Guide to the MIKONOS Operating System Project

Version 0.4

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(based on the “Guide to the AMIKaya Operating System Project” by Enrico Cataldi)

June 02, 2008

1. Introduction

The MIKONOS Operating System (OS) described below is inspired to the previous experiences of Kaya OS[1], AMIKE OS[2] and AMIKaya OS[8] projects. All of them are descending (not directly) from the THE OS[3] outlined by E. Dijkstra. In his papers he described an OS divided into six layers. Each layer *i* provides an abstraction layer to the *i+1* layer. Kaya derives from the past experiences of the TINA OS and MPS [6], a rework of the HOCA OS and CHIP [4,5]. The AMIKE and AMIKaya specifications introduced microkernel operating systems, based on the message passing facility. MIKONOS will be yet another microkernel operating system, based this time on an unusual variant of message passing inspired by Toth's primitives and the Qnix OS.

The OS we are going to describe is not complete as Dijkstra's one.

- Level 0: µMPS hardware, described in the µMPS Principles of Operation)
- Level 1: services provided in ROM (fully described in µMPS Principles of Operation):
  - processor state save/load
  - ROM-TLB-Refill handler
  - LDST, FORK, PANIC, HALT
- Level 2: the Queues Managers (Phase 1A – described in Chapter 2). Based on the key operating system concept that active entities at one layer are just data structures at lower layers, this layer support management of queues of ThreadBLK structures
- Level 3: the Nucleus (Phases 1B and 2 – described in Chapters 3 and 4). This level implements the thread scheduling, interrupt handling, message passing, deadlock detection, System Service Interface and its services. The boostrap phase (phase 1B) will be implemented and tested before the rest of the nucleus.

The AMIKaya project actually provides a source code that implements all these levels. Further levels could be developed:

- Level 4: the Support Level. The 3rd level is extended to a system that can support multiple user-level cooperating threads that can request I/O and which run on their own virtual address space. Furthermore, this level adds user-level synchronization, message passing and a thread sleep/delay facility
- Level 5: the Network Level. This level implements a minimal TCP/IP stack to get provide access with existing virtual Ethernet devices to a real network, through VDE[7]
- Level 6: the File System. This level implements the abstraction of a flat file system with primitives to create, rename, delete, open, close and modify files
- Level 7: the Interactive Shell

2. Phase 1A – Level 2: The Queue Managers

Level 2 of MIKONOS instantiates the key operating system concept that active entities at one layer are just data structures at lower layers. In this case, the active entities at a higher level are threads, and what represent them at this level are thread control blocks (ThreadBLKs). Each thread control block is identified by a thread identifier (TID) chosen from a set of 255 identifiers. An additional data structure needs to be implemented to map TIDs to pointers to ThreadBLKs.

```
typedef unsigned int status_t; /* thread status */

typedef unsigned char tid_t;   /* thread identifier */

typedef struct tcb_t {         /* thread control block */

        tid_t           tid;            /* thread identifier */

        struct status_t status;         /* thread's status */

        struct state_t proc_state;      /* processor state */

        struct tcb_t    *t_next,        /* pointer to next entry in the thread queue */

                        *inbox;         /* threads waiting to send a message to this thread */

        /* other fields will be added during phase2 development */

} tcb_t;
```

The Thread Queue Manager will implement functions to provide these services:

- Allocation/de-allocation of single ThreadBLK elements
- Resolution of TIDs to pointers to ThreadBLK elements
- Maintenance of ThreadBLK queues

2.1 ThreadBLK Allocation/De-allocation

One may assume that MIKONOS supports no more than MAXTHREADS concurrent threads; this parameters should be set to 32 (const.h). Thus, this level needs a number of MAXTHREADS ThreadBLKs to allocate from and de-allocate to. Assuming that there is a set of MAXTHREADS ThreadBLKs, one word in memory can act as a bitmap to identify the unused blocks. Entity allocation and de-allocation will be provided by these procedures, that can be directly accessed only from the functions described in Sect. 2.2.

```
void initTcbs(void);
```

Initializes the bitmap. This method will be called only from initTidTable.

```
void freeTcb(tcb_t *t);
```

Un-marks the element pointed by t in the bitmap. This function will be called only from killTcb.

```
tcb_t * allocTcb(void);
```

Returns NULL if all blocks are marked as used in the bitmap. Otherwise it marks an unmarked block and returns a pointer to it. All fields of the returned ThreadBLK (including the tid field) must be reset to default values (I.e. NULL and/or 0). ThreadBLKs get reused, so it is important that no previous value remains in a ThreadBLK when it gets reallocated. This function will be called only from newTcb.

Since MIKONOS will run without any dynamic memory allocation/deallocation facility, runtime resource request is not allowed. The best way to solve this problem is to have a initial allocation of all the required space, whose lifetime would be exactly the same of the kernel's one. This can be done during initialization of data structures, using a statical allocation of one array for the MAXTHREADS ThreadBLKs.

