μPandOS: Phase 1

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Introduction

The μPandOS operating system described below is inspired to the previous experience of PandOSplus and AMIKaya OS.

1 Phase 1 - Level 2: The Queue Managers

Level 2 of μPandOS 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 processes (i.e. programs in execution) and the data structure(s) that represent them at this level are *Process Control Blocks* (PCBs).

```c
/* process table entry type */
typedef struct pcb_t
{
    /* process queue  */
    struct list_head p_list;

    /* process tree fields */
    struct pcb_t *p_parent;   /* ptr to parent  */
    struct list_head p_child; /* children list */
    struct list_head p_sib;   /* sibling list  */

    /* process status information */
    state_t p_s;  /* processor state */
    cpu_t p_time; /* cpu time used by proc */

    /* First message in the message queue */
    struct list_head msg_inbox;

    /* Pointer to the support struct */
    support_t *p_supportStruct;

    /* process id */
    int p_pid;
} pcb_t, *pcb_PTR;
```

The Process Queue Manager will implement three PCB related sets of functions:

- The allocation and deallocation of PCBs.
- The maintenance of queues of PCBs.
- The maintenance of trees of PCBs.

Modules will communicate with the kernel through message passing. At this level, messages are represented by a message block (`msg_t`).

```c
/* message entry type */
typedef struct msg_t
{
    /* message queue */
    struct list_head m_list;

    /* thread that sent this message */
    struct pcb_t *m_sender;

    /* the payload of the message */
    unsigned int m_payload;
} msg_t , *msg_PTR;
```

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

- Allocation/deallocation of single message elements.
- Maintenance of messages' queues.

2 Processes

2.1 The Allocation and Deallocation of PCBs

One may assume that μPandOS supports no more that `MAXPROC` concurrent processes; where `MAXPROC` should be set to 40 (in the `const.h` file). Thus this level needs a "pool" of `MAXPROC` PCBs to allocate from and deallocate to. Assuming that there is a set of `MAXPROC` PCBs, the free or unused ones can be kept on a double, circularly linked list (using the `p_list` field), called the `pcbFree` list, whose head is pointed to by the variable `pcbFree_h`.

To support the allocation and deallocation of PCBs there should be the following three externally visible functions:

- PCBs which are no longer in use can be returned to the `pcbFree_h` list by using the method:

  `void freePcb(pcb_t *p)`
  Insert the element pointed to by `p` onto the `pcbFree` list.

- PCBs should be allocated by using:

  `pcb_t *allocPcb()`
  Return NULL if the `pcbFree` list is empty. Otherwise, remove an element from the `pcbFree` list, provide initial values for ALL of the PCBs fields (i.e. NULL and/or 0) and then return a pointer to the removed element. PCBs get reused, so it is important that no previous value persist in a PCB when it gets reallocated.

There is still the question of how one acquires storage for `MAXPROC` PCBs and gets these `MAXPROC` PCBs initially onto the `pcbFree` list. Unfortunately, there is no `malloc()` feature to acquire dynamic (i.e. non-automatic) storage that will persist for the lifetime of the OS and not just the lifetime of the function they are declared in. Instead, the storage for the `MAXPROC` PCBs will be allocated as static storage. A `static pcb_t pcbTable[MAXPROC]` will be declared in `initPcbs()`. Furthermore, this method will insert each of the `MAXPROC` PCBs onto the `pcbFree` list.

- To initialize the `pcbFree` list:

  `initPcbs()`
  Initialize the `pcbFree` list to contain all the elements of the static array of `MAXPROC` PCBs. This method will be called only once during data structure initialization.

2.2 Process Queue Maintenance

The methods below do not manipulate a particular queue or set of queues. Instead they are generic queue manipulation methods; one of the parameters is a pointer to the queue upon which the indicated operation is to be performed.

The queues of PCBs to be manipulated, which are called process queues, are all double, circularly linked lists, via the `p_list` field.

To support process queues there should be the following externally visible functions:

`void mkEmptyProcQ(struct list_head *head)`
: This method is used to initialize a variable to be head pointer to a process queue.

