Implementation designs for fine-grained scheduling in kernel space

Sreeram Sadasivam
M.Sc Distributed Software Systems
TU Darmstadt, Germany
sreeram.sadasivam@stud.tu-darmstadt.de

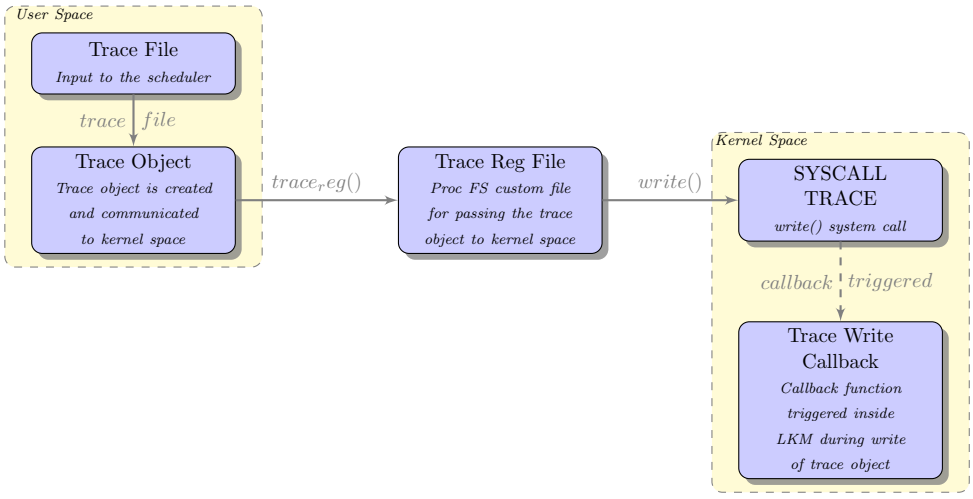
Design with no checking in user space

In the following designs, we address the use of check permission of memory access method entirely in Kernel space.

Design with no additional scheduler thread

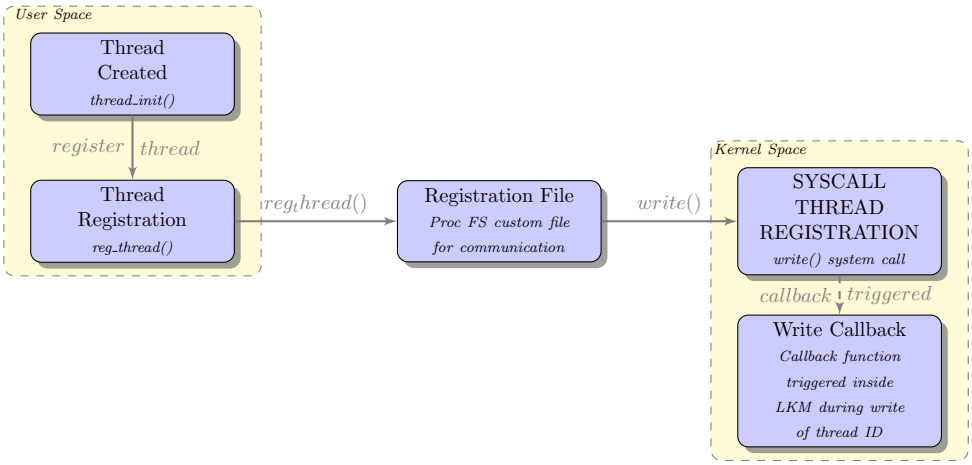
The design described in this section addresses the use of no additional scheduler thread.

Trace Registration



The trace file is passed on as an input for the scheduler. In the above flow diagram, the trace file is read by the main user thread at the start of its execution. It parses the file, creates and passes the trace object to the kernel space as string via a custom file created in the proc file system.

