Retro

Tiny

Multitasking

kernel

for Z80 based computers

RTM/Z80

Software and documentation by Szilagyi Ladislau v1.4

Copyright (c) 2021 Ladislau Szilagyi (ladislau_szilagyi@yahoo.com)

Permission is hereby granted, free of charge, to any person obtaining a copy of this software and associated documentation files (the "Software"), to deal in the Software without restriction, including without limitation the rights to use, copy, modify, merge, publish, distribute, sublicense, and/or sell copies of the Software, and to permit persons to whom the Software is furnished to do so, subject to the following conditions:

The above copyright notice and this permission notice shall be included in all copies or substantial portions of the Software.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.

Contents

Introduction – learning about multitasking

The RTM/Z80 project is intended to offer to the retro-computer hobbyists and to anyone willing to learn about multitasking systems the necessary resources needed to understand and learn the basics of this interesting but difficult area of software engineering.

Nothing compares to learning through practice, and I hope that using RTM/Z80 will help.

I was “exposed” to the “multitasking” topic some 40 years ago.

Back in 1978, as a programmer, I was allowed to use a computer named PDP-11, built by the late Digital Equipment Corporation, using RSX-11M as operating system. This was one of the first good multitasking, real-time operating systems ever designed.

Also, my job included programming an INTEL 8080 based computer.

I managed to write for this INTEL 8080 computer a small kernel (less than 8 Kbytes), containing multitasking support, I/O drivers (on interrupts) for the real-time clock, serial console, digital and analog inputs/outputs, punched paper tape (!) reader, etc.

It was used in Romania until the late 80’s in various industrial projects.

40 years after, I switched to ZILOG Z80, using the occasion provided by the creators of the RC2014 home-brew Z80-based computer, and I tried to re-build my old multitasking kernel on this new Z80 environment.

This is how the RTM/Z80 project started.

Some months later, I finished my first version of RTM/Z80 and I opted to make-it accessible to anyone interested.

In my opinion, it is a very good tool if you want to learn about multitasking.

I consider that, when someone tries to learn something connected to complex software systems, the best way is to be provided with all the possible resources, including the source code, a working hardware-software system, user manuals and implementation examples or demo programs.

Therefore, all the parts of this project, including the source code, are made accessible to anyone.

Summary

In computing, **multitasking** is the concurrent execution of multiple tasks over a certain period of time. New tasks can interrupt already started ones before they finish, instead of waiting for them to end.

As a result, a computer executes segments of multiple tasks in an interleaved manner, while the tasks share common processing resources such as central processing units (CPUs) and main memory.

Multitasking automatically interrupts the running program, saving its state (computer register contents) and loading the saved state of another program while transferring control to it.

Multitasking is a common feature of computer operating systems. It allows more efficient use of the computer hardware; where a program is waiting for some external event such as a user input or an input/output transfer with a peripheral to complete, the central processor can still be used with another program.

RTM/Z80 is a multitasking kernel, built for Z80 based computers, written in Z80 assembly language, providing its users with an Application Programming Interface (API) accessible from programs written in the C language and the Z80 assembly language.

It is intended to be a simple and easy to use learning tool, for those who want to understand the tips and tricks of the multitasking software systems.

Basic RTM/Z80 characteristics and features:

- May be run directly under CP/M 2.2 on any vintage Z80 based computer as a .COM executable program, or may be run on any simulated/emulated Z80 system, or on any Z80 retro/home brew computer (e.g. RC2014).
- It's very easy to build applications that use RTM/Z80. Using the HiTech vintage C compiler, assembler and linker, the application can be quickly compiled, assembled and linked with the RTM/Z80 library, in a minimal number of steps.
- It's easy to configure. It can be quickly tailored according to the user options. Can be built as an object code library or can be ported to a (E)EPROM + RAM configuration.
- It's quite small. In its minimal version, it requires less than 4KB ROM plus 8K RAM
- It's fast enough. The following measurements are valid for a Z80 CPU running at 7.3728 MHz:
    - Task switching time (switching from a task executing a semaphore "signal" to another task "waiting" for the semaphore) is under 160 microseconds.
    - Allocate/deallocate a block of dynamic memory takes under 130 microseconds
    - Run/stop task operations are executed in less than 220 microseconds
- Its functions are easy to be used (no complicated C or assembler data structures need to be initialized)
- Provides 8KB of RAM dynamic memory, enabling users to allocate/deallocate blocks of memory of variable sizes, from 16 bytes to 4 Kbytes.

- Users can define and run up to 32 concurrent tasks. The highest priority task gains CPU access.
- RTM/Z80 is basically a “cooperative” multitasking system; however, round-robin pre-emptive scheduling is possible, and can be switched on/off using the API
- Semaphores can be used to control access to common resources. Semaphores are implemented as “counting” semaphores. There is no limit regarding the number of semaphores that can be used.
- Queues and mailboxes can be used for inter-task communication. Messages can be sent and received between tasks. There is no limit regarding the number of queues or mailboxes that can be used.
- Timers can be used to delay/wait for variable time intervals (multiple of 5 milliseconds). There is no limit regarding the number of timers that can be used.
- Interrupt driven I/O drivers are used to perform I/O requests targeted to serial hardware devices (console, printer, etc.) for baud rates up to 115.2 K

RTM/Z80 is a “low profile” multitasking system; it is written entirely in Z80 assembler language and uses as a building platform the vintage HiTech Z80 software, which may be run on a “real” Z80 computer or on a Z80 “simulator”. However, you can use also the C language and “mix” C code with Z80 assembly code when writing RTM/Z80 applications.

RTM/Z80 does not pretend to be a “real-time” system; for this target, you need much more powerful CPU power; the 7.3728 MHz Z80 is a low-placed processor in this perspective.

Building RTM/Z80 applications does not imply the use of any Unix/Linux development platform. All you need is CP/M, knowledge of Z80 assembly language or C language and being used to operate the HiTech tools (assembler, C compiler, linker).

RTM/Z80 is not a “competitor” of the many Z80 multitasking systems available on the market, it is only a learning tool for those who want to understand the “tips & tricks” of multitasking; because of this, it’s structure is simple and straightforward. However, the author tried to build also a versatile and efficient system, with performances comparable with other popular Z80 multitasking systems.

Many “hot” multitasking topics are discussed here, including dynamic memory management, priority inversion issue, task synchronization and communication mechanisms, starting from the basics but exposing also more complicated multitasking issues.

All the RTM/Z80 configuration options are grouped in a single text file, named “config.mac”. CP/M SUBMIT files are provided to help building RTM/Z80 and/or the RTM/Z80 applications.

Details explaining how to configurate RTM/Z80, how to build applications written for RTM/Z80 and how to execute them on CP/M or RC2014 are included in the last part of this manual.

Porting RTM/Z80 to any Z80-based, interrupts enabled (IM2) computer is possible.

Have a nice time studying this manual!

Of course, any improvement suggestions related to the manual and/or the software are welcome!

Cooperative vs. Preemptive multitasking

In **preemptive** multitasking, the operating system can initiate a context switching from the running process to another process.

In other words, the operating system allows stopping the execution of the currently running process and allocating the CPU to some other process.

The OS uses some criteria to decide for how long a process should execute before allowing another process to use the operating system.

The mechanism of taking control of the operating system from one process and giving it to another process is called preempting or preemption.

In **cooperative** multitasking, the operating system never initiates context switching from the running process to another process.

A context switch occurs only when the processes voluntarily yield control periodically or when idle or logically blocked to allow multiple applications to execute simultaneously.

Also, in this multitasking, all the processes cooperate for the scheduling scheme to work.

Early versions of both Windows and Mac OS used cooperative multitasking. Later on, preemptive multitasking was introduced in Windows NT 3.1 and in Mac OS X. However, preemptive multitasking has always been a core feature of Unix based systems.

RTM/Z80 is basically a cooperative multitasking system; however, a mechanism called “round-robin scheduling” may be enabled/disabled using the API, providing access to (limited) preemptive multitasking.

See the “**Round robin scheduling**” chapter for details.

RTM/Z80 Application Programming Interface

RTM/Z80 functions may be called from C and/or Z80 assembler source code.

All these functions must be called after RTM/Z80 is started-up (using the StartUp function, which is the only exception to this rule).

At RTM/Z80 start-up, hardware interrupts are enabled. In applications written for RTM/Z80, disabling hardware interrupts should be used with care (if hardware interrupts are disabled for long periods of time, interrupt driven I/O and the real time clock will be critically affected and the system may crash).

For the C language, the calling procedure of RTM/Z80 functions is simple, you need only to insert in your source code the appropriate #include statements, then use the C language procedure calling, for example:

```
#include <dlist.h>
#include <balloc.h>
#include <rtsys.h>
#include <stdio.h>
…
struct Semaphore* S;
void (*fp)(void);
…

void AnotherTask(void)
{
…
  S=MakeSem();
  Signal(S);
  StopTask(GetCrtTask());
}

void Task(void)
{
  fp = AnotherTask;
  RunTask(0x60, (void*)fp, 5); /* Run AnotherTask with stack size=60H, prio=5 */
…
  Wait(S);
…
  ShutDown();
}

void main(void)
{
…
  fp = Task;
  StartUp(0x1E0, (void*)fp, 10); /* Start up, run Task with stack size=1E0H, prio=10 */
  printf("\r\nMAIN resumed...");
}
```

When using code written in **Z80 assembler**, there are two possible approaches:

1) **The first approach** (“function parameters on the stack”) uses the stack to pass the parameters values to the RTM/Z80 functions:

```
; Calling Routine, defined as:
;char, short, void* Routine(P1, P2, ..., Pn);
;
       PUSH   Pn           ;last param pushed first!
       ...
       PUSH   P2
       PUSH   P1
       CALL   _Routine     ; !!! NOTE the leading _
;             ; return value in HL, or L
;             ; P1, P2, ..., PN are still on the stack
```

This approach has also the advantage of saving and restoring the values of all the Z80 registers from the main Z80 set of registers (AF, BC, DE, HL, IX, IY). If the function returns values, these are stored in HL (or L) registers, depending on the size of the returned value.

This way, the user can call any RTM/Z80 function without affecting the values of the main set of Z80 registers (except for the case of functions returning values in HL or L registers, when HL or L is affected).

The secondary Z80 set of registers (A’, BC’, DE’ and HL’) is used internally by RTM/Z80; the applications may use this secondary set of registers, but these registers will not be saved/restored by the RTM/Z80 functions.

Remember to push the parameters of a function in the reverse order and prefix the function name with a _ (underline), for example:

```
       LD           HL,5               ;task priority
       PUSH         HL
       LD           HL,TStart          ;task start address
       PUSH         HL
       LD           HL,0E0H            ;stack size
       PUSH         HL
       CALL         _RunTask           ;HL returned as new task TCB addr
       POP          BC                 ;drop parameters
       POP          BC
       POP          BC
```

2) **The second approach** (“function parameters values in registers”) is faster, loading the function parameters values directly into the Z80 registers, but does not save/restore the Z80 registers.

```
; Calling Routine, defined as:
;char, short, void* Routine(P1, P2, ..., Pn);
;
       LD     HL,…         ;Load parameters into registers
       LD     C,…
       CALL   __Routine    ; !!! NOTE the leading __ (double _)
                           ; return value in HL, or L
```

Remember to prefix the function name with a double _ (underline), for example:

```
LD          E,5                 ;task priority
LD          HL,TStart           ;task start address
LD          BC,0E0H             ;stack size
CALL        __RunTask           ;HL returned as new task TCB addr
```

The full set of API functions is described in the following chapters.

The “include” file and the list of parameters, in the case of C language (which is relevant also for the first Z80 assembler language approach), and the Z80 registers to be used for the parameters in case of the second Z80 assembler language approach (the returned value is always stored into HL or L register), are shown for each function.

RTM/Z80 can be configured (using the DEBUG option) to check the parameters of all the API functions. However, if DEBUG option is not selected, no such check will be performed.

The advantage of using the DEBUG option is that wrong API parameters will be detected; the disadvantage is the loss of performance (API calls are slowed down by this parameter checking).

The advantage of not using the DEBUG option is of course the speed gained; the disadvantage is that any wrong-value parameter used at any API call may cause (big) trouble, possible leading to system crash.

It is advisable to start testing an RTM/Z80 application always in DEBUG mode, to find all the possible programming errors, and only then to switch to the faster non-DEBUG mode.

All the “objects” used by RTM/Z80 (semaphores, task control blocks, queues, mailboxes, timers) are allocated in / deallocated from / the “common” dynamic memory, allowing for an efficient use of the available RAM memory.

Starting and shutting down RTM/Z80

#include <rtsys.h>

RTM/Z80 will execute a ”call _**main**” instruction, after being booted. The **“_main**” function must issue an RTM/Z80 **StartUp** call, in order to initialize all the system data structures and to start the first user task. Until **StartUp** is executed, no other RTM/Z80 functions must be called.

Examples:

(as the C language main() function)

```
void   main(void)
{
       …
       StartUp(TaskStackSize, MyFirstTask, TaskPriority);
}
```

(or as a label in assembler)

```
       psect  text
       GLOBAL _main
_main:
       ld     bc,0E0H      ;stack size
       ld     hl,Task      ;task start address
       ld     e,5          ;task priority
       call   __StartUp
       ret
```

(A **psect** is a named section of the program, in which code or data may be defined at assembly time. Usually **text** = code section, **data** = read-only data section and **bss** = read/write data section).

If RTM/Z80 is resident in ROM, then _**main** is set equal to 2800H (at boot, the system code will be copied from (E)EPROM to RAM and executed there, and the area starting from 2800H is reserved for the user) (see the Chapter Using RTM/Z80 in a ROM/RAM configuration).

void* StartUp(short stack_size, void* StartAddr, short Prio);
BC= Stack_Size, HL= StartAddr, E=Prio, returns Task Control Block (TCB) address of the task (or zero) in HL.

Data structures are initialized, hardware is setup, interrupts enabled, and the provided parameters are used to start the first task (See Chapter Tasks).

From this first task, other user tasks may be started. The address of the TCB for this task is returned (or NULL (zero) if no more dynamic memory was available).

void   ShutDown(void);
All active, waiting and suspended tasks are stopped, pending I/O operations are aborted, the real-time clock is reset and the RTM/Z80 is shut down.

Control is passed to the caller of the StartUp function, exactly as executing a “return” from StartUp.

short GetHost(void);
Returns HL=0 if RTM/Z80 is executed on Z80SIM’s CPM, or HL=1 if RTM/Z80 is executed on RC2014.

Lists handling

RTM/Z80 uses double-linked lists to manage all the “system objects” (allocated blocks of memory, tasks control blocks, semaphores, queues, mailboxes, timers, I/O requests, etc.).

All these system objects are resident in the dynamic memory (see the next chapter).

Each list has a “list header”, 4 bytes, containing the pointers to first and last list elements.

Each list element has a “link area”, 4 bytes, containing the pointers to the previous and next list elements.

The lists handling routines must be used only for lists with headers and elements allocated in the dynamic memory (using Balloc, see next chapter).

This is because the routines are optimised for speed, and the list and header pointers are incremented / decremented using only the low byte “part” of the 2-byte pointer (e.g. INC L, instead of INC HL).

Given the fact that all the addresses of the memory blocks allocated in the dynamic memory have values with their last 4 bits zero, this works well, but, again, it will not work for list headers and/or list elements placed randomly in the memory (consider the case when the header is placed at 0FFFH, incrementing only the low part of this address will produce the “next” address as 0F00H, which is, of course, wrong).

These functions are accessible only from Z80 assembler, passing the arguments via registers (second approach) and must be called only under interrupts disabled.

__***InitList*** – Initialize a list header

```
;       must be called under interrupts DISABLED
;       HL=ListHeader, returned
;       affected regs: HL,DE
;       A,BC,IX,IY not affected
```

__***AddToL*** – Adds a new list element to a list

```
;       must be called under interrupts DISABLED
;       HL=list header, DE=new
;       return HL=new
;       affected regs: A,BC,DE,HL
;       IX,IY not affected
```

__***FirstFromL*** – Returns a pointer to the first list element, or zero if list is empty

```
;       must be called under interrupts DISABLED
;       HL=list header
;       returns (HL=first and Z=0) or (HL=0 and Z=1 and CARRY=0)
;       affected regs: DE,HL
;       A,BC,IX,IY not affected
```

__***LastFromL*** – Returns a pointer to the last list element, or zero if list is empty

```
;       must be called under interrupts DISABLED
;       HL=list header
;       returns (HL=last and Z=0) or (HL=0 and Z=1)
;       affected regs: DE,HL
;       A,BC,IX,IY not affected
```

__***NextFromL*** – Returns a pointer to the next list element, or zero if this was the last one

```
;       must be called under interrupts DISABLED
;       DE=list header, HL=current element
;       returns (HL=next after current and Z=0) or (HL=0 and Z=1 if end-of-list)
;       affected regs: A,DE,HL
;       BC,IX,IY not affected
```

__***RemoveFromL*** – Removes a list element from the specified list

```
;       must be called under interrupts DISABLED
;       HL=element to be removed
;       Returns HL=Element
;       affected regs: A,BC,DE,HL
;       IX,IY not affected
```

__***InsertInL*** – Inserts a new list element before the specified current element of a list

```
;       must be called under interrupts DISABLED
;       HL=current element, BC=new element
;       returns HL=new element
;       affected regs: A,BC,DE,HL
;       IX,IY not affected
```

__***GetFromL*** – Removes the first element from the specified list (if any), or returns zero

```
;       must be called under interrupts DISABLED
;       HL=list header
;       returns (HL=element and Z=0) or (HL=0 and Z=1 if list empty)
;       affected regs: A,BC,DE,HL
;       IX,IY not affected
```

__***RotateL*** – Rotates the list elements (last becomes first, first becomes second, etc)

```
;       must be called under interrupts DISABLED
;       HL=list header
;       returns (HL=0 and Z=1 if list empty or has 1 element), else (HL=1 and Z=0)
;       affected regs: A,BC,DE,HL
;       IX,IY not affected
```

Memory allocation / deallocation

#include <balloc.h>

Dynamic memory allocation is when an executing task requests that the operating system give it a block of main memory. The task then uses this memory for some purpose.

Tasks may request memory and may also “return” previously dynamically allocated memory. Memory may be returned whenever it is no longer needed. Memory can be returned in any order without any relation to the order in which it was allocated.

8 Kbytes of RAM dynamic memory is available in RTM/Z80. All the “objects” (TCB’s, semaphores, queues, mailboxes, timers, etc.) created and managed by the RTM/Z80 system are allocated / deallocated from this area of memory.

The allocation algorithm used is the so-called “buddy-system” method (see Donald Knuth, The art of computer programming, vol 1-fundamental algorithms).

The buddy memory allocation technique is a memory allocation algorithm that divides memory into partitions to try to satisfy a memory request as suitably as possible. This system makes use of splitting memory into halves to try to give a best fit.

The size of a block is 2^n. Power-of-two block sizes make address computation simple, because all buddies are aligned on memory address boundaries that are powers of two.

When a larger block is split, it is divided into two smaller blocks, and each smaller block becomes a unique buddy to the other. A split block can only be merged with its unique buddy block, which then reforms the larger block they were split from.

In RTM/Z80, the smallest memory block that can be allocated has 16 (2^4) bytes, while the largest has 4096 (2^{12}) bytes.

void* Balloc(short Size);
C=”Size” (0 to 8), returns the address of the allocated memory block in HL, registers A,BC,DE are affected. NULL (zero) is returned if no more free memory is available.

Allocates a block of size 2^{Size+4} bytes and returns its address. Therefore, users may request to allocate blocks of memory starting from the minimal size of 10H(2^4) bytes to the maximal size of 1000H(2^{12}) bytes.

Each allocated memory block contains a “prefix” area (6 bytes), located at the beginning of the block. This area contains a “link” space (4 bytes, see previous chapter), then a byte containing the ID of the owner task, and then a byte containing the block size (0 to 8).
The last two bytes of the “prefix” of an allocated memory block must not be changed by the user, e.g. data must be stored outside (after) this “protected area”.
However, the “link” part of an allocated memory block (first 4 bytes) can be used by the list handling routines.