`int emptyProcQ(struct list_head *head)`
: Return TRUE if the queue whose head is pointed to by `head` is empty. Return FALSE otherwise.

`void insertProcQ(struct list_head *head, pcb_t *p)`
: Insert the PCB pointed by `p` into the process queue whose head pointer is pointed to by `head`.

`pcb_t *headProcQ(struct list_head *head)`
: Return a pointer to the first PCB from the process queue whose head is pointed to by `head`. Do not remove this PCB from the process queue. Return NULL if the process queue is empty.

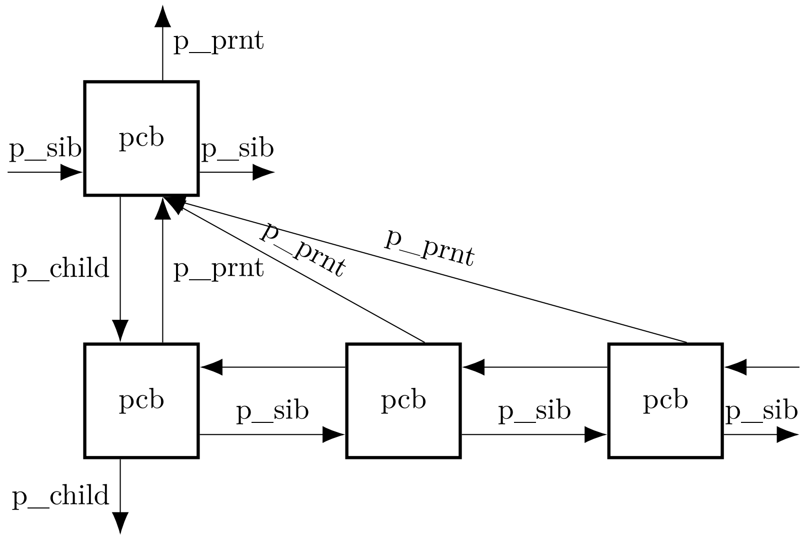
`pcb_t *removeProcQ(struct list_head *head)`
: Remove the first (i.e. head) element from the process queue whose head pointer is pointed to by `head`. Return NULL if the process queue was initially empty; otherwise return the pointer to the removed element.

`pcb_t *outProcQ(struct list_head *head, pcb_t *p)`
: Remove the PCB pointed to by `p` from the process queue whose head pointer is pointed to by `head`. If the desired entry is not in the indicated queue (an error condition), return NULL; otherwise, return `p`. Note that `p` can point to any element of the process queue.

2.3 Process Tree Maintenance

In addition to possibly participating in a process queue, PCBs are also organised into trees of PCBs, called *process trees*. `p_prnt`, `p_child`, and `p_sib` are used for this purpose.

The process trees should be implemented as follows. A parent PCB contains a list of children PCBs (`p_child`), each child process `p_sib` can be used to add the child to this list. Each child process has a pointer to its parent PCB (`p_prnt`).



To support process trees there should be the following externally visible functions:

`int emptyChild(pcb_t *p)`
Return TRUE if the PCB pointed to by `p` has no children. Return FALSE otherwise.

`void insertChild(pcb_t *prnt, pcb_t *p)`
Make the PCB pointed to by `p` a child of the PCB pointed to by `prnt`.

`pcb_t *removeChild(pcb_t *p)`
Make the first child of the PCB pointed to by `p` no longer a child of `p`. Return NULL if initially there were no children of `p`. Otherwise, return a pointer to this removed first child PCB.

`pcb_t *outChild(pcb_t *p)`
Make the PCB pointed to by `p` no longer the child of its parent. If the PCB pointed to by `p` has no parent, return NULL; otherwise, return `p`. Note that the element pointed to by `p` could be in an arbitrary position (i.e. not be the first child of its parent).

3 Messages

3.1 The Allocation and Deallocation of Messages

One may assume that μPandOS supports no more that `MAXMESSAGES` concurrent messages; where `MAXMESSAGES` should be set to 40 (in the `const.h` file). Thus this level needs a "pool" of `MAXMESSAGES` messages to allocate from and deallocate to. Assuming that there is a set of `MAXMESSAGES` messages, the free or unused ones can be kept on a double, circularly linked list (using the `m_list` field), called the `msgFree` list, whose head is pointed to by the variable `msgFree_h`.

