }
                    else
                    {
                        close(filedes[1]);
                        dup2(filedes[0], STDIN_FILENO);
                        execvp(pipe_args[0], pipe_args);
                        close(filedes[0]);
                        wait(NULL);
                    }
                }
            }
            else
            {
                execvp(args[0], args);
                wait(NULL);
            }
        }
```

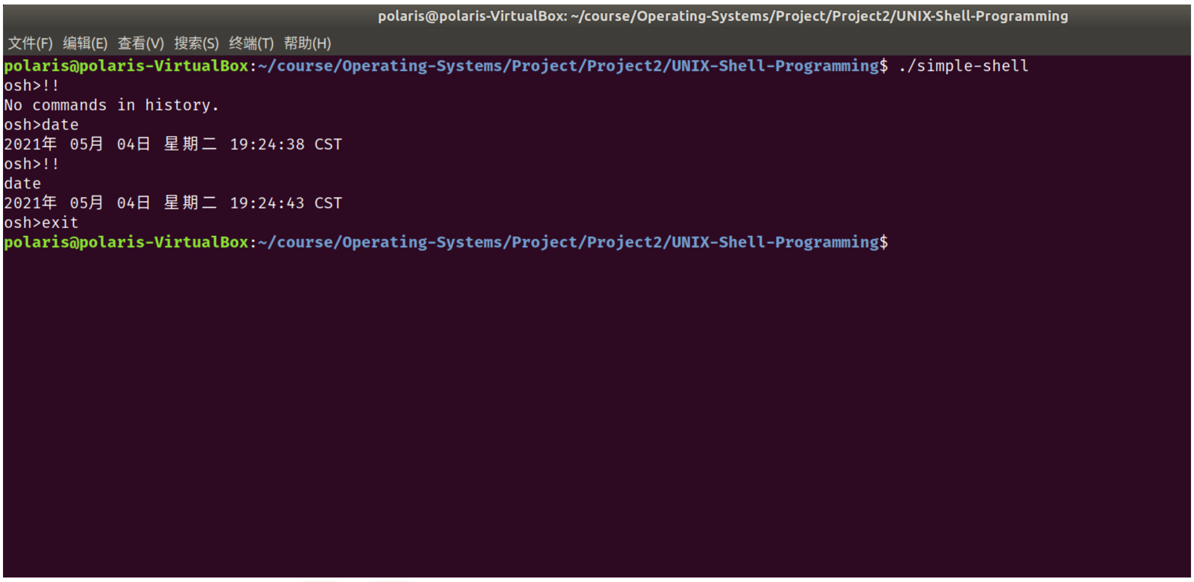
对于父进程，只需判断是否需要等待即可:

```
        else
        {
            if (parent_wait)
                wait(NULL);
        }
```

这样我们就完成了基本的UNIX Shell的编写。

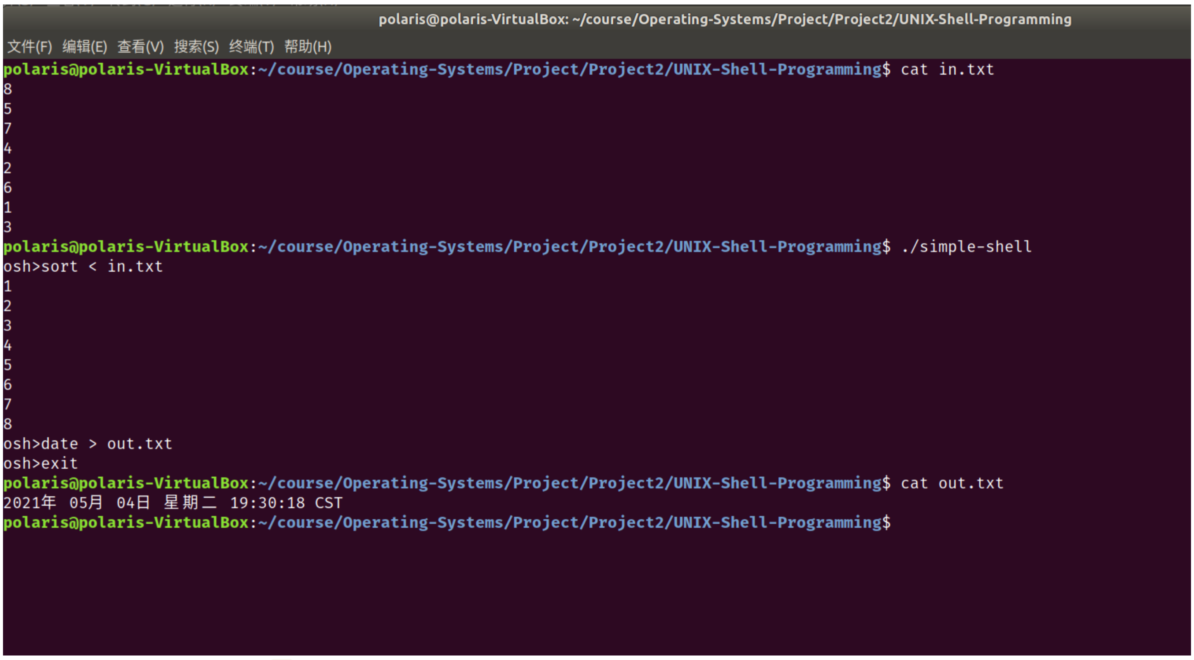
测试

检查历史记录功能(`!!`命令):


polaris@polaris-VirtualBox: ~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming
文件(F) 编辑(E) 查看(V) 搜索(S) 终端(T) 帮助(H)