For example, in Z80 assembler code, after obtaining the address of a block of 10H bytes:

```
            DI
            LD    C,0
            CALL  __Balloc     ;HL=allocated block address
            EI
```

, the caller will use for storage only the area starting from HL+6:

```
            PUSH  HL           ;save block address on stack
            LD    DE,6         ;skip protected area
            ADD   HL,DE        ;HL=address of the storage area (size=0AH)
            EX    DE,HL        ;DE=address of the storage area (size=0AH)
            LD    HL,source    ;move 10 bytes from "source" to the allocated block
            LD    BC,10
            LDIR
            DI
            LD    HL,ListHeader
            CALL  __InitList   ;init list
            POP   DE           ;HL=header,DE=block address
            CALL  __AddToL     ;add block to the list
            EI
            …
ListHeader: defs  4
```

, but the block may be added to a list without any problem (however, this part must be executed under interrupts disabled).

In C code, this "protected" area is evident examining the structure of the allocated memory block:

```
struct bElement {
       void* next;
       void* prev;
       char Status; /* 0 = available, else ID of owner task */
       char Size; /* 0=10H to 8=1000H */
       /* DATA – must be stored here */
};
```

Note: calling __Balloc from assembly language (parameter values in registers) must be done under interrupts disabled.

short BallocS(short MemSize);
BC=MemSize (size in bytes, should be <= 1000H), returns BC=block size (0 to 8). If the parameter provided is > 1000H, it is "cut" to 1000H.

Returns the block size (0 to 8) corresponding to the provided memory buffer size; may be used to compute the parameter to be used at Balloc call, given the size of the buffer to be allocated, for example:

```
Balloc(BallocS(0x100)); /* allocate 0x100 = 256 bytes */
```

short Bdealloc(void* addr_block, short Size);
HL=block, C=Size (0 to 8) (Size is used only if compiled with DEBUG option), returns HL=NULL(0) if deallocation failed, else not NULL, registers A,BC,DE are affected.

Deallocates (frees) the specified memory block of address addr_block and size = 2^{Size+4}.

If DEBUG option was used at compiling the system, size is provided as a check parameter in order to avoid deallocating wrong blocks of memory. In this case, NULL (zero) is returned if wrong address or wrong size is provided or if the memory block is not allocated.

Note: calling __Bdealloc from assembly language (parameter values in registers) must be done under interrupts disabled.

void* Extend(void* addr_block);
HL=block, returns HL=extended block or NULL if extending fails, registers AF,BC,DE are affected.

Allocates a new memory block, double the size of the specified block, copies all the data from the old block to the new block, deallocates the old block, returns the new block address.

Note: calling __Extend from assembly language (parameter values in registers) must be done under interrupts disabled.

short GetMaxFree(void);
Returns in HL the “size” of the largest free memory block, as a value in the range 0 to 8.
Registers A,BC,DE,HL are affected.

If no more memory is available, returns -1 (0FFFFH).

short GetTotalFree(void);
Returns in HL the total amount (in bytes) of free memory available to be allocated.
Registers A,BC,DE,HL,IX are affected.

void* GetOwnerTask(void* adrblock)
HL= block. Returns HL=TCB address of task who owns the block of memory (the task who made the allocation of the block).

Storing large amounts of data in the upper 64KB RAM memory (if available)

Usually, the RC2014 hardware has 64K RAM plus 32K EPROM.

Certain RC2014 hardware configurations (e.g. Steve Cousins SC108, Phillip Stevens MemoryModule) are provided with two banks of 64KB RAM (the “lower” and the “upper” 64KB RAM bank).

For these configurations, RTM/Z80 provides a practical way to store large amounts of data (up to 56KB) in the “upper” RAM bank:

void LowToUp100H(void* From, void* To)
IX=address of the source data (in the lower RAM bank), IY=address of the destination buffer (in the upper RAM bank).

A total of 256 bytes (100H) are moved from the lower RAM to the upper RAM, and the IX and IY registers are incremented with 256 (in case you are using a call from Z80 assembly language, this means the pointers are updated, in position to handle a next (possible) LowToUp100H call).

This function is provided only when, in the configuration file **config.mac**, the following two settings are chosen when building the RTM/Z80 system:

```
WATSON      equ 0  ;1=Watson is used (not for CP/M)
RAM128K     equ 1  ;0=only 64K RAM, 1= 2 x 64K RAM available
```

This means that we indicated that we have 2 x 64KB RAM, but we do not want that WATSON utility uses the upper 64KB RAM bank, making thus possible to use this upper 64KB RAM as a temporary storage-area for our RTM/Z80 application data.

The highest address, from this upper 64KB RAM bank, that is allowed to be accessed by this function must not exceed 0DF00H; this is critical to be respected as a mandatory rule, because after the mentioned address there are stored the “service” routines that move bytes from the “lower” to the “upper” RAM banks (these routines, loaded by the **hexboo**t program, are stored at the same addresses in both the “lower” and “upper” RAM banks, in order to make possible the execution of these “service” routines).

If overwritten, these routines will fail to perform their duty, causing even a system crash.

So, as a basic rule, less than 56K bytes must be “stored” using the LowToUp100H function calls.

After the execution of the RTM/Z80 application that stored his data in the “upper” RAM bank, the data may be retrieved easily (e.g. to be written into a CP/M file), using a simple CP/M program that accesses the “upper” RAM bank and “moves” the data from there into the “lower” RAM bank.

Remember, the same basic trick must be followed: the “service” routines that move bytes from “up” to “low” RAM must be stored at the same physical address in both the “lower” and “upper” RAM, somewhere in the high CP/M TPA area of memory.

Tasks

#include <rtsys.h>

In RTM/Z80, up to 32 tasks can be started concurrently. Each task has a “TCB” (Task Control Block), allocated by RTM/Z80 at task start, which contains also its “private stack” placed in the high (last) part of the TCB. Each task is uniquely defined by the address of its “TCB” (Task Control Block), created when the task is ‘started’.

A task may have one of the following states: *active, waiting* or *suspended*.

User tasks priorities range from 1 to 127, while the RTM/Z80 system tasks (I/O drivers, CMD task) are assigned with the range of priorities from 128 to 255 (with the special case of the garbage collector task, having the lowest possible priority = 0).

Active tasks are given access to the CPU time according to their priority (highest priority first), but in the situation when there are more than one active concurrent tasks, an optional round robin mechanism is provided to facilitate a fair sharing of the CPU time (CPU time slices are given according to the tasks priorities).

Tasks have also a unique ID (from 1 to 255), used by RTM/Z80 to “stamp” every block of memory allocated by the task. The “garbage cleaner” task will search for blocks of memory “stamped” with the task ID when trying to deallocate blocks of memory owned by terminated (stopped) tasks.

Active tasks may be suspended or stopped when necessary. After stopping a task, it can be started again, but a limit of 255 total “task executions” is imposed because the need for a unique ID for each task.

For example, it is possible to start then stop a task repeatedly, in a loop, for a limited number of times, but no more than 255 times.

void* RunTask(short Stack_Size, void* StartAddr, short Prio);
BC= Stack_Size, HL= StartAddr, E=Prio (1 to 127), returns TCB address of the task in HL.

A task with the provided start address and priority is created (a TCB is allocated in the dynamic memory) and started, becoming active (its TCB address is inserted into the active tasks queue, according to its priority, then control is passed to the highest priority task from the active tasks queue). If the priority provided does not fit in the range 1 to 127, it will be set to 1.

If the TCB could not be allocated (there is no more free memory), or the maximum number of active tasks was reached, or more than 255 tasks were started, NULL(0) is returned.

The first parameter (Stack_Size) sets the size of stack for the new task.

The first 32 (20H) bytes in the TCB are used as a “private” area by the RTM/Z80 to store important data related to the task (priority, stack pointer, ID etc.), but the rest of the TCB area is used as the task stack area.

Because of this structure of the TCB area, and considering that all allocated memory blocks are sized as powers of 2, it is important to choose carefully the value of stack_size.

For example, it make sense to use the value 0E0H, because added to 20H (size of “private” area), it gives 100H, a power of 2 (the system will allocate for the TCB exactly 100H).

It would be unwise to use the value 0E8H, because it will make the system to allocate 200H (0E8H + 20H = 108H, and the “next” power of 2 is 200H), and it will generate a “loss” of 0F8H bytes (the system allocates 200H, but since the stack_size requested is 0E8H, it will set SP=TCB+20H+0E8H, wasting the last 0F8H bytes of the TCB – these bytes cannot be accessed nor used by the current task or other tasks).

Special care must also be given to correctly select an appropriate magnitude of the stack size, depending on the stack usage of the task.

Normally, 60H should be enough for a task written in Z80 assembly language (60H=96 bytes, equivalent to 48 CALL or PUSH instructions), but in the case when the task is written in C and heavily uses C library functions (e.g. sprintf), a larger size must be chosen (e.g. 1E0H).

If the system was built using the DEBUG setting, RTM/Z80 checks (at task switching time) the current active task stack pointer value versus the “remaining” stack space and issues a warning if the remaining stack space drops below 20H, by printing on the terminal (console) the current task TCB address (in hexadecimal) followed by an ‘!’.

Also, the ***StackLeft*** function (see below) may be used to obtain the amount of available stack space, and in case the available stack space dropped too low, the ***IncTaskStack*** function (see below) may be used to increase the task stack size.

It is important to keep low the number of concurrent active tasks; too many active tasks will affect the performance of the system.

short StopTask(void* taskTCB);

HL=taskTCB, returns HL=NULL(0) if the parameter provided is not the address of a task TCB, else not NULL. Only valid parameters are accepted, a NULL (zero) value is returned when the function is called using a non-existent TCB address.

The specified task is terminated (task is removed from the active tasks queue), task’s TCB is deallocated, all timers started by the task are stopped, all I/O operations issued by the task are stopped. Control is passed to the highest priority task from the remaining active tasks queue.

The garbage cleaner task will automatically deallocate all the blocks of memory allocated but not yet deallocated by the terminated task (memory leaks).

After the last active user task executes StopTask, the RTM/Z80 system hosting the user applications is automatically shutdown.

void* GetCrtTask(void);
Returns HL=address of current task TCB. Returns the TCB address of the current task.

void Suspend(void);

Suspends the execution of the current task (task is removed from the active tasks queue). Control is passed to the highest priority task from the active tasks queue.

short Resume(void* taskTCB);
HL=taskTCB, returns HL=NULL(0) if the parameter provided is not the address of a task TCB, or if the task is not suspended, else returns not NULL.

Resumes the execution of the specified suspended task (it is inserted into the active tasks queue, according to its priority, then control is passed to the highest priority task from the active tasks queue), and not NULL is returned.

The parameter passed to the function must be a valid TCB address of a suspended task, otherwise NULL (zero) is returned.

short StackLeft(void* taskTCB);
DE=taskTCB, Returns in HL the size of the stack still available for the specified task. Registers A,BC,DE,HL are affected. The size of the stack still available is calculated subtracting from the stack size the size of the area already “used” by the PUSH operations executed before this call.

For example, if the task was created with a stack size of 60H (96 bytes), and the previous 2 CALL and 5 PUSH instructions “consumed” 7*2=14 bytes before the call of the function, the StackLeft function returns the value 82=96-14.

If the “stack left” drops below 20H (32 bytes), future CALL or PUSH operations risks “altering” the task TCB “private area”, leading to unpredictable system behaviour or even system crash.

In the case of “stack-hungry” code or “re-entrant” algorithms or tasks written in the C language using extensive C library functions, this function should be used frequently in order to provide an early warning.

As a generic rule, tasks written in C language using C library functions must have larger stack sizes (1E0H is a safe choice), while for the tasks written in Z80 assembler, an acceptable TCB size is 60H.

short IncTaskStack(short stackSize);
BC = stackSize. Returns not NULL if stack size was increased to the new value, else 0 if no more memory available or the provided size is less than the actual size of the stack.

This function sets the size of the current active (executing) task stack to the value provided as a parameter. A new (larger) TCB is built for the task, old stack is moved to new TCB, then the old TCB is deallocated. This way, the old contents of the stack is entirely preserved.

short GetTaskSts(void* taskTCB);
BC=task TCB. Returns HL=1 if the task is active, 2 if is waiting a semaphore or 3 if is suspended. Returns HL=NULL(0) if the parameter provided is not the address of a task TCB.
This function returns the status of the specified task.

void* GetTaskByID(short ID);
C=ID. Returns the task TCB with the provided ID, or NULL if no such task exists.

This function searches the TCB of a task by its ID. Might be used to find out the owner of an allocated block of memory (see also ***GetOwnerTask*** from memory allocation/deallocation).

void GetTaskPrio(void* taskTCB);
BC=TaskTCB. Returns HL=priority, or -1 if the parameter provided is not the address of a real task TCB.

This function returns the specified task's priority.

void SetTaskPrio(void* taskTCB, short Prio);
BC=TaskTCB, E=Prio. Returns HL=0 if the parameter provided is not the address of a real task TCB, or if the priority specified is > 127, else returns 1.

The specified priority is set to the specified task, then control is passed to the highest priority task from the active tasks queue. That means, the current task may loose/gain access to the CPU, depending on the chosen new priority.

Semaphores

#include <rtsys.h>

A **semaphore** is a mechanism used to control the tasks access to a common resource.

Semaphores which allow an arbitrary resource count are called counting semaphores, while semaphores which are restricted to the values 0 and 1 (or locked/unlocked, unavailable/available) are called binary semaphores and are used to implement locks. RTM/Z80 implements **counting semaphores**; they contain a counter (2 bytes) and a priority-ordered queue of tasks waiting for this semaphore.

The counter indicates how many resources are available, while the queue is used to manage the tasks willing to access those resources. The queue is managed as a priority-ordered queue.

Two basic operations are defined: Signal and Wait.

Basically, Signal may be described as “if the waiting queue is empty, increment the counter, else take the first task from the queue and insert-it into the active tasks list (highest priority task will be given access to CPU)”, and Wait as “if the counter is zero, insert the current task into the queue (the remaining highest priority task will be given access to CPU), else decrement the counter and resume execution”.

For example, suppose we have a queue with limited storage capacity, let’s say 16 bytes.

In order to allow the access to this queue, two counting semaphores are needed:

- AvailableSpace, initialized with the counter=16
- AvailableData, initialized with the counter=0

Write-to-queue can be described as:

Wait(AvailableSpace)
Move a byte from the caller to the queue
Signal(AvailableData)

Read-from-queue can be described as:

Wait(AvailableData)
Move a byte from the queue to the caller
Signal(AvailableSpace)

void* MakeSem(void);
returns HL=SemAddr (or NULL if no dynamic memory available).

Allocates memory for the semaphore, set counter=0 and sets-up an empty queue.

void* ResetSem(void* SemAddr);
HL=SemAddr. If the parameter provided is not the address of a real semaphore or if a task is waiting for the semaphore, NULL(0) is returned, else a not NULL value is returned.

Resets the already allocate semaphore (set counter=0 and sets-up an empty queue).

short Signal(void* SemAddr);
HL=SemAddr. If the parameter provided is not the address of a real semaphore, NULL(0) is returned, else a not NULL value is returned. The __Signal assembler function returns only CARRY=1 if wrong semaphore address provided, else CARRY=0.

If the semaphore queue is not empty, the first task is extracted from the queue and inserted into the active tasks queue, according to its priority, then control is passed to the highest priority task.

If the queue was empty, the semaphore counter is incremented. The queue of tasks waiting for the semaphore is not a FIFO or LIFO queue, but a priority-ordered queue (according to the priority of the tasks waiting for the semaphore). Therefore, always the highest-priority task waiting for the semaphore will obtain the access to CPU time.

short Wait(void* SemAddr);
HL=SemAddr. If the parameter provided is not the address of a real semaphore, NULL(0) is returned, else a not NULL value is returned. The __Wait assembler function returns only CARRY=1 if wrong semaphore address provided, else CARRY=0.

If the semaphore counter is > 0, it is decremented and execution of the current task continues. Else, the current task is extracted from the active tasks queue and inserted into the semaphore queue, according to its priority, then control is passed to the highest priority task from the active tasks queue.

short DropSem(void* SemAddr);
HL=SemAddr. Returns a NULL when the parameter provided is not a semaphore or the semaphore queue is not empty, else returns a not NULL value. Frees the memory allocated for the semaphore.

short GetSemStatus(void* SemAddr);
HL=semaphore address. Returns in HL the semaphore counter. Returns a NULL when the parameter provided is not a semaphore.

Data Queues

#include <queue.h>

A data queue can store a number of data batches in a buffer allocated when making the queue.

Each data batch is a vector of 2-byte (word) elements.

An obvious use of the data queue is to send/receive pointers between tasks.

A queue may accept data batches with sizes up to 255 * 2 bytes.

The number of data batches allowed for a queue is limited to 255.

However, there is also a limitation related to the total size of such a buffer containing data batches (buffer size must be smaller than 1000H, the maximum size of a memory block possible to be allocated).

Examples of queues:

- A queue of 255 words (total size = 200H)
- A queue of 32 sets of 16 words (total size = 400H)
- A queue of 16 sets of 128 words (total size = 1000H)

A data queue is “guarded” by two private semaphores, used to manage the full/empty queue events.

Practically, the Write to queue and Read from queue operations can be described as follows:

Write:

Wait for available space in the queue
Move the data batch from the caller to the queue
Signal data available

Read:

Wait for data available
Move the data batch from the queue to the caller
Signal space available in the queue

void* MakeQ(short batch_size, short batch_count);

B=batch size (number of 2-bytes to be moved), C=batches count, returns HL=queue header (or NULL if no dynamic memory available). Returns NULL (zero) if the batch_size>255 or batch_count > 255 or no memory was available for the queue or buffer.

Allocates memory for the queue and initializes the data queue according to the provided batch_size and count of batches, allocates the necessary buffer to store the batches.

short DropQ(struct Queue* queue);

BC=queue. Returns NULL if the parameter provided is not the address of a queue or if the queue contains data not being read yet, else returns a not NULL value.

Deallocates the buffer allocated to the queue and to the data batches.

short WriteQ(struct Queue* queue, void* info);
BC=queue, DE=pointer to data. Returns NULL if the parameter provided is not the address of a queue, else returns a not NULL value.

Adds the data batch pointed by the provided address “info” to the queue. Practically, a number of 2*batch_size bytes will be copied from “info” to the queue. If no more space is available in the queue buffer, the caller will wait for the next ReadQ to free the necessary space.

short ReadQ(struct Queue* queue, void* buf);
BC=queue, DE=pointer to buffer. Returns NULL if the parameter provided is not the address of a queue, else returns a not NULL value.

Read and extract from the queue buffer the next data batch and stores it to the provided buffer. Practically, a number of 2*batch_size bytes will be copied from the queue to the provided buffer. If no data batch is available in the queue, the caller will wait for the first WriteQ to put a data batch in the queue.

short GetQSts(struct Queue* queue);
HL=queue. Returns in HL the number of data batches not yet read. Returns -1 if the parameter provided is not the address of a queue.

Mailboxes

#include <mailbox.h>

Mailboxes are provided to facilitate sending and receiving messages of fixed length between tasks. The length of a message is limited to 249 bytes.

For each message sent, a block of memory is allocated and the data is copied to it from the sender memory area.

When receiving a message, the data is copied from this block of memory to the receiver buffer, then the block of memory used to transport the data is deallocated.

To synchronize between senders and receivers of mails, an internal semaphore belonging to the mailbox is used.

Practically, the Write to mailbox and Read from mailbox operations can be described as follows:

Write:

Allocate a block of memory to store the message
Move the message from the caller to the block of memory
Add the block of memory to the mailbox list of messages
Signal message available

Read:

Wait for message available
Get the first block of memory from the mailbox list
Move the message from the block of memory to the caller
Deallocate the block of memory

void* MakeMB(short MesageSize);
C=MessageSize, returns HL=mailbox or NULL if no dynamic memory is available.

Allocates memory for the mailbox and initializes the mailbox message queue, sets the given size as the length (in bytes) of the messages and resets the internal semaphore. Returns NULL (zero) only if the given message size was > 249.

short DropMB(struct Mailbox* mb);
HL=mailbox

Deallocates the buffer allocated to the mailbox. Returns NULL if the parameter provided is not the address of a mailbox or if the mailbox queue is not empty (there are messages not yet read), else returns a not NULL value.

short SendMail(struct MailBox* MBox, void* Msg);
HL=MBox, DE=Msg

Allocates a memory buffer, copies the message to this buffer, adds-it to the mailbox list. Returns NULL (zero) only if could not allocate or the provided parameter is not a real mailbox.

short GetMail(struct MailBox* MBox, void* DestBuffer);
HL=Mbox, DE=buffer. Returns NULL (zero) only if the provided parameter is not a real mailbox.