2.2 Resolution of TIDs to pointers to ThreadBLK elements.

Since MIKONOS is based on message passing, it is important to avoid immediate re-assignment of the TID of a terminated thread to a new thread. Otherwise, it is possible that a message will be erroneously delivered to a thread that was randomly assigned the TID of the deceased recipient. TIDs will be 8-bit integer values. 255 is not a valid TID. The next TID to be assigned is the successor (modulo 254) of the previously assigned TID, unless the TID is still in use. Several data structures (e.g. associative arrays, hashtables) can be used to implement the map from TIDs to ThreadBLK pointers.

```
void initTidTable(void);
```

Initializes the thread control block bitmap (by calling initTcbs) and the data structure used to map TIDs to ThreadBLK pointers. This method will be called only once.

```
tid_t newTcb(void);
```

Allocates a new ThreadBLK by calling allocTcb. If allocTcb fails, newTcb returns 255. Otherwise it returns the TID of the thread whose ThreadBLK has just been allocated. The rule to choose the TID is the one described above. The tid field of the ThreadBLK is set by the function to the chosen value.

```
void killTcb(tid_t tid);
```

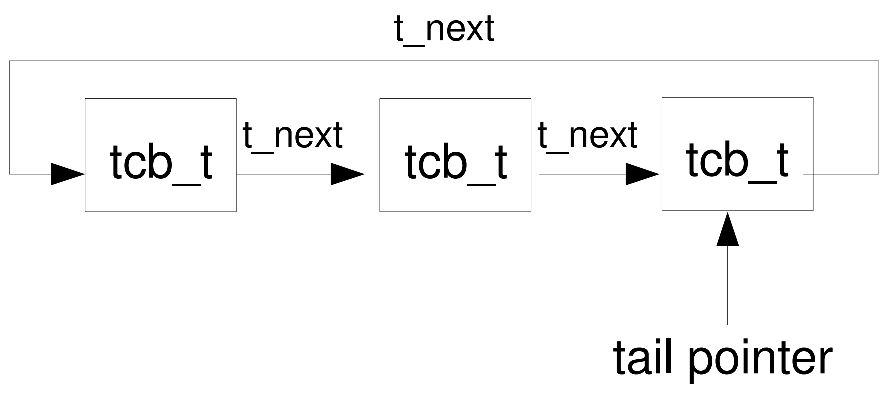
De-allocates (by calling freeTcb) the ThreadBLK identified by tid. The TID tid can now be reused.

```
tcb_t* resolveTid(tid_t  tid);
```

Returns the pointer to the ThreadBLK identified by tid.

2.3 Thread Queue Maintenance

The functions below do not manipulate a particular thread queue or set of queues. Instead they are generic queue manipulation methods; one of the parameters is a pointer to the thread queue upon which the indicated operation is to be performed. Queues to be manipulated are circular, singly linked and tail pointed lists. One may optionally make them doubly linked for greater efficiency.



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To provide support to thread queues, the following externally visible functions should be implemented:

```
tcb_t * mkEmptyThreadQ(void);
```

Used to initialize a variable to be tail pointer to a thread queue; returns a pointer to the tail of an empty thread queue, i.e. NULL

```
int emptyThreadQ(tcb_t *tp);
```

Returns TRUE if the queue whose tail is pointed to by tp is empty, FALSE otherwise.

```
void insertBackThreadQ(tcb_t **tp, tcb_t *t_ptr);
```

Insert the ThreadBLK pointed to by t_ptr at the back of the thread queue whose tail-pointer is pointed to by tp; note the double indirection through tp to allow for the possible updating of the tail pointer as well

```
void insertFrontThreadQ(tcb_t **tp,tcb_t *t_ptr);
```

Insert the ThreadBLK pointed to by t_ptr at the front of the thread queue whose tail-pointer is pointed to by tp; note the double indirection through tp to allow for the possible updating of the tail pointer as well

```
tcb_t * removeThreadQ(tcb_t **tp);
```

Remove the first (i.e. head) element from the thread queue whose tail-pointer is pointed to by tp. Return NULL if the thread queue was initially empty; otherwise return the pointer to the removed element. Update the thread queue's tail pointer if necessary

```
tcb_t * outThreadQ(tcb_t **tp, tcb_t *t_ptr);
```

Remove the ThreadBLK pointed to by t_ptr from the queue whose tail-pointer is pointed to by tp. Update the queue's tail pointer if necessary. If the desired entry is not in the queue (an error condition), return NULL; otherwise, return t_ptr. Note: t_ptr can point to any element of the queue

```
tcb_t * headThreadQ(tcb_t *tp);
```

Return a pointer to the first ThreadBLK from the queue whose tail is pointed to by tp. Do not remove the ThreadBLK from the queue. Return NULL if the queue is empty

2.5 Nuts and Bolts

There isn't just one way to implement the functionality of this level. Regarding optimization, efficiency may be improved by introducing doubly-linked queues, adding eg. t_prev to ThreadBLKs. Each module should export its public interface using a .e file. As with any non-trivial system, you are strongly encouraged to use the make program to maintain your code. Initial structure initialization can be accomplished by statical allocation of three data structure, an array for ThreadBLKs, a one word bitmap for ThreadBLK allocation and an array or an hashtable to map TIDs to ThreadBLK pointers. Eg.:

HIDDEN tcb_t tcbTable[MAXTHREADS];

2.5 Testing

There is a provided test file, p1test.c that will "exercise" your code. You CANNOT modify p1test.c. You should compile the source files separately using the commands eg.:

```
mipsel-linux-gcc -ansi -pedantic -Wall -c tcb.c
mipsel-linux-gcc -ansi -pedantic -Wall -c tid.c
mipsel-linux-gcc -ansi -pedantic -Wall -c p1test.c
```

The object files should then be linked together using the command:

```
mipsel-linux-ld -T $SUPDIR/elf32ltsmip.h.umpscore.x $SUPDIR/crtso.o $SUPDIR/libumps.o
tcb.o tid.o p1test.o -o kernel
```

Where $SUPDIR must be replaced with the path to the µMPS support directory and elf32ltsmip.h.umpscore.x, crtso.o and libumps.o are part of the µMPS distribution.