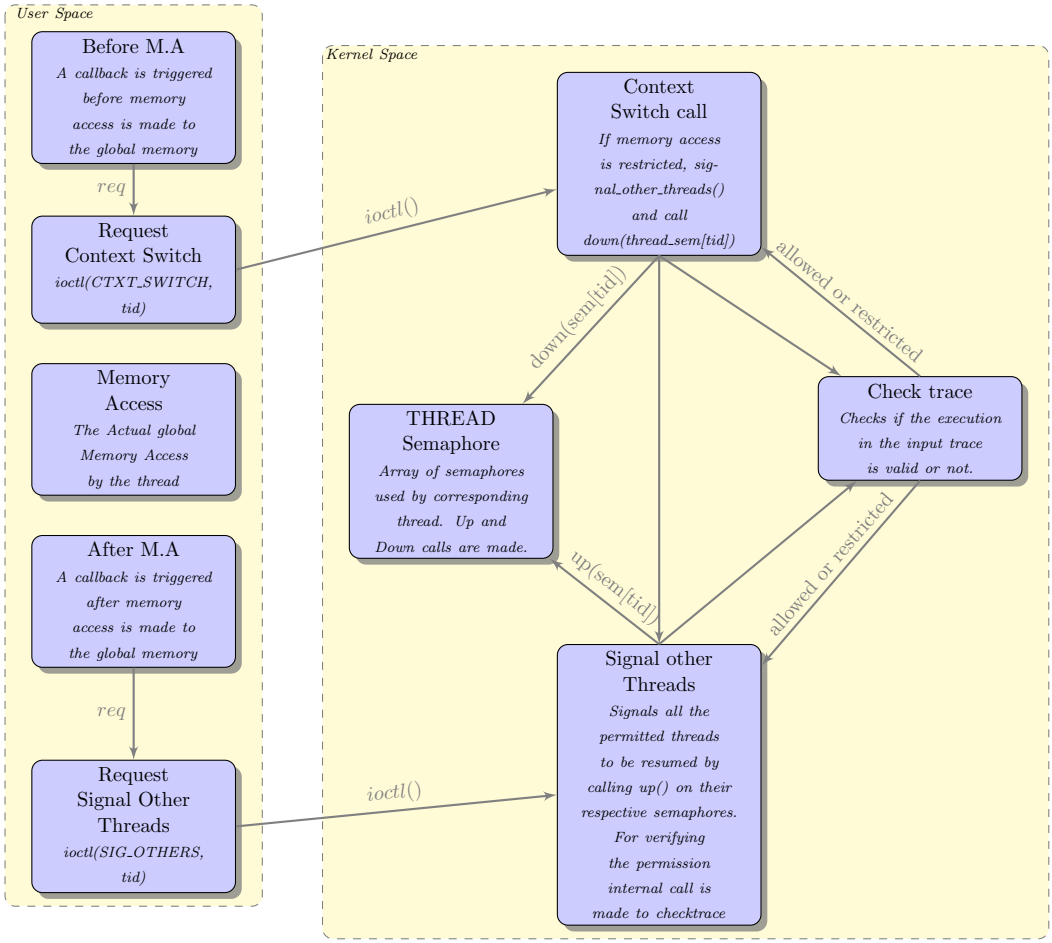
Thread Registration



In the above picture, the registration block happens when a user thread is created. The registration happens via a custom proc file system.

Memory Assessment

Prior to any global memory access, the given design would invoke *IOCTL* command with *CTXT_SWITCH* and thread id of the thread which addressed the memory event as its parameters.


User Space
Before M.A
A callback is triggered before memory access is made to the global memory
req
Request Context Switch
ioctl(CTXT_SWITCH, tid)
Memory Access
The Actual global Memory Access by the thread
After M.A
A callback is triggered after memory access is made to the global memory
req
Request Signal Other Threads
ioctl(SIG_OTHERS, tid)
ioctl()
Kernel Space
Context Switch call
If memory access is restricted, signal_other_threads() and call down(thread_sem[tid])
down(sem[tid])
allowed or restricted
THREAD Semaphore
Array of semaphores used by corresponding thread. Up and Down calls are made.
Check trace
Checks if the execution in the input trace is valid or not.
up(sem[tid])
allowed or restricted
Signal other Threads
Signals all the permitted threads to be resumed by calling up() on their respective semaphores. For verifying the permission internal call is made to checktrace
ioctl()

Pseudo Implementation

Data Types Section used by user space and kernel space

```
enum IOCTL_CMDS  {
        GET_CURR_CLK = 1,
        CTXT_SWITCH = 2,
        SIGNAL_OTHER_THREADS = 3,
        RESET_CLK = 4,
        SET_MY_CLK = 5
}
enum  mem_access{
        e_ma_restricted = 0,
        e_ma_allowed    = 1
}
struct vec_clk {
        int clocks[THREAD_COUNT],
}
struct trace_node {
        thread_id_t tid;
        vec_clk clk;
        int valid;
}

struct trace {
        trace_nodes trace_obj_arr[TRACE_LIMIT];
}
```

Check Permission for memory access

```
mem_access check_mem_acc_perm(vec_clk* curr_vec_clk, vec_clk*
    trace_inst, thread_id_t tid) {

   int i;
   if(trace_inst->clocks[tid-1] == curr_vec_clk->clocks[tid-1])
   {
     for i in range(0, THREAD_COUNT)
     {
        if(i!=(tid-1))
        {
         if(trace_inst->clocks[i] <= curr_vec_clk->clocks[i])
         {
                continue;
         }
         else
         {
                return e_ma_restricted;
```

```
          }
        }
      }
    }
    else if(trace_inst->clocks[tid-1] < curr_vec_clk->clocks[tid
        -1])
    {
          return e_ma_restricted;
    }
    return e_ma_allowed;
}
```