Waits for the first available mail, then extracts the first mail from the mailbox list, copies the content to the destination buffer and deallocates the space needed for the message.

short GetMBSts(struct MailBox* Mbox);
HL=Mbox. Returns in HL the number of mails not yet read. Returns -1 only if the provided parameter is not a real mailbox.

Timers

When certain code sequences need to be executed repeatedly at certain time intervals, RTM/Z80 timers must be used.

#include <rtclk.h>

void* MakeTimer(void);
Returns HL=Timer or NULL if no dynamic memory available.

Allocates dynamic memory for the timer.
.
short DropTimer(RTClkCB* Timer);
HL=timer

Deallocates the buffer allocated to the timer. Returns NULL if the parameter provided is not the address of a timer or the timer is started (in this case, it must be stopped first).

short StartTimer(struct RTClkCB* Timer, struct Semaphore* Sem, short Ticks, char Repeat);
HL = Timer, DE = Sem, BC = Ticks, A=Repeat

Initializes and starts the Timer, using the provided Ticks parameter. After 5 * Ticks milliseconds, a **Signal**(Sem) will be executed by the real-time clock driver. If the Repeat parameter is zero, the timer is then stopped, else it continues to issue a **Signal**(Sem) each 5*Ticks milliseconds. A NULL(0) is returned if the Timer is already started.

Too many started Timers may affect the performance of the system!

short StopTimer(struct RTClkCB* Timer);
HL = Timer. Stops the specified timer. A NULL(0) is returned if the parameter provided is not a Timer.

long GetTicks(void);
Returns current counter of ticks (4 bytes: DE=low(counter), HL=high(counter)).

The system maintains a 4-bytes counter of 5ms ticks, which is made accessible using this function.

This counter is incremented each time a real time interrupt occurs (at each 5ms), in a round-robin manner (when reaching the maximum 4-bytes storage capacity, it is reset to zero).

Therefore, time intervals shorter than 2^{32} x 5 ms can be measured with 5ms accuracy.

short GetTimerSts(struct RTClkCB* Timer);
HL=Timer. Returns in HL the current (remaining) ticks for the timer. HL= -1 is returned if the parameter provided is not a real Timer.

void RoundRobinON(void);
Enables (starts) the use of “round-robin” scheduling.

void RoundRobinOFF(void);
Disables (stops) the use of “round-robin” scheduling.

Input/Output - Console (terminal) I/O functions

#include <io.h>

Read and write functions are provided, enabling reading or writing strings of characters from/to the terminal (console). The usual way to issue an I/O request should be:

```
I/O function(buffer, count, &Sem);
Wait(&Sem);
```

The I/O requests are sent from the user task to the CON_Driver, a high priority task, using a queue to handle these requests.

The CON_Driver reads from the queue the I/O request and initiates the I/O operation; at the completion of the I/O operation, a Signal will be issued for the semaphore specified in the I/O request.

In the case of the read function:

- the ENTER key will be interpreted as an end of the read request, in this case the read buffer will contain only the characters read before ENTER, followed by the 'string terminator' character (0).

- the BACKSPACE key is processed as "erase last entered character", enabling line editing.

void CON_Read(void* buf, char len, void* SemAddr);
HL=buf, DE=Sem, C=len

Issues a read request to the terminal console, providing a buffer address, a counter (<=255 chars) and a semaphore address. The characters read will be stored into the buffer, followed by an extra byte with 0 (zero) value, acting as a 'string terminator' character (space must be provided in the buffer to accommodate this extra byte).

The console device driver will "process" the command and after finishing it will issue a Signal for the given semaphore. The Semaphore must be initialized before issuing any I/O command.

void CON_Write(void* buf, short len, void* SemAddr);
HL=buf, DE=Sem, BC=len

Issues a write request to the terminal console, providing a buffer address, a counter(,=255 chars) and a semaphore address. The requested number of characters will be written, without any other extra characters (no CR, LF or zero will be appended).

The console device driver will "process" the command and after finishing it will issue a Signal for the given semaphore.

The Semaphore must be initialized before issuing any I/O command.

short CTRL_C(void);
Returns HL=1 if CTRL C was pressed, else returns HL=0. The control for CTRL C is made only during write operations or if no input/output operations are active.

Asynchronous serial communications I/O functions

void Reset_RWB(void);
Initializes the communications support routines.

void WriteB(void* buf, short len, void* SemAddr);
HL=buf, DE=Sem, C=len (up to 255 bytes)

Issues a write request, providing a buffer address, a counter and a semaphore address. The device driver will ”process” the command and after finishing it will issue a Signal for the given semaphore. The Semaphore must be initialized before issuing any I/O command.

void ReadB(void* buf, char len, Semaphore* S, void* Timer, short TimeOut);
HL=buf, DE=Sem, C=len (up to 255 bytes), IY=Timer, IX=TimeOut

Issues a read request, providing a buffer address, a byte counter, a semaphore address, a timer address and a timeout interval (in 5ms units). If the requested number of bytes is read before the timeout expires, or if the timeout expires before receiving all the requested bytes, a Signal(S) is issued.

For example, if 255 bytes are expected to be read at a baud rate of 115.2K, a timeout equal to 10 is recommended (10*5=50 milliseconds).

short GetCountB(void);
Returns A (or low part of returned value) = the number of NOT read characters, and H (or high part of returned value) = I/O error code (10H=parity err, 20H=rx overrun err, 40H=crc/framing err), if any (0=no error).

Called after a ReadB, returns the number of NOT read bytes and the error/success code of the read request.

An example of how to use the “communications” read function:

```
            call  __Reset_RWB
            call  __MakeTimer
            ld    (Timer),hl
            call  __MakeSem
            ld    (Sem),hl
            ex    de,hl         ;DE=sem addr
            ld    hl,Buf
            ld    c,255
            ld    ix,10         ;timeout 50 ms
            ld    iy,(Timer)
            call  __ReadB
            ld    hl,(Sem)
            call  __Wait
            call  __GetCountB
            or    a             ;check # NOT read
            jr    z,AllBytesRead
            ld    a,h
            cp    …             ;see err code
            …
AllBytesRead:                   ;all CHAR_COUNT were read
```

These functions are intended to read and write bytes via the Z80 SIO serial asynchronous interface, offering support to implement communication protocols. The ability to handle such I/O functions is based on some technical characteristics of RTM/Z80 and Z80 SIO.

The RTM/Z80 has no “disabled” instruction sequences that execute longer than 175 microseconds (for a Z80 running at 7.3728 MHz). The ZILOG SIO has an internal 3-byte buffer to handle “not-read” bytes. These circumstances enable the RTM/Z80 serial communications driver to handle baud rates up to 115.2 K. Let’s explain why.

A baud rate of 115.2Kbits is equivalent to an average of 80 microseconds/byte.

Because RTM/Z80 has no “disabled” instruction sequences that execute longer than 175 microseconds, this leads to up to 3 bytes “waiting to be read” inside the disabled 175 microseconds interval, compatible with the size of the ZILOG SIO 3-byte internal buffer mentioned above.

Furthermore, a special 256 bytes “ring” buffer is used to accumulate incoming unsolicited inputs. When no I/O operation is active or during a WriteB request, the “unsolicited” inputs are stored in this buffer. These bytes will be included in the response to the next ReadB request.

This way, the “bytes receiver” task may stay “busy” (without effectively reading bytes) several milliseconds, before risking to lose inputs.

This makes possible safe serial communications at baud rates up to 115.2K even under heavy data processing, with the condition that “data communication” tasks will keep “I/O-less” computing sequences shorter than 20 milliseconds.

The CMD console handler system task provides a command (HEX) able to read a .HEX file, and optionally execute-it. Large (~16 K bytes) .HEX files may be loaded, even while the system is busy executing other user application tasks.

Of course, a too heavy use of some “critical” RTM/Z80 functions (e.g. RunTask, StopTask, IncTaskStack, Balloc, Bdealloc) while reading bytes on the serial interface will raise the likelihood of I/O errors (reported by SIO), therefore it is recommended to keep such function’s calls at a low frequency.

Also, because the system checks frequently for incoming unsolicited inputs, to store them in the “ring” buffer, the overall performance of the system is affected. If your application does not need to support I/O communications protocols, it’s best to deselect the IO_COMM configuration option, enhancing the system performance (see Chapter Configuring RTM/Z80).

X-MODEM protocol support functions

XMODEM is a simple file transfer protocol developed by Ward Christensen for use in his 1977 MODEM.ASM terminal program.

It allowed users to transmit files between their computers when both sides used MODEM.

Keith Petersen made a minor update to always turn on "quiet mode", and called the result XMODEM.

XMODEM, like most file transfer protocols, breaks up the original data into a series of "128 byte packets" that are sent to the receiver, along with additional information allowing the receiver to determine whether that packet was correctly received.

If an error is detected, the receiver requests that the packet be re-sent.

Using its asynchronous serial communications platform, RTM/Z80 provides the following functions to implement the XMODEM protocol:

short XmSend(struct MailBox* MB_Data);
HL=pointer to user data mailbox; returns 1=OK, -1=Cancelled, -2=Communications failure

Sends the data stored into the mailbox via the XMODEM protocol to a receiver.

The data mailbox must be created using the call MB_Data = MakeMB(129).

Before calling XmSend, all the data to be sent via XMODEM must be stored in the mailbox, using SendMail(MB_Data, user_data) calls; the user_data will contain 128 data bytes plus a byte with the value different from EOT=CTRL D (4).

A last mail (end-of-data) must contain in its last byte (byte nr. 129) the value EOT=CTRL D (4); its first 128 bytes are ignored.

As indicated in the original XMODEM protocol, the last 128-byte packet sent must be padded with special SUB bytes (value=1AH), up to the limit of 128 bytes.

short XmRecv(struct MailBox* MB_Data);
HL=pointer to user data mailbox; returns 1=OK, -1=Cancelled, -2=Communications failure

Receives data via the XMODEM protocol from a sender and stores-it to the user mailbox.

The data mailbox must be created using the call MB_Data = MakeMB(129).

After calling XmRecv, the data received via XMODEM will be stored in the mailbox.

The data may be retrieved using GetMail(MB_Data, user_data) calls; the user_data will contain 128 data bytes plus a byte serving as “end” marker (if this byte is equal to EOT=CTRL D (4), it marks the end of the data received – the first 128 bytes from this mail must be ignored).

How to use XmSend / XmRecv

Because the mails containing the user data, to be sent/received via XMODEM, are stored in the dynamic memory, the amount of data sent/received must be limited (4Kbytes is a decent upper limit), if we are using simple XmSend / XmRecv calls.

If we want to handle large amounts of data, then we must use another way of working with these functions.

Here is how: (example of XmRecv handling). We must create and run a separate task to handle XmRecv, and use GetMail to obtain the data.

```
#include <dlist.h>
#include <balloc.h>
#include <rtsys.h>
#include <mailbox.h>
#include <io.h>
#include <xmodem.h>

#define EOT 'D'- 0x40

short Xsts;
struct Semaphore* S;
struct MailBox* MB;
char buf[129];

void Xtask(void)
{
  Xsts = XmRecv(MB);
  StopTask(GetCrtTask());
}

void myTask(void) /* low priority */
{
  S = MakeSem();
  MB = MakeMB(129);
  fp = Xtask;
  RunTask(0xE0, fp, 100); /* priority must be high */
  do
  {
    GetMail(MB,buf);
    if (buf[128] == EOT)
      break;
    CON_Write(buf, 128, S); /* …or process in another way the data… */
    Wait(S);
  }
  while(1==1);
  /* then look at the Xsts, just in case… */
  StopTask(GetCrtTask());
}
```

(see **testxr.c** in the **Demo** chapter)

If we want to handle XmSend the same way, we must use SendMail to “feed” the data to be sent via XMODEM; in this case, we will “mark” buf[128]=EOT before the last SendMail to notify XmSend to stop sending data.

The “memory leaks” issue

Sometimes, the tasks allocating blocks of dynamic memory “forget” to deallocate them, before exiting.

These “forgotten” memory blocks are named “memory leaks”; if these accumulate, they rise the fragmentation degree of the dynamic memory (which brings down the performance of the allocation/deallocation mechanisms) and may even lead to “full” dynamic memory.

When memory leaks occur frequently, the applications seem to slow down or even halt.

RTM/Z80 tries to solve this issue using a dedicated “garbage cleaner” task.

A **memory garbage cleaner** (a zero-priority internal task) is provided, automatically deallocating “memory leaks” (memory blocks owned by stopped tasks, but not deallocated by the owner task before stopping).

This special task is started at system start-up and is the last task to exit before system shutdown.

It uses the “ID stamp” contained in each allocated memoty block to identify the blocks to be deallocated.

As a task is terminated (using StopTask), the system “stores” the task ID in a queue reserved for the private use of the garbage cleaner, to notify him about a new “job” to clean the possible memory leaks.

The memory garbage cleaner will run only when there are no other active tasks to run (e.g. all other active tasks are terminated or suspended or waiting for semaphores, timers or for the completion of I/O operations).

The Round Robin scheduling

RTM/Z80 is provided with an optional **round robin scheduling** mechanism, enabling a fair sharing of execution time among active tasks.

For example, when the 3 top-priority active tasks with priorities equal to 10, 5, 2 are running continuous sequences of instructions, without executing signal/wait functions, the time slices given to these tasks will be equal to 10*5=50 ms, 5*5=25 ms, 2*5=10 ms, in a round robin sequence.

The round-robin scheduling can be enabled/disabled using dedicated functions (see 2.7 Timers).

The algorithm used to implement this round robin scheduling is simple, not very accurate, but it works without consuming large extra computing power. It is implemented inside the clock interrupt routine.

The steps of the algorithm are:

- When an active task obtains access to the CPU, its priority is loaded into a special counter
- Each real-time clock interrupt (at 5 ms) the special counter is decremented
- When the counter reaches zero, the list of active tasks is “rotated” (first becomes last) and the control is passed to the first active task from the list

Practically, each task is given a “continous” run time interval equal to its priority multiplied with 5 ms.

Of course, this algorithm interferes with the usual rule of “highest priority task gains the CPU access” and because of this, round robin scheduling must be used with care.

After round-robin scheduling is enabled, the basic rule of “highest priority gains the CPU access” is not anymore valid, therefore this facility must be used only when it is absolutely vital to “share” the CPU time between several tasks executing long sequences of “computation-like” code.

As a basic rule, it is a bad practice to enable round-robin scheduling when the current active tasks will execute frequently Wait, Signal, WriteQ, ReadQ, SendMail, GetMail or I/O operations, because all these API calls imply switching the CPU-control from one task to the other, without the need to apply a “round-robin” switching logic.

On the other hand, it is also a bad practice to disable round-robin scheduling when we have several active tasks busy with lengthy computations or data handling sequences, when a “fair” sharing of the CPU-time is critical.

As a final remark, the RoundRobinON and RoundRobinOFF calls should be used wisely, according to the context and also knowing the fact that the “time-slices” provided are proportional to the tasks priorities.

The “priority inversion” issue

Every multitasking scheduler tries to ensure that of those tasks that are ready to run, the one with the highest priority is always the task that is actually running.

Because tasks share resources, events outside the scheduler's control can prevent the highest priority ready task from running when it should. **Priority inversion** is the term for a scenario in which the highest-priority ready task fails to run when it should.

The real trouble arises at run-time, when a medium-priority task pre-empts a lower-priority task using a shared resource on which the higher-priority task is pending. If the higher-priority task is otherwise ready to run, but a medium-priority task is currently running instead, a priority inversion is said to occur.

Consider the following theoretical case: we have a low-priority task L, a medium-priority task M and high-priority task H. H and L share a resource. Shortly after Task L takes the resource, Task H becomes ready to run. However, Task H must wait for Task L to finish with the resource, so it pends. Before Task L finishes with the resource, Task M becomes ready to run, pre-empting Task L. While Task M (and perhaps additional intermediate-priority tasks) runs, Task H, the highest-priority task in the system, remains in a pending state.

How to deal with the “priority-inversion” in RTM/Z80?

In an application written using RTM/Z80, suppose T has the greatest priority among all tasks.

T may gain access to CPU when:

- RunTask(T) was executed by another task
- StopTask was executed by the current running task
- Suspend was executed by the current running task
- Resume(T) was executed by another task (T executed prior to this a Suspend)
- Another task executes a Signal for a semaphore that contains T in its queue of waiting tasks and T has the greatest priority among all tasks from the queue (T executed prior to this a Wait for that semaphore)
- SetTaskPrio(T) was executed, raising T’s priority above all other tasks’ priorities
- Round-robin mechanism is enabled and T is given access to the CPU (for a number of clock ticks equal to its priority)

Notice that the only case when T obtains the CPU time and (possibly) has not the highest priority among all active tasks is the last, round-robin case.

Let’s consider now the practical case of 3 RTM/Z80 tasks running in the scenario of round-robin being enabled: L with priority 2, M with priority 5 and H with priority 10. Suppose L and H use a semaphore S to obtain access to a shared buffer of data.

H just executed a Wait(S) to gain access to the buffer of data. The scheduler will insert task H into the semaphores’ queue, then will pass the control to the highest priority active task available.

Both M and L are active and available, competing for the use of the CPU time.

But they are made form a quite different stuff:

- L is finishing some short (15 milliseconds) calculus using the data and then will call a Signal(S) to indicate he does not need any more exclusive access to the data
- M has some lengthy calculus to do (during 15 seconds), before stopping.

```
Data:  …
TaskH:
       …
       Wait(S); ← - - - we are here
       …
TaskM:
       …
       Long_computation(); /* takes 15 seconds */
       StopTask(GetCrtTask());
TaskL:
       …
       Quick_calc();/* takes 15 milliseconds */
       Signal(S);
       …
```

After H executes Wait(S), the scheduler gives the control to M, but because the round-robin algorithm, after 5*5=25 milliseconds the control is passed to L, for 2*5=10 milliseconds, then back to M, and so forth.

Now, L is about to finish his part of calculus, but his 10 milliseconds first “time-slice” terminates before finishing its 15 milliseconds calculus to be able to issue the Signal(S). M is given the control for another 25 milliseconds slice, and only then L regains control, spends another 5 milliseconds, finished his calculus and issues the Signal(S). Only 25+10+25+5=65 milliseconds were waisted, from the H’s perspective. But it could be better: the last M's 25 milliseconds were waisted also from the L’s perspective.

We can see that running of M has delayed the running of both L and H. Precisely speaking, H is of higher priority and doesn’t share the semaphore S with M; but H had to wait for M. This is where Priority based scheduling didn’t work as expected because priorities of M and H got inverted. That’s Priority Inversion in action.

In this case, if those 25 milliseconds waisted are important, the solution is to use the SetTaskPrio function. Task H will call SetTaskPrio(TCB_M, 1) before entering Wait(S), to make sure that L will have, for a short period of time, higher priority than M. Then, when resuming from Wait(S), task H will restore the old M priority : SetTaskPrio(TCB_M, 5).

```
TaskH:
…
SetTaskPrio(TCB_M,1);
Wait(S);
SetTaskPrio(TCB_M,5);
…
```

This way, only 10+25+5=40 milliseconds will take from task H Wait to the task L Signal.

Of course, the best solution will be to use also the RoundRobinOFF and RoundRobinON functions:

```
TaskH:
…
RoundRobinOFF();
SetTaskPrio(TCB_M,1);
Wait(S);
SetTaskPrio(TCB_M,5);
RounRobinON();
…
```

As a result, in this later case task H will have to wait only 15 milliseconds.

The “priority-inversion” issue is always difficult to handle.

In the theory of multitasking systems, when using binary semaphores or mutexes, priority inversion can be dealt with some complicated algorithms: priority ceiling, priority inheritance, random boosting, etc. This is mainly because of the binary semaphores and mutexes implementation, prone to (unwanted) automatic task pre-emption.

RTM/Z80 uses counting semaphores, and this avoids a lot of the “priority-inversion” risks, because automatic task pre-emption is not possible when using Wait/Signal for counting semaphores, it can be done only by the round-robin mechanism. And, as shown before, some RTM/Z80 functions (SetTaskPrio, RoundRobinON/OFF), can be used to mitigate this risk.