If one is working on a big-endian machine one should modify the above commands appropriately; substitute mips- for mipsel- and elf32btsmip.h.umpscore.x for elf32ltsmip.h.umpscore.x.

The linker produces a file in the ELF object file format which needs to be converted prior to its use with µMPS. This is done with the command:

```
umps-elf2umps -k kernel
```

which produces the file kernel.core.umps

Finally, your code can be tested by launching µMPS. Entering:

```
umps
```

without any parameters loads the file kernel.core.umps by default.

Hopefully the above will illustrate the benefits for using a Makefile to automate the compiling, linking, and converting of a collection of source files into a µMPS executable file.

The test program reports on its progress by writing messages to TERMINAL0.

These messages are also added to one of two memory buffers; errbuf for error messages and okbuf for all other messages. At the conclusion of the test program, either successful or unsuccessful, µMPS will display a final message and then enter an infinite loop.

The final message will either be SYSTEM HALTED for successful termination, or KERNEL PANIC for unsuccessful termination.

3. Phase 1B – Level 3: Bootstrap

The bootstrap code is still part of the Nucleus of MIKONOS. It is the code that is called by the ROM code responsible for initialization of the machine. Its role consists in:

1. Filling up the tables used by the ROM-Excpt handler (in Level 1) to handle exceptions. In particular, the bootstrap phase must provide the exception handler for: Program Traps (PgmTrap), SYSCALL/Breakpoint (SYS/Bp), TLB Management (TLB), and Interrupts (Ints). More details on the initialization of exception handling is given in Sect. 3.1.

   The final code for the exception handlers will be developed in Phase 2. To test the bootstrap phase during Phase 1B, the exception handler code will be provided in p1test.c.

2. Initializing the data structures used by the scheduler and the other parts of the Nucleus. In particular, the bootstrap code must invoke initTidTable(). During Phase 2, this code will be extended to fill the ready queue of the scheduler with the threads initially alive at the end of the bootstrap phase.

3. Calling the scheduler (I.e. invoking schedule()). To test Phase 1B, a fake schedule() function is provided by test1.c. The fake function simply exercises the bootstrap code by generating exceptions and veryfing that the right exception handlers are called.

Once the scheduler has been invoked, the role of the bootstrap code is finished. In particular, the schedule() function will never return. From now on, the only way to re-enter the Nucleus is through an exception handler.

3.1 Initialization of the New Areas in the ROM Reserved Frame

Every program needs an entry point (i.e. main()), even MIKONOS. The entry point for MIKONOS performs the nucleus initialization, which includes the population of the four New Areas in the ROM Reserved Frame. For each New processor state, you need to:

1. Set the PC to the address of your nucleus function that is to handle exceptions of that type
2. Set the $SP to RAMTOP. Each exception handler will use the last frame of RAM for its stack.
3. Set the Status register to mask all interrupts, turn virtual memory off, and be in kernelmode.

At boot/reset time the nucleus is loaded into RAM beginning with the second frame of RAM; 0x2000.1000. The first frame of RAM is the ROM Reserved Frame, as defined in Section 3.2.2pops. Furthermore, the processor will be kernel-mode with virtual memory disabled and all interrupts masked. The PC is assigned 0x2000.1000 and the $SP, which was initially set to RAMTOP at boot-time, will now be some value less than RAMTOP due to the activation record for main() that now sits on the stack.

4. Phase 2 – Level 3: The Rest of the Nucleus

Level 3 of MIKONOS builds on previous levels in two key ways: Building on the exception handling facility of Level 1 (the ROM-Excpt handler). Provide the exception handlers that the ROM-Excpt handler "passes" exception handling "up" to. There will be one exception handler for each type of exception: Program Traps (PgmTrap), SYSCALL/Breakpoint (SYS/Bp), TLB Management (TLB), and Interrupts (Ints). Using the data structures from Level 2 (Chapter 2), and the facility to handle both SYS/Bp exceptions and Interrupts –timer interrupts in particular– provide a thread scheduler, message passing facility, System Service Interface and other minor services. The purpose of the nucleus is to provide an environment in which asynchronous sequential threads exist, each making forward progress as they take turns sharing the CPU. Furthermore, the nucleus provides these threads with exception handling routines, message passing primitives. Last but not least, the core provides functionality specified in the SSI (System Service Interface). SSI provides mechanisms to allow threads to proliferate, to synchronize with devices (I/O or Pseudo-Clock), and to provide them the ability to specify the thread that must be used as their trap handler. Trap that can be raised and handled are Pgm, TLB and certain SYS/Bp exceptions. Since virtual memory is not supported by MIKONOS Level 3, all addresses at this level are assumed to by physical addresses. Nevertheless, the nucleus needs to preserve the state of each thread. If a thread is executing with virtual memory on (Status.VMc=1) when it is either interrupted or executes a SYSCALL, then Status.VMc should still be set to 1 when it continues its execution.