```
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming$ ./simple-shell
osh>!!
No commands in history.
osh>date
2021年 05月 04日 星期二 19:24:38 CST
osh>!!
date
2021年 05月 04日 星期二 19:24:43 CST
osh>exit
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming$
```

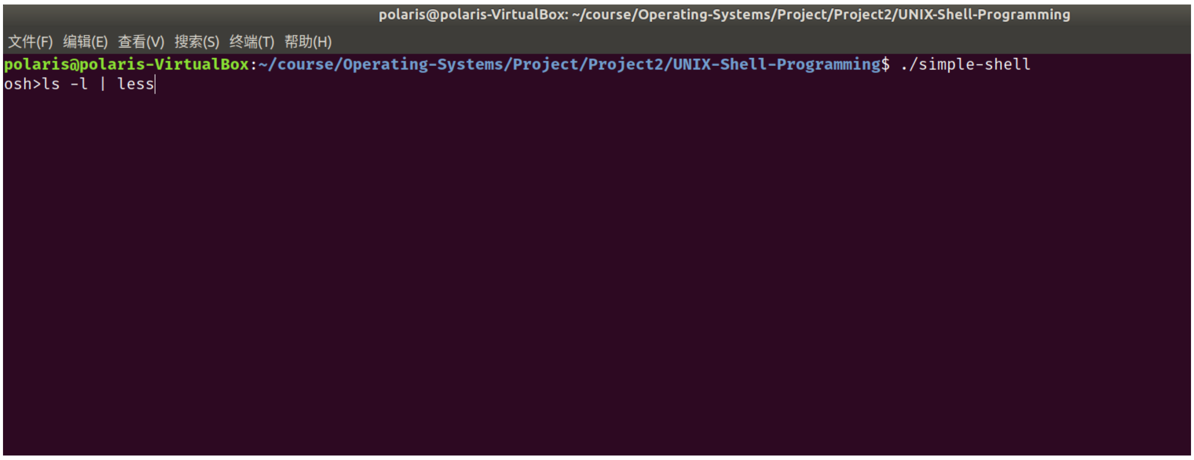
检查输入输出重定向(< 和 > 命令)：


polaris@polaris-VirtualBox: ~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming
文件(F) 编辑(E) 查看(V) 搜索(S) 终端(T) 帮助(H)