But, in any particular case, the application context must be carefully studied in order to choose the best solution, which in many cases will be to make a compromise between response times and a fair use of CPU for all tasks.

Queues vs. Mailboxes

The queue mechanism is faster, compared with mailboxes, because no allocation / deallocation of memory blocks is performed during the queue “write” or “read” operations (a single allocation is performed when creating the queue).

However, special care is needed to correctly calibrate the size of the queue buffer (a too low *batch_count* will “block” too frequently in wait the data producer, and a too high *batch_count* will result in an unwisely consume of dynamic memory by using a huge buffer).

Mailboxes assure a safe method of communication between producers and consumers of data, with the disadvantage of being 10% to 20% slower compared with the queues mentioned earlier (the mailbox mechanism of sending/receiving data does allocate/deallocate buffers for each exchanged message).

When the number of messages to be sent is large, and the receiver cannot “read” enough quickly the received messages, the mailbox offers however an advantage, compared to the queues , because the quantity of data sent via a mailbox is limited only by the size of available dynamic memory, while in the case of a queue, the total number of messages that can be “stored” in the queue is limited by the “batch_count” parameter of the queue.

For example, suppose a queue is created using the call MakeQ(5, 7). This will create a queue able to send/receive messages of 10 bytes(=5*2), but with the capability to “store” only 7 of such messages without putting the sender in wait.

If the receiver is too slow to “read” the messages, the sender will be “blocked” in the WriteQ by “Wait for available space in the queue” when the queue will contain 7 messages not yet read by the receiver, being “unblocked” only when the receiver will “read” a message using ReadQ.

The solution will be to use a mailbox (using MakeMB(10)). Now, the only constraint will be the amount of free dynamic memory available to allocate space for the messages being sent, not the number of the messages.

Of course, after some hundreds of messages sent but “non-yet-consumed” by the receiver, the dynamic memory will be entirely “spent”, but this choice (queue speed of handling messages vs. mailbox large number of messages not-yet-processed) is enough flexible to solve most common producer-consumer practical contexts.

Configuring RTM/Z80

RTM/Z80 was written in Z80 assembler, using the vintage HiTech's ZAS assembler and LINK linker, with the Udo Munk's Z80SIM as a development platform (see next chapter for details).

It was tested, until now, on the following configurations:

- CP/M running under Z80SIM Z80 simulator
- RC2014, with the following configurations:
  - SC112 + SC108(Z80 + 32KB SCM EPROM + 2x64KB RAM) + SC110(CTC, SIO) + Digital I/O module
  - SC112 + SC108(Z80 + 32KB RTM/Z80 EPROM + 2x64KB RAM) + SC110(CTC, SIO) + Digital I/O module
  - SC112 + SC108(Z80, with EPROM & RAM removed) + Memory Module(32KB RTM/Z80 EPROM + 2x64KB RAM) + SC110(CTC, SIO) + Digital I/O module

On RC2014, RTM/Z80 and its applications can be executed in the following scenarios:

1. RTM/Z80 loaded from SCM: Under Z80SIM, compile the application and link-it to the RTM/Z80 library, then, from the SCM monitor, load the RTM/Z80 and the application in RAM as a single HEX file, and execute-it in RAM (this is the "classic" way of running RTM/Z80, without modifying the RC2014 hardware configuration)
2. RTM/Z80 stored on EPROM: Under Z80SIM, compile the application and link-it to the RTM/Z80 library, then, boot RTM/Z80 from EPROM (it will move itself to RAM), then it will load the application as a HEX file and will execute-it in RAM (this is possible when the EPROM from the SC108 or Memory Module is changed with an EPROM containing a boot-able image of RTM/Z80 – in fact, it contains 4 RTM/Z80 versions + Watson)
3. In both previous situations, after the application terminates, Watson can be loaded to inspect the aftermath of the application execution

The choice of these RC2014 configurations was imposed because of the need to use Z80 Interrupt Mode 2 (IM2), in order to have separate interrupt servicing routines for the CTC real-time clock interrupts and the read/write SIO serial interface interrupts.

RTM/Z80 can be ported to any other Z80 based computer that enables the use of IM2; if 128 KB of RAM are available, also the Watson utility program may be ported.

A number of configuration options are available (in **config.mac**), including:

- **CPM** – if selected, the RTM/Z80 application will be built to run as a CP/M .COM program;

```
;Memory map for CP/M version
;
;      0100H - 7B00H       sys code & data, apps code & data
;      7B00H - 7D00H       HEX loader buffers
;      7D00H - 7E00H       CleanReqB
;      7E00H - 7F00H       SIO receive buffer
;      7F00H - 8000H       Tasks vectors, sys data
;      8000H - 9FFFH       Dynamic Memory
;      A000H - DC00H       reserved for ZSID.COM
;      DC00H - FFFFH       reserved for CP/M
```

- **CPM** - if deselected, the system will be built for RC2014, with the following parameters as options:

  (pay attention at the **bss** segment length – your application read-write RAM bss segment, added to the RTM/Z80's bss, must fit into the range of addresses 0D000H – 0DF00H)

- **RAM128K** - if selected, it means that 2 banks of 64KB RAM are available

- **ROM** – if not selected, RTM/Z80 will be built to be loaded in the RAM at 0000H

```
;Memory map for RC2014
;
;      0000H - 0100H       RSTs, sys code
;      0100H - D000H       INTs vector, sys code, apps code & read-only data
;      D000H - D100H       BSS: CleanReqB
;      D100H - D200H       BSS: SIO receive buffer
;      D200H - D400H       BSS: HEX loader buffers
;      D400H - DF29H       BSS: Watson pointers, sys & apps read-write data
;      DF29H - DFE3H       BSS: low - up routines (echo in Upper RAM)
;      DFE3H - DFE8H       BSS: RTM/Z80 exit code
;      DFE8H - E000H       BSS: regs & PC for breakpoint
;      E000H - FFFFH       Dynamic Memory
```

- **ROM** – if selected, RTM/Z80 will be built to be stored in the SC108 32KB EPROM or the Memory Module's 32K EPROM, with the following parameters as options:

  - **MM** - if selected, the RTM/Z80 will be built to be stored in the Memory Module's 32KB EPROM
  - **MM** - if deselected, the RTM/Z80 will be built to be stored in the SC108's 32KB EPROM
  - **BOOT_CODE** – if selected, the RTM/Z80 will be stored at offset 0 in the EPROM, with a supplementary bootstrap code
  - **BOOT_CODE** - if deselected, the RTM/Z80 will be stored at a not null offset in the EPROM, without the bootstrap code

  There is sufficient space in the EPROM's 32KB to store 4 different RTM/Z80 versions and the Watson utility program.

  These RTM/Z80 versions include a palette of configurations, starting from a "full" version and ending with an "only assembly API" version.
  The following versions of RTM/Z80 are stored in the EPROM:

    - Version 1 (FULL: debug,C&assembly API, CMD, async comm I/O) : 10KB

```
DEBUG       equ 1  ;1=debug mode ON: verify task SP, task TCB, dealloc, lists, etc.
CPM         equ 0  ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO      equ 1  ;1=RC2014 Digital I/O module is used
CMD         equ 1  ;1=CON CMD task is included
RSTS        equ 1  ;1=use RST for list routines (not for CP/M)
WATSON      equ 1  ;1=Watson is used
C_LANG      equ 1  ;1=Support for C language API
IO_COMM     equ 1  ;1=Support for async communications I/O
```

```
MM          equ 1  ;1=Memory Module is used
RAM128K     equ 1  ;0=only 64K RAM, 1= 2 x 64K RAM available
ROM         equ 1  ;1=sys code on ROM, 0=ROM not used
BOOT_CODE   equ 1  ;1=bootstrap code included in code, 0=no bootstrap code
```

- Version 2 (no debug,C&assembly API, no CMD, async comm I/O) : 5KB

```
DEBUG       equ 0  ;1=debug mode ON: verify task SP, task TCB, dealloc, lists, etc.
CPM         equ 0  ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO      equ 1  ;1=RC2014 Digital I/O module is used
CMD         equ 0  ;1=CON CMD task is included
RSTS        equ 1  ;1=use RST for list routines (not for CP/M)
WATSON      equ 1  ;1=Watson is used
C_LANG      equ 1  ;1=Support for C language API
IO_COMM     equ 1  ;1=Support for async communications I/O
MM          equ 1  ;1=Memory Module is used
RAM128K     equ 1  ;0=only 64K RAM, 1= 2 x 64K RAM available
ROM         equ 1  ;1=sys code on ROM, 0=ROM not used
BOOT_CODE   equ 0  ;1=bootstrap code included in code, 0=no bootstrap code
```

- Version 3 (no debug,C&assembly API, CMD, no async comm I/O) : < 7KB

```
DEBUG       equ 0  ;1=debug mode ON: verify task SP, task TCB, dealloc, lists, etc.
CPM         equ 0  ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO      equ 1  ;1=RC2014 Digital I/O module is used
CMD         equ 1  ;1=CON CMD task is included
RSTS        equ 1  ;1=use RST for list routines (not for CP/M)
WATSON      equ 1  ;1=Watson is used
C_LANG      equ 1  ;1=Support for C language API
IO_COMM     equ 0  ;1=Support for async communications I/O
MM          equ 1  ;1=Memory Module is used
RAM128K     equ 1  ;0=only 64K RAM, 1= 2 x 64K RAM available
ROM         equ 1  ;1=sys code on ROM, 0=ROM not used
BOOT_CODE   equ 0  ;1=bootstrap code included in code, 0=no bootstrap code
```

- Version 4 (no debug, only assembly API, no CMD, no async comm I/O) : <4KB

```
DEBUG       equ 0  ;1=debug mode ON: verify task SP, task TCB, dealloc, lists, etc.
CPM         equ 0  ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO      equ 0  ;1=RC2014 Digital I/O module is used
CMD         equ 0  ;1=CON CMD task is included
RSTS        equ 1  ;1=use RST for list routines (not for CP/M)
WATSON      equ 1  ;1=Watson is used
C_LANG      equ 0  ;1=Support for C language API
IO_COMM     equ 0  ;1=Support for async communications I/O
MM          equ 1  ;1=Memory Module is used
RAM128K     equ 1  ;0=only 64K RAM, 1= 2 x 64K RAM available
ROM         equ 1  ;1=sys code on ROM, 0=ROM not used
BOOT_CODE   equ 0  ;1=bootstrap code included in code, 0=no bootstrap code
```

- **DEBUG** – if selected, all possible “defensive” checks will be performed for all the system functions parameters. TCB, queue, mailbox, timer, semaphore addresses will be checked for validity, Suspend/Resume functions will be checked for non allowed situations (for example, an

active task cannot be “resumed”, and a task waiting for a semaphore cannot be “resumed”), available stack space will be checked (with warnings issued when stack space drops below 20H). In the case when RTM/Z80 is compiled in DEBUG mode, many of the system functions will return error codes if the parameters are incorrect or the context does not allow the function to be executed. These checks will be skipped completely if RTM/Z80 is compiled without the DEBUG setting. Therefore, the main benefit of executing RTM/Z80 code in DEBUG mode is the “safe” environment provided, enabling the identification of incorrect use of the system facilities, with the downside of being slower compared with executing the same code without DEBUG mode. It is advisable to start testing an RTM/Z80 application always in DEBUG mode, to catch all the possible programming errors, and only then to switch to the faster non-DEBUG mode.

- **C_LANG** – if selected, all RTM/Z80 functions will be available from programs written in the C language. If deselected, only Z80 assembler programs may use the RTM/Z80 functions.

- **IO_COMM** – if selected, support for the communications I/O is provided. If deselected, no such support will be provided.

- **WATSON** – if selected, support for breakpoints execution and code for saving the “snapshot” image on the second bank of 64 KB RAM is provided, making possible to launch the WATSON utility after reaching a breakpoint or after the system shutdown. This option should be used only with RC2014 hardware configurations that provide 128 KB RAM (2 x 64 KB), for example with the SC108 or the Memory Module.

- **CMD** – if selected, a console utility task is provided, offering the following commands:

    - ACT – list of active tasks

```
>act
Active tasks:
TCB: 4200H Priority: 240 Free stack:1A7H
TCB: 4400H Priority: 10 Free stack:1E3H
TCB: 7F16H Priority: 0 Free stack:4AH
>
```

    - TAS – list of all tasks

```
>tas
TCB: 7F16H Priority: 0 Free stack:4AH, running
TCB: 4000H Priority: 250 Free stack:C1H, waiting for semaphore: 7FF4H
TCB: 4200H Priority: 240 Free stack:16FH, running
TCB: 4400H Priority: 10 Free stack:1E3H, running
>
```

    - MEM – status of the dynamic memory

```
>mem
Block of size 80H at address 4000H owned by task with TCB 7F16H
Block of size 40H at address 4080H owned by task with TCB 4000H
Block of size 10H at address 40C0H owned by task with TCB 4200H
Block of size 200H at address 4200H owned by task with TCB 7F16H
Block of size 200H at address 4400H owned by task with TCB 7F16H
Available blocks of size 10H : 40D0H
Available blocks of size 20H : 40E0H
Available blocks of size 100H : 4100H
Available blocks of size 200H : 4600H
```

```
Available blocks of size 800H : 4800H
Available blocks of size 1000H : 5000H
Total free dynamic memory : 1B3OH
>
```

- MAP – map of the dynamic memory

```
>map
Dynamic memory map (* = allocated 10H block)
     _____________+100_____________+200_____________+300_____________
4000|*************                 ******************************|
4400|********************************                              |
4800|                                                              |
4C00|                                                              |
5000|                                                              |
5400|                                                              |
5800|                                                              |
5C00|                                                              |
     _____________+100_____________+200_____________+300_____________
>
```

- HEX – load (and optionally execute) a .HEX file.

```
>hex
```

The system issues the message:

```
Ready to read HEX file (timeout=10 sec)
```

, and the user must ‘feed’ on the screen the .HEX file (by example copying the file and pasting it to the screen). The following outcomes are possible:

- The file is correctly loaded, and the user is asked if he wants to execute-it
- The file is corrupted (no end-of-file record)
- No dynamic memory is available for the read buffer
- 10 seconds passed and no file was provided (time-out)
- The checksum is incorrect

- EXI – terminates CMD execution

- STP addr – stops the task with TCB=addr

- RES addr – resumes the task with TCB=addr

- PRI addr,pr – sets pr as new priority for the task with TCB=addr

- RRB on (or off) – sets the round robin mode

- SHD – shuts down RTM/Z80

Building and running an RTM/Z80 application on CP/M

RTM/Z80 applications can be built and run on Z80 simulated environments (Z80 emulators).
RTM/Z80 was developed on a popular Z80 simulator, the Udo Munk's Z80SIM.

Z80SIM was installed on Cygwin (a Linux-like) running under Windows 10, and all the necessary software tools and RTM/Z80 source files were stored on the 4MB disk "J" (that's why you will see, in all the examples, the command line prefix J>).

Z80SIM CP/M implementation provides a 10 milliseconds real-time clock, on interrupts, making it a best fit for building and executing a multitasking system on a Z80 simulator.

The vintage HiTech Z80 software pack was used (C compiler, ZAS assembler, LINK linker, …).

Some useful links:

- Z80SIM: https://www.autometer.de/unix4fun/z80pack/ (contains also a link to HiTech tools)
- Documentation for HiTech tools: http://koyado.com/Heathkit/My_Backups_files/Z80DOC.pdf

About running RTM/Z80 applications on CP/M, some important issues must be mentioned.

First of all, be aware that running RTM/Z80 applications on CP/M comes with some important limitations, mainly related to the fact that no interrupt-based serial I/O is possible.
In fact, in the CP/M version of RTM/Z80 the "SIO input/output" interrupts are simulated!

More exactly:

- after a CON_Read call, the next Wait call is used to "loop" until all characters are entered
- the CON_Write call "loops" until all characters are written on the terminal

It is true that these "loops" are calling the "real" interrupt routines, but it is only a compromise!

Also, all CON_Read and CON_Write calls must use Semaphores (and be coupled with Wait calls for the specified Semaphore).

The asynchronous serial I/O communications calls are also affected; simulated calls of SIO input/output interrupts must be used in order to solve the issue. This does not mean, however, that these functions cannot be used at all (e.g. loading .HEX files - using CMD HEX command - can be done also on the CP/M implementation).

Another issue is related to the fact that on Z80SIM, the real-time clock interrupts come at each 10 ms, not at 5 ms as in the case of RC2014, and because this the RTM/Z80 "timer-related" functions are affected.

The use of **GetHost** function may solve this issue, but some code must be used to handle the difference between the 5 ms and 10 ms tics while computing "number of tics per second".

That being said, the implementation of RTM/Z80 on CP/M still ensures the proper functioning of all system facilities.
Note: at RTM/Z80 StartUp, a small check verifies if CP/M runs under Z80SIM; in case Z80SIM is not detected, a message eror is issued and CP/M is re-booted.

An example of how to build and run an RTM/Z80 application on CP/M is presented.

Let's take for example **rtmdemo.c** (see the source code in ***RTM/Z80 demo applications***)

First, the file **config.mac** must be edited to set the desired system configuration; here is the result:

```
J>type config.mac
DEBUG           equ 0   ;1=verify task SP, task TCB, dealloc, lists
CPM             equ 1   ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO          equ 0   ;1=RC2014 Digital I/O module
CMD             equ 0   ;1=CON CMD task
RSTS            equ 0   ;1=use RST for list routines (not for CP/M)
WATSON          equ 0   ;1=Watson will be used
C_LANG          equ 1   ;1=Functions called from C language
IO_COMM         equ 0   ;1=Support for async communications I/O
…
```

Then, we build the RTM/Z80 components and store them into an object code library:

```
J>submit make
J>zas -j dlist.as
J>zas -j balloc.as
J>zas rtsys1a.as
J>zas -j rtsys1b.as
J>zas -j rtsys2a.as
J>zas -j rtsys2b.as
J>zas -j rtclk.as
J>zas -j queue.as
J>zas -j mailbox.as
J>zas -j io.as
j>zas -j util.as
J>libr r rt.lib rtsys1.obj rtsys2.obj io.obj queue.obj rtclk.obj mailbox.obj balloc.obj util.obj
dlist.obj
```

Next, we compile **rtmdemo.c**, link-it to the RTM/Z80 library and build **rtmdemo.com** as result:

```
J>c -iJ0: -o rtmdemo.c rand.as rt.lib
```

Now, **rtmdemo.com** is ready to run, on Z80SIM's CP/M:

```
J>rtmdemo
RTM/Z80
RTM/Z80 Demo program
Showing two concurrent games being played: Chess Knight's tour & Tower of Hanoi
Please extend the VT100 compatible window size to at least 48 rows x 80 columns
Please press ENTER to start!
(you will be able to vary the speed by pressing CTRL_C)
...
```

(see the screen output in ***RTM/Z80 demo applications***)

NOTE : if we configure RTM/Z80 to include the CMD task, setting in config.mac:

```
CMD             equ 1
```

, then when executing **rtmdemo.com**, you will need first to exit from CMD, using the EXI command:

```
J>rtmdemo
RTM/Z80
>EXI<CR>
RTM/Z80 Demo program
...
```

When building RTM/Z80 applications intended to be run on Z80SIM's CP/M, special care must be given to the RTM/Z80 CP/M version's memory map:

```
;Memory map for CP/M version
;
;      0100H - 7B00H       sys code & data, apps code & data
;      7B00H - 7D00H       HEX loader buffers
;      7D00H - 7E00H       CleanReqB
;      7E00H - 7F00H       SIO receive buffer
;      7F00H - 8000H       Tasks vectors, sys data
;      8000H - 9FFFH       Dynamic Memory
;      A000H - DC00H       reserved for ZSID.COM
;      DC00H - FFFFH       reserved for CP/M
```

The code and data space for an RTM/Z80 application in CP/M is limited to 100H – 7B00H.
Of course, the application can allocate extra space for its data using the 8KB dynamic memory.

Also, the WATSON utility can be used in CP/M to investigate the results of an application execution.