4.1. Bootstrap Revised

The boostrap phase already implemented in Phase 1B (see Chapter 3) must be modified to:

- Initialize all nucleus maintained variables (see further on)
- Instantiate a single thread for the SSI and place its ThreadBLK in the Ready Queue (see further on). A thread is instantiated by allocating a ThreadBLK (i.e. allocTcb()), and initializing the processor state that is part of it. In particular this thread may have interrupts enabled or disabled (see further on), virtual memory off, kernel-mode on, $SP set to RAMTOP - FRAMESIZE (i.e. use the penultimate RAM frame for its stack), and its PC set to the address of SSI function entry point. One can assign a variable (i.e. the PC) the address of a function by using . . . = (memaddr)SSI_function_entry_point; where memaddr, in TYPES.H has been aliased to unsigned int. Remember to declare the SSI function entry point as “external” in your program by including the line: extern void SSI_function_entry_point(); Remember that for technical reasons, whenever one assigns a value to the PC one must also assign the same value to the general purpose register t9. (a.k.a. t9 as defined in TYPES.H.) Hence this will be done when initializing the four New Areas as well as the processor state that defines this single thread.
- Instantiate a single thread for test and place its ThreadBLK in the Ready Queue. Test is a supplied function/thread that will help you debug your nucleus. The same rules described for SSI apply here. test should start with interrupts enabled, virtual memory off, kernel-mode on, $SP set to RAMTOP-(2*FRAMESIZE) (i.e. use the second-to-last RAM frame for its stack), and its PC set to the test address. Remember that test will require quite a large stack space to instantiate all its children threads.

Once main() calls the scheduler (as in Phase 1B), its task is completed, since control will never return to main(). At this point the only mechanism for re-entering the nucleus is through an exception; which includes device interrupts. As long as there are threads to run, the processor is executing instructions on their behalf and only temporarily enters the nucleus long enough to handle the device interrupts and exceptions when they occur.

4.2. Scheduling

Your nucleus should guarantee finite progress; consequently, every ready thread will have an opportunity to execute. For simplicity's sake this chapter describes the implementation of a simple round-robin scheduler with a time slice value of 5 milliseconds. There will be exceptions to the round-robin politic, in particular when a thread wakes up after a msgSend or a msgReceive. The scheduler also needs to perform some simple deadlock detection, and if deadlock is detected perform some appropriate action; e.g. invoke the PANIC ROM service/instruction. We define the following:

- Current Thread: the thread that has currently the control of the CPU
- Ready Queue: the queue which identifies all threads that are awaiting for the CPU control
- Thread Count: the number of threads in the system
- Soft-Block Count: the number of threads that are blocked awaiting for I/O or completion of a service request by the SSI

The scheduler should behave in the following way manner if the Ready Queue is empty:

- if the thread count = 1 and the SSI is the only thread in the system: perform normal system shutdown, that is, calling the HALT ROM routine
- if a deadlock is detected (that is, after system boot, if the thread count is higher than zero but the soft-block count is zero): perform emergency shutdown, that is, calling the PANIC ROM routine
- if thread count and soft-block count are higher than zero, some threads are waiting for I/O to complete: the system should enter in a wait state (that is, waiting until some device completes its operation). This is typically implemented by the execution of an infinite loop with interrupts enabled.

4.3. System Service Interface and Trap Management Threads

The System Service Interface (SSI), according to the MikonOS OS Project specifications, is a fundamental component of the kernel, since it provides services which are needed to build up higher levels of MIKONOS, such as thread synchronization with I/O operation completion, pseudo-clock tick management, thread proliferation (creation of new threads), thread termination and trap management threads specifications. The SSI runs inside the Kernel address space; each relevant system event will become a message managed by the SSI. The SSI will manage thread requests on behalf of the nucleus; for example, a thread which requires to know its accounted CPU time will send a message to the SSI, and wait for the answer. If the SSI ever gets terminated, the system must be stopped performing an emergency shutdown. The SSI thread should implement the following RPC server algorithm:

```
while (TRUE) { receive a request; satisfy the received request; reply the results; }
```

Services that the SSI provides are: Create Request Thread Creation Facility: thread creation. Thread Termination Request Thread Termination Facility: thread termination. PRG or TLB or SYS Trap Manager Specification Thread Trap Manager Specification Facilities: this will let specify an appropriate Trap Management Thread for each of these exceptions. Get CPU Time Provides the total CPU Time that has been used from the requesting thread since its creation. Freeze until next pseudo-clock tick Freezes requesting thread until the next pseudo-clock tick event. Freeze until I/O operation completion Freezes requesting thread until I/O completion. A thread makes a service request by using a specific function:

```
void SSIRequest(unsigned int service, unsigned int payload, unsigned int *reply)
```

where service is a mnemonic code identifying the service requested, payload contains an argument (if required) for the service, and reply will point to the area where the answer (if required) should be stored. If service does not match any of those provided by the SSI, the SSI should terminate the thread. Also, when a thread requires a service to the SSI, it must wait for the answer. While SSIRequest has to be implemented depending on specific SSI implementation, these general issues have to be addressed:

- SSI requests should be implemented using message passing SYSCALLS
- SSI must be given the TID 0; similarly, the thread that executes the test must be given the TID 1
- SSI requests and answers could require more than one parameter; the payload could be used in a creative way and/or expanded to allow the transport of “fat” messages

Beside the SSI, in a complete kernel other threads will perform specific functions on behalf of the nucleus; in MIKONOS, these will be named Trap Management Threads. The SSI is the only server thread which you must write in MIKONOS Phase 2: some sample trap management threads will be provided for testing purposes (the real implementation is demanded to MIKONOS's successive phases). Trap Management Threads will run inside the Kernel address space, and will not exchange messages directly with other threads. Each Management Thread implements the following RPC server algorithm:

while (TRUE) { receive a trap management request; manage the request; reply to the thread the decision upon continuing the trapped thread or not; }

Upon exception, the current thread is stopped and its state is saved in the old area; the nucleus should update the thread processor state with the one saved in the old area, and dispatch a message to the trap management thread with the current thread as sender, and the value of the CAUSE register as payload. The trap manager will act upon the request and, at last, will reply to the thread raising the trap with TRAPCONTINUE or TRAPTERMINATE as return value; the nucleus must then intercept this message and cause the thread termination or continuation.

4.4. SYS/Bp Exception Handling

A SYSCALL or Breakpoint exception occurs when a SYSCALL or BREAK assembler instruction is executed. Assuming that the SYS/Bp New Area in the ROM Reserved Frame was correctly initialized during nucleus initialization, then after the processor's and ROM-Excpt handler's actions when a SYSCALL or Breakpoint exception is raised, execution continues with the nucleus's SYS/Bp exception handler. A SYSCALL exception is distinguished from a Breakpoint exception by the contents of Cause.ExcCode in the SYS/Bp Old Area. SYSCALL exceptions are recognized via an exception code of Sys (8) while Breakpoint exceptions are recognized via an exception code of Bp (9). By convention the executing thread places appropriate values in user registers a0–a3 immediately prior to executing a SYSCALL or BREAK instruction. The nucleus will then perform some service on behalf of the thread executing the SYSCALL or BREAK instruction depending on the value found in a0. In particular, if the thread making a SYSCALL request was in kernel-mode and a0 contained 1 or 2 then the nucleus should perform a message passing related action.

4.4.1 MsgSend

This system call cause the transmission of a message to a specified thread. This is a synchronous operation (the sender waits for receiver to perform a SYS3) that returns the value that is replied by the receiver using the MsgReply system call. When MsgSend returns, the caller must be immediately scheduled (as an exception to the round-robin politics). When MsgSend is invoked, the sender is put in the queue of senders associated to the target in the target thread TCB. A request will be well formed if: a0 contains 1 a1 contains the destination thread identifier a2 contains the payload of the message. By setting SYS_SEND = 1, the following C macro can be used to request a SYS1:

#define MsgSend(dest,payload) (SYSCALL(SYS_SEND,(unsigned int) (dest),(unsigned int) (payload),0))

or a wrapper function can be used:

unsigned int MsgSend(tid_t dest, unsigned int payload) { unsigned int retcode; retcode = SYSCALL(SYS_SEND, (unsigned int) dest, payload, 0); return retcode; }

4.4.2 MsgRecv

This system call is used by a thread to extract a message from its inbox or, if this one is empty, to wait for a message. This is a synchronous operation since the requesting thread will be frozen untill a message matching the required characteristics doesn't arrive. When a thread blocked on a MsgRecv receives a message, it is immediately scheduled as an exception to the round-robin politics. This system call provides as returning value the identifier of the thread which sent the message extracted. This system call may cause the thread to lose its remaining time slice, since if its inbox is empty it has to be frozen. A request will be well formed if: a0 contains 2 a1 contains the sender thread or ANYTID a2 contains the pointer to the address where the payload will be found. If a1 contains a ANYTID pointer, then the requesting thread is looking for the first message in its inbox, without any restriction about the sender. In this case it will be frozen only if the queue is empty, and the first message sent to it will wake up it and put it in the Ready Queue. By setting SYS_RECV = 2, the following C macro can be used to request a SYS2:

#define MsgRecv(source,payload) (((tid_t) SYSCALL(SYS_RECV,(unsigned int) (source),(unsiged int) (payload),0)))

or a wrapper function can be used:

tid_t MsgRecv(tid_t source, unsiged int *payload) { tcb_t * sender; sender = (tid_t *) SYSCALL(SYS_RECV, (unsigned int) source, (unsigned int) payload); return sender; }

4.4.3 MsgReply

This system call is used by the receiver of a message, I.e. a thread that woke up from a MsgReceive system call. This is a synchronous operation that always causes the thread to lose its remaining time slice, since the thread the reply is directed to will be immediately scheduled as an exception to the round-robin politics. A request will be well formed if: a0 contains 3 a1 contains the thread the reply must be sent to a2 contains the value to be transmitted in order to be returned from MsgSend. The return value is 0 in case of success, an error code otherwise. As an exception, if MsgReply is performed by the SSI and if there are pending interrupts, the interrupt is marked as processed and a special message (with sender=ANYTID) is delivered to the caller. The corresponding reply (that must be done to ANYTID) will do nothing.