User Space Implementation

```
BeforeMA() {
        ioctl(CTXT_SWITCH, thread_id);
}

AfterMA() {
        ioctl(SIGNAL_OTHER_THREADS, thread_id);
}

reset_clock() {
        ioctl(RESET_CLK);
}

//This method is defined by the thread library which is used by
     the user
thread_create_impl(thread t) {
        t ->thread_init(tid);
        t ->thread_exec(thread_function);
}

thread_function() {
        reg_thread();   //This method increments a threadcount
            variable in kernel space.
        ....
        Before_MA();    //function triggered before accessing
            the global memory
        Mem_Access();   //global memory access permitted for
            the thread
        AfterMA();              //function triggered after
            accessing the global memory
        ....
        thread_exit()
}

trace_reg() {
```

```
        fd = open("/proc/trace_reg",O_RDWR);
        close(fd);
}

main() {
        trace_reg()
        thread t = thread_create(tid, thread_function);
        //thread_create_impl() is called internally
        .....
        t.join();
        return EXIT_SUCCESS;
}
```

Kernel Space - General module definitions

```
semaphore threads_sems[THREAD_COUNT];
int wait_queue[THREAD_COUNT];
trace trace_obj;
vec_clk curr_clk;
int thread_count = 0;

module_init() {
        for i in range(0,THREAD_COUNT) {
                init(threads_sem[i] = 0;
                wait_queue[i] = 0;
                curr_clk[i] = 0;
        }
        alloc_ioctl_device();//method used to allocate ioctl
            device.
}

trace_reg_callback() {
        //The method parses the trace which is passed as string
             and stores in trace_obj
}

reg_thread_callback() {
        thread_count++;
}
```

Kernel Space - IOCTL

```
/* This method is triggered whenever ioctl commands are issued
    from the user space */
ioctl_access(IOCTL_CMDS cmd) {
        switch(cmd) {
                case CTXT_SWITCH:
                        req_ctxt_switch(thread_id);//requests
                            for context switch
                        break;
                case SIGNAL_OTHER-THREADS:
                        Increment_curr_clk(thread_id); //this
                            will increment the current clk for
                            the given thread id.
                        signal_all_other_threads(thread_id);
                        break;
                case GET_CURR_CLK:
                        get_curr_clk();//returns the current
                            vector clock.
                        break;
                case RESET_CLK:
                        reset_clk(); //reset the current vector
                             clock to zero.
                        break:
                case SET_CURR_CLK:
                        set_curr_clk(clk);//sets the current
                            vector clock with the clk received.
        }
}

//Methods of interest with respect to the ioctl cmds
mem_access check_mem_access_with_trace(thread_id_t tid) {
        ...
        //method internally calls check_mem_acc_perm() with
            current clock time and uses the first valid
            instance vector clock registered for a given thread
             in the trace array.

        //returns e_ma_allowed e_ma_restricted based on the
            check_mem_acc_perm()
}

void ctxt_switch_thread(thread_id_t tid) {
        down(threads_sem[tid-1]); //perform semaphore down
            operation respective semaphore.
        /**if the value is already 0 when performing the down,
            the thread waits until the value is positive.*/
}
```