To support the allocation and deallocation of messages there should be the following three externally visible functions:

- Messages which are no longer in use can be returned to the `mesgFree_h` list by using the method:

  `void freeMsg(msg_t *m)`
  Insert the element pointed to by `m` onto the `msgFree` list.

- Messages should be allocated by using:

  `msg_t *allocMsg()`
  Return NULL if the `msgFree` list is empty. Otherwise, remove an element from the `msgFree` list, provide initial values for ALL of the messages fields (i.e. NULL and/or 0) and then return a pointer to the removed element. Messages get reused, so it is important that no previous value persist in a message when it gets reallocated.

There is still the question of how one acquires storage for `MAXMESSAGES` messages and gets these `MAXMESSAGES` messages initially onto the `msgFree` list. Unfortunately, there is no `malloc()` feature to acquire dynamic (i.e. non-automatic) storage that will persist for the lifetime of the OS and not just the lifetime of the function they are declared in. Instead, the storage for the `MAXMESSAGES` messages will be allocated as static storage. A `static msg_t msgTable[MAXMESSAGES]` will be declared in `initMsgs()`. Furthermore, this method will insert each of the `MAXMESSAGES` messages onto the `msgFree` list.

- To initialize the `msgFree` list:

  `initMsgs()`
  Initialize the `msgFree` list to contain all the elements of the static array of `MAXMESSAGES` messages. This method will be called only once during data structure initialization.

3.2 Message Queue Maintenance

The functions below do not manipulate a particular message queue or set of queues. Instead they are generic queue manipulation methods; one of the parameters is a pointer to the message queue upon which the indicated operation is to be performed.

Queues to be manipulated are circular, double linked and head pointed lists.

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

`void mkEmptyMessageQ(struct list_head *head)`
: Used to initialize a variable to be head pointer to a message queue; returns a pointer to the head of an empty message queue, i.e. NULL.

`int emptyMessageQ(struct list_head *head)`
: Returns TRUE if the queue whose tail is pointed to by `head` is empty, FALSE otherwise.

`void insertMessage(struct list_head *head, msg_t *m)`
: Insert the message pointed to by `m` at the end of the queue whose head pointer is pointed to by `head`.

`void pushMessage(struct list_head *head, msg_t *m)`
: Insert the message pointed to by `m` at the head of the queue whose head pointer is pointed to by `head`.

`msg_t *popMessage(struct list_head *head, pcb_t *p_ptr)`
: Remove the first element (starting by the head) from the message queue accessed via `head` whose sender is `p_ptr`.

  If `p_ptr` is NULL, return the first message in the queue. Return NULL if the message queue was empty or if no message from `p_ptr` was found; otherwise return the pointer to the removed message.

`msg_t *headMessage(struct list_head *head)`
: Return a pointer to the first message from the queue whose head is pointed to by `head`. Do not remove the message from the queue. Return NULL if the queue is empty.

4 Nuts and Bolts

There is no one right way to implement the functionality of this level. The recommended approach is to create two modules (i.e. files): one for the Message Queue and one for PCB initialisation/allocation/deallocation, process queue maintenance, and process tree maintenance. The second module, `pcb.c`, in addition to the public and HIDDEN/private helper functions, will also contain the declaration for the `pcbTable` and for the private global variable that points to the head of the `pcbFree` list.

```
static pcb_t pcbTable[MAXPROC];
LIST_HEAD(pcbFree_h);
static int next_pid = 1;
```

The Message queue module, `msg.c`, in addition to the public and HIDDEN/private helper functions, will also contain the declarations for `msgTable` and `msgFree_h`

```
static msg_t msgTable[MAXMESSAGES];
LIST_HEAD(msgFree_h);
```

The declarations for `pcb_t` and `msg_t` would then be placed in the `types.h` file. This is because many other modules will need to access these definitions.