By setting SYS_REPLY = 3, the following C macro can be used to request a SYS3:

#define MsgReply(source,reply) (((tcb_t *) SYSCALL(SYS_REPLY,(unsigned int) (source),(unsigned int) (reply),0)))

or a wrapper function can be used:

unsigned_int MsgReply(tid_t source, unsigned int reply) { unsiged_int result; results = (unsingned int) SYSCALL(SYS_REPLY, (unsigned int) source, (unsigned int) reply, 0); return result; }

4.4.4 Other SYSCALLs

Otherwise, if the value of a0 is different from 1, 2 or 3, or the request was made from a thread in user-mode, then the exception must be managed in another way. The nucleus’s SYSTrap exception handler will take one of two actions depending on whether the offending (i.e. current) thread has specified a SYSTrap Management Thread:

- if the offending thread hasn't specified a thread to manage a SYSTrap Exception, then the current thread must be terminated.
- If the offending thread has specified a thread to manage a SYSTrap Exception, then the thread must be frozen, a message to the SYSTrap Management Thread must be sent with the cause of the exception as payload, and the offending thread as sender.

- The Management Thread then must decide where the execution of the thread must be terminated or can continue.
- The Management Thread will reply to the offending thread with TRAPCONTINUE or TRAPTERMINATE as return value; the nucleus must intercept this message and cause the thread termination or continuation.

4.5. PgmTrap Exception Handling

A PgmTrap exception occurs when the executing thread attempts to perform some illegal or undeﬁned action. Assuming that the PgmTrap New Area in the ROM Reserved Frame was correctly initialized during nucleus initialization, then after the processor’s and ROM-Excpt handler’s actions when a PgmTrap exception is raised, execution continues with the nucleus’s PgmTrap exception handler. The cause of the PgmTrap exception will be set in Cause.ExcCode in the PgmTrap Old Area. The nucleus’s PgmTrap exception handler will take one of two actions depending on whether the offending (i.e. Current) thread has specified a PgmTrap Management Thread:

- If the offending thread hasn't specified a thread to manage a PgmTrap Exception, then the current thread must be terminated.
- If the offending thread has specified a thread to manage a PgmTrap Exception, then the thread must be frozen, a message to the PgmTrap Management Thread must be sent with the cause of the exception as payload and the offending thread as sender.
- The Management Thread then must decide where the execution of the thread must be terminated or can continue.
- The Management Thread will reply to the offending thread with TRAPCONTINUE or TRAPTERMINATE as return value; the nucleus must intercept this message and cause the thread termination or continuation.

4.6. TLBTrap Exception Handling

A TLBTrap exception occurs when µMPS fails in an attempt to translate a virtual address into its corresponding physical address. Assuming that the TLBTrap New Area in the ROM Reserved Frame was correctly initialized during nucleus initialization, then after the processor’s and ROM-Excpt handler’s actions when a TLBTrap exception is raised, execution continues with the nucleus’s TLBTrap exception handler. The cause of the TLBTrap exception will be set in Cause.ExcCode in the TLBTrap Old Area. The nucleus’s TLBTrap exception handler will take one of two actions depending on whether the offending (i.e. Current) thread has specified a TLBTrap Management Thread:

- If the offending thread hasn't specified a thread to manage a TLBTrap Exception, then the current thread must be terminated.
- If the offending thread has specified a thread to manage a TLBTrap Exception, then the thread must be frozen, a message to the TLBTrap Management Thread must be sent with the cause of the exception as payload and the offending thread as sender.
- The Management Thread then must decide where the execution of the thread must be terminated or can continue.
- The Management Thread will reply to the offending thread with TRAPCONTINUE or TRAPTERMINATE as return value; the nucleus must intercept this message and cause the thread termination or continuation.

4.7. Interrupt Exception Handling

A device interrupt occurs when either a previously initiated I/O request completes or when the Interval Timer makes a 0x0000.0000 → FFFF.FFFF transition. Assuming that the Ints New Area in the ROM Reserved Frame was correctly initialized during nucleus initialization, then after the processor's and ROM-Excpt handler's actions when an Ints exception is raised, execution continues with the nucleus's Ints exception handler. Which interrupt lines have pending interrupts is set in Cause.IP. Furthermore, for interrupt lines 3–7 the Interrupting Devices Bit Map will indicate which devices on each of these interrupt lines have a pending interrupt. Since MIKONOS will not generate software interrupts, interrupt lines 0 and 1 may safely by ignored. It is important to note that many devices per interrupt line may have an interrupt request pending, and that many interrupt lines may simultaneously be on. Also, since each terminal device is two sub-devices, each terminal device may ave two pending interrupts simultaneously as well. You are strongly encouraged to process only one interrupt at a time: the interrupt with the highest priority. The lower the interrupt line and device number, the higher the priority of the interrupt. When there are multiple interrupts pending, and the Interrupt exception handler only processes the single highest priority pending interrupt, the Interrupt exception handler will be immediately reentered as soon as interrupts are unmasked again; effectively forming a loop until all the pending interrupts are processed. Terminal devices are actually two sub-devices; a transmitter and a receiver. These two subdevices operate independently and concurrently. Both sub-devices may have an interrupt pending simultaneously. For purposes of prioritizing pending interrupts, terminal transmission (i.e. writing to the terminal) is of higher priority than terminal receipt (i.e. reading from the terminal). Hence the Interval Timer is the highest priority interrupt and reading from terminal 7 is the lowest priority interrupt. The nucleus's Interrupts exception handler will perform a number of tasks:

- Acknowledge the outstanding interrupt: for all devices except the Interval Timer this is accomplished by writing the acknowledge command code in the interrupting device's device register. Alternatively, writing a new command in the interrupting device's device register will also acknowledge the interrupt. An interrupt for the Interval Timer is acknowledged by loading the Interval Timer with a new value.
- If the interrupt is raised from an I/O device this will be translated (as a special case of MsgRcv and MsgReply) into a message for the SSI. The sender of message will be ANYTID. The payload will be the base address of the device raising the interrupt exception. This information may have to be stored by the SSI.
- If the interrupt was caused from the Interval Timer, the reason could be:
    - the current thread time-slice has expired: in this case, the scheduler must take the necessary actions to give the CPU access to another thread
    - a pseudo-clock tick has occurred: the nucleus should send the SSI a message to let the SSI unblock all threads who requested a WAITFORCLOCK service. In both cases, CPU time accounting should be performed by the nucleus on behalf of threads.

4.8. Nucleus Services

These services should be implemented by the SSI on behalf of the nucleus, and could be requested by threads running in Kernel mode. These services will be identified by mnemonic values.

4.8.1 CREATE

This service should allow the requestor to create a new thread whose initial processor state is passed by reference as payload. If the creation went fine, this service should return the created thread identifier, otherwise should return CREATENOGOOD.

4.8.2. TERMINATE

This service should allow the requestor to terminate itself (by passing ANYTID) or another thread (by passing its thread identifier). If the thread that must be terminated is blocked waiting for a MsgReply, it will be terminated only when the MsgReply is performed. The motivation is to allow the receiver to read and alter the payload of the message received, that lives in the sender address space and that would be invalidated by the termination of the sender. There are no return codes.

4.8.3 SPECPRGMGR

This service should allow the requestor to specify his own trap management thread for Program Trap exceptions. The trap manager thread identifier is passed as payload; if the management thread does not exist, the requestor thread should be terminated. Once assigned , the trap manager thread cannot be redefined: further service requests of this type should cause the termination of the thread.

4.8.4 SPECTLBMGR

This service should allow the requestor to specify his own trap management thread for TLB Management exceptions. The trap manager thread identifier is passed as payload; if the management thread does not exist, the requestor thread should be terminated. Once assigned , the trap manager thread cannot be redefined: further service requests of this type should cause the termination of the thread.

4.8.5 SPECSYSMGR

This service should allow the requestor to specify his own trap management thread for SYSCALL and Break exceptions. The trap manager thread identifier is passed as payload; if the management thread does not exist, the requestor thread should be terminated. This is the trap management thread that will be called when "pass up" of SYSCALLs and service requests is attempted. Once assigned, the trap manager thread cannot be redefined: further service requests of this type should cause the termination of the thread.

4.8.6 GETCPUTIME

This service should allow the requestor get back the CPU time used up until now (in microseconds). The scheduler policy should define how SYSCALLs, interrupts and other nucleus' activities on behalf of threads should be accounted.

4.8.7 WAITFORCLOCK

One of the services the nucleus has to implement is the pseudo-clock, that is, a virtual device which sends out an interrupt (a tick) every 100 milliseconds. This interrupt will be translated into a message to the SSI, as for other interrupts. WAITFORCLOCK should allow the requestor to suspend its execution until the next pseudoclock tick. Pseudo-clock management should be quite precise: at most one of such messages should wait in the SSI inbox. This could be obtained by prioritizing the message.

4.8.8 WAITFORIO

Threads may start I/O operations by writing commands in device registers. To avoid busy waiting, WAITFORIO should allow threads to request to be suspended until the I/O operation is completed. The device is identified by the thread by specifying its device register base address (that is, the address of its STATUS register) as payload. If the device does not exist, the thread should be terminated. Upon I/O operation completion, the STATUS register value of the device should be returned to the requestor thread. Because of CPU scheduling, the I/O operation could be completed before the service request could be processed by the SSI: the STATUS upon I/O completion has to be recorded until the thread performs the service request.

4.8.9 GETTSTATE

This service should allow the sender to pass the thread identifier of a process to obtain its processor state (of type struct state_t). In order to obtain his own processor state, the thread can pass ANYTID. If the thread identifier does not correspond to any existing thread, the caller must be terminated.