```
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming$ cat in.txt
8
5
7
4
2
6
1
3
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming$ ./simple-shell
osh>sort < in.txt
1
2
3
4
5
6
7
8
osh>date > out.txt
osh>exit
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming$ cat out.txt
2021年 05月 04日 星期二 19:30:18 CST
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming$
```

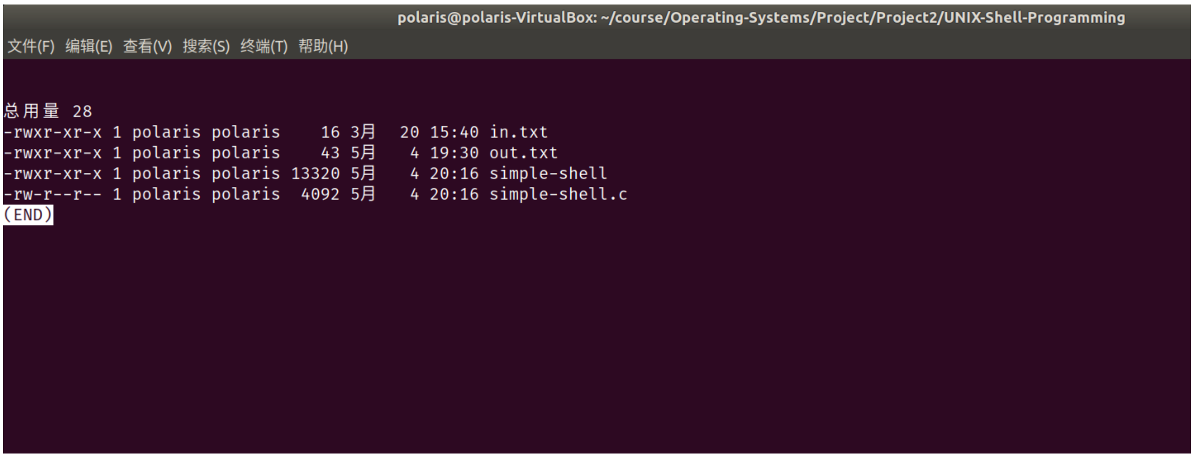
检查管道通讯功能(| 命令)：

输入命令：


polaris@polaris-VirtualBox: ~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming
文件(F) 编辑(E) 查看(V) 搜索(S) 终端(T) 帮助(H)

```
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming$ ./simple-shell
osh>ls -l | less
```

结果显示：


polaris@polaris-VirtualBox: ~/course/Operating-Systems/Project/Project2/UNIX-Shell-Programming
文件(F) 编辑(E) 查看(V) 搜索(S) 终端(T) 帮助(H)

```
总用量 28
-rwxr-xr-x 1 polaris polaris    16 3月   20 15:40 in.txt
-rwxr-xr-x 1 polaris polaris    43 5月    4 19:30 out.txt
-rwxr-xr-x 1 polaris polaris 13320 5月    4 20:16 simple-shell
-rw-r--r-- 1 polaris polaris  4092 5月    4 20:16 simple-shell.c
(END)
```

至此，全部功能测试完成。

3.2 Linux Kernel Module for Task Information

这部分我们要完成的是内核态代码，写法和Project1类似。

初始化的实现

首先声明变量pid：

```
static long l_pid;
```

proc_init() 和 proc_exit() 函数代码如下所示：

```
static int proc_init(void)
{
        proc_create(PROC_NAME, 0666, NULL, &proc_ops);

        printk(KERN_INFO "/proc/%s created\n", PROC_NAME);

        return 0;
}


static void proc_exit(void)
{
        remove_proc_entry(PROC_NAME, NULL);

        printk(KERN_INFO "/proc/%s removed\n", PROC_NAME);
}

```

读的实现

proc_read() 函数如下，根据pid读取相关信息并展示。若pid不存在，输出0；否则分别输出命令名称、pid的值和进程状态：

```
static ssize_t proc_read(struct file *file, char __user *usr_buf, size_t count, loff_t *pos)
{
    int rv = 0;
    char buffer[BUFFER_SIZE];
    static int completed = 0;
    struct task_struct *tsk = NULL;

    if (completed)
    {
        completed = 0;
        return 0;
    }

    tsk = pid_task(find_vpid(l_pid), PIDTYPE_PID);
    if (tsk == NULL)
        rv = sprintf(buffer, "%d\n", 0);
    else
        rv = sprintf(buffer, "command = [%s], pid = [%ld], state = [%ld]\n", tsk->comm, l_pid, tsk->state);
    completed = 1;