5 Testing

There is a provided test file, `p1test.c`, that will check the behaviour of your code.

As with any non-trivial system, you are strongly encouraged to use the `make` program to maintain your code. A sample `Makefile` has been supplied for you to use. See Chapter 10 in the POPS reference for more compilation details.

Once your source files have been correctly compiled, linked together (with appropriate linker script, `crtso.o`, and `libumps.o`), and post-processed with `umps3-elf2umps` (all performed by the sample `Makefile`), your code can be tested by launching the µMPS3 emulator.

At a terminal prompt, enter: `umps3`. Create a new machine configuration in the project folder.

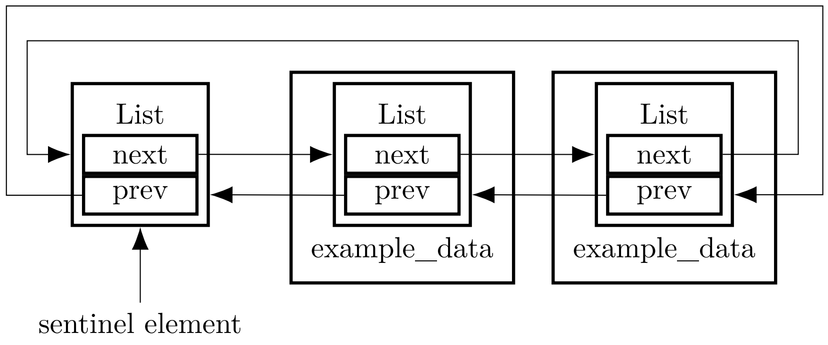
The test program reports on its progress by writing messages to Windows > Terminal 0. These messages are also added to one of two memory buffers; `errbuf` for error messages and `okbuf` for all other messages. At the conclusion of the test program, either successful or unsuccessful, µMPS3 will display 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 (you could have to click the play button a second time if Exceptions is enable in the emulator Stop Mask).

Linux kernel lists

We will use the generic and type-oblivious lists of the Linux kernel. If it's needed to create a list for an existing data type, just add a `list_head` field in the struct (this means that the `list_head` struct is type-oblivious). These are double linked lists, so every element of the list is pointed to the next and previous element in the list. There is a sentinel element that isn't an element of the list, but it's used to link the first and last elements of the list. This data type comes with a useful range of macros and functions, located in the `listx.h` file (it's suggested to take a look at the file and read the code to understand its functionality).

```
struct list_head {
    struct list_head *next;
    struct list_head *prev;
}

struct example_data {
    int value;
    // ...
    struct list_head e_list;
}
```



`#define LIST_HEAD_INIT(name)`
Macro to create an empty list.

`#define LIST_HEAD(name)`
Macro to create an empty list (declare also the variable).

`void INIT_LIST_HEAD(struct list_head *list)`
Inline function to create an empty list.

`int list_empty(const struct list_head *head))`
Return 1 if the list pointed by `head` is empty.

`void list_add(struct list_head *new, struct list_head *head)`
Add element point by `new` to the head of list pointed by `head`.

`void list_add_tail(struct list_head *new, struct list_head *head)`
Add element point by `new` to the tail of list pointed by `head`.

`void __list_add(struct list_head *new, struct list_head *prev, struct list_head *next)`
Add element point by `new` in an arbitrary position of list pointed by `head`.

`void list_del(struct list_head *entry)`
Remove element point by `entry` from the list in which it is contained.

`#define container_of(ptr, type, member)`
Macro to get the struct containing the `list_head` pointed by `ptr`, `type` is the struct name that contain the `list_head`, `member` is the name of the `list_head` inside the struct.

`#define list_for_each(pos, head)`
Scroll through the list pointed by `head`, the current position will be pointed by `pos`.

`#define list_for_each_entry(pos, head, member)`
Scroll through the content of the list pointed by `head`, the current element will be pointed by `pos`, `member` is the name of the `list_head` inside the struct.

Credits

This document took inspiration from Enrico Cataldi's "Guide to the AMIKaya Operating System Project" and the Principles of Operation book.