This must be done as follows:

- the application code must include one or more WATSON calls:
  - watson() /* in C language */
  - jp _watson ; in assembly (declaring also GLOBAL _watson)
- the WATSON object files must be built, using:

```
J>submit makew
zas -j watson.as
zas -j wutil.as
zas -j wuplow.as
zas -j wdiss.as
```

- then the application code (tw.obj) must be linked with the RTM/Z80 object library and the WATSON object files, e.g.:

```
J>link
 -c100H -ptext=0H -ow.com tw.obj watson.obj wutil.obj wuplow.obj wdiss.obj rt.lib
```

When executing W.COM, at the first executed WATSON call, the RTM/Z80 application will be stopped and WATSON launched:

```
J>w
RTM/Z80
(watson call occurred…)
Searching for RTM/Z80... Found!
Watson at your service!
:
```

See the Chapter "**WATSON - Investigating the results of an RTM/Z80 application run** " for details about using WATSON.

Running an RTM/Z80 application on RC2014

An example of how to build and run an RTM/Z80 application on RC2014 is presented.
RC2014 must be configured with the SC108 and SC110 boards.

Let's take for example **rtmdemo.c** (see the source code in ***RTM/Z80 demo applications***).

We use again CP/M on Z80SIM to build the RTM/Z80 system and its applications.

First, the file **config.mac** must be edited to set the desired system configuration; here is the result:

```
J>type config.mac
DEBUG        equ 0  ;verify task SP, task TCB, dealloc, lists
CPM          equ 0  ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO       equ 1  ;RC2014 Digital I/O module
CMD          equ 0  ;CON CMD task
RSTS         equ 1  ;use RST for list routines (not for CP/M)
WATSON       equ 0  ;Watson will be used (only for CP/M)
C_LANG       equ 1  ;Functions called from C language
IO_COMM      equ 0  ;Support for async communications I/O
```

We then build the RTM/Z80 components:

```
J>submit make
J>zas -j dlist.as
J>zas -j balloc.as
J>zas rtsys1a.as
J>zas -j rtsys1b.as
J>zas -j rtsys2a.as
J>zas -j rtsys2b.as
J>zas -j rtclk.as
J>zas -j queue.as
J>zas -j mailbox.as
J>zas -j io.as
J>zas -j snapshot.as
J>zas -j hexload.as
J>zas -j util.as
J>zas -j cmd.as
```

We will compile **rtmdemo.c**, link-it to RTM/Z80 system object code, and use the **objtohex** command to build **rtmdemo.hex**:

```
J>c -iJ0: -c -o rtmdemo.c
J>zas rand.as
J>link
link>  -x -z -Ptext=0,data,bss=0D000H -os.obj rtsys1a.obj rtsys1b.obj rtsys2a.obj rtsys2b.obj
cmd.obj hexload.obj queue.obj io.obj rtclk.obj mailbox.obj \
link>  balloc.obj dlist.obj util.obj snapshot.obj crtcpm.obj rtmdemo.obj rand.obj csv.obj libc.lib
J>objtohex s.obj rtmdemo.hex
```

To run the rtmdemo application, we need first to load the rtmdemo code into SC2014.

First, let's start RC2014; the SCM prompt will be displayed:

```
Small Computer Monitor - S3
*
```

We will then copy_paste the RTM/Z80 bootstraper **hexboot.hex** to the terminal app , let's say, TeraTerm, used to connect with SC2014:

```
J>type hexboot.hex
```

```
:20E00000F33166E22141E211E3DF010500EDB021ABE1114DDF019600EDB0DD21ABE1114DD4
...
(copy hex file on clipboard)
```

Now, on TeraTerm screen, we paste the clipboard contents:

```
Small Computer Monitor - S3
*
(paste the clipboard contents…)

*Ready
```

We start the bootstrapper:

```
*gE000
```

The bootstrapper now waits to load the RTM/Z80 application HEX file:

```
Ready to read RTM/Z80 HEX file:
```

Next, we need to copy-paste **rtmdemo.hex** to the terminal app used to connect with SC2014 and then boot RTM/Z80:

```
J>type rtmdemo.hex
:20000000C33C1D0000000000C3461D0000000000C36D1D0000000000C30E1D000000000063
...
(copy hex file on clipboard)
```

Now, on TeraTerm screen, we paste the clipboard contents:

```
Ready to read RTM/Z80 HEX file:
(paste the clipboard contents…)
```

The bootstrapper asks for optional breakpoints to be set (when reaching a breakpoint, a full 64KB copy (snapshot) of the code and data is saved, and you may use the Watson utility to investigate the aftermath of the application run):

```
Breakpoint (4 hex digits, .=no more breakpoints to set): .
```

…then asks if we want to boot RTM/Z80:

```
Boot? (Y/y=yes) : Y
Booting RTM/Z80...

RTM/Z80
RTM/Z80 Demo program
Showing two concurrent games being played: Chess Knight's tour & Tower of Hanoi
Please extend the VT100 compatible window size to at least 48 rows x 80 columns
Please press ENTER to start!
(you will be able to vary the speed by pressing CTRL_C)
```

(see the screen output in ***RTM/Z80 demo applications***)

NOTE : if RTM/Z80 was configured to contain the CMD task, you need first to exit from CMD, using: >EXI<CR>

Important memory constraints

The RTM/Z80 system, application code (text segment) and read-only data (data segment) must fit into the range of addresses 0000H to 0D000H (52 K bytes).

The size of RTM/Z80 system code alone varies between 4K and 8K bytes, according to the selected configuration; this means the largest application code size is between 44 to 48 K bytes.

The application read-write data (bss segment) must be smaller than 3 K bytes (the exact limit is 0A00H, however, the application may access also the 8 K bytes dynamic memory area, to get access to more space for its read-write buffers).

Using RTM/Z80 in a ROM/RAM configuration

RTM/Z80 applications can be configured to run on RC2014 using the RTM/Z80 system code stored on (E)EPROM. The RC2014 must be provided with the SC108 and SC110 boards (optionally also with the Memory Module board) and RTM/Z80 versions stored on EPROM (SC108 or Memory Module). The RTM/Z80 system will be copied on RAM at boot-time, then the user will be asked to load his application. An example of how to build and run an RTM/Z80 application for this configuration is presented. To build RTM/Z80 we will use again CP/M on Z80SIM.

The user is provided with the source files **romrtm**__**n**__**.as** (__**n**__=1 to 4), containing the RTM/Z80 API definitions; these files were obtained using the utility **symtoas.com** (e.g):

```
J>symtoas romrtm1.as romrtm1.sym
J>zas romrtm1.as
```

The file **romrtm1.sym** was produced by the link command used to build RTM/Z80.

On Z80SIM, we will compile **rtmdemo.c**, link-it to the RTM/Z80 API, and use the **objtohex.com** command to build **rtmdemo.hex** (the code must be built to be loaded and executed at 2800H):

```
J>c -iJ0: -c -o rtmdemo.c
J>zas rand.as
J>link
link> -x -z -Ptext=2800H,data,bss -os.obj jp.obj crtcpm.obj rtmdemo.obj rand.obj romrtm1.obj\
link> csv.obj libc.lib
J>objtohex s.obj rtmdemo.hex
```

The **jp.obj** must be placed first in the list of object files; it contains only a “jp _main” (see below)

```
JP.AS:
psect text
global _main
jp _main
```

Next, we boot RC2014; on the TeraTerm screen we will have the following message:

```
Press 1,2,3,4 to boot an RTM/Z80 version, or 5 to start Watson :
```

(see Ch. Configuring RTM/Z80)

If we choose to boot an RTM/Z80 version, the following message will be displayed:

```
Ready to read RTM/Z80 HEX file:
```

…and we will then paste the **rtmdemo.hex** file contents:

```
(paste the clipboard contents…)
```

The bootstraper asks for optional breakpoints to be set:

```
Breakpoint (4 hex digits, .=no more breakpoints to set): .
```

…then asks if we want to boot RTM/Z80:

```
Boot? (Y/y=yes) : Y
Booting RTM/Z80...

RTM/Z80
RTM/Z80 Demo program
...
```

NOTE : if RTM/Z80 was configured with the CMD task, you need first to exit from CMD, using:

```
>EXI<CR>
```

After system shutdown, we may choose next to launch Watson, to investigate the RTM/Z80 application run aftermath.

Debugging an RTM/Z80 application

As mentioned before, it is important to run first our RTM/Z80 application using an RTM/Z80 built with the DEBUG option ON.

This way, all the API call parameter values will be verified and, if incorrect, the call will not be executed, eliminating the risk to crash the RTM/Z80 system because of a wrong parameter value.

In case of executing the application on RC2014, if the DIG_IO option was selected and if the Digital I/O module is present, the following events will be shown as a led turned ON:

LED nr.0: ON=RTM/Z80 is running
LED nr.1: ON/OFF every one second
LED nr.2: ON=(if DEBUG option ON) stack warning (a Task stack space is below 20H)
LED nr.3: ON=(if DEBUG option ON) wrong TCB address used in API parameter value
LED nr.4: ON=(if DEBUG option ON) wrong Semaphore address used in API parameter value
LED nr.5: ON=(if DEBUG option ON) no more free memory (dynamic memory is full)
LED nr.6: ON=SIO A External Status Change
LED nr.7: ON=SIO A Special Receive Condition

If the DEBUG option is turned OFF, no such checks will be performed, leading to potential issues related to RTM/Z80 API called with wrong parameter values (e.g. calling Wait with a wrong Semaphore address will store some data at wrong RAM memory addresses, possibly leading to application and/or system crash).

When executing an RTM/Z80 application under CP/M, it is possible to debug-it using the CP/M command ZSID.

In order to prepare the symbols file to be read by ZSID, it is necessary to convert-it to uppercase, using the command **toupper.com**:

```
J>toupper upcase.sym lowcase.sym
```

Also, you must “patch” the RTM/Z80 code in order to “skip” the real-time clock initialization (otherwise, CP/M will crash when reaching a breakpoint):

```
J>c -ij0: -o rtmdemo.c rand.as -ftt.sym rt.lib
J>toupper t.sym tt.sym
J>zsid rtmdemo.com t.sym
ZSID VERS 1.4
#s._initints
157D F3
157E 3E c9
157F C3 .
#g
RTM/Z80
RTM/Z80 Demo program…
```

Also, after executing an RTM/Z80 application, using the WATSON utility is recommended to inspect the aftermath of the application run, or to view the status of the system/application after a breakpoint was reached (see chapters WATSON & Running applications on RC2014).

WATSON - Investigating the results of an RTM/Z80 application run

WATSON is a tool designed to investigate the results of executing an RTM/Z80 application on the RC2014 homebrew Z80 computer.

The RC2014 must be provided with 128KB of RAM, on the SC108 board (32 KB ROM and 2 x 64KB RAM) or the Phillip Stevens ‘s Memory Module (32KB ROM and 2 x 64KB RAM).

The application written to be run under RTM/Z80 is loaded and executed on the first bank of 64KB RAM. When the application executes the Shutdown function (or when a breakpoint is reached), a full 64KB copy (snapshot) of the code and data is moved to the second bank of 64KB RAM and the RC2014 is re-booted.

Then, WATSON can be loaded and executed, to investigate the results of the application run.

The functions provided by WATSON will made possible to examine the user data, code, registers, RTM/Z80 system data.

The addresses used as parameters for these functions will be the “real” addresses of data or code from the RTM/Z80 application that has been run.

WATSON will “load” the data/code from the snapshot and will display it exactly as it was after the RTM/Z80 shutdown or breakpoint.

The following functions are provided:

- Memory
- List
- Semaphore
- TCB
- Active task list
- All task list
- Current active task
- Dynamic memory status
- Queue
- Mailbox
- Timer list
- Timer
- Disassemble
- Registers
- Exit

The functions syntax is simple: after WATSON displays its prompt (a colon :) each function is called using a single letter (possibly followed by a hexadecimal address) followed by <CR>. The command line can be “edited” using the BACKSPACE key.

A full list of the functions will be printed using as input a question mark :?<CR>

An example of using WATSON is presented below. Let’s consider the following simple application:

```
                psect   text
        _main:
                ld      bc,1E0H
                ld      hl,_Task
                ld      e,10H
                call    __StartUp
                ret
        _Task:
                ld      bc,0
                call    __Balloc
                ld      bc,1
                call    __Balloc
                ld      bc,2
                call    __Balloc
                ld      bc,3
                call    __Balloc
                ld      bc,4
                call    __Balloc
                ld      bc,5
                call    __Balloc
                ld      bc,6
                call    __Balloc
                ld      bc,7
                call    __Balloc
                ld      bc,8
                call    __Balloc
                call    __MakeSem
                ld      (sem),hl
                call    __MakeTimer
                ld      (timer),hl
                ld      de,(sem)
                ld      bc,10
                xor     a
                call    __StartTimer
                ld      bc,1007H
                call    __MakeQ
                ld      (queue),hl
                ld      bc,50H
                call    __MakeMB
                ld      (mailbox),hl
                 call   __Shutdown
```

After running the application, let's start WATSON, copy-pasting **watson.hex** and launching-it:

```
Small Computer Monitor - S3
*
(paste the clipboard contents…)
*Ready
*gE000
Searching for RTM/Z80... Found!
Watson at your service!
:?
M<addr><CR>    Memory display (*)
L<addr><CR>    Double linked list display
S<addr><CR>    Semaphore display
T<addr><CR>    TCB display
A<CR>          Active tasks list display
O<CR>          All tasks list display
C<CR>          Current active task display
D<CR>          Dynamic memory display
Q<addr><CR>    Queue display
B<addr><CR>    Mailbox display
K<CR>          Display list of Timer Control Blocks
J<addr><CR>    Display Timer Control Block
E<addr><CR>    Disassemble (*)
R<CR>          Registers
X<CR>          Exit
where <addr> = 4 hexa digits
(*) autorepeat at <CR>
```

```
:m016d
016D 46 41 D6 40 66 41 06 4C 21 00 7F E5 21 3A 0C CD FA.@fA.L!...!:..
017D C9 0F E1 11 04 00 01 02 00 E5 21 42 02 CD C9 0F ..........!B....
018D E1 CD B2 10 E5 21 3A 0C CD C9 0F E1 19 E5 21 59 .....!:.......!Y
019D 02 CD C9 0F E1 CD B2 10 E5 21 3A 0C CD C9 0F E1 .........!:.....
:k 4146
:q4166 Write pointer=4506 Read pointer=4506 Buffer=4506 Size=00E0 Batch size=20
:s40d6 TCB waiting: Counter:0000
:l7f04->4200->7F16
:t4200 Size=0200 Priority=10 SP=43F2 Status=Active
:a 4200 7F16
:o 7F16 4000 4200
:c 4200
:d
Available blocks of size 0010: 4150
Available blocks of size 0020: 4C20
Available blocks of size 0040: 4C40
Available blocks of size 0080: 4C80
Available blocks of size 0100: 4D00
Available blocks of size 0200: 4E00
Available blocks of size 0800: 5800
Total free dynamic memory : 0BF0
Block of size=0080 at address=4000 owned by TCB=7F16
Block of size=0040 at address=4080 owned by TCB=4000
Block of size=0010 at address=40C0 owned by TCB=4200
Block of size=0010 at address=40D0 owned by TCB=4200
Block of size=0020 at address=40E0 owned by TCB=4200
Block of size=0040 at address=4100 owned by TCB=4200
Block of size=0010 at address=4140 owned by TCB=4200
Block of size=0020 at address=4160 owned by TCB=4200
Block of size=0080 at address=4180 owned by TCB=4200
Block of size=0200 at address=4200 owned by TCB=7F16
Block of size=0100 at address=4400 owned by TCB=4200
Block of size=0100 at address=4500 owned by TCB=4200
Block of size=0200 at address=4600 owned by TCB=4200
Block of size=0400 at address=4800 owned by TCB=4200
Block of size=0020 at address=4C00 owned by TCB=4200
Block of size=0800 at address=5000 owned by TCB=4200
:b4c06 TCB waiting: Mails list: Message size=50
:j4146 Tics:000A Sem:40D6
:e0100
0100: 01 00 02     ...   LD BC,0200
0103: 21 0B 01     !..   LD HL,010B
0106: 1E 10        ..    LD E,10
0108: CD 39 1D     .9.   CALL 1D39
010B: 01 00 00     ...   LD BC,0000
010E: CD 78 29     .x)   CALL 2978
0111: 01 01 00     ...   LD BC,0001
0114: CD 78 29     .x)   CALL 2978
0117: 01 02 00     ...   LD BC,0002
011A: CD 78 29     .x)   CALL 2978
011D: 01 03 00     ...   LD BC,0003
:r AF= F3E1 BC= 3031 DE= CD0F HL= 08B2 AF'=0F28 BC'=4C21
DE'=CD0D HL'=0FC9 IX =000E IY =05C3 SP =AF00 PC =000E
:x
```

RTM/Z80 Demo applications

Some demo applications are included.

You can build these applications, like all the RTM/Z80 applications, using the following procedure:

- Edit **config.mac** to choose the RTM/Z80 desired configuration (CP/M, RC2014, …)
- Build RTM/Z80, (on Z80SIM, using J>**submit make**)
- Build application, using :
    a. (for CP/M): J>**submit bcpm sourcefile.ext**
    b. (for RC2014):
        i. for assembler source: J>**submit barc2014 sourcefile** (without extension)
        ii. for C source: J>**submit bcrc2014 sourcefile** (without extension)
        iii. for C+as: J>submit bxrc2014 srcC (no ext) scrAS (no ext)

Example 1: build Merge Sort demo (C language) for CP/M:

Build config.mac: (e.g.)

```
DEBUG           equ 1   ;1=debug mode ON: verify task SP, task TCB, dealloc, lists, etc.
CPM             equ 1   ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO          equ 0   ;1=RC2014 Digital I/O module is used
CMD             equ 0   ;1=CON CMD task is included
RSTS            equ 0   ;1=use RST for list routines (not for CP/M)
WATSON          equ 1   ;1=Watson is used (relevant only for CP/M)
C_LANG          equ 1   ;1=Support for C language API
```

Then:

J>submit make
J>submit bcpm msort.c rand.as
J>msort

Example2: build Merge Sort demo (C language) for RC2014:

Build config.mac: (e.g.)

```
DEBUG           equ 1   ;1=debug mode ON: verify task SP, task TCB, dealloc, lists, etc.
CPM             equ 0   ;1=Runs under CP/M, 0=Runs on RC2014(SC108+SC110)
DIG_IO          equ 0   ;1=RC2014 Digital I/O module is used
CMD             equ 0   ;1=CON CMD task is included
RSTS            equ 1   ;1=use RST for list routines (not for CP/M)
WATSON          equ 0   ;1=Watson is used (relevant only for CP/M)
C_LANG          equ 1   ;1=Support for C language API
```

Then:

J>submit make
J>submit bxrc2014 msort rand

For the following demo applications, the RTM/Z80 API calls are printed in **bold**.