4.9 Nuts and Bolts

4.9.1 Timing Issues

While µMPS has two clocks, the TOD clock and Interval Timer, only the Interval Timer can generate interrupts. Hence the Interval Timer must be used simultaneously for two purposes: generating interrupts to signal the end of threads time slices, and to signal the end of each 100 millisecond period (a pseudo-clock tick). The nucleus should be able to to load the most appropriate value into the Interval Timer to manage both requirements, and to tell if the Interval Timer interrupt has happened because of pseudo-clock tick or time slice expiration, and act accordingly. The CPU time used by each thread must also be kept track of (GETCPUTIME). This could be implemented by adding a field to the ThreadBLK structure. While the Interval Timer is useful for generating interrupts, the TOD clock is useful for recording the length of an interval. By storing off the TOD clock’s value at both the start and end of an interval, one can compute the duration of that interval. The Interval Timer and TOD clock are mechanisms for implementing MIKONOS's scheduler policy. Scheduler policy questions that need to be worked out include: While the time spent by the nucleus handling an I/O or Interval Timer interrupt needs to be measured for pseudo-clock tick purposes, which thread, if any, should be “charged” with this time. Note: it is possible for an I/O or Interval Timer interrupt to occur even when there is no current thread. While the time spent by the nucleus handling a SYSCALL request needs to be measured for pseudo-clock tick purposes, which thread, if any, should be “charged” with this time. It is also necessary to decide if manage the CPU time accounting using only a 32-bit counter (easier to implement, but introduces limits on maximum CPU time values) or a 64-bit counter, which has no limitations could be split in two like TODHI/TODLO, but requires 64-bit algebra to be devised. Another important issue to be managed is the conversion of CPU ticks into microseconds or milliseconds: there is a Timescale register which allows such a conversion to be made.

4.9.2 Returning from a SYS/Bp Exception

SYSCALLs that do not result in thread termination or suspension return control to the requesting threads execution stream. The PC that was saved is, as it is for all exceptions, the address of the instruction that caused that exception – the address of the SYSCALL assembly instruction. Without intervention, returning control to the SYSCALL requesting thread will result in an infinite loop of SYSCALL’s. To avoid this the PC must be incremented by 4 (i.e. the µMPS wordsize) prior to returning control to the interrupted execution stream. While the PC needs to be altered, do not, in this case, make a parallel assignment to t9.

4.9.3 Loading a New Processor State

It is the job of the ROM-Excpt handler to load new processor states; either as part of “passing up” exception handling (the loading of the processor state from the appropriate New Area) or for LDST processing. Whenever the ROM-Excpt handler loads a processor state a pop operation is performed on the KU/IE and VM stacks. This has implications whenever one is setting the Status register’s VM, KU, or IE bits. One must set the previous bits (i.e. VMp, IEp & KUp) and not the current bits (i.e. VMc, IEc & KUc) for the desired assignment to take effect after the ROM-Excpt handler loads the processor state.

4.9.4 Thread Termination Issues

Termination may be accomplished by the SSI (TERMINATE service) and by the nucleus; it could be easier to develop just one general termination function (eg. belonging to the nucleus) and have both SSI and nucleus use it.

4.9.5 Data Structures for I/O Management

The SSI has to match requests made by threads (WAITFORCLOCK, WAITFORIO) with events from devices, that is, messages notifying device interrupts and pseudo-clock ticks. Requests and events may arrive in any order, so the SSI has to keep track of threads waiting, device STATUSes, and so on. All this data has to be collected and managed by the SSI, and could be implemented by adding fields to tcb_t data structure and/or by adding whole new data structures to the SSI, eg. an I/O waiting thread queue, a device STATUS array, and so on. It also depends also on scheduler implementation; eg. if the scheduler does have a I/O wait queue, it could be used to handle threads waiting on I/O on behalf of SSI.

4.9.6 Accessing the libumps Library

Accessing the CP0 registers and the ROM-implemented services/instructions in C is via the libumps library. Simply include the line: #include “$SUPDIR/e/libumps.e” The file libumps.e is part of the µMPS distribution. $SUPDIR must be replaced with the absolute path to the µMPS support directory. Make sure you know where it is installed in your local environment and alter this compiler directive appropriately.

4.9.7 Sample Module Decomposition

There isn't just one way to implement the functionality of this level. One simple approach is to create:

- a module which takes care of starting the system (boot.c)
- a module for implementing the SSI (ssi.c)
- a module for the scheduler (scheduler.c)
- a module for exception management (exception.c), which could be replaced by two or more specialized modules (syscall.c interrupt.c tlbtrap.c prgtrap.c) in various combinations

4.10 Testing

There is a provided test file, p2test.c that will "exercise" your code. The procedure for building it is the same described in § 2.5. Remember that both Phase 1 and Phase 2 modules should be compiled and linked together with p2test.c to get the full kernel.

Further Development

MIKONOS Project source code is not complete, in fact only Phase1 and Phase2 have been implemented. The authors strongly encourages the development of feature improvements to provide all remaining phases to make MIKONOS truly complete.

Credits

The authors would like to thank: Renzo Davoli, Michael Goldweber, Mauro Morsiani and Enrico Cataldi for the great work made with µMPS, Kaya, AMIKE and AMIKAYA [1,2,8].

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