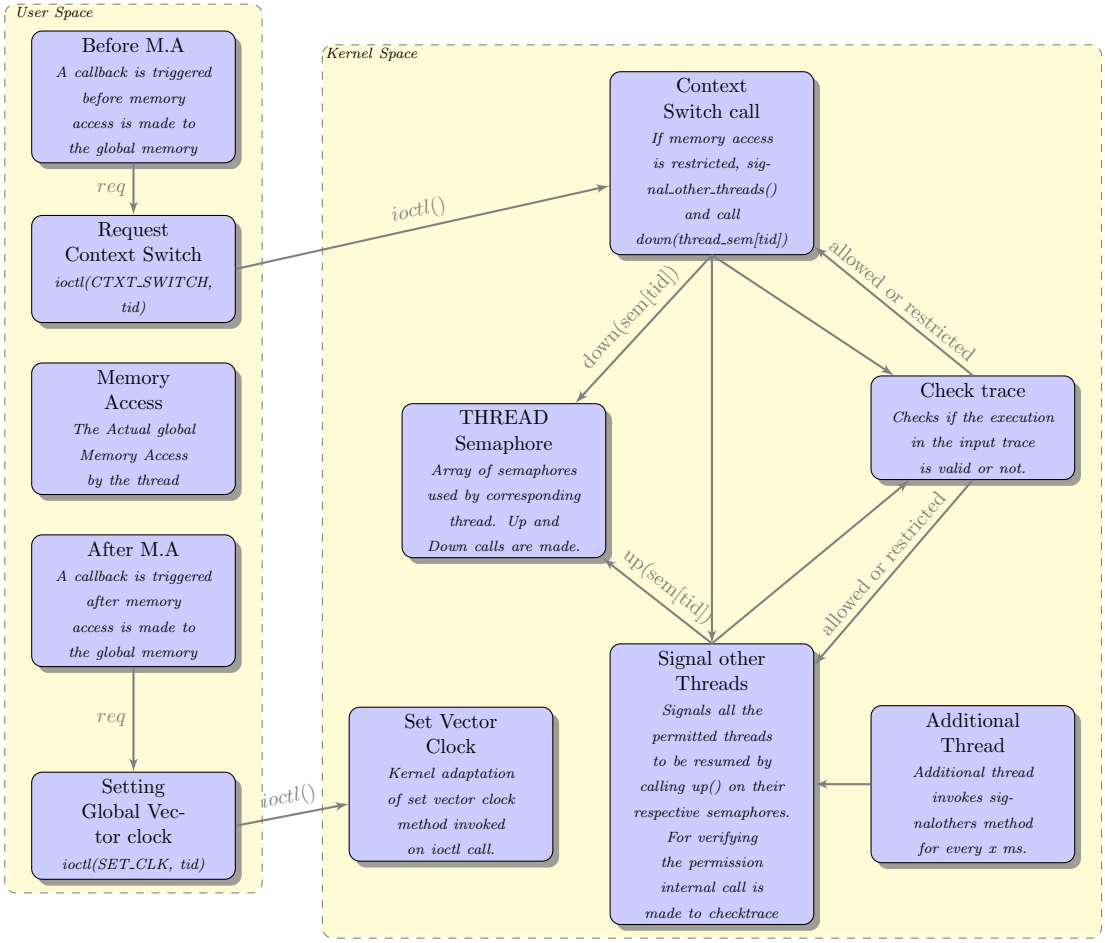
```
void signal_all_other_threads(thread_id_t tid) {
        //critical section for wait queue
        for i in(0,THREAD_COUNT) {
                if(i!=(tid-1)) {
                        if(check_mem_access_with_trace(i+1) ==
                            e_ma_allowed) {
                                /**Performs up operation on the
                                     respective thread
                                    semaphore.*/
                                up(threads_sem[i]);
                                wait_queue[i]=0;
                        }
                }
        }

        //critical section ends.
}

void req_ctxt_switch(thread_id_t tid) {
                if(check_mem_access_with_trace(tid) ==
                    e_ma_restricted) {

                signal_all_other_threads(tid);

                //critical section for waitqueue
                wait_queue[tid-1] = 1; //sets the thread inline
                     for waiting
                //critical section ends.

                ctxt_switch_thread(tid);

        }
}
```

Design with an additional scheduler thread

In this design we create an additional scheduler thread primarily addressing the signaling mechanism pertained in the previous design. By having an additional scheduler thread, we move the entire signaling system to the scheduler thread. Thus, reducing the execution overhead encountered in the user space thread for signaling other threads.

The major change from the previous design apart from additional thread is in the memory assessment block.

Memory assessment block



Pseudo Implementation

The major changes are in kernel space code. However, there are minor variations in the AfterMA() in user space.

User Space Implementation

```
//Rest of the code remains the same

AfterMA() {
        ioctl(SET_MY_CLK, thread_id);
}

//Rest of the code remains the same
```

Kernel Space - General module definitions

```
//code remains the same

void signal_permitted_threads() {
        //critical section for wait queue
        for i in(0,THREAD_COUNT) {
                if(wait_queue[i] == 1) {
                        if(check_mem_access_with_trace(i+1) ==
                            e_ma_allowed) {
                                /**Performs up operation on the
                                     respective thread
                                    semaphore.*/
                                up(threads_sem[i]);
                                wait_queue[i]=0;
                        }
                }
        }

        //critical section ends.
}

module_init() {
        //code remains the same

        kernel_thread tk = create_kernel_thread(
            signal_permitted_threads)
        tk->setTimerCallForEvery(x) //this method will make
            call to signal permitted threads for every x ms.
}

//code remains the same
```

Variant in blocking implementation

In the previous designs, the blocking was done using semaphores. In the variant design, we use the combination of *schedule()* and *wake_up_process()* functions provided by the linux scheduler APIs. The kernel level tasks associated for the provided user level threads are moved from running queue to wait queue by initially setting the task status as *TASK_INTERRUPTIBLE* and yielding the processor by invoking *schedule()*. The task added in wait queue is later resumed, when *wake_up_process(sleeping_task)* is invoked by another task. On calling the *wake_up_process(sleeping_task)*, the task status for *sleeping_task* is set as *TASK_RUNNING*. It would be pushed to run queue and executed in future by the operating system scheduler on the basis of priority of tasks in run queue.

Design with checking in user space

In the following designs, we address the use of check permission of memory access method both in User Space and Kernel space.

Design with no additional scheduler thread

//more to come

Design with an additional scheduler thread

//more to come