Round Robin pre-emptive scheduling demo (C)

```
/*
 * RTM/Z80
 *
 * Copyright (C) 2021 by Ladislau Szilagyi
 *
 * ROUND ROBIN DEMO PROGRAM
 *
 * Round Robin pre-emptive scheduling demo
 *
 */

#include <dlist.h>
#include <balloc.h>
#include <rtsys.h>
#include <stdio.h>
#include <string.h>
#include <io.h>

void (*fp)(void);

void* S;

unsigned short n5=0;
unsigned short n3=0;
unsigned short n2=0;

void* T2;
void* T3;

char buf[30];

void Task3(void)
{
  do
    n3++;
  while (T3 != 0);
}

void Task2(void)
{
  do
    n2++;
  while (T2 != 0);
}

void Task5(void)
{
  RoundRobinON();
  S=MakeSem();
  fp = Task3;
  T3=RunTask(0x1E0, (void*)fp, 3);
  fp = Task2;
  T2=RunTask(0x1E0, (void*)fp, 2);

  do
    n5++;
```

```
  while (n5 != 50000);

  StopTask(T3);
  StopTask(T2);

  sprintf(buf,"\r\n T5 counted %u",50000);
  CON_Write(buf,strlen(buf),S);
  Wait(S);

  sprintf(buf,"\r\n T3 counted %u",n3);
  CON_Write(buf,strlen(buf),S);
  Wait(S);

  sprintf(buf,"\r\n T2 counted %u",n2);
  CON_Write(buf,strlen(buf),S);
  Wait(S);

  ShutDown();
}

void main(void)
{
  fp = Task5;
  StartUp(0x1E0, (void*)fp, 5);
}

*** Run on RC2014

RTM/Z80
T5 counted 50000
T3 counted 30653
T2 counted 20337
```

Merge Sort multitasking demo (C & Z80 assembler)

```
/*
 * RTM/Z80
 *
 * Copyright (C) 2021 by Ladislau Szilagyi
 *
 * MERGE SORT DEMO PROGRAM
 *
 */

#include <stdio.h>
#include <string.h>

#include <dlist.h>
#include <balloc.h>
#include <rtsys.h>
#include <io.h>
#include <rtclk.h>

int    xrnd(void);
void   xrndseed(void);

/* number of elements in array */
#define MAX 1000

/* number of tasks */
#define THREAD_MAX 4

/* array of size MAX */
short a[MAX];

/* task selector */
short part = 0;

char*  no_dyn_mem = "\nDynamic memory full, quitting...";
char*  no_stack = "\nStack too small, quitting...";
short  ret;
char   buf[30];
void   (*fp)(void);

struct Semaphore* S1, *S2, *S3, *S4, *SW;
void*  S[4];

long ts,te;
short TicsPerSec;
short i;

/* Print from RTM/Z80 */
void my_print(char* msg)
{
       CON_Write(msg, strlen(msg), SW);
       Wait(SW);
}

void QUIT(void)
{
       my_print(no_dyn_mem);
```

```
	ShutDown();
}

void STACK(void)
{
	my_print(no_stack);
	ShutDown();
}

/* merge function for merging two parts */
void merge(short low, short mid, short high)
{
	short *L, *R, LS, RS;
	short* left;
	short* right;
	short k = low;

	/* n1 is size of left part and n2 is size of right part */
	short n1 = mid - low + 1, n2 = high - mid, i, j;

	/* allocate two temporary arrays */

	if (StackLeft(GetCrtTask()) < 20)
		STACK();

	LS=BallocS(mid - low + 1 + 6);
	L=Balloc(LS+1);
	if (!L)
		QUIT();

	RS=BallocS(high - mid + 6);
	R=Balloc(RS+1);
	if (!R)
		QUIT();

	left=L+3;
	right=R+3;

	/* storing values in left part */
	for (i = 0; i < n1; i++)
		left[i] = a[i + low];

	/* storing values in right part */
	for (i = 0; i < n2; i++)
		right[i] = a[i + mid + 1];

	i = j = 0;

	/* merge left and right in ascending order */
	while (i < n1 && j < n2)
	{
		if (left[i] <= right[j])
			a[k++] = left[i++];
		else
			a[k++] = right[j++];
	}

	/* insert remaining values from left */
	while (i < n1) {
```

```
            a[k++] = left[i++];
      }

      /* insert remaining values from right */
      while (j < n2) {
            a[k++] = right[j++];
      }

      Bdealloc(L,LS+1);
      Bdealloc(R,RS+1);
}

/* merge sort function */
void merge_sort(short low, short high)
{
      /* calculating mid point of array */
      short mid = low + (high - low) / 2;

      if (StackLeft(GetCrtTask()) < 20)
            STACK();

      if (low < high)
      {
            /* calling first half */
            merge_sort(low, mid);

            /* calling second half */
            merge_sort(mid + 1, high);

            /* merging the two halves */
            merge(low, mid, high);
      }
}

/* merge sort task function for multi-tasking */
void merge_sort_t(void)
{
      /* which part out of 4 parts */
      short task_part = part++;

      /* calculating low and high */
      short low = task_part * (MAX / 4);
      short high = (task_part + 1) * (MAX / 4) - 1;

      /* evaluating mid point */
      short mid = low + (high - low) / 2;
      if (low < high) {
            merge_sort(low, mid);
            merge_sort(mid + 1, high);
            merge(low, mid, high);
      }

      Signal(S[task_part]);
      StopTask(GetCrtTask());
}

/* Function to print an array */
void printArray(short A[], short size)
{
```

```
	for (i = 0; i < size; i++)
	  {
	   sprintf(buf, "%d ", A[i]);
	    my_print(buf);
	}
}

void Create4T(void)
{
	xrndseed();

	for (i=0; i < MAX; i++)
		a[i] = xrnd();

	/* prepare semaphores */
	SW = MakeSem();

	S1 = MakeSem();
	S2 = MakeSem();
	S3 = MakeSem();
	S4 = MakeSem();

	S[0]=S1;
	S[1]=S2;
	S[2]=S3;
	S[3]=S4;

	if (GetHost())
	  TicsPerSec=200;
	else
	  TicsPerSec=100;

	my_print("\r\nGiven array is\r\n");
	printArray(a, MAX);

	ts=GetTicks();

	/* creating 4 tasks */
	fp = merge_sort_t;
	if (!RunTask(0x1E0, (void*)fp, 4))
		QUIT();
	if (!RunTask(0x1E0, (void*)fp, 3))
		QUIT();
	if (!RunTask(0x1E0, (void*)fp, 2))
		QUIT();
	if (!RunTask(0x1E0, (void*)fp, 1))
		QUIT();

	/* wait for each task completion */
	Wait(S1);
	Wait(S2);
	Wait(S3);
	Wait(S4);

	/* merging the final 4 parts */
	merge(0, (MAX / 2 - 1) / 2, MAX / 2 - 1);
	merge(MAX / 2, MAX/2 + (MAX-1-MAX/2)/2, MAX - 1);
	merge(0, (MAX - 1)/2, MAX - 1);
```

```
	te=GetTicks();

	my_print("\r\nSorted array is\r\n");
	printArray(a, MAX);

	sprintf(buf, "\r\nElapsed time: %ld seconds", (te-ts)/TicsPerSec);
	 my_print(buf);

	DropSem(S1);
	DropSem(S2);
	DropSem(S3);
	DropSem(S4);
	DropSem(SW);

	ShutDown();
}

void main(void)
{
	fp = Create4T;
	StartUp(0x1E0, (void*)fp, 10);
}

; Xorshift is a class of pseudorandom number generators discovered
; by George Marsaglia and detailed in his 2003 paper, Xorshift RNGs.
;
; 16-bit xorshift pseudorandom number generator by John Metcalf
; returns   hl = pseudorandom number
; corrupts   a

; generates 16-bit pseudorandom numbers with a period of 65535
; using the xorshift method:

; hl ^= hl << 7
; hl ^= hl >> 9
; hl ^= hl << 8

; some alternative shift triplets which also perform well are:
; 6, 7, 13; 7, 9, 13; 9, 7, 13.

	psect  text
	GLOBAL _xrnd, _xrndseed, Counter
_xrnd:
  ld hl,1       ; seed must not be 0
  ld a,h
  rra
  ld a,l
  rra
  xor h
  ld h,a
  ld a,l
  rra
  ld a,h
  rra
  xor l
  ld l,a
  xor h
  ld h,a
  ld (_xrnd+1),hl
```

```
  ret

_xrndseed:
  ld   hl,(Counter)
  ld   a,l
  or   h      ; HL must be not NULL
  jr   nz,1f
  inc  hl
1:
  ld   (_xrnd+1),hl
  ret
```

*** Run on RC2014

```
Given array is
-32383 24609 -5735 11787 -19042 -9821 12071 17913 -25563 27874 -3604 -5905 -16608 6199 -19018 -
4223 14614 -689 -18206 20358 19648 -1322 3998 16126 -24610 -26906 29076 29385 21570 3448 -28384
8480 -13960 14146 -24823 -24700 -2134 -26181 23833 8433 1373 9096 7419 10827 -15412 -1058 -16172
11137 -24716 17254 -4578 -28818 19058 14411 -10043 -24040 -7857 -21780 24194 -28019 -19609 -6169
31085 17802 19146 -3363 -28909 -26992 8703 -12784 -19085 -1547 30580 -8430 28473 13248 31401 4158
13881 -31060 5316 -30209 12868 23628 2929 7080 207 7036 -29906 15392 6710 14134 -13216 -7650 -
31384 16752 -2804 17973 -14437 5150 2067 -28013 -23170 26995 19355 -8616 -11487 -15488 -32127 -
23968 -17623 -28226 -10343 3860 -11434 4714 24185 -21816 25007 -15756 -4088 -31118 -28115 27631 -
17119 -25929 -27049 13449 16689 1245 616 17779 29069 -7850 14707 13235 -21434 -29183 18630 -1837 -
30181 24536 12929 19000 17683 14837 -10476 26426 -17081 -10552 9105 -28828 18298 -761 -14664 28661
-21953 20709 22132 11842 19013 -26127 8257 -15935 28753 -23043 2896 -24063 29392 -14371 24649 -
20501 7238 26201 -18692 20632 -30058 14326 23696 -29030 14587 7257 -3647 22601 -29705 16207 7043 -
19346 -21457 18930 6826 -15731 -13489 -27143 9293 -12596 12440 -9562 27618 13743 -17314 -31721
24528 15499 20023 -14179 -10146 -11739 1477 -11978 22803 11259 -14832 -18057 -2826 16049 25602
21808 -25770 32334 15202 -21209 -31048 4053 -15833 7887 2675 -9750 -12036 1451 -27837 -5926 7576
8688 17820 21209 30790 12395 -4887 -17115 -25166 -11120 17118 -6712 -13880 -3106 -13104 9858 -
10575 -1930 -11241 10232 20117 4887 17371 -24052 -1442 -7884 29193 -15182 25084 11443 31753 -12875
10558 -11419 -19243 -7110 -16570 21576 112 21612 16221 1173 31794 25856 -26766 19301 24729 8975
31197 -32490 6419 19419 -20984 -2211 -22287 -14055 -325 -13974 10324 22357 22187 10538 -14220 -243
-14159 -5767 -31021 -13532 20744 -18590 26465 23946 24262 -6696 -10788 -1343 -27124 -11196 -14017
-15724 22736 -1848 6790 -3158 -24647 23320 -23437 8381 31746 16700 -29613 9345 22323 6868 -25364
29593 -1722 12651 11689 -21419 4246 -8005 -10139 31376 -17527 18742 -29345 -4914 139 27689 -4715
8454 -2729 -22792 20373 -11689 21163 12072 -12683 31631 -4783 -18701 -9452 27964 -18875 7055 -
17055 -5401 -19925 24568 2729 22534 28715 -871 -3775 -18199 -15601 -5715 3378 -5000 -16368 -17292
-20169 -30558 6094 18102 -23112 -636 -23397 -31121 1719 17433 -2627 808 -2973 17537 1795 18112 -
2605 16733 17834 29410 -7965 -17877 21500 1962 4547 -13509 -14704 22999 -17394 -6061 29363 3366 -
2199 -29752 -28417 -6392 23097 -9062 17362 11655 -24976 -31453 -16983 29725 -9568 28645 -18901
23034 3240 -9084 21963 -23789 -21370 7921 9282 17728 -10446 23317 11517 1620 28226 10853 -3607
28267 -25146 -30727 16196 -26870 4355 23499 -21996 -7100 -7897 -4962 27855 16714 -9160 -26536 -
18942 -4519 31416 -29269 24327 13801 -14327 9199 -12027 -84 -28232 -11362 -29552 14066 -25899 -
8915 -15480 -29557 -22929 13991 28693 -11608 28139 -16601 -25167 22035 -7236 -24670 -13435 2049 -
29307 27938 -24484 -27365 -28777 28981 11200 28325 1851 27894 -5379 -23753 -27733 19976 26413 9429
15474 30064 -9450 28222 30470 -30596 -28377 -23386 10973 15231 14781 -22194 18249 23480 31995
31355 -24616 -27935 -3568 -26771 -8963 -29140 -1952 -13308 -21149 -3603 26990 -8447 -3666 -25667
23071 -8011 -11672 -741 -11357 8226 2874 -6287 -32290 -30743 9040 -25067 19423 -22259 -19046 -8538
28128 13230 14556 -24073 90 24908 -6097 12240 29875 2085 -19800 15835 -7373 -2930 25815 24400 -
9173 1743 7807 -12561 -30157 27130 9392 -3442 25044 6801 27192 29955 3577 -4095 2553 -2557 4088
29313 10776 11531 30687 -29933 -28526 10238 19090 -28525 -22913 10931 30986 -30604 -24787 -24407 -
22701 -9516 15500 -13391 11064 -11165 29841 13071 25045 -25840 2585 -25446 9202 17823 -12198 -9948
18945 -4444 18170 -8985 -24784 13363 -30555 -28088 -23277 -22139 23344 -28079 13964 -15180 26107 -
20681 -26195 17674 -21910 -17883 23025 -32735 31209 -24017 16629 21096 15707 915 -17290 -19915
18913 -31683 27376 -5127 25970 -16356 -19077 -2049 29563 21148 -29038 14065 6230 31823 -17950 -
28986 23984 30706 15285 -23483 134 -7001 -13444 13126 -25074 -9406 1407 6306 -12410 -29568 10982 -
27702 -30735 12622 -27899 -25459 -17824 -20699 -31045 -29354 25413 25765 2110 8757 -28247 19979 -
```

6738 -31305 17944 30525 8393 12139 15526 -367 -950 -218 31760 24106 17423 -4690 -30285 19227 16120
-25639 5474 -27600 -1418 -10474 25656 31748 17723 4055 -16091 -8308 -26240 -2644 -24899 -25251 -
2108 -9266 -4912 5778 -7491 -8349 -17708 27836 -26715 16903 -6489 -14211 28806 -21345 -29330 18803
31627 -5548 -3020 -21181 -13883 31568 -5575 13506 -16920 -31284 -24835 -4851 -11336 -20289 -22712
19017 -28418 26249 14872 13571 28121 -26599 18387 -22012 -1968 -6088 -18878 -25079 24260 -6438
5279 26930 -17846 -26107 20937 -23021 27588 2432 11748 21643 4611 -26230 -1884 23537 -31968 14889
-28482 5849 7780 24178 9793 -15166 13712 5102 30876 -20089 19518 17431 -80 -31581 -25527 11669 -
32410 19839 29830 -21859 -29841 -12815 24171 -18978 -22029 2907 11912 -10307 12345 -31825 20741
16364 16776 20426 13727 -26526 -24778 12340 2849 30700 11692 10961 12912 32629 21143 539 -27748 -
4174 -24663 18188 -21140 31329 -28988 24242 -18767 -22458 -30717 20167 31825 -20485 82 28486 -5088
-23970 -27368 3348 -12201 20906 27880 -796 11683 -24227 -10790 -314 5512 12768 16768 16832 12688
5612 32413 13573 27102 7069 -23945 8891 31492 -32392 23398 -1518 -26517 4285 21530 28470 -18356 -
25341 -28275 28966 -19113 -14632 10125 -25475 3756 -10112 21708 -6187 24147 -24600 -18723 -5839 -
1911 -5289 -18441 7505 16011 19766 -29859 -5425 -31735 18889 -19937 31937 21327 16821 -7304 2135 -
6714 -15419 29781 -23302 20374 20692 -3127 21826 -13256 -32688 -21500 -685 -20999 81 -4667 19778 -
10188 -26795 -2357 -28414 6666 6661 -28279 30243 -2160 -20337 -31884 20840 -230 20771 963 -12238 -
24746 30796 15715 10661 -23720 20575 -24608 -18217 -4802 29959 2812 -19770 32686 21242 -15635 -
31945 -23621 31236 16440 18966 30518 -21440 -30202 -13502 7543 676 -9076 23489 -22756 8456 -166
8563 10175 -17597 -11058 9367 20256 -28593 9108 2528 26012 25289 19530 6014 -32214 -2463 17538 -
31360 -6238 -28743 17168 -16779 13239 -21693 -13114 16017 23594 18190 -20882 -17630 7479 29428 -
1808 12464
Sorted array is
-32735 -32688 -32490 -32410 -32392 -32383 -32290 -32214 -32127 -31968 -31945 -31884 -31825 -31735
-31721 -31683 -31581 -31453 -31384 -31360 -31305 -31284 -31121 -31118 -31060 -31048 -31045 -31021
-30743 -30735 -30727 -30717 -30604 -30596 -30558 -30555 -30285 -30209 -30202 -30181 -30157 -30058
-29933 -29906 -29859 -29841 -29752 -29705 -29613 -29568 -29557 -29552 -29354 -29345 -29330 -29307
-29269 -29183 -29140 -29038 -29030 -28988 -28986 -28909 -28828 -28818 -28777 -28743 -28593 -28526
-28525 -28482 -28418 -28417 -28414 -28384 -28377 -28279 -28275 -28247 -28232 -28226 -28115 -28088
-28079 -28019 -28013 -27935 -27899 -27837 -27748 -27733 -27702 -27600 -27368 -27365 -27143 -27124
-27049 -26992 -26906 -26870 -26795 -26771 -26766 -26715 -26599 -26536 -26526 -26517 -26240 -26230
-26195 -26181 -26127 -26107 -25929 -25899 -25840 -25770 -25667 -25639 -25563 -25527 -25475 -25459
-25446 -25364 -25341 -25251 -25167 -25166 -25146 -25079 -25074 -25067 -24976 -24899 -24835 -24823
-24787 -24784 -24778 -24746 -24716 -24700 -24670 -24663 -24647 -24616 -24610 -24608 -24600 -24484
-24407 -24227 -24073 -24063 -24052 -24040 -24017 -23970 -23968 -23945 -23789 -23753 -23720 -23621
-23483 -23437 -23397 -23386 -23302 -23277 -23170 -23112 -23043 -23021 -22929 -22913 -22792 -22756
-22712 -22701 -22458 -22287 -22259 -22194 -22139 -22029 -22012 -21996 -21953 -21910 -21859 -21816
-21780 -21693 -21500 -21457 -21440 -21434 -21419 -21370 -21345 -21209 -21181 -21149 -21140 -20999
-20984 -20882 -20699 -20681 -20501 -20485 -20337 -20289 -20169 -20089 -19937 -19925 -19915 -19800
-19770 -19609 -19346 -19243 -19113 -19085 -19077 -19046 -19042 -19018 -18978 -18942 -18901 -18878
-18875 -18767 -18723 -18701 -18692 -18590 -18441 -18356 -18217 -18206 -18199 -18057 -17950 -17883
-17877 -17846 -17824 -17708 -17630 -17623 -17597 -17527 -17394 -17314 -17292 -17290 -17119 -17115
-17081 -17055 -16983 -16920 -16779 -16608 -16601 -16570 -16368 -16356 -16172 -16091 -15935 -15833
-15756 -15731 -15724 -15635 -15601 -15488 -15480 -15419 -15412 -15182 -15180 -15166 -14832 -14704
-14664 -14632 -14437 -14371 -14327 -14220 -14211 -14179 -14159 -14055 -14017 -13974 -13960 -13883
-13880 -13532 -13509 -13502 -13489 -13444 -13435 -13391 -13308 -13256 -13216 -13114 -13104 -12875
-12815 -12784 -12683 -12596 -12561 -12410 -12238 -12201 -12198 -12036 -12027 -11978 -11739 -11689
-11672 -11608 -11487 -11434 -11419 -11362 -11357 -11336 -11241 -11196 -11165 -11120 -11058 -10790
-10788 -10575 -10552 -10476 -10474 -10446 -10343 -10307 -10188 -10146 -10139 -10112 -10043 -9948 -
9821 -9750 -9568 -9562 -9516 -9452 -9450 -9406 -9266 -9173 -9160 -9084 -9076 -9062 -8985 -8963 -
8915 -8616 -8538 -8447 -8430 -8349 -8308 -8011 -8005 -7965 -7897 -7884 -7857 -7850 -7650 -7491 -
7373 -7304 -7236 -7110 -7100 -7001 -6738 -6714 -6712 -6696 -6489 -6438 -6392 -6287 -6238 -6187 -
6169 -6097 -6088 -6061 -5926 -5905 -5839 -5767 -5735 -5715 -5575 -5548 -5425 -5401 -5379 -5289 -
5127 -5088 -5000 -4962 -4914 -4912 -4887 -4851 -4802 -4783 -4715 -4690 -4667 -4578 -4519 -4444 -
4223 -4174 -4095 -4088 -3775 -3666 -3647 -3607 -3604 -3603 -3568 -3442 -3363 -3158 -3127 -3106 -
3020 -2973 -2930 -2826 -2804 -2729 -2644 -2627 -2605 -2557 -2463 -2357 -2211 -2199 -2160 -2134 -
2108 -2049 -1968 -1952 -1930 -1911 -1884 -1848 -1837 -1808 -1722 -1547 -1518 -1442 -1418 -1343 -
1322 -1058 -950 -871 -796 -761 -741 -689 -685 -636 -367 -325 -314 -243 -230 -218 -166 -84 -80 81
82 90 112 134 139 207 539 616 676 808 915 963 1173 1245 1373 1407 1451 1477 1620 1719 1743 1795
1851 1962 2049 2067 2085 2110 2135 2432 2528 2553 2585 2675 2729 2812 2849 2874 2896 2907 2929

```
3240 3348 3366 3378 3448 3577 3756 3860 3998 4053 4055 4088 4158 4246 4285 4355 4547 4611 4714
4887 5102 5150 5279 5316 5474 5512 5612 5778 5849 6014 6094 6199 6230 6306 6419 6661 6666 6710
6790 6801 6826 6868 7036 7043 7055 7069 7080 7238 7257 7419 7479 7505 7543 7576 7780 7807 7887
7921 8226 8257 8381 8393 8433 8454 8456 8480 8563 8688 8703 8757 8891 8975 9040 9096 9105 9108
9199 9202 9282 9293 9345 9367 9392 9429 9793 9858 10125 10175 10232 10238 10324 10538 10558 10661
10776 10827 10853 10931 10961 10973 10982 11064 11137 11200 11259 11443 11517 11531 11655 11669
11683 11689 11692 11748 11787 11842 11912 12071 12072 12139 12240 12340 12345 12395 12440 12464
12622 12651 12688 12768 12868 12912 12929 13071 13126 13230 13235 13239 13248 13363 13449 13506
13571 13573 13712 13727 13743 13801 13881 13964 13991 14065 14066 14134 14146 14326 14411 14556
14587 14614 14707 14781 14837 14872 14889 15202 15231 15285 15392 15474 15499 15500 15526 15707
15715 15835 16011 16017 16049 16120 16126 16196 16207 16221 16364 16440 16629 16689 16700 16714
16733 16752 16768 16776 16821 16832 16903 17118 17168 17254 17362 17371 17423 17431 17433 17537
17538 17674 17683 17723 17728 17779 17802 17820 17823 17834 17913 17944 17973 18102 18112 18170
18188 18190 18249 18298 18387 18630 18742 18803 18889 18913 18930 18945 18966 19000 19013 19017
19058 19090 19146 19227 19301 19355 19419 19423 19518 19530 19648 19766 19778 19839 19976 19979
20023 20117 20167 20256 20358 20373 20374 20426 20575 20632 20692 20709 20741 20744 20771 20840
20906 20937 21096 21143 21148 21163 21209 21242 21327 21500 21530 21570 21576 21612 21643 21708
21808 21826 21963 22035 22132 22187 22323 22357 22534 22601 22736 22803 22999 23025 23034 23071
23097 23317 23320 23344 23398 23480 23489 23499 23537 23594 23628 23696 23833 23946 23984 24106
24147 24171 24178 24185 24194 24242 24260 24262 24327 24400 24528 24536 24568 24609 24649 24729
24908 25007 25044 25045 25084 25289 25413 25602 25656 25765 25815 25856 25970 26012 26107 26201
26249 26413 26426 26465 26930 26990 26995 27102 27130 27192 27376 27588 27618 27631 27689 27836
27855 27874 27880 27894 27938 27964 28121 28128 28139 28222 28226 28267 28325 28470 28473 28486
28645 28661 28693 28715 28753 28806 28966 28981 29069 29076 29193 29313 29363 29385 29392 29410
29428 29563 29593 29725 29781 29830 29841 29875 29955 29959 30064 30243 30470 30518 30525 30580
30687 30700 30706 30790 30796 30876 30986 31085 31197 31209 31236 31329 31355 31376 31401 31416
31492 31568 31627 31631 31746 31748 31753 31760 31794 31823 31825 31937 31995 32334 32413 32629
32686
Elapsed time: 8 seconds
```