    // copies the contents of kernel buffer to userspace usr_buf
    if (copy_to_user(usr_buf, buffer, rv))
    {
        rv = -1;
    }

    return rv;
}

```

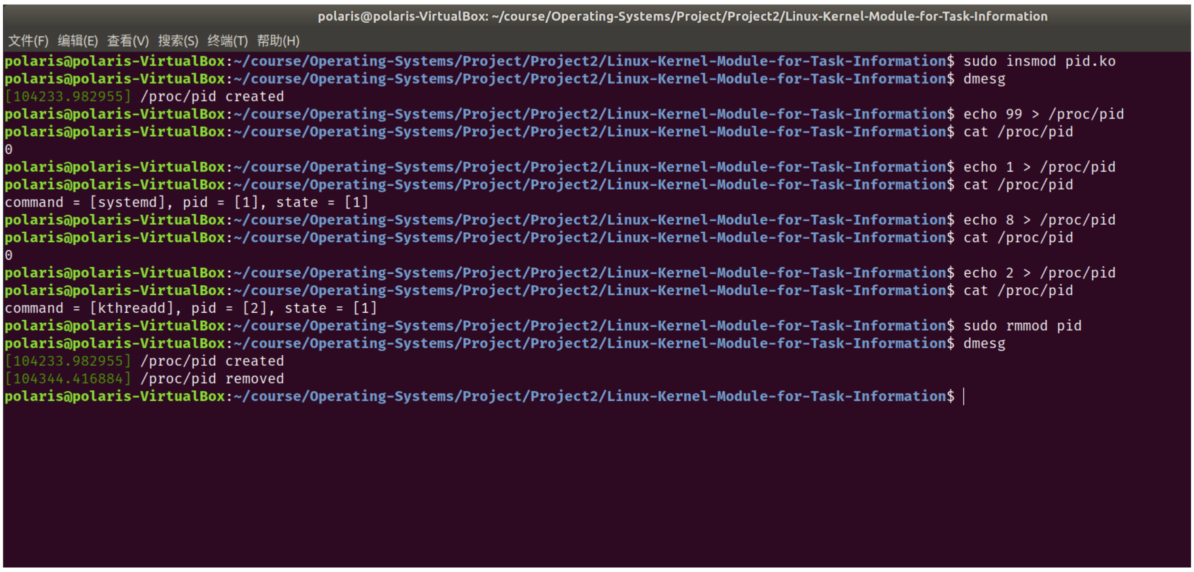
写的实现

proc_write() 函数如下，写入pid的值。按照提示先用 sscanf() 处理字符串，再调用 kstrtol() 函数。同时还要注意释放内存，避免内存泄漏：

```
static ssize_t proc_write(struct file *file, const char __user *usr_buf, size_t count, loff_t *pos)
{
```

```c
    char *k_mem;
    char buffer[BUFFER_SIZE];
    // allocate kernel memory
    k_mem = kmalloc(count, GFP_KERNEL);

    /* copies user space usr_buf to kernel buffer */
    if (copy_from_user(k_mem, usr_buf, count))
    {
        printk(KERN_INFO "Error copying from user\n");
        return -1;
    }

    sscanf(k_mem, "%s", buffer);
    kstrtol(buffer, 10, &l_pid);

    kfree(k_mem);

    return count;
}
```

测试


polaris@polaris-VirtualBox: ~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information
文件(F) 编辑(E) 查看(V) 搜索(S) 终端(T) 帮助(H)

```
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ sudo insmod pid.ko
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ dmesg
[104233.982955] /proc/pid created
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ echo 99 > /proc/pid
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ cat /proc/pid
0
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ echo 1 > /proc/pid
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ cat /proc/pid
command = [systemd], pid = [1], state = [1]
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ echo 8 > /proc/pid
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ cat /proc/pid
0
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ echo 2 > /proc/pid
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ cat /proc/pid
command = [kthreadd], pid = [2], state = [1]
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ sudo rmmod pid
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ dmesg
[104233.982955] /proc/pid created
[104344.416884] /proc/pid removed
polaris@polaris-VirtualBox:~/course/Operating-Systems/Project/Project2/Linux-Kernel-Module-for-Task-Information$ 
```

# 4 实验总结

1. UNIX Shell Programming 较为复杂，在重定向与管道通讯功能上花费了大量时间调试
2. Linux Kernel Module for Task Information 完成的较为顺利

# 5 实验参考资料

- 实验参考书籍：Operating System Concept， 10^{th} edition
- 实验源代码网址： https://github.com/greggagne/osc10e