Concurrent games : Chess Knight tour & Hanoi Tower demo (C & Z80 assembler)

```
/*
 * RTM/Z80
 *
 * Copyright (C) 2021 by Ladislau Szilagyi
 *
 * DEMO PROGRAM
 *
 * Two concurrent tasks play two different games:
 *
 * 1. Knight's tour: a sequence of moves of a knight on a chessboard such that he visits every
square exactly once
 *            and returns to the starting square
 * 2. Tower of Hanoi: you have three rods and a number of disks of different diameters, which can
slide onto any rod.
 *     The game starts with the disks stacked on one rod in order of decreasing size, the smallest
at the top,
 *     thus approximating a conical shape. The objective of the puzzle is to move the entire stack
to the last rod,
 *     obeying the following 3 simple rules:
 *     - Only one disk may be moved at a time
 *     - Each move takes the upper disk from one of the stacks and placing it on top of another
stack or an empty rod
 *     - No disk may be placed on top of a disk that is smaller than it
 *
 * The user can interrupt the games anytime to change the moves speed or quit
 *
 */
#include <stdio.h>
#include <string.h>

#include <dlist.h>
#include <balloc.h>
#include <rtsys.h>
#include <rtclk.h>
#include <io.h>

struct Semaphore* Chess_Sem;
struct Semaphore* Hanoi_Sem;
struct Semaphore* IO_Sem;
void* TCB_Chess, *TCB_Hanoi;

void my_printf(char* s)
{
  CON_Write(s,strlen(s),IO_Sem);
  Wait(IO_Sem);
}

/* ----------------------------------------------VT100-----------------------------------------
- */

/* escape sequences for VT100 compatible terminal */

#define ESC 27

char ClearScreen[5]={ESC,'[','2','J',0};
char SetYXPos[9]={ESC,'[',' ',' ',';',' ',' ','H',0};
```

```
/* 2,3 must be filled with Y coordinates, in decimal */
/* 5,6 must be filled with X coordinates, in decimal */

void SetYX(short y0, short y1, short x0, short x1, char* buf)
{
  SetYXPos[2]=(char)y0;
  SetYXPos[3]=(char)y1;
  SetYXPos[5]=(char)x0;
  SetYXPos[6]=(char)x1;
  strcpy(buf,SetYXPos);
}

/* ------------------------------------------------CHESS-------------------------------------------
-- */

void xrndseed(void);
short xrnd(void);

short FirstRun=1;

unsigned long ChessCnt=0;

/* Move pattern on basis of the change of x coordinates and y coordinates respectively */
short cx[8]={1,1,2,2,-1,-1,-2,-2};
short cy[8]={2,-2,1,-1,2,-2,1,-1};/* to maintain the knight's position */

/* the chess board */
short board[8*8];

short x,y,sx,sy;

char Column[8] = {'A','B','C','D','E','F','G','H'};
char Row[8] = {'1','2','3','4','5','6','7','8'};
char Moves[128];
char bufChess[40];

void PrintMoves(void)
{
  short i,j,index;

  for (i=0;i<64;i++)
    Moves[i*2]=0;

  for (i=0;i<8;i++)
    for (j=0;j<8;j++)
    {
      index=board[j*8+i]-1;
      if (index>=0)
      {
        Moves[index*2]=Column[j];
        Moves[index*2+1]=Row[i];
      }
    }

  for (i=0;i<64;i++)
  {
    if (Moves[i*2] != 0)
    {
      sprintf(bufChess, "\r\nMove nr.%d: Knight %c%c", i+1, Moves[i*2], Moves[i*2+1]);
```

```
      my_printf(bufChess);
    }
    else
      break;
  }
}

void PrintLine1(char* buf)
{
  strcat(buf,"+--+--+--+--+--+--+--+--+");
  my_printf(buf);
}

void PrintLine2(char* buf)
{
  strcat(buf,"|  |  |  |  |  |  |  |  |");
  my_printf(buf);
}

void PrintBaseLine(char* buf)
{
  strcat(buf,"A  B  C  D  E  F  G  H");
  my_printf(buf);
}

void PrintBoard(void)
{
  if (FirstRun)
  {
    SetYX('0','1','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('0','2','0','1',bufChess);
    strcat(bufChess,"8");
    PrintLine2(bufChess);
    SetYX('0','3','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('0','4','0','1',bufChess);
    strcat(bufChess,"7");
    PrintLine2(bufChess);
    SetYX('0','5','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('0','6','0','1',bufChess);
    strcat(bufChess,"6");
    PrintLine2(bufChess);
    SetYX('0','7','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('0','8','0','1',bufChess);
    strcat(bufChess,"5");
    PrintLine2(bufChess);
    SetYX('0','9','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('1','0','0','1',bufChess);
    strcat(bufChess,"4");
    PrintLine2(bufChess);
    SetYX('1','1','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('1','2','0','1',bufChess);
    strcat(bufChess,"3");
    PrintLine2(bufChess);
```

```
    SetYX('1','3','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('1','4','0','1',bufChess);
    strcat(bufChess,"2");
    PrintLine2(bufChess);
    SetYX('1','5','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('1','6','0','1',bufChess);
    strcat(bufChess,"1");
    PrintLine2(bufChess);
    SetYX('1','7','0','2',bufChess);
    PrintLine1(bufChess);
    SetYX('1','8','0','3',bufChess);
    PrintBaseLine(bufChess);
    SetYX('2','0','0','8',bufChess);
    strcat(bufChess,"Knight's tour");
    my_printf(bufChess);
  }
  else
  {
    Wait(Chess_Sem);
    SetYX('0','2','0','1',bufChess);
    strcat(bufChess,"8");
    PrintLine2(bufChess);
    Wait(Chess_Sem);
    SetYX('0','4','0','1',bufChess);
    strcat(bufChess,"7");
    PrintLine2(bufChess);
    Wait(Chess_Sem);
    SetYX('0','6','0','1',bufChess);
    strcat(bufChess,"6");
    PrintLine2(bufChess);
    Wait(Chess_Sem);
    SetYX('0','8','0','1',bufChess);
    strcat(bufChess,"5");
    PrintLine2(bufChess);
    Wait(Chess_Sem);
    SetYX('1','0','0','1',bufChess);
    strcat(bufChess,"4");
    PrintLine2(bufChess);
    Wait(Chess_Sem);
    SetYX('1','2','0','1',bufChess);
    strcat(bufChess,"3");
    PrintLine2(bufChess);
    Wait(Chess_Sem);
    SetYX('1','4','0','1',bufChess);
    strcat(bufChess,"2");
    PrintLine2(bufChess);
    Wait(Chess_Sem);
    SetYX('1','6','0','1',bufChess);
    strcat(bufChess,"1");
    PrintLine2(bufChess);
  }
}

short LineToY(register line)
{
  return (8-line)*2;
}
```

```
short ColumnToX(register column)
{
  return (column*3)+3;
}

MarkLineCol(register line, register col)
{
  register y,x;

  y=LineToY(line);
  x=ColumnToX(col);

  SetYX((short)('0'+(y/10)),(short)('0'+(y%10)),(short)('0'+(x/10)),(short)('0'+(x%10)),bufChess);
  strcat(bufChess,"K");
  my_printf(bufChess);
}

UnMarkLineCol(register line, register col)
{
  register y,x;

  y=LineToY(line);
  x=ColumnToX(col);

  SetYX((short)('0'+(y/10)),(short)('0'+(y%10)),(short)('0'+(x/10)),(short)('0'+(x%10)),bufChess);
  strcat(bufChess," ");
  my_printf(bufChess);
}

/* Warnsdorff algorithm code by Uddalak Bhaduri */

/* function restricts the knight to remain within the 8x8 chessboard */
short limits(short x, short y)
{
  if((x>=0 && y>=0) && (x<8 && y<8))
    return 1;

  return 0;
}

/* checks whether a square is empty or not */
short isempty(short x, short y)
{
  if((limits(x,y)) && (board[y*8+x]<0))
    return 1;

  return 0;
}

/* returns the number of empty squares */
short getcount(short x, short y)
{
  short i,count=0;

  for(i=0;i<8;++i)
    if(isempty((x+cx[i]),(y+cy[i])))
      count++;
```

```
  return count;
}

/* calculates the minimum degree(count) of unvisited square among its neighbours and assigns the
counter to that square */
short progress(void)
{
  short start,count,i,flag=-1,c,min=(8+1),nx,ny;

  Wait(Chess_Sem);

  start = xrnd()%8;

  for(count=0;count<8;++count)
  {
    i=(start+count)%8;
    nx=x+cx[i];
    ny=y+cy[i];

    if((isempty(nx,ny))&&(c=getcount(nx,ny))<min)
    {
      flag=i;
      min=c;
    }
  }

  if(min==8+1)
    return 0;

  nx=x+cx[flag];
  ny=y+cy[flag];

  board[ny*8+nx]=board[y*8+x]+1;

  MarkLineCol(nx,ny);
  ChessCnt++;

  x=nx;
  y=ny;

  return 1;
}

/* checks its neighbouring squares */
/* If the knight ends on a square that is one knight's move from the beginning square, then tour
is closed */
short neighbour(void)
{
  short i;

  for(i=0;i<8;++i)
    if(((x+cx[i])==sx)&&((y+cy[i])==sy))
      return 1;

  return 0;
}

/* generates the legal moves using warnsdorff's heuristics */
short generate()
```

```
{
  short i,j;

   for(i=0;i<8;i++)
     for(j=0;j<8;j++)
       board[i*8+j]=-1;/* filling up the chessboard matrix with -1's */

  if (!FirstRun)
    PrintBoard();

  FirstRun=0;

  sx=x=0;
  sy=y=0;

  board[y*8+x]=1; /* initial position */
  MarkLineCol(x,y);
  ChessCnt++;

  for(i=0;i<8*8-1;++i)
    if(!progress())
      return 0;

  if(!neighbour())
    return 0;

  return 1;
}

void Chess(void)
{
  xrndseed();

  while(!generate());

  SetYX('2','1','1','2',bufChess);
  strcat(bufChess,"DONE!");
  my_printf(bufChess);

  StopTask(TCB_Chess);
}

/* ------------------------------------------------CHESS---------------------------------------- */

/* ------------------------------------------------HANOI-----------------_--------------------- */
#define      MAX_N_disks 13

short size[3][MAX_N_disks];      /* disk_size=1,2,...N_disks */
short count[3];           /* how many disks on the peg = 1,2,...N_disks */
short N_disks;
unsigned long HanoiCnt=0;
char bufHanoi[60];

void SetDiskPos(short layer, short peg)
{
  short y0,y1,x0,x1;
  short y,x;

  y=34-layer;
```

```
  x=2+layer+26*peg;

  y0=(short)('0'+(y/10));
  y1=(short)('0'+(y%10));
  x0=(short)('0'+(x/10));
  x1=(short)('0'+(x%10));

  SetYX(y0,y1,x0,x1,bufHanoi);
}

void DrawDisk(short len)
{
  char buf[30];
  short n;

  for (n=0; n<len; n++)
    buf[n]='*';

  buf[n]=0;
  strcat(bufHanoi,buf);
  my_printf(bufHanoi);
}

void EraseDisk(short len)
{
  char buf[30];
  short n;

  for (n=0; n<len; n++)
    buf[n]=' ';

  buf[n]=0;
  strcat(bufHanoi,buf);
  my_printf(bufHanoi);
}

/* Set cursor at the peg's top disk first char
   p = 0,1,2
*/
void GetTopPos(short p)
{
  short y0,y1,x0,x1;
  short y,x;
  short index;

  index=count[p]-1;

  y=34-index;
  x=15-size[p][index]+26*p;

  y0=(short)('0'+(y/10));
  y1=(short)('0'+(y%10));
  x0=(short)('0'+(x/10));
  x1=(short)('0'+(x%10));

  SetYX(y0,y1,x0,x1,bufHanoi);
}

void move(short frompeg, short topeg)
```

```
{
  short index;
  short sz;

  GetTopPos(frompeg);
  index=count[frompeg]-1;
  sz=size[frompeg][index];
  EraseDisk((2*sz)-1);
  count[frompeg]--;

  index=count[topeg];
  size[topeg][index]=sz;
  count[topeg]++;
  GetTopPos(topeg);
  DrawDisk((2*sz)-1);

  HanoiCnt++;
}

void towers(short num, short frompeg, short topeg, short auxpeg)
{
  if (num == 1)
  {
    Wait(Hanoi_Sem);
    move(frompeg, topeg);
    return;
  }

  towers(num - 1, frompeg, auxpeg, topeg);
  Wait(Hanoi_Sem);
  move(frompeg, topeg);
  towers(num - 1, auxpeg, topeg, frompeg);
}

void InitDisks(void)
{
  short n;

  N_disks=MAX_N_disks;

  count[0]=N_disks;
  count[1]=0;
  count[2]=0;

  for (n=0; n<N_disks; n++)
    size[0][n]=N_disks-n;

  for (n=0; n<N_disks; n++)
  {
    SetDiskPos(n, 0);
    DrawDisk((2*N_disks)-1-(2*n));
  }

  SetYX('3','6','0','8',bufHanoi);
  strcat(bufHanoi,"Tower of Hanoi");
  my_printf(bufHanoi);
}

void Hanoi(void)
```

```
{
  towers(N_disks, 0, 1, 2);

  SetYX('3','7','1','2',bufHanoi);
  strcat(bufHanoi,"DONE!");
  my_printf(bufHanoi);

  StopTask(TCB_Hanoi);
}

/* ----------------------------------------------HANOI-------------------------------------- */

void (*fp)(void);

char* Wellcome="\r\nRTM/Z80 Demo program\r\nShowing two concurrent games being played: Chess
Knight's tour & Tower of Hanoi";
char* ScreenWarning="\r\nPlease extend the VT100 compatible window size to at least 48 rows x 80
columns";
char* Ctrl_C_notice="\r\nPlease press ENTER to start!\r\n(you will be able to vary the speed by
pressing CTRL_C)";
char* Ctrl_C_event="Please enter your choice (0=faster, 1=slower, 2=quit):";

struct Semaphore* Timer_Sem;

char Speed[2];
short Pause, MinPause, TicsPerSec;
struct RTClkCB* Timer;
unsigned long ts,te;
char bufMain[100];

void ReportAndQuit(void)
{
  SetYX('4','1','0','1',bufMain);
  my_printf(bufMain);
  te=GetTicks();
  sprintf(bufMain, "\r\nHanoi Towers moves (so far): %ld", HanoiCnt);
  my_printf(bufMain);
  sprintf(bufMain, "\r\nChess moves (so far): %ld", ChessCnt);
  my_printf(bufMain);
  PrintMoves();
  sprintf(bufMain, "\r\nTime elapsed: %ld seconds", ((unsigned long)(te-ts)/TicsPerSec));
  my_printf(bufMain);
  ShutDown();
}

void MainTask(void)
{
  IO_Sem = MakeSem();
  Chess_Sem = MakeSem();
  Hanoi_Sem = MakeSem();
  Timer_Sem = MakeSem();
  Timer = MakeTimer();

  my_printf(Wellcome);
  my_printf(ScreenWarning);

  if (GetHost())
  {
    Pause=200;
```

```
  MinPause=10;
  TicsPerSec=200;
}
else
{
  Pause=100;
  MinPause=5;
  TicsPerSec=100;
}

my_printf(Ctrl_C_notice);

CON_Read(Speed,1,IO_Sem);
Wait(IO_Sem);

ts=GetTicks();

my_printf("\033[2J");   /* clear screen */

PrintBoard(); /* print Chess board */
InitDisks(); /* init Hanoi */

fp = Chess;
TCB_Chess = RunTask(0x7E0, (void*)fp, 6);

fp = Hanoi;
TCB_Hanoi = RunTask(0x7E0, (void*)fp, 5);

StartTimer(Timer, Timer_Sem, Pause, 1);

do
{
  Wait(Timer_Sem);

  if (GetTaskSts(TCB_Chess))
    Signal(Chess_Sem);

  Wait(Timer_Sem);

  if (GetTaskSts(TCB_Hanoi))
    Signal(Hanoi_Sem);

  if (!GetTaskSts(TCB_Chess) && !GetTaskSts(TCB_Hanoi))
    ReportAndQuit();

  if (CTRL_C())
  {
    StopTimer(Timer);

    StartTimer(Timer, Timer_Sem, Pause*2, 0); /* wait 2 seconds */
    Wait(Timer_Sem);

    SetYX('4','1','0','1',bufMain);

    strcat(bufMain,Ctrl_C_event);
    my_printf(bufMain);

    CON_Read(Speed,1,IO_Sem);
    Wait(IO_Sem);
```

```
      SetYX('4','1','0','1',bufMain);
      strcat(bufMain,"\033[2K"); /* erase line */
      my_printf(bufMain);

      if (Speed[0] == '2')
      {
        StopTask(TCB_Chess);
        StopTask(TCB_Hanoi);
        ReportAndQuit();
      }

      if (Speed[0] == '0')
      {
        Pause=Pause/2;

       /* limit the speed */
        if (Pause<MinPause)
          Pause=MinPause;
      }
      else
        Pause=Pause*2;

      StartTimer(Timer, Timer_Sem, Pause, 1);
    }
  } while (1==1);
}

void main(void)
{
  fp = MainTask;
  StartUp(0x1E0, (void*)fp, 10);
}
```

```
*** Run on RC2014 (SC108+SC110), TeraTerm

RTM/Z80 Demo program
Showing two concurrent games being played: Chess Knight's tour & Tower of Hanoi
Please extend the VT100 compatible window size to at least 48 rows x 80 columns
Please press ENTER to start!
(you will be able to vary the speed by pressing CTRL_C)
(ENTER is hit)

 +--+--+--+--+--+--+--+--+
8|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
7|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
6|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
5|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
4|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
3|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
2|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
1|  |  |  |  |  |  |  |  |
 +--+--+--+--+--+--+--+--+
  A  B  C  D  E  F  G  H

       Knight's tour
```

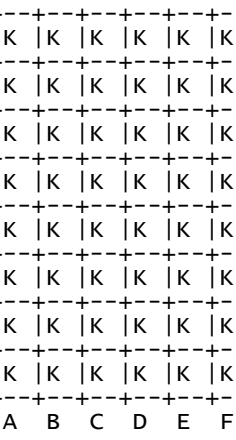
Tower of Hanoi

(CRTL C hit…)

Please enter your choice (0=faster, 1=slower, 2=quit):

(0 hit until full speed acquired…)

(…after a quarter of hour)



Knight's tour
DONE!

Tower of Hanoi
DONE!

Hanoi Towers moves (so far): 8191
Chess moves (so far): 2612
Move nr.1: Knight A1
Move nr.2: Knight C2
Move nr.3: Knight A3
Move nr.4: Knight B1
Move nr.5: Knight D2
Move nr.6: Knight F1

```
Move nr.7: Knight H2
Move nr.8: Knight G4
Move nr.9: Knight H6
Move nr.10: Knight G8
Move nr.11: Knight E7
Move nr.12: Knight C8
Move nr.13: Knight A7
Move nr.14: Knight B5
Move nr.15: Knight C7
Move nr.16: Knight A8
Move nr.17: Knight B6
Move nr.18: Knight A4
Move nr.19: Knight B2
Move nr.20: Knight D1
Move nr.21: Knight E3
Move nr.22: Knight G2
Move nr.23: Knight E1
Move nr.24: Knight F3
Move nr.25: Knight G1
Move nr.26: Knight H3
Move nr.27: Knight F2
Move nr.28: Knight H1
Move nr.29: Knight G3
Move nr.30: Knight H5
Move nr.31: Knight G7
Move nr.32: Knight E8
Move nr.33: Knight F6
Move nr.34: Knight H7
Move nr.35: Knight G5
Move nr.36: Knight E4
Move nr.37: Knight C3
Move nr.38: Knight D5
Move nr.39: Knight F4
Move nr.40: Knight E2
Move nr.41: Knight C1
Move nr.42: Knight A2
Move nr.43: Knight B4
Move nr.44: Knight A6
Move nr.45: Knight B8
Move nr.46: Knight D7
Move nr.47: Knight F8
Move nr.48: Knight E6
Move nr.49: Knight D8
Move nr.50: Knight F7
Move nr.51: Knight H8
Move nr.52: Knight G6
Move nr.53: Knight H4
Move nr.54: Knight F5
Move nr.55: Knight D6
Move nr.56: Knight C4
Move nr.57: Knight E5
Move nr.58: Knight D3
Move nr.59: Knight C5
Move nr.60: Knight B7
Move nr.61: Knight A5
Move nr.62: Knight C6
Move nr.63: Knight D4
Move nr.64: Knight B3
Time elapsed: 832 seconds
```

HEX loader – loads into memory the contents of a .HEX file (Z80 assembler)

```
;
;      Copyright (C) 2021 by Ladislau Szilagyi
;
*Include config.mac
*Include apiasm.mac

       psect  text

COND   CPM
RawBuf1      equ    7B01H  ;buffer #1 used for RawRead
RawBuf2      equ    7C01H  ;buffer #2 used for RawRead
ENDC

COND   CPM=0
COND   NOROM
RawBuf1      equ    0D201H ;buffer #1 used for RawRead
RawBuf2      equ    0D301H ;buffer #2 used for RawRead
ENDC
COND   ROM
RawBuf1      equ    0DA01H ;buffer #1 used for RawRead
RawBuf2      equ    0DB01H ;buffer #2 used for RawRead
ENDC
ENDC
;
;      Intel HEX loader
;
       GLOBAL _ReadHEX

MACRO  CharToNumber
       sub    '0'
       cp     10
       jr     c,1f
       sub    7
1:
ENDM

MACRO  CheckA_and_IncL
       or     a
       jr     z,badnews
       inc    l
       call   z,ReadBuf
ENDM

MACRO  SkipToRec
1:     ld     a,(hl)
       CheckA_and_IncL
       cp     ':'
       jr     nz,1b
ENDM

MACRO  GetActiveBuf
       ld     a,(?buf)
       or     a
       jr     z,1f
       ld     hl,RawBuf2
       ld     iy,(Timer2)
```

```
       jr     2f
1:     ld     hl,RawBuf1
       ld     iy,(Timer1)
2:
ENDM

MACRO  GetInactiveBuf
       ld     a,(?buf)
       or     a
       jr     nz,1f
       ld     hl,RawBuf2
       ld     iy,(Timer2)
       jr     2f
1:     ld     hl,RawBuf1
       ld     iy,(Timer1)
2:
ENDM

BIGTMO equ    2000

;
;      Reads a .HEX file from the CON(SOLE) device
;
;      Return HL=FFFF (-1) if alloc fails
;      If 10 sec passed and nothing was read, return HL=FFFE (-2)
;      If checksum was wrong, return HL=FFFD (-3)
;      If sequence of chars unexpectedly stops before end of EOF record, return FFFC (-4)
;      else return HL=address of loaded code
;
ALLOC_FAIL   equ    0FFFFH
TIME_OUT     equ    0FFFEH
BAD_CHECK    equ    0FFFDH
EOF_NOT_FOUNDequ    0FFFCH
;
_ReadHEX:
       ld     (SavedSP),sp ;prepare for bad news...
       xor    a
       ld     (FirstRead),a;mark first read
       ld     (?buf),a     ;mark Buf1,Timer1 active
       call   __MakeSem
       jr     nz,1f
                           ;quit if alloc failed
       ld     hl,ALLOC_FAIL
       ret
1:     ld     (Sem),hl
       call   __MakeTimer
       jr     nz,2f
                           ;quit if alloc failed
       ld     hl,(Sem)
       call   __DropSem
       ld     hl,ALLOC_FAIL
       ret
2:     ld     (Timer1),hl
       call   __MakeTimer
       jr     nz,3f
                           ;quit if alloc failed
       ld     hl,(Sem)
       call   __DropSem
       ld     hl,(Timer1)
```

```
        call    __DropTimer
        ld      hl,ALLOC_FAIL
        ret
3:      ld      (Timer2),hl
                        ;reset Raw I/O
        call    __Reset_RWB
        call    ReadBuf

        ld      a,(NOT_Read)
        cp      255             ;any char read?
        jr      nz,go
                        ;no, 10 seconds passed, nothing was read
        ld      hl,TIME_OUT
        jr      reterr
go:                     ;first block of chars was read, HL=pointer of chars
        ld      c,0             ;init checksum
        call    GetFirstRecord      ;get first hex record (store Code base)
        jr      z,eof
loop:   call    GetNextRecord;get next record
        jr      nz,loop
eof:                    ;EOF reached
        ld      a,c
        or      a               ;checksum = 0 ?
        ld      hl,BAD_CHECK
        jr      nz,reterr
ok:
        ld      hl,(Sem)
        call    __DropSem
        ld      hl,(Timer1)
        call    __DropTimer
        ld      hl,(Timer2)
        call    __DropTimer
        ld      hl,(Code)       ;return Code base address
        ret
;
reterr:                         ;HL=err code
        push    hl
        ld      hl,(Sem)
        call    __DropSem
        ld      hl,(Timer1)
        call    __DropTimer
        ld      hl,(Timer2)
        call    __DropTimer
        pop     hl
        ld      sp,(SavedSP)
        ret
;
;       (Raw)Read from CON 255 bytes
;
;       if less than 255 bytes were read,
;       store a NULL (zero) byte after the chars read
;
;       registers AF,BC,DE not affected
;
ReadBuf:
        push    af              ;save regs
        push    bc
        push    de
        ld      hl,FirstRead
```

```
       ld     a,(hl)       ;is this the first read?
       or     a
       jr     z,First
                           ;no
       ld     hl,(Sem)     ;wait for the previous read to finish
       call   __Wait
       call   __GetCountB  ;A=counter of bytes NOT read
                           ;move 255 bytes from secondary buffer to main buffer
       jr     seenotr             ;...and go see the outcome

First:
       ld     (hl),1       ;erase FirstRead flag
       ld     c,0FFH       ;try to read 255 chars

       GetActiveBuf

       ld     de,(Sem)
       ld     ix,BIGTMO    ;2000 x 5ms = 10 sec timeout for the first read op
       call   __ReadB             ;read from CON (SIO)
       ld     hl,(Sem)
       call   __Wait
       call   __GetCountB  ;A=counter of bytes NOT read
seenotr:ld    (NOT_Read),a ;save counter of bytes NOT read
       or     a
       jr     z,allread    ;if 0 NOT read (all 255 bytes were read), return
                           ;else (zero or not all chars were read)
                           ;this was the last read
       ld     b,a          ;save counter of bytes NOT read
       GetActiveBuf
       ld     a,b          ;A=counter of bytes NOT read
       push   hl
       neg                 ;ex: 1 NOT read ==> FFH
       ld     l,a          ;HL=pointer after the block that was read
       ld     (hl),0       ;store a NULL after the block
       pop    hl           ;HL=pointer of chars read (if any...)
       pop    de
       pop    bc
       pop    af
       ret
allread:
                           ;start again a read command in the not active buffer
       GetInactiveBuf
       ld     c,0FFH
       ld     de,(Sem)
       ld     ix,20        ;100ms timeout for the next read ops
       call   __ReadB
                           ;then return HL=active buf
       GetActiveBuf
       ld     a,(?buf)     ;then switch bufs
       xor    1
       ld     (?buf),a
       pop    de
       pop    bc
       pop    af
       ret
;
;      Get Byte
;
;      HL=pointer of 2 ASCII hex chars
```

```
;      C=checksum
;      returns A=byte, HL incremented by 2, Checksum updated
;      registers not affected (except AF)
;
GetByte:
       push   de
       ld     a,(hl)       ;hi nibble
       CheckA_and_IncL
       CharToNumber
       rlca
       rlca
       rlca
       rlca
       ld     e,a
       ld     a,(hl)       ;low nibble
       CheckA_and_IncL
       CharToNumber
       or     e
       ld     e,a          ;save in E
       add    a,c          ;add to checksum
       ld     c,a          ;save checksum
       ld     a,e          ;restore from E
       pop    de
       ret
;
;      Get First Record
;
;      HL=pointer in the HEX file
;      C=current checksum
;
;      returns C=checksum updated,
;      record data stored,
;      saves Code base address
;      HL incremented at end-of-record (after "checksum")
;      Z=1 if end-of-file, else Z=0
;
GetFirstRecord:
       SkipToRec           ;we are now past the ':'
       call   GetByte             ;A=len
       ld     b,a          ;B=len
       call   GetByte             ;addr hi
       ld     d,a          ;D=addr hi
       call   GetByte             ;addr low
       ld     e,a          ;E=addr low
       ld     (Code),de    ;save Code base address
       call   GetByte             ;record type
       push   af           ;on stack
       ld     a,b
       or     a            ;len zero?
       jr     z,2f         ;if yes, go get the record checksum
1:                         ;no, get the data
       call   GetByte             ;data
       ld     (de),a       ;store at addr
       inc    de           ;increment addr
       djnz   1b           ;loop until B=0
2:                         ;get record checksum byte
       call   GetByte             ;checksum byte
       pop    af           ;record type
       cp     1            ;Z=1 if EOF
```

```
        ret
;
;
badnews:                ;a NULL char was found in the stream of chars
                        ;before reaching EOF record end
        di
        ld      hl,(Sem)
        call    __DropSem
        ld      hl,EOF_NOT_FOUND
        ld      sp,(SavedSP)
        ret
;
;       Get Next Record
;
;       HL=pointer in the HEX file
;       C=current checksum
;
;       returns C=checksum updated,
;       record data stored,
;       HL incremented at end-of-record (after "checksum")
;       Z=1 if end-of-file, else Z=0
;
GetNextRecord:
        SkipToRec           ;we are now past the ':'
        call    GetByte             ;A=len
        ld      b,a         ;B=len
        call    GetByte             ;addr hi
        ld      d,a         ;D=addr hi
        call    GetByte             ;addr low
        ld      e,a         ;E=addr low
        call    GetByte             ;record type
        push    af          ;on stack
        ld      a,b
        or      a           ;len zero?
        jr      z,2f        ;if yes, go get the record checksum
1:                          ;no, get the data
        call    GetByte             ;data
        ld      (de),a      ;store at addr
        inc     de          ;increment addr
        djnz    1b          ;loop until B=0
2:                          ;get record checksum byte
        call    GetByte             ;checksum byte
        pop     af          ;record type
        cp      1           ;Z=1 if EOF
        ret

        psect   bss

Timer1:       defs    2
Timer2:       defs    2
FirstRead:defs      1             ;set to 1 after the first read
Sem:    defs    2           ;used at I/O
Buf:    defs    2           ;allocated 400H pointer
?buf:   defs    1           ;buffer used for read , 0:Buf1, 1:Buf2
NOT_Read:defs1              ;counter of bytes NOT read after a RawRead(255)
Code:   defs    2           ;address of loaded code
SavedSP:defs 2
```

(this code is used in CMD – the console utility task, mentioned in Configuring RTM/Z80)

XMODEM test – receiving a large text file and storing-it into upper RAM (C)

```
/*
      Copyright (C) 2021 by Ladislau Szilagyi
*/
#include <dlist.h>
#include <balloc.h>
#include <rtsys.h>
#include <mailbox.h>
#include <io.h>

#include <stdio.h>
#include <string.h>

#define EOT 'D'- 0x40
#define SUB 0x1A

void (*fp)(void);

struct MailBox* MB;
struct Semaphore* S;
char buf[257];
char* msgOK="\r\nOK";
char* msgCAN="\r\nCAN";
char* msgFAIL="\r\nFAIL";
short status;
short nB128;
char* pUpRAM;
char msgCount[40];

void TaskXmRecv(void)
{
  status = XmRecv(MB);
  StopTask(GetCrtTask());
}

void Task(void)
{
  S=MakeSem();
  MB=MakeMB(129);

  fp = TaskXmRecv;
  RunTask(0xE0, (void*)fp, 20);

  pUpRAM=(char*)0;
  nB128=0;

  do
  {
    GetMail(MB,buf);

    if (buf[128] == EOT)
      break;

    nB128=1;
```

```
    GetMail(MB,buf+128);

    if (buf[256] == EOT)
      break;

    LowToUp100H((void*)buf, (void*)pUpRAM);

    pUpRAM += 256;
    nB128=0;
  }
  while(1==1);

  if (nB128==1) /* half buffer contains data */
  {
    buf[128] = SUB;
    LowToUp100H((void*)buf, (void*)pUpRAM);
    pUpRAM += 128;
  }

  if (status==1)
  {
    CON_Write(msgOK,4,S);
    Wait(S);
    sprintf(msgCount, "\r\n%x bytes written to upper RAM", pUpRAM);
    CON_Write(msgCount,strlen(msgCount),S);
    Wait(S);
  }
  else
  {
    if (status==-1)
    {
      CON_Write(msgCAN,5,S);
      Wait(S);
    }
    else
    {
      /* status==-2 */
      CON_Write(msgFAIL,6,S);
      Wait(S);
    }
  }

  StopTask(GetCrtTask());
}

void main(void)
{
  fp = Task;
  StartUp(0x1E0, (void*)fp, 10);
}
```

Contents of the RTM/Z80 project on GitHub

Here is the description of the GitHub RTM/Z80 project (folders):

- SOURCES: Z80 assembly language source files of the RTM/Z80 system, plus the configuration file config.mac , plus include files needed to compile an application written in the C language, plus the make.sub file used to build the system object files and library
- WATSON: Z80 assembly language files, parts of the WATSON utility, plus the makew.sub file used to build the object files
- ROM: jp.as, plus:
    - makeromN.sub (N=1..4), makeromw.sub files used to build the RTM/Z80 system and WATSON to be stored on the SC108 or Memory Module EPROM
    - SC108 folder: the .HEX files of the SC108 EPROM and the games demo to be used with RTM/Z80 version 1
    - MM folder: the .HEX files of the Memory Module EPROM and the games demo to be used with RTM/Z80 version 1
- TESTS: various tests that I used to test RTM/Z80 plus the submit files used to build them
- DEMO: the demo applications sources, plus:
    - HEX folder, containing the .HEX files of the games demo (both for the CP/M version and the SC108 version)
- RESOURCES: various sources for utility-type programs plus submit files used to build the demo applications, plus the HEXBOOT.HEX file that must be used to load an RTM/Z80 application on SC108

Porting RTM/Z80 to other hardware

RTM/Z80 can be easily modified to be run on another hardware.

However, there are some constraints to be considered:

- the processor must be compatible with Z80
- interrupt mode 2 must be used
- a real time clock, on interrupts
- a serial asynchronous device, on interrupts
- at least 4 KB EPROM space
- at least 8 KB RAM space

The list below contains all the places where hardware ports are used or hardware-dependent constants are configured:

- CONFIG.MAC
  - RAM128K set to 0 means only (up to) 64 KB RAM will be used; in this case, WATSON must be also set to 0 and all the macros related to selecting low/up banks of RAM will be ignored
  - Real time clock ports (CTC_1…CTC_3) must be modified
  - Serial asynchronous ports (SIO_*) must be modified
  - BMEM_BASE must be set to the RAM address of the 8K dynamic memory
  - _main must be set to the start addr of the app, in case of a RAM/ROM configuration
  - TICS_PER_SEC must be set to obtain 1 second (multiplied with the clock interrupt interval)
- BOOT.AS contains code used only in RAM/ROM configurations
- CPMDATA.AS is relevant only for Z80SIM
- IO.AS contains the serial asynchronous driver code; a ring-based buffer is used for serial communications related functions
- RTCLK.AS contains the real time clock driver
- RTSYS1A.AS
  - _InitInts contains the interrupts initialization code
  - StopHardware contains the code to stop using interrupts
  - SIO_*_TAB contains data used when initializing the serial device (SIO)
  - INTERRUPTS is the interrupts vector
  - SIO_buf is the ring buffer used for serial communications related functions
- SNAPSHOT.AS contains code used only in case of 128 KB RAM systems

Acknowledgements

I want here to thank all those who helped me, directly or without even knowing it, to finish this work:

- Stephen C. Cousins, for his essential contribution related to building my RC2014 computer; without his expertise, patience and wisdom, I surely would have failed to make-it run. He kindly allowed me to use part of his SCM code (the Z80 disassembler). He also was the first to review this manual and advice me in making it better
- Phillip Stevens, for his advices related to the use of his RC2014 Memory Module
- Karl Albert Brokstad, for helping me to setup his Compact Flash Storage Module for RC2014
- Donald E. Knuth, for his excellent book (The art of computer programming), who inspired me 40 years ago to start coding multitasking software systems
- Udo Munk, for his outstanding Z80SIM, used to develop this project
- The (unknown to me) programmers who contributed to build the vintage HiTech Z80 C compiler, ZAS assembler, LINK linker and all the auxiliary tools

… and all others who offered me sources of inspiration in their articles about multitasking software.